Evaluating Biodiversity Response to Forecasted Land Use Change: A Case Study in the South Platte River Basin, Colorado

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Abstract

Effects of future land use change on watersheds have important management implications. Seamless, national-scale land-use-change scenarios for developed land were acquired from the U.S. Environmental Protection Agency Integrated Climate and Land Use Scenarios (lCLUS) project and extracted to fit the South Platte River Basin, Colorado, relative to projections of housing density for the period 2000 through 2100. Habitat models developed from the Southwest Regional Gap Analysis Project were invoked to examine changes in wildlife habitat and biodiversity metrics using five ICLUS scenarios. The scenarios represent a U.S. Census base-case and four modifications that were consistent with the different assumptions underlying the A1, A2, B1, B2 Intergovernmental Panel on Climate Change global greenhouse gas emission storylines. Habitat models for terrestrial vertebrate species were used to derive metrics reflecting ecosystem services or biodiversity aspects valued by humans that could be quantified and mapped. Example metrics included richness of species of greatest conservation need, threatened and endangered species, harvestable species (e.g., upland game, big game), and total vertebrate species. Overall, the defined scenarios indicated that housing density and extent of developed lands will increase throughout the century with a resultant decrease in area for all species richness categories. The A2 Scenario in general showed greatest effect on area by species richness category. Areas with low or high species richness were projected to experience the greatest declines. The integration of the land use scenarios with biodiversity metrics derived from deductive habitat models may prove to be an important tool for decisionmakers involved in impact assessments and adaptive planning processes.

Keywords: deductive habitat models, wildlife habitat, biodiversity metrics, ecosystem services, land use scenarios, South Platte River Basin

Introduction

While many direct and indirect stressors can affect biodiversity, land use change is considered to be the most significant (Sala et al. 2000, Mattison and Norris 2005, Swetnam et al. 2010). Land use and land cover change are two processes that have consequences on a global scale and are driven by population trends and urban growth (Bierwagen et al. 2010). The United States population is projected to be between 402-616 million in 2090, an increase of 31-55% from 2000 (EPA 2010).

The U.S. Environmental Protection Agency (EPA) has investigated the future impacts of population growth

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and urban development in depth. The Integrated Climate and Land Use Scenarios (ICLUS) dataset was created by the EPA to address the potential scenarios of population growth and housing development from 2000 to 2100 (Bierwagen et. al 2010, EPA 2009).

The U.S. Geological Survey Gap Analysis Program (GAP) has developed datasets for biodiversity conservation purposes in the continental United States (Prior-Magee et al. 2007). The GAP process provides landscape-level assessment for the conservation of biological diversity. GAP maps the distribution of plant communities and predicts the distribution of suitable habitat for terrestrial vertebrate species and compares these distributions with land stewardship to identify biotic elements at potential risk of endangerment. The baseline datasets GAP provides are uniquely suited for use with biodiversity assessments at broad multiple scales. The Southwest Regional Gap Analysis Project (SWReGAP) provides these datasets for the American Southwest states of Arizona, Colorado, Nevada, New Mexico, and Utah (Prior-Magee et al. 2007).

Evaluating the effect of urban encroachment and development on biodiversity is becoming increasingly important. Synthesis and analysis of future land use scenarios using datasets such as the ICLUS and SWReGAP habitat models are valuable to science and the future of conserving biodiversity, especially for informing land managers and decisionmakers about potential consequences and benefits of environmental management choices.

Study Area

The South Platte River Basin ranges from the plains of western Nebraska, eastern Colorado, and Wyoming to the mountains of the Front Range in Colorado (Figure 1). Within the South Platte River Basin are many rapidly growing cities, such as Denver and Fort Collins, Colorado, each with increasing pressures on terrestrial and aquatic environments caused by land use change and water development. This area has a projected population growth exceeding 50 percent by 2050 (U.S. Census Bureau 2005), suggesting continued growth and land use change in the future.

Overall, the South Platte River Basin spans 62,580 km^2 with vegetation ranging from grasslands in the plains to mixed conifer forests in the mountains. The study area comprised the portion of the basin within Colorado due to the availability of spatial data and habitat models from SWReGAP (Figure 1). Of the 49,030 km^2 within Colorado, approximately 28 percent is classified as agriculture, 22 percent as Rocky Mountain Ponderosa Pine, and 7 percent as Western Great Plains Sandhill Shrubland (Prior-Magee et al. 2007).

Figure 1. Location and extent of the study area (black) within the South Platte River Basin (black and grey).

