Ecological Applications, 25(1), 2015, pp. 160–171

Future land-use scenarios and the loss of wildlife habitats in the southeastern United States

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Abstract. Land-use change is a major cause of wildlife habitat loss. Understanding how changes in land-use policies and economic factors can impact future trends in land use and wildlife habitat loss is therefore critical for conservation efforts. Our goal here was to evaluate the consequences of future land-use changes under different conservation policies and crop market conditions on habitat loss for wildlife species in the southeastern United States. We predicted the rates of habitat loss for 336 terrestrial vertebrate species by 2051. We focused on habitat loss due to the expansion of urban, crop, and pasture. Future land-use changes following business-as-usual conditions resulted in relatively low rates of wildlife habitat loss across the entire Southeast, but some ecoregions and species groups experienced much higher habitat loss than others. Increased crop commodity prices exacerbated wildlife habitat loss in most ecoregions, while the implementation of conservation policies (reduced urban sprawl, and payments for land conservation) reduced the projected habitat loss in some regions, to a certain degree. Overall, urban and crop expansion were the main drivers of habitat loss. Reptiles and wildlife species associated with open vegetation (grasslands, open woodlands) were the species groups most vulnerable to future land-use change. Effective conservation of wildlife habitat in the Southeast should give special consideration to future land-use changes, regional variations, and the forces that could shape land-use decisions.

Key words: biodiversity conservation; habitat loss; land-use change; land-use planning; southeast United States; wildlife habitat.

Introduction

Habitat loss due to land-use change is a major threat to biodiversity globally. It is estimated that 39% of the Earth's terrestrial habitats have been replaced by cropland and urban settlements, and another 37% have been degraded and fragmented (Ellis et al. 2010). With less available habitat, wildlife populations have declined and 20–35% of the world's amphibians, reptiles, and mammals are threatened with extinction (Young et al. 2004, Schipper et al. 2008, Böhm et al. 2013). This bleak picture may worsen in the future. Human population is expected to increase from 7 billion in 2011 to 9 billion people in 2050, and an additional 10–20% of natural grasslands and forests are expected to be replaced by agriculture and urban infrastructure (Alcamo et al. 2006), potentially reducing wildlife habitats further.

Understanding the impact of future land-use changes on wildlife habitat loss is therefore critical to support conservation efforts, but there are several knowledge gaps. First, while major efforts have been made to model climate change impacts on wildlife species, much less progress has been made on modeling land-use change impacts (see Pereira et al. 2012). Yet, land-use changes in the 21st century are expected to have a large effect on terrestrial ecosystems, potentially larger than climate change (Sala et al. 2000). Second, because land use is strongly influenced by market forces, understanding the effects of economic markets and conservation policies on wildlife habitats is a top priority to inform future conservation planning (Pereira et al. 2010, Fleishman et al. 2011). Third, there is a need to understand species responses to land-use change spatially, as environmental threats can vary across regions and from taxon to taxon.

Land-use models that can simulate future land-use changes under different potential policies and economic scenarios provide a unique opportunity to evaluate the consequences of human decisions on the environment (Polasky et al. 2011). For wildlife habitats, land-use change data can be integrated with species–habitat associations to quantify changes in habitat area. In previous studies, land-use models were used to evaluate

Manuscript received 14 November 2013; revised 11 April 2014; accepted 8 May 2014; final version received 7 July 2014. Corresponding Editor: D. Brunton.
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the impact of conservation policies, such as payments for afforestation and land conservation (Matthews et al. 2002, Langpap and Wu 2008, Nelson et al. 2008), changing agricultural practices (Santelmann et al. 2006), and land-use zoning regulations (Wilhere et al. 2007) on total habitat availability for wildlife species as well as on future rates of habitat loss (Beaudry et al. 2013). A common finding was that different groups of species tend to respond differently to future land-use trends, and that these responses varied by region. In an agricultural watershed of central Iowa, USA, for example, extensive agricultural production is expected to reduce the habitat area for reptile and bird species (30–37%), increase the habitat area for mammal species (15%), and to have very little effect on the habitat area for amphibians (−1%). Policies directed at improving water quality could result in substantial increase in the mean habitat area for all groups though (Santelmann et al. 2006). In contrast, habitat area for reptiles in the Willamette Basin, Oregon, USA, increased consistently under future land-use change scenarios (Schumaker et al. 2004).

In the United States, habitat destruction is the most pervasive threat to vertebrates, affecting over 92% of imperiled mammals, birds, reptiles, amphibians, and fish (Wilcove et al. 1998). Forecasts for the United States suggest that future land-use changes will be substantial, and that urbanization will be a major driver of land transformation. Between 2001 and 2051, for example, urban cover is expected to expand by 79% (Radeloff et al. 2012). However, little is known about the potential effect of urban expansion on wildlife habitats in the United States or elsewhere, nor about the potential benefit of "smart growth" policies aimed at containing future urban growth. Similarly, recent increase in crop commodity prices have raised major conservation concerns in the United States as the higher economic returns have created an incentive for land owners to convert natural grasslands into croplands and to take marginal lands out of the Conservation Reserve Program. Between 2006 and 2011, for example, 530 000 ha of grass-dominated land cover have been lost in the western Corn Belt alone (Wright and Wimberly 2013). However, the impact of changing crop commodity prices on wildlife habitats is largely unknown.

For conservation planning, it is also important to understand the spatial patterns of habitat loss and drivers of habitat loss across the landscape (Koh and Gardner 2010). This includes identifying the regions with the highest rates of habitat loss for wildlife species, the drivers of habitat loss across regions (urbanization, crop expansion, etc.), and the potential impact on areas with particularly high species richness. Such spatial understanding of wildlife habitat loss is important to support conservation planning at regional scales, including for prioritizing regions and conservation actions. At the same time, quantifying changes in wildlife habitat under future policy and economic scenarios for individual species can help identify which species are particularly threatened by future land-use changes, and may thus require special attention. Ultimately, both regional and species level information are needed to mitigate the potential negative consequences of land-use change. Finally, species vulnerable to future environmental change may not be recognized currently as species of conservation concern, which highlights the need to consider both listed and non-listed species. The great majority of the world's birds, amphibians, and corals that are highly vulnerable to climate change (51–83%), for example, are currently not on the International Union for Conservation of Nature (IUCN) Red List (Foden et al. 2013).

