CHAPTER 4

MODELING RISKS TO SAGEBRUSH

In this chapter we 1) describe the basis for selecting threats to model, 2) describe models we constructed to predict the relative risk to sagebrush from four threats, and 3) provide and discuss maps of risk to sagebrush from each threat, and combined risk from all threats.

Selection of Threats to Model in the Assessment Area

General threats to sagebrush in the assessment area are described in Chapter 2. We selected threats to model based on three criteria: 1) the threat is likely to affect sagebrush-dependent wildlife species, 2) the threat is widespread in the assessment area, and 3) the threat can reasonably be modeled based on existing spatial data available to us at a regional scale. The third criterion precluded modeling of threats such as sagebrush understory impacts by grazing or drought, soil erosion or compaction, etc., because no suitable spatial data exist to predict the extent of such impacts.

We chose to model risks to sagebrush of pinyon-juniper encroachment and herbaceous invasive plant encroachment following procedures similar to models for Great Basin sagebrush by Wisdom et al. (Wisdom et al. 2003a). Spatial data similar to data used by Wisdom et al. (2003b) were available for Colorado. However, less information is available for Colorado on ecosystem processes of pinyon-juniper encroachment into sagebrush compared to the Great Basin, where the threat is perhaps more pervasive and more research has been done. Great Basin sagebrush also bears a considerably greater risk from invasive herbaceous plants (particularly cheatgrass), which interacts with altered fire regimes to cause widespread stand replacement. In Colorado, the risk of sagebrush stand replacement by annual weed encroachment exists in some arid sagebrush stands, particularly in southwestern Colorado (S. Monsen, pers. comm.), but more typically the risk to sagebrush habitat from herbaceous weed invasions is less from stand replacement and more from degradation of habitat characteristics due to changes in herbaceous understory density, height, species composition, or persistence through the growing season or winter period.

We also chose to model risks to sagebrush from energy development and residential development. Energy development on sagebrush-dominated lands has increased substantially in recent years, and spatial data are available from various sources on potential and actual developments. Residential development is a rapidly increasing threat to some sagebrush-dominated areas, and an existing spatial model predicting future residential growth in Colorado was available.

Methods

For each threat model, we used GIS to classify the unfiltered current sagebrush dataset described in Chapter 3.

Encroachment by Pinyon-Juniper

Similar to the process used by Wisdom et al. (2003b) for the Great Basin, we reviewed the literature and sought expert knowledge to identify the environmental factors believed to be most important for predicting the risk that sagebrush will be displaced by pinyon pine or juniper. We selected the following environmental variables for the model, each described in the following sections: ecological province, proximity to current pinyon-juniper, sagebrush taxa present, precipitation, and elevation. Using the variables and parameters described below, we

constructed a model (Table 4-1) and used GIS to classify sagebrush in the assessment area at none, low, moderate, or high risk of encroachment by pinyon-juniper.

Proximity to Current Pinyon-Juniper—the proximity of sagebrush to pinyon-juniper is the most important element of our model. Fruits of pinyon pine and juniper are large, and seeds dispersed more than 100 m from parent trees are most often transported by birds and mammals (see review of pinyon-juniper seed dispersal by Wisdom et al. [2003b]). The likelihood of seed dispersal attenuates rapidly with distance from the parent tree, and most seeds are transported ≤1.6 km, rarely beyond 5 km (Schupp et al. 1999). For our model, we used SW ReGAP land cover types dominated by pinyon-juniper or juniper species (collectively, "pinyon-juniper," see Table 6-1). We chose conservative values of higher risk levels for sagebrush within 800 m of pinyon-juniper, lower risk values between 800 and 2,000 m, and no risk beyond 2,000 m.

Ecological Province—we used Bailey's ecological provinces (Bailey et al. 1994). Because small parts of several provinces occur in the assessment area, we combined the Southern Rocky Mountains, Intermountain Semidesert, and Nevada-Utah Mountains Semidesert provinces to create a Northwest Desert-Mountains province, covering the high mountains and northwest quarter of Colorado. We combined the remaining Bailey's provinces into a Southwest Deserts province, covering lower and more arid regions of southwestern Colorado and the San Luis Valley. In the risk model, different environmental variables were sometimes applied in the two ecological provinces.

Sagebrush Taxa—West et al. (1978) summarized the relationships of various sagebrush taxa to environmental conditions associated with pinyon-juniper woodlands in the Great Basin, and Wisdom et al. (2003b) regarded the distribution of sagebrush taxa as useful in predicting relative risk of pinyon-juniper encroachment. Similar ecological relationships have been reported for sagebrush taxa in Colorado (Monsen 2004a, 2004b); Wyoming big sagebrush occurs in warmer and drier sites, in soils of medium depth; and mountain big sagebrush favors the cooler and moister sites with moderately deep soils. Pinyon-juniper establishment is more likely on wetter, cooler sites with fair to moderate soil depth (Burkhardt and Tisdale 1969; Wisdom et al. 2003b). Wetter, cooler sites are also more likely to support mountain big sagebrush. Therefore, we constructed a model rule for "montane big sagebrush" (typically dominated by mountain big sagebrush) to be more susceptible to pinyon-juniper encroachment than "basins sagebrush" (typically dominated by Wyoming big sagebrush, basin big sagebrush, and other arid site sagebrush taxa including low sagebrush and black sagebrush). The distribution of sagebrush taxa used is shown in Figure 3-4.

