FINAL REPORT

Decision-support tools for conserving Greater Sage-Grouse during fire and fuels management projects in pinyon and juniper woodlands

JFSP 09-1-08-4

Erica Fleishman, University of California, Davis (principal investigator)

Jeanne C. Chambers, USDA Forest Service, Rocky Mountain Research Station, Reno, Nevada (co-principal investigator)

David S. Dobkin, High Desert Ecological Research Institute, Bend, Oregon (co-principal investigator)

Brett G. Dickson, Conservation Science Partners, Truckee, California (co-principal investigator)

ABSTRACT

Prescribed fire and other fuels management treatments have been suggested as mechanisms to slow expansion of pinyon and juniper woodlands while minimizing potential expansion of cheatgrass (*Bromus tectorum*) and increasing habitat quality and quantity for Greater Sage-Grouse (*Centrocercus urophasianus*). These treatments also may reduce the probability of severe wildfires, which can have undesirable effects on social, economic, cultural, and ecological values. However, achieving long-term goals related to fire and fuels may conflict with short-term goals related to survival and viability of native species. Fire can fragment high-quality habitat for species associated with woodlands, including more than 20 native species of breeding birds. Additionally, expansion of pinyon and juniper woodlands may have been patchy but common and natural before European settlement of the Great Basin. Evaluation of spatial and temporal trade-offs of actions to reduce probability of wildfire, maintain sagebrush steppe, and conserve native species, including rare or endangered species, can identify strategies that are either consistent or incompatible with achieving these and other objectives simultaneously.

We monitored use by Greater Sage-Grouse of areas treated with fire or proposed for treatment. We sampled other native species of breeding birds associated with sagebrush steppe, pinyon and juniper woodlands, and riparian woodlands throughout four mountain ranges in the central Great Basin that are under the jurisdiction of federal resource agencies. We sampled vegetation structure and composition as components of bird habitat. Additionally, we sampled 0.1-ha field plots to examine topography and microclimate, tree cover and biomass, residual perennial understory species, and composition and abundance of non-native invasive species along elevational gradients.

Apparent use of burned areas by Greater Sage-Grouse was limited. However, Greater Sage-Grouse were present throughout the study area, and occured both in valleys and along ridgelines. The proportion of cheatgrass tended to increase following fire, although interactions with land use (e.g., grazing by domestic livestock, recreation) likely affect presence and density of cheatgrass. Humans appear to be removing a substantial proportion of dead wood after fires, which may decrease post-fire habitat quality for breeding birds. Resilience to invasion of non-native species and potential for recovery of native species after a disturbance appeared to be greater at higher-elevation sites than at a lower-elevation site, and fire appeared less likely to result in regeneration of native species at lower-elevation sites than at higher-elevation sites. Our work complements ongoing research on responses of native and non-native species and ecological processes to changes in fire dyanmics and related environmental changes across the Great Basin.

BACKGROUND AND PURPOSE

Among the highest priorities of management agencies in the Great Basin is increasing the viability of Greater Sage-Grouse (*Centrocercus urophasianus*), a candidate for listing under the U.S. Endangered Species Act, and other species associated with native sagebrush (*Artemisia* spp.) steppe. Decision-makers also are charged with decreasing the distribution and abundance of cheatgrass (*Bromus tectorum*), a non-native invasive annual grass that is dominant across about

6% of the ecoregion and potentially could dominate at least 25%. Cheatgrass is associated with substantial increases in the extent and frequency of fire and loss and fragmentation of native perennial grasses and sagebrush. Greater Sage-Grouse breed in and feed on sagebrush. Area burned and proximity to high-intensity human activities explain considerable variation in persistence of Greater Sage-Grouse leks (Knick and Hanser 2011) and are among the disturbances that increase probability of cheatgrass invasion.

More than 50% of the potential habitat of Greater Sage-Grouse has been lost since 1800 (Schroeder et al. 2004). Stressors, which are not mutually exclusive, include increases in agriculture, urbanization, and recreational use; development of renewable and nonrenewable sources of energy; expansion of cheatgrass; increases in fire size and frequency; and climate change (Aldridge et al. 2008, Baker 2011, Wisdom et al. 2011). Abundance of the species decreased by about 50–66% between commencement of rangewide surveys in 1965 and the early 2000s (Connelly et al. 2004). Garton et al. (2011) estimated that the genetically effective sizes (*N*e) of 75% of populations will be less than 500 by about 2100, which suggests the long-term viability of those populations is uncertain, especially if they become isolated.

Greater Sage-Grouse currently dominate most discussions about conservation of native animals in the Great Basin. Nevertheless, more than 350 other species of animals are associated with sagebrush steppe (Hanser and Knick 2011), and many have population trends similar to those of Greater Sage-Grouse. For example, abundances of populations of Brewer's Sparrow (*Spizella brewerii*) are estimated to be declining by 3% per year (Sauer et al. 2005). The habitat requirements of Greater Sage-Grouse and other sagebrush-associated species often are sufficiently distinct that conservation of the former, in a strict sense, may not confer protection to co-occurring species (Rowland et al. 2006, Hanser and Knick 2011). However, actions to minimize fragmentation of sagebrush and expansion of cheatgrass almost certainly will increase probabilities of persistence of other native species across the Great Basin.

Percent cover of sagebrush and cheatgrass across extensive areas is highly relevant to prioritization of vegetation treatments in the absence of fire and to fire management across the Great Basin. Areas dominated by sagebrush typically burn relatively hot. There is believed to be a one-year window in which native shrubs, grasses, and forbs can be reseeded successfully before cheatgrass gains a competitive advantage, but results of empirical studies are equivocal (Pyke et al. 2013). Also, as sagebrush cover before fire increases, the probability of cheatgrass colonization after fire, and therefore the necessary resource commitment to monitoring and seeding, may decrease.

Prescribed fire and other fuels management treatments have been suggested as mechanisms to slow expansion of pinyon and juniper woodlands while minimizing potential expansion of non-native plants and increasing habitat quality and quantity for Greater Sage-Grouse. These treatments also may reduce the probability of severe wildfires, which can have undesirable effects on social, economic, cultural, and ecological values. However, achieving long-term goals related to fire and fuels may conflict with short-term goals related to survival and viability of native species. Fire can fragment high-quality habitat for species associated with woodlands, including more than 20 native species of breeding birds (Gillihan 2006). Additionally, expansion of pinyon and juniper woodlands may have been patchy but common and natural before

European settlement of the Great Basin (Bukowski and Baker 2013). Evaluation of spatial and temporal trade-offs of actions to reduce probability of wildfire, maintain sagebrush steppe, and conserve native species, including rare or endangered species, can identify strategies that are either consistent or incompatible with achieving these and other objectives simultaneously.

