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Chapter 11: Management Considerations

Steven T. Knick, Steven E. Hanser, Matthias Leu, Cameron L. Aldridge, Scott E. Nielsen, Mary M. Rowland, Sean P. Finn, and Michael J. Wisdom

Abstract. We conducted an ecoregional assessment of sagebrush (*Artemisia* spp.) ecosystems in the Wyoming Basins and surrounding regions (WBEA) to determine broad-scale species-environmental relationships. Our goal was to assess the potential influence from threats to the sagebrush ecosystem on associated wildlife through the use of spatially explicit occurrence and abundance models. These models were developed using information from field surveys conducted along gradients of vegetation productivity and human disturbance integrated with spatial datasets delineating land cover, topography, and human land use in the WBEA area. Our evaluation included all sagebrush-associated wildlife species across multiple taxa whose habitat requirements and distributions were appropriate for modeling and interpretation at the broad scales of this assessment. Dominant land uses were included in delineating the human footprint. Although overall levels of the cumulative human footprint were generally low across the WBEA area, oil and gas activities have decreased the amount of shrubland habitats and increased fragmentation within development regions over the last century. At the scale of this assessment, the influence of humans was primarily expressed as an indirect function through actions that altered or reduced available habitat. We identified 65 plant species of conservation concern; 28 of 40 vertebrate species associated with sagebrush were species of concern in at least one state. We modeled environmental relationships for 15 wildlife species from data collected from surveys conducted in 2005 and 2006 designed to sample multiple species and taxa along land cover and land use gradients across the WBEA area. Occurrence of 3 species was negatively influenced by human features; anthropogenic features were a positive influence for 3 species, 8 had a mixed response, and 1 had no measureable relationship. Sagebrush land cover, considered in all wildlife models, was important to most species but differed among species in the proportion of sagebrush required and at what spatial extent. For most species examined, the spatial extent at which sagebrush cover influenced the probability of occupancy was much larger than an individual's home range size. Exotic plants were strongly associated with human features, particularly roads, which may function as linear vectors to facilitate spread of exotic plants across the WBEA area. We used coarse-grained spatial and thematic data because of the large spatial extent (350,000 km^2) of the WBEA area and the need for a consistent land cover map for the region. Distributions of species occurrence or abundance mapped in this assessment need to be corroborated with information on population demographics. In addition, our results should be interpreted relative to assumptions inherent in broad-scale ecoregional assessments. Our assessment provides managers with extensive and detailed maps of occurrence and abundance, allowing for status assessments of native species, diversity and richness, natural communities, and ecological systems present within the Wyoming Basins.

Key words: ecoregional assessment, land use, management considerations, sagebrush, species habitat models, Wyoming Basins.

The Wyoming Basins Ecoregional Assessment (WBEA) area encompasses one of the most expansive regions of sagebrush (*Artemisia* spp.) habitats remaining in western North America. Two-thirds of the WBEA area and half of the 131,000 km^2 covered by sagebrush is public land managed for multiple use (Ch. 1). Thus, some of the largest extant populations of sagebrush-obligate species, such as greater sage-grouse (*Centrocercus urophasianus*), Brewer's sparrows (*Spizella breweri*), pygmy rabbit (*Brachylagus idahoensis*), and pronghorn (*Antilocapra americana*), co-occur in areas that also are important for energy development and transmission, livestock grazing, and recreation. As such, management strategies and land use activities within the WBEA area have a substantial effect on a large portion of the range-wide distribution of sagebrush and persistence of many species that depend on these habitats. The WBEA area contains some of the most significant onshore energy resources in the United States (U.S. Departments of the Interior, Agriculture, and Energy 2006, 2008). Oil and natural gas reserves coupled with the potential for wind energy within this region can supply much of the nation's increasing demand for energy (Doherty et al. 2011). Effects of energy development often are quantified for the area immediately surrounding the physical structures associated with development. Individual and combined effects of different disturbance types and intensities on plants and wildlife, cumulatively defined as the human footprint, often are difficult to quantify for a single region. The broad-scale effects created by multiple developments with accompanying infrastructure for energy transmission across large spatial extents are even more difficult to assess. Yet understanding these broad-scale impacts is an important aspect of conservation because of their potential to influence species at a population or range-wide scale (Leu et al. 2008).

Ecoregional assessments consist of a series of spatial analyses conducted in a Geographic Information Systems (GIS) to identify relationships among species distributions and environmental and human features over broad spatial extents spanning regions to continents (Table 11.1). The information derived from these analyses can help address large-scale, range-wide factors likely to affect the well-being of species of concern, guide the development of management plans to reduce further loss or degradation of their habitats, and establish a basis for restoring habitats in the most time- and cost-effective manner possible (Ricketts et al. 1999, Noss et al. 2001, Jones et al. 2004, Wisdom et al. 2005a).

We conducted an ecoregional assessment of the Wyoming Basins and surrounding regions to provide a regional

TABLE 11.1. Primary steps in an ecoregional assessment (Wisdom et al. 2005a).

1. Identify the ecoregion and spatial extent to be included in the analysis
2. Identify the species of conservation concern
3. Determine habitat associations of species
4. Delineate boundaries of the species range and map distribution within the range
5. Identify natural disturbances and human activities
6. Identify potential risks to species or its habitat
7. Map the extent of individual and cumulative risk factors
8. Identify and develop management actions

broad-scale understanding from which local conservation and restoration actions can be designed. Broad-scale information can provide significant regional perspectives to management by land and wildlife agencies. When integrated with an understanding of patterns and processes from other scales of an ecological system's organization, managers have a powerful array of information from which to understand habitat relationships for species of concern and to develop or adapt land use actions that enhance their conservation. Our objectives were to: (1) identify the primary land uses and their potential influence on sagebrush habitats; (2) identify plant and wildlife species of concern; (3) delineate the distribution of sagebrush habitats and environmental and anthropogenic features from existing and updated GIS coverages; (4) conduct field surveys to determine distribution and abundance of wildlife species and invasive plants; (5) integrate field and GIS-based information to determine habitat relationships using spatially explicit models; and (6) apply spatially explicit models of habitat relationships to delineate species occurrence and abundance. Results of our regional assessment thus provide an increased understanding of the dominant distributional patterns and an enhanced insight into the underlying ecological processes that shape sagebrush ecosystems across the WBEA area.