Precipitation—Literature reviewed by Wisdom et al. (2003b) indicates that precipitation is a main factor in determining the risk of pinyon-juniper encroachment into sagebrush. Average annual precipitation is positively correlated with juniper growth and reproduction (Dealy et al. 1978), pinyon pine seedling establishment (Harrington 1987), and tree densities in pinyon-juniper woodlands (Koniak 1986). We compared SW ReGAP pinyon-juniper land cover types to a statewide average annual precipitation dataset in GIS, and found that pinyon-juniper woodlands in the assessment area occurred in areas with annual precipitation from 20 cm to over 90 cm; pinyon-juniper woodlands in areas with more than about 50 cm of annual precipitation were mainly on south-facing slopes where frost conditions are presumably moderated. In the intermountain west, pinyon-juniper woodlands generally occur where annual precipitation is at least 25 cm, and greatest tree densities usually occur where annual precipitation exceeds 35 cm (Woodbury 1947; Tueller and Clark 1975). For our model, we used different precipitation values for different ecological provinces. We regarded sagebrush in the annual precipitation range of 30 to 41 cm in the southwest deserts province and 26 to 41 cm in the northwest deserts and mountains province as higher risk, and sagebrush with less or more precipitation as lower risk. We used a higher minimum precipitation for higher risk of encroachment in the southwest

deserts province because mean temperatures are typically higher, making less soil moisture available during the growing season from a given amount of annual precipitation.

Elevation—Pinyon-juniper woodlands throughout their range occur within fairly limited and predictable elevation limits (Evans 1988). Pinyon-juniper is limited at upper elevations by temperature and at lower elevations by precipitation (Wright et al. 1979). Based on literature reviewed by Wisdom et al. (2003b) and analysis of SW ReGAP-mapped pinyon-juniper land cover types in GIS with a Digital Elevation Model (DEM), we concluded that pinyon-juniper in the assessment area generally occurs between elevations of 1,800 and 2,500 m. In the Great Basin, downslope expansion of pinyon-juniper woodlands is more extensive than upslope (Tausch et al. 1981), and our observations in Colorado suggest the same is likely in the assessment area.

Encroachment by Invasive Herbaceous Plants

Invasive herbaceous plants are a growing problem in western rangelands, particularly in more arid regions and where natural vegetation communities are disturbed by human or natural causes (Sheley and Clark 1999). Cheatgrass, the most common invasive plant in sagebrush stands in the assessment area, is an annual grass of serious concern to sagebrush communities (BLM 2002). Cheatgrass, along with other annual forb species, invades the understory of sagebrush stands and may subsequently reduce establishment of perennial grasses, shifting the plant composition to a sagebrush/annual grass community (Whisenant 1990). In fire-prone areas, invasive annuals provide extensive fine fuel in summer and can increase fire frequency and intensity in sagebrush (Miller and Edlleman 2000). Sagebrush is killed by fire, and increased fire frequencies induced by invasive weeds are leading to large-scale conversion of sagebrush to annual grasslands in the Great Basin and on the Columbia Plateau. Weed-induced conversion of sagebrush by fire is not a widespread problem in Colorado, although it has occurred locally in the more arid counties from Mesa County southward and is expected to accelerate (S. Monsen, pers. comm.; A. Stevens, pers. comm.). More typically in the assessment area, invasive annual weeds alter understory vegetation and may impact sagebrush-dependent species habitat by increasing herbaceous cover, decreasing perennial grasses, and affecting soil moisture or nutrient balances.

We reviewed the literature and sought expert knowledge to identify the environmental factors believed to be most important for predicting the risk that sagebrush will be invaded by invasive herbaceous plants. We then constructed a GIS-based model similar to Wisdom et al. (2003b) using the following environmental variables: ecological province, proximity to areas dominated by herbaceous weeds, proximity to disturbance, precipitation, and slope. Table 4-2 shows the model variables and parameters.

Ecological Province—we divided the assessment area into two ecological provinces, as described above for the pinyon-juniper encroachment model, and in some cases used different model parameters in the two ecological provinces because of environmental differences in the assessment area.

Proximity to Areas Dominated by Herbaceous Weeds—invasive herbaceous plants in a rangeland setting typically spread from adjacent occurrences (Sheley and Clark 1999), and this is the most important variable in our model. We used SW ReGAP land cover types that are dominated by upland herbaceous weeds (invasive perennial grassland, invasive perennial forbland, invasive annual grassland, and invasive annual and biennial forbland, see Table 6-1) as source data for areas dominated by herbaceous weeds. In the GIS model, sagebrush within 1,200 meters of these areas was considered to be at high risk of encroachment by invasive herbaceous vegetation, and areas at a greater distance at variable risk depending on other factors.

Proximity to Disturbance—invasion of herbaceous weeds is often associated with activities that disturb natural vegetation and soils (Sheley and Clark 1999; Getz and Baker in review). Some disturbances in the assessment area that could contribute to herbaceous weed invasion—such as livestock grazing, small roads and reservoirs, and recreational use—could not be modeled because no suitable spatial data exist. However, we used SW ReGAP land cover types that reflect recent disturbance, including developed low intensity, developed medium-high intensity, agriculture, disturbed-non-specific, recently burned, recently mined or quarried, recently logged areas, recently chained pinyon-juniper areas, and disturbed-oil well. In the GIS model, sagebrush within 800 meters of these disturbed areas was considered at greater risk of invasion by herbaceous weeds, and sagebrush at greater than 800 meters was considered at less risk. The distance of 800 meters was chosen to encompass the area of presumed greater probability that invasive weeds could spread into sagebrush from adjacent disturbed areas.