Our goal here was to evaluate the consequences of future land-use changes under different conservation policies and crop market conditions on habitat loss for wildlife species in the southeastern United States, one of the priority regions for global biodiversity conservation (Olson and Dinerstein 2002). Specifically, our objectives were to (1) quantify future rates of habitat loss for wildlife species from 2001 to 2051 under four different scenarios of future land-use change; (2) evaluate which ecoregions will experience the most wildlife habitat loss under different scenarios; (3) identify the main drivers of wildlife habitat loss in each region and under each scenario; and (4) identify the regions where changing land-use policies and economic conditions could have the largest effects on wildlife habitat loss. As part of this study, we also identified the species most vulnerable to future land-use change.

Methods

Study area and general approach

The southeastern United States (hereafter the Southeast) covers 120 million hectares and includes portions of 16 different Omernik's ecoregions (Fig. 1). The Southeast provides breeding habitat for 580 terrestrial vertebrate species (amphibians, birds, mammals, reptiles) many of which are endemic and/or endangered. The Southeast has a long history of land-use change, most recently in the form of rapid housing expansion and low-density development, forest loss and fragmentation, and competition between forestry and agriculture (Griffith et al. 2003, Napton et al. 2009).

We focused on habitat loss as the primary indicator of threat to wildlife species relevant for conservation, similar to Beaudry et al. (2013). We measured habitat loss as the proportion of a given species' habitat predicted to convert into non-habitat across a given species' entire geographic range. Specifically, we focused on habitat loss caused by the expansion of three major human land-uses, including urban, crop and pasture, from 2001 to 2051. For quantifying habitat loss, we first obtained predictive maps of the current (2001) distribution of wildlife species. Second, we identified which land uses corresponded to non-habitat for each species, and

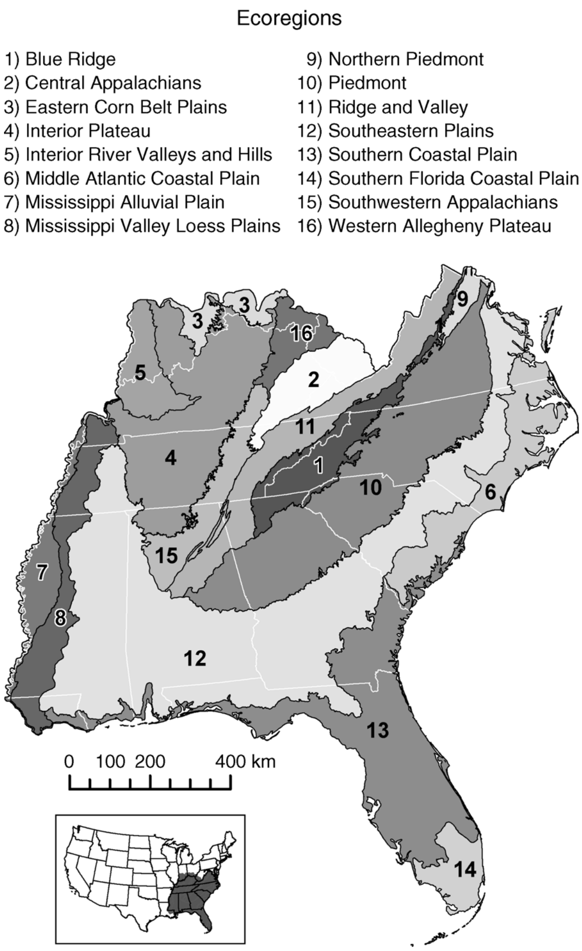

FIG. 1. The southeastern United States and its Omernik's ecoregions. State boundaries are shown in white.

third, we used projections of future land-use change (2051) to quantify the amount of current habitat predicted to be replaced by non-habitat.

Wildlife species data

We obtained current species distribution maps of wildlife species from the Southeast Gap Analysis Program (SEGAP), which is part of the U.S. Geological Survey National Gap Analysis Program (GAP), a major governmental effort assessing the distribution and conservation of wildlife species for the nation (Scott et al. 1993, Boykin et al. 2010). GAP maps species distribution by reflecting known species–habitat associations with land-cover classes from the 2001 National Land Cover Database (NLCD 2001 *in* Homer et al. 2007) and other environmental layers, within the geographic range of the species. The SEGAP database from the Biodiversity and Spatial Information Center (North Carolina State University, Raleigh, North Carolina, USA) provides detailed information about each species habitat use, including whether the species occur (or not) in urban, crop, and/or pasture lands.

The species included in this study were a subset of the native vertebrates known to breed in the Southeast, including 336 of 580 species (58%). We focused on "strongly terrestrial" vertebrates and excluded species whose mapped habitat from SEGAP occurs mostly (i.e., >50% in terms of area) within wetlands. The land-use model used in this study (described in the next subsection) is best suited for forecasting land-use changes in terrestrial ecosystems, which is why we restricted our study to terrestrial species. We also excluded species for which the distinction between habitat/non-habitat according to SEGAP depends on detailed configurations of land cover such as specific ecotones, because the data from our land-use change forecasts did not provide that level of detail. As a result, we included 83 amphibians (63% of total), 131 birds (58%), 61 mammals (64%), and 61 reptiles (49%). Of these 336 species, 58 (17%) are of conservation concern, i.e., endangered, threatened, or vulnerable according to the Endangered Species Act (ESA), Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), or IUCN (Supplement).