OBJECTIVES

1. Identify the Primary Land Uses and Their Potential Influence on Sagebrush Habitats

The primary threats to the sagebrush steppe ecosystem were: (1) weather, climatic changes, and catastrophes; (2) highways, secondary roads, and trails/two-tracks; (3) improper livestock grazing practices; and (4) oil and natural gas field development (Ch. 1). Sagebrush areas in the Wyoming Basins represent a stronghold compared to current status and predicted changes from land use or climate change for other ecoregions (Aldridge et al. 2008, Knick and Hanser 2011, Wisdom et al. 2011). However, the synergistic effect of human land use and other disturbances, such as invasion of exotic plants, may offset this relative stability. In addition, the overarching long-term impact of climate change further increases the concern for long-term conservation in the WBEA area.

Roads and trails were dominant features in the Wyoming Basins. Secondary roads (21% of the study area using maximum effect zone) and agriculture (7%) were major land-use features covering the WBEA area (Ch. 1, 3). Roads and other anthropogenic features were associated with the presence of four common invasive plant species (Ch. 10). In particular, cheatgrass (*Bromus tectorum*), crested wheatgrass (*Agropyrum cristatum*), and Russian thistle (*Salsola* spp.) were strongly associated with roads and energy well sites. Russian thistle was likely to occur within 0.55 km of interstates and highways, and 1.3 km of oil and gas wells. Crested wheatgrass, a species commonly planted by land management agencies, was likely to occur within 852 m of interstates and highways and 270 m of oil and gas wells (Ch. 10). Roads can function as a conduit for spreading these exotic plants, which increases the effective area of disturbance in addition to the physical habitat displaced by the road surface (Gelbard and Belnap 2003). Cheatgrass invasion and dominance in the sagebrush understory is of particular concern, especially in lower-elevation xeric landscapes, because it increases the probability of large-scale stand-replacing fires that ultimately affect ecosystem composition, structure, and function (Billings 1990, Brooks et al. 1994, Baker 2006, Miller et al. 2011).

Livestock grazing is a dominant land use throughout the WBEA area. Although local influences of livestock grazing have been described (Beck and Mitchell 2000, Jones 2000, Freilich et al. 2003), we lacked suitable information on livestock numbers and distribution to spatially model impacts of grazing on sagebrush landscapes. In the initial phase of this assessment, we contacted all Forest Service and Bureau of Land Management administrative units to obtain spatial data on livestock grazing. No consistent data were available at any jurisdictional level of either agency. Consequently, we could not assess the potential relations of livestock grazing with habitats or occurrence of the species of conservation concern.

Oil and gas extraction influence the landscape and wildlife but is restricted primarily to the Powder River Basin in northeastern Wyoming and southern Montana (outside the boundaries of our assessment), and the Upper Green River Basin in southern and western Wyoming (Ch. 3). Almost 34,000 oil and gas wells have been drilled and 110,000 km of service roads have been constructed in the WBEA area from 1900 to 2009; in designated fields in Wyoming, well pads and associated roads have eliminated an estimated area >200 km^2 of shrubland habitats since 1900 (Ch. 3). In the WBEA area, oil and gas development removed approximately 1,703 km^2 of sagebrush and other native habitats owing to construction of well pads and supporting infrastructure, such as roads, power lines, and pipelines. Shrubland and grassland land cover were most affected; only 3% of land cover conversions were in riparian or forest land cover. Landscapes have become increasingly fragmented due to decreased patch size of sagebrush and increased number of habitat edges associated with the networks of road, power, and transmission infrastructure. The spatially pervasive pattern of oil and gas wells, the substantial loss in habitat resulting from their development, and their effects on adjacent areas indicate that management and mitigation of this land use will have substantial influence on persistence of the suite of species of concern in the WBEA area (Walston et al. 2009, Naugle 2011, Naugle et al. 2011).

The WBEA area had relatively low influence from human activities when mapped at broad spatial scales compared to other western U.S. regions (Leu et al. 2008). Across the western United States, human footprint intensity increased at lower elevations and in regions containing deeper soils (Leu et al. 2008). Areas surrounding cities received the greatest influence from humans; national parks were least influenced. Although most of the WBEA area (81%, including all habitats) had relatively low influence, high footprint scores (indicating localized, high intensity disturbance) were mapped in 5% of the WBEA area.

2. Identify Plant and Wildlife Species of Conservation Concern

Multi-species evaluations, such as those presented in this assessment, are effective in that management activities or conservation reserves may be designed to benefit several species at once, with costs often little more than those associated with managing for single species (Block et al. 1995, Jennings 2000). Management of sagebrush habitats currently is directed towards benefitting greater sage-grouse (Dobkin 1995, Rowland et al. 2006, Doherty et al. 2011, Hanser and Knick 2011). However, an increasing number of sagebrush-obligate species also are experiencing population declines (Dobkin and Sauder 2004). Therefore, a coarse-filter approach, such as used in this assessment, may be required to manage an appropriate amount and arrangement of all representative land areas and habitats that will provide for the needs of the suite of associated species (Groves et al. 2000, Wisdom et al. 2005a). Understanding the range of sagebrush characteristics required by this suite of species is important if this approach is to be successful and to conserve these ecosystems within the WBEA area.

We identified plant and animal species of concern within the WBEA area by reviewing existing literature and state lists of species of concern, and consulting with experts (Ch. 2). Primary criteria for species selection were a strong association with sagebrush ecosystems and a recognized status of conservation concern due to habitat loss or declining populations. We filtered this list by including species having relatively widespread distribution and whose habitats can be mapped accurately at regional scales. Species lists were reviewed by agency and non-governmental biologists. Of 65 plant species of concern, 59 were found in Wyoming, 40 in Colorado, 43 in Utah, 28 in Montana, and 15 in Idaho. We listed 40 species of vertebrate animals that depend on sagebrush habitats for some or all of their annual life cycle, including 1 amphibian, 4 reptiles, 18 birds, and 17 mammals. Twenty-eight of the 40 vertebrate species were listed as a species of concern by at least one state in the WBEA area. The large number of species of concern, and the diverse taxonomic groups represented, suggest that no single species or environmental characteristic can be used to manage lands effectively for all species of concern in the Wyoming Basins. Instead, our results suggest that more comprehensive multi-species approaches will be required for management planning.