Precipitation—little information is available on environmental factors favoring invasive annual weeds other than cheatgrass. For this reason and because cheatgrass is the most common herbaceous weed of concern in sagebrush habitats, we used information for cheatgrass to develop model parameters for precipitation and slope. In the cooler parts of the Intermountain West, cheatgrass is most common in more arid, lower elevation areas (see review by Wisdom et al. [2003b]). Lack of continuous snow cover and winter precipitation in the form of rain rather than snow strongly enhance winter emergence of cheatgrass, which contributes to its competitive advantage over many native perennials (Mack and Pyke 1983). Cheatgrass germinates best at temperatures above 10 degrees C, and germination is reduced if seeds when wet. As a consequence, cheatgrass performs best at lower and somewhat drier elevations in the assessment area. Because precipitation correlates strongly with elevation in the assessment area, we only modeled precipitation, although some of the effect may be due to temperature varying with elevation. In our model, we used a statewide mean annual precipitation dataset, and classified sagebrush at greatest risk of invasion by herbaceous weeds when it receives less than 41 cm annual precipitation in the southwest deserts ecological province, and less than 30 cm annual precipitation in the northwest deserts and mountains province. In both provinces, sagebrush receiving between 41 and 76 cm annual precipitation were classified at intermediate risk, and sagebrush receiving more than 76 cm was classified at the least risk.

Slope—the slope of the ground influences sun angle and, on steeper slopes, soil stability. Cheatgrass responds positively to increased insolation on gentle to moderate slopes tipped toward the sun (Hedrick 1965); slopes tipped away from the sun receive less insolation and are less favorable sites for cheatgrass. The effect increases with the steepness of the slope. Soil instability and rockiness become important factors on very steep slopes. For these reasons, in our model we classified sagebrush on slopes 30 percent or less as having a greater risk of herbaceous weed invasion than steeper slopes. Slope was determined in GIS using a DEM.

Energy Development

Energy development in the assessment area is accelerating in some sagebrush-dominated areas, and is regarded as an increasing threat to sagebrush-dependent wildlife (GSRSC 2005). We constructed a GIS model to predict the risk to sagebrush in the assessment area of oil and gas, coal, and uranium-vanadium development. The most extensive energy industry in the assessment area is oil and gas (including coal-bed methane), and site-disturbing actions include exploratory drilling and seismic operations, waste water disposal, well drilling and operations, and construction and operation of pipelines, roads, and other infrastructure. Coal mining is less extensive but occurs in several sagebrush-dominated areas. Site-disturbing actions include exploration drilling, surface mining (mostly in northwestern Colorado) or underground mining, waste rock and water disposal, mine reclamation, and construction and operation of roads, ore

conveyors, transmission lines, and other infrastructure. Uranium-vanadium mining occurs in limited areas, and site-disturbing actions are similar to coal mining except that no surface mining for uranium-vanadium currently occurs in Colorado. Other energy development including geothermal energy is of limited extent in the assessment area and was not modeled.

Some potential impacts of energy development to sagebrush habitats for species of concern include removal of sagebrush and other natural vegetation, disturbance by human presence and noise, increased roadkill or poaching, increased predation by human-associated predators, increased avian predation by providing raptor hunting perches, changes in water availability or quality, and increased risk of introduced weeds (BLM 1991; GSRSC 2005).

To construct the threat model, we used a combination of several existing spatial datasets in GIS to rank the risk to sagebrush in the assessment area as none, low, moderate, or high. The datasets and classification process are described below.

Oil and Gas—we classified as high risk from oil and gas development all sagebrush within oil and gas fields depicted in the Colorado Geological Survey (CGS) *Oil and Gas Fields Map of Colorado* (Wray et al. 2002). We also classified as high risk all sagebrush within 1,000 meters of Colorado Oil and Gas Conservation Commission (COGCC) Drill Permits and producing wells (COGCC 2005) not within an existing oil or gas field depicted by Wray et al. (2002). We used 1,000 meters to encompass the area of reasonable probability of impacts to species of concern or their habitats from oil and gas development, including disturbance. We classified as moderate risk from oil and gas development all sagebrush within areas classified as "high oil and gas potential" by the BLM *State of Colorado Oil and Gas Potential* map (BLM no date). This map depicts geologic structural basins considered to have high potential by the BLM, but is less specific than the datasets we used to indicate high risk from oil and gas development. We classified as low risk from energy development all sagebrush within BLM "moderate or low oil and gas potential," and as no risk all areas within BLM "no oil and gas potential."

Uranium/Vanadium Potential—we used the U.S. Geological Survey (USGS) *Energy Resources Map of Colorado* (USGS and CGS 1977), to model risk to sagebrush from uranium/vanadium development. The map was scanned, the resulting image geo-referenced in GIS, and selected map features digitized into shapefiles. We classified as high risk from uranium/vanadium development all sagebrush within the mapped uranium/vanadium fields. As a check, we noted that uranium/vanadium mines shown in a USGS mine database for the Gunnison-Uncompahgre-Grand Mesa National Forests (Wilson et al. 2000) correlated well with the 1977 fields depicted by USGS and CGS (1977). We classified as moderate risk from uranium/vanadium development all sagebrush within 2,500 meters of an existing uranium/vanadium mine or resource area shown on the USGS map (USGS and CGS 1977). The 2,500 m distance was used to capture the area of reasonable probability of impacts to species of concern from uranium/vanadium development, including disturbance. These locations were fairly general, yet indicate areas of past or current activity that may undergo development in the future. We also classified as moderate risk all sagebrush within areas shown by BLM data (BLM 1999), as having uranium/vanadium potential, defined by BLM to include known deposits, productive areas, or favorable areas. We did not classify any sagebrush at low risk of uranium/vanadium development; all sagebrush not classified as high or moderate was classified as no risk.

