Human–Wildlife Interactions 7(2):250–259, Fall 2013

Winter habitat use by juvenile greater sage-grouse on Parker Mountain, Utah: implications for sagebrush management

Danny Caudill,[1] Jack H. Berryman Institute, Department of Wildland Resources, Utah State University, Logan, UT 84322-5230, USA *Charles.caudill@myfwc.com*

Terry A. Messmer, Jack H. Berryman Institute, Department of Wildland Resources, Utah State University, Logan, UT 84322-5230, USA

Brent Bibles, Center for Natural Resources Management and Protection, Unity College, Unity, ME 04988, USA

Michael R. Guttery, Department of Forest and Wildlife Ecology, University of Wisconsin, Madison, WI 53706, USA

Abstract: Greater sage-grouse (*Centrocercus urophasianu*s; hereafter, sage-grouse) are entirely dependent on sagebrush (*Artemisia* spp.) for food and cover during winter. Loss or fragmentation of important wintering areas could have a disproportionate affect on population size. We radio-marked and monitored 91 juvenile sage-grouse in south-central Utah from 2008 to 2010. Thirty-four individuals survived to winter (January to March) and were used to evaluate winter habitat use. Resource use was calculated using kernel density estimation of radio-marked individuals and compared to available habitat using a G-test. We found that juvenile sage-grouse used winter habitats characterized by 0 to 5% slopes regardless of aspect and slopes 5 to 15% with south-to-west facing aspects. The importance of high slope (5 to 15%) wintering habitats has not been previously documented in sage-grouse. Most winter use was on a small proportion (3%; 2,910 ha) of available habitat. Important wintering habitats may not be readily identifiable in typical years, and consequently, due to their elevation, may be more susceptible to land management treatments focused on increasing early season livestock or big game winter forage, rendering them unsuitable for winter use by sage-grouse. Prior to implementing land management treatments in lower elevation sagebrush sites with slopes ≤5% regardless of aspect and slopes 5 to 15% south to west in aspect, managers should consider the potential effects of such treatments on the availability of suitable winter habitat to mitigate against winters with above-normal snowfall.

Key words: *Centrocercus urophasianus*, Geographic Information System, GIS, greater sage-grouse, habitat, human–wildlife conflicts, topography, Utah, winter

The historic range of greater sage-grouse (*Centrocercus urophasianus*; hereafter, sage-grouse) has declined in area by >55% (Connelly et al. 2004, Schroeder et al. 2004). Sage-grouse are completely dependent on sagebrush (*Artemisia* sp.) for forage during the winter (Patterson 1952, Dalke et al. 1963, Wallestad et al. 1975) and exhibit some degree of site fidelity to wintering areas (Eng and Schladweiler 1972, Berry and Eng 1985, Connelly et al. 1988). Doherty et al. (2008) concluded that impacts to wintering habitats could disproportionately affect population size. Lower elevation sagebrush habitat used by sage-grouse may constitute important winter areas for big game and early spring forage areas for domestic livestock (Connelly et al. 2004). Land management treatments on lower elevation sagebrush areas to increase big game or livestock forage at the expense of sagebrush cover could have long-term consequences for sage-grouse if treatment areas constitute important, winter habitat during winters with above normal snowfall.

Burke et al. (1989) reported that the distribution of vegetation in a mountain big sagebrush (*A. tridentata vaseyana*) steppe community was dependent upon wind exposure and topography. Similarly, sage-grouse habitat selection during winter has been shown to be related to exposure and topography, with grouse typically using south to west aspects (Beck 1977) with slopes <5%, and avoiding slopes >5 to 10% (Eng and Schladweiler 1972, Beck 1977). Further, Doherty et al. (2008) reported that slope was an important topographic predictor of whether sage-grouse

[1]Present address: Fish and Wildlife Research Institute, Florida Fish and Wildlife Conservation Commission, 1105 S. W. Williston Road, Gainesville, FL 32601, USA

used an area. Similar wintering habitats have been described for the closely related Gunnison sage-grouse (*Centrocerus minimus*), with the addition of steeper slopes (drainages and slopes >8%; Hupp and Braun 1989). Snow cover also has been shown to be an important parameter determining winter use areas (Beck 1977, Hupp and Braun 1989). It is likely that winter habitat selection is related to both the availability of exposed forage (sagebrush) and protection from climatic conditions.