Our assessment has improved understanding of environmental relationships for many species across a range of taxa in the WBEA area. Habitat requirements of commodity species (game or furbearer species, such as greater sage-grouse) and species listed under the Endangered Species Act are well understood in comparison to species that have neither commodity nor TE status (Wisdom et al. 2002). Also, our understanding of habitat requirements is better for birds than for mammals and for mammals than reptiles and amphibians (Bonnet et al. 2002, Wisdom et al. 2002, Dobkin and Sauder 2004). Even for birds, the WBEA area is among the areas least consistently sampled among all physiographic provinces (Dobkin and Sauder 2004). Therefore, our spatially explicit models provide new information on habitat relationships and distribution for species of conservation concern within the WBEA area.

3. Delineate the Distribution of Sagebrush Habitats and Environmental and Anthropogenic Features from Existing and Updated GIS Coverages

We used the Existing Vegetation Type map (Landfire 2007) to delineate land cover in the WBEA area. Although we focused on sagebrush, we also included grassland, coniferous forest, mixed shrubland, riparian, and salt-desert shrub land covers. In addition, our set of environmental variables included metrics for vegetation productivity, soil characteristics, terrain-derived variables, distance to water, and climate.

Eleven anthropogenic features were used to model the human footprint in the WBEA area (Ch. 4). A relative ranking based on a linear summation of features was used to delineate the distribution and cumulative intensity of human disturbance. The footprint score summarized the number of human disturbance types but did not account for potential synergistic or threshold effects. We also estimated the distance to anthropogenic features.

Each land cover type, two environmental variables (topographic ruggedness and vegetation productivity), and density of roads, were averaged within a circular window that varied in size corresponding to 7 representative species home ranges (Ch. 4). We calculated landscape metrics (contagion, patch size, edge density) for sagebrush at 3 representative circular window sizes (McGarigal et al. 2002). We also derived non-linear proximity metrics for six anthropogenic features using an exponential decay equation at 5 different distance parameters (Ch. 4, 10). In all, we used 154 predictor variables to develop species-environmental relationships. Consequently, our assessment represented a comprehensive evaluation of the land-cover and land-use variables that influence a broad suite of species associated with sagebrush in the WBEA area.

4. Conduct Field Surveys to Determine Distribution and Abundance of Wildlife Species and Invasive Plants

Ecoregional assessments based on existing data are increasingly used as a cost- and time-effective alternative in conservation and management planning. However, extrapolating statistical functions developed from other regions can limit the effectiveness of this approach because modeled relationships may not be directly transferable and are rarely evaluated with field data collected within the assessment area. Therefore, we conducted field surveys within the WBEA area during 2005 and 2006 to determine species-environmental relationships (Ch. 4). Many of the species-environment associations developed for the WBEA area differed from other regions and emphasized the importance of including field surveys in developing ecoregional assessments. For example, our field surveys documented new occurrences of pygmy rabbits more than 100 km outside their previously known distribution. Species-specific responses to individual environmental variables and maps of occurrence and abundance derived from those relationships would have differed greatly if based on information derived from other regions. Our study presents some of the first empirically-based models of species' relationships to land use measured across a broad spatial extent.

We stratified our field sampling along gradients of NDVI, a productivity index derived from satellite imagery, and human land use (based on a human footprint score) within sagebrush-dominated land cover in the WBEA area. Our survey design addressed multiple criteria:

1. The broad-regional extent of the WBEA encompassed an extremely wide variation in environmental and land use gradients operating at multiple spatial and ecological scales.
2. The list of species of concern included a large number of species and taxa across a broad range of home range sizes and distributions.
3. Survey methods, timing of surveys, and observer ability varied by species.
4. Available funding, personnel, and logistics limited survey effort.

The design was hierarchical and incorporated survey transects and blocks sampled at different spatial scales. Multiple survey methods were employed, and observer expertise was focused to most effectively sample the range of taxa associated with sagebrush habitats. Finally, our design efficiently and effectively focused resources for sampling the WBEA area (Ch. 4).

5. Integrate Field- and GIS-based Information to Determine Habitat Relationships Using Spatially Explicit Models

We determined the habitat associations underlying the mapped distributions of species from field-collected data. We followed a naive approach in the statistical analyses to develop species-environment relationships (Ch. 4). For most species, we lacked knowledge about specific responses to land use or land cover variables and which spatial scales governed the response. We used an Information Theoretic Approach (Burnham and Anderson 2002) to evaluate candidate models in a hierarchical process to identify final models of species-environment relationships having the best fit to the data. We evaluated our results using data available from independent sources, such as Breeding Bird Surveys (Sauer et al. 2008) and lek distributions for greater sage-grouse. Model evaluation is an important step in any model process. However, model evaluation is not often incorporated into ecoregional assessments due to lack of time or independent data. Positive results obtained using independent data strengthens the value of our conclusions. Species responded differently to the broad suite of habitat variables used to develop the models; specific variables and coefficients varied widely among the species.

We constrained the final models to include sagebrush and/or NDVI. Consequently, sagebrush presence within at least one spatial scale of the sampling point was an important factor in predicting presence for most species (Table 11.2). The proportion of the landscape dominated by sagebrush habitats and the spatial scale of the landscape differed among species. The landscape scale that influenced the probability of occurrence was much larger than the size of individual home ranges for all species except pronghorn and greater sage-grouse. For many species, the amount of sagebrush within a 1- and 5-km radius of the survey point had a strong influence on their presence. The landscape surrounding survey points, at the selected scale, had more sagebrush at occurrence locations for all species except deer mouse (*Peromyscus maniculatus*) and least chipmunk (*Tamias minimus*) (Table 11.2). Mean percent sagebrush land cover was >10% higher at occurrence compared to absence sites for 6 of the 15 modeled species. Our modeled outcomes indicate that greater sage-grouse (roost and general use), sage thrasher (*Oreoscoptes montanus*), harvester ant (*Pogonomyrmex* spp.), short-horned lizard (*Phrynosoma hernandesi*), white-tailed jackrabbit (*Lepus townsendii*), cottontail rabbit (*Sylvilagus* spp.), least chipmunk, and pronghorn were likely to occur in landscapes in which >50% of the land cover was dominated by sagebrush (Table 11.2). Therefore, managing to maintain sagebrush as the dominant land cover at large spatial scales (5-km radius = 79 km^2; 18-km radius = 1,018 km^2) will be important to conserving many of these species. Loss of sagebrush habitats below thresholds identified by the dose-response curves because of natural or human-related disturbance likely will have a negative effect on a species.