Land-use model and scenarios

We used projections of future land-use change for the United States developed by Radeloff et al. (2012) as refined by Hamilton et al. (2013) and Martinuzzi et al. (2013). These projections are based on an econometric model that predicts future changes in U.S. land-use based on observed landowner decisions in response to economic returns to different land uses. The model predicts changes in urban, crop, pasture, forest, and natural rangelands between 2001 and 2051. Natural rangelands in the Southeast are grasslands, shrublands, and open woodlands. The parameters for the econometric model were estimated based on 844 000 plot-level observations of land-use change during the 1990s from the U.S. Department of Agriculture National Resources Inventory (NRI) together with county-level data on economic return to different land uses. Thus, what drives the land-use model are empirical observations from the NRI, not potential assumptions. Radeloff et al. (2012) adapted this model to make spatially explicit projections of land-use change by using spatial data on current land cover, as our starting conditions, and soil type. For each combination of initial land use from the NLCD 2001, soil type from the U.S. Department of Agriculture Soil Survey Geographic Database (SSURGO), and county-level economic returns, the model provides land-use transition probabilities at a 100-m-pixel resolution. Only private lands were allowed to change; the area of public lands and wetlands were assumed to be determined by non-market factors and to remain in the same land use.

Econometric models can simulate potential scenarios of future land-use change by altering the level of economic returns to the different land uses, due to policies like taxes and subsides (policy induced) or through changes in future demand for land-based commodities such as crops (market induced). We explored four different scenarios of future land-use change from Hamilton et al. (2013) and Martinuzzi et al. (2013), including: a Business as Usual scenario, which projected future conditions with no subsidies or taxes other than the ones present when the model was developed and following 1990 trends; a Native Habitat scenario, which levied a US$100/acre (1 acre = 0.405 ha) annual tax on landowners who convert forest and natural rangelands to crop, pasture, or urban, which is an approximation of a REDD-type (reducing emissions from deforestation and forest degradation) mechanism that provides incentives to maintain land in natural vegetation; a High Crop Demand scenario, which assumed a 2% exogenous annual increase in all crop prices while maintaining all lands in the Conservation Reserve Program (CRP); and, finally, an Urban Containment scenario, which restricted urban expansion to metropolitan counties only, as defined by the U.S. census, and reflecting a potential smart growth zoning regulation. The 2% annual increase in crop prices simulated in the High Crop Demand scenario reflected observed trends during boom periods, resulting in a 160% increase in crop price from 2001 to 2051. The Native Habitat and Urban Containment scenarios reflected potential conservation policies. Land-use changes under each of these scenarios result in changes in the supply of commodities (e.g., timber, crops). Supply changes have the further effect of changing commodity prices, which feedback into the returns to each of the land uses. For example, under the Urban Containment scenario, the supply of urban land was reduced, which raised the returns to urban land and increases the incentive for landowners to convert land to urban uses in metropolitan counties. The land-use projection model accounts for endogenous feedbacks into the returns from all uses. Finally, our results are projections and not predictions in the strict sense. That is, the Business as Usual scenario reflects what land use would look like by 2051 if drivers that were in place in the 1990s were to persist. This is an assumption and not a claim that those exact same conditions will persist over the study period. Such an approach is a way of constructing a vision of the future against which we can test the influences of policy and economic changes.

Objective 1: Quantify future rates of habitat loss for wildlife species from 2001 to 2051 under four different scenarios of future land-use change

In order to quantify future habitat loss, we first reviewed the individual species–habitat associations from SEGAP and identified which of our land uses of interest (urban, crop, and pasture) are non-habitat for the species. Then, for each species, we overlaid the current species distribution map from SEGAP with the future land-use projections, and extracted the new area of non-habitat predicted to occur within the current species distribution. We expressed the new area of non-habitat as a percent value relative to the 2001 habitat area, i.e., percentage of habitat loss over 50 years. We repeated this process for each species and each scenario.

Land uses in which the species does not occur according to the SEGAP habitat models were considered to be non-habitat and therefore potential drivers of habitat loss. For example, if a species does not occur in croplands according to the SEGAP species–habitat models, then crop was considered non-habitat for that species. Similarly, if a species does not occur in pasture according to the SEGAP models, then pasture was considered non-habitat. The fact that the species-habitat associations from SEGAP and the land-use model from Radeloff et al. (2012) were based on the same land cover data (NLCD 2001) ensured consistency in the definition and mapping of land-use classes. For urban cover, the approach for assigning habitat/non-habitat was slightly different because SEGAP and NLCD 2001 have four different land-cover classes describing urban features, while our land-use model combined those into a single, urban class. The four classes include highly developed/built-up areas, two classes of single-family housing units (i.e., surrounded by impervious surface or by vegetated surfaces), and developed open space (vegetated parks and golf courses). Like crop and pasture, if a species does not occur in any of these classes or only in developed open space according to SEGAP, then urban was considered non-habitat for the species.

We considered the Business as Usual scenario as our baseline and reported the number of species expected to occur in different categories of habitat loss (i.e., 0–10% loss, 10–20% loss, etc.), for all species combined (n = 336), and by species groups (amphibians, birds, mammals, reptiles, and species of concern). Results for the other scenarios were summarized by the number of species expected to occur in the previous categories of habitat loss rates, and the difference from the baseline.

Objective 2: Evaluate which ecoregions will experience the most wildlife habitat loss under different scenarios

To assess regional patterns, we summarized the results by Omernik Level III ecoregions (U.S. Environmental Protection Agency 2011). Ecoregions provide a meaningful way to understand land-use changes in the Southeast (Griffith et al. 2003, Napton et al. 2009). We clipped the SEGAP species distribution maps by ecoregion and calculated the percentage of habitat lost per species in each ecoregion. We summarized the results by reporting the proportion of species with >10% habitat loss in each ecoregion. We chose the 10% habitat-loss threshold to identify the species with substantial levels of habitat loss, facilitating the comparison of the intensity of habitat loss across the landscape, scenarios, and species groups. We also calculated the species richness values (total number of species) for each ecoregion, in order to compare patterns of habitat loss with patterns of biodiversity.

TABLE 1. Projected land-use changes under different policy and socioeconomic scenarios from 2001 to 2051.