The Parker Mountain sage-grouse population is one of the southernmost populations in the species' range, and it is geographically proximal to the range of the Gunnison sage-grouse. The purpose of our research was to estimate core juvenile wintering areas on Parker Mountain and whether the metrics of winter habitat previously described in the sage-grouse (both greater and Gunnison) literature are adequate for identifying habitats used by juvenile sage-grouse on Parker Mountain.

Study area

We conducted our study on Parker Mountain in south-central Utah. Parker Mountain is a high elevation plateau that lies at the southern edge of the range of greater sage-grouse (Schroeder et al. 2004). Parker Mountain ranges in elevation from 2,200 to 3,000 m and rises in elevation gradually from east to west. The area typically experiences 65 to 80 frost-free days and receives 40 to 50 cm of precipitation annually, most (60%) of which occurs during winter as snow, and the remainder as rain in the late summer (Jaynes 1982). The vegetation is primarily black sagebrush (*A. nova*) on ridges, and mountain big sagebrush in the swales. Quaking aspen (*Populus tremuloides*) clones are present in the higher elevations. Limited amounts of pinyon pine (*Pinus edulis*) and juniper (*Juniperus* spp.) occur at lower elevations. The study area consisted of lands managed by the Utah School and Institutional Trust Lands Administration (SITLA), the U.S. Bureau of Land Management (BLM) and U.S. Forest Service (USFS). These agencies managed 46% (43,745 ha), 44% (42,643 ha), and 9% (8,327 ha) of the study area, respectively. Private lands accounted for 1% (1,363 ha) of the study area. The primary land use was cattle and sheep grazing. Domestic livestock typically were placed in lower elevation pastures in the early spring and moved to higher elevation pastures based on projected available forage utilization or plant desiccation dates (Parker Mountain Adaptive Resource Local Woking Group 2006).

Methods

We captured juvenile sage-grouse using night spotlighting (Giesen et al. 1982, Wakkinen et al. 1992, Connelly et al. 2003). Trapping was conducted annually between August 1 and September 30. Adults were distinguished from juveniles using characteristics of the first secondary flight feather (Beck et al. 1975). Sex was ascertained using length of primary feathers, molt progression (Beck et al. 1975), and DNA analysis. Individuals were fitted with either suture-on backpack or necklace-style transmitters (American Wildlife Enterprises, Monticello, Fla.). All transmitters weighed 15 g and did not exceed 3% of the individual's body weight (Thirgood et al. 1995). The transmitters were battery powered and equipped with mortality switches set to trip after 12 hours of inactivity. The type of transmitter the individual received (backpack or necklace) was randomly selected. Backpack transmitters were fitted using modifications of Burkepile et al. (2002; see also Caudill 2011). The study protocol was approved by the Utah State University Institutional Animal Use and Care Committee.

Marked individuals were located at least monthly through March 31 of the year following capture. Individuals were located from the ground by radio-telemetry following direction of antenna and signal strength until the individual was observed (Mech 1983) or by circling the location of the strongest signal strength (Springer 1979). Upon locating the individual, the Universal Transverse Mercator coordinates (datum, North American 1983; projection, UTM Zone 12) were documented. If contact with the individual was not made, the UTM coordinates, azimuth (to estimated location) and estimated radius of the circle were recorded. Aerial radio-tracking (Mech 1983) also was used (bimonthly from January to March) to locate individuals. The aircraft was equipped with 2 side-facing, H-type antennas. Mortality signals detected aerially were immediately confirmed from the ground.