Coal Potential—we evaluated BLM data on coal potential in Colorado (BLM 1998), but determined that the map was too general to be useful. We used the CGS *Historic Coal Mines of Colorado* map (Carroll and Bauer 2002), which depicts the location and date of coal mines as well as geologic basins with known coal reserves. We classified as high risk from coal development all sagebrush within 1,500 meters of coal mines active since 1941. We excluded

earlier coal mines because most of those were small operations that often supplied coal to single households, and are no longer economically feasible. We classified as low risk all sagebrush within coal basins depicted by Carroll and Baker (2002). Since about 1941, coal mining has been concentrated at basin edges where coal occurs near the ground surface. In most of the unexploited basin areas, coal is too far below the surface for economical mining. However, as technology and demand change, some of these areas are likely to be developed. We were not able to classify any sagebrush as moderate risk, and all sagebrush not classified as high or low risk was classified as no risk from coal development.

We combined the oil and gas, uranium/vanadium, and coal risks into one combined energy development risk model. Each 30 x 30 m sagebrush pixel was classified as the highest risk score it received from any of the individual energy threat models; in other words, if a sagebrush pixel was classified as high risk from any individual energy threat, it was classified as high risk of energy development.

Residential Development

Residential development and other features of urban growth are accelerating in some sagebrush habitat in the assessment area. Residential development removes sagebrush habitat where buildings, landscaping and pastures, and roads are constructed. Development also fragments the remaining sagebrush habitat. Finally, residential development also causes indirect impacts to sagebrush-dependent species in surrounding sagebrush habitats. Indirect impacts may include roadkill or poaching, predation by pets, predation by human-associated predators or avian predators utilizing enhanced hunting perches, disturbance by human presence, and increased invasion of herbaceous weeds.

We were not able to model all aspects of urban growth, but we focused on residential growth because of the existence of spatial data. We used version 1 of the *Spatially Explicit Regional Growth Model* (SERGoM v. 1) by Theobald (in review). The model and its limitations are discussed in detail in the *Gunnison Sage-grouse Rangewide Conservation Plan* (GSRSC 2005). In summary, the model is useful for predicting the general trend and location of future residential growth, but has several limitations. The SERGoM model tends to underestimate development risk in outlier areas surrounding Colorado resort communities such as Telluride, where very high land prices tend to spread growth as much as 70 miles away. Also, the SERGoM model may not adequately account for the significant second-home development occurring in Colorado, also often associated with resort communities.

The model was designed to depict the location and density of current and projected future private land housing units across the coterminous U.S., and provides spatial data for the years 2000 and projections for the year 2020. We used GIS to compare sagebrush with the SERGoM 2020 projection, and classified the risk to sagebrush from residential development according to the following reclassification of the SERGoM classes:

No risk:	Public lands (not included in SERGoM model)
Low risk:	0 private, no housing units 1 ≥ 80 acres per housing unit (rural)
Moderate risk:	2 50 to 80 acres per housing unit 3 40 to 50 acres per housing unit
High risk:	4 through 9 ≤ 40 acres per housing unit

In developing these risk categories, we were constrained by the existing classification of the SERGoM data output; the data did not discriminate among areas at less than 1 house per 80 acres (SERGoM category 1, above). The categories we chose are based on the assumptions

that residential development of any density poses at least some risk to species, that densities between 40 and 80 acres per house represent an increased risk over lower densities, and that the greatest risk to species occurs at densities greater than 1 house per 40 acres. These categories represent a balance between species, which probably differ substantially in their vulnerability to residential development.

Combined Risks

We combined risks from each of the four threats models (pinyon-juniper encroachment, invasive herbaceous plant encroachment, energy development, and residential development) to calculate and depict the extent of sagebrush at risk from any of these threats. To create the combined risk model, we classified each 30 x 30 m cell of sagebrush equal to the highest risk level (none, low, moderate, or high) the sagebrush pixel was assigned from any of the individual threats models. In other words, if a sagebrush cell was classified as no higher than moderate risk for any individual threat, it was classified as moderate for combined risk.

Results

Table 4-3 shows the area and percent of sagebrush in the assessment area predicted by the models to be at risk from the individual threats and combined threat. Figures 4-1 through 4-5 show the locations of sagebrush in the assessment area at risk from each of the threats and combined threats. It is important to note that the base data sets (Figures 4-6 through 4-11) used for these analyses are generalized in nature (for example, mean annual precipitation was classed in 2 to 4-inch increments), and in vector (polygon) rather than raster (grid) format. One outcome of these characteristics is relatively abrupt changes in risk categories depicted in Figures 4-1 through 4-5, but risks are likely to blend across the landscape.

