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Vitals rates and seasonal movements of two isolated greater sage-grouse populations in Utah's West Desert

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Abstract: Declines in greater sage-grouse (*Centrocercus urophasianus*; hereafter, sage-grouse) populations in Utah over the last century parallel range-wide trends. However, little is known about the ecology of sage-grouse populations that inhabit Utah's naturally fragmented habitats. Utah's West Desert sage-grouse populations occupy sagebrush (*Artemisia* spp.) habitats that are geographically separated by the Great Salt Lake, and largely confined to the Sheeprock and Deep Creek watersheds. From 2005 to 2006, we monitored sage-grouse that were radio-collared in each watershed to determine the factors affecting the vital rates in these isolated populations. Livestock grazing by domestic cattle was the dominate land use, and mammalian predator control for livestock protection was conducted in both watersheds. Corvid control was conducted only in the Sheeprock watershed. During the study, we identified 6 leks that had not been previously documented. Seasonal migration patterns for individual radio-collared sage-grouse in both watersheds varied across the sites. Habitat structure metrics were similar at brood-rearing and random sites for both areas. Nesting and brood success and the ratio of chicks per successful brood were higher for both populations in 2005 than 2006. We attributed these annual differences in vital rates to seasonal variation in precipitation. Spring precipitation in 2005 was twice the 30-year average following a 5 year drought. However, chick recruitment estimates for both populations regardless of year were lower than reported in the published literature. Adult sage-grouse survival rate estimates in Sheeprock and Deep Creek watersheds were lower and higher, respectively, than published reports indicated. These differences may reflect a difference in meso-predators communities. Sage-grouse conservation strategies in both areas should continue to emphasize protection of brood-rearing and seasonal habitat, but the risk of population extirpation as a consequence of extended droughts predicted by climate change models and the invasion of small meso-predators may remain problematic for these populations.

Key words: *Centrocercus urophasianus*, climate change, ecology, greater sage-grouse, human–wildlife conflicts, precipitation, predator control, populations, Utah, vital rates, West Desert

Greater sage-grouse populations (*Centrocercus urophasianus;* hereafter, sage-grouse) have been a management concern for several decades (Patterson 1952, Connelly et al. 2004). Sage-grouse occupy an estimated 56% of the pre-settlement distribution of potential habitat (Schroeder et al. 2004). Long-term studies suggest that sage-grouse populations have steadily declined range-wide (Garton et al. 2011), with Utah populations exhibiting similar trends (Beck et al. 2003).

Although much has been published about the biology of the species (see Connelly et al. 2011 for a review), the primary factors limiting regional and local populations may differ (Dalke et al. 1963, Braun 1998, Connelly et al. 2004, Crawford et al. 2004, Baxter et al. 2008, Gregg et al. 1994, Coates and Delehanty 2010). In Utah, sage-grouse inhabit diverse habitats ranging from large contiguous stands of sagebrush (*Artemisia* spp.; Figure 1) to areas that exhibit smaller, naturally fragmented sagebrush cover (Beck et al. 2003). In these areas, population stability may hinge on the ability of the birds to engage in extended seasonal movements or adapt to local conditions (Schroeder 1997, Utah Division of Wildlife Resources [UDWR] 2002, 2009). Although, the vegetation cover within most of the areas occupied by sage-grouse in Utah may approximate range-wide habitat guidelines (Connelly et al. 2000), annual variation in precipitation may have a dramatic influence on sage-grouse production (UDWR 2002, 2009, Robinson 2007). This influence may be more dramatic at lower elevations prone to periodic drought.

In 1996, Utah State University and the UDWR began convening regional local sage-grouse working groups to develop sage-grouse conservation plans to identify species threats and actions to mitigate them (UDWR 2009). In many of these areas, lek count data were the only readily available information about sage-grouse populations.

The West Desert Adaptive Resource Managment (WDARM) local working group was organized in 2004 to develop and implement a sage-grouse conservation plan for sage-grouse population inhabiting this area (WDARM 2007). The UDWR believed that the sage-grouse populations in this area were isolated from other populations by the Great Salt Lake and largely restricted to small watersheds within the area.

Figure 1. Sage-grouse in Utah. (*Photo courtesy Todd Black*)

The objectives of our research were to describe vital rates and seasonal movements for sage-grouse populations inhabiting Utah's West Desert. Specifically, we were interested in determining if the 2 populations were geographically-isolated and if they had similar factors that limited population productivity and recruitment. Climate change models suggest the Great Basin area of Utah where this study was conducted may also experience reduced annual precipitation, resulting in prolonged winter droughts (Mote 2009).