Response to human features varied by species and spatial scale (Table 11.3). Greater sage-grouse, a candidate species for protection under the Endangered Species Act (U.S. Department of the Interior 2010), was most consistent among species in a negative response to presence of oil and gas wells, interstates/major highways, and power lines (Ch. 5). The proximity to interstates and major highways consistently had an influence at the largest decay distance tested, and five of the six species that responded were negatively affected by these features. Similarly, sage-grouse lek trends across the species range show a negative association with proximity to these features (Johnson et al. 2011). Long-term conservation will require off-site mitigation or offsets if current levels of energy and infrastructure development continue (Kiesecker et al. 2009, Doherty et al. 2011).

Other wildlife species had either mixed or positive responses (Table 11.3), which illustrates the complexity of managing habitats for multiple species. However some of these responses, or lack of response, may have been an artifact of our sampling. A survey design less widely dispersed may be more appropriate for identifying direct influences of human activities that create localized disturbance patterns. At the broad-scale of an ecoregional assessment, changes resulting from human land use may be expressed as altered occupancy/abundance patterns due to habitat loss or altered habitat conditions rather than a specific identified predictor variable. This may be particularly true across the WBEA area, where multiple land uses contribute to a larger cumulative human footprint. Thus, species models to predict occupancy or abundance may reflect measured habitat variables rather than the underlying driver of habitat characteristics.

TABLE 11.2. Summary of sagebrush habitat, scale of influence, and proportion of sagebrush habitat required to support occurrence or abundance of 15 modeled sagebrush associated species. Differences between present/absent survey block locations are shown for each key sagebrush variable. All models also contained other habitat and/or abiotic variables, which are not presented here (see Chapter 5-9). Predicted area in the Wyoming Basins Ecoregional Assessment (WBEA) area indicated the area where a given species is predicted to be present (occurrence models) or be present at the lowest recorded density, based on model defined thresholds.

			Sagebrush					NDVI		Sagebrush/ NDVI interaction
Species	Model type	Predicted area in WBEA km² (%)	Variable	Response[a]	Radius km	Threshold proportion needed for occurrence	Difference between presence and absence survey locations %	Response[a]	Radius km	Response
Greater sage-grouse	Roost occurrence	52,979 (32.4)	All sagebrush[b]	+	1	0.88	14.6			
	General use occurrence	63,784 (39.2)	All big sagebrush[c]	+	1	0.81	13.2			
Brewer's sparrow	Abundance	302,891 (87.7)	All big sagebrush	+	1	0	9.3	+/-[d]	0.27	
Green-tailed towhee	Occurrence	230,078 (67.5)	Mountain sagebrush[e]	+	5	0	15.4	+	5	
Lark sparrow	Occurrence/ abundance	209,010 (60.5)	All big sagebrush	-/+	18	0	2.8	+/-	18	
Sage sparrow	Occurrence/ abundance	169,300 (49.0)	All sagebrush	-/-	18	0	6.1	-/+,+/-[d]	18	
Sage thrasher	Occurrence/ abundance	109,054 (31.6)	All big sagebrush	+/+	0.27	0.5	15.8	-/+, -/+[d]	18	
Vesper sparrow	Occurrence/ abundance	292,896 (74.8)	Big sagebrush	+/-	18	0	5.9	+/+	3	-/+
Harvester ant	Occurrence	99,555 (34.4)	All big sagebrush	-	5	>0.63 and <0.75	4.5	-	1	
Thatch ant	Occurrence	201,031 (58.2)	All sagebrush	+	3	0	5.9	+	5	
Short-horned lizard	Occurrence	46,648 (20.6)	All big sagebrush	+	5	0.81	10.7	-	18	

TABLE 11.2. Continued

			Sagebrush					NDVI		Sagebrush/ NDVI interaction
Species	Model type	Predicted area in WBEA km² (%)	Variable	Response[a]	Radius km	Threshold proportion needed for occurrence	Difference between presence and absence survey locations %	Response[a]	Radius km	Response
White-tailed jackrabbit	Occurrence	63,890 (22.1)	Big sagebrush[f]	+	0.27	0.82	13.6			
Cottontail rabbit	Occurrence	121,131 (41.9)	All sagebrush	+/-[d]	5	>0.60 and <0.75	1.6	-	5	
Least chipmunk	Occurrence	153,437 (44.4)	Big sagebrush	-	5	<0.60 or >0.91	-9.7			
Pronghorn	Occurrence	9,439 (13.3)	All sagebrush	+	0.27	<0.07 or >0.76	13.3	+	0.27	-
Deer mouse	Occurrence	180,321 (52.5)	All big sagebrush	-	0.27	0.41	-3.5	+/-[d]	270	

[a] Response is dependent on model type: occurrence or abundance models have a single response; occurrence/abundance models have a response for both occurrence and abundance (occurrence/abundance)
[b] All sagebrush: *Artemisia* spp.
[c] All big sagebrush: *A. tridentata* ssp. *tridentata, A. t.* ssp. *wyomingensis, A. t.* ssp. *vaseyana*
[d] Quadratic form (variable + variable^2): response listed includes both the single and squared term (single/squared)
[e] Mountain big sagebrush: *A. t.* ssp. *vaseyana*
[f] Big sagebrush: *A. t.* ssp. *tridentata, A. t.* ssp. *wyomingensis*

TABLE 11.3. Anthropogenic features that influenced species occurrence/abundance for 15 wildlife species modeled within the Wyoming Basins Ecoregional Assessment area and the relationship (+/-) and spatial extent (km) of measured response[a] (Ch. 5-9).