Methods

The EPA-ICLUS (Version 1.3.1) dataset was used to assess habitat change and effects on biodiversity metrics. These seamless, national-scale land-use-change scenarios for developed land were acquired from EPA's Office of Research and Development (EPA 2010). The data were extracted from the national coverages for the South Platte River Basin. This dataset allowed for analysis of projections of housing density for the period 2000 through 2100 for the five ICLUS scenarios, including a U.S. Census baseline and four modifications consistent with the different assumptions underlying the A1, A2, B1, and B2 Intergovernmental Panel on Climate Change (IPCC) global greenhouse gas emission storylines (Table 1; Bierwagen et al. 2010). The five ICLUS datasets were reclassified to identify urban (1) or nonurban areas (0).

For this analysis we characterized 4 biodiversity metrics of 17 available (Table 2). These were total vertebrate species richness (maximum=239), state designated Species of Greatest Conservation Need (SGCN) richness (maximum=98), federally Threatened and Endangered (T&E) species richness (maximum=12), and all harvestable species (e.g., upland game, big game) richness (maximum=50). The remaining 13 biodiversity metrics will be examined in subsequent study.

Table 1. EPA land-use-change scenarios for the conterminous United States (Bierwagen et al. 2010).

Scenario	**Description**
Baseline condition (BC)	Represents a level of medium fertility rates, medium domestic migration, and medium international migration.
A1	Represents fast economic growth, low population growth, and high global integration. Fertility is low with high domestic and international migration.
B1	Represents a globally integrated world but with more emphasis on environmentally sustainable economic development. Fertility and domestic migration are low while international migration is high.
A2	Represents continued economic development, with more regional focus and slower economic convergence between regions. Fertility and domestic migration are high and international migration is medium.
B2	Represents a regionally-oriented world of moderate population growth and local solutions to environmental and economic issues. Fertility rates are medium with low domestic migration and medium international migration.

The four biodiversity metrics were derived from 817 terrestrial vertebrate habitat models developed from SWReGAP (Boykin et al. 2007, 2010). We categorized each metric into four equal intervals of species richness (Appendix A).

Using ESRI ArcGIS 10, the current (year 2000) condition was characterized for the four biodiversity metrics. Current condition provides a baseline comparison for subsequent scenarios. The areas of each species richness category for each biodiversity metric were then quantified for nonurban land cover using the five ICLUS future development scenarios. ICLUS classified areas with housing density greater than 0.8 hectares per housing unit as nonurban (EPA 2010). The change in square kilometers and relative change of land classified as urban and nonurban were calculated and compared among the 5 future development scenarios for the year 2100. This change analysis allowed for examination of biodiversity metrics under each scenario.

Table 2. List of 17 available biodiversity metrics for species richness derived from the Southwest Regional Gap Analysis Project (Prior-Magee et al. 2007). Metrics in italics were used in the present study.

Biodiversity metrics
All vertebrate species
Reptiles
Amphibians
Birds
Mammals
Threatened and Endangered species
All Species of Greatest Conservation Need
Reptile Species of Greatest Conservation Need
Amphibian Species of Greatest Conservation Need
Bird Species of Greatest Conservation Need
Mammal Species of Greatest Conservation Need
All harvestable species
Harvestable upland game species
Harvestable big game species
Harvestable furbearer species
Harvestable waterfowl species
Bat Species of Greatest Conservation Need

Results

Ninety-seven percent of the South Platte River Basin study area was classified as nonurban using the Baseline 2000 Scenario (Table 3). This extent decreased by 2100 in all scenarios to 92-94%, with scenario A2 decreasing the greatest. The majority of area classified as nonurban within the study area was associated with species richness categories 2 and 3 (Figure 2).

Table 3. Nonurban and urban area (km^2) and % of total for baseline 2000 and five future land-use change scenarios (A1, A2, B1, B2, and BC; see text)

	Nonurban		Urban	
	(km2)	(%)	(km2)	(%)
Baseline 2000	47,425	97	1,523	3
A1 2100	45,708	93	3,240	7
A2 2100	44,873	92	4,074	8
B1 2100	46,219	94	2,729	6
B2 2100	45,852	94	3,095	6
Baseline 2100	45,867	94	3,081	6