Study area

Our study focused on sage-grouse populations inhabiting the Sheeprock and Deep Creek watersheds in the West Desert sage-grouse conservation area. The sage-grouse conservation area encompassed 2 million ha (Figure 2; WDARM 2007). The Sheeprock Watershed (490,943 ha) was located on the eastern side of Utah's West Desert, approximately 120 km east of the Deep Creek Watershed (269,929 ha). The 2 study sites were separated by the southern end of the Great Salt Lake Desert. Elevations in the study areas ranged from 1200 to 2200 m. There was no evidence that sage-grouse inhabited or used the desert salt flats or if they can cross the flats (UDWR 2002, 2009).

The U.S. Bureau of Land Management (BLM) managed 202,234 ha (75%) and 201,627 ha (41%) of the Deep Creek and Sheeprock watersheds, respectively. Private lands encompassed 156,273 ha (31%) and 14,350 ha (5%) of the Sheeprock and Deep Creek watersheds, respectively. The U. S. Forest Service (USFS) managed 72,473 ha (15%) in the Sheeprock Watershed but had no holdings in Deep Creek. The second largest landowner in the Deep Creek watershed was the Goshute Tribe (37,703 ha; 14%). Other lands in the conservation area were owned and managed by the Department of Defense, state of Utah, and U.S. Fish and Wildlife Service (WDARM 2007).

The West Desert was characterized by hot, dry summers and cold winters. The 50-year average maximum summer temperature was 33° C in July and the average minimum winter temperature was -11.0° C in January. Average total precipitation (25.9 cm) was greatest in the spring (8.3), lower in summer (6.4) and autumn (6.4), and lowest in winter (5.0). Average total snowfall was 85.0 cm per year, with November-March receiving the majority of the snowfall. Spring 2005 was exceptionally wet with 16.1 cm of precipitation falling from March 1 to May 31, twice the 30-year average. The wet spring of 2005 came after 5 years of below-average precipitation statewide (Western Regional Climate Center 2007).

Ranching was the major industry for private

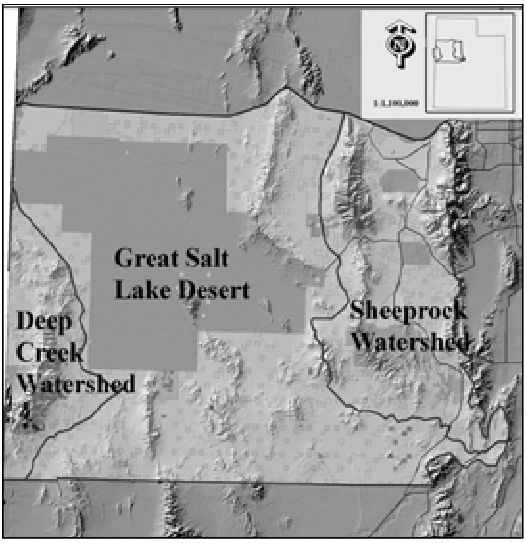

Figure 2. The West Desert study area showing the Deep Creek and Sheeprock watersheds study sites, separated by the Great Salt Lake Desert, Utah, USA.

landowners, with USFS and BLM grazing allotments being essential to their operations (WARM 2007). The Sheeprock Watershed also had a large population of wild mustangs (*Equus ferus caballus*). Lower elevations were dominated by crested wheatgrass (*Agropyron cristatum*) interspaced with Wyoming big sagebrush (*A. tridentata* spp. *wyomingensis*). Both watersheds at lower elevations were dominated by saltbush (*Atriplex* spp.) and greasewood (*Sarcobatus* spp.). At mid-elevations, the dominant shrub species was Wyoming big sagebrush interspersed with silver sagebrush (*A. cana*) in the mesic drainages. As elevations increased, the vegetation included a variety of shrubs, such as Saskatoon serviceberry (*Amelanchier alnifolia*), common snowberry (*Symphoricarpos albus*), antelope bitterbrush (*Purshia tridentata*), chokecherry (*Prunus virginiana*), and stands of juniper (*Juniperus* spp.). At the higher elevations, mountain big sagebrush (*A. t. vaseyana*), and quaking aspen (*Populus tremuloides*) dominated the drainages. Douglas rabbitbrush (*Chrysothamnus viscidiflorus*) and rubber rabbitbrush (*C. nauseous*) occurred throughout the study sites at all elevations.

Both watersheds experienced extensive wildfires in recent years. In these areas, cheatgrass (*Bromus tectoreum*) and rabbitbrush replaced sagebrush (WDARM 2007). Other grasses and forbs included onion grass (*Melica bulbosa*), crested wheatgrass, sandberg bluegrass (*Poa secunda*), bulbous bluegrass (*P. bulbosa*), bluebunch wheatgrass (*Elymus spicatus*), western wheatgrass (*E. smithii*), squirreltail (*E. elymoides*), Indian ricegrass (*Stipa hymenoides*), basin wildrye (*Leymus cinereus*), acuminate onion (*Allium acuminatum*), lupine (*Lupinus* spp.), mountain dandelion (*Agoseris* spp.), milkvetch (*Astagalus* spp.), hawksbeard (*Crepis* spp.), arrowleaf balsamroot (*Balsamorhiza sagittata*), phlox (*Phlox* spp.), blue-eyed Mary (*Collinsia parviflora*), and clover (*Trifolium* spp.).

