ASSESSING THE IMPACT OF HUMAN DEVELOPMENT ON HIGH PRIORITY FOREST BIRDS

Todd Jones-Farrand, American Bird Conservancy, 302 Natural Resources Building, University of Missouri, Columbia, MO 65211-7240
Frank R. Thompson III, North Central Research Station, 202 Anheuser-Busch Natural Resources Building, University of Missouri, Columbia, MO 65211-7260
Anna M. Pidgeon, Department of Forest and Wildlife Ecology, University of Wisconsin-Madison, 1630 Linden Drive, Madison, WI 53706-1598
Jane Fitzgerald, American Bird Conservancy, 8816 Manchester suite 135, Brentwood, MO 63144

Summary

Conservation planning efforts focused on sustaining wildlife populations require information on how threats to populations and their habitats are likely to manifest in the future. Expanding development is widely recognized as a driving force behind forest loss and fragmentation. We combined information on current bird abundance (circa 2000), and concurrent and projected (2030) levels of housing density (HD) to examine how this threat might affect bird populations within 3 Bird Conservation Regions in the central and south-central U.S. We developed models from Breeding Bird Survey (BBS) data to predict abundance for 34 priority species from HD and land cover data around each route. Next we developed models predicting developed area from HD and land cover classes to project future landscapes resulting from increases in HD. Finally, we predicted avian response to the projected future landscapes by applying our BBS models. HD affected the abundance of most of our focal species. Although a model containing only HD was not the best predictor of abundance for any species, HD was included in the best predictive model for 26 species (76%) and the abundance of 7 species was best predicted by land use changes associated with changes in HD. Thirty bird populations were predicted to decline overall from 2000 to 2030, but declines were not ubiquitous. Rather, species-specific population changes (positive and negative) were observed to result from the spatial variability in human population and land use patterns. Concentrating future development within 400 m of existing development lessened impacts on populations. The spatially explicit predictions produced by this project can help land planners to mitigate the impacts of future development on bird populations. Because this work is based on national datasets, similar products can be developed for other regions of the US.

Introduction

Many conservationists fear that the sprawl of urban and rural development associated with burgeoning human populations will negatively affect bird and other wildlife populations through the loss, degradation and fragmentation of habitat. This fear is supported by a growing body of literature showing that urbanization alters ecological structure and function (McDonnell et al. 1997) and leads to a homogenization of biotic communities (McKinney 2006). The process of urbanization impacts individual species differently (Chace & Walsh 2006, McKinney 2008), but typically promotes generalists and at the expense of more specialized species (Nilon et al. 1995, Blair 2004, Fitzgerald et al. 2005, Devictor et al. 2006).

Human settlement patterns create complex landscape mosaics (Blair 2004) that typically fall on a gradient from natural areas through exurban and suburban to urban (Marzluff et al. 2001). The amount and degree of habitat fragmentation that results from development varies depending on the interspersion of housing or other infrastructure and natural areas within a landscape (Bolger et al. 1996). One way to measure humanity's ecological footprint (Brown & Laband 2006) is the density of housing units. Housing density (HD) is negatively correlated with the amount of interior forest (i.e. positive with fragmentation; Radeloff et al. 2005) and when combined with land cover information is a significant predictor of forest bird species richness (Pidgeon et al. 2007). Relatively low levels of HD outside urban areas (i.e. exurban development) can elicit significant reductions in some avian populations (Odell & Knight 2001, Merenlender et al. 2009). Exurban development may have a larger per house impact than suburban development due to its occurrence in less-altered areas and because the degree to which development patterns impact bird and other wildlife populations depends upon the habitat value or degree of degradation within the landscape prior to development (Radeloff et al. 2005).

Approaches that quantify spatial and temporal patterns of housing growth (e.g. Hammer et al. 2004, Radeloff et al. 2005) allow for an assessment of the impacts of development patterns on wild populations over large spatial scales. Examination of this data showed that landscape context and regional processes play important roles in determining species response to HD (Pidgeon et al. 2007). Such information is vital to national and international conservation plans such as the North American Landbird Conservation Plan (Rich et al. 2004) that seek to conserve wildlife populations through creation of landscapes capable of sustaining populations. Recently, the approach of Hammer et al. (2004) and Radeloff et al. (2005) has been used to forecast future growth in HD between 2000 and 2030. This forecast provides a critical piece of planning information that allows the development of proactive approaches to meeting conservation goals.

Whereas it is clear that continued human population growth and its associated land use changes pose a challenge for conservation, spatially explicit predictions of the impact of future development on species are lacking. We need such information to provide science-based decision support to conservation and land use planners. Thus, the purpose of this research effort was to assess the impact of predicted growth in HD on populations of priority forest birds. Our specific objectives were to: (1) model bird abundance as a function of housing density and land cover (circa 2000), (2) predict land cover change as a function of growth in housing density, and (3) project bird populations in 2030 resulting from projected changes in housing density and land cover.

Methods

Study Area

We focused our research on 3 adjacent Bird Conservation Regions (BCR) in the central and south-central United States (Fig. 1). Regional boundaries were defined by the North American Bird Conservation Initiative (U.S. NABCI Committee 2000) and encompass fairly distinct ecoregions. The Central Hardwoods (BCR 24) encompasses approximately 30 million ha currently dominated by extensive oak (*Quercus* spp.)-hickory (*Carya* spp.) forests. Primary threats to forest birds in this region are agricultural conversion and urbanization. The West Gulf Coastal Plain/Ouachitas (BCR 25) encompasses approximately 21 million ha and is currently dominated by pine (*Pinus* spp.) forests. The primary threat to forest birds in this region is land use conversion, especially to pine plantations. The Mississippi Alluvial Valley (BCR 26) encompasses approximately 11.5 million ha of alluvial floodplain currently dominated by agricultural land uses. Restoration of bottomland hardwood forests is a primary objective in this region.