STUDY DESCRIPTION AND LOCATION

We conducted our study in the Shoshone Mountains and Toiyabe, Toquima, and Monitor Ranges (Lander, Nye, and Eureka Counties, Nevada). Bounding coordinates were -117.547 (west), -116.412 (east), 39.488 (north), 38.647 (south), with an elevational range of 1892 to 3211 m. The Western Association of Fish and Wildlife Agencies designated seven management zones for ecoregion-based assessment of population and habitat trends for Greater Sage-Grouse; our study area is in the Southern Great Basin Management Zone.

Changed Circumstances

At the time we submitted our proposal, the Humboldt–Toiyabe National Forest planned to implement prescribed burns during 2010 in two watersheds in the Monitor Range (south-central Nevada): Big Ten Hat Peak in the southern Monitor Range, and Antelope Peak in the northern Monitor Range. At each location, we planned to delineate study areas encompassing ~100 km^2 (10,000 ha^2) for spatial analyses and fire treatments. Within the study areas, we planned to select two sets of paired upland watersheds of 800–1000 ha^2 with similar geology and vegetation. We anticipated that one watershed in each pair, selected at random, would be treated with fire, whereas the second watershed would serve as an unburned control.

By autumn 2010, the Humboldt–Toiyabe National Forest changed its plans for implementation of prescribed burns. The Forest decided not to apply fire in the Big Ten Hat Peak area, and delayed planned implementation in the northern Monitor Range (Charnoc Basin) until autumn 2012. Therefore, we focused our efforts on the northern Monitor Range, especially Charnoc Basin, and on collection of robust pre-treatment data on Greater Sage-Grouse, other native species of breeding birds, and associated vegetation. In June 2012, the Forest indicated it was unable to complete reporting associated with archaeological clearances within a time frame that would allow implementation within the project period.

If fire ultimately is applied to our study areas, we have robust pre-treatment data to which post-treatment data can be compared. Regardless, our data and findings allow inference to potential responses of breeding birds and vegetation to fire or other changes in land cover and land use. Our data and findings also may inform design of biological monitoring associated with environmental change.

Methods

Greater Sage-Grouse. In 2010, we established transects to assess the presence and relative abundance of Greater Sage-Grouse in anticipated treatment areas and other locations that have burned since 2001. We established eight paired transects (i.e., four pairs of two transects) in each of two areas in Charnoc Basin, five paired transects in Elkhorn [burned when a prescribed fire escaped in summer 2008], six paired transects in Wall Canyon [burned in a wildfire in summer 2000] and in Grass Springs [burned in an accidental fire in autumn 2005], and four paired transects in Birch Canyon [burned in an accidental fire in autumn 2006]. Each transect was 100 m long. Transects were positioned throughout the anticipated or actual treatment area. We used a global positioning system (GPS) with about 5 m horizontal accuracy to record the geographic coordinates (measured in Universal Transverse Mercator units; UTMs) of each survey point. On three evenly spaced visits between late May and early July, an observer slowly walked the length of each transect and recorded the location of any Greater Sage-Grouse scat detected on or adjacent to the transect. We also recorded live birds and scats detected in other locations throughout the study area.

Other species of breeding birds. We sampled birds during the breeding seasons (late May through June) with 100-m fixed-radius point counts. Most point centers were placed >350 m apart. During each visit, we recorded by sound or sight all birds using terrestrial habitat within the survey area. Point counts were conducted only in calm weather, and few were conducted >3.5 hours after dawn. Points were sampled for 8 min per visit. However, we noted all detections from 5:01 to 8:00 to allow direct comparison with data collected from 2001–2004, during which points were sampled for 5 min. Sampling points were located along the full elevational gradient of the canyons we sampled, typically with two or three points per 100 m of vertical elevation change. Points were positioned to sample the dominant vegetation types in proportion to the approximate extent of each vegetation type. We recorded the geographic coordinates of each survey point with a GPS.

Numerous birds were detected during fixed-radius point counts but outside the radius of the sample point or flying over the point rather than apparently using resources within the point. Birds were detected before or after point counts, while observers were traveling to point-count locations, or at other times while observers were in the field. In some cases, juveniles (individuals that are not included within the current year's breeding population) were recorded. Observers were encouraged to document all incidental observations in as much detail as possible (e.g., time of day, location, age class). We are archiving these incidental and long-distance detections separately from those recorded during the formal point-based sampling.

Bird habitat. We used a 50-m surveyor's tape to measure three radial 30-m lines from the center of the bird sampling point or end point of a 100-m transect along which we searched for Greater Sage-Grouse scats. Lines were separated from each other by 120˚. The distal end of each line was the center of a circle (referenced as a plot in the tree data) with 11.3-m radius (0.04 ha). Within each circle, we recorded identities and sizes (either diameter at breast height or basal diameter, depending on plant morphology) of all live trees and standing dead trees. Each circle was divided into four quadrants to simplify field measurements (i.e., field personnel found it easier to measure trees within four successive quadrants than to measure trees within one circle).

We used a concave spherical densiometer was used to estimate proportion of canopy cover. The proportion of squares marked on the densiometer (of 24) in which a given species was observed allows one to estimate the proportion of canopy cover of that species. To estimate frequency of shrubs and ground vegetation, we used an ocular tube (piece of a PVC pipe about 11.5 cm long and 2.5 cm diameter) and took measurements at a 45˚ angle downward from the line of sight. We recorded the occurrence of approximately 20 dominant tree, shrub, and herbaceous taxa. We collected 21 densiometer and ocular tube readings at each plot: one each at 8 m, 16 m, and 24 m, along the 30-m line from the center of the plot to the perimeter of each circle, and one while facing in four directions, separated by 90˚, from the center of each circle.

We collected data on presence or absence of cheatgrass along a 50-m transect extending 25 m on either side of the center of the bird-survey point or end point of a Greater Sage-Grouse transect. The transect was oriented at random. The observer noted whether cheatgrass was present (1) or absent (0) at 5, 10, 15, 20, and 25 m on either side of the line.

Location, quality, and connectivity of habitat for breeding birds. We estimated the current location, quality, and connectivity of habitat for 50 species of breeding birds across four mountain ranges and projected the future location, quality, and connectivity of habitat for these species given different scenarios of climate-induced land-cover change. For each species, we used boosted regression trees to model incidence (proportion of years a location was surveyed in which the species was present) as a function of covariates related to topography and current land cover and climate. To assess model fit, we calculated the proportion of binomial deviance explained. We used cross-validation to estimate the predictive accuracy of the models. We applied program Zonation, which was designed for spatial conservation prioritization, to identify the set of cells that maximized summed incidences for multiple species through time given current land cover and two scenarios of land-cover change (expansion of pinyon–juniper woodland and contraction of riparian woodland). We based the first scenario on Bradley's (2010) estimates, which assumed that relative probability of expansion of pinyon–juniper woodland decreases as distance from contemporary woodland increases. The latter assumption was based on observed expansion of woodland from 1986 through 2005. For the second scenario, we reduced the extent of riparian woodland. The total area of riparian woodland was approximately halved, but the total length of riparian woodland changed relatively little (20%).