		Anthropogenic features						
		Proximity (km)[b]						Density[c]
Species		Agricultural land	Oil/gas wells	Pipelines	Power lines	Interstate/highways	Secondary roads	All roads
Greater sage-grouse	Roost occurrence		-1		-0.5	-1		
	General use occurrence		-1		-0.5	-1		
Brewer's sparrow	Abundance	+0.25						+18
Green-tailed towhee	Occurrence					-1		
Lark sparrow	Occurrence/abundance	-1/+1	+1/-1					
Sage sparrow	Occurrence/abundance		+0.25/+0.25					+18/-18
Sage thrasher	Occurrence/abundance						-1/+1	
Vesper sparrow	Occurrence/abundance			-1/-1				+3/+3
Harvester ant	Occurrence	+1	-0.25	+1				
Thatch ant	Occurrence	+1	-1		+1	-1		+18km
Short-horned lizard	Occurrence							
White-tailed jackrabbit	Occurrence			+0.5	-0.5	-1		-3
Cottontail rabbit	Occurrence				+1			
Least chipmunk	Occurrence		+0.5	-0.25	+1	+1		
Pronghorn	Occurrence				+1			+5
Deer mouse	Occurrence			-1				

[a] Response is dependent on model type: occurrence or abundance models have a single response; occurrence/abundance models have a response for both occurrence and abundance (occurrence/abundance)
[b] Proximity metrics were calculated as distance decay functions (value = $e^{(\text{Euclidean distance from feature (km)/-distance parameter})}$) using 3 distance parameters (0.25, 0.5, and 1 km). Distance parameters correspond to asymptotic values of 1.2, 2.4, 4.5 km, respectively.
[c] Road density was calculated using 6 moving window radii (0.27, 0.54, 1, 3, 5, 18 km) to model spatial extent

TABLE 11.4. Anthropogenic features that influenced invasive plant occurrence in the Wyoming Basins Ecoregional Assessment area (Ch. 10)

	Proximity[a] (threshold distance[b])								
Species	Agricultural land	Oil/gas wells	Pipelines	Powerlines	Interstate/highways	Secondary roads	Railways	Populated areas	Communication towers
Crested wheatgrass	-Dist (100 m)	+0.05 km (270 m)			+1 km (825 m)	+0.05 km	+5 km (2.5 km)	-Dist (1.6 km)	
Cheatgrass		+0.05 km			+0.05 km		-Dist	+1 km	
Halogeton	-Dist	+0.05 km		+0.05 km		+1 km	-Dist		+0.5 km
Russian thistle	-Dist	+1 km (1.3 km)	+0.25 km (1 km)		+0.5 km (550 m)	+0.25 km (90 m)		-Dist (700 m)	

[a] Proximity metrics were calculated as Euclidean distances (Dist) and distance decay functions (value = $e^{(\text{Euclidean distance from feature (km)}/\text{-distance parameter})}$) using 5 distance parameters (0.05, 0.25, 0.5, 1, and 5 km). Distance parameters correspond to asymptotic values of 1.2, 2.4, 4.5 km, respectively. Species positively associated with a particular feature type have a negative response to the Euclidean distance metric and positive response to distance decay values.

[b] Species are likely to occur at distances below the threshold distance. In cases without a threshold distance value, the species either did not have a strong response or were likely to occur across the entire range of potential distance values.

Invasive plant species all had positive relationships with proximity to human features (Table 11.4). The response to human features varied substantially among species and disturbance types. In general, roads and oil/gas wells had local to mid-scale effect zones; railroads, agriculture, and populated areas had large effect zones, possibly as a result of the development history within the WBEA area. Railroads, agriculture, and population centers have been a part of the landscape in the Wyoming Basins since the development of the transcontinental railroad in the late 1800s (Flores 2001), resulting in greater opportunity for establishment and invasion of exotic plants in association with these features. The profusion of secondary roads and oil/gas wells is a result of the recent rapid expansion of energy development in the Wyoming Basins, for which large-scale effects may be seen in the future.

6. Apply Spatially Explicit Models of Habitat Relationships to Delineate Species Occurrence and Abundance

We mapped the probability of occurrence or abundance for 15 vertebrate and 4 plant species within the WBEA based on environmental relationships determined from the spatially explicit empirical models. Coupling occurrence and abundance values across the landscape with an occurrence threshold allowed us to delineate areas where each species was likely to occur. Only six of the 15 wildlife species were predicted to likely occur in more than 50% of the region, and three species (pronghorn, short-horned lizard, and white-tailed jackrabbit) were likely in less than 30% (Table 11.2).

Our models for exotic plants emphasized the role of disturbance from anthropogenic features in facilitating invasion and establishment. Crested wheatgrass (*Agropyron cristatum*) was predicted to occur along roads and energy well pads throughout the WBEA area. Cheatgrass

(*Bromus tectorum*) and halogeton (*Halogeton glomeratus*) were predicted to occur in similar regions of the WBEA, especially the Wind River/Bighorn Basin, although their distribution was more limited by climatic factors. Nevertheless, local effects from roads and especially energy wells were noticeable in the species models, and spatial delineations illustrated the strong association with these disturbances (Ch. 10). Finally, the distribution of Russian thistle (*Salsola* spp.) was predicted to be common along Interstate 80 and other major highways, as well as across large areas of the Wind River/Bighorn Basin, and the area south of the Uinta Mountains of Utah.

The response curves developed for each of the modeled species in the WBEA represented the changes in the probability of a species presence or species abundance relative to changes in environmental variables in the context of all other variables influencing the species distribution. The threshold value identified a single or range of values required for presence to occur (Table 11.2). Thus, by using maps of predicted habitat change coupled with knowledge of the species response, managers can establish habitat protection and restoration plans that promote effective use of available and projected resources.

Our broad-scale maps depicting distributions for species of concern in sagebrush ecosystems can help to prioritize regions and guide selection of individual land treatments when restoring habitats (Wisdom et al. 2005b, Meinke et al. 2009). Similarly, maps delineating strongholds for individual or multiple species can be important for identification of specific locations for conservation, as well as for evaluating impacts of potential land cover changes. As such, this ecoregional assessment forms one part of an integrated multi-scale approach to developing management and conservation strategies.

Maps developed at the ecoregional scale can help inform management decisions from regional level down to the local level (Example 11.1). Knowledge of the locations across the ecoregion where species are likely to occur or have higher densities can be used to conserve important habitat in these areas and identify areas where restoration or mitigation may be most effective. These datasets are building blocks for future regional assessments and with the appropriate field validation the underlying equations can be used to create future predictions when updated GIS data on habitat and disturbance variables become available.