Models of Bird Abundance

We focused on 40 bird species identified as conservation priorities in BCR 24 & 25 (Tirpak et al. 2009; Table 1). This list includes priority species in BCR 26 (Twedt et al. 1998). We gathered abundance information for each species from Breeding Bird Survey (BBS) routes within the study area. We included routes if their geographic center was within one of our focal BCRs and was run at least once during a 5-year period centered on 1990 (1988-1992) and 2000 (1998-2002). We processed the BBS data in several ways. First, we calculated mean abundance for each species on each route for each period after filtering out route runs that did not meet minimum data quality requirements (i.e. Runtype=1; Sauer et al. 2008). Then, we examined the data for temporal correlations and spatial patterns between mean abundance and the number of times a route was surveyed in a period to determine if we should exclude infrequently run routes from the analysis. We found no support for excluding infrequently surveyed routes. Finally, we examined species representation (i.e. the number of routes on which the species was recorded as present) to determine if an adequate sample size was available. We did not exclude any species at this step because we believed setting a sample size threshold would be arbitrary. Instead we deferred to model fit statistics to inform our decision to retain or exclude species.

We generated HD and land cover variables for each route in each period by summarizing information within a 1219 km^2 landscape (19,700-m radius circle) around the geographic center of each route (Pidgeon et al. 2007). We calculated HD for each landscape in each period from data developed by Hammer et al. (2004). We calculated the proportion of aggregated land use data (Anderson Level I; Anderson et al. 1976) for each landscape from National Land Cover Data products (1992 and 2001). We aggregated land cover classes to simplify our abundance models and facilitate comparison between the 2 periods. However, 1992 NLCD and 2001 NLCD are not directly comparable due to changes in development protocols (Homer et al. 2007) even using aggregated classes, so we limited our use of NLCD information to the 2001 dataset.

We developed a set of 6 candidate models to predict the abundance of each species on each route. The BCR model tested for a categorical effect of ecoregion. For the HD model, we first examined whether a linear (i.e. HD) or quadratic (i.e. $HD + HD^2$) relationship was most supported for each species using data from both time periods (1990 and 2000). The LC model included percent of the landscape in upland forest (deciduous, evergreen, and mixed; FOR), in native grass or shrub-scrub (GRSH), and in wetland (woody and herbaceous; WET). Proportion of the landscape in agricultural use (crop and pasture/hay; AG) was excluded from this analysis because it was highly correlated to the proportion of other land uses. Similar to the HD model, we tested whether inclusion of a quadratic forest term (i.e. FOR^2) was supported by the data (2000 period only). Other candidate models included a Null model (intercept only), a Global model (BCR + HD + LC models), and an Interaction model. The interaction model added a BCR*FOR term to the global model and was included in the candidate set because of the inherent differences in the quantity and type of forests among the BCRs. We used the GENMOD procedure in SAS (SAS Inc., Cary, NC) to develop the models after determining that a negative binomial response distribution consistently produced better fit global models than the other distributions tested (normal and Poisson).

Landscape Change

We assumed that increases in HD would alter landscape composition and examined methods for using changes in HD to estimate changes in landscape composition. First, we attempted to estimate rate of landscape change by comparing changes in HD from 1990 to 2000 to changes in land use categories in the NLCD Change Product (http://www.mrlc.gov/index.php). Although, change in HD within BBS route buffers was correlated ($R^2=0.35$) to change in the developed (a.k.a. Urban) class, we still were unable to differentiate between land cover change due to development and change due to improved classification methods (Homer et al. 2007).

We abandoned the rate of change approach in favor of a model selection approach using only data from the 2000 time period. The data set used in this analysis included all Partial Block Group census polygons (Hammer et al. 2004) that overlapped the study area and had HD values > 0 (*n*=53,277). Requiring positive HD values eliminated polygons representing conservation areas, industrial areas, water bodies, and other areas lacking residences. We developed a set of 6 candidate models to predict the proportion of census polygons in a developed class (Low Intensity, Moderate Intensity, High Intensity, and Open Space). We included HD, FOR, AG, and/or BCR as predictor variables and applied appropriate transformations to address deviations from normality. We used the GENMOD procedure in SAS to determine the best response distribution (i.e. normal) and develop the models, and used minimum AIC value (Burnham and Anderson 1998) to determine the top model. We used the top model to predict the developed area of each polygon included in the dataset for 2000 (based on HD in 2000) and 2030 (based on predicted HD in 2030), and calculated the proportional increase in developed area by subtracting the 2000 estimate from the 2030 estimate. We ignored negative values (i.e. converted to 0) that arose due to declines in predicted HD because we reasoned that although populations may decline is some areas evidence of human occupation (e.g. roads, houses) would remain in 2030.

We generated 2 future land use scenarios: unrestricted development (2030ud) and restricted development (2030rd). For the 2030ud scenario, we calculated the number of cells to convert to developed land use in each census polygon based on the predicted proportional change in developed land cover and the existing developed area of the polygon. Next we identified all cells within each census polygon that were available for change (i.e. all land cover types except water and developed). We then divided the number of cells predicted to convert to developed by the number of available cells to get the proportion of available cells that needed to change land use class in each polygon. Next we created a raster data set that assigned that proportional value to each available cell. For example, available cells in a polygon where we predicted 2% of the undeveloped area would convert to developed land use were assigned a value of 0.02. Then we created a raster with random values between 0 and 1 for the study area. Finally, we compared the available raster to the random raster. If the random value was less than the available value, then the land cover class of that cell was changed to the developed class. For the 2030rd scenario, we followed the same procedure except that the definition of available cells was restricted to cells within 400 m of existing development.

Impact on Bird Abundance

We estimated the impact of projected changes in HD on bird abundance by applying the abundance models developed under Objective 1 to the future land use maps developed under Objective 2 and comparing the results to current conditions. To accomplish this, we divided the study area into 1,219 km^2 grid cells (i.e. the size of the BBS route buffers) and assigned each grid cell to the BCR that overlapped its geographic center. Next we calculated the mean HD value for 2000 and 2030 for each grid cell and its proportional land use composition from the current (i.e. 2001 NLCD) and the 2 future (i.e. 2030ud and 2030rd) land use scenarios. We generated estimates of abundance within each grid cell for each scenario within SAS and calculated the proportional change in bird abundance for each grid cell and each BCR.

