Assessment of Habitat Threats to Shrublands in the Great Basin: A Case Study

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Abstract

The sagebrush (*Artemisia* spp.) ecosystem is one of the most imperiled in the United States. In the Great Basin ecoregion and elsewhere, catastrophic wildland fires are often followed by the invasion of cheatgrass (*Bromus tectorum* L.), eliminating or altering millions of hectares of sagebrush and other shrublands. Sagebrush in the Great Basin also is threatened by displacement from encroaching pinyon-juniper woodlands. Despite these changes, the ecoregion retains some of the Nation's largest remaining expanses of sagebrush, most of which are federally managed. Because of these losses and degradation, sagebrush-associated species are declining. To address these issues, we conducted a regional assessment of habitat threats for 40 sagebrush-associated vertebrates of concern in the Great Basin. Our goals were to (1) evaluate habitat conditions for species of concern for conservation planning and management, (2) demonstrate the application of new methods of regional threat assessment in shrubland communities, and (3) describe implications of results for management. Our analyses suggested that more than 55 percent (4.8 million ha) of sagebrush in the Great Basin is at moderate or high risk of being displaced by cheatgrass. Cheatgrass invasion also threatens other shrubland communities, particularly salt desert scrub (96 percent; 7.1 million ha at moderate or high risk). Substantial areas of sagebrush (41 percent; 2.0 million ha) were predicted to be at moderate or high risk of displacement by pinyon-juniper in the eastern Great Basin. Although little sagebrush (less than 1 percent) was at high risk to both threats, more than one-third was at high risk to cheatgrass and low or moderate risk from woodlands. Habitat loss, including sagebrush and other native plant communities, to cheatgrass could exceed 65 percent (8 million ha) for some of the 40 vertebrate species evaluated. Maintenance and restoration of native shrublands in the Great Basin will require both active and passive management to mitigate the formidable threats posed by cheatgrass and pinyon-juniper woodland expansion.

Keywords: Cheatgrass, Great Basin, models, pinyon-juniper woodlands, sagebrush, threats.

Setting the Stage: Shrublands at Risk

The vast shrublands of Western North America, including the sagebrush (*Artemisia* spp.) ecosystem, provide a wide range of resource values, including recreation, livestock grazing, mining, energy extraction, wildlife habitat, and wilderness. Increasingly, however, these arid and isolated lands have faced a wide range of threats, including wildland fires, invasive plants, roads, oil and gas development, and climate change (Connelly and others 2004, Knick 1999, Wisdom and others 2005a). (In this paper we define a threat as a potentially detrimental human activity or ecological process as it affects native species or their habitats [Wisdom and others 2005a] and risk as "the potential, or probability, of an adverse event" [Burgman and others 1993].)

Despite the recognized values of shrublands and grasslands—collectively known as rangelands—such lands have seldom benefited from the long-term research and monitoring traditionally focused on forested ecosystems in the United States. This lack of a well-established body of research and monitoring presents special challenges in evaluating and predicting effects of disturbances, both natural and anthropogenic, on rangeland habitats and wildlife in the United States. The dearth of attention is especially noteworthy in that rangelands compose about 50 percent (39 million ha) of the 77 million ha managed under the National Forest System. Nationwide, rangelands total 312 million ha, with 43 percent managed by the Federal Government (http://www.fs.fed.us/rangelands/).

To address the needs of land managers charged with conservation planning and management of shrublands and associated wildlife, Wisdom and others (2005a) described methods for conducting regional assessments in native shrubland ecosystems of Western North America. They applied those methods in a prototype assessment of habitat threats within the Great Basin ecoregion. Their goals were to (1) evaluate habitat conditions for species of concern for conservation planning and management, (2) demonstrate the application of newly developed methods of regional assessment of threats in shrubland communities, and (3) describe implications of results for management.

The following text draws heavily from their book. A requirement of the Great Basin prototype assessment as funded by the Bureau of Land Management (BLM) was that it be conducted with existing data (spatial and other) as a demonstration of products that could be readily delivered. Such pragmatism is often a necessity in natural resource management.

The reader is referred to the Wisdom and others (2005a) book for additional details of the Great Basin case study, especially background material and methods. Appendices with materials not published within the book can be found at http://www.fs.fed.us/pnw/pubs/sagebrush-appendices/.

Status and Threats in the Sagebrush Ecosystem

The sagebrush ecosystem covers more than 43 million ha within the Western United States and Canada and constitutes one of the largest ecosystems in North America (Center for Science, Economics, and Environment 2002; Wisdom and others 2005a). More than two-thirds of the total area covered by sagebrush in the United States is on land publicly owned and managed by State or Federal agencies; the BLM alone manages 52 percent of the sagebrush in the United States (Knick and others 2003). Conservation and restoration of the sagebrush ecosystem are of special concern to State and Federal resource management agencies owing to extensive habitat degradation and loss (Knick 1999, Knick and others 2003, Wisdom and others 2005a). Since European settlement, the area covered by sagebrush has been reduced more than 40 percent (Connelly and others 2004), and only a small fraction remains unaltered by anthropogenic disturbances (West 1999).