Resource availability was calculated using

ArcView 9.2 (Environmental Systems Research Institute Inc., Redlands, Calif.). Southwest Regional Gap Analysis Project (SWReGAP) land cover data (U.S. Geological Survey 2004) and 10-m resolution digital elevation models (obtained from the Natural Resources Conservation Services' geospatial data gateway) were the base data. We reclassified the SWReGAP into sagebrush dominant habitats and other. Sagebrush dominant habitats were assigned a value of 3 and others (non-sagebrush habitats) were assigned a value of 1. The digital elevation model was transformed to percentage slope and aspect. Slope was then reclassified into 3 categories: ≤5% (assigned value of 3), >5 to 15% (assigned value of 2), and >15% (assigned value of 1). Aspect was reclassified such that values ranging from 157.5 to 292.5 (representing south through west) and flat land were assigned a value of 3. All other aspects were assigned a value of 1. The weighted sum overlay tool was used to combine the 3 reclassified layers into a model for winter habitat.

Winter use areas were calculated in ArcView 9.2. Animal Space Use 1.3 (Horne and Garton 2009) was used to calculate the bandwidth for kernel density estimations. When selecting a bandwidth for kernel density estimation both likelihood cross-validation (hereafter CVh) and least-squares, cross-validation (hereafter, LSCVh) performed poorly. The CVh = 1,602 over-smoothed the data, and LSCVh = 447 under-smoothed the data. The 1,000-m bandwidth fit the data well and is roughly the mid-point of the 2 bandwidth calculations. The kernel density tool was used to perform the estimates for winter (January to March) use areas. The winter period was calculated to represent the period of constant snow cover on the study area. November and December were considered transitional time periods from fall to wintering areas. Locations from both years were pooled. The winter period kernel density estimates were reclassified and converted from raster to polygon data to assess composition of slope and winter habitat at higher and lower use areas. Winter kernel densities were categorized using 10 natural break categories, which were grouped to create 6 biologically meaningful groups: 0 to 0.94(3), 0.94 to 2.55(3), 2.55 to 3.39, 3.39 to 4.41, 4.41 to 5.53, and 5.53 to 6.66 locations/km^2 (number in parenthesis indicates the number of natural break categories combined to create group). Winter habitat-use versus availability was compared using a G-test. Habitat use was defined by the density categories from the kernel density estimation, and availability was defined as the percentage occurring within the study area.

To assess potential impacts of differing transmitter attachment methods, home ranges for each individual surviving from August 22 through March 1 were calculated in ArcView 9.2, utilizing the Home Range Extension (Rodgers et al. 2007) to create 100% minimum convex polygons (hereafter, MCP; Mohr 1947).

Results

In 2008 and 2009, we captured and radio marked 30 and 61 juvenile sage-grouse (58 females and 33 males), respectively. We recorded 352 locations over the 2 years of our study. Eighty-four locations (representing 34 individuals [27 females and 7 males]) were collected during January to March of both years, primarily by aircraft, for winter habitat use. Permanent snow coverage began in mid-December both years. Of all known locations, 94% were on lands managed by SITLA, and 6% were on lands managed by the BLM. Although the backpack transmitter type was shown to negatively affect survival (Caudill 2011), transmitter type did not affect home range size (backpack average = 5,007 ha [n = 7], necklace average = 4,443 ha [n = 28]). As such, both backpack and necklace transmitters were used to assess resource use and home ranges. Additionally, no mortalities, from either transmitter type, were recorded from December 1, 2009, to March 31, 2010 (n = 27) or January 4, 2009, to March 31, 2009 (n = 7), which constituted the focal period for winter habitat use (January to March).