Expansion of pinyon and juniper along elevational gradients. Most recent expansion of pinyon and juniper is occurring at lower elevations in areas dominated by Wyoming big sagebrush (*Artemisia tridentata wyomingensis*) or black sagebrush (*Artemisia nova*) and at higher elevations in areas dominated by mountain big sagebrush (*Artemisia tridentata vaseyana*) or mountain brush. We established and sampled 0.1-ha field plots to examine topography and microclimate, tree cover and biomass, residual perennial understory species, and composition and abundance of non-native invasive species along elevational gradients. Within each plot, we used line transects to estimate tree and shrub cover and 0.25 m^2 plots to estimate basal and aerial cover of all herbaceous species. We measured the height and tree diameter at base height of all trees > 0.5 m in height.

Relations between distributions of shrubs and climate water deficit. Distributions of plants reflect not only precipitation per se but seasonal storage of water by soils, potential evapotranspiration, and actual evapotranspiration. We examined the distribution of dominant shrubs in the Great Basin (i.e., locations where a given shrub species comprises > 25% cover) relative to gradients of water availability. We used data from the Southwest Regional Gap Analysis Project for Nevada and Utah for black greasewood (*Sarcobatus vermiculatus*), shadscale (*Atriplex confertifolia*), winterfat (*Krascheninnikovia lanata*), Wyoming big sagebrush, black sagebrush, low sagebrush (*Artemesia arbuscula*), and mountain big sagebrush. We validated a subset of the classifications with data from sage-stich (see sagemap.wr.usgs.gov). We derived data on 18 variables related to climate water deficit from a water balance model (Lutz et al. 2010) and custom scripts for ArcGIS (version 10.0, ESRI, Redlands, California). Ultimately, we retained seven variables for analysis: difference between actual evapotranspiration at the summer low and autumn peak, cumulative actual evapotranspiration during growing degree days, steepest rate of decline of actual evapotranspiration, month of soil water balance recess, difference between peak water supply and soil water balance, difference between water supply and actual evapotranspiration in autumn, and cumulative climate water deficit. We also calculated monthly potential and actual evapotranspiration, climate water deficit, water supply, and soil water balance (Lutz et al. 2010).

Project Trajectory

In October 2009, we convened the project team and collaborators and Forest Service personnel to discuss objectives for implementation of prescribed fire. It was apparent that there is no consensus on the full suite of objectives. Nevertheless, three objectives or management targets were shared among participants: recovery of perennial herbaceous vegetation, minimizing the probability of expansion of cheatgrass, and establishing or maintaining some proportion of sagebrush that is considered desirable (we deferred discussion of a quantitative target with respect to extent or configuration of sagebrush). We successfully achieved consensus on a qualitative conceptual model of the drivers of the status and trend of those three targets.

In 2010, we established a total of nine new sampling points for birds in two areas of the Charnoc Basin that were expected to be treated with prescribed fire in autumn 2012. We sampled these points from 2010–2013. From 2010–2013 we also sampled 13 points in Wallace Canyon and nine points in Allison Canyon (the canyons on either side of Charnoc Basin) that had been established in 2006 and had sampled annually since. The topography, vegetation composition and structure, and species composition of birds in Wallace and Allison canyons is sufficiently similar to that of the Charnoc Basin that the canyons can serve as controls if fire ultimately is implemented. One point in Allison Canyon overlapped the anticipated treatment area.

In 2010, we established four new survey points to the south of Barley Canyon in an area that burned in summer 2008 (Elkhorn); we sampled these points from 2010–2013. From 2010–2013 we also sampled up to 47 additional points elsewhere in the Monitor Range that were established during previous work supported by JFSP (six in White Sage Canyon [2010–2013], seven in Ryegrass Canyon [2010–2013], nine each on the east and west sides of Dobbin Canyon [2010 and 2013], and 16 in Barley Canyon [2010–2013]). Additionally, each year we sampled up to 49 points in the Shoshone Mountains, 59 points in the Toquima Range, and 123 points in the Toiyabe Range, some of which have been sampled most years since 2001. Among this set of locations are points in Wall Canyon, Birch Canyon, and Grass Springs (all Toiyabe Range) that were treated with wildfire and points in Underdown Canyon (Shoshone Mountains) that were treated with prescribed fire.

In 2010 we measured vegetation composition and structure at all newly established sampling points. In 2011 we measured vegetation composition and structure at the endpoints of all transects for Greater Sage-Grouse (n = 74) and in all points treated intentionally or inadvertently with fire (n = 41). In 2013 we remeasured vegetation at all points in the study area.

In 2010 we established and sampled 98 field plots to examine topography, microclimate, and vegetation in areas in which pinyon and juniper cover is increasing. We resampled the plots in 2012. We established 22 plots in a lower-elevation expansion zone at the north end of the Monitor Range, where the Forest currently anticipates cutting trees and leaving the wood on site. This study area (about 344 ha) covers a series of north- to northwest- facing alluvial fans. Annual precipitation is about 20–25 cm. Vegetation included relatively low densities of black sagebrush, Wyoming sagebrush, Sandberg's bluegrass (*Poa secunda*), bottlebrush squirreltail (*Elymus elymoides*), and needle-and-thread grass (*Hesperostipa comata*).

We also established 57 and 19 plots, respectively, in each of two higher-elevation expansion zones in Charnoc Basin. One of the higher-elevation study areas (upper 1) is approximately 526 ha and is located on a west to southwest facing slope. The second upper elevation study area (upper 2) is approximately 227 ha and is located on a largely north facing slope. Annual precipitation in both areas is about ≥ 35–40 cm. Vegetation included moderate densities of mountain big sagebrush, snowberry (*Symphoricarpos* spp.), Idaho fescue (*Festuca idahoensis*), prairie Junegrass (*Koeleria macrantha*), and Sandberg's bluegrass.

KEY FINDINGS

1. Apparent use of burned areas by Greater Sage-Grouse is limited. However, Greater Sage-Grouse are present throughout the study area, and occur both in valleys and along ridgelines.

> The only burned area in which we detected scats along or adjacent to transects was Elkhorn (scats along three transects in 2012). In areas that were not burned, we detected scats along transects in the southern Charnoc Basin in 2010 (one scat) and 2011 (scats along two transects). We detected scats elsewhere in 2011, 2012, and 2013. In 2011, we detected scats along and on top of a ridge leading up to Bald Mountain (a peak in the northeastern Charnoc Basin, south of Allison Canyon). Additionally, we detected approximately seven piles of scats at the crests of Meadow Canyon (Toquima Range). In 2012, we detected scats near the crests of Meadow Canyon and Birch Canyon (Toiyabe Range). In 2013, we detected scats near the crest of Birch Canyon, on the east side of the north summit of Mount Jefferson (Toquima Range), and near Elkhorn.
>
> We detected numerous live Greater Sage-Grouse from 2010–2013. In 2010, we detected five individuals in upper Meadow Canyon. In 2011, we detected three or four individuals, including a female, at the crest of Meadow Canyon. In 2012, we detected at least eight individuals in upper Birch Canyon, one in Washington Canyon (Toiyabe Range), and one in Stewart Canyon (Toiyabe Range). We detected at least ten individuals, including two females, in Antone Canyon (Toquima Range). In 2013, we detected one individual in the middle of Barrett Canyon (Shoshone Mountains), two males each in Meadow Canyon

and on Antelope Valley Road, and four males on the Pine Creek Side of the ridge between the Pine Creek drainage and Buck Canyon (Toquima Range). We also found one dead individual near Monitor Ranch.