ASSUMPTIONS AND LIMITATIONS

All ecological assessments, regardless of the series of process steps or the scale at which they are conducted, require an explicit listing of assumptions and limitations for appropriate management use (Wisdom et al. 2005a). These assumptions and limitations are applicable to any regional assessment that uses remotely-sensed imagery to evaluate habitats, effects of anthropogenic disturbance, and environmental conditions for species of concern across large areas such as an ecoregion (Wisdom et al. 2005a). Thus, we list the primary caveats and guidance for appropriate use and interpretation of our results from the WBEA.

Species Selection and Range Mapping

The number and type of species of conservation concern selected for regional assessments will vary according to the criteria and methods used to develop the list. We used criteria and methods that were inclusive because (1) this ensured that all, or nearly all, potential species of concern were identified; and (2) a more comprehensive set of species of concern ensured that a wide range of associated habitats and anthropogenic effects can be assessed and considered in management (Ch. 2). The conservation status of many species is not clearly understood because a relatively large number of taxa are not yet ranked or have rankings that are inexact or uncertain (NatureServe 2001).

Several species of conservation concern in the WBEA area, such as rare plants, depend on fine-scale or micro-site environmental features that could not be mapped with the spatial layers available for our assessment. Ultimately, their distributions and environmental requirements may be too fine-scale and should not be included in a regional assessment.

We did not evaluate species of concern that occur in riparian zones or other localized habitat types within the sagebrush matrix. Linear habitats, such as narrow riparian corridors, could not be mapped at the spatial resolution of the available vegetation layer used in our assessment. Many of these species, such as MacGillivray's warbler (*Oporornis tolmiei*), have declining trends within shrub steppe landscapes (Dobkin and Sauder 2004, Rich et al. 2005) and should be considered when classified land cover data at finer thematic and spatial resolution are available. Despite these limitations, estimates of the common land

EXAMPLE 11.1

Application: Greater Sage-Grouse and The Human Footprint Across Spatial Scales and Organizational Structure

Land management agencies such as the U.S. Bureau of Land Management address issues at multiple scales simultaneously while allocating resources to the various levels of the organization (Fig. 11.1). We outline a process for conducting a multi-scale analysis using the greater sage-grouse general probability of occurrence model as a case study (Ch. 5). This example is intended to outline a potential application of spatial data to assess species distributions and threats to those species. The number of potential overlays that can be conducted is numerous, and these types of analyses should be question driven. At a national level (National) greater sage-grouse is listed as a candidate species under the Endangered Species Act (U.S. Department of the Interior 2010). Knowledge of a species range can help to identify zones, states, or regions that are important for addressing conservation concerns for a species (Stiver et al. 2006, Aldridge et al. 2008). However, sagebrush landscapes vary across the range of species in factors such as precipitation, temperature, soils, topographic position, elevation, and disturbance gradients (Miller et al. 2011). This makes it necessary to partition species ranges into manageable but ecologically similar analysis units. This is the organizational level at which the Wyoming Basins Ecoregional Assessment was conducted. Probability of occurrence was modeled and thresholds applied to depict areas of potential habitat (Regional). Assessment of threats to habitats and species is also appropriate at this scale. The human footprint is a cumulative assessment of human disturbance factors and can be used as an independent analysis or as an overlay to examine individual species responses. These maps can provide tools useful for directing resources to individual field offices. Further analysis can be used to assist in identifying high priority field offices through summary analyses (Subregional). Work within a field office may be conducted within discreet units such as range allotments or pastures. Summaries of conditions within these units can help identify potential areas where restoration may reconnect habitat patches or depict those areas of high habitat quality where steps should be taken to conserve current conditions (Local).