Predator control for protection of domestic livestock was conducted in both watersheds for the duration of the study by the U. S. Department of Agriculture Animal and Plant Health Inspection Service, Wildlife Services (WS). The area covered by WS encompassed about 68,152 ha. In the Sheeprock Watershed, WS removed 80 coyotes (*Canis latrans*) and 3 coyote dens and 103 coyotes, 5 coyote dens, and 12 red foxes (*Vulpes vulpes*) in 2005 and 2006 respectively. Wildlife Services also conducted predator control in the Deep Creek Watershed, but no records were kept on the number of predators removed (M. Tamllos, WS, personal communication). No red foxes were removed by WS or observed by study personnel in the Deep Creek Watershed study site.

Common ravens (*Corvus corax*) have been implicated in affecting nest success of greater sage-grouse in the Strawberry Valley area of Utah (Bunnell et al. 2000) and other areas (Willis et al. 1993, Coates and Delehanty 2010). In addition to mammalian control, WS conducted control measures for common ravens within the Sheeprock Watershed. In 2005, WS placed 430 soft-boiled eggs injected with DRC-1339 (3-chloro-p-toluidine hydrochloride;) in sage-grouse breeding habitat during the breeding season. In 2006, WS placed 400 DRC-1339 eggs near nesting habitats identified using 2005 telemetry data. Wildlife Service's estimated 95 and 85 common ravens were killed by these eggs in 2005 and 2006, respectively. Treated eggs were placed only during sage-grouse nesting periods. Because no DRCC-1339 treated eggs were placed within the Deep Creek Watershed during this study (M. Tamllos, USDA, WS, personal communication), we were able to compare the effect of these treatments on sage-grouse nest and brood success.

Methods

Radio-telemetry

To determine vital rates, habitat use, and seasonal movements, we captured adult and yearling sage-grouse and fitted themwith very high frequency (VHF) necklace-mounted 16.5 g radio-collars equipped with mortality sensors (mortality signal cycle: 5 hours off, 19 hours on) Advanced Telemetry Solutions™ (Isanti, Minn.). Sage-grouse were captured at night with a spotlight and long dip net while they roosted near the leks (Giesen et al. 1982, Connelly et al. 2003). Captured sage-grouse were weighed using a Pesola AG™ (Baar, Switzerland) 2500-g spring scale, and each bird was aged according to Gill (1967) and Dalke et al. (1963). We recorded the location (Universal Transverse Mercator [UTM] NAD27) for each capture site using a global positioning system (GPS). Each bird was released at the capture after information had been recorded. All sage-grouse were handled according to protocol approved by the Institutional Animal Care and Use Committee at Utah State University and a UDWR Certificate of Registration.

Lek counts

Methods used to obtain sage-grouse lek count data followed standard UDWR (2002) protocols and those of Connelly et al. (2003). We conducted lek counts once a week from the first week in March to the first part of May 2005 and 2006. We recorded the highest number of males observed in a single count, out of 3 counts. This procedure was repeated with ≤3 leks per morning. The highest numbers of males seen during the season are the reported totals. The study areas were also systematically searched by study personnel and WDARM members in both 2005 and 2006 for the presence of undocumented leks. New leks documented were censused using the protocols described above and the UTM location recorded.

Nesting ecology

Radio-collared birds were located using Telonics Inc.™ (Mesa, Ariz.) and ICOM America Inc.™ (Bellevue, Wash.) receivers, handheld 3-element Yagi folding antennas ,and vehicle-mounted Omni antennas (RA-2A). Hens were located every 4 to 5 days until they initiated nesting activity. Hens were monitored to determine nest initiation rates, dates, distance between lek and nests, nesting success rates, nest predation rates, clutch size, and vegetation structure at nests. During the nesting period, hens were located every 2 to 3 days to try to account for all nesting attempts. Hens located under the same shrub 2 days in a row were considered to be nesting. Nest UTM locations were recorded. Nests were subsequently observed from a distance of >10 m every 2 to 3 days, so that their fates could be determined. For depredated nests, we attempted to identify the type of predator by the state of any eggshells, scat, tracks, and hairs present (Patterson 1952). A nest was considered successfully hatched by the presence of ≥1 eggshell with loose membranes. Nest initiation dates were estimated using a 27-day incubation period with 1 day added for each egg in the nest (Schroeder 1997).