2. Annual variation in species richness of breeding birds was lower than annual variation in species composition.

From 2010–2013, we detected 60 species of breeding birds in in Charnoc Basin and in two adjacent canyons in the same watershed (Table 1). Across the four years, we detected 30 species in Charnoc Basin, 55 in Wallace Canyon, and 39 in Allison Canyon. The total number of species detected per year was fairly consistent, from a high of 46 in 2013 to a low of 42 in 2010. Species composition, however, was relatively variable. We detected 34, 4, 7, and 15 species in four, three, two, and one years, respectively. Complete data through 2012 have been archived with the USDA Forest Service Research Data Archive (see below), and data for 2013 will be archived by early 2014.

Table 1. Species richness of breeding birds in Charnoc Basin (Monitor Range, Eureka County, Nevada) before treatment with fire and in two adjacent canyons in the same watershed.

	year				
geographic area	2010	2011	2012	2013	total
Charnoc Basin	24	18	22	22	30
Wallace Canyon	38	36	42	43	55
Allison Canyon	28	30	21	24	39
total	42	45	44	46	60

3. Probabilities of detection and occupancy vary among species of breeding birds and among years.

Occupancy is the probability that a given species occupies a given location during a defined period of time. For birds, that period of time typically is either one year (generally one breeding season) or a multiple-year period of record. The reliability of estimates of occupancy is increased by estimating detection probability, the probability of detecting a species during a single season (year) conditioned on its presence in the sample unit. Estimates of detection probability allow one to account for potential false absences (MacKenzie et al. 2006). Imperfect detection can reflect inexperienced observers, but also results from variation in abiotic or biotic environmental attributes such as annual or growing season precipitation, time of day, vegetation structure, and magnitude of stream flow. Multiple visits (ideally three or more) in a breeding season allow one to estimate detection probability.

Across all sample points (8 min point counts), detection probabilities for 18 species in 2012 and 26 species in 2013 were > 0.3, a threshold generally accepted as sufficient to estimate probabilities of occupancy. In 2012, probabilities of occupancy ranged from 0.02 ± 0.01 (SE) (Western Kingbird [*Tyrannus verticalis*]) to 0.67 ± 0.03 (Green-tailed Towhee [*Pipilo chlorurus*]). In 2013, probablilities of occupancy ranged from 0.01 ± 0.01

(Ruby-crowned Kinglet [*Regulus calendula*]) to 0.67 ± 0.03 (Green-tailed Towhee). Among species with detection probabilities > 0.3 in both years, the change in probability of occupancy among years ranged from 0 (Green-tailed Towhee) to 0.187 (American Robin [*Turdus migratorius*], with probabilities of occupancy in 2012 and 2013 of 0.57 ± 0.05 and 0.38 ± 0.04, respectively). Annual differences of such magnitude likely are not anomalous. For example, probabilities of occupancy for American Robin in 2009, 2010, and 2011 were 0.45 ± 0.04, 0.67 ± 0.06, and 0.52 ± 0.05, respectively.

4. The proportion of cheatgrass tends to increase following fire, although interactions with land use may affect presence and density of cheatgrass.

We found that the prevalence of cheatgrass within burned areas tended to increase steadily as time since the fire increased (e.g., Figure 1). Within paired treatment and control areas (e.g., burned areas within Underdown Canyon as compared to areas in Underdown Canyon that were not burned and to Riley Canyon, which was not treated with fire), the prevalence of cheatgrass generally was correlated, but much higher in burned areas (Figure 2). However, to the best of our knowledge, the only burned area we sampled that was not grazed by domestic livestock was Elkhorn. All other areas were grazed by cattle and, in some cases, received moderate to heavy recreational use (e.g., Wall and Birch canyons).

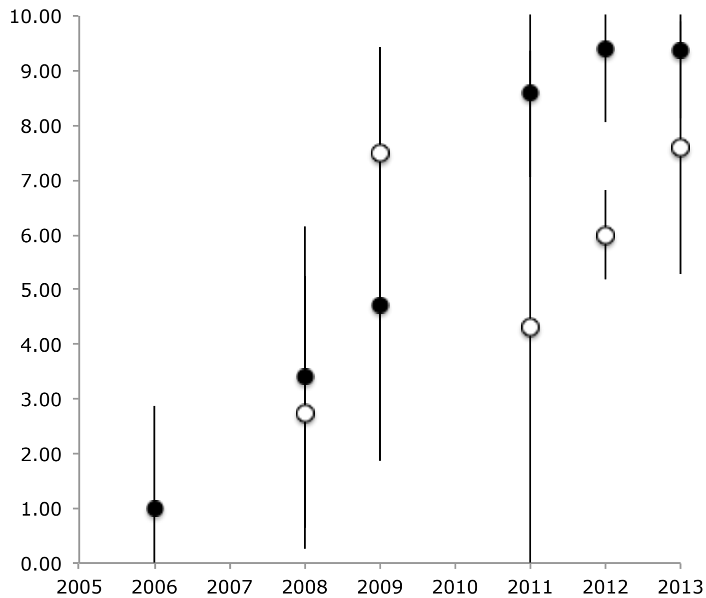

Figure 1. Mean (SD) number of points (of a maximum of 10) in which cheatgrass was present at bird-sampling locations or endpoints of Greater Sage-Grouse transects. Black circles, Grass Springs (burned in autumn 2005); white circles, Birch Canyon (burned in autumn 2006).

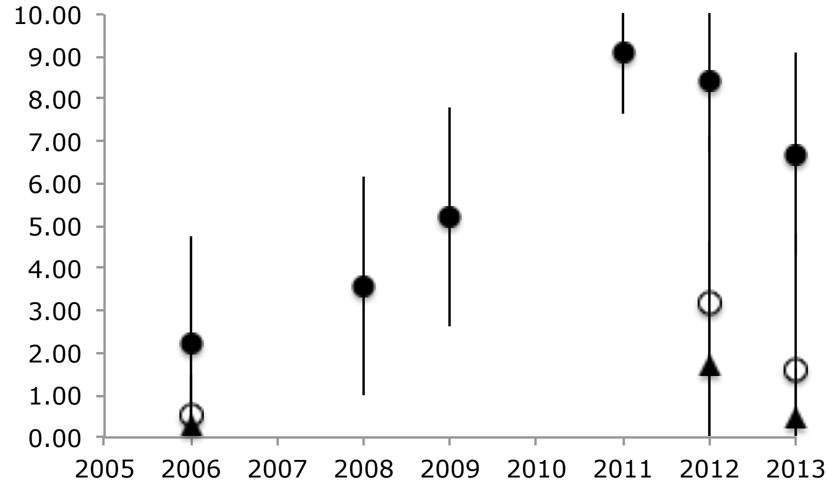

Figure 2. Mean (SD) number of points (of a maximum of 10) in which cheatgrass was present at bird-sampling locations. Black circles, burned areas in Underdown Canyon (burned in autumn 2005); white circles, Riley Canyon (not treated with fire); black triangles, areas in Underdown Canyon that were not treated with fire.