Results

Models of Bird Abundance

Global models failed or fit very poorly for 6 species, likely due to poor representation or skewed distributions (Tables 1 and 2). Species representation in the BBS data set for the study area varied substantially, with 3 species recorded on 5 (2.5%) or fewer routes and 3 species recorded on 204 (97.5%) or more routes (Table 1). Representation also varied among BCRs with 8 species absent from 1 BCR and 2 species absent from 2 of the 3 BCRs. We excluded the species whose global models failed (American Woodcock [*Scolopax minor*], Bell’s Vireo [*Vireo bellii*], Cerulean Warbler, Red-cockaded Woodpecker [*Picoides borealis*], and Swallow-tailed Kite [*Elanoides forficatus*]) or fit poorly (Painted Bunting [*Passerina ciris*]) from further analyses. Of the remaining 34 species, the top model for 26 species (76%) included an HD effect (Table

2), half of which included a quadratic term (i.e. HD^2). However, the model including HD as the sole predictor was not supported for any species. The top model for 7 species (21%) was the LC model, but for 4 of these species a model including an effect of HD was supported. A quadratic effect of forest was included in the top model for 22 species (65%).

Landscape Change

The model that best predicted the proportion of developed land use within census polygons included HD, proportion of the polygon in agricultural land uses, and BCR (Table 3). This model explained approximately 80% of the variance in the data set (i.e. R^2=0.7973). No other model was supported.

We used the top model to develop future land use scenarios (Figure 2) that predict the spatial pattern of development that may result from increases in HD by 2030. As expected, development reduces the area of other land uses and the quantity of loss is determined by the current land use composition of each BCR (Figure 3). However, the land use scenarios differ in the composition of land use class replacement (Table 4). Nearly 1 million ha of new development was predicted for BCR 24 under both scenarios, but the restricted development scenario converted more open land (i.e. AG and GRSH) area and less forest and wetland area. A similar pattern was noted for BCRs 25 and 26.

Impact on Bird Abundance

Bird abundance declined for 30 species (86%) across the study area as a result of increases in HD and associated reductions in undeveloped land use (Table 5). However, change in bird populations varied by BCR, with 5 species showing opposite trends. Patterns of species declines varied within each BCR (Figure 4), but these differences did not reflect spatial variability in total land use change patterns within BCRs. Rather, they reflect specific initial and projected conditions within each grid cell landscape.

Discussion

Conservation planning efforts focused on sustaining wildlife populations require information on how threats to populations and their habitats are likely to manifest in the future. We used predicted patterns of future housing density to quantify potential impacts on high priority forest bird species. Conservation planners in these BCRs can use this information to help design and protect landscapes capable of sustaining populations.

Models of Bird Abundance

Our approach to quantifying relationships between bird abundance and urbanization relied on existing large-scale datasets. This allowed us examine relationships across large ecoregions quickly and sample landscapes spanning the urbanization gradient (Marzluff et al. 2001). We found that models incorporating HD and land cover information were supported for most (30 of 34) species. This result concurs with Pidgeon et al. (2007), who found that HD and residential land cover were significant predictors of species richness. Of the 4 species where models including an effect of HD were not supported, Louisiana Waterthrush (*Seiurus motacilla*), Pileated Woodpecker (*Dryocopus pileatus*), and Whip-poor-will (*Caprimulgus vociferus*) were best predicted by land cover attributes. All 3 species had a negative relationship with HD but the relationship was not significant for Louisiana Waterthrush. These species share few commonalities in terms of habitat use patterns, spatial distribution across the study area, or route representation, which points to the need to understand the response of individual species to urbanization.

This approach to developing bird abundance models yielded several potential biases. First, roadside bias and other well-known sampling issues associated with the BBS dataset (Bart et al. 1995, Lawler & O'Connor 2004, Harris & Haskell 2007) likely resulted in our inability to develop models for all 40 of our focal species. Additionally, the length of routes made local-scale relationships impossible to detect and the restriction to secondary roads may have under sampled urban areas and weakened relationships for some species. Second, we used aggregated land cover classes to simplify our models. Although this undoubtedly introduced some noise, the inclusion of BCR in the Global model and FOR*BCR in the Interaction model should have captured large scale differences in forest composition. Finally, we based our models on only 1 time period (circa 2000). We would have preferred to model change in bird abundance relative to changes in HD and land cover. Unfortunately, improvements in the generation of national land cover datasets (Homer et al. 2007) have severely limited their use in time series analysis.

Landscape Change

The inability to make direct comparisons of land cover across time periods forced us to project land cover changes based on the spatial covariance in HD and land cover. This approach is not ideal because it assumes that the relationship between HD and developed land cover will remain constant. Urban land area tends to grow faster than human population growth (Marzluff et al. 2001). Thus, our estimates of land conversion may be biased low. An advantage of this approach, however, is that we were able to project changes over a large area (approximately 63 million ha) under 2 different scenarios. More detailed approaches that include factors such as topography and economics are being developed to project development patterns at larger scales (e.g. Project Gigalopolis; http://www.ncgia.ucsb.edu/projects/gig/project_gig.htm), but were considered too time consuming given the scope of this project.

We generated 2 future scenarios to compare development patterns. Although these scenarios are admittedly oversimplified, they highlight the potential conservation benefits of planned development. Forest interior migrant species are sensitive to development pattern, with lower abundance at clustered development sites compared to dispersed single homes and highest abundance in natural areas (Nilon et al. 1995). However, over larger spatial scales it is better to promote clustered development (Odell & Knight 2001) because it reduces the fragmentation effects of development (but see Brown & Laband 2006). Due to slight differences in the randomization routine we used to select cells for conversion, the restricted development scenario

(2030rd) converted more land than the unrestricted development scenario (2030ud) within BCR 24 and the study area as a whole. However, this scenario had a smaller impact (positive or negative) on each of our focal species.

