Chapter 1: Study area description

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Chapter 1: Study Area Description

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Abstract. The boundary for the Wyoming Basins Ecoregional Assessment (WBEA) was largely determined by the co-occurrence of some of the largest tracts of intact sagebrush (*Artemisia* spp.) remaining in the western United States with areas of increasing resource extraction. The WBEA area includes two ecoregions in their entirety, Wyoming Basins and Utah-Wyoming Rocky Mountains, and portions of two others (Southern Rocky Mountains and Middle Rockies-Blue Mountains). Over half the study area is in Wyoming; the remainder includes parts of Colorado, Utah, Idaho, and Montana. Private landowners manage most (33.1%) of the land base in the WBEA, followed by the U.S. Forest Service (27.3%) and U.S. Bureau of Land Management (25.6%). Sagebrush is the dominant land cover type in the study area, totaling >130,000 km^2; nearly half the sagebrush in the WBEA is managed by the U.S. Bureau of Land Management. Sagebrush in the WBEA faces many potential threats that also influence the broader sagebrush ecosystem. Climate change, drought, land-use practices (e.g., livestock grazing, oil and gas development), and human development have eliminated and fragmented the sagebrush ecosystem, altered fire regimes, and accelerated the invasion of exotic plants such as cheatgrass (*Bromus tectorum*). Less than 2% of sagebrush in the WBEA is permanently protected from land cover conversion.

Key words: ecoregional assessment, land cover, sagebrush, threats, Wyoming Basins.

Ecoregions have been widely adapted in conservation planning and are used by a variety of organizations and agencies such as The Nature Conservancy (TNC), World Wildlife Fund, U.S. Environmental Protection Agency (EPA), U.S. Bureau of Land Management (BLM), U.S. Forest Service (FS), and the U.S. Natural Resources Conservation Service (NRCS). Applications include regional conservation planning, biodiversity analysis, sustainable development, and agricultural census (Groves et al. 2000, McMahon et al. 2001, Noss et al. 2001, Bailey 2002). Ecoregions are large areas of relatively uniform climate, within which sites with similar landforms, slope, soils, and drainage systems support similar ecosystems (Groves et al. 2000, Noss et al. 2001, Bailey 2002). Ecosystems in turn are areas of interacting biological and physical components such that changes in any one component effect change in other components and the system as a whole (Bailey 2002). Although an ecoregion may contain a diversity of ecosystems, characteristic patterns of sites recur predictably due to the overriding influence of climate (Bailey 2002).

Regional conservation planning in the sagebrush (*Artemisia* spp.) ecosystem is especially critical because this ecosystem faces many potential threats. Climate change, drought, land-use practices, and human development have altered fire cycles and accelerated the invasion of exotic plants such as cheatgrass (*Bromus tectorum*) (D'Antonio and Vitousek 1992, Tausch et al. 1993, Knight 1994, Miller and Eddleman 2000, Smith et al. 2000, Neilson et al. 2005). Woody species, such as juniper (*Juniperus* spp.) and Douglas-fir (*Pseudotsuga menziesii*), are encroaching into the sagebrush ecosystem due to changes in fire regimes (Miller et al. 2000, Tausch and Nowak 2000, Miller and Tausch 2001, Grove et al. 2005). Habitat loss, degradation, and fragmentation associated with

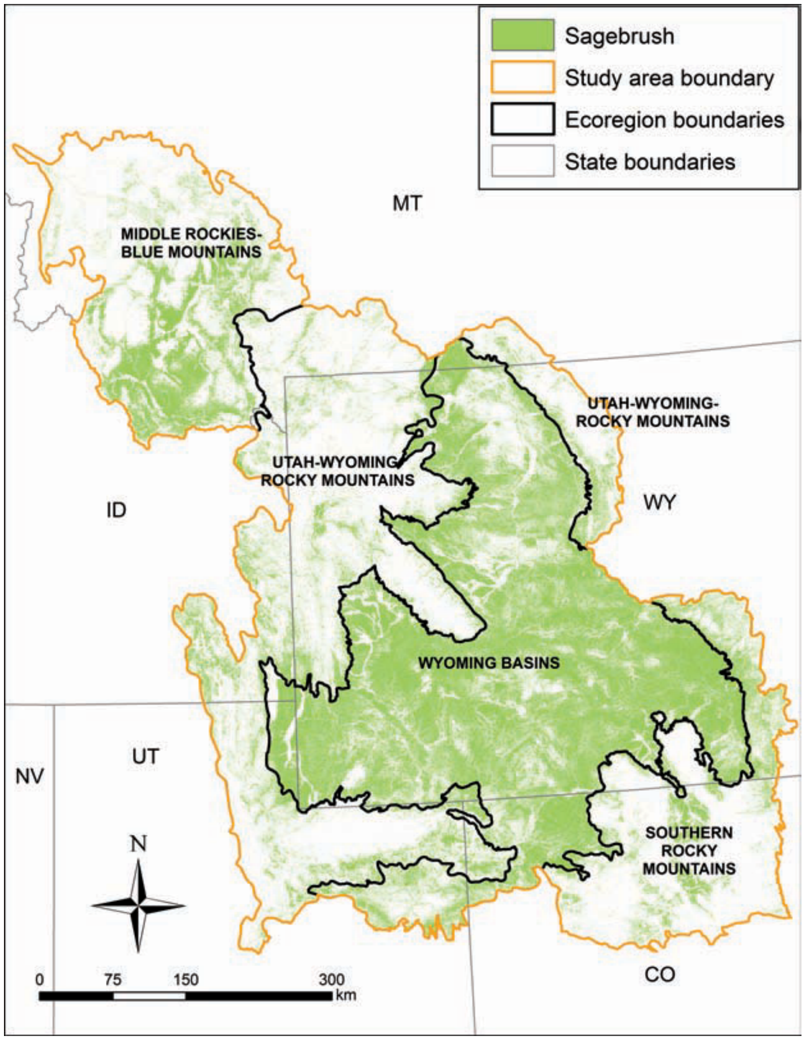

FIG. 1.1. Sagebrush plant communities within the Wyoming Basins Ecoregional Assessment study area. (See Appendix 1.1 for all sagebrush land cover types mapped as sagebrush). Ecoregion boundaries are those delineated by The Nature Conservancy, which are in turn a slightly modified version of ecoregions described by Bailey (1995); see Groves et al. (2000) and <http://gis.tnc.org/data/MapbookWebsite/map_page.php?map_id=9>.

road development are increasing (Forman et al. 2003, Gelbard and Belnap 2003, Thomson et al. 2005). Energy development has accelerated across the sagebrush ecosystem, resulting in increasing rates of habitat fragmentation and disturbance to native wildlife, such as greater sage-grouse (*Centrocercus urophasianus*), pronghorn (*Antilocapra americana*), and mule deer (*Odocoileus hemionus*) (Weller et al. 2002, Lyon and Anderson 2003, Holloran 2005, Thomson et al. 2005, Sawyer et al. 2006, Knick and Connelly 2011).

Wyoming and portions of adjacent states encompass some of the most expansive sagebrush plant communities remaining in North America (Fig. 1.1; Knick et al. 2003) as well as areas of rapidly increasing development, especially of oil and gas fields (Weller et al. 2002, Thomson et al. 2005, Ch. 3). We conducted our regional assessment in this area and refer to it in this book as the Wyoming Basins Ecoregional Assessment (WBEA) area. The assessment name is derived from the largest ecoregion of the four that are wholly or partially contained within its boundaries. This ecoregion, the Wyoming Basins (The Nature Conservancy 2008) – hereafter, "Wyoming Basins" refers to the WBEA area, and when specifically referring to the area defining the Wyoming Basins Ecoregion we use "Wyoming Basins Ecoregion" – ranks third among all ecoregions in the western United States in extent of sagebrush cover (88,300 km^2), surpassed only by the Columbia Plateau (159,200 km^2) and Great Basin (98,400 km^2) ecoregions. The Utah-Wyoming Rocky Mountains Ecoregion contributes another 19,800 km^2 of sagebrush within the study area; sagebrush in this ecoregion and the Wyoming Basins Ecoregion, combined, comprises >20% of the sagebrush in the nation. Moreover, the percentage of the land base covered by sagebrush in the Wyoming Basins Ecoregion (60%) is greater than in any other ecoregion in the nation.

The Wyoming Basins Ecoregional Assessment was completed to provide information for developing strategies for conservation and management of sagebrush in this key area (Introduction). In this chapter, we describe: (1) rationale for selection of the study area boundary; (2) environmental and management conditions within the study area, including vegetation (emphasizing sagebrush ecosystems), wildlife, and land management status; and (3) potential threats to sagebrush ecosystems and associated habitats for species of concern in the WBEA.

DEFINING THE ASSESSMENT AREA BOUNDARIES

Regional assessment boundaries can be ecological, administrative, or a combination, depending on objectives of the assessment. Boundary selection, in turn, influences application of the results in land management and conservation planning. Ecologically based evaluations provide a biologically meaningful spatial framework for resource management agencies and conservation organizations (Groves et al. 2000, McMahon et al. 2001). However, management based solely on ecological boundaries may not effectively consider information gathered at administrative scales, because of the mismatch of spatial extents. The boundary for the Wyoming Basins Ecoregional Assessment was largely determined by the co-occurrence of some of the largest tracts of intact sagebrush remaining in the western United States with areas of increasing resource extraction. That is, the assessment boundary was first derived ecologically and then expanded to include adjacent regions of management concern.