5. Humans appear to be removing a substantial proportion of dead wood after fires, which may decrease post-fire habitat quality for breeding birds.

Large trees that have been burned or partially burned serve as perches for many species of birds associated with pinyon and juniper woodlands. Some species also will nest or forage in dead trees. However, because there is little to no restriction on firewood cutting after fires on Forest Service lands in the central Great Basin, humans often remove the dead trees, reducing habitat quality for breeding birds. Human removal of dead wood exceeds the rate at which dead trees fall naturally, and reduces structural complexity, cover of litter, and decomposition on site.

During vegetation sampling in burned point-count locations in Underdown Canyon, for example, we recorded 189 snags in 2009 and 118 in 2011. In Wall Canyon, we recorded 247 snags in 2009 and 87 snags in 2011. In Grass Springs, we recorded 349 snags in 2009 and 169 in 2011. The mean diameter of snags (cm), however, increased in each area (Underdown Canyon: 15.16 ± 8.31 in 2009, 17.46 ± 9.54 in 2011; Wall Canyon: 12.39 ± 6.96 in 2009, 16.49 ± 10.97 in 2011; Grass Springs: 14.61± 9.11 in 2009, 17.07 ± 13.23 in 2011). The latter may suggest that humans are unable to easily remove or transport relatively large snags, either because the size per se or the location of the snags is prohibitive.

6. Models suggested little change in the spatial distribution of high-quality habitat for 41 of 50 species of breeding birds following projected expansion of pinyon–juniper woodland by 2100.

Projected incidences of breeding birds given a scenario of expansion of pinyon–juniper woodland suggested that area occupied would be reduced by 10–30% for nearly all species associated primarily with sagebrush shrubsteppe. In contrast, projected area occupied increased by 10 – >30% for most species associated primarily with pinyon–juniper woodland. Changes in a measure of landscape contagion given the woodland expansion scenario largely mirrored changes in total occupied area (the correlation between change in occupied area and change in contagion was 0.85). Zonation results suggested little change in the spatial distribution of high-quality habitat following expansion of pinyon and juniper woodland. The riparian-contraction scenario reduced the area projected to be occupied for nearly all riparian-associated species, but the estimated reductions in total area occupied were < 4% for most species. Projected area occupied did not increase by more than 1% for any species, regardless of land-cover association. Landscape contagion (connectivity) did not change substantially for any species given the riparian contraction scenario; proportional changes ranged from -0.05 through + 0.04.

7. In an area of pinyon and juniper expansion in the northern Monitor Range, the percent cover of bare ground was lower, whereas the percent cover of vegetation, litter, gravel, and rock were higher, on higher-elevation sites than at lower elevations (Table 2).

Table 2. Means and standard errors (SE) of percent cover at relatively high-elevation and low-elevation study sites in an area of pinyon and juniper expansion in the northern Monitor Range.

	ground cover (%)			
	higher elevation		lower elevation	
cover type	mean	SE	mean	SE
vegetation	12.32	0.25	5.84	0.23
bare ground	32.63	0.63	59.57	1.30
gravel	13.60	0.39	10.22	0.64
rock	5.84	0.30	0.91	0.14
litter	35.18	0.82	21.68	1.31
cryptogam	0.60	0.13	1.65	0.22
feces	0.19	0.09	0.07	0.04

8. In an area of pinyon and juniper expansion in the northern Monitor Range, resilience to invasion of non-native species and potential for recovery of native species after a disturbance appeared to be greater at higher-elevation sites than at a lower-elevation site.

Aerial and basal cover of herbaceous species is strongly associated with resilience to invasion of non-native species and potential for recovery of native species after a disturbance. Higher-elevation sites had higher productivity and greater percent cover (aerial and basal) of herbaceous species than the lower-elevation site (Table 3).

Cheatgrass was present but not dominant at the lower-elevation site; it has the potential to expand following cutting of trees or fire.

Table 3. Means and standard errors (SE) of percent cover of herbaceous species at relatively high-elevation and low-elevation study sites in an area of pinyon and juniper expansion in the northern Monitor Range.

	aerial cover (%)				basal cover (%)			
	higher elevation		lower elevation		higher elevation		lower elevation	
	mean	SE	mean	SE	mean	SE	mean	SE
perennial grass	4.85	0.11	2.42	0.11	1.28	0.03	1.03	0.11
annual forb	0.20	0.02	0.23	0.03	0.06	0.01	0.05	0.03
perennial forb	6.10	0.19	2.73	0.18	1.77	0.06	1.15	0.18
subshrub	1.17	0.08	0.42	0.06	0.32	0.02	0.17	0.06
unknown forb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
unknown	-	-	0.03	0.01	-	-	0.02	0.01

9. In an area of pinyon and juniper expansion in the northern Monitor Range, fire appeared less likely to result in regeneration of native species at lower-elevation sites than at higher-elevation sites.

On the whole, stand age, basal diameters, tree heights, and tree densities were greater at higher-elevation sites than at the lower-elevation site (Table 4). Mean stem density at the lower-elevation site was about 23.5% of the mean stem density at the higher-elevation sites. Fuel loads (abundance of trees and vegetation cover) were lower at the low-elevation site than at the higher-elevation sites.

Table 4. Basal diameter, height, and densities of live and dead trees at relatively high-elevation and low-elevation study sites in an area of pinyon and juniper expansion in the northern Monitor Range.

	live trees and stems				dead trees	
	higher elevation		lower elevation		higher elevation	
	mean	SE	mean	SE	mean	SE
basal diameter (cm) per ha	11.77	0.21	10.85	0.41	15.87	1.21
height (dm) per ha	24.25	0.30	21.30	0.49	25.37	1.81
basal area per ha	5.55	0.69	0.84	0.16	0.16	0.03
# trees > 0.5 m / ha	254.51	22.90	28.00	4.30	5.86	1.27
# trees < 0.5 m / ha	9.40	0.75	2.00	0.78	0.00[1]	0.00[1]
# stems / ha	269.40	23.11	63.27	9.86	5.95	1.30
# trees (all) / ha	260.37	23.66	30.00	4.76	5.71	1.27

[1]One dead *Pinus monophylla* < 0.5 m in one plot; data not included. No dead trees present at lower-elevation

site.

10. Variables related to climate water deficit can explain considerable variance in the distributions of many dominant shrubs in the Great Basin.