Encroachment by Pinyon-Juniper

The model predicts that over 1.2 million ha (56 percent) of sagebrush in the assessment area is at no risk of pinyon-juniper encroachment (Table 4-3). Nearly 400,000 ha (18 percent) is predicted at high risk, and nearly 650,000 ha (30 percent) is predicted at high or moderate risk. Most of the sagebrush predicted at high risk occurs in the western tier of counties south of the Yampa River, and in Eagle and southern La Plata counties (Figure 4-1). Principal sagebrush areas at moderate risk are in the same areas, but also occur in the San Luis Valley and in Gunnison County both in the Gunnison Basin and farther north in the North Fork Gunnison River watershed.

Risk of sagebrush to pinyon-juniper encroachment varies among landowners (Table 4-3). Among the two principal landowners, sagebrush on BLM land is more at risk (36 percent at moderate or high risk) than sagebrush on private land (25 percent). Sagebrush on USFS lands is at comparatively little risk (14 percent in moderate or high risk), although the relatively minor amount of sagebrush on federal lands other than BLM or USFS is at considerable risk (75 percent moderate or high risk). Sagebrush on Colorado State Land Board lands is at the least risk compared to other landowners (12 percent moderate or high risk).

Encroachment by Invasive Herbaceous Plants

The model predicts that just over 510,000 ha (23 percent) of sagebrush in the assessment area is at high risk of encroachment by invasive herbaceous plants, and just over 910,000 ha (41 percent) of sagebrush is at high or moderate risk (Table 4-3). Most of the remaining is predicted at low risk, and only a small amount (less than 1 percent) is predicted at no risk. Geographically, the areas of sagebrush at high or moderate risk are most concentrated in the western tier of counties, the southern San Luis Valley, and elsewhere at lower elevations near centers of human development (Figure 4-2).

Herbaceous weed risk patterns associated with land ownership (Table 4-3) are similar to the predicted results for pinyon-juniper encroachment risk. Sagebrush on BLM lands is at greater predicted risk of herbaceous weed encroachment (49 percent at moderate or high risk) than sagebrush on private lands (39 percent at moderate or high risk). Sagebrush on USFS lands are at comparatively lower risk (14 percent at moderate or high risk), but the relatively minor areas of sagebrush on federal lands other than BLM and USFS have comparatively the greatest risk (70 percent at moderate or high risk).

Energy Development

The model predicts that the majority of sagebrush in the assessment area is at moderate risk of energy development (1.27 million ha, 58 percent of the sagebrush in the assessment area; see Table 4-3). A much smaller amount of sagebrush (165,000 ha, 7 percent) is predicted at high risk, and nearly 365,000 ha (17 percent) is predicted at no risk of energy development. Areas of sagebrush at high risk are concentrated energy development areas in the northwest counties (Roan Plateau, Piceance Basin, and Moffat-Routt county areas), western Montrose and San Miguel counties (Paradox Basin), Montezuma and La Plata counties (the San Juan Basin), and relatively small areas of North Park (Jackson County). Broad areas of sagebrush at moderate risk of energy development occur in these areas, as well as in much of Delta and eastern Montrose counties, and the San Luis Valley (Figure 4-3).

The risk of energy development in sagebrush on private and BLM lands is similar to the overall risk throughout the assessment area (65 percent at moderate or high risk, Table 4-3). Sagebrush on USFS lands is at substantially lower risk from energy development (25 percent at moderate or high risk). Sagebrush on Colorado State Land Board lands is at comparatively higher risk (81 percent at moderate or high risk).

Residential Development

The predicted risk to sagebrush of residential development is mainly none or low across the assessment area as a whole, with about 50,000 ha (2 percent) at high risk and 35,000 ha (2 percent) at moderate risk (Table 4-3). Just over 1.2 million ha (56 percent) is predicted at no risk from residential development. Small fractions of sagebrush in all public land categories are predicted at some level of risk from residential development. These fractions constitute 2 percent or less for all public lands except federal lands other than BLM and Forest Service (43 percent of sagebrush at low risk, 2 percent at moderate or high risk). Some of these fractions probably reflect minor differences between the land ownership dataset used by the SERGoM model and the dataset we used to map land ownership. However, some residential development occurs on public lands (recreational facilities, employee housing, administrative facilities, etc.), and the model results suggest that sagebrush on “other federal lands” is at a similar risk from residential development as private lands, although the overall amount of sagebrush at risk is far greater on private lands.

Sagebrush areas predicted to be at risk of residential development are concentrated in areas around cities and towns experiencing substantial population growth and suburban/exurban development (Figure 4-4). Principal areas of sagebrush at moderate or high risk occur in areas surrounding Craig (Moffat County), Steamboat Springs and surrounding valleys (Routt County), Granby (Grand County), the Eagle River Valley (Eagle County), Glenwood Springs (Garfield County), Roaring Fork Valley (Pitkin and adjacent counties), Glade Park (Mesa County), rural Delta County, the northern Gunnison Basin (Gunnison County), Cortez (Montezuma County), and southern La Plata and Archuleta counties. In addition, much of the relatively small and scattered sagebrush occurring in the Front Range counties is predicted at moderate to high risk form residential development. The limitations of the SERGoM-derived model (discussed in

Methods, above, and in Assumptions and Limitations, below) should be kept in mind when interpreting these results.

