CalVeg types included: **SGB**: Sagebrush species (*Artemisia* spp.), **BBR**: Rabbitbrush species (*Chrysothamnus* spp., *Ericameria* spp., *Lorandersonia* spp.), **LSG**: Horsebrush (*Tetradymia* spp.)

Sensitivity Assessment

1. Direct sensitivities to changes in temperature and precipitation

- Temperature
  - Means and extremes
  - System's sensitivity, composition and response to temperature
- Precipitation
  - Means and extremes
    - *Artemisia* spp.: usually occurs where total annual precipitation ranges from 10-25 inches, but is higher in the northern coastal sites (Montalvo et al. 2010).
  - System's sensitivity, composition and response to precipitation

2. Sensitivity of component Species

- Dominant species
  - *Artemisia* spp. shallow, branched roots allow for rapid water absorption and growth in response to shallow rains (see: Gray 1982). Seedlings emerge during the winter rainy season (Montalvo et al. 2010).
- Ecosystem engineers
- Keystone species

3. Sensitivities to changes in disturbance regimes

- Wildfire
  - Sagebrush steppe: Lightning ignited fired historically created disturbances necessary to maintain the sagebrush grassland community (Hanna 1012; see: Bates et al. 2009). Fire may reduce the availability of suitable habitat for sage grouse, but following fire, herbaceous cover and biomass of forbs and grasses utilized by the sage grouse may increase (Hanna 2012).
    - *Artemisia* spp. is a facultative seeder: seeds germinate after fire, in canopy opening, or in small grassland clearings (Montalvo et al. 2010). Seedling emergence after fire is variable and low (see: Zedler et al. 1983, Keeley 1998). Resprouting appears to be lower in burns through dense vegetation, where plants are older, or if fire intensity is high (see: Malanson & O'Leary 1982, Keeley 1998, Minnich & Dezzani 1998). Seedlings sometimes appear the second year from seeds of resprouts or seeds blown in from adjacent areas (Montalvo et al. 2010).

  - Grasslands: Observations from coastal central California show that frequent fires allow grasslands to readily replace woody communities (see: Callaway and Davis 1993, Keeley 2002)
- Disease
  - Infection by wood-boring beetle (*Perarthrus vittatus*) have been observed, although whether these infections are lethal is not known (see Tyson 1981). *Artemisia californica* is also known to host scarab beetle (*Phobetus comatus*) larvae (Montalvo et al. 2010).
- Flooding
  - *Artemisia* spp.: Occurs in infrequently inundated and well-drained areas of flood plains along streams and on alluvial fans and alluvial scrub vegetation (see: Burk et al 2007).
- Insects
- Wind
- Drought
  - *Artemisia* spp. is drought tolerant. May drop larger, early season leaves, and shift to small leaf production and maintenance during the summer drought.
  - Forecasted reductions in effective moisture until the end of the century may favor drought tolerant grasses, resulting in expansions of grasslands in the Sierra Nevada (Lenihan et al. 2008).
- Other - CO2 concentration

4. Sensitivity to other types of climate and climate-driven changes

- Altered hydrology
- Altered fire regimes
  - Models indicate that fire will play an important role in adjusting semi-arid vegetation to altered precipitation regimes, either slowing or limiting the encroachment of woody vegetation, or hastening the transition from woody communities to grasslands (Lenihan et al. 2008). Under some scenarios, grassland is projected to replace mixed-evergreen woodland and shrubland, due to reduction in moisture and increased fire (Lenihan et al. 2008). Increased grass biomass may result in more fires, and further expansion of grasslands (Lenihan et al. 2008). Large increases in cover of grassland (C3 & C4 grasses) are projected for the Sierra Nevada by the end of the century (Lenihan et al. 2008).
    - A 20% projected increase in grass carbon is expected, largely protected from fire belowground, and annually renewed aboveground (Lenihan et al. 2008).
  - Sagebrush steppe: Most scenarios project lower cover of east-side sagebrush in the Sierra Nevada and Sierra Nevada foothills by the end of the century, principally due to increasing extent and frequency of fire (North 2012). Under high fire intensities or frequency, California sagebrush will likely be extirpated because of its poor re-sprouting ability and poor competitive ability of seedlings (see: Malanson & O'Leary 1982, Malanson & Westman 1991).