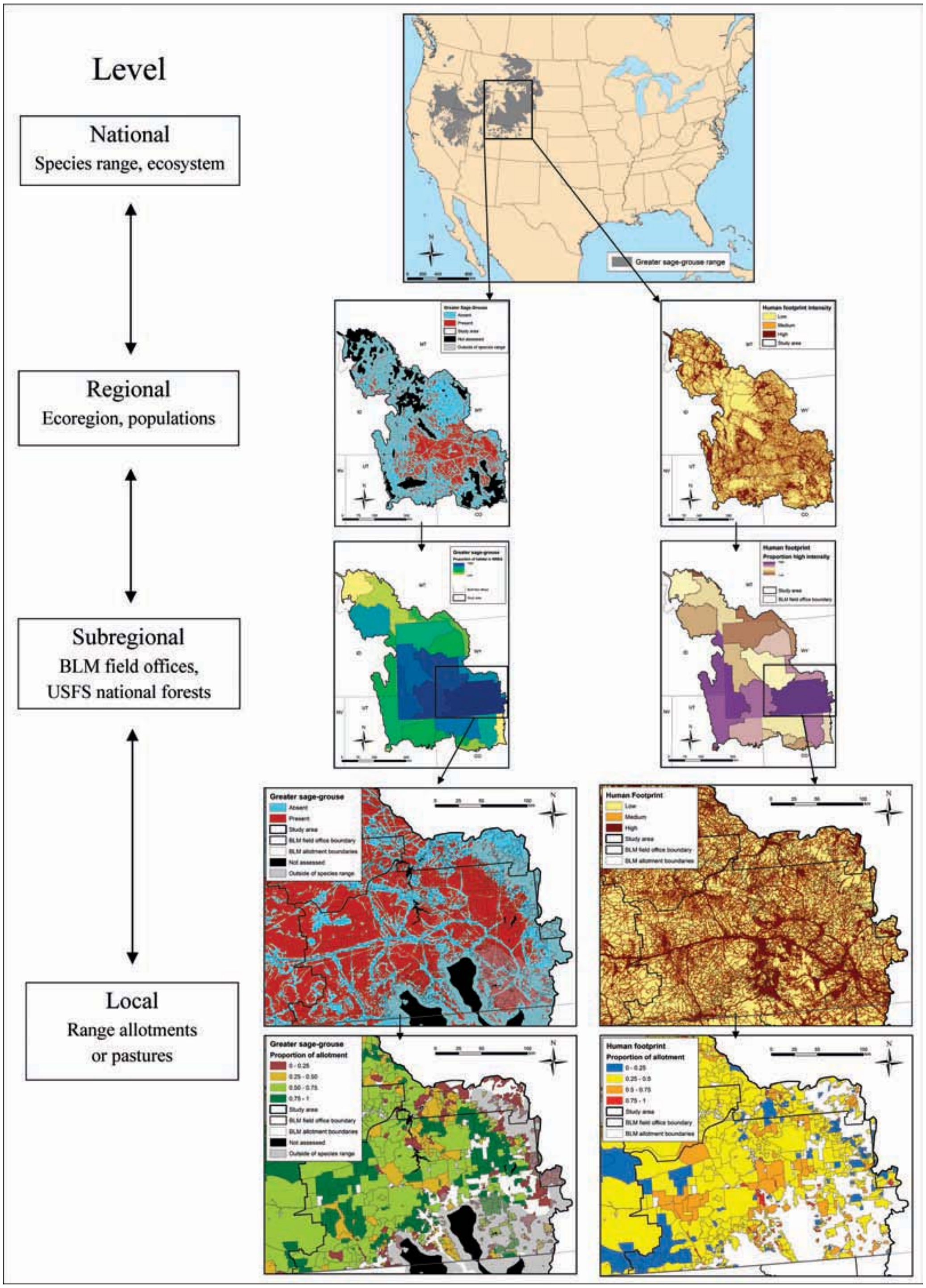

FIG. 11.1. Spatial scales and application of results from the Wyoming Basins Ecoregional Assessment using the greater sage-grouse general probability of occurrence model and an assessment of the human footprint.

cover types that are distributed over large spatial extents, such as the region covered by a BLM Field Office or the extent of our assessment area, can be accurately delineated and quantified for analysis in broad-scale ecoregional assessments (Hann et al. 1997, Wisdom et al. 2000).

Spatial Data and Land Cover Maps

Broad-scale assessments conducted for conservation and land-use planning, such as the Wyoming Basins Ecoregional Assessment, both assemble and incorporate a broad variety of types and sources of spatial data. Levels of accuracy and applicability vary according to the problems and questions addressed in the assessment. Thus, the quality of an ecoregional assessment depends largely on the availability of accurate spatial data. Many data coverages already exist and can be downloaded from websites such as the USGS SAGEMAP site (U.S. Geological Survey 2001). However, developing and obtaining accurate datasets in rapidly changing regions, such as areas of energy development, remains a continuing challenge. Building new or updating existing data sets that span one or more ecoregions will require reliance on large programs such as the U.S. Departments of the Agriculture and Interior LANDFIRE project (www.landfire.gov), the U.S. Geological Survey Gap Analysis Program (www.gapanalysis.usgs.gov), and the series of Rapid Ecoregional Assessments currently being conducted for the BLM.

Availability of accurate spatial data across our assessment area was a primary limitation in model development. These data gaps may result in models that excluded some of the most important drivers of animal distribution. We also assumed that variables included in each species model operate at the scale at which the model was developed and applied (Wiens 1989). In spite of these limitations, development of landscape models and their subsequent evaluation with empirical data are necessary steps for increasing our understanding of large-scale landscape processes influencing species, such as greater sage-grouse and Brewer's sparrow, that show declining population trends (Dobkin 1995, Rotenberry and Knick 1999, Knick and Rotenberry 2002).

Habitat variables used in our models also may not include information that may be important to determine occurrence or abundance of a species. For many bird species, breeding locations are selected based on a hierarchical process to first evaluate broad-scale features followed by successively finer features in the environment (Wiens 1989, Kristan 2006). Thus, areas dominated by sagebrush can be mapped and appear suitable to many species in a broad-scale assessment. However, sagebrush communities vary widely in composition and quantity of understory vegetation. The quantity of understory vegetation can range from high abundance of grasses and forbs to virtual absence of any understory in more xeric environments; composition can vary from all native species to complete dominance by exotic species (West and Young 2000). Because land cover maps identify dominant cover types but not the characteristics of understory vegetation, the amount of habitat for some sagebrush-associated species may be overestimated. For example, greater sage-grouse depend on an understory of native grasses and forbs for nesting and brood-rearing (Schroeder et al. 1999, Connelly et al. 2011). We caution that some areas identified as habitats for sage-grouse from a land cover model may be unsuitable due to lack of native understory plants, either naturally occurring or due to displacement by exotic grasses and forbs; we could not quantify this in our landscape models.

Models of Predicted Occurrence and Abundance

Our spatial models based on species-environmental relationships delineated probability of occurrence, or categorical ordinal estimates of relative abundance, or densities. Probability of occurrence is the statistical likelihood that a species will be present at that location. Although a higher probability of occurrence may be correlated with population density, the extent of that correlation is uncertain and likely varies by species and the effects of extrinsic factors not included in our models. In addition, time lags in species response to habitat loss and anthropogenic effects may not be seen for a number of years, suggesting that observations of species under varying environmental conditions at any one time may not always correlate well with previous habitat loss (Wiens et al. 1986, Knick and Rotenberry 2000).

The response curves developed from our species models are best viewed as a set of hypotheses about the rate at which species distributions can change relative to changes in habitat components. These changes have seldom been demonstrated with empirical data through time. Rather, these estimates of change are developed from differences in species abundance or occurrence relative to habitat characteristics at points distributed in space. Although there is support in the literature for the importance of various life history traits with regard to abundance and extinction risk and thus, presumably, response to disturbance (Purvis et al. 2000, Zuckerberg et al. 2009), information about many of these relations for the Wyoming Basins species of concern is limited. Our abundance models provide additional insights that may help future interpretation of population trends, fitness, and probability of displacement by disturbance.

Analysis of Human Disturbance

Many anthropogenic features that influence species occurrence, particularly linear features such as roads and power lines, were substantially under-estimated in our assessment. For example, roads were under-estimated in existing maps by at least 30% (Ch. 3). Consequently, our analysis of the human footprint under-estimated the presence of anthropogenic impacts in the Wyoming Basins and under-estimated their potential influence. Updated spatial layers that represent a current census of all anthropogenic infrastructure (especially roads, power lines and fence lines) are a large investment but will be necessary to correct this data deficiency.

Global climate change may result in the elimination of up to 80% of the remaining sagebrush in large areas of the sagebrush ecosystem (Neilson et al. 2005, Miller et al. 2011), potentially overwhelming the effects of other anthropogenic disturbances. Many of these effects are complex and difficult to model, and others require substantial effort and investment to collect accurate and up-to-date data.