To capture their extensive sagebrush communities, the WBEA contains two entire ecoregions: Wyoming Basins and Utah-Wyoming Rocky Mountains (Fig. 1.1). We extended the study area beyond these two ecoregions to include: (1) a portion of the northern extent of the Southern Rocky Mountains Ecoregion in Colorado and Wyoming; and (2) portions of the Middle Rockies-Blue Mountains Ecoregion in southwestern Montana, primarily the Bitterroot Valley and Beaverhead Mountain sections. We included the northern reaches of the Southern Rocky Mountains Ecoregion specifically to assess ongoing and proposed energy development, primarily of oil and natural gas in this area. By contrast, we included southwestern Montana to incorporate sagebrush ecosystems and associated species omitted from the broad-scale assessment of the Interior Columbia Basin (Hann et al. 1997, Wisdom et al. 2000). Southwestern Montana supports some of the most extensive stands of sagebrush in Montana, and populations of greater sage-grouse in this area are of concern due to long-term declines (Connelly and Braun 1997, Dusek et al. 2002, Roscoe 2002, Knick and Connelly 2011).

The WBEA complements other regional assessments in the Wyoming Basins area. The Nature Conservancy has developed conservation plans for all four ecoregions within the WBEA boundaries: Middle Rockies-Blue Mountains (The Nature Conservancy 2000); Southern Rocky Mountains (Neely et al. 2001); Utah-Wyoming Rocky Mountains (Noss et al. 2001); and Wyoming Basins (Freilich et al. 2001). The general objective of TNC plans is to identify a suite of conservation targets at multiple levels (e.g., species, communities) for long-term conservation of biodiversity. TNC plans and the WBEA share several common features: (1) a comprehensive and systematic approach, (2) a regional scope, (3) a scientific and ecoregional basis, (4) geographic area, (5) an identification of species of concern, and 6) a management and conservation focus. The WBEA differs from those developed by TNC; our assessment provides a broad-scale assessment of (1) anthropogenic disturbances and their effects explicitly focused on sagebrush communities and (2) sagebrush-associated vertebrates and plants in the Wyoming Basins.

Other conservation plans and assessments have been developed in this region. The Heart of the West Conservation Plan had boundaries similar to the WBEA and described a wildlands network incorporating the Wyoming Basins Ecoregion, Utah-Wyoming Rocky Mountains Ecoregion, and adjacent lands (Jones et al. 2004). Other work complementary to our assessment has been conducted within the sagebrush ecosystem across broader scales, such as the SAGEMAP Project [http://sagemap.wr.usgs.gov] (U.S. Geological Survey 2001) and the range-wide conservation assessment of greater sage-grouse (Connelly et al. 2004).

Although the WBEA area includes areas of exceptional biodiversity and national significance, such as Rocky Mountain and Yellowstone National Parks, our focus was on the sagebrush ecosystem and its management, with emphasis on lands managed by the BLM and FS. Thus, this book evaluates the current status of lower elevation shrublands and associated species in the WBEA area.

STUDY AREA

Overview

The WBEA area includes a diversity of habitat types, ranging from alpine tundra to arid shrublands, and a tremendous array of wildlife species. The Greater Yellowstone Ecosystem harbors populations of grizzly bears (*Ursus arctos horribilis*) and gray wolves (*Canis lupus*), as well as the entire suite of native ungulates of the Rocky Mountain West, including bighorn sheep (*Ovis canadensis*), moose (*Alces alces*), white-tailed (*Odocoileus virginianus*) and mule (*O. hemionus*) deer, Rocky Mountain elk (*Cervus elaphus*), bison (*Bison bison*), and pronghorn. Wyoming supports more pronghorn than any other state (Clark and Stromberg 1987); the Sublette herd unit alone has an estimated 48,000 animals, more than the entire population in most western states (WEST 2003). The WBEA area also contains some of the key strongholds for greater sage-grouse populations (Knick and Hanser 2011).

For further details on the flora, fauna, and abiotic environment of the study area as a whole, the reader is referred to: TNC plans that apply to the study area (The Nature Conservancy 2000, Freilich et al. 2001, Neely et al. 2001, Noss et al. 2001); a summary of terrestrial ecoregions of North America (Ricketts et al. 1999); and the synthesis of Wyoming landscapes found in Knight (1994). Additional descriptions of sagebrush-associated vascular plants and vertebrates of concern are provided in Chapter 2.

The WBEA area incorporates 345,300 km^2, of which the majority (51.0%) is in Wyoming. The study area also includes parts of southwestern Montana (21.1%), northern Colorado (12.6%), northeastern Utah (10.4%), and a small part of eastern Idaho (4.9%). Among TNC ecoregions in the study area, 38.7% of the study area is within the Wyoming Basins, 31.7% in the Utah-Wyoming Rocky Mountains, 16.4% in the Middle Rockies-Blue Mountains, and 13.2% in the Southern Rocky Mountains.

Wyoming Basins

The Wyoming Basins Ecoregion encompasses 134,000 km^2 in five states (Fig. 1.1). The bulk (84%) of the ecoregion lies in Wyoming, with 15% in Utah and Colorado and only a trace in Montana and Idaho (1%; see Freilich et al. [2001] for further details). Climate is arid, with an average annual precipitation of 15-25 cm; the Wyoming Basins Ecoregion includes the most arid parts of the state of Wyoming (Freilich et al. 2001). Extremes of cold, wet winters and hot, dry summers in the region are typical of continental climate patterns.

Major river systems (including the North Platte, Bighorn, Upper Green, Yampa, and Sweetwater) support riparian corridors vital for maintaining biodiversity in the region. Although some mountain peaks exceed 3,300 m, most of the ecoregion lies between 1,800 m and 2,400 m. More than a dozen mountain ranges (e.g., Ferris and Pryor Mountains, Wyoming Range) dissect the ecoregion, forming "islands" in the surrounding sagebrush matrix (Freilich et al. 2001).

Vegetation communities in the Wyoming Basins Ecoregion are dominated by rolling sagebrush uplands, and Wyoming big sagebrush (*A. t.* ssp. *wyomingensis*) is the dominant sagebrush taxon. Black sagebrush (*A. nova*) reaches its easternmost extension in Wyoming, and large expanses of little sagebrush (*A. arbuscula*) are present. Salt desert shrubs, such as greasewood (*Sarcobatus vermiculatus*) and saltbush (*Atriplex* spp.), replace sagebrush in more arid sites.

Despite its vast size, this ecoregion remains one of the least densely populated areas in the United States. Laramie, Wyoming, is the largest city in the ecoregion (population 25,700 in 2006), and most people are located in isolated rural areas (Freilich et al. 2001).

Utah-Wyoming Rocky Mountains

The Utah-Wyoming Rocky Mountains Ecoregion covers >42,100 km^2 in parts of five states: Colorado, Idaho, Montana, Utah, Wyoming (Fig. 1.1; Noss et al. 2001). Climate in this ecoregion is cold continental, with long winters and short summers (Noss et al. 2001). Precipitation is highly variable across the ecoregion, with some of the most arid portions of the region receiving <16 cm rainfall a year, contrasting with >200 cm in the southeastern portion of Yellowstone National Park (Noss et al. 2001). The ecoregion includes the Greater Yellowstone Ecosystem, along with much of the Beartooth Plateau in Montana, the Bighorn Mountains in eastern Wyoming, the Wasatch Range in Utah, and the Uinta Mountains in Colorado and Utah.

Shrub-grass communities dominate lower elevations in the ecoregion, whereas higher elevations, such as those in the Bighorn and Uinta Mountains, are forested. Common sagebrush species in lower elevation shrublands include basin big sagebrush (*A. t.* ssp. *tridentata*) and Wyoming big sagebrush, with mountain big sagebrush (*A. t.* ssp. *vaseyana*) found at somewhat higher elevations. Other high elevation sites support spiked sagebrush (*A. t.* ssp. *spiciformis*). Saltbush and greasewood shrublands also occur in lower elevations. Douglas-fir is the most abundant tree species in lower-elevation forests, whereas Englemann spruce (*Picea engelmanni*), lodgepole pine (*Pinus contorta*), and subalpine fir (*Abies lasiocarpa*) dominate mid-elevation forests. Alpine tundra occurs at the highest elevations, often >3,000 m.

Human populations in the Utah-Wyoming Rocky Mountain Ecoregion are largely concentrated along the Wasatch Front in Utah; however, counties in the Greater Yellowstone Ecosystem have also seen rapid growth in recent decades, particularly Teton County in both Wyoming and in Idaho (Noss et al. 2001).

Southern Rocky Mountains

The relatively small proportion of the Southern Rocky Mountains Ecoregion in the study area lies in Wyoming and Colorado (Fig. 1.1). Climate in this ecoregion is characterized as temperate semiarid steppe, with mean annual temperatures ranging from 1.7 to 7.2 C (Neely et al. 2001). Precipitation is generally higher in the northern portion of the ecoregion, reaching 140 cm annually in the Park Range. The Continental Divide is a dominant feature of the ecoregion. The many mountain ranges (including the Laramie Mountains, Medicine Bows, Front Range, Park Range, and Sierra Madres) and associated topographic relief greatly influence local weather patterns. Headwater watersheds of the Colorado, Mississippi, and Rio Grande rivers are located in the ecoregion (Neely et al. 2001).