Across the Great Basin, black greasewood and shadscale were dominant in relatively dry sites with high cumulative climatic water deficits, a large number of cumulative growing degree days, and a small seasonal spike in water supply relative to soil water holding capacity. The distribution of black greasewood was similar to that of shadscale. However, locations where the former occurred had more-variable measures of climate water deficit than locations where the latter occurred, and actual evapotranspiration declined less from May through July. Black sagebrush and Wyoming big sagebrush typically were dominant along the intermediate range of the moisture gradient. Relative to locations where Wyoming big sagebrush was dominant, locations where black sagebrush was dominant had more-variable spring water in excess of potential evapotranspiration, slightly more variability in number of growing degree days, and a slightly smaller average cumulative climatic water deficit. Although Wyoming big sagebrush dominated locations with higher mean annual temperatures and lower precipitation than those dominated by black sagebrush, its higher soil-water holding capacity allowed it to occupy locations with lower cumulative climatic water deficit and higher cumulative actual evapotranspiration than would be expected on the basis of temperature and precipitation alone.

Winterfat dominated the lower to intermediate portion of the dominant moisture gradient. Relative to locations where Wyoming big sagebrush and black sagebrush were dominant, locations dominated by winterfat had a slightly greater but more variable number of cumulative growing degree days, a smaller water supply in excess of potential evaporation in the spring, and a larger cumulative annual climatic water deficit. Low sagebrush and mountain big sagebrush dominated locations near the mesic end of the dominant moisture gradient. Locations dominated by these species had relatively small cumulative climatic water deficits and numbers of cumulative growing degree days, and a spike in spring water supply that greatly exceeded potential evapotranspiration. Actual evapotranspiration during the growing season was more variable among sites dominated by mountain big sagebrush than by low sagebrush.

MANAGEMENT IMPLICATIONS

1. Application of fire in pinyon and juniper woodlands is unlikely to increase habitat quality for Greater Sage-Grouse for decades or longer.

There are many records of Greater Sage-Grouse, but few (from any study) from recently burned areas. Leks typically have little to no tree cover, but loss of a lek is not synonymous with loss of a population. Nesting and brood-rearing may not be affected by presence of conifers, and females can nest successfully under pinyon and juniper. Additionally, land-management agencies may not have the option of excluding livestock grazing and moderate- to high-intensity human activity from burned areas until post-fire vegetation recovery is complete. In these circumstances, there may be a high probability of cheatgrass colonization and expansion, which likely will reduce long-term habitat quality for Greater Sage-Grouse.

2. Viability of many species of breeding birds that are associated closely with pinyon and juniper woodlands may be decreased by fuels-reduction treatments.

After a fire or mechanical removal of trees, vegetation structure and composition often take 25–100 years to develop in mountain and basin big sagebrush, and longer in Wyoming big sagebrush. During time, habitat quality for the many native species of breeding birds strongly associated with sagebrush steppe or pinyon–juniper woodlands will be relatively low. Local changes in habitat quality are more likely to affect survival and reproduction over the moderate to long term when populations are isolated or otherwise stressed by natural barriers or human activity.

3. Reliable inference about faunal responses to fire in the Great Basin currently is limited by the number and size of fire treatments.

Study designs that are developed by teams of researchers and managers often are difficult to implement because, for example, archaeological clearances cannot be obtained, trained fire crews are not available during the allowable treatment window, or the treatments are challenged in court. In some cases small or highly patchy fires may allow measurement of floral responses, but often not faunal responses. Sampling of naturally ignited or accidental fires rather than planned treatments may provide some information relevant to management. In the latter cases, however, it may be difficult to separate effects of fire per se from the interaction between fire and human activity (e.g., livestock grazing, vehicle use, and recreation; Reisner et al. 2013).

4. Sampling breeding birds on one visit, or even on multiple visits during one season, is unlikely to provide reliable estimates of occupancy.

Occupancy is the probability that a given species occupies a given location during a defined period of time. The reliability of estimates of occupancy is increased by estimating detection probability, the probability of detecting a species during a single season (year) conditioned on its presence in the sample unit. Even when observers are experienced, highly skilled ornithologists, detection probabilities are well below 1.0. A minimum of two visits, and ideally three or more, are necessary to estimate detection probability. Furthermore, probabilities of occupancy of many species are quite variable in space and time, reflecting weather patterns, resource distributions, interspecific interactions, and other phenomena. One visit during a breeding season, or even multiple visits during one season, does not allow one to estimate with confidence whether a given location is inhabited by a given species of breeding bird.

5. Responses to different actions taken to reduce woody fuel loads and revegetate native perennial herbaceous species and shrubs vary in space and time, but can be estimated.

Actions taken to reduce woody fuel loads and increase cover of native herbaceous species and shrubs may include prescribed fire, mechanical treatments, herbicide applications, and seeding. In shrublands in the Great Basin, the probability that an ecosystem's structure and function will recover after a disturbance is strongly associated by soil temperature and precipitation. This probability of recovery, also called resilience, tends to increase along a local climatic gradient from warm and dry to cool and moist. Widespread invasion and increasing dominance of cheatgrass and other annual invasive species in areas that are relatively warm and dry, and from which perennial herbaceous species largely have been extirpated, may be irreversible.

Ecosystems with low resilience and resistance (the capacity to retain structure and function during or after stresses or disturbance), such as salt desert shrub and relatively warm areas dominated by Wyoming big sagebrush, are relatively unresponsive to manipulation of vegetation and seeding. In ecosystems with relatively high resource availability and resilience, such as cool and moist areas dominated by mountain big sagebrush, maintaining or increasing the function diversity of shrubs, perennial grasses, and forbs may require changes in grazing management and reducing the probability of colonization by non-native invasive species. Restoration treatments are most likely to succeed in these types of ecosystems.

RELATION TO OTHER RECENT FINDINGS AND ONGOING WORK

The work summarized in this report is related to many ongoing efforts throughout the Great Basin and western United States. We highlight three of these below.

Colleagues in the Southwest Climate Science Center who are based at Scripps Institution of Oceanography, University of California, San Diego and the US Geological Survey (USGS) are downscaling the latest generation of global climate models (GCMs) to 6 km and daily resolution. The Western Regional Climate Center and Desert Research Institute, also collaborators in the Southwest Climate Science Center, plan to make station data, gridded observational data, and simulated model outputs available for the time period 1950–2100. With partners in the California Energy Commission, Bureau of Reclamation, and U.S. Army Corps of Engineers, our colleagues at Scripps and USGS will use downscaled outputs on temperature and precipitation as input to the Variable Infiltration Capacity (VIC) macroscale hydrologic model, which simulates surface water and energy balances. The suite of new climate- and VIC-model outputs will serve as inputs to models of resilience and resistance of native flora and fauna to environmental change. Similarly, the climate outputs can be imputed to models of probability of colonization or expansion of non-native annual plants, associated fire dynamics, and occupancy of native or non-native species of animals.