Nest site vegetation

Nest site vegetation was measured after the hen ceased her nesting effort and the fate of the nest was known. A pole was placed in the center of the nest bowl, and used as the center point for vegetation measurements. We recorded vegetation measurements in 4 directions, at every 90° starting with a randomly chosen direction from the center pole. We measured shrub canopy coverage for 15-m from the center along each of the 4 transects using a modified line-intercept method (Canfield 1941). Gaps in the foliage ≥ 5 cm were not counted. Heights were recorded for the tallest part of each shrub along each transect.

We used a Robel pole (Robel et al. 1970) to measure nest site concealment. Using the pole, we recorded visual obstruction readings into the nest (Robel In, a measure of vegetation concealment) and from the nest (Robel Out, a measure of a hen's obstruction). We used a 20- by 50-cm Daubenmire (1959) quadrant to estimate forb, grass, bare ground, rock, and litter canopy cover to the nearest percentage point. A Daubenmire quadrant measurement was taken every 3-m along each of the 4 transects, yielding 20 quadrants per nest site. The tallest height of each species of forb and grass (droop height) in each Daubenmire quadrant was recorded. Nest shrub species, maximum height and diameter, date of vegetation measurements, hatch date, clutch size, whether or not nest was predated, predator type, UTM location, and general habitat were recorded for all nests.

Brood monitoring

We located bi-weekly each bird that had successfully nested. Hens without broods were relocated once a week through August. At each location, we recorded a UTM location, dominant vegetation, number of chicks observed, and number of grouse flushed. Broods were considered successful if ≥1 chicks survived to ≥50 days.

Vegetation at brood site locations was measured 3 to 5 days after the brood location was recorded, which allowed time for the brood to leave the area. Brood site vegetation was measured using the same methods as for nest site vegetation with a few exceptions. We measured shrub canopy coverage for 10 m from the center along each of the 4 transects. We recorded only a Robel In measurement from 4 m from the center on each of the 4 transects. A Daubenmire quadrant measurement was taken every 2.5 m along each of the 4 transects, yielding 16 quadrants per brood site. At each brood site, we recorded the date of vegetation measurement, date the brood was located, UTM location, and general habitat. Vegetation attributes also were measured at 3 random sites within 500 m of each brood site. Vegetation measurements were recorded only if the hen was still brooding.

Arthropod sampling

Arthropods are an important component of early brood-rearing habitat (Patterson 1952). Ants (Hymenoptera) and beetles (Coleoptera) are often the most important groups of arthropods eaten by young sage-grouse (Johnson and Boyce 1990, Gregg et al. 2003), and their abundance can be assessed using pitfall traps.

We sampled arthropods in the Sheeprock Watershed using pitfall traps with 8-cm-wide openings to determine if their relative abundance differed by brood and random sites. We were also interested in determining the effects of seasonal variation in weather on arthropod indices. We did not conduct arthropod sampling in the Deep Creek Watershed because of our limited sample of radio-collared hens.

We placed the pitfall traps in a grid pattern so the openings were flush with the ground (Nelle 1998). We established 4, 10-m transects at all locations containing 8 pitfall traps, 2 per transect. Traps were placed at 5 and 10 m from the center of each transect. We collected samples from each pitfall trap weekly for 7 weeks after a nest hatched and during brood-rearing periods. Samples were collected at brood locations and at random sites located within 500 m of brood locations. Samples were collected by opening the pitfall traps for 48 hours, then the trap contents were emptied and the traps closed. Arthropods collected at each trap site were placed in separate containers with a 70% ethyl alcohol solution (Pedigo and Buntin 1993). Collected arthropods where classified to order and families. We also counted the number of individuals and determined the total volume of the different groups collected at each site.

Seasonal movements

Seasonal movements of sage-grouse were determined by locating birds weekly during spring and summer and monthly in fall and winter. A combination of ground and aerial surveillance was used to locate birds. A UTM location, number of birds observed, and general habitat were recorded at all bird locations. If a bird was in the same area for an extended period of time, a general description of the location was used instead of an exact UTM location.

Mortalities

When a radio-collared bird mortality signal was detected, we examined the carcass and remains, including feathers, for signs of talon, claw, or tooth marks, and searched the surrounding area for remains, hair, feathers, tracks, and scat to identify predators. We recorded the location, general habitat, and possible signs of the predator. It was difficult to assign a predator type to the birds because of scavengers disturbing them. In most cases only the collar and a few feathers were located, and predators could not be positively identified.

Raven surveys

In 2005 and 2006, we conducted weekly morning (0630 hours to 0900 hours) raven surveys along a 12.8-km transect in the

Sheeprock Watershed from May 1 to August 1 to determine the number of ravens observed in nesting and breeding areas treated by WS. We traveled the transect at speeds ranging from 24 to 40 km/h, stopping only to positively identify and count ravens.