A plethora of threats to sagebrush and other native shrubland communities has been identified (Connelly and others 2004, Wisdom and others 2005a). Among these are invasion of exotic vegetation, altered fire regimes, road development and use, mining, energy development, climate change, encroachment of pinyon (*Pinus* spp.) and juniper (*Juniperus* spp.) woodlands, intensive livestock grazing, and conversion to agriculture or urban areas. The cumulative effects of these stressors have resulted in the sagebrush ecosystem being regarded as one of the most endangered in the Nation (Noss and others 1995), and 20 percent of the plants and animals associated with this ecosystem may be at risk of extirpation (Center for Science, Economics, and Environment 2002).

Several scientific assessments have addressed the effects of multiple threats in the sagebrush ecosystem (e.g., Boyle and Reeder 2005, Connelly and others 2004, West 1999); however, despite the knowledge gained from these studies and others, efforts to abate the degradation and elimination of sagebrush have not been successful at large scales (Hemstrom and others 2002, West 1999).

Ecological Setting and Status of the Great Basin

The Great Basin ecoregion spans more than 29 million ha from the eastern Sierra Nevada Mountains in California to central Utah east of the Great Salt Lake (Figure 1). Federal lands dominate (80 percent) the landscape; thus, the role of Federal agencies is paramount in conservation planning and management in this area. Although classified as arid, with mean annual precipitation of 216 mm, precipitation is highly variable and falls primarily during winter and spring. Climate change has been pronounced during the past 150 years, with warmer temperatures and increased carbon dioxide levels (Tausch and Nowak 2000, West 1999). Riparian systems of the Great Basin are particularly sensitive to effects of climate change (Chambers and Miller 2004).

The Great Basin supports one of the largest extant concentrations of sagebrush in North America at more than

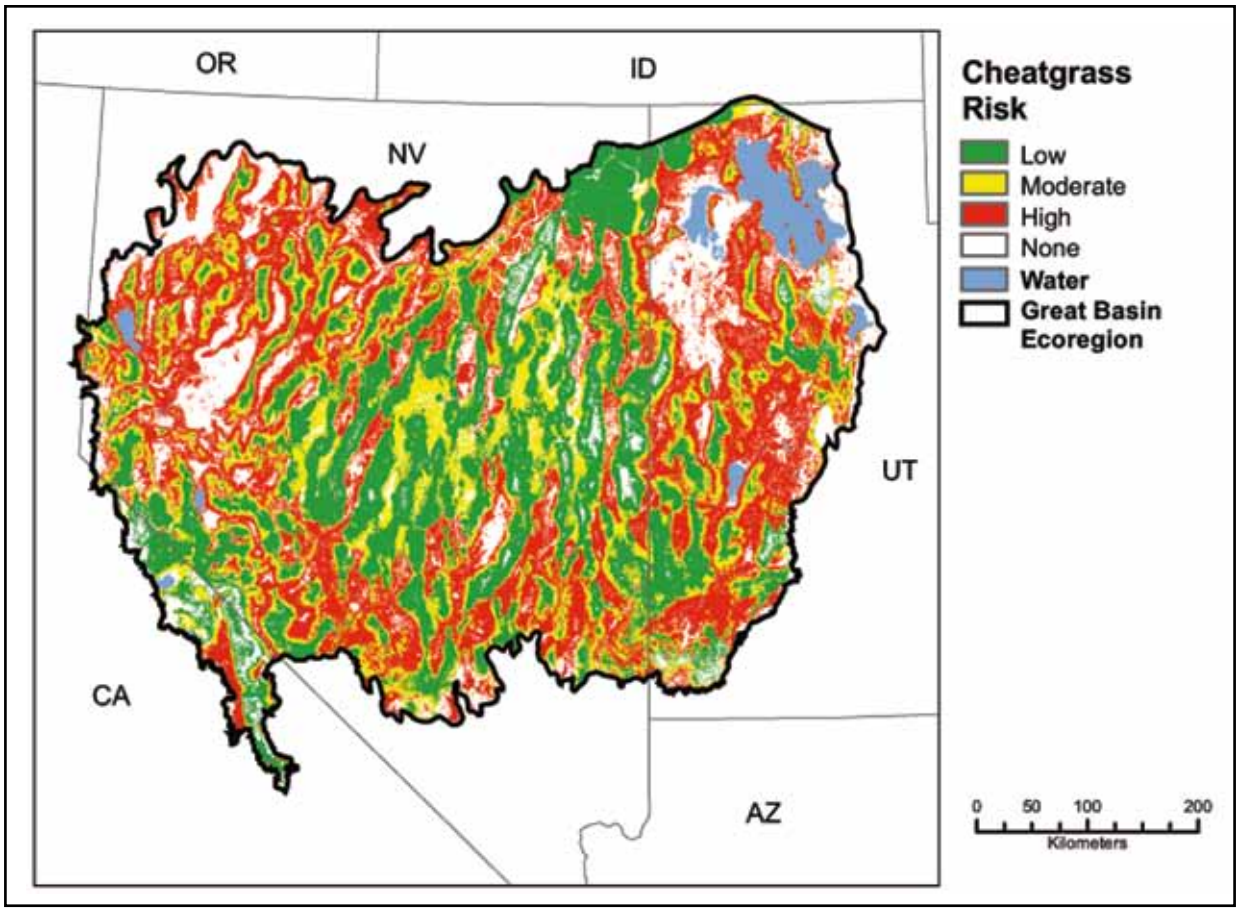

Figure 1—Estimated risk of cheatgrass displacement of sagebrush and other susceptible landcover types in the Great Basin ecoregion (from Wisdom and others 2005a).