This ecoregion includes large intermontane basins (e.g., North Park and Middle Park) that support extensive higher elevation sagebrush ecosystems of primarily mountain big sagebrush, little sagebrush, and silver sagebrush (*A. cana*) (Neely et al. 2001). Much of the research on greater sage-grouse in Colorado has been conducted in these parks (e.g., Petersen 1980, Remington and Braun 1985, Braun and Beck 1996, Johnson and Braun 1999, Zablan et al. 2003).

Major ecological zones range from lower montane-foothill, which includes more arid sagebrush ecosystems, pinyon (*Pinus edulis*)-juniper woodlands, and Douglas-fir/ponderosa pine (*Pinus ponderosa*) forests, to upper montane, subalpine, and alpine zones. Rates of human population increase are among the highest in the nation, with an average increase at the county level of 31% from 1990–2000 (Neely et al. 2001).

Middle Rockies-Blue Mountains

Two sections of the Middle Rockies-Blue Mountains Ecoregion are in the WBEA area – Beaverhead Mountains and Bitterroot Valley; both are in Montana (Fig. 1.1; The Nature Conservancy 2000). The climate here is characterized as cold, dry continental, with highly variable precipitation, falling primarily as snow in fall, winter, and spring. Elevation in the valleys ranges from 1,200 m to 2,100 m. This area is topographically complex, with steep, heavily glaciated mountains and intermontane valleys that have been widely developed for housing and other structures in the Bitterroot Valley. Rivers include the Bitterroot, Beaverhead, Blackfoot, and Clark Fork; major mountain ranges in this portion of the study area are the Anaconda Range, Centennial Mountains, and Madison Range (The Nature Conservancy 2000).

Sagebrush-grasslands are the dominant non-forest land cover type in this portion of the study area, with most of the sagebrush occurring in the southwestern corner of Montana (Fig. 1.1). Development of primary and secondary homes and resorts are considered major threats in this ecoregion (The Nature Conservancy 2000).

Land Management Status

Private landowners in the WBEA area manage >114,000 km^2 (33.1%) of the study area, more than any other management entity (Table 1.1). Private lands were well distributed across the entire study area and formed a "checkerboard" pattern where they are intermingled with lands managed by BLM and state agencies, especially in a wide swath across southern Wyoming (Fig. 1.2). Two federal land management agencies, the FS and BLM, are responsible for the majority of the non-private lands; the FS manages 94,300 km^2 (27.3%) and the

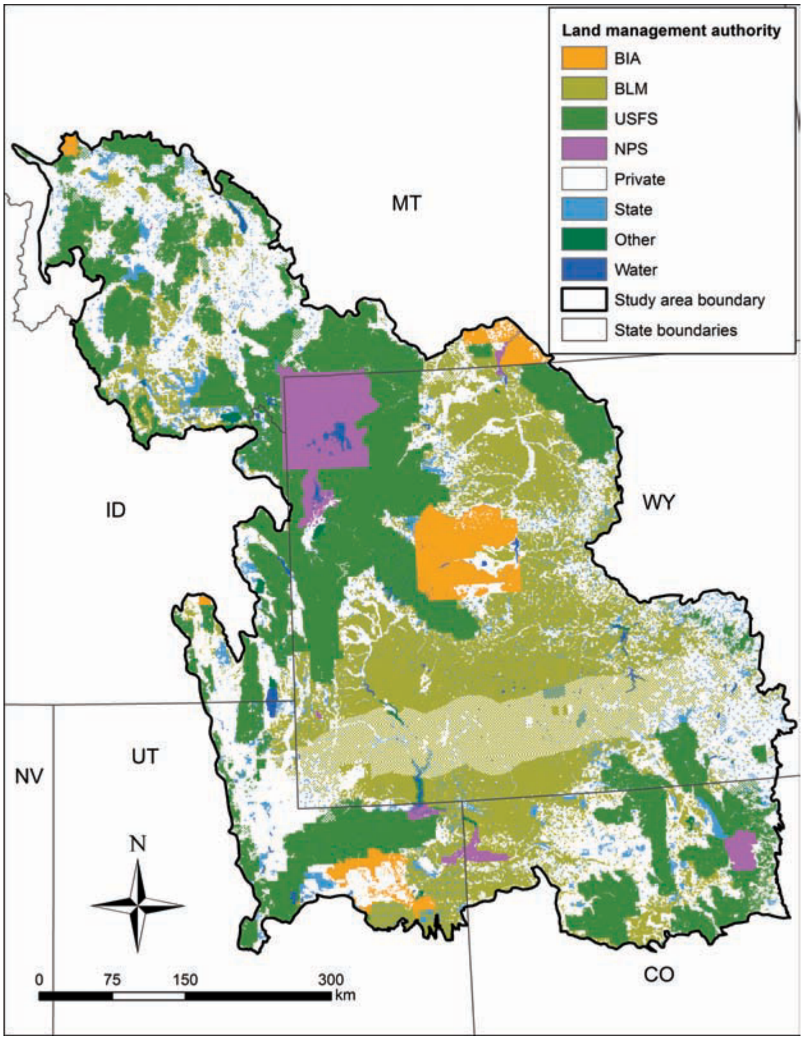

FIG. 1.2. Land management authority within the Wyoming Basins Ecoregional Assessment area.

BLM 88,300 km^2 (25.6%) within the study area. Most of the remaining land management authority rests with states (5.4%), the National Park Service (3.5%), and the Bureau of Indian Affairs (3.4%). The latter is comprised largely of the Wind River Indian Reservation in Wyoming (Fig. 1.2), whereas the majority of the National Park Service lands are in Yellowstone, Teton, and Rocky Mountain national parks.

Land stewardship patterns within the five states included in the WBEA differed somewhat from those for the study area as a whole (Table 1.1). For example, although private land was the dominant category across the WBEA, at the state level this was only true for Colorado, Montana, and Utah. Wyoming had the smallest percentage (28.0%) of private land and the largest percentage (37.3%) of land managed by the BLM among the states in the study area; public lands under BLM management extended across 65,500 km^2 of the study area in Wyoming. The FS had management responsibility for a relatively large percentage of the land within the

TABLE 1.1. Land stewardship by state and agency within the Wyoming Basins Ecoregional Assessment area.

Agency	Colorado		Idaho		Montana		Utah		Wyoming		Total	
	km²	%	km²	%	km²	%	km²	%	km²	%	km²	%
BIA[a]	<1	0.0	131	0.8	2,109	2.9	2,030	5.6	7,331	4.2	11,601	3.4
BLM	10,108	23.2	955	5.6	6,243	8.6	5,477	15.2	65,537	37.3	88,320	25.6
NPS	1,683	3.9	142	0.8	786	1.1	528	1.5	8,824	5.0	11,963	3.5
Private	15,143	34.7	6,457	38.1	29,724	40.8	13,812	38.4	49,208	28.0	114,346	33.1
State	2,202	5.0	841	5.0	4,348	6.0	2,179	6.1	8,980	5.1	18,551	5.4
FS	14,361	32.9	7,961	47.0	28,854	39.6	9,135	25.4	33,986	19.3	94,297	27.3
Other[b]	120	0.3	468	2.8	828	1.1	2,825	7.9	1,981	1.1	6,222	1.8
Total	43,618	100.0	16,955	100.0	72,892	100.0	35,987	100.0	175,847	100.0	345,300	100.0

[a] BIA – Bureau of Indian Affairs; BLM – U.S. Bureau of Land Management; NPS – National Park Service; FS – U.S. Forest Service.

[b] Includes Bureau of Reclamation, Department of Defense, The Nature Conservancy, U.S. Fish and Wildlife Service, water, local ownerships, and miscellaneous federal lands.

study area in Idaho (47.0%) and Montana (39.6%) (Table 1.1).

Land Cover

Use of LANDFIRE

For all WBEA analyses based on land cover type, including sagebrush, we used the LANDFIRE existing vegetation type (EVT) data layer (LANDFIRE 2007). The LANDFIRE project was designed to produce consistent maps of vegetation, fuels, and fire regimes for wildland fire management across the United States (http://www.landfire.gov/index.php). To increase accuracy of mapped land cover types and meet study objectives, we reclassified the LANDFIRE EVT map from the original 102 land cover types that occurred in the study area to 24 more generalized types (Appendix 1.1). The resulting land cover map was used to model the distribution and/or abundance of wildlife and invasive plants in the study area (Ch. 5–10). For summary statistics presented in this chapter, we further collapsed the 24 land cover types to 14 (Appendix 1.1). The primary reclassification of this second step was within the shrubland cover types; all sagebrush land cover types were combined as "sagebrush," and various shrub types (e.g., mountain mahogany [*Cercocarpus* spp.]) were reclassified as "mixed shrubland."