Combined Threats

Most of the sagebrush in the assessment area is at moderate or high risk of all threats combined (Table 4-3). Almost 1.8 million ha (81 percent) of sagebrush is predicted at moderate or high combined risk, and an insignificant amount is predicted at no risk from any of the modeled threats. The greatest concentration of sagebrush at high combined risk occurs in Rio Blanco and western Moffat counties (Figure 4-5). Other extensive areas at high combined risk include much of the Colorado River watersheds below Middle park, the western parts of Montrose, San Miguel, and Dolores counties, and Montezuma and Archuleta counties. Pockets of high combined risk are also predicted near and north of Craig, surrounding Steamboat Springs, parts of North Park and Middle Park, Delta and eastern Montrose counties, parts of the Gunnison Basin, and southern San Luis Valley. The Gunnison Basin, particularly south and east of Gunnison, represents the largest contiguous area of sagebrush predicted to have low or no risk from combined threats.

The risk of combined threats to sagebrush on lands held privately or by BLM (the principal landowners in the assessment area) is similar to the overall risk throughout the assessment area, although BLM has a somewhat greater percentage of sagebrush at high combined risk (43 percent) than sagebrush on private lands (38 percent). Sagebrush on USFS lands, however, is predicted at comparatively less combined risk, with 15 percent at high combined risk and 39 percent at moderate or high combined risk. Sagebrush on federal lands other than BLM or USFS is predicted at a relatively elevated combined risk, with over 31,000 ha (59 percent) at high combined risk.

Discussion

The results of the threat models should be interpreted with caution (see Assumptions and Limitations, below). Nevertheless, we believe the model results provide insights into the spatial extent and severity of the various threats at the broad scale of the assessment area.

Overall, the most extensive threat is encroachment by invasive herbaceous plants, with 41 percent of sagebrush in the assessment area at moderate or high risk and almost none predicted at no risk. Energy development, however, has the most extensive area of risk exceeding low, with 65 percent of sagebrush in the assessment area at moderate or high risk (although the area of sagebrush at moderate risk greatly exceeds sagebrush at high risk). Residential development is the least extensive threat we modeled, confined primarily (though not exclusively) to private lands and with 4 percent of sagebrush in the assessment area at moderate or high risk.

Risks of sagebrush to pinyon-juniper and invasive herbaceous plant encroachment are both strongly associated with lower elevations and more arid sagebrush, and invasive weed risk is additionally associated with proximity to centers of agriculture and other human development. Energy development risk is primarily influenced by oil and gas development, by far the most extensive energy-related industry in the assessment area. Oil and gas activities are centered on major geological basins that provide economically viable reserves, and these tend to occur in the larger low-elevation basins that often support sagebrush as well. Much of the sagebrush area predicted by our model at moderate risk from energy development is not currently being developed for energy resources, and some of this may never be. However, technologies for profitably extracting coal, oil, and gas are rapidly changing and it likely that some new energy fields will be developed in the foreseeable future.

Risk to sagebrush of residential development is based on the SERGoM model, which makes various assumptions that are not always met. Field verification of the SERGoM model for Gunnison sage-grouse habitat by CDOW revealed that some sagebrush areas receiving substantial residential development were underestimated by the model (P. Schnurr, pers. comm.), especially around resort towns where distorted economic factors often drive residential development at great distances from the resorts. The residential model should be interpreted with caution in these areas. In particular, the model's performance within about 70 miles of resort communities is of concern, and the model underestimates the risk of development in these areas. Also, the risk categories we used may not be adequate to reflect impacts of residential development at lower densities (less than 1 house per 40 acres). The impacts of residential development to species of concern and their habitats are likely to extend outward from a homesite, affecting a much larger area than the immediate vicinity of a house (e.g., increased recreation and disturbance, presence of domestic animals and pets, clearing of sagebrush for landscaping and farming).

The models predict that the risk of sagebrush from all threats combined is very extensive, and extends into all areas of sagebrush in the assessment area. The general trend is for increased predicted combined risk in basins and valleys with lower elevation, lower annual precipitation, higher average temperatures, and proximity to human disturbance. These factors are interrelated; for example, landscape and environmental factors that favor agriculture and residential development also tend to favor invasive herbaceous plants and pinyon-juniper encroachment, and energy development is favored by broad geologic structural basins that also tend to possess the warmer, drier conditions that favor invasive herbaceous plants.

Land ownership patterns help to indicate which landowner categories have sagebrush with the most serious risks. Sagebrush on BLM land has elevated risk of encroachment by pinyon-juniper and invasive herbaceous plants compared to private land or USFS. Risk to sagebrush of energy development is similar on BLM and private lands, much lower for sagebrush on USFS lands, and somewhat elevated for sagebrush on Colorado State Land Board lands. The residential development risk is mostly confined to private lands, although the small fraction of sagebrush on federal lands other than BLM and USFS has similar risk to private land sagebrush. For all threats combined, risk to sagebrush on BLM lands and private lands are roughly similar, USFS sagebrush has substantially lower levels of risk than other landowner categories, and other federal lands have a high proportion of sagebrush at high combined risk.

Assumptions and Limitations

- Our models are based on generalized land cover types and other broadly general datasets. Besides inherent errors in the various datasets, some of the information used in our models is dated and has undoubtedly changed since the datasets were created. At a more fundamental level, the models represent our attempts to predict the effects of several environmental variables and mapped land cover conditions influencing the risk of sagebrush to various threats. Cause-effect relationships are not fully understood, and our models are oversimplified representations of the actual factors and processes that predispose sagebrush to each type of threat.
- Some of the datasets used in the models are generalized in nature (for example, mean annual precipitation was classed in 2 to 4-inch increments), and thus are quite coarse in scale. One outcome of this fact is relatively abrupt changes in risk categories depicted on the map figures, when the risks are actually likely to blend across the landscape.
- The models were not field-tested because of budget limitations, and would benefit greatly from doing so.