8 million ha (29 percent of the landcover in the ecoregion). Indeed, among ecoregions of the sagebrush biome, the Great Basin ranks second in total extent of sagebrush, exceeded only by the Columbia Plateau (Wisdom and others 2005a). Although sagebrush loss in the ecoregion has occurred from a variety of causes, wildland fires have been especially devastating. More than 500 000 ha of sagebrush (6.4 percent of the sagebrush in the ecoregion) burned between 1994 and 2001 (Wisdom and others 2005a). Closely tied to losses from wildfire is the spread of cheatgrass (*Bromus tectorum* L.), introduced to the United States in the 1800s and now a pervasive problem throughout much of the arid West (Billings 1994, Booth and others 2003, Peterson 2006). Cheatgrass is estimated to currently occupy more than 2 million ha (7 percent) of the Great Basin (Bradley and Mustard 2006).

Beyond its reputation as a stronghold for sagebrush, the Great Basin is recognized as an area of rich biodiversity, with its extremes of topography and climate contributing to a diverse assemblage of endemic plants and animals (Nachlinger and others 2001, Ricketts and others 1999). Among terrestrial ecoregions of North America, the Great Basin Shrub Steppe was among the most diverse in both number and endemism of vascular plants (Ricketts and others 1999).

Regional Assessment of Habitats

To address concerns about ongoing degradation of sagebrush habitats and associated species, Wisdom and others (2005a) identified steps for spatial analysis to be used in regional assessment. Those steps were subsequently applied in the Great Basin ecoregion in a case study approach.

The following sections describe the methods and results of the Great Basin assessment, with primary emphasis on results and their interpretation for management. These methods involved selection of species for analysis, describing species-habitat relationships, identification of primary threats, quantification of vegetation and habitat in the study area, and development of predictive models of selected threats.

Selecting and Grouping Species of Concern

Using a variety of screening criteria (e.g., habitat association, estimated risk of extirpation), Wisdom and others (2005a) compiled a comprehensive list of more than 350 sagebrush-associated species of concern. Species of concern were defined as those with populations or habitats that are rare or declining, or both. This list was dominated by vascular plants (68 percent), but also included terrestrial invertebrates (7 percent) and vertebrates (25 percent). For the Great Basin study, this list was narrowed by selecting species suitable for broad-scale assessment in the study area. The screening process yielded 40 species of concern, including 1 amphibian, 9 reptiles, 17 birds, and 13 mammals. Among those selected, greater sage-grouse (*Centrocercus urophasianus*) and pygmy rabbit (*Brachylagus idahoensis*) are of particular concern due to recent petitions to list these species under the U.S. Endangered Species Act (USDI Fish and Wildlife Service 2008, 2010).

The 40 species of concern were assigned to one of five groups according to similarities in habitat associations and amount of habitat in the ecoregion (see Table 1 for a list of species groups). The use of species groups, in combination with individual species, allows managers to:

1. Address either single- or multispecies needs.
2. Identify regional patterns of habitats, especially habitats at risk, that affect multiple species similarly.
3. Address the needs of many species efficiently and holistically.
4. Determine how well regional strategies for groups of species meet the needs of individual species.

Describing Species-Habitat Relationships

Evaluation of the condition (e.g., risk levels) and spatial pattern of habitat for multiple species of concern provides essential context for the development of regionally based management and conservation strategies. A first step in habitat evaluation is defining the relationship between each species and environmental attributes, often vegetation cover types. For the Great Basin assessment, we identified vegetation associated with each species as habitat based on a recently completed landcover map (Comer and others 2002; [http://sagemap.wr.usgs.gov/]). This map was developed explicitly for regional assessment of sagebrush habitats across the Western United States and included the delineation of 8 sagebrush and 38 other landcover types in the Great Basin.

To define habitat relationships for Great Basin species of concern, we used the landcover types to construct a species-habitat association matrix, relying on literature sources and existing wildlife-habitat relationships databases. We then asked species experts to review the matrix, and we refined the habitat designations as necessary. This matrix was the basis for subsequent quantification of amount of habitat, and habitat at risk, within each species' range in the Great Basin ("Quantifying Vegetation and Habitat in the Great Basin").

Identifying Regional Threats

Wisdom and others (2005a) outlined a process for identifying threats to consider in regional assessment, using criteria such as spatial extent of the threat, available resources to address the threat, and cost-benefit analysis. The threats confronting sagebrush habitats in the Great Basin ecoregion typify those in most sagebrush-dominated ecoregions of Western North America. Two of these are pervasive and accelerating: the displacement of native vegetation by cheatgrass invasion and by encroaching pinyon-juniper woodlands.