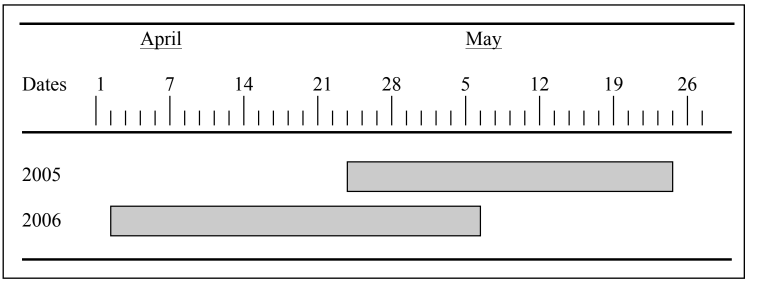

Figure 3. Sage-grouse nest initiation dates for all nests, both populations combined, West Desert study area, Utah, USA, 2005 to 2006.

Data analysis

We used SAS Institute Inc. software to run 1-way analysis of variance (ANOVA) to compare female capture weights and nest and brood vegetation parameters within and between years and study sites. We used paired t-tests to compare nest shrub height (measured) to surround shrub height (average height of all shrubs along each of 4 transects). We set all tests at the alpha = 0.05 level of significance. We used descriptive statistics to describe nest initiation rates, nest initiation dates, clutch size, nest success, brood success, annual survival, seasonal movements, and arthropod densities. We analyzed data for 2005 and 2006 separately, except for winter data because of an unusually wet spring in 2005, which impacted the metrics. We used ArcGIS 9 (Environmental Systems Research Institute, Redlands, Calif.) GIS software to analyze movement data.

Results

Demographics

We captured 37 greater sage-grouse in the Sheeprock Watershed and twelve in the Deep Creek Watershed during the study. In the Sheeprock Watershed, we captured 7 adult males (three in 2005 and four in 2006), 7 yearling females (five in 2005 and two in 2006), and 23 adult females (sixteen in 2005 and seven in 2006). The mean elevation for captures sites was 1,940.3 m (SD = 173.4, range = 1,594 to 2,161). Average weights for adult and yearling females differed (P = 0.005); yearlings weighed 1,310 g (SE = 37, range = 1,160 to 1,440 g), and adults weighed 1,454 g (SE = 22, range = 1,270 to 1,685 g).

In the Deep Creek Watershed, we captured 3 adult males in 2005 and 4 adult females (three in 2005 and one in 2006) and 5 yearling females (all in 2005). The mean elevation of the capture site was 1,804 m (SD = 36, range = 1,771 to 1,883 m). The average weight for adult and yearling females did not differ (P = 0.37); yearlings weighed 1,306 g (SE = 61.4, range = 1,080 to 1,410 g), and adults weighed 1,377 g (SE = 30.1, range = 1,300 to 1,430 g).

Vital rates

We counted 202 and 283 males on all known leks within the West Desert study area in 2005 and 2006, respectively. For the Sheeprock Watershed population we counted 143 males on 3 leks and 190 males on 5 leks in 2005 and 2006, respectively. For the Deep Creek Watershed population we counted 59 males on 3 leks and 93 males on 4 leks in 2005 and 2006, respectively. Our systematic lek searches in both areas resulted in the discovery of 6 undocumented leks.

More nests were monitored in the Sheeprock than Deep Rock watersheds. Hen nest initiation rates and success varied by site and year (Table 1). Hens nesting in both watersheds initiated nests 2 to 3 weeks earlier during the 2006 breeding season when precipitation was average ($\bar{x}$ = April 19) than in 2005 ($\bar{x}$ = May 7) when precipitation was above normal (Figure 3). No re-nesting attempts were documented. In both study areas, >80% of all nest and brood locations in both study areas were located within 3.2 km of a lek or nest site, respectively. Average clutch size was higher in 2006 than in 2005 for both populations and higher for the Deep Creek Watershed (range = 4 to 9; Table 1).

Six hens nested in both 2005 and 2006 in the Sheeprock Watershed, with the same 3 hens being successful in both years. Three hens nested in both 2005 and 2006 in the Deep Creek Watershed, with two being successful in both years. The average distance these hens nested

Table 1. Sage-grouse vital rates, Sheeprock and Deep Creek watersheds, Utah, USA, 2005 to 2006.