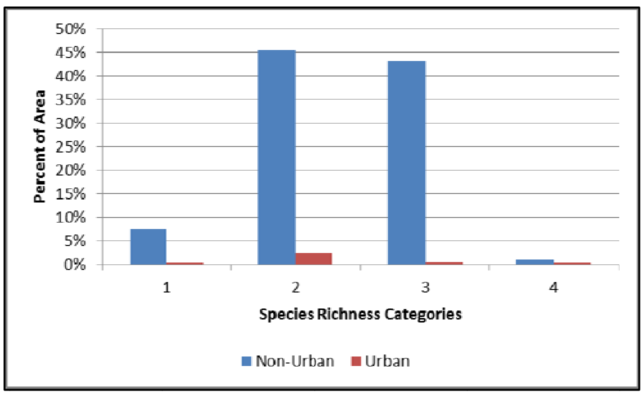


Figure 2. Percent of urban or nonurban area within the South Platte study area by total vertebrate species richness category for the baseline 2000 reference condition. Categories range from 1 (lowest richness) to 4 (highest richness; Appendix A).

A reduction in area based on predicted suitable habitat was identified for all species richness categories for all biodiversity metrics in all scenarios (Figures 3A–D). The decrease in area ranged from 1 to 12%. The A2 Scenario resulted in the greatest decreases with 7 of the category-metric comparisons resulting in a 7% or greater change. The A2 Scenario represents continued economic growth, high population growth and high domestic and medium international migration.

Species richness categories 1 and 4 had the highest decreases in total species richness, SGCN richness and T&E richness (Figure 3A–D). Thus, the analysis suggests that the most species rich (category 4) and species poor (category 1) areas will be detrimentally affected by urbanization. Each species categories contained equal number of species; however the amount of area for these categories was quite different (Figure 2). Categories 1 and 4 had a very small extent in 2000 (Figure 2), and thus small changes in area lost can have large effects on the percentage of area lost for these categories.

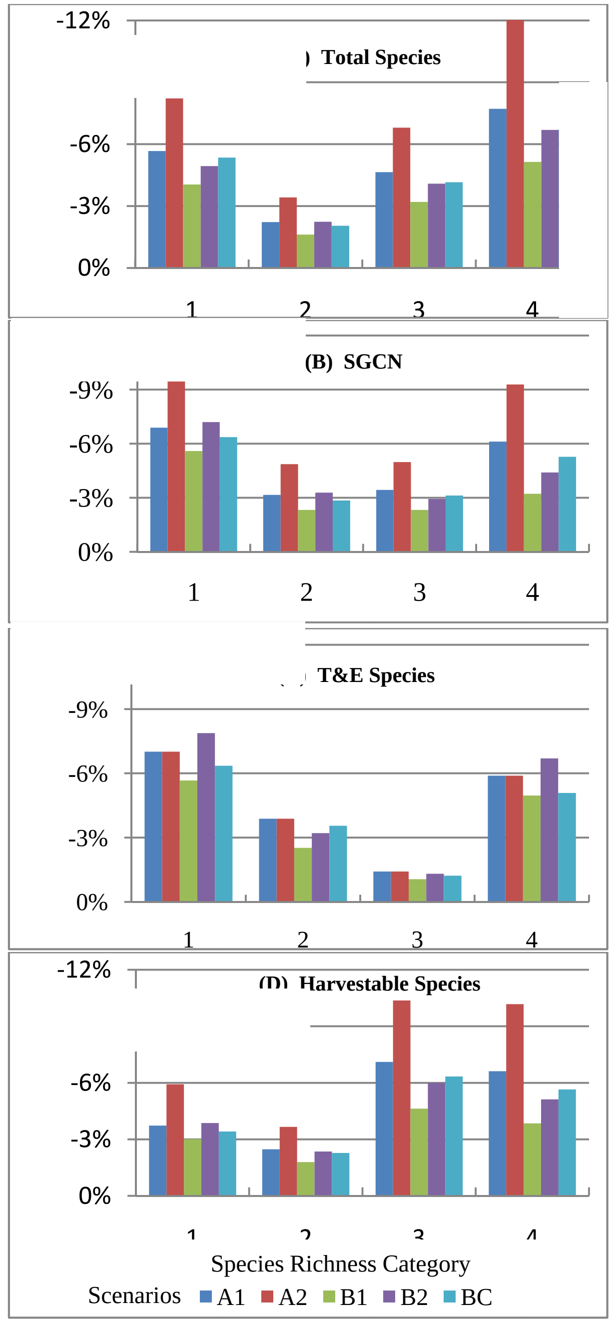
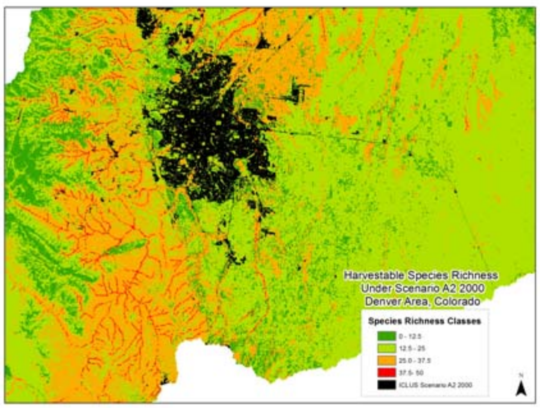