Sagebrush in the WBEA

Sagebrush is the dominant land cover in the WBEA area (38.1%; 131,600 km²; Table 1.2, Fig. 1.3). The overwhelming majority (67.8%) of sagebrush is in Wyoming (89,200 km²), but substantial amounts (37,400 km²) also are found in portions of southwestern Montana, northeastern Utah, and northwestern Colorado (Fig. 1.3).

The BLM has management authority for 43.5% (57,300 km²) of the sagebrush in the study area (Fig. 1.4), comparable to the 52% of sagebrush managed by BLM nationwide (Knick et al. 2003). This pattern varied, however, among states in the WBEA area.

For example, in Wyoming, BLM manages nearly 52% of the sagebrush vegetation (45,700 km^2); by contrast, BLM manages only 10.9% (530 km^2) of the sagebrush in the Idaho portion of the WBEA area (Fig. 1.4). Private landowners manage the second largest percentage (37.5%) of sagebrush in the study area, totaling 49,400 km^2 (Fig. 1.4). The remainder is evenly divided between the FS, state lands, and "other" management entities (e.g., National Park Service, Bureau of Indian Affairs).

The percentage of sagebrush on FS-managed lands in the WBEA (6.1%) is comparable to the percentage of sagebrush across the United States that is managed by the agency (9%; Wisdom et al. 2005). Relatively higher percentages of FS-managed sagebrush were found in Idaho, with considerably lower percentages in Colorado and Wyoming. Although a small percentage of sagebrush in the study area is managed by the FS, the majority of it is mountain big sagebrush. Management considerations for mountain big sagebrush and other sagebrush taxa found at higher elevations differ from those for sagebrush found at lower, warmer sites (U.S. Bureau of Land Management 2002, Miller et al. 2011). High elevation sagebrush types are often more resistant to fire, tend to occur within more diverse plant communities than sagebrush at lower elevations, and are often seasonally important for sagebrush-associated species of concern, such as providing late brood-rearing habitat for sage-grouse (Connelly et al. 2004).

TABLE 1.2. Area contained within land cover classes of the Wyoming Basins Ecoregional Assessment area.

Land cover class[a]	km^2	%
Agriculture	15,523	4.5
Aspen	11,311	3.3
Barren	9,275	2.7
Conifer forest	89,330	25.9
Developed	2,607	0.7
Grasslands	28,748	8.3
Greasewood	1,922	0.6
Juniper	5,387	1.6
Mixed shrubs	21,035	6.1
Riparian	12, 637	3.7
Sagebrush	131,573	38.1
Salt desert shrubland	12,780	3.7
Water	2,633	0.8
Wetland	592	0.2
Total	345,354	100

[a] For crosswalk of land cover classes from the LANDFIRE existing vegetation types map see Appendix 1.1.

Protected status of sagebrush

Only a small percentage of the sagebrush ecosystem is permanently protected (for example, in national parks or designated wilderness areas) from alteration or conversion (Wright et al. 2001, Knick et al. 2003, Knick et al. 2011). We evaluated the relative amount of sagebrush within the WBEA area by the four land status classes commonly used by TNC and the Gap Analysis Program (GAP) in assessing degree of protection for conservation targets (Scott et al. 1993, Crist 2000). These categories are: class 1 – areas permanently protected from conversion of natural land cover, with natural disturbance events allowed to proceed; class 2 – permanently protected as above, but where management practices or uses may degrade the natural communities; class 3 – permanently protected from conversion, but subject to resource extraction (e.g., logging, mining) and protection offered to federally listed species; and class 4 – no known mandates, either public or private, to prevent conversion of natural vegetation types (Crist 2000).

The dominant land status class for sagebrush in the WBEA was class 3 (51.1% of sagebrush), followed by class 4 (45.8%) (Figs. 1.5, 1.6). By contrast, only 1.7% of the sagebrush in the WBEA was under permanent legal protection (i.e., status class 1); sagebrush in this class is located primarily within National Park Service lands in Yel-

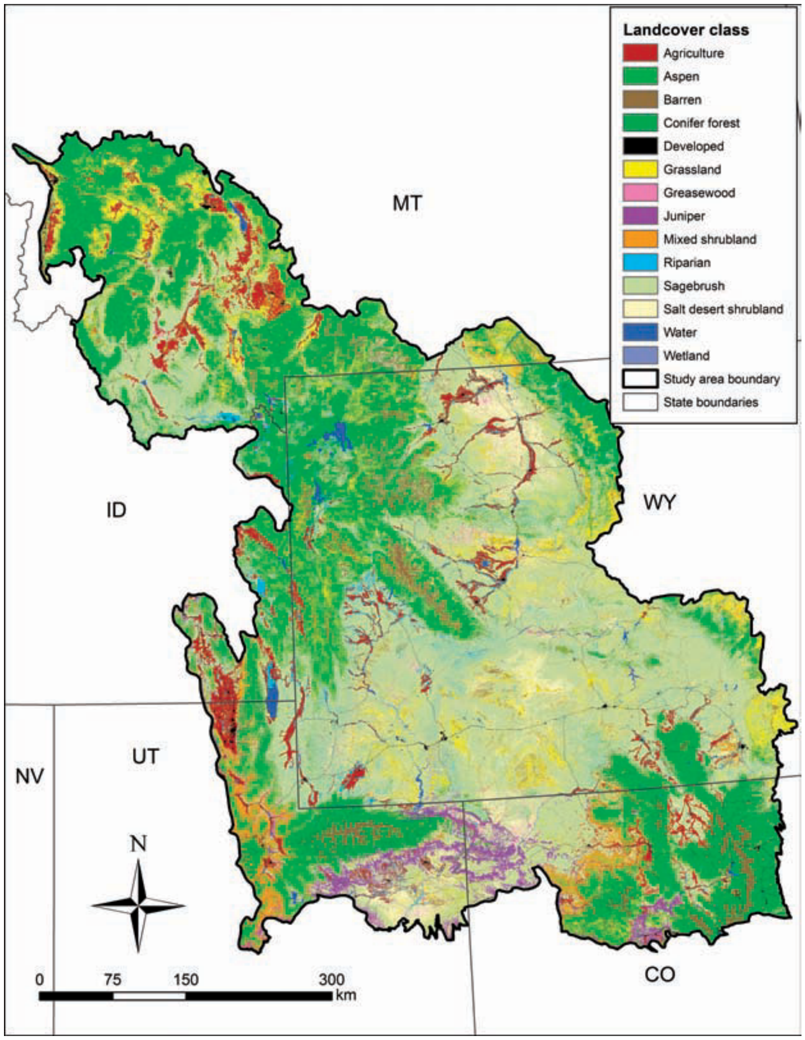

FIG. 1.3. Land cover classes within the Wyoming Basins Ecoregional Assessment area; cover types were modified from the existing vegetation type layer from LANDFIRE. See Appendix 1.1 for details on reclassification of the original map.

lowstone and Grand Teton National Parks, as well as in designated wilderness areas managed by the Forest Service (Fig. 1.6). This percentage is similar to that reported by Wright et al. (2001) for all sagebrush in the western United States. A similarly small fraction (1.4%) of sagebrush in the WBEA is in class 2. Compared to all land cover types within the study area, a disproportionately smaller percentage of sagebrush is protected (i.e., in status class 1 and 2; Fig. 1.5). Most of the sagebrush in class 4 is on privately owned lands or the Wind River Indian Reservation in central Wyoming. Therefore, multiple uses will likely continue to affect management policies related to sagebrush.

Other land cover classes in the WBEA

The second most common land cover class in the study area was "coniferous forest" (25.9%, or 89,300 km^2; Table 1.2).

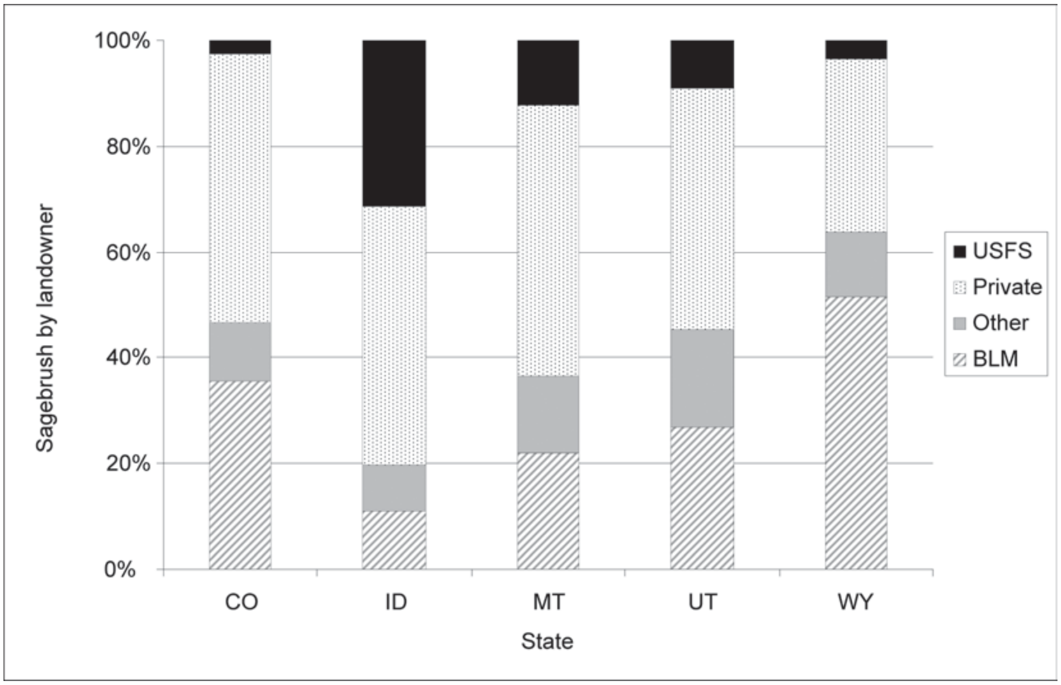

FIG. 1.4. Percentage of sagebrush by primary land management authority within states of the Wyoming Basins Ecoregional Assessment boundary.