Invasion by exotic species, particularly cheatgrass, is consistently cited as one of the major challenges to maintenance of healthy sagebrush communities (Connelly and others 2004, Knick 1999, Pyke 2000). In addition to its

Table 1—Percentage of watersheds in the Great Basin by combined classes of habitat abundance and risk that habitats will be displaced by cheatgrass, summarized for each of the five groups of species of conservation concern

		Risk of habitat displacement by cheatgrass			
Species group	**Habitat abundance**	**None-low**	**Low-moderate**	**Moderate-high**	**All risk classes combined**
			Percent		
Sagebrush (n = 519)	Low	14	10	9	33
	Moderate	7	21	18	46
	High	2	14	7	23
	Total[a]	24	44	32	100
Salt desert shrub (n = 507)	Low	6	8	21	35
	Moderate	4	4	23	31
	High	5	3	26	34
	Total	14	15	71	100
Shrubland (n = 521)	Low	2	1	2	5
	Moderate	3	4	10	17
	High	7	21	51	79
	Total	11	26	63	100
Sagebrush-woodland (n = 519)	Low	7	9	9	25
	Moderate	3	18	8	29
	High	5	32	8	45
	Total	15	59	26	100
Generalist (n = 521)	Low	1	<1	1	2
	Moderate	3	1	5	9
	High	14	37	37	88
	Total	18	39	43	100

Total number of watersheds for each species group is given below the group name. See "Selecting and Grouping Species of Concern" for methods used to group the species and "Characterizing Habitat Conditions" for characterization of habitat conditions for species groups.

[a] Total refers to all habitat abundance classes (low, moderate, and high) combined.

Source: Wisdom and others 2005a.

displacement of native understory species, the autecology of cheatgrass leads to an increased risk of catastrophic wildfires that eliminate the sagebrush overstory (Billings 1994, Booth and others 2003). The presence of cheatgrass exacerbates fire hazard because of its high flammability. Cheatgrass can drastically shorten the fire recurrence interval in native sagebrush communities from 20 to 100 years to 3 to 5 years in some sites.

Pinyon-juniper woodlands have expanded greatly in the Great Basin when compared to their distribution more than 150 years ago (Miller and Tausch 2001). Tree density also has increased in established woodlands. These changes have been linked to a decrease in area burned by wildfire, a result of increased fire suppression and removal of fine fuels by livestock; climate change; historical patterns of livestock grazing; and increased atmospheric carbon dioxide (Polley and others 2002, Sakai and others 2001).

Detrimental outcomes of pinyon-juniper woodland expansion include increased soil erosion, changes in soil fertility, losses in forage production, reductions in wildlife habitat for some species, and alteration of presettlement native plant communities (Miller and Tausch 2001). In reporting its findings for a petition to list greater sage-grouse under the Endangered Species Act, the U.S. Fish and Wildlife Service explicitly cited habitat degradation from invasive species, such as cheatgrass, and encroachment of pinyon-juniper woodlands as key threats to greater sage-grouse (USDI Fish and Wildlife Service 2010).

Although many other threats affect sagebrush habitats in the Great Basin such as overgrazing by domestic and wild ungulates (Nachlinger and others 2001), empirical data are often insufficient to model or estimate the risks posed by these threats at large scales. We chose these two threats—cheatgrass and pinyon-juniper woodlands—in the Great Basin assessment to exemplify the **process** of evaluating threats to sagebrush ecosystems at regional scales.

Quantifying Vegetation and Habitat in the Great Basin

To estimate vegetation at risk in the Great Basin, we first quantified the total area of each landcover type present in the study area using the landcover map described in "Describing Species-Habitat Relationships" (Comer and others 2002). The area burned in the Great Basin, especially sagebrush, increased dramatically beginning in 1994 (Connelly and others 2004). To accurately assess these landcover changes, areas in the Great Basin burned by large-scale fires since 1994 were reclassified as recently burned. We used fire data from 1994 to 2001 because the cover type map accounted for area burned prior to 1994.

The amount of habitat for each species was calculated by overlaying the landcover map—selecting only those cover types identified as habitat for the species ("Describing Species-Habitat Relationships")—with the species' geographic range within the Great Basin. These habitat maps were the basis for subsequent quantification and mapping of habitats at risk for each species ("Species' Habitats at Risk") and for species groups ("Characterizing Habitat Conditions").

Modeling of Displacement by Woodlands and Cheatgrass

We developed two independent, rule-based predictive models of displacement of sagebrush and other native vegetation by encroaching pinyon-juniper woodlands and cheatgrass, employing a variety of topographic and vegetation variables (Suring and others 2005). Simple rule-based models may be effective in displaying broad-scale patterns of risk in susceptible plant communities (Woodbury and Weinstein, this volume). The models were deterministic (i.e., the model assumptions completely determine the outcome of the model, with no element of randomness involved), and were intended to display broad-scale patterns of risk across the ecoregion, summarized at watershed (i.e., 5th hydrologic unit code) or larger scales. The models were applied first to vegetation, and then to habitats for individual species of concern (pinyon-juniper and cheatgrass models) and species groups (cheatgrass model only). The models were intended to display risk of displacement of native vegetation in 30 years by the two stressors; thus, areas mapped as high risk may or may not have been converted to cheatgrass or woodland-dominated sites at present.