	Sheeprock Watershed		Deep Creek Watershed	
Parameter	2005	2006	2005	2006
Hens monitored	19	22	8	8
Males monitored	3	6	3	3
Nest initiation	53%	82%	50%	75%
$\bar{x}$ Nest initiation date	May 7	April 19	May 5	April 15
$\bar{x}$ Distance, lek to nest	1.95 km	1.6 km	2.14 km	2.7 km
Nest success	70%	57%	100%	50%
$\bar{x}$ Clutch size	6.0	6.3	7.25	8.7
Brood success[a]	29%	30%	50%	66.7%
$\bar{x}$ Chicks in successful broods	3.5	1.7	3	2
Female survival rate	57%	52%	100%	75%
Male survival sate	67%	33%	100%	33%[b]

[a] Represents the % of hens that successfully nested that had successful broods. A brood was considered successful if ≥1 chicks lived to an age of 50 days.
[b] Unknown if mortality occurred; 2 of 3 males' collars disconnected during lekking activities.

in 2006 from their nests in 2005 was 470 m (range = 63 to 880 m).

Brood success was higher in 2006 than in 2005 for both populations, but the average number of chicks per successful brood was higher in 2005 (Table 1). Sage-grouse in the Deep Creek Watershed had higher annual survival rates than sage-grouse in the Sheeprock Watershed (Table 1).

Nest and brood site habitat use

Although nest site vegetation metrics differed between years and watersheds, they approximated recommended range wide habitat guidelines for percent cover for shrubs and grass (Connelly et al. 2000; Table 2). The percentage of grass and forb cover was higher in 2005 in both watersheds after a wet winter. The percentage of forb cover in the Deep Creek Watershed did not meet recommended guidelines during either years of the study.

Within the Sheeprock Watershed, twenty-two of 28 hens that nested during the study selected sites under Wyoming sagebrush. Other nests were located under juniper, rabbitbrush, Indian ricegrass, and basin wildrye. The mean elevation for nests was 2,038 m (SD = 139, range = 1,605 to 2,210 m). Nest shrub diameter (P = 0.047), forb cover (P = 0.002), forb height (P = 0.001), grass cover (P < 0.0001), grass height (P = 0.002), rock cover (P = 0.007) differed between 2005 and 2006. Grass and forb height was higher in 2005. Nests were located under shrubs that were taller than the surrounding shrubs (P < 0.0001).

Within the Deep Creek Watershed, nine of the 10 hens that initiated nests during the study did so under Wyoming sagebrush. The mean elevation for nests was 1,806 m (SD = 59.0, range = 1,756 to 1,900 m). Nests were located under shrubs taller than the surrounding shrubs (P = 0.0001). Nest site vegetation did not differ between 2005 and 2006, with the exception of grass height (P = 0.0001; Table 1).

There was no difference in nest site vegetation parameters between the watersheds in 2005, except for forb cover (P = 0.03). In 2006, the percentage of forb (P = 0.003) and rock cover (P = 0.02), and grass (P = 0.0002), and forb height differed by watersheds (P = 0.01; Table 2).

Brood site vegetation parameters also varied between years and watersheds (Table 3). Within the Sheeprock Watershed in 2005, the vegetation parameters at brood sites did not differ from

Table 2. Sage-grouse nest-site vegetation metrics, Deep Creek and Sheeprock watersheds, Utah, USA, 2005 to 2006.

	Deep Creek Watershed				Sheeprock Watershed			
	2005		2006		2005		2006	
Parameter	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Nest shrub height (cm)	87.5	6.4	79.2	10.9	91.2	7.4	96.2	8.2
Nest shrub diameter (cm)	185.0	14.5	125.2	22.9	230.3*	30.1	171.4*	13.2
Shrub cover (%)	29.5	2.0	29.7	4.0	33.5	3.1	34.2	3.6
Shrub height (cm)	40.6	4.3	46.9	5.3	55.2	12.3	61.0	7.0
Sagebrush cover (%)[a]	91.5	5.7	86.5	7.7	62.6	11.7	83.5	3.9
Sagebrush height (cm)	54.1	6.9	56.8	7.8	55.5	8.9	64.3	4.2
Forb cover (%)	5.3	3.4	1.5	1.0	34.5*	7.4	13.9*	2.1
Forb height (cm)	16.9	3.6	17.8	4.3	18.0*	2.3	10.4*	0.8
Grass cover (%)	27.2	3.6	17.1	3.1	33.9*	3.5	14.7*	1.5
Grass height (cm)	33.6*	2.1	13.2*	1.0	34.0*	4.2	22.6*	1.2
Bare ground (%)	28.7	3.6	21.5	4.0	24.1	3.1	17.7	2.5

[a] Represents the percentage of total shrub cover that is sagebrush.
* Denotes a significant difference within watershed.

Table 3. Greater sage-grouse brood-site vegetation metrics, Deep Creek and Sheeprock watersheds, Utah, USA, 2005 to 2006.