Coniferous forest is found in mountainous and high elevation regions (e.g., Yellowstone National Park, FS wilderness areas in northeastern Utah and western Wyoming). No other land cover class spanned >10% of the study area (Table 1.2). Grasslands covered 8.3% (28,700 km^2) of the study area and were most prevalent in eastern Wyoming and southwestern Montana (Fig. 1.3). The salt desert shrubland class encompassed 3.7% (12,800 km^2) of the WBEA area, primarily in northcentral Wyoming, northeastern Utah, and northwestern Colorado. This class includes saltbush and a variety of other, primarily xeric, upland shrub types. Agricultural lands covered 4.5% (15,500 km^2) of the WBEA area, with large blocks found in northcentral Wyoming, southeastern Idaho, and across southwestern Montana. Juniper occupied a small portion (1.6%, 5,400 km^2) of the study area and was most common in Colorado, northeastern Utah, and northcentral Wyoming (Fig. 1.3). Only a small fraction (0.7%) of the study area was classified as “developed” (Table 1.2).

POTENTIAL THREATS TO SAGEBRUSH-ASSOCIATED SPECIES AND HABITATS IN THE WYOMING BASINS

Potential threats to habitats and species in the sagebrush ecosystem range from climate change and altered fire regimes to fragmentation by a multitude of anthropogenic disturbances (Knick et al. 2003, Connelly et al. 2004, Wisdom et al. 2005; Table 1.3). Threats previously identified within the WBEA area include: conversion of sagebrush to non-native perennial grasses, spread of exotic annual grasses, hard-rock mining, oil and gas exploration, inappropriate grazing by domestic livestock, logging, fire suppression, and expansion of recreational and residential developments (Ricketts et al. 1999, Freilich et al. 2001,

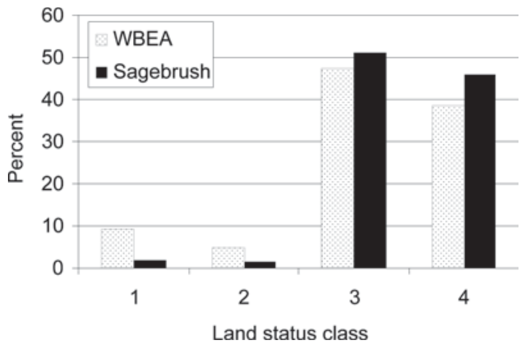

FIG. 1.5. Comparison of GAP land status class for all land cover types within the Wyoming Basins Ecoregional Assessment (WBEA) area versus only sagebrush. Land status was derived from standard GAP classifications (Crist 2000) and indicates the relative degree of protection from alteration.

Neely et al. 2001, Noss et al. 2001, Weller et al. 2002, U.S. Departments of the Interior, Agriculture, and Energy 2003). Although the level of risk posed by each threat varies geographically and temporally across the vast range of sagebrush, all of the threats listed in Table 1.3 have been documented to some extent within the WBEA. However, effects of many of these threats, especially anthropogenic disturbance, on sagebrush-associated wildlife have not been well quantified with empirical data (Freilich et al. 2001, WEST 2003). Furthermore, the synergistic effects of combined threats in the sagebrush ecosystem have not been fully investigated (Wisdom et al. 2005). The development and evaluation of predictive models to test hypotheses about cumulative effects of key threats in sagebrush ecosystems, as described in Chapters 4-10, will allow land managers to better address management actions that may influence the large landscapes of shrubland communities in the Wyoming Basins.

Primary Threats in the Wyoming Basins Ecoregional Assessment Area

Decisions about which potential threats to address in a particular assessment may be based on any of several criteria, including: (1) spatial extent or pervasiveness of the threat across the ecoregion, (2) capability to quantify and map the threat, (3) agreement among those conducting the assessment about the relative importance of the threat in the ecoregion, (4) available resources to address the threat, (5) timeframe required to implement effective treatments across the ecoregion, (6) costs versus benefits of addressing the threat, (7) significance of the threat in altering habitat or wildlife population dynamics, and (8) potential effects of addressing the threat on non-target species (Wisdom et al. 2005). We present below a brief summary of some of the key threats to sagebrush-associated species and their habitats in the WBEA.

Climate change and drought

There is increasing recognition of the effect of land cover change and human activities on global climate change (e.g., U.S. Environmental Protection Agency 1998, Schneider and Root 2002, Marland et al. 2003, Neilson et al. 2005, Parmesan 2006, Mawdsley et al. 2009). In Wyoming, mean temperature in Laramie has increased almost 1 C over the last 100 years, and precipitation levels have decreased by as much as 20% in parts of the state (U.S. Environmental Protection Agency 1998). Climate models for Wyoming predict an increasing frequency of extremely hot days in summer, continued increases in temperature during all seasons (e.g., 3.3 C in winter), and increasing fire frequencies (U.S. Environmental Protection Agency 1998). Estimates of future rainfall regimes are more variable, with slight decreases in summer rainfall, but increases in spring, fall, and winter precipitation (U.S. Environmental Protection Agency 1998). Precipitation in the Colorado River Basin, including southwestern Wyoming, is predicted to decrease slightly (1–6%) through the end of the century under a range of climate models (Christensen et al. 2004); however, model estimates for precipitation are highly variable, and regional patterns of precipitation may not follow more global models (Neil-

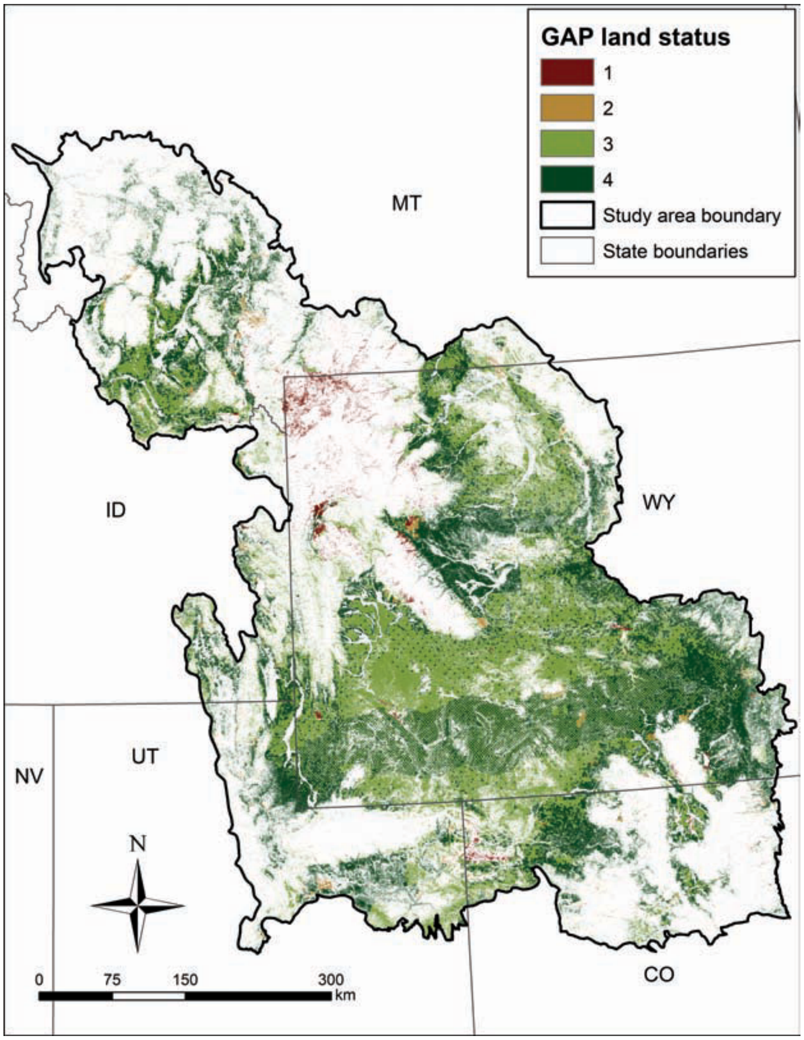

FIG. 1.6. Land status categories for sagebrush land cover types in the Wyoming Basins Ecoregional Assessment area based on the U.S. Geological Survey GAP program Protected areas database of the United States (PAS-US) <http://gapanalysis.usgs.gov/data/padus-data/>.

son et al. 2005). Shrublands and arid lands in the United States are predicted to decrease in spatial extent under a variety of climate change models and scenarios (e.g., Bachelet et al. 2001, Neilson et al. 2005). However, sagebrush in southwestern Wyoming is predicted to be the least affected by climate-induced losses of all sagebrush in the United States, and thus may represent a future stronghold for this ecosystem (Neilson et al. 2005). Although public lands management may have little effect on climate change in the WBEA, awareness of the potential synergistic effects of climate change with other ecological processes and land management actions (e.g., invasions by exotic, warm-season annual grasses [Smith et al. 2000], livestock grazing) will lead to more informed decision making concerning shrublands in this area.