We identified environmental variables thought to be most important for estimating the risk that sagebrush will be displaced by pinyon-juniper woodlands or cheatgrass by reviewing the literature, including studies of dispersal mechanisms for pine seeds and juniper berries, and consulting with species experts on the ecological relationships and traits of pinyon and juniper species and cheatgrass. The rule sets for both models used ecological provinces (described by Miller and others 1999b and West and others 1998) as a geographic basis for model development. The characterization of landscape conditions within the provinces provided a useful ecological context for model development.

Model Development

Pinyon-Juniper Woodland Model—
Variables selected for the pinyon-juniper risk model included landcover (i.e., sagebrush taxon), elevation, potential for seed dispersal (based on proximity of pinyon-juniper woodlands to sagebrush), precipitation, and landform. Variables were parameterized differently for groups

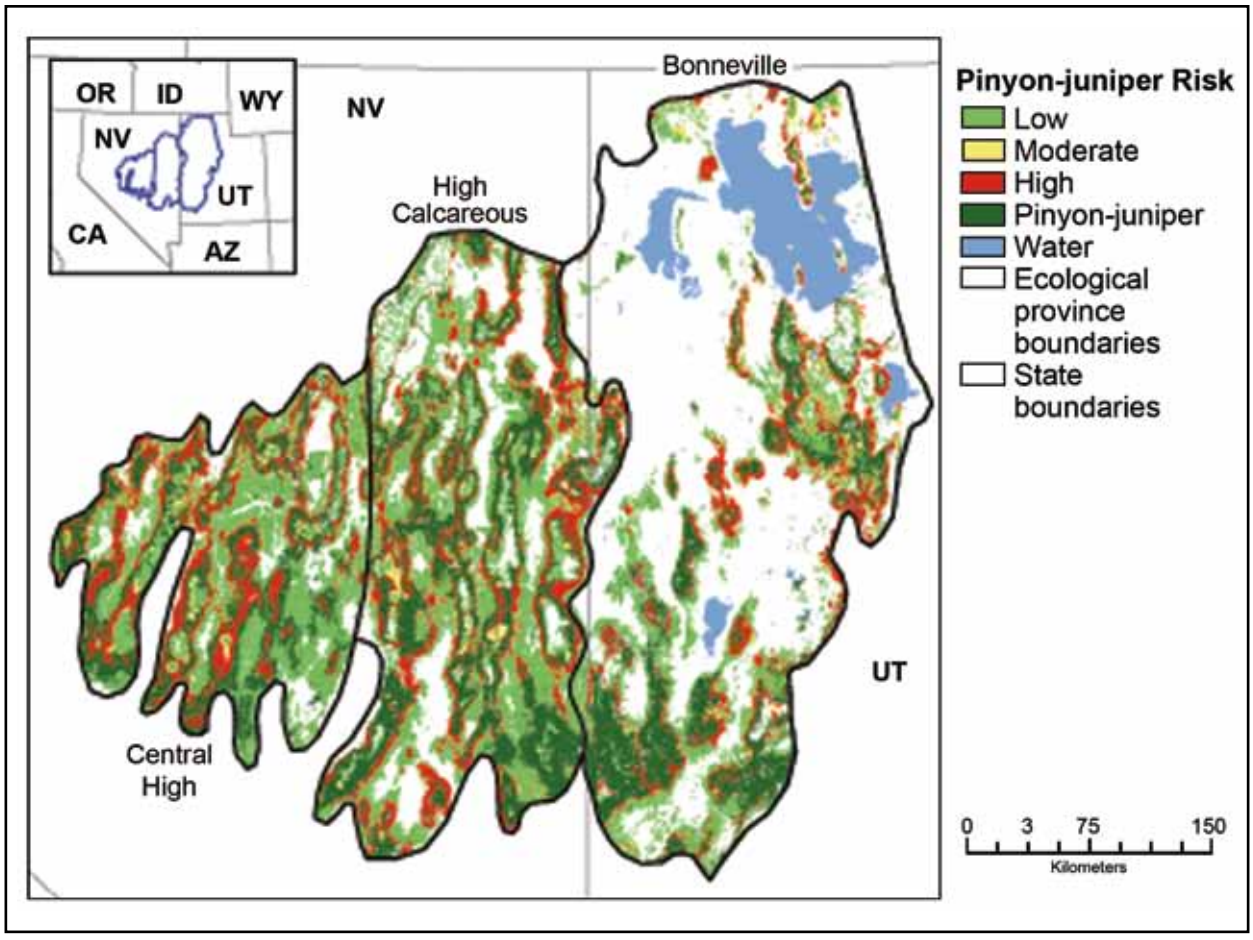

Figure 2—Estimated risk of pinyon-juniper displacement of sagebrush in the Great Basin ecoregion. Levels of risk of sagebrush displacement are mapped in relation to all sagebrush cover types in the three ecological provinces in which the model was applied: Central High, High Calcareous, and Bonneville. Areas not considered to be at risk are landcover types other than sagebrush and are depicted in white (from Wisdom and others 2005a).

of ecological provinces within the Great Basin. Evaluation of the landcover map indicated that, within the study area, the spatial representation of pinyon-juniper woodlands was most accurate in three provinces in the eastern Great Basin. Consequently, our application of the risk model was restricted to those provinces (Figure 2).