	Deep Creek Watershed				Sheeprock Watershed			
	2005		2006		2005		2006	
Parameter	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Shrub cover (%)	23.8*	3.0	14.0*	1.8	23.6*	2.9	34.4*	2.0
Shrub height (cm)	41.4*	6.9	51.4*	6.8	42.2*	2.3	51.1*	2.7
Sagebrush cover (%)[a]	78.1	4.8	74.7	6.4	73.6	3.8	72.7	3.4
Sagebrush height (cm)	42.0	2.9	57.7	5.3	49.0	3.1	58.7	2.8
Forb cover (%)	5.7	1.1	5.6	1.9	24.1*	2.1	9.9*	0.8
Forb height (cm)	16.9	2.1	17.6	2.2	17.3*	0.7	11.6*	0.4
Grass cover (%)	23.3*	2.9	12.9*	2.0	28.6*	2.2	18.3*	1.0
Grass height (cm)	34.7*	2.2	23.6*	1.7	34.0*	1.1	24.6*	0.8
Bare ground (%)	35.0	3.3	28.3	2.9	26.0*	2.5	19.0*	1.0
Litter cover (%)	35.3	2.9	38.9	2.7	35.3	2.0	38.3	1.1

[a] Represents the percentage of total shrub cover that is sagebrush.
* Denotes a significant difference within watershed.

those at random sites, except for forb height (P = 0.01). In 2006, the vegetation parameters at brood sites did not differ from random sites, except for the percentage of rock (P = 0.02) and bare ground cover (P = 0.03). At brood locations, the average elevation for brood sites was 2,109 m (SD = 96, range = 1,707 to 2,252 m). There was a difference in Robel In (P = 0.023), shrub cover (P = 0.002), shrub height (P = 0.032), forb cover (P < 0.0001), forb height (P < 0.0001), grass cover (P = 0.0001), grass height (P < 0.0001), rock cover (P = 0.004), and bare ground (P = 0.0005)

Table 4. Arthropod numbers and volume (mL) collected at brood and random sites, Sheeprock Watershed, Utah, USA, 2005 to 2006.

Parameter	2005 Brood	2005 Random	2006 Brood	2006 Random
	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)	$\bar{x}$ (SE)
Number of families	22	21	22	22
# of ants fFormicidae)	1112 (521)	211 (160)	797 (392)	171 (69)
Volume of ants	15.1 (7.1)	2.7 (2.6)	10.9 (5.2)	1.7 (0.8)
# of other *	17.6 (2.7)	20.8 (3.7)	17.7 (2.3)	13.9 (2.1)
Volume of other	8.2 (4.5)	3.2 (1.5)	1.2 (0.2)	0.5 (0.1)

* Includes Carabidae, Tenebrionidae, Cicadellidae, Araneida, and 16 other families.

between 2005 and 2006. Forb and grass cover and height was higher in 2005. Shrub cover and height, and Robel In were all higher in 2006.

Within the Deep Creek Watershed there was no difference in vegetation parameters at brood and random sites ($P > 0.05$). The mean elevation for brood sites was 1,812 m (SD = 97, range = 1,677 to 2,047 m). Shrub ($P = 0.008$) and grass cover ($P = 0.005$), and grass height ($P = 0.0002$) differed at brood locations between 2005 and 2006. In 2005, 2 brood site vegetation metrics differed between watersheds; percent forb cover ($P = 0.0001$) and percentage of bare ground cover ($P = 0.02$). In 2006, percentage of shrub ($P = <0.0001$), forb ($P = 0.01$), forb height ($P = 0.0001$) and grass cover ($P = 0.01$) differed between watersheds.

Arthropods

Total arthropod abundance in terms of volume and numbers was higher in 2005 than in 2006 at both brood and random sites. More arthropods were also collected at brood than random sites during the study (Table 4). Ants (Formicidae) were the most abundant arthropod collected based on number of individuals (99%) and by volume (77%).

Seasonal movements

The Sheeprock Watershed population was largely migratory. Sage-grouse used the Sheeprock Mountains for breeding, nesting, and brood-rearing, then migrated to lower elevations to the north and south of the mountain range during winter. Winter ranges were lower in elevation in Wyoming's big sagebrush dominated areas. Most birds (20 of 24) traveled to the south winter range. The average distance a bird traveled to reach the south winter range was 14.6 km (n = 24, range = 10.3 to 16.6 km) from the site of capture. Males tended to travel farther from their captures sites than did females. The greatest distance traveled by males was 23.5 km.

The Deep Creek Watershed population was largely non-migratory. These birds used the Ibapah Valley year-round. During winter, birds generally moved northwest into Nevada. The average distance a bird moved from its capture site to a winter location was 8.9 km (n = 11, range = 1.7 to 16.9 km). If the 2 birds that moved the farthest were excluded from this data set; the average distance traveled from breeding areas to winter range was 5.5 km (range 1.7 to 12 km). One radio-collared male traveled 18.1 km from his capture site to use summer ranges >2,200 m in elevation. With the 1 exception, this population would be considered largely non-migratory (Connelly et al. 2000). We could not determine if these birds shared winter habitats with sage-grouse from Nevada.