- Some needed data were not available. Soil characteristics are perhaps the most important environmental factor for predicting pinyon-juniper encroachment, and may also be applicable to predicting invasive herbaceous plant encroachment. However, soil data are not available for the assessment area at an appropriate scale and with the necessary soil characteristics delineated. When such data become available, our predictive models could be greatly improved by incorporating data on soil characteristics.
- The pinyon-juniper encroachment model was identified during expert review as over-estimating the risk to sagebrush in western Moffat County and Rio Blanco County north of the White River (B. Petch, pers. comm.). We attempted to account for this limitation in the conclusions drawn later in this assessment. Further refinement of the model is needed in the northwest deserts ecological province.
- The residential development model on which our risk model was based does not adequately predict the effect of development at some distance from resort communities (P. Schnurr, pers. comm.). As a result, the risk to sagebrush from residential development is underestimated in some sagebrush stands up to perhaps 70 miles from some resort communities. In addition, the categories of risk based on housing unit density may be too low for some species of concern. The *Gunnison Sage-grouse Rangewide Conservation Plan* (GSRSC 2005), for instance, identified 1 housing unit per 320 acres as a significant impact to sage-grouse. However, the data from the SERGoM model used for the Gunnison sage-grouse plan had been classified differently than the data from the same model that we obtained, and we utilized the housing density categories we were provided as best we could for this project.

Key Findings

- The threats models provide a generalized and fairly coarse estimate of the predicted risk to sagebrush of four widespread threats. Although subject to various limitations, the risk predictions provide useful comparative information on the extent and severity of sagebrush at risk in the assessment area.
- The risk to sagebrush of pinyon-juniper encroachment is predicted high on nearly 400,000 ha (18 percent of sagebrush in the assessment area), and predicted moderate or high on nearly 650,000 ha (30 percent), concentrated in the western counties of the assessment area but also in the San Luis Valley and Gunnison Basin. Sagebrush on BLM lands has elevated risk compared to sagebrush on private lands, and sagebrush on USFS and Colorado State Land Board lands has relatively little risk from pinyon-juniper encroachment.
- The risk to sagebrush of encroachment by invasive herbaceous plants is predicted high on about 510,000 ha (23 percent of sagebrush in the assessment area) and moderate or high on about 910,000 ha (41 percent). Less than 1 percent of sagebrush in the assessment area is predicted at no risk. Sagebrush areas at moderate or high risk are most concentrated in the western counties and elsewhere at lower elevations near human development. Sagebrush on BLM lands has relatively greater risk than sagebrush on private lands, and sagebrush on USFS lands has substantially lower risk than sagebrush in other land ownership categories.
- The risk to sagebrush of energy development is predominantly moderate (1.27 million ha, 58 percent of sagebrush in the assessment area), with 165,000 ha, (7 percent) predicted at high risk. Substantial areas of sagebrush at moderate or high risk occur in the northwest counties, Paradox Basin, San Juan Basin, and other localized areas. The risk to sagebrush of energy development on private and BLM lands is similar, but substantially lower on USFS lands and higher on Colorado State Land Board lands.

- The predicted risk to sagebrush of residential development is none on 1.2 million ha (56 percent of the assessment area, all on public lands), and moderate or high risk on about 85,000 ha (4 percent of sagebrush in the assessment area). Sagebrush areas at moderate or high risk are concentrated around cities and towns with increasing human populations and development. However, the SERGoM model does not adequately predict the effects of development over large areas surrounding some resort communities (P. Schnurr, pers. comm.), and the distance units selected for high, moderate, and low risk may not be suitable for all species of concern (see Assumptions and Limitations, above). The model predicts small areas of sagebrush on public lands at risk, partly due to model errors but also reflecting some development on public lands, particularly on federal lands other than BLM or USFS.
- When the risk to sagebrush from all threats is combined, almost 1.8 million ha (81 percent) of sagebrush is predicted at moderate or high risk in the assessment area, and an insignificant amount is predicted at no risk. Sagebrush concentrations at high combined risk occur in the northwest counties, the Colorado River watersheds, and southwestern counties bordering Utah and New Mexico with other areas at high risk scattered in the assessment area. Part of the Gunnison Basin forms the largest sagebrush area predicted to have low or no combined risk. Sagebrush on BLM lands has slightly greater combined risk than sagebrush on private lands, and sagebrush on USFS lands has comparatively less combined risk.
- Overall, most sagebrush in the assessment area is predicted by our models to be at some level of risk of one or more of the threats we modeled. Among the principal landowners with sagebrush in the assessment area, sagebrush on BLM land is generally predicted at more elevated risk, sagebrush on private land is intermediate, and sagebrush on USFS land is predicted at lower risk. Differences between the landowners in elevation, annual precipitation, and proximity to human development are the most likely factors in the differences in level of risk.

Recommendations

- The pinyon-juniper and invasive weed encroachment models should be refined by ground-truthing, and revised as needed.
- The energy development model should be refined by ground-truthing, and by reviewing new spatial data on development areas as they become available.
- The residential development model should be revised by ground-truthing. Also, the SERGoM model on which our model is based could be evaluated for improvements in predicting residential development in areas surrounding resort communities, and to better account for second home development. Finally, the SERGoM model should be updated periodically as new census data become available, and development projected beyond 2020 as needed.

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Table 4-1. Rules for estimating risk to sagebrush of pinyon-juniper encroachment.