Risk classes were defined as follows:

- Low—the probability that pinyon-juniper woodlands will displace existing sagebrush cover types within 30 years is minimal; currently, little or no pinyon-juniper is likely to be present in the overstory of these sage-brush stands.
- Moderate—the probability of displacement within 30 years is likely, but less so than for sagebrush at high risk; currently, pinyon-juniper is likely to be a minor to common component of the overstory of these stands. This class represents a transition phase in the conversion of sagebrush cover types to pinyon-juniper woodlands (Miller and others 1999a).
- High—the probability of displacement within 30 years is high; currently, pinyon-juniper is likely to be a common to dominant component of the overstory of these stands.

Cheatgrass Model—

Variables selected for the cheatgrass model included aspect, slope, elevation, and landform by ecological province. Recently published research based on remotely sensed data from the Great Basin supports the use of several of these

variables (Bradley and Mustard 2006, Peterson 2006). The model was applied to all susceptible landcover types within the Great Basin ecoregion (Figure 1). Nonsusceptible landcover types (e.g., marsh/wetland) were assigned to the "none" risk level. The remaining risk classes were defined as follows:

- Low—the probability that cheatgrass will displace existing sagebrush or other susceptible cover types within 30 years is minimal; currently, native plants are likely to dominate the understory of these stands.
- Moderate—the probability of displacement within 30 years is moderate, but lower than for types at high risk; currently, either cheatgrass or native plants can dominate the understory.
- High—the probability of displacement within 30 years is very likely; currently, cheatgrass is likely to dominate the understory.

Results of Model Application in the Great Basin

Outputs from both the pinyon-juniper and cheatgrass models were summarized by landcover type and by species (i.e., habitats at risk). Maps and associated spatial data in tabular form are in Wisdom and others (2005a); we present a brief summary of results below.

Vegetation at Risk of Displacement by Pinyon-Juniper— Of the 4.8 million ha of sagebrush in the three provinces of the eastern Great Basin, 35 percent (1.7 million ha) was estimated to be at high risk of displacement by pinyon-juniper woodlands, whereas 60 percent (2.9 million ha) was at low risk. Very little sagebrush was in the moderate risk category (6 percent), which represents a transitional phase of encroachment. Mountain big sagebrush (*Artemisia tridentata* Nutt. *vaseyana* (Rydb.) Beetle) appeared to be the most susceptible sagebrush taxon (42 percent at high risk). However, Wyoming-basin big sagebrush (*A. t. wyomingensis* Beetle and Young-*A. t. tridentata*) was the dominant sagebrush cover type in the modeled area and made up 55 percent of all the high-risk sagebrush, exceeding 930 000 ha.

The spatial pattern of areas estimated to be at high risk of displacement by pinyon-juniper closely followed the distribution of pinyon-juniper woodlands throughout the three provinces (Figure 2). Areas of moderate and high risk tended to occur on the side slopes, with areas of low risk in the valley bottoms.

Vegetation at Risk of Displacement by Cheatgrass— Nearly 80 percent of the landcover in the Great Basin was estimated to be susceptible to displacement by cheatgrass (i.e., low or greater risk; Figure 1). Of the susceptible area, 26 percent was estimated to be at moderate risk and 40 percent at high risk. Among vegetation types, salt desert scrub was most at risk, with 96 percent (7.1 million ha) estimated to be at moderate or high risk of displacement by cheatgrass. Sagebrush was also at risk from cheatgrass, with 38 percent at moderate risk and 20 percent at high risk, a total of 4.8 million ha. The overwhelming majority (88 percent) of the sagebrush at high risk was Wyoming-basin big sagebrush.

Spatial patterns of risk of displacement by cheatgrass followed the typical north-south alignment of topographic features in the Great Basin. Areas of high risk generally occurred at lower elevations and on valley bottoms, whereas areas of low risk were typically in mountain ranges and higher elevation valleys.

Species' Habitats at Risk— For 35 of the 40 species of concern considered in our assessment, more than 30 percent of their sagebrush habitat was at high risk of displacement by pinyon-juniper woodlands in the three provinces in which this risk was modeled. Twelve species each had about 1.6 million ha of sagebrush habitats at high risk; these species used all eight sagebrush cover types as habitat and were widely distributed across the three provinces.

Within the Great Basin, the dominant category for species' habitat at risk of displacement by cheatgrass was high risk (mean = 36 percent, n = 40). For 33 species (88 percent), more than half of their habitat in the study area was at moderate or greater risk of displacement by cheatgrass. Ten species, including one amphibian, three reptiles, five raptors, and one small mammal, had more than 8 million ha of habitat at high risk, an area equivalent to about

one-fourth of the ecoregion. Relative to other species in our assessment, habitat for greater sage-grouse and pygmy rabbit was at lower risk of displacement by cheatgrass.