Oil and gas development

One threat of special urgency in the WBEA is resource extraction, especially of natural gas and oil (Freilich et al. 2001, Neely et al. 2001, Weller et al. 2002, Thomson et al. 2005, Walker et al. 2007, Doherty et al. 2011; Ch. 3). Infrastructure associated with energy development was ranked second among threats confronting current populations of greater sage-grouse (U.S. Fish and Wildlife Service 2010). The area encompassed by the Wyoming Basins and Utah-Wyoming Rocky Mountains Ecoregions and surrounding areas in Colorado, Idaho, Montana, and Utah were identified as the center of the largest concentration of onshore oil and gas reserves in the contiguous 48 United States (U.S. Departments of the Interior, Agriculture, and Energy 2003). Moreover, the Greater Green River Basin, centered in southwestern Wyoming and northwestern Colorado (Fig. 3.1), holds the largest volume of oil and natural gas reserves among the key geologic basins inventoried for national oil and gas reserves (U.S. Departments of the Interior, Agriculture, and Energy 2003). The natural gas produced in the Intermountain West constitutes 20% of the nation's annual supply, and that region in turn holds 41% of the nation's gas reserves (Limerick et al. 2003).

Although oil, coal, and natural gas reserves in the WBEA have been tapped for decades (Weller et al. 2002, Connelly et al. 2004; Ch. 3), the development of advanced technologies to extract these reserves has led to an unprecedented proliferation of requests for permits to drill (Limerick et al. 2003, Walker et al. 2007, Kiesecker et al. 2009). Of particular concern in the WBEA is production of coal bed natural gas, also known as coal bed methane (CBM) (Braun et al. 2002, Gilbert 2002, Morton et al. 2002, Walker et al. 2007, Doherty et al. 2008). The development of technologies to profitably extract methane from water in coal bed seams has led to the drilling of thousands of wells in CBM fields, particularly in the Powder River Basin of northeastern Wyoming, which lies east of the study area boundary (Braun et al. 2002, U.S. Bureau of Land Management 2003, Walker et al. 2007; Ch. 3). Potentially profitable CBM reserves have been identified in many other portions of the Rocky Mountain region, including eastern Utah and southwestern Wyoming (U.S. Departments of the Interior, Agriculture, and Energy 2003). The Greater Green River Basin (Fig. 3.1) is projected to contain eight times the CBM reserves of the Powder River Basin.

Among the potential environmental effects from development of oil and gas wells and associated facilities are: (1) temporary displacement of wildlife or range abandonment due to disturbance from vehicle traffic and noise associated with compressor stations and other well-related structures; (2) direct loss of habitat from road and well-pad construction; (3) habitat fragmentation from the pipelines, power lines, roads, and other facilities associated with field development; (4) invasion of exotic plant species facilitated by soil disturbance around structures and connecting corridors; (5) depletion of aquifers from the pumping and discharge of millions of gallons of water during the extraction of methane in CBM fields; (6) changes in local hydrologic regimes as water is discharged into ephemeral streams; and (7) the potential for diseases such as West Nile virus to infect both humans and wildlife, a result of the creation of hundreds of water storage ponds for discharge from CBM wells (Walker and Naugle 2010; Table 1.3).

Despite nearly a century of energy extraction amid some of the greatest concentrations of native wildlife populations – particularly ungulates – in the western United States, a paucity of published research was available on effects of these activities on native plant and animal communities in the Wyoming Basins when we began our assessment (but see Weller et al. 2002, Powell 2003, WEST 2003, Wyoming Game and Fish Department 2004, Thomson et al. 2005). Several research projects have now been initiated or completed that rigorously examine effects of oil and

TABLE 1.3. Potential threats and associated effects on habitats and species in the sagebrush ecosystem, with example references (adapted from Wisdom et al. 2005).[a]

Potential threat	Associated effects	Examples	Example references
Weather, climate change, and catastrophes	*Environmental* – habitat loss or degradation	Drought and more severe and frequent wildfires from increasing temperatures, escalating spread of invasive plants such as cheatgrass; drought years in close succession, leading to losses of key forbs used by sagebrush-associated species	Tausch et al. 1993, U.S. Environmental Protection Agency 1998, Bachelet et al. 2001, Miller and Eddleman 2000, Smith et al. 2000, Schneider and Root 2002, Neilson et al. 2005, Hunt et al. 2006
	Population – stochastic events	Catastrophic events such as floods and severe drought, contributing to extirpation of small populations	Burgman et al. 1993, Andelman et al. 2001, Morris and Doak 2002, Aldridge et al. 2008
	Population – altered communities	Altered phenology leading to mismatches in timing of migrant arrivals and prey availability, changes in productivity; shifts in animal and plant distributions	Walther et al. 2002
Roads, highways, and associated rights-of-way	*Environmental* – habitat loss	Direct loss of habitat from road construction	Forman et al. 1997, 2003; Forman 2000; Trombulak and Frissell 2000; Gucinski et al. 2001; Spellerberg 2002
	Environmental – habitat fragmentation and degradation	Fragmented habitats; accelerated spread of invasive plants	Forman et al. 1997, 2003; Braun 1998; Parendes and Jones 2000; Gucinski et al. 2001; Neely et al. 2001; Havlick 2002; Spellerberg 2002; Gaines et al. 2003; Gelbard and Belnap 2003; Gelbard and Harrison 2003; Munger et al. 2003
	Population – barrier to migration or road avoidance	Movement or migration barriers to less mobile species; animals may avoid traffic, other activities associated with roads	Mader 1984; Bennett 1991; Reijnen et al. 1997; Wisdom et al. 2000; Berger 2004; Spellerberg 2002; Forman et al. 2003; Gaines et al. 2003; Brock and Kelt 2004; Ingelfinger and Anderson 2004; Sawyer et al. 2005, 2007; Aldridge and Boyce 2007
	Population – direct and indirect mortality	Death or injury from collisions with vehicles; increased mortality from poaching due to improved access	Patterson 1952, Olendorff and Stoddart 1974, Blumton 1989, Wisdom et al. 2000, Todd 2001, Havlick 2002, Forman et al. 2003

TABLE 1.3. Continued

Potential threat	Associated effects	Examples	Example references
Intensive livestock grazing	*Environmental* – habitat degradation	Ecologically inappropriate grazing by domestic stock, especially cattle and sheep, leading to loss of native perennial grasses and forbs in understory (changes in composition and structure) and declines in forage and other habitat components for species of concern and their prey (e.g., invertebrates); trampling, leading to destruction of burrows (e.g., of burrowing owls, pygmy rabbits)	Bock et al. 1993, Saab et al. 1995, Guthrey 1996, Schroeder et al. 1999, Beck and Mitchell 2000, Miller and Eddleman 2000, Johnson and O'Neil 2001, Freilich et al. 2001, Noss et al. 2001, Holmes et al. 2003, Knick et al. 2003, Dobkin and Sauder 2004, Thines et al. 2004
	Population – direct mortality	Mortality from trampling of nests	Beck and Mitchell 2000, Holmes et al. 2003
Oil and natural gas field development	*Environmental* – habitat loss and fragmentation	Fragmented habitat from pipelines, roads, well pads, and associated collection facilities; disruption of migration corridors; outright loss of habitat from roads and well pads, other facilities constructed for field development	Braun 1998, Braun et al. 2002, Weller et al. 2002, Berger 2004, Connelly et al. 2004, Sawyer et al. 2005, Thomson et al. 2005, Aldridge and Boyce 2007, Walker et al. 2007, Doherty et al. 2008
	Population – disturbance	Avoidance and potential abandonment of habitat due to vehicular traffic, other noise (e.g., compressor stations), and related human activity at well sites	Gillin 1989, Easterly et al. 1992, Bowles 1995, Warrick and Cypher 1998, Dyer 1999, Braun et al. 2002, Lyon and Anderson 2003, Powell 2003, Holloran 2005, Walker et al. 2007, Doherty et al. 2008
	Environmental – habitat degradation	Invasive species occupy disturbed sites (e.g., roadsides and well pads)	Zink et al. 1995, Parendes and Jones 2000, Trombulak and Frissell 2000, Forman et al. 2003, Gelbard and Belnap 2003, Bergquist et al. 2007
Fences	*Environmental* – habitat fragmentation	Fragmented habitats, interference with animal movement (e.g., pronghorn)	Braun 1998, Connelly et al. 2004, O'Gara and Yoakum 2004
	Population – direct mortality	Collisions or entanglement of animals with fences, leading to injury or death	Riddle and Oakley 1973, Fitzner 1975, Call and Maser 1985, Todd 2001, O'Gara and Yoakum 2004