Impact on Bird Abundance

We produced spatially explicit predictions of bird population changes within each BCR in our study area. Population changes varied spatially and for most species at least some grid cells showed changes in the opposite direction of the BCR or study area trend. Further the number of species declining in each cell did not closely reflect the area of land converted. This suggests that population changes reflect preexisting habitat quality (Radeloff et al. 2005) as well as the amount and configuration of land conversion at this scale. Although this reality makes generalized prescriptions for mitigating development difficult (Pidgeon 2007), spatially explicit predictions will be useful for conservationist as they develop conservation designs for landscapes to sustain wildlife species. As those designs are implemented, monitoring will be necessary to validate our results.

We chose to express population change under each scenario as percent change from the baseline because it put all species on a common scale. The models output abundance in birds per route, but expressing change in these units would result in reporting fractions of a bird per route for most species. Alternatively, a method exists for converting birds per route to total population (Rosenberg & Blancher 2005). This method makes some tenuous assumptions (Thogmartin et al. 2006, Thogmartin 2009), but might have advantages when marketing planned development outside the conservation community. For example, Acadian Flycatcher declined 5.3% in the unrestricted development scenario and 5.1% in the restricted development scenario. Using the Rosenberg and Blancher (2005) approach, this equates to declines of roughly 70,900 and 68,500 birds and implies that restricted development could save habitat for approximately 2,400 individuals.

Modeling correlational relationships between avian abundance and development patterns is a good place to start (Marzluff et al. 2001). However, patterns of urbanization impact demographics (Blair 2004, Borgmann & Rodewald 2004, Reale & Blair 2005, Burhans & Thompson 2006). Modeling for conservation planning is an iterative process (Will et al. 2005, National Assessment Team 2006) and future iterations of this line of research need to incorporate demographic effects.

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Table 1. Mean abundance (MA) and representation (R) for focal species on Breeding Bird Survey routes (1998-2002) in each Bird Conservation Region (BCR).

	AOU	BCR 24		BCR 25		BCR 26		Total	
Species Common Name	Code[a]	R[b]	MA	R	MA	R	MA	R	MA
Acadian Flycatcher	ACFL	88	2.7	52	2.3	20	1.1	160	2.3
American Woodcock	AMWO	4	0.0	1	0.0	0	0.0	5	0.0
Bachman's Sparrow	BACS	0	0.0	11	0.2	1	0.0	12	0.1
Black-and-white Warbler	BAWW	36	0.6	42	1.8	2	0.0	80	0.8
Bell's Vireo	BEVI	11	0.1	7	0.4	1	0.0	19	0.1
Bewick's Wren	BEWR	25	0.3	8	0.1	0	0.0	33	0.2
Blue-gray Gnatcatcher	BGGN	107	8.1	53	7.8	25	3.0	185	7.2
Brown-headed Nuthatch	BHNU	0	0.0	36	0.9	2	0.1	38	0.3
Brown Thrasher	BRTH	112	4.7	45	1.9	33	3.4	190	3.7
Blue-winged Warbler	BWWA	38	0.5	0	0.0	1	0.0	39	0.3
Carolina Chickadee	CACH	110	7.2	60	10.6	35	7.0	205	8.1
Cerulean Warbler	CERW	19	0.2	0	0.0	0	0.0	19	0.1
Chimney Swift	CHSW	112	8.7	57	7.8	35	7.6	204	8.3
Chuck-will's-widow	CWWI	40	0.7	37	1.7	8	0.5	85	0.9
Eastern Wood-Pewee	EAWP	112	9.7	57	5.1	25	3.8	194	7.5
Field Sparrow	FISP	113	14.8	32	2.2	9	1.4	154	9.0
Great Crested Flycatcher	GCFL	108	4.4	58	4.2	33	3.7	199	4.2
Hooded Warbler	HOWA	23	0.4	50	6.7	7	0.5	80	2.2
Kentucky Warbler	KEWA	89	2.8	51	3.7	14	0.4	154	2.7
Louisiana Waterthrush	LOWA	47	0.4	20	0.2	3	0.0	70	0.3
Mississippi Kite	MIKI	3	0.0	19	0.2	22	0.9	44	0.2
Northern Bobwhite	NOBO	113	15.8	56	4.7	31	7.9	200	11.4
Northern Parula	NOPA	92	2.2	37	1.0	22	3.2	151	2.1
Orchard Oriole	OROR	108	4.6	56	4.1	30	4.5	194	4.4
Painted Bunting	PABU	5	0.2	42	3.1	20	2.9	67	1.4
Pileated Woodpecker	PIWO	97	2.7	56	3.2	26	1.6	179	2.7
Prairie Warbler	PRAW	82	1.8	41	2.0	5	0.1	128	1.5
Prothonotary Warbler	PROW	30	0.3	26	0.6	30	6.0	86	1.3
Red-cockaded Woodpecker	RCWO	0	0.0	2	0.0	0	0.0	2	0.0
Red-headed Woodpecker	RHWO	88	1.4	46	0.8	27	2.0	161	1.3
Swallow-tailed Kite	STKI	0	0.0	1	0.0	2	0.0	3	0.0
Swainson's Warbler	SWWA	0	0.0	24	0.6	1	0.1	25	0.2
White-eyed Vireo	WEVI	101	5.1	58	19.0	35	6.1	194	9.1
Worm-eating Warbler	WEWA	36	0.4	15	0.2	0	0.0	51	0.3
Wood Thrush	WOTH	104	5.2	53	3.7	20	2.2	177	4.3
Whip-poor-will	WPWI	38	0.6	7	0.2	1	0.0	46	0.4
Yellow-breasted Chat	YBCH	111	9.5	57	22.9	31	5.4	199	12.5
Yellow-billed Cuckoo	YBCU	113	8.4	60	9.8	35	9.3	208	8.9
Yellow-throated Vireo	YTVI	91	1.5	42	2.0	16	0.5	149	1.5
Yellow-throated Warbler	YTWA	68	1.1	28	0.6	8	0.1	104	0.8

[a] Pyle & DeSante (2003).