Application of Risk Models in Shrubland Management (Application to Management)

Federal agencies need information about habitat requirements and conditions for species and groups of species at spatial extents that are typically used in land management planning. To demonstrate the application of our threats modeling results ("Species' Habitats at Risk") to land management in the Great Basin, we used species groups ("Selecting and Grouping Species of Concern") to generalize the spatial patterns of habitat at risk at the watershed scale in the Great Basin.

Characterizing Habitat Conditions

We used two habitat variables, habitat abundance and habitat at risk of displacement by cheatgrass, to characterize the composite habitat conditions for each species group at the watershed extent within the Great Basin. For each variable, watersheds were assigned to one of three classes, resulting in nine possible combinations of habitat abundance and risk (Table 1, Figure 3).

The percentage of watersheds in each of the nine condition classes was relatively even for the sagebrush and salt desert shrub species groups, but one or two condition classes dominated the other three groups (Table 1, Figure 3). The best condition class, that of high habitat abundance coupled with none to low risk, was consistently uncommon, with the exception of the generalist group of species (Table 1). Notably, the sagebrush group, which included both greater sage-grouse and pygmy rabbit, had the smallest percentage (2 percent) in this class (Table 1, Figure 3).

Prioritizing Restoration Activities

Different combinations of habitat abundance and habitat risk have different implications for conservation and restoration. Those characterizations can inform and guide restoration priorities. For example, watersheds with habitats of relatively higher abundance and lower risk may represent habitat strongholds (i.e., optimal habitat amount, quality, and spatial arrangement) for a group of species. Management objectives for these watersheds would likely be tailored to maintain current conditions through prudent management of human activities and potential threats that can alter the amount, quality, and spatial pattern of desired native habitats. In general, targeting management of native shrublands at moderate risk may be the most prudent approach, given (1) the relative security of low-risk habitats and (2) the vast resources required to prevent high-risk areas from passing beyond ecological thresholds, after which restoration of native habitats may be difficult or impossible to achieve (Wisdom and others 2005b). Areas at high risk from these stressors may have already passed such thresholds.

By contrast, watersheds with limited habitat area and higher risk may be suboptimal relative to the requirements of a species group. Watersheds in this condition would likely have smaller patch sizes, lower habitat quality, or poor habitat connectivity in relation to the group's needs. Management objectives for such watersheds would likely focus on retention of existing habitats, combined with substantial emphasis on restoration activities to mitigate past habitat losses and degradation. Identification of broad-scale patterns of habitat risk for species of concern helps determine whether restoration activities need to be initiated (Wisdom and others 2005b).

Integration of Multiple Stressors

The combined risk of displacement by cheatgrass and by pinyon-juniper woodlands was evaluated for the 4.8 million ha of sagebrush in the three ecological provinces in which the pinyon-juniper model was applied. Of the five combined risk classes, the two dominant classes were high cheatgrass (high risk from cheatgrass and low or moderate from pinyon-juniper; 35 percent) and low to moderate (moderate risk from both stressors; 33 percent). Only a trace amount (less than 1 percent) of sagebrush in this region was at high risk to both stressors (see Wisdom and others 2005a for details). Other stressors not considered in our prototype assessment, such as climate change, may be critical in future modeling of risks in the Great Basin from both cheatgrass and pinyon-juniper expansion. Under one modeling approach,