		Projected changes under different scenarios (%)			
Land use class	Total 2001 (ha)	Business as usual	Native habitat	High crop demand	Urban containment
Crop	13 084 334	9.7	1.3	74.0	13.7
Pasture	15 586 815	−49.3	−55.1	−66.7	−47.4
Forest	53 506 138	4.5	4.9	−2.2	8.5
Urban	10 294 392	60.6	61.8	52.7	28.8
Range	9 169 812	−24.2	−6.3	−38.6	−21.2
Others	21 048 509	0	0.0	0	0

Objective 3: Identify the main drivers of wildlife habitat loss in each region and under each scenario

In order to identify the drivers of habitat loss, we first calculated the proportion of each species' habitat loss caused by the expansion of urban vs. expansion of crop vs. expansion of pasture for each ecoregion. These measures provided an indication of the contribution of the different land-use classes to habitat loss for each species in each ecoregion. We then calculated the average habitat loss caused by each land use for all species in each ecoregion, which provided a measure of the contribution of the different land-use classes to wildlife habitat loss at the level of ecoregion. We summarized the results by reporting the top two land uses with the highest contribution to habitat loss in each ecoregion, in order of their contribution, e.g., "urban, then crop", or only one land use if the contribution of the second class was very low (<20% out of 100%).

Objective 4: Identify the regions where changing land-use policies and economic conditions could have the largest effects on wildlife habitat loss

For each scenario, we calculated the difference in the proportion of species with >10% habitat loss in each ecoregion relative to the Business as Usual scenario (scenario minus Business as Usual), which provided an indication of the regions where each individual scenario had its largest effect. Then, we calculated for each ecoregion the maximum difference in the proportion of species with >10% habitat loss among scenarios, which provided an indication of the overall sensitivity of each ecoregion to policies and economic conditions. In ecoregions with values close to 0, there is little difference among scenarios in the number of species projected to experience >10% habitat loss, while ecoregions with positive values exhibited more variation among scenarios in terms of the amount of habitat loss. Finally, we used the rates of habitat loss to identify the most vulnerable species to future land-use change, defined as those species with the highest average rates of habitat loss across scenarios (top 10%).

RESULTS

Projected land-use changes

Under our Business as Usual scenario, urban, crop, and forest cover were projected to increase (61%, 10%, and 5%, respectively), while pasture and range were projected to decrease (49% and 24%, respectively; Table 1). Under the Native Habitat scenario, range cover was projected to decrease but at a much lower rate (i.e., 6% decrease vs. 24% under the Business as Usual). Under the High Crop Demand scenario, on the other hand, crop cover was projected to expand the most among scenarios (74%) and forest, pasture, and range were projected to decrease. Finally, under the Urban Containment scenario, urban expansion was projected to be about half of that under Business as Usual (61% vs. 29% urban expansion).

Rates of habitat loss under Business as Usual and alternative scenarios

Under our Business as Usual scenario, one in every four species was predicted to see 10–20% habitat loss, and a few species (3%) were predicted to see >20% habitat loss (Fig. 2a). Among groups, reptiles and species of conservation concern were predicted to see the highest habitat loss, with 40–49% of these species expected to see >10% habitat loss vs. 21–28% of amphibians, birds, and mammals.

For all species combined (n = 336), habitat loss projected under Urban Containment was somewhat lower than under Business as Usual, with 16% of all species expected to see >10% habitat loss, vs. 25% under Business as Usual (Fig. 2d). On the other hand, habitat loss projected under the High Crop Demand scenario was substantially higher, with 48% of the species expected to see >10% habitat loss and 11% of species expected to see >20% loss (vs. 3% under Business as Usual; Fig. 2c). For all species combined, the results from the Native Habitat and Business as Usual scenarios were very similar (Fig. 2b).

Generally all groups of species showed some variation in habitat loss under the different scenarios. These variations were smaller under Urban Containment and particularly Native Habitat, but larger under High Crop Demand. For example, under Urban Containment, fewer species were expected to see >10% habitat loss within all groups compared to Business as Usual (8–18% less; Fig. 2d). For example, the proportion of amphibians expected to see >10% habitat loss decreased from 23% under Business as Usual to 8% under Urban Containment. Under the Native Habitat scenario, 12–13% fewer reptiles and species of concern were projected

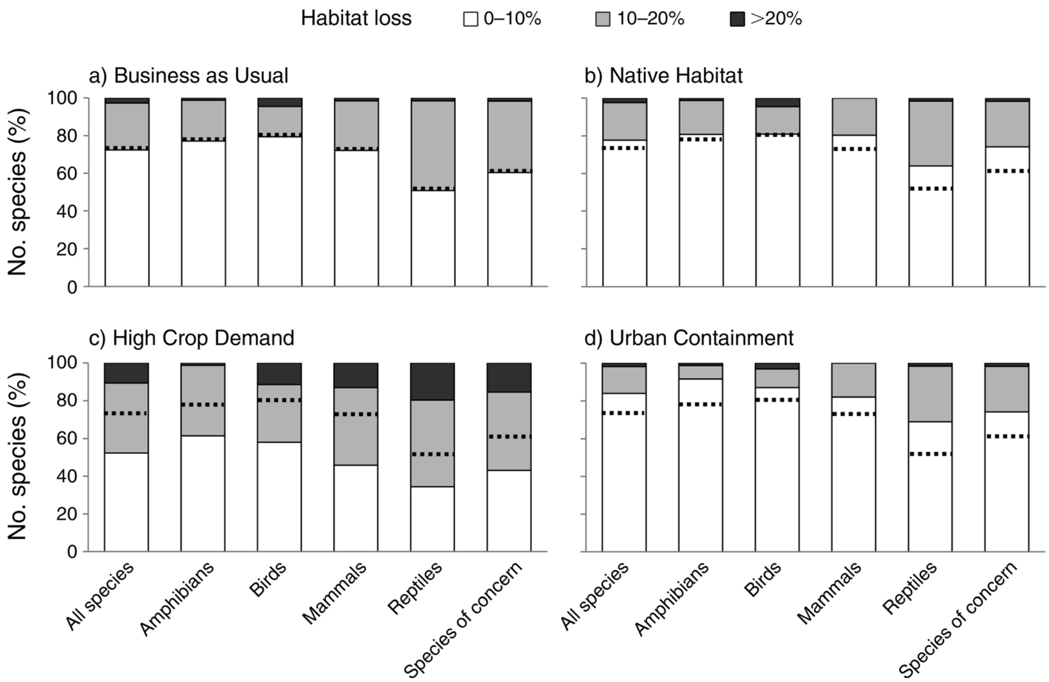

FIG. 2. Projected rates of habitat loss for wildlife species under different scenarios of future land-use change 2001–2051. The values for the percentage of species with >10% habitat loss from the Business as Usual scenario are shown in all scenarios for reference, as dashed lines.