Raven surveys

We observed an average number of ravens per week of 7.3 and 7.2 in 2005 and 2006, respectively. During the period when WS placed treated eggs (May 1 to June 14), the average number of ravens observed was 2.6 and 3.3 in 2005 and 2006, respectively. After WS had ended the treatments, (June 15 to August 1), the average number of ravens observed increased to 11.8 and 12.6 in 2005 and 2006, respectively.

Discussion

Adult hen survival, nest success, and chick survival have been identified as the vital rates having the greatest effect on sage-grouse population dynamics (Dahlgren et al. 2010, Guttery 2011, Taylor et al. 2012). These factors are largely an artifact of habitat availability and quality and may be influenced by environmental factors, including land uses and weather (Connelly et al. 2011).

Adult hen survival and chick survival to fledging rates were lower in the Sheeprock than Deep Creek watersheds during both years of our study. However, in 2005, a year of above normal spring precipitation, adult hen survival, nest success, chick survival and the number of chicks per successful broods was high in both watersheds than 2006, a normal precipitation year.

Our study area experienced a 5-year drought in the early 2000s, but in 2005, both study sites received twice the annual average spring precipitation. The wet spring of 2005 affected nesting nest initiation dates and vegetation responses in both areas. Nest initiation dates were 2 weeks later in 2005 than in 2006 in both populations. The percentage of forb and grass cover was greater in 2005 than in 2006. Grass height was also greater in 2005 than in 2006. Both the higher percentage of forb and grass cover and the increased grass heights may have been a contributing factor to the higher nest success rates in both populations in 2005 (Delong et al. 1995, Gregg et al. 1994).

The increase in precipitation in 2005 and subsequent increase in forb production, may have caused an increase in number and volume of arthropods collected in the Sheeprock Watershed. During both years of the study, the numbers and volumes of arthropods collected were greater at brood than in random sites. Arthropod abundance generally increases with forb abundance (Potts 1986, Drut et al. 1994). This increase in forbs and arthropods may be a contributing factor in the higher number of chicks per successful brood in 2005, compared to 2006.

Overall annual adult sage-grouse survival rates were higher in the Deep Creek than in the Sheeprock Watershed. This observation was unexpected given that predator control was more intense in the Sheeprock Watershed. A possible explanation for this disparity, may be related to our smaller Deep Creek sample size, as well as the presence of red foxes in the Sheeprock Watershed. No red foxes were observed in the Deep Creek Watershed site during our study, but foxes were frequently seen in the Sheeprock Watershed site. Red foxes have been documented to be limiting factors for sage-grouse recovery (Bunnell et al. 2000, Baxter et al. 2008).

Sage-grouse nest and brood success rates also were higher in the Deep Creek Watershed, suggesting that corvid removal conducted in the Sheeprock Watershed may have had a limited effect on nest and brood success in this watershed. Our small hen and nest sample size in the Deep Creek Watershed are a potential source of bias. However, even given our small sample sizes, population vital rates were well within those reported range wide (Connelly et al. 2011). The most notable difference in the predator community in the watersheds was the presence of red foxes.

Based on seasonal movements of radio-collared birds, most of the Sheeprock Watershed sage-grouse population used distinct seasonal ranges, migrating from the Sheeprock Mountain breeding range to winter at lower elevations. The seasonal movement patterns for the Deep Creek population were less clear. Hens used the Ibapah Valley year-round with a few individuals, mostly males, traveling to higher elevations in the Deep Creek Mountains to summer. Most of the birds moved to <2 km into Nevada to winter. Fedy et al. (2012) reported similar variation in individual movement for sage-grouse populations located in core regions of Wyoming. Based on their research, they suggested defiitions of populations as migratory or non-migratory may be inappropriate for conservation purposes. We did not find any evidence to suggest that the West Desert populations interact.

Management implications

Identifying leks and associated habitats is vital to protecting sage-grouse in the West Desert. Leks in the West Desert are the focal points for breeding, nesting, and brood-rearing. We identified 6 new leks in Utah during our study. This information will be crucial to identity and implement regional conservation plans that protect important habitats. We recommend that both Utah and Nevada include systematic searches for leks a regular part of their annual lek survey protocols. Such leks surveys may be particularly important to identify and protect habitats used by interstate populations.

In our study, seasonal variation in precipitation appeared to have a greater effect on sage-grouse vital rates than did predation management. Thus, protection of the existing sage-grouse habitat in the Sheeprock and Deep Creek watersheds must remain an important management strategy. Because of increasing invasive species, the risk of wildfires destroying important sage-grouse seasonal habitats will remain problematic. With climate change, wildlife risks will likely increase, further impacting population vital rates. Thus, sage-grouse conservation strategies in the West Desert must include management actions to protect the best habitats and abate the risk of wildfires.

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