TABLE 1.3. Continued

Potential threat	Associated effects	Examples	Example references
Expansion of juniper and other coniferous species in sagebrush communities	*Environmental* – habitat loss and degradation	Changes in climate and fire suppression leading to expansion of pinyon pine and juniper woodlands into sites previously occupied by sagebrush; especially mountain big sagebrush, Wyoming big sagebrush	Blackburn and Tueller 1970; Burkhardt and Tisdale 1976; Miller and Wigand 1994; Miller and Rose 1995, 1999; Commons et al. 1999; Miller and Eddleman 2000; Miller and Tausch 2001; Grove et al. 2005
Invasions of exotic plants	*Environmental* – habitat loss and degradation	Altered fire regimes and habitat degradation (e.g., from intensive livestock grazing), leading to increases in exotic plants (e.g., cheatgrass) in sagebrush ecosystems; noxious weeds accidentally introduced during reclamation of oil and gas well sites	Yensen 1981, Billings 1994, D'Antonio and Vitousek.1992, Knick 1999, West 1999, D'Antonio 2000, Miller and Eddleman 2000, Booth et al. 2003, Menakis et al. 2003, Dobkin and Sauder 2004, Bergquist et al. 2007
Reservoirs, dams, and other water developments	*Environmental* – habitat loss	Outright loss of habitat from construction of reservoirs	Braun 1998, Schroeder et al. 1999, Nachlinger et al. 2001
	Environmental – habitat degradation	Altered stream flows and hydrological regimes, degrading or altering habitat for aquatic and riparian species	Pierson et al. 2001, 2002, 2003
Herbicides	*Environmental* – habitat loss and fragmentation	Conversion and removal of sagebrush (especially prior to 1980), especially if native understory vegetation in relatively good condition	Best 1972; Braun and Beck 1977; Braun 1998; Connelly et al. 2000, 2004; Miller and Eddleman 2000
Power lines	*Environmental* – habitat degradation	Disturbance of vegetation and soils in power line corridors, leading to increased invasion of exotic species	Zink et al. 1995, Braun 1998
	Population – increased rates of predation	Poles and towers for transmission lines serving as perches or nest sites for corvids and raptors; increased potential for predation on sagebrush-associated species	Gilmer and Wiehe 1977, Knight and Kawashima 1993, Steenhof et al. 1993, Braun 1998, Boarman 2002
	Population – direct mortality	Collisions of birds and bats with power lines, resulting in injury or death; electrocution of perching raptors and other birds	O'Neil 1988, Harmata et al. 2001

TABLE 1.3. Continued

Potential threat	Associated effects	Examples	Example references
Communication towers	*Population* – direct mortality	Collisions of birds and bats with cell and radio towers, leading to injury and mortality	Evans and Manville 2000, Mabey and Paul 2007
Altered fire regimes	*Environmental* – habitat loss	Complete removal of sagebrush cover (i.e., type conversion), from increases in catastrophic wildfires, often related to invasions of cheatgrass, especially in Wyoming big sagebrush	Whisenant 1990, Billings 1994, D'Antonio and Vitousek 1992, Knick and Rotenberry 1997, Neely et al. 2001, Menakis et al. 2003
	Environmental – habitat degradation	Altered fire cycles in sagebrush ecosystems from fire suppression, resulting in changes in vegetation composition and structure, e.g. encroachment of woodlands into sagebrush	Schroeder et al. 1999, Miller and Eddleman 2000, Connelly et al. 2004
Loss of open space and housing development	*Environmental* – habitat loss	Direct loss of sagebrush from development of urban areas and "ranchettes" surrounding urban sites	Theobald et al. 1997, Braun 1998, Connelly et al. 2004, Hammer et al. 2007
	Population – human disturbance	Increasing human activities in urban and exurban areas, negatively affecting populations of sagebrush-associated species by displacement or abandonment; increases in predation rates on wildlife in sagebrush ecosystems from domestic dogs and cats in urban and rural settings, also from increased populations of predators (e.g., corvids) due to increased availability of food resources associated with human waste (e.g., garbage dumps).	Berry et al. 1998, Millsap and Bear 2000, Arrowood et al. 2001, Neely et al. 2001, Knick et al. 2003, Sawyer et al. 2005
Herbivory effects from wild ungulates	*Environmental* – habitat degradation	Localized, excessive herbivory by native ungulates, leading to degraded understory vegetation (e.g., changes in species composition and structure) and reduced sagebrush densities and canopy cover	McArthur et al. 1988, Singer and Renkin 1995, Wambolt and Sherwood 1999, Groves et al. 2000 (Appendix 20), Wisdom et al. 2006

TABLE 1.3. Continued

Potential threat	Associated effects	Examples	Example references
Disease transmission	*Population* – direct mortality	Disease transmission during winter season, exacerbated by human disturbance that causes concentrations of native ungulates on winter ranges; man-made water sources, esp. those changing from ephemeral to permanent, leading to increased transmission of mosquito-borne diseases such as West Nile virus.	Naugle et al. 2004, 2005; Rowland 2004; Walker et al. 2004; U.S. Fish and Wildlife Service 2005, Walker and Naugle 2010
Brood parasitism by brown-headed cowbirds	*Population* – direct mortality	Parasitism from brown-headed cowbirds, a species that may increase in human-altered environments (e.g., livestock feedlots and overgrazed pastureland), affecting populations of some birds (e.g., lark and vesper sparrows)	Friedmann and Kiff 1985, Robinson et al. 1995, Shaffer et al. 2003
Recreation	*Environmental* – habitat degradation	Degraded habitats from off-road vehicle use, e.g., by increasing establishment of exotic annual grasses like cheatgrass	Berry 1980, Havlick 2002, Munger et al. 2003, Chin et al. 2004, The Wilderness Society 2006
	Population – disturbance	Negative response, such as displacement or nest abandonment, to recreation-related disturbance, e.g., off-road vehicles; recreational shooting of small mammals	Berry 1980, White and Thurow 1985, Braun 1987, Knight and Gutzwiller 1995, Schroeder et al. 1999, Havlick 2002, Munger et al. 2003, Wisdom et al. 2004, Barton and Holmes 2007
Conversion of sagebrush to cropland or tame pasture for livestock	*Environmental* – habitat loss	Direct removal of sagebrush cover (e.g., via brush-beating, chaining, disking, or burning) and planting with crops or non-native perennial grasses such as crested wheatgrass for livestock forage	Vale 1974, Dobler 1994, Fischer et al. 1997, Braun 1998, Knick 1999, Schroeder et al. 1999, West 1999, Miller and Eddleman 2000, Johnson and O'Neil 2001, Knick et al. 2003
	Environmental – habitat fragmentation	Fragmented habitats from removal of sagebrush, resulting in interference with animal movements, dispersal, or population fragmentation	Knick and Rotenberry 1995, 1997, 2000; Johnson and O'Neil 2001; Knick et al. 2003; Connelly et al. 2004
	Population – direct mortality	Nest and egg destruction, or directly mortality of animals, from mechanical or other methods used to remove sagebrush or cultivate lands adjacent to sagebrush	Patterson 1952

TABLE 1.3. Continued

Potential threat	Associated effects	Examples	Example references
Mine development	*Environmental* – habitat loss and fragmentation	Fragmentation and outright loss of habitat to surface mines and associated mine tailings and roads, especially coal mines	Braun 1998, Remington and Braun 1991, Ricketts et al. 1999, Neely et al. 2001
	Population – disturbance	Disturbance and potential abandonment of habitat due to traffic, noise, and related human activity at mine site	Bednarz 1984, Braun 1998
Pesticides	*Environmental* – habitat degradation	Decreased forage base by killing insects used as prey by sagebrush-associated species	Johnson 1987, Holmes et al. 2003
	Population – mortality	Direct mortality of birds and other vertebrates exposed to pesticides and indirect mortality through consumption of contaminated insects	Patterson 1952, Blus et al. 1989, Blus 1996
Saline-sodic water	*Environmental* – habitat degradation	Salinization of surrounding soils and aquatic systems from disposal of millions of barrels of water produced during coal bed methane (CBM) extraction; high mortality rates (up to 100%) in vegetation exposed to sodic water discharge	Groves et al. 2000 (Appendix 20), McBeth et al. 2003
Wind energy development	*Environmental* – habitat degradation	Increased noxious weeds in areas around turbines or along roads needed to access turbines; loss of habitat from road construction and turbine installation; avoidance by wildlife of area near turbines from association of structures with nests or perches of avian predators	Forman et al. 1997, 2003; Leddy et al. 1999; Gelbard and Belnap 2003; U.S. Bureau of Land Management 2005; Mabey and Paul 2007, Doherty et al. 2011
	Population – mortality	Deaths and injuries of birds and bats from collisions with wind turbines	Leddy et al. 1999, Erickson et al. 2001, Young et al. 2003, Johnson et al. 2004, Arnett et al. 2008
Collection of specimens for personal, commercial, or scientific uses	*Population* – loss of individuals from the wild	Collection of rare plants and animals, especially herptiles such as midget faded rattlesnake, posing unknown risks to populations of these species	Wisdom et al. 2000, Freilich et al. 2001, Schlaepfer et al. 2005