to see >10% loss compared to Business as Usual. Under the High Crop Demand scenario, on the other hand, habitat loss increased substantially in all species groups, with 16–26% more species in each group projected to see >10% habitat loss compared to Business as Usual (Fig. 2c). Mammals and birds showed the greatest increase in the number of species with habitat loss (21–26% more species than under Business as Usual). Furthermore, the High Crop Demand scenario substantially increased the number of species expected to see >20% habitat loss in all species groups (from 1–6% under Business as Usual to 8–15%). Amphibians were the exception as they were the only group expected to see the same proportion of species with >20% habitat loss in all scenarios (only 1%). Across scenarios, reptiles, and species of concern typically showed the highest habitat loss values.

For individual species, the rates of habitat loss projected for the entire Southeast region under the Native Habitat and Urban Containment scenarios differed only slightly from those projected under Business as Usual. One-half of the species were projected to see the same amount of habitat loss in these three scenarios, and the other half were projected to have slightly (1–5%) lower habitat loss in the Native Habitat and Urban Containment compared to the Business as Usual (Fig. 3). On the other hand, the rates of habitat loss projected under the High Crop Demand scenario were substantially higher than those projected under Business as Usual for most of the species, with 65% of the species expected to see an additional 1–10% loss under High Crop Demand, and up to 10–35% greater habitat loss in some cases (8% of all species).

Patterns of habitat loss

The Piedmont and Northern Piedmont ecoregions in the East, and the Interior Plateau and Eastern Corn Belt Plains ecoregions in the West, showed the highest values of habitat loss under all scenarios (Fig. 4). For example, in those ecoregions under the Business as Usual and High Crop Demand scenarios, 40–60% and 60–70% of the species, respectively, were predicted to see >10% habitat loss. The proportion of species expecting loss was typically lower under the Urban Containment

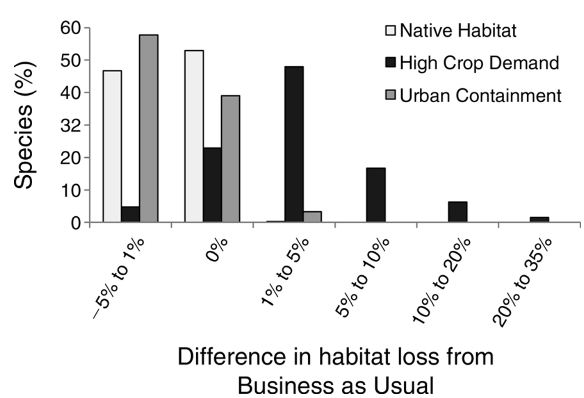

FIG. 3. Projected rates of species habitat loss under different scenarios relative to the baseline at the scale of the entire Southeast (i.e., scenario minus Business as Usual).

scenario, yet in the Piedmont, still 30–40% of all species were expected to see >10% habitat loss. In terms of different groups of species, amphibians and birds typically had the highest habitat loss in Piedmont, the Interior Plateau and Eastern Corn Belt Plains, while mammals, reptiles, and species of concern had the highest habitat loss in the Southeastern Plains (in the south), the interior Plateau, the Eastern Corn Belt, and, in some cases, the Piedmont.

In regard to patterns of species richness, the four ecoregions with the highest levels of species richness, i.e., the Blue Ridge, Ridge and Valley, Piedmont, and Southeastern Plains, showed different levels of wildlife habitat loss. Among these ecoregions, habitat loss was projected to be lower in the Blue Ridge and Ridge and Valley ecoregions, which support the highest number of amphibians, mammals, and birds, but higher in the Piedmont and Southeastern Plains, which include some of the ecoregions with the highest number of reptile species (Fig. 4).

Drivers of habitat loss

Urban and crops were the main drivers of future wildlife habitat loss, but their relative contribution to habitat loss varied among regions and scenarios (Fig. 5). Under Business as Usual and Native Habitat scenarios, for example, urban expansion was the main driver of habitat loss in more interior ecoregions such as Piedmont, Ridge and Valley, and Southwestern Appalachians. In contrast, crop expansion was the main driver of habitat loss in western ecoregions and Southeastern Plains. Under High Crop Demand, crop expansion was the main (and sometimes the only) driver of habitat loss, followed by urban expansion the Piedmont and Southeastern Plains. Under Urban Containment, crop expansion was the main driver of habitat loss, followed by pasture expansion (Fig. 5).

Regions with the largest effects from scenarios

Regions with the greatest variation in habitat loss among scenarios were located in the northwestern part of the study area, followed by the Southeastern plains, and the Piedmont (Fig. 6). In these regions, the proportion of species with >10% habitat loss varied from 30% to 45% among scenarios. Compared to the patterns of habitat loss expected under Business as Usual, the Urban Containment had its maximum effect (in terms of reducing rates of wildlife habitat loss) in western ecoregions, followed by the Piedmont and the Southeastern Plains (Fig. 6). The High Crop Demand increased habitat loss in almost every ecoregion compared to Business as Usual, and had the largest effect in western valleys, some coastal ecoregions, and the Piedmont. Finally, the Native Habitat had its maximum effect in the south.