Ecological Province	Proximity to Current Pinyon-Juniper	Sagebrush Taxa	Mean Annual Precipitation	Elevation	Risk
SW Desert	< 800 m	Mountain	12 to 16 in	any	High
			<12 or >16 in	any	Moderate
		Basin	12-16 in	≤ 2,200 m	High
				> 2,200 m	Moderate
			<12 or >16 in	any	Low
	800 to 2,000 m	Mountain	12 to 16 in	any	Moderate
			<12 or >16 in	any	Low
		Basin	any	any	Low
	>2,000 m	any	any	any	None
NW Desert and Mountains	< 800 m	Mountain	10 to 16	any	High
			<10 or >16 in	any	Moderate
		Basin	10 to 16 in	≤ 2,350 m	High
				> 2,350 m	Moderate
			<10 or >16 in	any	Low
	800 to 2,000 m	Mountain	10 to 16 in	any	Moderate
			<10 or >16 in	any	Low
		Basin	any	any	Low
	>2,000 m	any	any	any	None

Note: For descriptions of ecological provinces and sagebrush taxa categories, see Chapter 4 text.

Table 4-2. Rules for estimating risk to sagebrush of encroachment by invasive herbaceous plants.

Ecological Province	Proximity to Invasive Land Cover Types	Proximity to Disturbance	Mean Annual Precipitation (inches)	Slope (%)	Risk
SW Desert	≤1,200 m	All	All	All	High
	>1,200 m	≤800 m	<16	≤30	Moderate
				>30	Low
			>16	≤30	Low
				>30	Low
		>800 m	<16	≤30	Moderate
				>30	Low
			16 to 30	All	Low
			>30	All	None
NW Desert and Mountains	≤1,200 m	All	All	All	High
	>1,200 m	≤800 m	<12	≤30	Moderate
				>30	Low
			>12	≤30	Low
				>30	Low
		>800 m	<12	≤30	Moderate
				>30	Low
			12 to 30	All	Low
			>30	All	None

Note: For descriptions of ecological provinces and sagebrush taxa categories, see Chapter 4 text.

Table 4-3. Sagebrush habitat by landowner at risk of pinyon-juniper encroachment, encroachment by invasive herbaceous plants, energy development, residential development, and combined threats.

			Pinyon-juniper Encroachment		Encroachment by Invasive Herbaceous Plants		Energy Development		Residential Development		Combined Threats	
Land Ownership	Total Sagebrush Area (ha)	Risk	Sagebrush Area at Risk (ha)	Percent of Land Ownership	Sagebrush Area at Risk (ha)	Percent of Land Ownership	Sagebrush Area at Risk (ha)	Percent of Land Ownership	Sagebrush Area at Risk (ha)	Percent of Land Ownership	Sagebrush Area at Risk (ha)	Percent of Land Ownership
Private	975,880	None	573,130	59	1,582	0.2	121,564	12	31,132	3	10	<0.1
		Low	160,803	16	599,579	61	199,628	20	863,137	88	139,684	14
		Mod	108,650	11	143,231	15	585,895	60	33,665	3	463,539	47
		High	133,297	14	231,487	24	68,793	7	47,946	5	372,647	38
U.S. Bureau of Land Mgmt (BLM)	891,033	None	442,226	50	1,261	0.1	161,207	18	889,346	100	154	<0.1
		Low	126,436	14	452,302	51	119,967	13	475	<0.1	155,608	17
		Mod	98,027	11	212,429	24	528,244	59	692	<0.1	349,261	39
		High	224,345	25	225,041	25	81,615	9	521	<0.1	386,010	43
U.S. Forest Service (USFS)	156,769	None	113,385	72	4,156	3	65,462	42	154,950	99	1,134	1
		Low	20,477	13	131,786	84	52,743	34	1,373	1	94,701	60
		Mod	19,379	12	2,636	2	37,196	24	120	<0.1	37,892	24
		High	3,528	2	18,191	12	1,368	1	326	0.2	23,026	15
Other Federal Lands	52,746	None	7,423	14	87	0.2	5,733	11	28,827	54.7	0	<0.1
		Low	5,954	11	15,565	30	12,723	24	22,627	43	2,302	4
		Mod	17,965	34	21,326	40	27,578	52	657	1	19,262	37
		High	21,403	41	15,768	30	6,713	13	635	1	31,182	59
Colorado State Land Board	99,233	None	79,344	80	129	0.1	5,431	5	97,193	98	1	<0.1
		Low	7,769	8	63,670	64	13,727	14	1,979	2	11,606	12
		Mod	4,817	5	18,832	19	74,256	75	34	<0.1	62,902	63
		High	7,304	7	16,601	17	5,819	6	27	<0.1	24,725	25
Other Colorado State Lands	23,912	None	10,301	43	9	<0.1	5,070	21	23,542	98	0	<0.1
		Low	4,370	18	16,096	67	5,602	23	329	1	6,985	29
		Mod	4,894	20	2,581	11	12,596	53	10	<0.1	8,273	35
		High	4,346	18	5,226	22	644	3	30	0.1	8,654	36
Assessment Area Total	2,199,573	None	1,225,809	56	7,224	0.3	364,467	17	1,224,990	56	1,298	<0.1
		Low	325,809	15	1,278,999	58	404,390	18	889,920	40	410,886	19
		Mod	253,732	12	401,035	18	1,265,765	58	35,178	2	941,129	43
		High	394,223	18	512,315	23	164,952	7	49,485	2	846,244	38