- Evapotranspiration and soil moisture
- Extreme precipitation and temperature
- Water temperature
- Storm frequency and intensity

5. Sensitivity to impacts of other non-climate related threats

- Residential and commercial development
  - The sagebrush steppe landscape has been fragmented by urban expansion, agriculture and energy and mining operations in the Intermountain West (Hanna 2012). Spread of invasive species and overgrazing has led to degradation of sagebrush communities (Hanna 2012).
- Agriculture and aquaculture
- Energy production and mining
- Transportation and service corridors
- Biological resource use
- Altered interspecific interactions
- Human intrusions and disturbance
- Natural system modification
- Invasive and other problem species
  - Sage scrub is declining inland on north-facing slopes, where it is being replaced by exotic annual grasses (Montalvo et al. 2010, see: Minnich and Dezzani 1998). Seed germination of *A. californica* is poor under grass thatch or amidst even low densities of standing grass (Montalvo et al. 2010).
- Pollution and poisons
- Geological events

6. Other Sensitivities

- Management
  - Fire suppression policies, which increased the mean fire return interval, sagebrush stands have become more dense, reducing the productivity of annual grasses and forbs (Hanna 2012).

<u>Adaptive Capacity</u>

1. Extent and Characteristics

- Geographic extent in California.
  - Sagebrush (*Artemisia* spp.) occurs in central western and southwestern California, from Contra Costa Co. south into Baja California, including Channel Islands (Montalvo et al. 2010). Generally occurs below 800m, although has been reported at

1200m (see Sawyer et al. 2009). Historically, was dominant shrub on north facing slopes in coastal sage scrub but has declined to about a third of its past abundance in areas of southern California, especially inland on north-facing slopes, where it is being replaced by exotic annual grasses.
    - Shrublands (including sagebrush steppe, southern coastal scrub and chamise chaparral) (Lenihan et al. 2008) currently cover approximately 21% of Sierra Nevada landscape, and about 3 % of Sierra Nevada Foothills (North 2012).
  - Grasslands (C3 & C4 grasses) currently cover approximately 10% of the Sierra Nevada landscape, and 50% of the Sierra Nevada Foothills (Lenihan et al. 2008, North 2012).
  - Subtropical arid lands (creosote brush scrub, saltbrush scrub, Joshua tree woodland) (Lenihan et al. 2008) currently make up only about 2% of current Sierra Nevada Foothills landscape (North 2012).

2. Landscape Permeability

- Barriers to dispersal or fragmentation
  - *Artemisia* spp. seeds are thought to be wind dispersed (Montalvo et al. 2010).

3. System Diversity

- Diversity of component species
  - Sagebrush ecosystem: 30 native taxa of sagebrush (*Artemisia* spp.) in California (Montalvo et al. 2010, Hanna 2012, see: Winward 1980). Varying edaphic, climatic and topographic conditions produce a heterogeneity of sagebrush landscape (Hanna 2012, see: West 1983). The 15 taxa in southern California differ from northern taxa in habitat affinity, structure, or both (Montalvo et al. 2010).
  - Sagebrush landscape provides habitat for approximately 100 bird species and 70 mammal species (Hanna 2012).

Exposure

According to one estimate, by the end of the century, 55% of future landscapes in the West will likely have climates that are incompatible with vegetation types that now occur on those landscapes (Friggins et al. 2012). Increasing temperatures will hasten snowmelt and increase growing season length. Increasing temperatures and reduced snowpack will cause a drier water balance with less water entering the soil and percolating to deep soil layers and with earlier peaks and minima of soil water. The effects of climate change on water balance and vegetation activity across the climatic and elevation gradient of sagebrush ecosystems, however, are often nonlinear. Implications for big sagebrush ecosystems in the semiarid western United States under declining snow conditions depend on area-specific climatic conditions described by the snow-precipitation ratio. Big sagebrush is limited by summer moisture stress and aridity defines its southern range limit (Shafer et al. 2001). The driest areas of big sagebrush ecosystems are also the ones with the lowest snow-precipitation ratios. Drier areas may not experience dramatic changes in water balance, because there was not much snow to begin with (Schlaepfer et al. 2012b). Marginal areas near the southern limit of its range may become unsuitable for big sagebrush ecosystems in the future (Schlaepfer et al. 2012b).