Species with the highest rates of habitat loss

Those species that were most vulnerable to future land-use change averaged 14–34% habitat loss across scenarios (Supplement). Typically, these species showed the highest rates of habitat loss within the individual scenarios as well. The group included 13 birds (10% of all birds), 11 reptiles (18%), 8 mammals (13%) and 2 amphibians (2%). Of these, five birds, four reptiles, and one amphibian species (30% of the 34 species) were of conservation concern.

Discussion

Understanding future land-use changes and their impact on wildlife is critical to guide conservation efforts and policy making. Here we show that future land-use change scenarios in the southeastern United States will have important consequences for wildlife conservation, particularly in certain regions and for certain groups of species. We found, for example, that increase in crop commodity prices increased future rates of habitat loss throughout our study area, while the implementation of conservation policies reduced habitat loss in particular in western ecoregions, as well as in the Piedmont and the Southeastern Plains. Urban and crop expansion were the main drivers of habitat loss in our projections. Reptiles and species associated with open vegetated habitat were especially vulnerable to future land-use changes and may require special conservation attention.

It was encouraging to see that, for the Southeast as a whole, future land-use changes did not emerge as a major and widespread threat, as the associated rates of habitat loss for most species were generally low to modest (0–20% over a 50-year period). This result agrees with recent findings in forested areas of northern Wisconsin (USA), where the rates of habitat loss for forest birds are expected to be 0–8% during the same period (Beaudry et al. 2013). However, future land-use changes in the Southeast are expected to vary among ecoregions. The Piedmont, supporting a high number of wildlife species, is projected to undergo some of the greatest land conversion pressure and thus the highest levels of wildlife habitat loss, while the Blue Ridge ecoregion, which also supports high levels of biodiversity, was projected to see low rates of wildlife habitat loss in all scenarios. These differences are likely due to regional differences in land suitability for development (Griffith et al. 2003, Napton et al. 2009, Drummond and Loveland 2010). The Blue Ridge is a mountainous forested ecoregion with relatively steep topography and a large proportion of publicly owned lands (approximately one-third of the entire ecoregion), which constrains land-use activities (Napton et al. 2009). The Piedmont, on the other hand, is characterized by low elevation, rolling hills, high levels of urbanization and agricultural land use, and high deforestation rates (Drummond and Loveland 2010). For biodiversity conservation, an important finding is that some of the most species-rich areas may be relatively unaffected, while others are likely threatened. Land-use-based conservation strategies developed at regional scales

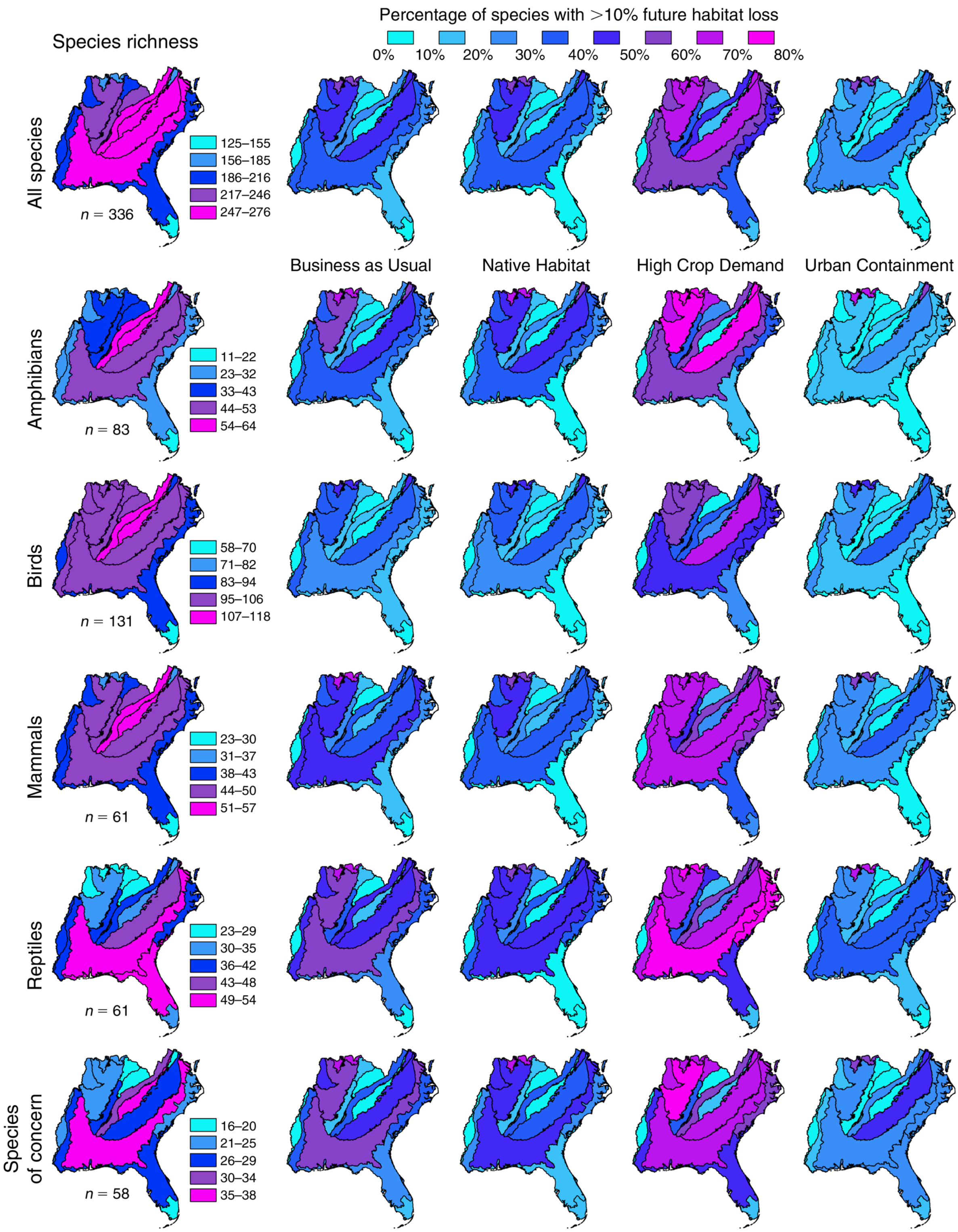

FIG. 4. Geographic patterns of habitats loss for wildlife species under different scenarios of future land-use change 2001–2051. Values of species richness are also shown.

should therefore consider prioritizing regions with high biodiversity and consistently high projected habitat loss (Lewis et al. 2009).