Figure 3. Relative change (%) in extent of nonurban land cover to 2100 across five future land use change scenarios within four species richness categories for (A) total vertebrate species (B) Species of Greatest Conservation Need (SGCN), (C) Threatened and Endangered species, and (D) harvestable species. Future change scenarios were A1, A2, B1, B2, and BC (see text). The four species richness categories range from 1 (lowest richness) to 4 (highest richness; Appendix A).

Harvestable species showed a different pattern for relative change by species richness categories under the 5 scenarios in comparison to the other three species richness metrics. Specifically, richness categories 3 and 4 showed the greatest extents of declines rather than categories 1 and 4 (Figure 3D). This resulted from categories 3 and 4 being well represented in areas of projected urban growth. The spatial pattern of harvestable species (Figure 4) identifies an abundance of categories 3 and 4 occurring near Denver and the cities of the Front Range. Urban growth also affects a large portion of Category 2 south of Denver; however, this is a smaller percentage of this category.

A



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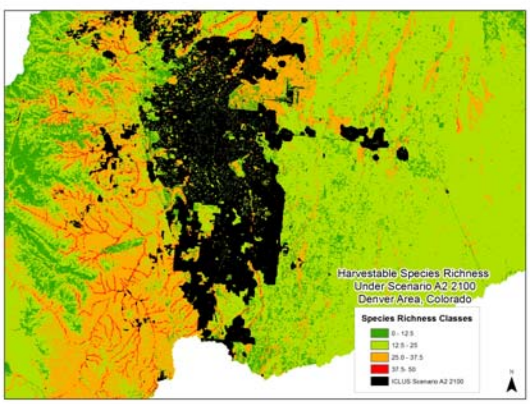

Figure 4. Distribution of harvestable species richness categories for current urban extent from Baseline 2000 (A) and future urban extent from A2 Scenario 2100 (B) surrounding Denver, Colorado within the South Platte River Basin study area.

Conclusions

The analysis indicated declines in nonurban extent over the next century. This change is projected to result in decreases in extent of area for all species richness categories for the four metrics examined: total vertebrate species, Species of Greatest Conservation Need, Threatened and Endangered species, and harvestable species. Among the five climate change scenarios, Scenario A2 presents the greatest increase in urban growth both in percent change and total area. Areas with low or high species richness are projected generally to experience the greatest declines. Areas with suitable habitat for high numbers of harvestable species will be affected by this urban growth.

Our purpose was to integrate available land use scenarios with deductive habitat models to provide an important tool for decisionmakers involved in impact assessments and adaptive planning processes across a variety of environmental management sectors. This initial analysis will be followed by future work on the remaining 13 biodiversity metrics (Table 2) and in different geographies to test transferability of the process.

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Appendix A

Extent and change in land cover types from the baseline scenario in 2000 for five climate change scenarios, four biodiversity metrics, and four categories of species richness (1, low; 4, high). Biodiversity metrics were species richness for total vertebrate species, Species of Greatest Conservation Need (SGCN), Threatened and Endangered (T&E) species, and harvestable species. For nonurban and urban "% of total" refers to % of total land cover in study area. Relative change (%) refers to area of nonurban land cover in scenario relative to area of nonurban land cover in Baseline Scenario 2000.