Of 146 evergreen species in the Southwest US modeled by Notaro et al. (2012), the two evergreen species with the largest projected range contractions are limber pine (*Pinus flexilis*) and big sagebrush (*Artemisia tridentata*). Bioclimate modeling predicts that big sagebrush (*A. tridentata*) in the interior American West will shift northward, in response to increases in the mean temperature of the coldest month, and exhibit substantial range contraction due to increased summer moisture stress (Shafer et al. 2001). These results support the Neilson et al. (2005) bioclimate model prediction that sagebrush habitat in the great Basin will decline due to synergistic effects of temperature increases and fire and disease, and to displacement by species moving north from the Mojave Desert in response to the northward shift in frost lines (Friggins et al. 2012). Areas currently occupied by big sagebrush are expected to become occupied by the northward expansion of the creosote bush (*Larrea tridentata*) (Shafer et al. 2001, Friggins et al. 2012). As the frequency of extreme drought increases, plant mortality is likely to occur in rapid pulses rather than gradual declines. This may result in isolated relict patches, which may inhibit the ability of the plant to recover and expand into more hospitable environments in northwestern Arizona (Gitlin et al. 2006).

Schlaepfer et al. (2012a) applied ecohydrology variables to forecast the future geographic pattern of sagebrush, and projected substantial decreases in big sagebrush in the southern part of the range and increases in the northern parts, and small increases at higher elevations, e.g. at the interface with coniferous forests. Low snow-precipitation ratios, and projected increases in spring and mean annual precipitation may increase habitat suitability for big sagebrush in the arid western US. Increases in habitat-suitability for big sagebrush ecosystems at high elevations may be a result of earlier and longer growing season (Schlaepfer et al. 2012b).

While both the climatic and ecohydrological species distribution models run by Schlaepfer et al. (2012a, 2012b) suggest large scale splitting of sagebrush ecosystem into disjunct areas is likely to occur, the ecohydrologic model predicts many smaller regions (i.e. Sierra Nevada, Washington, areas in Oregon and northern Nevada, central Idaho, and an area in eastern Utah, Wyoming, Colorado, and eastern Montana), while the climatic model predicts fewer, larger areas. Patchiness, size of patches, and fragmentation are important factors influencing genetic structure and dynamics of population and communities of sagebrush obligate species, such as greater sage-grouse (Schlaepfer et al. 2012a).

In the Great Basin, climate change poses a substantial risk for sagebrush ecosystems (Friggins et al. 2012). Forecasts to 2070 by Gardali et al. (2011) based on various models forecast decreases in the sagebrush/bitterbrush/low sage vegetation type (between 56 to 41%) and Friggins et al. (2012) forecast that habitat suitable for shrub/ grassland in the Great Basin will decrease by 40% and become fragmented.

Desert scrub

Gardali et al. (2011) predict that desert scrub in the Great Basin will increase (between 51 to 63%) by 2070. A model by Friggins et al. (2012) agrees that habitat favorable to Great Basin Desert montane scrub will expand in the short term, but suggest that it will then become fragmented as it contracts (69% decrease) later in the century (2060-2090) and experiences displacement as the Mojave desert scrub type migrates to the Great Basin and Snake and Columbia River Plains (Friggins et al. 2012). Desert scrub, the dominant habitat type in the Mojave Desert, is also predicted to expand moderately (4-6%) in response to climate change as it shifts northward.

Climate change may introduce fire to ecosystems that lack natural defenses and are unaccustomed to fire events (Karl et al. 2009). Increases in fire frequency would also contribute to range contraction, of big sagebrush, because it does not re-sprout after fire events (Shafer et al. 2001). Changes in historic fire regimes, poor grazing management, and other factors may also contribute to woody encroachment in semiarid systems in the Interior West, for example, the invasion of juniper (*Juniperus spp*.) species into sagebrush steppe (Meyer 2012).

Grasslands

By the end of the century, semi-desert grassland habitat is projected to expand northward from the Southwest into the Great Basin, Colorado Plateau, and southern Great Plains and occupy an area nearly four times that of the present (Friggins et al. 2012). In California grasslands, plant and soil characteristics influence the responses to elevated CO_2. A study by Fernandez-Going et al. (2012) in grasslands in Napa, Yolo and Lake Counties, lent support to Grime et al.'s (2000, 2008) results that undisturbed, resource poor natural communities are more resistant to climate change, including to forecasted increases in the variability of precipitation. In experiments by Houlton and Field (2010), elevated CO_2 did not necessarily stimulate plant productivity, although the authors concede that a future rise in CO_2 will occur more slowly than in experiments. They suggest that nutrients will likely limit plant responses to elevated CO_2 in California grasslands (Houlton and Field 2010).