We also found that increases in crop commodity prices could exacerbate wildlife habitat loss in the Southeast. Our baseline scenario of future land-use change reflected 1990s trends, which were characterized by relatively low crop prices that resulted in a projected 10% crop expansion for 2001–2051. However, when we increased crop prices in our *High Crop Demand* scenario, crop cover was projected to expand at a much higher rate (74%). This crop land expansion, coupled with the fact that 80% of the wildlife species do not use crop land as habitat (Appendix), help explain the substantial increase in the rates of wildlife habitat loss compared to the baseline scenario. Indeed, under High Crop Demand, crop cover emerged as the top driver of habitat loss across ecoregions. Recent increases in crop prices have raised major concerns for biodiversity conservation in the United States (Wright and Wimberly 2013) and highlight the need to better understand the connection between market changes and wildlife habitats (Fleishman et al. 2011). Our results show that wildlife habitats in the Southeast can be affected by commodity market changes, and that increases in crop commodity prices could potentially threaten our ability to conserve biodiversity in this important region.

The implementation of conservation policies reduced future wildlife habitat loss only slightly across the entire Southeast, but had more notable effects in some subregions. Restricting urban growth to metropolitan counties, our surrogate for a smart growth regulation, reduced future urban expansion by half, from 61% to 29%, and species in the Interior Plateau, the Piedmont, and the Southern Plains saw a notable reduction in future habitat loss. These ecoregions will likely experience high levels of urbanization, and our findings show that limiting suburban encroachment can have positive consequences in those areas (confirming Hanson et al. 2010). On the other hand, while the implementation of a REDD-like policy to conserve natural vegetation reduced the loss of natural rangelands from 24–39% to 6%, the effect on species as a whole was minimal. The small effect of conservation policies on wildlife habitat at the scale of the entire Southeast region may be due to the fact that the land area affected by these policies is small, relative to the total study area. For example, the difference in urban cover between the Business as Usual and the Urban Containment scenarios (3.3. million hectares) represents less than 3% of the Southeast's area. In addition, positive changes in one land-use class under a given policy often caused concomitant negative changes in other land uses. The Urban Containment scenario, for example, had less urban cover than the Business as Usual but had more crop and pasture cover, which can also cause habitat loss.

Reptiles emerged as the species group that was most threatened by our future land-use change projection within our set of mostly upland species, and this pattern was consistent across scenarios. Regions with the highest reptile species richness in the Southeast were also predicted to witness the highest rates of reptile-specific habitat loss. For amphibians, on the other hand, regions with the highest species richness had one of the lowest levels of habitat loss. Previous studies show that some reptiles in the Southeast are associated with open vegetation such as grassland and scrub/shrub (Steen et al. 2012), and changes in the amount of open habitat can impact habitat availability for reptiles (Schumaker et al. 2004). In our results, open vegetation areas were projected to decline under all scenarios, which might be one reason for the high habitat loss of this species groups. Otherwise the expectation would be that groups with the smallest habitat area would see the highest rates of habitat loss. However, this was not the case here as the median size of the predicted habitat for reptiles from the SEGAP maps was ten times larger than that for amphibians (10.8 million hectares vs. 1.1 million hectares).

Our results suggested that particular conservation attention should be given to wildlife species associated with open vegetated areas. Species with the highest rates of habitat loss all shared the trait of being associated with grasslands, pastures, prairies, and open woodlands (Supplement). The list includes species listed as endangered, threatened, or vulnerable according to ESA, CITES, or IUCN, such as Henslow's Sparrow, Bachman's Sparrow, Northern Bobwhite, and Eastern Box Turtle, and others that can be of conservation concern at the state level such as the Dickcissel, Loggerhead Shrike, and Prairie Kingsnake. Some of these species are grassland obligates, and the high declines of grasslands under most scenarios is likely the reason for their future habitat loss. Furthermore, our land-use scenarios show limited conversion of crop/pasturelands back into natural rangelands, which may limit opportunities for habitat expansion. Over the last few decades, grassland species across much of the U.S have declined rapidly due to habitat conversion (Vickery and Herkert 2001, Sauer et al. 2008). The Southeast is naturally a forested region and current conservation efforts are correctly focused on forested ecosystems; however, including non-forested habitats in future forest-based conservation efforts may help conserve some of the most vulnerable grassland species.

Our results can be used to guide regional conservation efforts such as by the Landscape Conservation Cooperatives at the federal level, or by state natural resource agencies, to identify regions and species that may deserve priority attention, to inform regional land-use planning, and to enhance understanding of the potential effect of conservation policies in different regions. When interpreting our results, it is important to consider the limitations of our approach. We quantified changes in wildlife habitat based on area only and without considering potential changes in fragmentation and

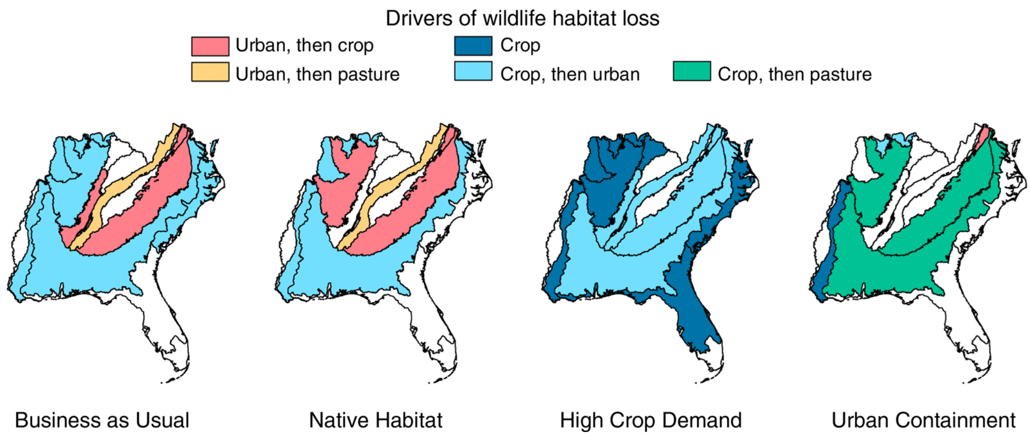

FIG. 5. Drivers of wildlife habitat loss under different scenarios of future land-use change 2001–2051. Only ecoregions with >10% species expecting >10% habitat loss are shown in color.