[b] Number of routes species recorded on..

Table 2. Top abundance model for each focal species, with model variables, AIC weights (ω), and list of other supported models (i.e. ΔAIC ≤ 2).

AOU Code	Top Model	Variables*	ω	Supported
ACFL	Interaction	BCR+HD+FOR+GRSH+WET+FOR*BCR	0.88	
BACS	BCR	BCR	0.71	
BAWW	Interaction	BCR+HD+FOR+GRSH+WET+FOR*BCR	0.79	
BEWR	Global	BCR+HD+FOR+FOR^2+GRSH+WET	0.58	
BGGN	LC	FOR+GRSH+WET	0.56	Interaction
BHNU	Global	BCR+HD+FOR+FOR^2+GRSH+WET	0.83	
BRTH	Global	BCR+HD+HD^2+FOR+FOR^2+GRSH+WET	0.52	Interaction
BWWA	Global	BCR+HD+FOR+FOR^2+GRSH+WET	0.84	
CACH	Interaction	BCR+HD+HD^2+FOR+GRSH+WET+FOR*BCR	0.73	
CHSW	Interaction	BCR+HD+FOR+FOR^2+GRSH+WET+FOR*BCR	0.64	Global
CWWI	Interaction	BCR+HD+FOR+GRSH+WET+FOR*BCR	0.81	
EAWP	Interaction	BCR+HD+HD^2+FOR+FOR^2+GRSH+WET+FOR*BCR	1.00	
FISP	Global	BCR+HD+HD^2+FOR+FOR^2+GRSH+WET	0.69	Interaction
GCFL	Interaction	BCR+HD+FOR+FOR^2+GRSH+WET+FOR*BCR	0.65	Global
HOWA	Interaction	BCR+HD+FOR+FOR^2+GRSH+WET+FOR*BCR	0.99	
KEWA	Global	BCR+HD+HD^2+FOR+FOR^2+GRSH+WET	0.37	LC, Interaction
LOWA	LC	FOR+FOR^2+GRSH+WET	0.90	
MIKI	Interaction	BCR+HD+HD^2+FOR+FOR^2+GRSH+WET+FOR*BCR	0.96	
NOBO	Interaction	BCR+HD+HD^2+FOR+FOR^2+GRSH+WET+FOR*BCR	0.72	
NOPA	Interaction	BCR+HD+HD^2+FOR+FOR^2+GRSH+WET+FOR*BCR	0.69	
OROR	Global	BCR+HD+FOR+GRSH+WET	0.88	
PIWO	LC	FOR+GRSH+WET	0.71	
PRAW	Interaction	BCR+HD+HD^2+FOR+FOR^2+GRSH+WET+FOR*BCR	0.97	
PROW	LC	FOR+FOR^2+GRSH+WET	0.63	Global
RHWO	Global	BCR+HD+HD^2+FOR+FOR^2+GRSH+WET	0.60	LC
SWWA	LC	FOR+FOR^2+GRSH+WET	0.63	Global
WEVI	LC	FOR+GRSH+WET	0.59	Global
WEWA	Global	BCR+HD+FOR+GRSH+WET	0.63	LC
WOTH	Global	BCR+HD+HD^2+FOR+FOR^2+GRSH+WET	0.87	
WPWI	LC	FOR+GRSH+WET	0.93	
YBCH	Interaction	BCR+HD+HD^2+FOR+FOR^2+GRSH+WET+FOR*BCR	0.54	Global
YBCU	Interaction	BCR+HD+FOR+FOR^2+GRSH+WET+FOR*BCR	0.54	Global
YTVI	Global	BCR+HD+HD^2+FOR+FOR^2+GRSH+WET	0.55	Interaction
YTWA	Global	BCR+HD+FOR+GRSH+WET	0.88	

*Variable definitions: Bird Conservation Region (BCR), Housing Density (HD), proportion upland Forest (FOR), proportion grass/shrub (GRSH), and proportion wetland (WET).

Table 3. Model selection results for predicting the proportion of land cover in census polygons classified as developed in the 2001 National Land Cover Database.

Candidate models*	Log Likelihood	k	AIC	ΔAIC	ω
HDl + AGs + BCR	20979.8	5	-41949.6	0.0	1.00
HDl + FORs + BCR	20711.3	5	-41412.6	537.0	0.00
HDl + AGs	20518.3	3	-41030.7	918.9	0.00
HDl + FORs	18853.3	3	-37700.6	4249.0	0.00
HDl + BCR	14846.3	4	-29684.6	12265.1	0.00
HDl	14216.3	2	-28428.6	13521.0	0.00
Intercept only	-21537.4	1	43076.8	85026.4	0.00

* Variable definitions: Bird Conservation Region (BCR), log transformed Housing Density (HDl), square-root transformed proportion upland Forest (FORs), and square-root transformed proportion agricultural (AGs).

Table 4. Composition of land uses replaced by newly developed land under the unrestricted development (2030ud) and restricted development (2030rd) scenarios for each Bird Conservation Region.

	BCR 24		BCR 25		BCR 26	
Class	2030ud	2030rd	2030ud	2030rd	2030ud	2030rd
Forest	55.9%	51.5%	50.1%	48.8%	11.1%	11.6%
Ag	40.3%	44.6%	22.6%	25.6%	50.6%	56.9%
Grass/Shrub	3.2%	3.3%	13.6%	14.5%	4.7%	5.6%
Wetland	0.7%	0.6%	13.7%	11.2%	33.6%	26.0%

Table 5. Proportional change in abundance for 34 avian species as a result of projected changes in housing density and land use composition under unrestricted (2030ud) and restricted (2030rd) development scenarios.