Plant functional groups within grassland communities vary widely in their sensitivity to climate and atmospheric change factors. Zavaleta et al. (2003) found that warming had no significant effect on grassland species richness at Jasper Ridge Biological Preserve, but tended to increase diversity, and that elevated precipitation treatments increased total species richness by 5%. Conversely, grassland species richness decreased with nitrogen deposition (by 5%) and elevated atmospheric CO_2 (by 8%). The plots captured large natural variation in species composition, and the changes in total diversity were driven mainly by gains and losses in forb species, while annual grass diversity was relatively unresponsive (Zavaleta et al. 2003).

Invasive annual grasses are displacing desert shrubs through increased frequency of fire following destruction of the perennial herbaceous understory through improper grazing management. The conversion to annual grassland results in a transformation from slow to rapid carbon cycling, the cessation of carbon deposition in deeper soil layers, and the direct and rapid transfer of aboveground biomass carbon to atmospheric carbon associated both with the initial loss through fire of standing shrub biomass carbon and with subsequent increased fire frequency (Meyer 2012).

Soil organic carbon

The ability of cold desert soils in the Interior West to retain soil organic carbon could be reduced by the effects of ongoing climate change. Aanderud et al. (2010) showed in an 11-year rain manipulation study that near-surface (0 to 30 cm) soil organic carbon stocks in a sagebrush steppe (*A. tridentata*) community were significantly reduced when precipitation was shifted from a winter pattern to a spring-summer pattern. They credited this loss to increased microbial activity in wet surface soil at warm temperatures. Shifts from winter to spring-summer rainfall patterns are predicted for many parts of the Interior West as climate continues to warm. Rainfall timing impacts on deep soil organic carbon would be expected to be lower, however, because deep soil organic carbon is more buffered from seasonal temperature changes. This would tend to mitigate the effects of increased warm-season precipitation on soil C storage (Meyer 2012).

Flowering onset

Divergent predictions exist for shifts in future flowering onset, suggesting that flowering species may be able to shift their flowering phenologies individualistically, rather than at consistent rates in the same direction (Crimmins et al. 2010). As precipitation is expected to continue to decrease in the future, species at all elevations may be driven to flowering later in spring, perhaps many days to weeks. Later flowering seems to be influenced by precipitation the previous autumn. Exceptionally low precipitation in autumn may not be sufficient to trigger some species to flower at all the following spring (Crimmins et al. 2010). Conversely, as temperatures are expected to warm, first flower dates for many species across all elevations may advance (Crimmins et al. 2010). Advances or delays in phonological events of only a few days can have significant and direct impacts on species population dynamics and ecosystems functioning (Crimmins et al. 2010).

Animals

In the Californian Great Basin, changes in vegetation communities will be important for wildlife. These changes will include projected increases in the amount of pine and juniper forest and desert scrub and grasslands, and a loss of and sagebrush and other shrub habitats. This shift may be hastened by changes in fire severity and frequency. High temperature events will become more common, and may increase by as much as 2.7°C. Given the arid conditions throughout the Great Basin, this increase in temperature may increase heat and water stress for some wildlife. Snow-fed rivers and streams will have less water, especially during the spring and summer, which may reduce habitat for some wildlife associated with riparian areas (Gardali et al. 2011). According to an analysis by Gardali et al. (2012), bird taxa in grassland habitats, along with oak woodland habitats, are the least vulnerable to climate change in California.

Sage-grouse and Pygmy rabbit

Little is known about potential for natural adaptation to climate change by Great Basin upland wildlife. What is certain, however, is that populations of sagebrush-obligate species, such as greater sage-grouse (*Centrocercus urophasianus*) and pygmy rabbits (*Brachylagus idahoensis*), would not be capable of adapting to loss of sagebrush in their range because it provides essential food and cover, and would therefore be restricted to areas where sagebrush is likely to persist. Sage-grouse also avoid areas where woodlands have encroached on shrublands (Finch et al. 2012).

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Rina Hauptfeld 3/1/13 12:07 PM
Comment [1]: Complete sources

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Comment [2]: Fernandez-Going 2012

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Comment [3]: Shafer et al 2001