Data on breeding birds are being incorporated into work supported by the Strategic Environmental Research and Development Program on methods for assessment of species richness and occupancy across space, time, taxonomic groups, and ecoregions. Measures of species richness are used widely to inform management planning and action. Species richness also is a popular metric for projecting the effects of natural and human-caused environmental change. Data on species richness alone may not provide insights to probabilities of species persistence. However, species richness can be represented as the cumulative probability of occupancy, or probability of occupying a given location, of many individual species. Occupancy can serve as a surrogate measure of a species' abundance. Abundance and range size, in turn, are strongly related to probability of persistence. Maximizing the probability of species persistence typically is a high priority for federal and state managers of natural resources. We are developing and validating practical, statistically rigorous, and transferable methods to estimate species richness and occupancy across space and time as functions of climate, topography, and vegetation structure and composition. These methods will make it feasible to estimate a species' pattern of occupancy across tens to tens of thousands of square kilometers, detect changes in its distribution, and make inference to its probability of regional persistence both currently and given alternative scenarios of environmental change. This project will allow us to continue sampling Greater Sage-Grouse and other species of breeding birds throughout the Shoshone Mountains and Toiyabe, Toquima, and Monitor ranges and to further sample vegetation in both treated and control sites.

Miller et al. (2013) reviewed the effects of fire on vegetation and soils in the Great Basin. They summarized literature on the relations among the effects of environmental gradients, ecological site, and vegetation characteristics on resilience to disturbance and resistance to non-native invasive species; the effects of fire on individual plant species and communities, biological soil crusts, seed banks, soil nutrients, and hydrology; and the responses of ecosystems to fire severity, fire versus fire surrogate treatments, and post-fire livestock grazing. They suggested that a site's resilience (ability to recover from disturbance) and resistance to non-native invasive species was most strongly associated with soil temperature, soil moisture, and the composition and structure of vegetation on the ecological site just prior to the disturbance event.

FUTURE WORK NEEDED

If implementation of prescribed fire continues to be considered as an option by resource management agencies in the Great Basin, then we think establishment of realistic treatments is necessary to develop realistic projections of ecological response. Although this may sound like common sense, it has been quite difficult to establish treatments likely to yield reliable data on non-trivial responses to fire, especially for mobile species. We also think the ability to collect time-series data over decades or longer will inform projections of responses of species and processes to natural and human-caused environmental change. Again this may sound like common sense, but our work indicates the extent to which probabilities of detection and occupancy of breeding birds, even of common and easily recognized species, vary considerably over complex terrain and years with different weather patterns. Population dynamics of plants and occupancy of rare species also can vary considerably among years.

Because management of Greater Sage-Grouse may be driven by assumptions and hypotheses in addition to empirical data, we think it is worthwhile to supplement ongoing telemetry studies of the species across its range and over time. These data will reduce uncertainty about associations of the species with different topographic features, microclimates, and vegetation attributes.

We believe there is considerable value to archiving data and metadata such as those from standardized point counts of breeding birds, incidental observations of fauna, vegetation measurements, and other research conducted on public lands in the Great Basin. Support from funding organizations and resource management agencies increases the probability that data holders will make archival a high priority and deliver timely information to agencies and the public.

DELIVERABLES

Publications

Chambers, J.C., B.A. Bradley, C.S. Brown, C. D'Antonio, M.J. Germino, J.B. Grace, S.P Hardegree, R.F. Miller, and D.A. Pyke. Resilience to stress and disturbance, and resistance to *Bromus tectorum* L. invasion in the cold desert shrublands of western North America. Ecosystems. doi 10.1007/s10021-013-9725-5.

Fleishman, E., J.R. Thomson, L. Kalies, B.G. Dickson, D.S. Dobkin, and M. Leu. In review. Projecting current and future location, quality, and connectivity of habitat for breeding birds in the Great Basin. Ecosphere.

Dilts, T.E., P.J. Weisberg, C.M. Dencker, J.C. Chambers, and D.I. Board. Modeling the distribution of desert shrub types along gradients of seasonal water balance using a climatic water deficit approach. Draft manuscript.

Invited presentations

Chambers, J.C. 2011. Vegetation resilience and the importance of the herbaceous understory. Great Basin Science Delivery workshop. Winnemucca, Nevada. 24–25 May.

Chambers, J.C. 2012. Sustainable management of piñon and juniper woodlands. Eastern Nevada Landscape Coalition. Ely, Nevada. 6–8 June.

Chambers, J.C. 2013. Cheatgrass Action Team. A strategic approach to managing cheatgrass. Reno, Nevada. 31 July.

Chambers, J.C. 2013. Managing for resilient ecosystems: examining the options. Great Basin Consortium Meeting. Boise, Idaho. 14–15 January.

Chambers, J.C. 2013. Using resilience concepts to manage sage-grouse habitat affected by invasive annual grasses and altered fire regimes – a multi-scale approach. Nevada Sagebrush Ecosystem Technical Team. Reno, Nevada. 20 November.

Chambers, J.C., and R.M Miller. 2012. Resistance to invasive annual grasses in fire prone sagebrush and piñon-juniper ecosystems: management implications. International Association of Fire Ecologists Meeting. Portland, Oregon. 4–7 December.

Chambers, J.C., J. Grace, and R. Miller. 2012. Understanding the importance of resilience and resistance to restoration of sagebrush rangelands. Forum on Disturbance, Resilience, and Thresholds in Sagebrush Ecosystems. Society for Range Management Meeting. Spokane, Washington. 28 January – 3 February.

Fleishman, E. 2009. Application of conservation science to management of public and private lands in the western United States. Bren School of Environmental Science & Management, University of California, Santa Barbara.
Fleishman, E. 2010. Application of conservation science to management of public and private lands in the western United States. Southern Illinois University, Carbondale, Illinois.
Fleishman, E. 2010. Assessment of current and future connectivity for species and land-cover types. Eastern Nevada Landscape Coalition, Ely, Nevada.
Fleishman, E. 2010. Proactive management of conservation-reliant species as land use and climate change. Interagency workshop on natural resource needs related to climate change in the Great Basin and Mojave Desert, Las Vegas, Nevada.
Fleishman, E. 2011. Projecting connectivity in the Great Basin as land use and climate change. University of Idaho, Moscow.
Fleishman, E. 2011. Projecting connectivity in the Great Basin as land use and climate change. Pepperdine University, Malibu, California.
Fleishman, E. 2011. Projecting occupancy and connectivity as land use and climate change. Texas State University, San Marcos.
Fleishman, E. 2012. Discriminating among ecological responses to weather and climate. Great Basin Climate Forum, Reno, Nevada.
Fleishman, E. 2012. Partnerships for conservation on public and private lands as land use and climate change. University of Chicago.
Fleishman, E. 2012. The impact of climate change on natural ecosystems. Southwest Climate Summit, Tucson, Arizona.
Fleishman, E. 2013. Deriving practical information about management of Great Basin ecosystems from pretty things with wings. Humboldt–Toiyabe National Forest Supervisor's Office, Sparks, Nevada.
Fleishman, E., B.G. Dickson (presenter), D.S. Dobkin, M. Leu, and J. Thomson. 2010. Changes in land cover, structural connectivity, and occupancy of riparian birds in the Great Basin. Symposium on incorporating and modeling patch dynamics in conservation planning. Society for Conservation Biology, Edmonton, Alberta, Canada.
Fleishman, E., B.G. Dickson, J. Thomson, E.C. Hansen, and D.S. Dobkin. 2011. Incorporating natural history into models of occupancy and connectivity. Symposium on a natural history initiative for ecology, stewardship, and sustainability. Ecological Society of America, Austin, Texas.
Salafsky, N. and E. Fleishman. 2010. Monitoring to inform policy decisions and management actions for large, complex systems. Symposium on requirements for successful monitoring of biological diversity. Society for Conservation Biology, Edmonton, Alberta, Canada.
Weisberg, P.J. 2013. Human influences on water-limited landscapes of the western United States: integrating natural disturbance, climate change and vegetation in the landscape ecological framework. Workshop on forests and people (invited). Università Politecnica delle Marche, Ancona, Italy. 21 November.
Weisberg, P.J. 2013. What controls the distribution of trees on water-limited landscapes: is it just about the water? Seminar series on forest ecology and silviculture (invited). University of Padua, Italy. 28 November.