habitat configuration, which can influence habitat use (Fahrig 2003) and changes in habitat quality. We did so because while our land-use model is spatially explicit, it is not designed to project land use at the scale of habitat patches. In addition, we did not measure potential habitat loss due to commercial forestry because our econometric model does not discriminate between managed and unmanaged forests. This fact makes our estimates of habitat loss quite conservative if managed forests replace natural forest in the future, as managed forests generally have less structural and compositional complexity. We also modeled no changes in wetlands, streams, or vernal pools, and excluded species that are mostly associated with wet areas, which may underestimate threats for species dependent on these habitats, such as amphibians. Furthermore, our land-use model did not include other localized but intensive land uses such as mining, which may also affect wildlife habitat in the Southeast (Hanson et al. 2010). Land cover data with more detailed classes would be desirable for the assessments of habitat availability based on habitat associations, in particular for specialist species. Unfortunately, such data do not exist for land use change, where we were limited by the NRI data classes.

In addition, we did not distinguish between prime habitat and non-prime habitat, which can mask some consequences of policy. The Native Habitat scenario, for example, substantially reduced the loss of natural rangelands compared to the other scenarios, which can be positive for species using natural rangelands as primary habitats; yet this potential benefit was not reflected in our numbers. We believe that this is because species present in natural rangelands were also present in pastures (based on the SEGAP species-habitat), and pastures were projected to decline at a high rate under the Native Habitat scenario. Moreover, we did not measure changes in habitat quality (e.g., reproduction, survival) that may occur without changes in predicted habitat area. For species that occur both in natural areas and urban environments (40% according to SEGAP), for example, the expansion of urban cover into natural areas will likely constitute an increase of habitat

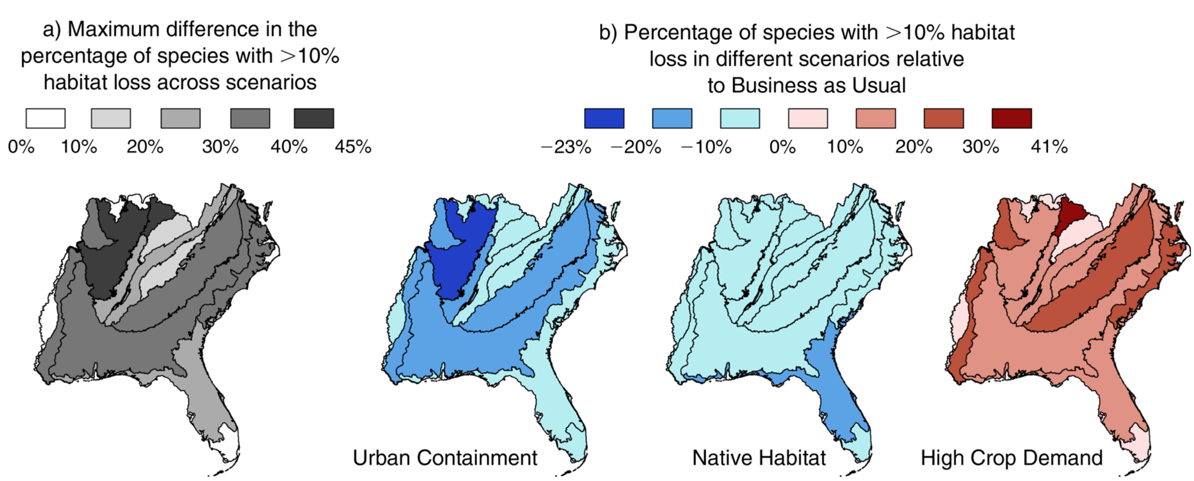

FIG. 6. Sensitivity of wildlife habitat loss in different ecoregions to land-use scenario.

degradation for most species, as abundance, density, and recruitment values are typically lower in urban areas (Borgmann and Rodewald 2004, Chamberlain et al. 2009), while a few species tolerant of anthropogenic changes dominate the avian community (Blair and Johnson 2008). We assumed no shifts in the geographic range of the species, which may occur due to climate change. For example, in the Blue Ridge ecoregion, where we observed generally low rates of habitat loss due to land-use changes, some species may see future declines due to climate change (Milanovich et al. 2010). Advances in these topics will improve our understanding of the consequences of future human decisions on land use and wildlife conservation. Finally, we acknowledge that there are errors in our input data, including the initial land cover (Wickham et al. 2010), the econometric model (Lubowski et al. 2006), and species-habitat associations based on expert knowledge (Iglecia et al. 2012), and that the type of models that we employed do not allow us to assess these errors fully. However, we have no reason to assume that these errors would have systematically affected one scenario more than any others.

Ultimately, future habitat loss due to land-use change will be an important threat to biodiversity globally, and the Southeast is not an exception. Our land use scenarios spanned a large range of potential policies and changes in economic conditions, but patterns of habitat loss were fairly consistent among them, and far from benign. Effective conservation of wildlife habitat in the Southeast will require special consideration to future land-use changes, regional variations, and the forces that shape land-use decisions.

Acknowledgments

We gratefully acknowledge support for this work by the National Science Foundation Coupled Natural-Human Systems Program, and by the U.S. Forest Service Northern Research Station. Two anonymous reviewers provided comments that greatly enhanced the manuscript.

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Supplemental Material

Ecological Archives

The Appendix and Supplement are available online: http://dx.doi.org/10.1890/13-2078.1.sm