AOU	BCR 24		BCR 25		BCR 26		Total	
Code	2030ud	2030rd	2030ud	2030rd	2030ud	2030rd	2030ud	2030rd
ACFL	-8.1%	-7.8%	-1.1%	-1.0%	-2.2%	-2.1%	-5.3%	-5.1%
BACS	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
BAWW	-18.6%	-18.2%	-7.6%	-7.4%	-15.9%	-16.0%	-10.9%	-10.7%
BEWR	-21.0%	-20.9%	-11.4%	-11.3%	-7.2%	-7.4%	-17.4%	-17.3%
BGGN	-5.2%	-5.0%	-2.9%	-2.9%	-0.5%	-0.5%	-4.1%	-4.0%
BHNU	5.4%	5.4%	-3.4%	-3.5%	-9.8%	-10.4%	-3.7%	-3.8%
BRTH	5.5%	5.4%	3.0%	2.8%	3.7%	3.5%	4.7%	4.7%
BWWA	-4.1%	-3.4%	2.0%	2.2%	-5.6%	-5.8%	-4.1%	-3.4%
CACH	4.8%	5.0%	2.6%	2.6%	5.9%	6.0%	3.9%	4.0%
CHSW	14.1%	14.0%	9.6%	9.7%	9.1%	9.1%	12.0%	12.0%
CWWI	-12.7%	-12.6%	-10.3%	-10.4%	-10.6%	-10.8%	-11.1%	-11.2%
EAWP	-6.1%	-6.0%	-1.6%	-1.6%	-5.7%	-5.8%	-4.9%	-4.9%
FISP	-2.8%	-2.9%	-0.7%	-1.0%	-3.0%	-3.3%	-2.6%	-2.8%
GCFL	-4.9%	-4.9%	-3.2%	-3.1%	-5.1%	-5.2%	-4.3%	-4.3%
HOWA	-12.3%	-11.9%	-12.6%	-12.5%	-26.9%	-26.6%	-13.2%	-13.1%
KEWA	-10.2%	-9.9%	-6.2%	-6.3%	-6.1%	-5.7%	-8.4%	-8.2%
LOWA	-3.2%	-2.8%	-0.8%	-0.7%	-3.2%	-3.4%	-2.5%	-2.2%
MIKI	6.7%	6.2%	-5.3%	-5.4%	-2.6%	-2.0%	-3.4%	-3.1%
NOBO	-0.7%	-0.8%	-0.8%	-0.8%	-1.6%	-1.6%	-0.8%	-0.9%
NOPA	-5.0%	-4.6%	-1.4%	-0.8%	-4.5%	-2.7%	-4.3%	-3.5%
OROR	-4.1%	-4.0%	-3.7%	-3.9%	-2.1%	-2.2%	-3.7%	-3.7%
PIWO	-6.2%	-5.9%	-4.0%	-4.0%	-1.9%	-1.5%	-4.9%	-4.7%
PRAW	-9.7%	-9.5%	-11.6%	-12.0%	-19.7%	-20.4%	-10.5%	-10.6%
PROW	2.1%	2.0%	-0.4%	0.0%	-3.0%	-1.9%	-1.9%	-1.1%
RHWO	0.3%	0.0%	0.0%	-0.1%	-2.2%	-2.3%	-0.5%	-0.6%
SWWA	-7.7%	-7.6%	-19.2%	-19.6%	-42.6%	-41.4%	-19.7%	-20.1%
WEVI	-7.5%	-7.4%	-7.0%	-7.2%	-6.1%	-5.5%	-7.1%	-7.1%
WEWA	-15.7%	-15.3%	-9.8%	-10.0%	-6.9%	-6.1%	-14.6%	-14.3%
WOTH	-6.1%	-5.9%	-4.6%	-4.8%	-4.0%	-4.3%	-5.5%	-5.4%
WPWI	-10.2%	-9.7%	-7.2%	-7.3%	-1.3%	-1.5%	-9.5%	-9.2%
YBCH	-11.7%	-11.7%	-8.8%	-9.0%	-9.8%	-10.0%	-10.0%	-10.1%
YBCU	-8.8%	-8.7%	-3.3%	-3.3%	-6.3%	-6.3%	-6.2%	-6.2%
YTVI	-5.1%	-4.9%	-6.8%	-6.9%	-8.8%	-8.1%	-6.0%	-5.9%
YTWA	-9.1%	-8.8%	-6.5%	-6.5%	-5.5%	-3.8%	-8.5%	-8.2%