	Total vertebrate species				**SGCN species**				**T&E species**				**Harvestable species**			
Species richness category (number of species)	1 (4–59)	2 (60–119)	3 (120–179)	4 (180–239)	1 (1–24)	2 (25–49)	3 (50–74)	4 (75–98)	1 (0–3)	2 (4–6)	3 (7–9)	4 (10–12)	1 (0–12)	2 (13–24)	3 (25–37)	4 (38–50)
Baseline Scenario 2000																
Nonurban (km^2)	3,590	22,229	21,105	501	3,010	12,214	31,555	646	6,276	27,959	13,090	100	5,800	31,405	9,694	526
Urban (km^2)	96	1,184	228	15	351	1,011	154	7	1,283	174	64	2	373	1,030	112	7
Nonurban (% of total)	7%	45%	43%	1%	6%	25%	64%	1%	13%	57%	27%	0%	12%	64%	20%	1%
Urban (% of total)	0%	2%	0%	0%	1%	2%	0%	0%	3%	0%	0%	0%	1%	2%	0%	0%
A1 Scenario 2100																
Nonurban (km^2)	3,387	21,734	20,125	462	2,802	11,829	30,471	607	5,836	26,874	12,904	94	5,584	30,629	9,005	492
Urban (km^2)	302	1,680	1,205	53	560	1,397	1,236	46	1,725	1,257	251	7	590	1,807	801	42
Nonurban (% of total)	7%	44%	41%	1%	6%	24%	62%	1%	12%	55%	26%	0%	11%	63%	18%	1%
Urban (% of total)	1%	3%	2%	0%	1%	3%	3%	0%	4%	3%	1%	0%	1%	4%	2%	0%
Relative change (%)	–6%	–2%	–5%	–8%	–7%	–3%	–3%	–6%	–7%	–4%	–1%	–6%	–4%	–2%	–7%	–7%
A2 Scenario 2100																
Nonurban (km^2)	3,295	21,468	19,670	440	2,683	11,620	29,985	586	5,836	26,874	12,904	94	5,457	30,256	8,688	473
Urban (km^2)	393	1,946	1,660	75	679	1,606	1,723	67	1,725	1,257	251	7	717	2,180	1,117	60
Nonurban (% of total)	7%	44%	40%	1%	5%	24%	61%	1%	12%	55%	26%	0%	11%	62%	18%	1%
Urban (% of total)	1%	4%	3%	0%	1%	3%	4%	0%	4%	3%	1%	0%	1%	4%	2%	0%
Relative change (%)	–8%	–3%	–7%	–12%	–11%	–5%	–5%	–9%	–7%	–4%	–1%	–6%	–6%	–4%	–10%	–10%
B1 Scenario 2100																
Nonurban (km^2)	3,445	21,869	20,430	475	2,841	11,930	30,822	625	5,921	27,253	12,951	95	5,625	30,842	9,245	506
Urban(km^2)	243	1,545	901	40	522	1,295	885	27	1,641	879	204	7	548	1,593	561	27
Nonurban (% of total)	7%	45%	42%	1%	6%	24%	63%	1%	12%	56%	26%	0%	11%	63%	19%	1%
Urban (% of total)	0%	3%	2%	0%	1%	3%	2%	0%	3%	2%	0%	0%	1%	3%	1%	0%
Relative change (%)	–4%	–2%	–3%	–5%	–6%	–2%	–2%	–3%	–6%	–3%	–1%	–5%	–3%	–2%	–5%	–4%
B2 Scenario 2100																
Nonurban (km^2)	3,413	21,730	20,242	467	2,793	11,812	30,630	618	5,782	27,060	12,917	93	5,576	30,666	9,112	499
Urban (km^2)	275	1,684	1,088	48	570	1,413	1,078	35	1,779	1,071	237	8	598	1,770	694	34
Nonurban (% of total)	7%	44%	41%	1%	6%	24%	63%	1%	12%	55%	26%	0%	11%	63%	19%	1%
Urban (% of total)	1%	3%	2%	0%	1%	3%	2%	0%	4%	2%	0%	0%	1%	4%	1%	0%
Relative change (%)	–5%	–2%	–4%	–7%	–7%	–3%	–3%	–4%	–8%	–3%	–1%	–7%	–4%	–2%	–6%	–5%
Baseline Scenario 2100																
Nonurban (km^2)	3,398	21,774	20,228	467	2,818	11,866	30,571	612	5,877	26,966	12,930	95	5,602	30,690	9,079	497
Urban (km^2)	290	1,640	1,103	48	544	1,359	1,136	41	1,684	1,166	225	7	572	1,746	727	37
Nonurban (% of total)	7%	44%	41%	1%	6%	24%	62%	1%	12%	55%	26%	0%	11%	63%	19%	1%
Urban (% of total)	1%	3%	2%	0%	1%	3%	2%	0%	3%	2%	0%	0%	1%	4%	1%	0%
Relative change (%)	–5%	–2%	–4%	–7%	–6%	–3%	–3%	–5%	–6%	–4%	–1%	–5%	–3%	–2%	–6%	–6%