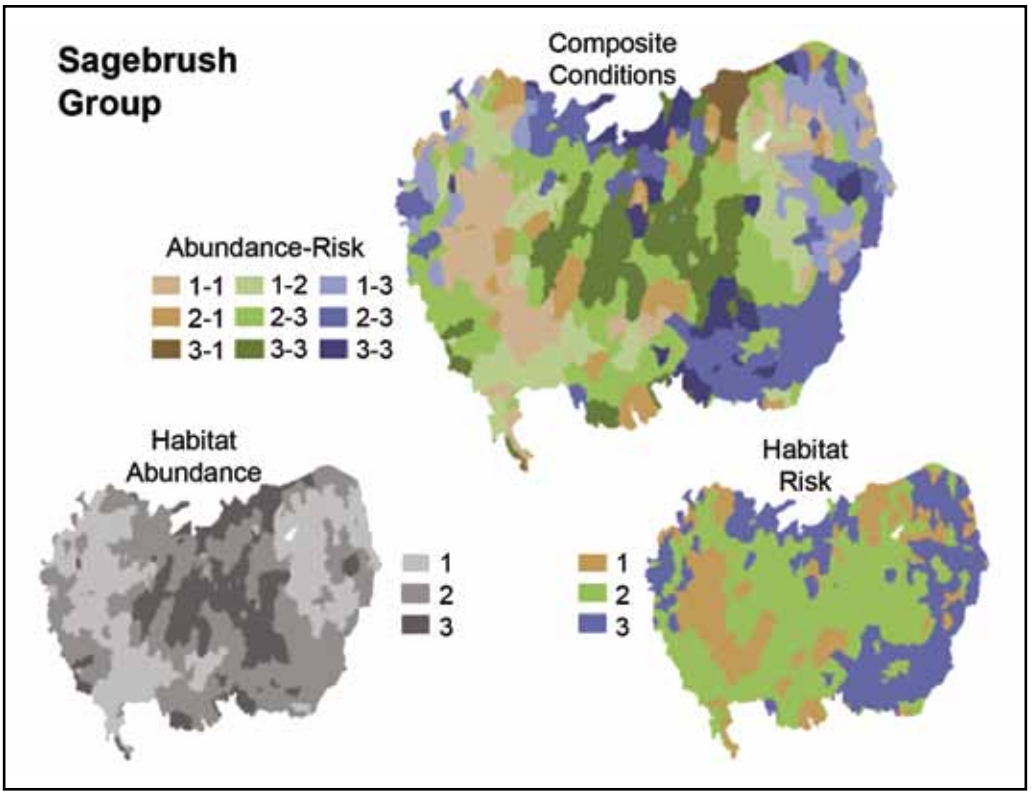

Figure 3—Habitat abundance (lower left), habitat risk (lower right), and composite conditions (top center) for the sagebrush group of species in watersheds of the Great Basin. For habitat abundance, 1 = low (<25 percent of the watershed is habitat), 2 = moderate (25 to 50 percent of the watershed is habitat), and 3 = high (>50 percent of the watershed is habitat). For the map of habitat risk, 1 = watersheds with habitats dominated by none to low risk of displacement by cheatgrass, 2 = watersheds with habitats dominated by low to moderate risk, and 3 = watersheds with habitats dominated by moderate to high risk. For the map of composite habitat conditions, the first number is for abundance, and the second number is for risk, using the definitions above for maps of habitat abundance and risk. For example, 1-1 denotes watersheds with habitats of low abundance and none to low risk, whereas 3-3 denotes watersheds of high habitat abundance and moderate to high risk. Map colors on the composite map follow those for the map of habitat risk (blue = moderate to high risk, green = low-moderate risk, and brown = none-low risk), and intensity of colors follows those for the map of habitat abundance (darkest shade = high habitat abundance, intermediate = moderate, and lightest = low) (from Wisdom and others 2005a). Mean size of the 367 watersheds that occur entirely within the ecoregion boundaries is 66 000 ha.

direct and indirect effects of global warming may result in the elimination of up to 80 percent of existing sagebrush in the United States (Neilson and others 2005).

Management Implications

Our analyses revealed that watersheds differ in spatial patterns of habitat abundance and risk, resulting in different implications for conservation and restoration of habitats. These differences in spatial patterns suggest that regional strategies could be developed for watersheds in each condition class to identify appropriate conservation and restoration prescriptions needed to meet management goals for each group of species. Targeting areas for management attention through this process complements other strategies to identify threats, such as the conservation by design approach used by The Nature Conservancy (Nachlinger and others 2001).

Results of our regional assessment serve as a working example for analysis of species of concern, but also provide a sound basis for comprehensive land use planning in the ecoregion. Cheatgrass invasion and woodland encroachment are two of the highest priority issues for both research

and management of native shrublands in the Great Basin. Because of the potential mismatch of administrative scales at which management occurs and the ecological scales at which these threats operate, regional assessment can provide key context for local management solutions. Integrated management of both threats is needed to conserve sagebrush habitats affected by both cheatgrass and pinyon-juniper expansion. For example, prescribed burning of some sagebrush habitats may curtail woodland encroachment but also may enhance expansion of cheatgrass on susceptible sites. Alternatively, combinations of mechanical treatments to reduce pinyon-juniper density, followed by chemical treatments to reduce cheatgrass abundance, may effectively reduce the combined risks posed by cheatgrass and woodlands.

With any regional assessment encompassing a diverse set of species and habitats, uncertainty exists at several levels about the assumptions inherent in the analyses. For the Great Basin assessment, example areas of uncertainty include:

- The cover types associated with each species as habitat are assumed to contribute to population persistence, but additional factors beyond habitat abundance and configuration may influence populations. We have limited knowledge of how species respond to landscape-scale changes in native habitats, as brought about by displacement from cheatgrass and pinyon-juniper woodlands. Further studies of this topic are a high priority for research and management.
- Our predictions of risk of displacement of native shrublands are based on a prior knowledge of environmental conditions affecting distribution of cheatgrass and pinyon-juniper and require extensive field evaluation before results are widely applied in management. Such validation is currently underway (Rowland and others 2006) and will reduce the uncertainty associated with model predictions.
- The combined effects of multiple threats, especially the potential synergy among threats, are not well understood. New research is needed to improve knowledge about cumulative effects on shrubland habitats and species.

Restoration in sagebrush and other arid shrubland communities will require substantial inputs of resources owing to the lack of resiliency in these systems and the recent undesirable trends in vegetation dynamics and fire regimes affecting these communities (Hemstrom and others 2002). Concomitant with restoration, prevention and mitigation of threats that go beyond cheatgrass and woodland expansion, such as infrastructure associated with anthropogenic activities (e.g., powerlines, roads, energy development), are critical for maintaining functioning habitats for shrubland-associated species of concern in the Great Basin and surrounding areas.

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