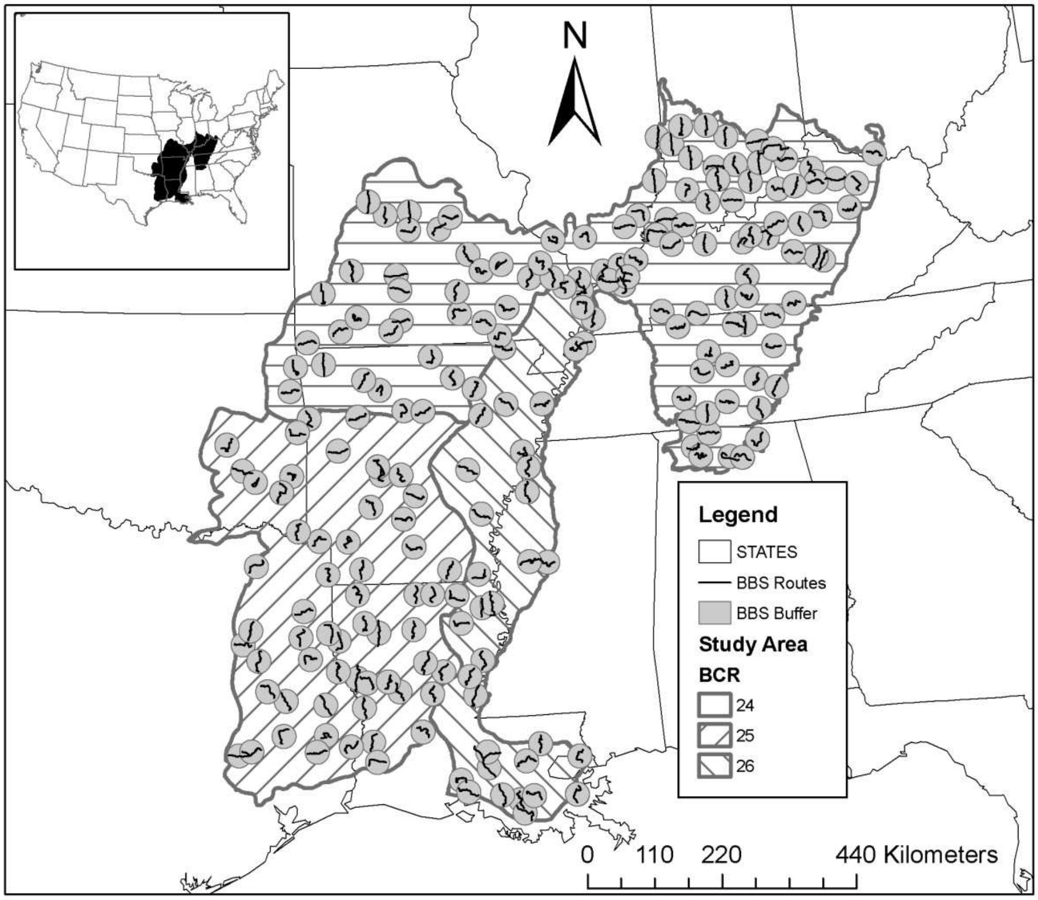

Figure 1. Location of Breeding Bird Survey routes & their associated buffers within the 3 focal Bird Conservation Regions in the central and south-central United States (inset).

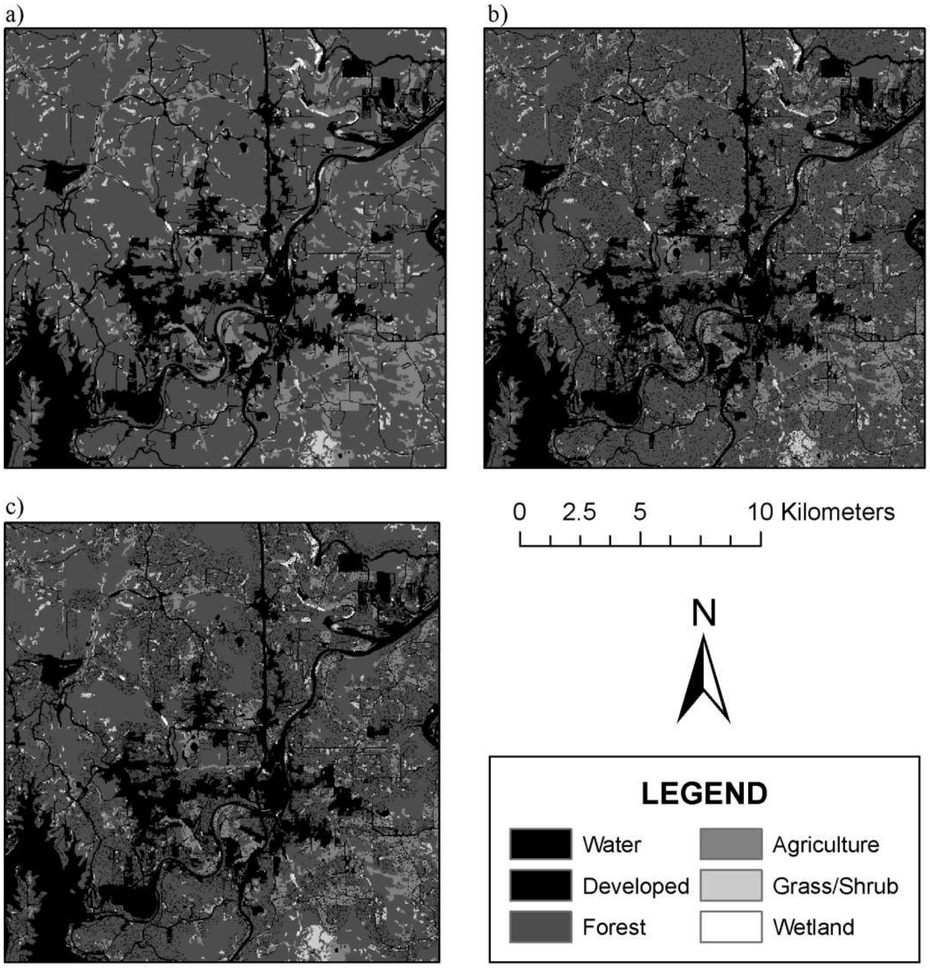

Figure 2. Land use patterns around Branson, MO under the (a) baseline (2000), (b) unrestricted development (2030ud), and restricted development (2030rd) scenarios.