Regionally consistent spatial data were unavailable for assessment of several impacts that may affect sagebrush-associated species and their habitats. Off-road vehicles and associated human impacts are believed to pose threats to sagebrush-associated species (Barton and Holmes 2007, Tull and Brussard 2007) but data on levels of off-road vehicle use (particularly on BLM lands where access by such vehicles is readily gained) are not widely available for modeling. Off-road vehicle use may affect wildlife through harassment or increases in poaching rates (Gaines et al. 2003, Ouren et al. 2007). Because we did not include off-road vehicle use in our model of the human footprint, our estimates of human impacts likely underestimate the true effects of anthropogenic features and processes on sagebrush ecosystems.

We also could not evaluate the potential effects of livestock grazing – the most pervasive land use in the sagebrush ecosystems in the Wyoming Basins (Ch. 1) – because of the lack of area-wide spatial data on animal unit months, stocking rates, grazing systems, and allotments for public lands managed by BLM, U.S. Forest Service, and other state and federal agencies

(Knick et al. 2011). Moreover, some of the available data pertaining to livestock grazing are inconsistent across administrative units, thus precluding their use in our assessment. Consequently, the potential influences of livestock grazing were not evaluated in our human footprint analysis or our species models despite the ubiquitous nature and recognized significance of grazing on ecosystem patterns and functions (Freilich et al. 2003, Knick et al. 2011).

Scales of Assessment

Regional assessments have been criticized as being "too coarse" or "too broad" to reflect ecological patterns and processes that affect species of conservation concern or dismissed as not useful for planning at local management levels. Most problems result from incorrect application of results or mismatch of the objectives relative to the intended scale of an assessment (Thompson et al. 2000). Thus, deficiencies can be present in assessments conducted at any scale. Most ecological processes that influence broad-scale patterns operate at large spatial and temporal scales (Urban et al. 1987, Shugart 1998). Therefore, the appropriate objectives of an ecoregional assessment are to develop an understanding of species distributions, habitat requirements, and habitat characteristics throughout an entire ecoregion.

The large number of plant species of conservation concern whose distributions are largely driven by micro-site variables not examined in our broad-scale assessment, emphasize the need for local assessments to estimate and monitor the status of these species' habitats and populations. How well our estimates of sagebrush fragmentation and spatial patterns of human footprint impacts relate to the needs and responses of plant species of concern is unknown. This uncertainty justifies the additional (and considerable) effort to conduct local assessments for the plants of conservation concern to complement our regional assessment.

The concepts of thematic and spatial resolution in data often are intermixed. Coarse-grained thematic land cover data sets are developed using plant species assemblages to define dominant land cover types. In the WBEA, accurate delineation of the sagebrush subspecies was not possible; different combinations of subspecies were grouped because of limitations in satellite imagery and availability of vegetation mapping efforts. Therefore, many of our land cover types are coarse and include multiple species or subspecies of sagebrush within a given thematic category or land cover type. Although the properties of thematic and spatial resolution are often linked, coarse-grained thematic data can be displayed or measured at relatively fine-grained spatial resolutions (e.g., 27-m pixels in a LANDSAT satellite image). Coarse-grained thematic data, such as dominant land cover, are most commonly used in ecoregional assessments because of availability for the large regions over which the analyses are conducted. With the exception of rare species that occupy localized micro-environments, few management actions are based on very fine-resolution thematic or spatial data. Use of continuous coverage maps of fine-grained spatial data (e.g., 1-m pixels) across an area as large as the Wyoming Basins (350,000 km^2) is impractical owing to limited availability of data at this resolution, the prohibitive cost of acquiring or developing these data, and current limitations on computer capacity and performance to manage such large volumes of data (but see Homer et al. in press). We delineated and summarized data in this assessment using 90-m grid cells.

We used a number of terms to describe the WBEA landscape (Table I.2), derive predictor variables, and quantify species-environment relationships. Understanding the technical aspects of the data and matching the correct characteristics to the ecological scale of interest is an important part of linking landscape patterns to ecological processes driving population and habitat change in space and time (Wiens 1989, Levin 1992). For example, a land-cover map having a resolution of 1-km grid cells can adequately delineate most agriculture cropland but will be inadequate for analysis of habitat features, such as narrow riparian zones, that have a smaller ecological scale. Similarly, our results describe the response by species to environmental features as measured across the WBEA area. Local characteristics not measured in our assessment can further influence site-specific responses.

CONCLUSIONS

Our results and spatially explicit models of species relationships with environmental variables and anthropogenic effects complement other assessments completed by The Nature Conservancy for the Wyoming Basins (The Nature Conservancy 2000, Freilich et al. 2001, Neely et al. 2001, Noss et al. 2001). Collectively, these assessments contain extensive and detailed compilations of the diversity, richness, and status of native species, natural communities, and ecological systems present within our assessment area. Thus, a large amount of information, much of it spatially depicted and in a GIS format, now is available for land managers to use in developing integrated, multi-scale approaches to managing natural resources in the Wyoming Basins.

Federal and state land and wildlife management agencies rely on information about species-environmental relationships and spatial distributions in order to make effective management decisions affecting species of concern, to prevent further population declines of these species, and to establish a basis for restoring habitats for these species in the most time- and cost-effective manner possible. The spatial delineations of species occurrence and abundance can help prioritize regions and focus limited resources for restoring habitats (Wisdom et al. 2005b, Aldridge et al. 2008, Meinke et al. 2009). Similarly, maps delineating strongholds for individual or suites of species can be important in assessing future impacts of potential land cover changes within these regions. As such, the results from this ecoregional assessment of the Wyoming Basins form an important contribution to our understanding of impacts from land uses and in developing comprehensive management and conservation strategies to minimize or mitigate these impacts. Results from this assessment can be directly integrated into management planning processes, such as environmental impact statements, environmental assessments, records of decision, travel management planning, and conservation for species of concern. Ultimately, these results can form a baseline accounting system (Aldridge and Boyce 2007) that can be used by agencies to monitor changes in habitat quantity and configuration, as well as distribution of human land use, and how species respond to these changes. Our assessment provides tools and models for use in the development of an integrated approach to conservation and management of the sagebrush ecosystem in the Wyoming Basins.

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