Posters

Dilts, T.E., C.M. Dencker, and P.J. Weisberg. 2013. Advances in modeling species distributions using GIS: the Climatic Water Deficit Toolbox. Poster and oral presentation, Nevada Geographic Information Society meeting. Reno, Nevada. 16 May.

Dilts, T.E., C.M. Dencker, and P.J. Weisberg. 2013. Predicting desert shrub community distributions using climatic water deficit variables. Poster. Main Station Field Day Reno, Nevada. 14 September.

Archived data

Fleishman, E. 2011a. Detections of breeding birds in the Shoshone, Toiyabe, Toquima, and Monitor ranges, Nevada. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado. http://dx.doi.org/10.2737/RDS-2011-0002

Fleishman, E. 2011b. Presence and absence of butterflies in the Shoshone Mountains and Toiyabe and Toquima ranges, Nevada. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado. http://dx.doi.org/10.2737/RDS-2011-0003

Fleishman, E. 2013a. Detections of breeding birds in the Shoshone, Toiyabe, Toquima, and Monitor ranges, Nevada. 2nd Edition. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado. http://dx.doi.org/10.2737/RDS-2011-0002.2

Fleishman, E. 2013b. Presence and absence of butterflies in the Shoshone Mountains and Toiyabe and Toquima ranges, Nevada. 2nd Edition. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, Colorado. http://dx.doi.org/10.2737/RDS-2011-0003.2

LITERATURE CITED

Aldridge, C.L., S.E. Nielsen, H.L. Beyer, M.S. Boyce, J.W. Connelly, S.T. Knick, and M.A. Schroeder. 2008. Range wide patterns of Greater Sage-Grouse persistence. Diversity and Distributions 14:983–994.

Baker, W.L. 2011. Pre-Euro American and recent fire in sagebrush ecosystems. Pages 185–201 in S.T. Knick and J.W. Connelly, editors. Greater Sage-Grouse: ecology and conservation of a landscape species and its habitats. Studies in Avian Biology 38. University of California Press, Berkeley, California.

Bukowski, B.E. and W.L. Baker. 2013. Historical fire regimes, reconstructed from land-survey data, led to complexity and fluctuation in sagebrush landscapes. Ecological Applications 23:546–564.

Connelly, J.W., S.T. Knick, M.A. Schroeder, and S.J. Stiver. 2004. Conservation assessment of Greater Sage-Grouse and sagebrush habitats. Western Association of Fish and Wildlife Agencies, Cheyenne, Wyoming.

Garton, E.O., J.W. Connelly, C.A. Hagen, J.S. Horne, A. Moser, and M.A. Schroeder. 2011. Greater Sage-Grouse population dynamics and probability of persistence. Pages 293–382 in S.T. Knick and J.W. Connelly, editors. Greater Sage-Grouse: ecology and conservation of a landscape species and its habitats. Studies in Avian Biology 38. University of California Press, Berkeley, California.

Gillihan, S.W. 2006. Sharing the land with pinyon-juniper birds. Partners in Flight Western Working Group. Salt Lake City, Utah.

Knick, S.T. and S.E. Hanser. 2011. Connecting pattern and process in Greater Sage-grouse populations and sagebrush landscapes. Pages 383–405 in S.T. Knick and J.W. Connelly, editors. Greater Sage-Grouse: ecology and conservation of a landscape species and its habitats. Studies in Avian Biology 38. University of California Press, Berkeley, California.

Lutz, J.A., J.W. van Wagtendonk, and J.F. Franklin. 2010. Climate water deficit, tree species ranges, and climate change in Yosemite National Park. Journal of Biogeography 37:936–950.

MacKenzie, D.I., J.D. Nichols, J.A. Royle, K.P. Pollock, L.L. Bailey, and J.E. Hines. 2006. Occupancy estimation and modeling: inferring patterns and dynamics of species occurrence. Academic Press, San Diego, California.

Miller, R.F., J.C. Chambers, D.A. Pyke, F.B. Pierson, and J.C. Williams. 2013. A review of fire effects on vegetation and soils in the Great Basin Region: response and ecological site characteristics. General Technical Report RMRS-GTR-308. US Department of Agriculture, Forest Service, Rocky Mountain Research Station. Fort Collins, Colorado.

Pyke, D.A., T.A. Wirth, and J.L. Beyers. 2013. Does seeding after wildfires in rangelands reduce erosion or invasive species? Restoration Ecology. doi: 10.1111/rec.12021

Reisner, M.D., J.B. Grace, D.A. Pyke, and P.S. Doescher. 2013. Conditions favoring *Bromus tectorum* dominance of endangered sagebrush steppe ecosystems. Journal of Applied Ecology 50:1039–1049.

Rowland, M.W., M.J. Wisdom, L.H. Suring, and C.W. Meinke. 2006. Greater Sage-Grouse as an umbrella species for sagebrush-associated vertebrates. Biological Conservation 129:323–335.

Sauer, J.R., J.E. Hines, and J. Fallon. 2005. The North American Breeding Bird Survey, results and analysis 1966–2004. Version 2005.2. USGS Patuxent Wildlife Research Center, Laurel, Maryland.

Schroeder, M.A., et al. 2004. Distribution of sage-grouse in North America. Condor 106:363–376.

Wisdom, M.J., C.W. Meinke, S.T. Knick, and M.A. Schroeder. 2011. Factors associated with extirpation of sage-grouse. Pages 451–474 in S.T. Knick and J.W. Connelly, editors. Greater Sage-Grouse: ecology and conservation of a landscape species and its habitats. Studies in Avian Biology 38. University of California Press, Berkeley, California.