TABLE 1.3. Continued

Potential threat	Associated effects	Examples	Example references
Groundwater depletion	*Environmental* – habitat degradation	Excessive groundwater withdrawal in well sites from pumping of water for CBM	Groves et al. 2000 (Appendix 20), Nachlinger et al. 2001
Grazing by feral horses	*Environmental* – habitat degradation	Loss of native perennial grasses and forbs in understory	U.S. Bureau of Land Management et al. 2000, Young and Sparks 2002, Beever 2003
Selenium and other environmental contaminants	*Population* – direct threat of mortality	Poisoning of animals from uptake of selenium in contaminated aquifers, primarily from agricultural runoff	Lemly 1997
Military training	*Environmental* – habitat fragmentation	Loss of shrubs from wildfire and destruction from tracked vehicles, leading to habitat fragmentation, from military training exercises in sagebrush ecosystems	Knick and Rotenberry 1997, Holmes and Humple 2000

[a] Threats are listed in order, from highest priority to lowest, based on rankings from BLM biologists working in the study area.

gas development on wildlife in sagebrush ecosystems, especially the Upper Green River Valley (contained within the WBEA area) and Powder River Basins in Wyoming. These projects incorporate radio telemetry and other techniques to evaluate potential impacts on wildlife, and include studies of greater sage-grouse (Lyon 2000, Lyon and Anderson 2003, Holloran 2005, Walker et al. 2007, Doherty et al. 2008), passerines (King and Holmes 2003, Gilbert and Chalfoun 2011), mule deer (Sawyer and Lindzey 2001, Sawyer et al. 2002, Sawyer et al. 2006), and pronghorn (Sawyer and Lindzey 2000, Sawyer et al. 2002). Long-distance migration of pronghorn in the Upper Green River Valley is severely compromised by existing and proposed development related to energy extraction in this area; furthermore, >75% of the traditional migration routes for this species in the Greater Yellowstone Ecosystem have been lost (Berger 2004).

Roads and trails

Roads, highways, trails, and off-highway vehicles affect wildlife habitats and biological systems in many ways; these effects have been succinctly described in reviews by Forman and Alexander (1998), Trombulak and Frissell (2000), Gucinski et al. (2001), Forman et al. (2003), and Gaines et al. (2003). Effects of roads and trails range from disturbance of wildlife due to vehicle traffic to the function of roads as conduits for invasive plants (see Table 1.3 for summaries of road effects in sagebrush ecosystems). Although past research focused largely on effects of roads and traffic on native ungulates, more recent research has demonstrated negative effects of roads and vehicles on a variety of taxa, such as sage-grouse (Oyler-McCance 1999, Braun et al. 2002, Lyon and Anderson 2003), passerines (Ingelfinger and Anderson 2004), small mammals (Brock and Kelt 2004), and snakes (Munger et al. 2003, Shine et al. 2004). Within the WBEA, the area affected by roads is increasing in part due to development of oil and natural gas fields. For example, in developed well fields in Wyoming, well pads and associated roads have eliminated >200 km^2 of shrublands since 1900 (Ch. 3).

One analysis evaluated impacts of the transportation network in the Upper Green River Valley near Pinedale, Wyoming (Thomson et al. 2005). Extensive roading in the study area has resulted in highly fragmented habitats for species such as greater sage-grouse, elk, pronghorn, and mule deer. Within the Jonah Field, a high-density natural gas field within the analysis area, road densities exceeded 1.2 km/km^2 across >95% of the area. Within the entire 11,700 km^2 analysis area, no greater sage-grouse lek was >5 km from a road, and 80% of the crucial winter range for pronghorn had road densities >0.6 km/km^2 (Thomson et al. 2005).

The impacts of roads and other infrastructure associated with human activities, such as urban and exurban developments, pipelines, power lines, oil and gas wells, and compressor stations, combine to impose an "ecological footprint" on the landscape (Sanderson et al. 2002, Weller et al. 2002, Leu et al. 2008; Ch. 4). Quantification of this footprint at broad scales has been greatly advanced because of the advent of spatial analysis conducted in Geographic Information Systems (GIS) and will be an important component of future analyses of impacts of anthropogenic disturbance on native ecosystems (Leu et al. 2008).

Invasive and noxious plants

An increasingly pervasive threat to the sagebrush ecosystem in the Wyoming Basins and elsewhere is the spread of noxious and invasive plants (Hartman and Nelson 2000, The Nature Conservancy 2000, Connelly et al. 2004, Miller et al. 2011; Ch. 10). Effects of invasive plants range from displacement of native vegetation to the creation of dense stands of fine fuels that carry wildfires (Table 1.3). Fragmented and disturbed habitats, which are increasing in the Wyoming Basins (Weller et al. 2002, Thomson et al. 2005, Ch. 3), are more susceptible to invasion by exotic plants (Pavek 1992; Knick and Rotenberry 1997, 2000; Pyke and Knick 2003).

In particular, the displacement of native sagebrush steppe by cheatgrass is one of the most dramatic changes observed in western landscapes (Billings 1994), and restoration of these communities will require tremendous resources (Knick 1999, Bunting et al. 2002, Hemstrom et al. 2002). It is estimated that greater than 50% of the sagebrush ecosystem in western North America has been invaded to some extent by cheatgrass (West 1999), with losses projected to accelerate in the future (Hemstrom et al. 2002, Suring et al. 2005, Miller et al. 2011). Cheatgrass invasion is most severe in Wyoming big sagebrush communities at lower elevations (Miller and Eddleman 2000, Hemstrom et al. 2002) and is less common in cooler, more mesic regions such as Montana and Wyoming. However, increases in atmospheric CO_2 predicted by climate change models will benefit C_3 plants such as cheatgrass (Smith et al. 2000, Miller et al. 2011).

Although cheatgrass is not considered a noxious weed in Wyoming (Wyoming Weed and Pest Control 2004), it poses an increasing threat in the study area as it expands into sites where it was previously thought unable to persist, possibly a result of climate change and the high degree of phenotypic plasticity that the species demonstrates (Knight 1994, Kinter 2003). The colder climate of Wyoming compared to the Great Basin, where cheatgrass has invaded vast acreages (Young and Sparks 2002), coupled with the absence of fall precipitation in many parts of the state, may have prevented comparable spread to date (Smith 2006). Cheatgrass currently is widespread in Wyoming (Ch. 10) but is not often a monoculture. However, the Bighorn Basin and eastern Wyoming have experienced recent increases in cheatgrass and other *Bromus* grasses (Smith 2006).

A compilation of invasive vascular plants in Wyoming listed 428 taxa, most of which originated outside North America (Hartman and Nelson 2000). The Wyoming Weed and Pest Council (2004) listed 24 plant species as noxious weeds. Knapweeds (*Centaurea* spp.), hardhead (synonym Russian knapweed) (*Acroptilon repens*), saltlover (synonym halogeton) (*Halogeton glomeratus*), slender Russian thistle (*Salsola collina*), and cheatgrass are of particular concern in Wyoming (Knight 1994, Wyoming Weed and Pest Council 2004).

Other threats

Livestock grazing is a pervasive management influence on the sagebrush ecosystem nationwide (Beck and Mitchell 2000, Crawford et al. 2004, Knick and Connelly 2011); however, we lacked consistent data on grazing seasons and stocking rates to conduct a formal analysis of its effects for our assessment. Grazing effects on sagebrush ecosystems are direct and indirect and include removal of nesting cover for birds, trampling of riparian vegetation, seeding of non-native grasses as livestock forage, increases in non-native annual grasses, and removal of sagebrush shrubs to increase forage production (Beck and Mitchell 2000, Crawford et al. 2004).

A variety of other threats impact the sagebrush ecosystem, such as transmission lines, fences, recreational use, urbanization and exurban expansion, encroachment of conifers, dams and reservoirs, and wind energy development (Table 1.3). Conversion of native shrub steppe in southwestern Montana to agriculture continues to remove habitat for sagebrush-associated species (The Nature Conservancy 2000, Dusek et al. 2002). An additional threat in this area is the encroachment of conifers, especially Douglas-fir, into mountain big sagebrush communities, resulting in reductions in sagebrush cover and habitat for sagebrush-associated species (Grove et al. 2005).

Wind farms currently are uncommon in the WBEA area although the potential for vastly increased wind energy development exists (Doherty et al. 2011). Within the study area, wind potential (i.e., wind speed and density) is greatest in northcentral Colorado and much of western Wyoming (U.S. Bureau of Land Management 2005). Effects of wind energy development on wildlife include: (1) mortalities of bats and birds from collisions with wind turbines (Table 1.3), (2) habitat loss and fragmentation due to the infrastructure needed to develop the wind farms, (3) disturbance from human and vehicle activities at wind energy sites (Leddy et al. 1999, Erickson et al. 2001, Young et al. 2003, U.S. Bureau of Land Management 2005, Mabey and Paul 2007), (4) noise that might disrupt reproductive and foraging behaviors, and (5) habitat degradation through the introduction and spread of invasive plants.

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APPENDIX 1.1

Crosswalk between existing vegetation types (mapped as ecological systems [Comer et al. 2003]) in LANDFIRE existing vegetation type (LANDFIRE 2007) and: (1) vegetation maps used to develop Wyoming Basins Ecoregional Assessment (WBEA) wildlife and invasive species models; (2) summary maps used for Chapter 1 tables and figures; and (3) vegetation maps used for Chapter 3 tables and figures. This appendix is archived electronically and can be downloaded at the following URL: http://sagemap.wr.usgs.gov/wbea.aspx.