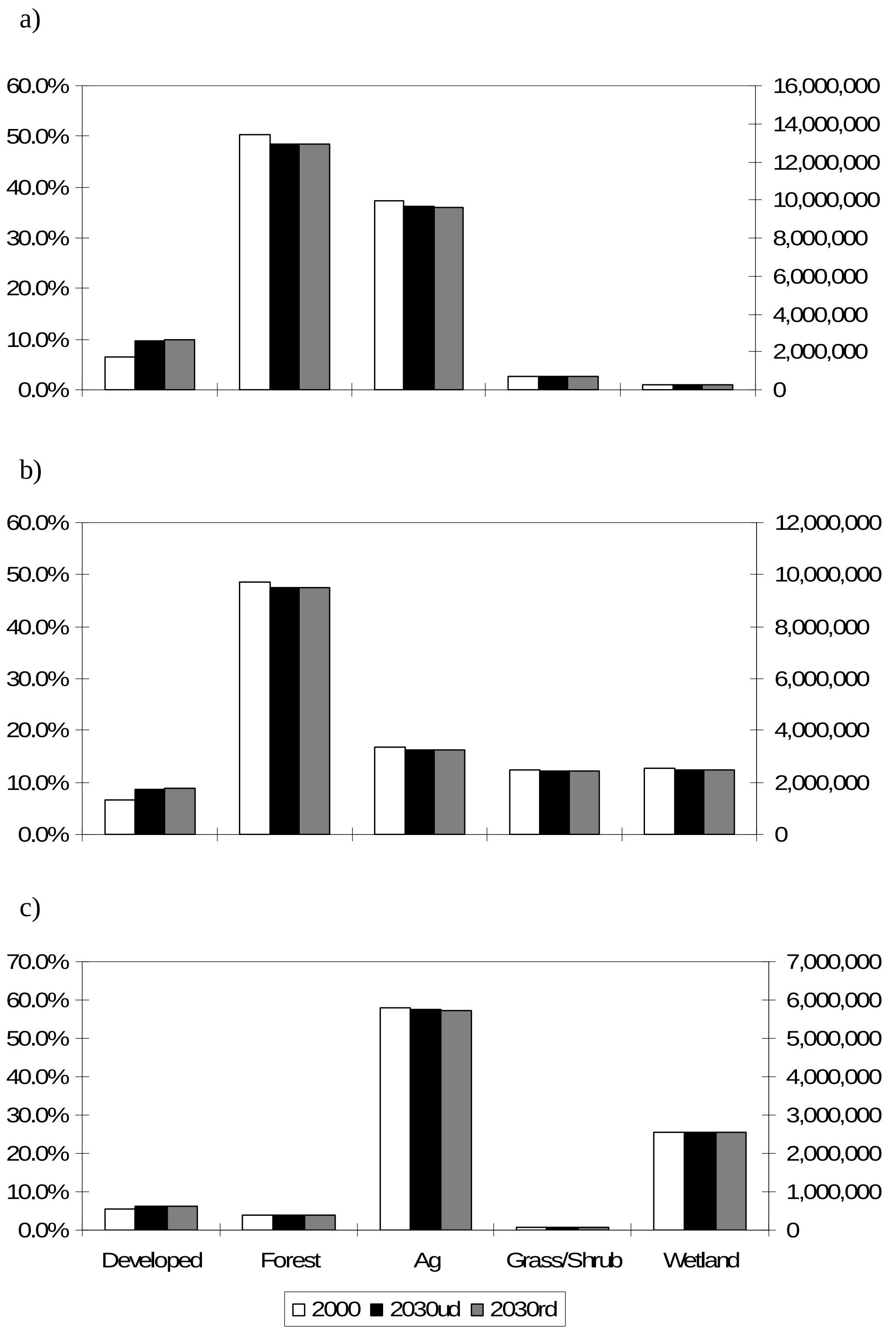

Figure 3. Land use proportion and area (ha) under the baseline (2000), the unrestricted development (2030ud), and the restricted development (2030rd) scenarios for Bird Conservation Regions 24 (a), 25 (b), and 26 (c).

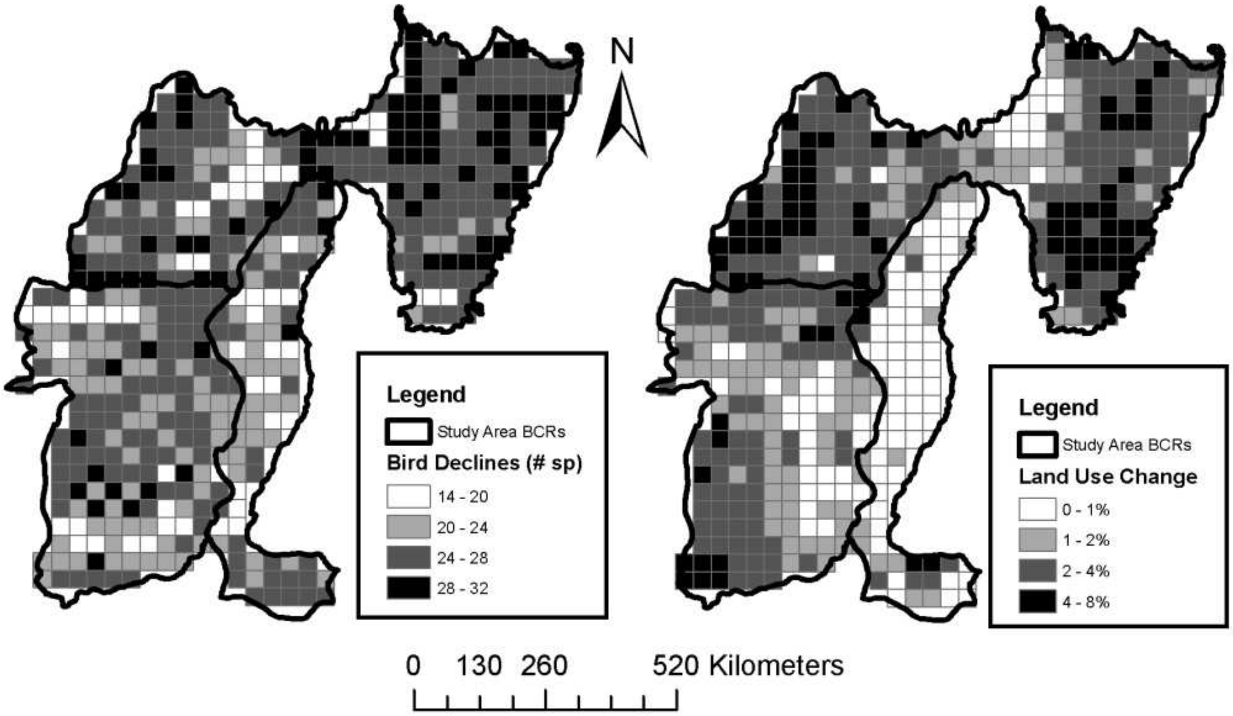

Figure 4. Variation within Bird Conservation Regions in patterns of species declines and proportion of land use change under the restricted development scenario within each 1,219-km^2 grid cell.