Resource availability was calculated using previously described sage-grouse winter habitat (Eng and Schladweiler 1972, Beck 1977, Hupp and Braun 1989). Only 8% of the study area was composed of sagebrush habitat, ≤5% slope, and oriented south to west (score of 9). An additional 11% of the study area was sagebrush habitat, >5 to 15% slope, and oriented south to west (score of 8). The study area consisted

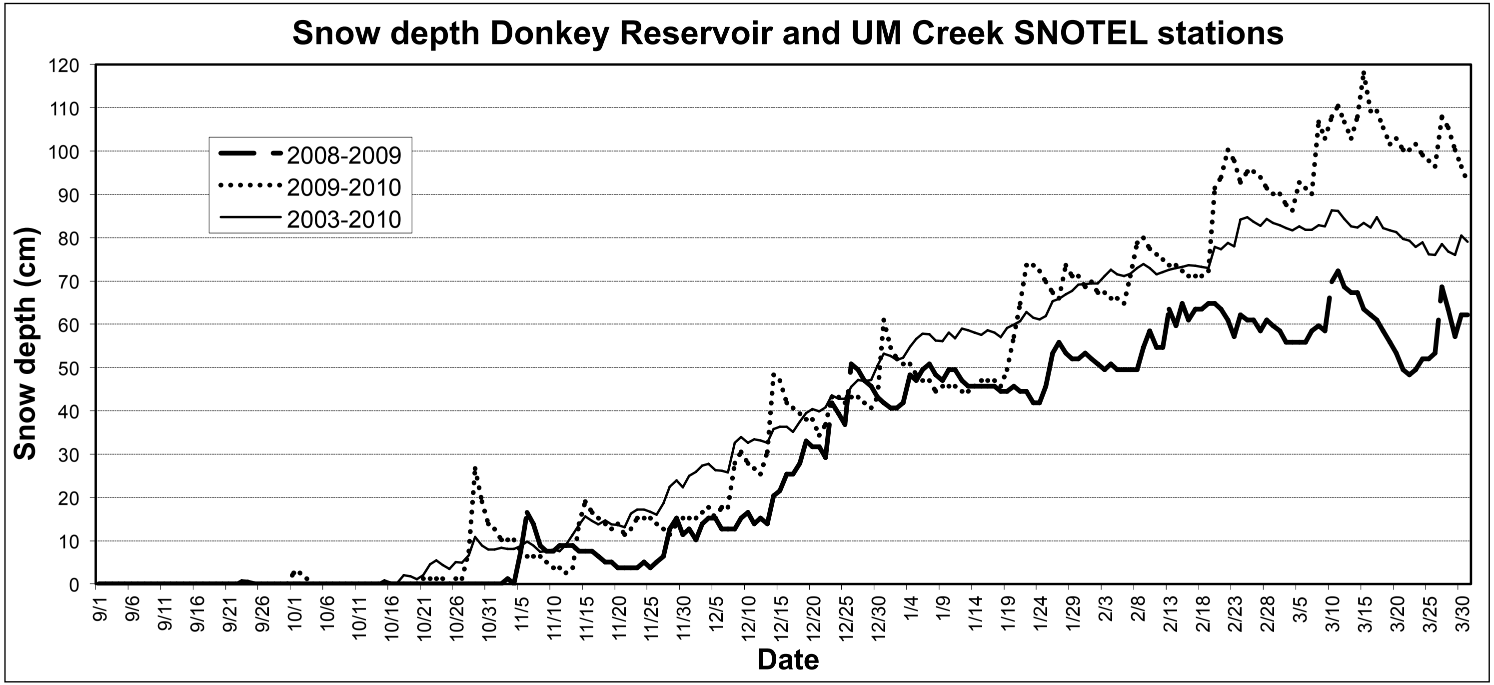

Figure 1. Historic winter snow depth for the Parker Mountain region, Utah, USA. SNOTEL = SNOw TELemetry, name of automated system used by the Natural Resources Conservation Service to monitor snowpack data.

Table 1. Winter habitat model categories used to assess availability vs. use by greater sage-grouse (*Centrocercus urophasianus*) on Parker Mountain, Utah, USA, 2008 to 2010.

	Use (locations per km^2)																	
	0–.94			.94–2.55			2.55–3.39			3.39–4.41			4.41–5.53			5.53–6.66		
Habitat parameters	Observed	Expected	G-Test	Observed	Expected	G-Test	Observed	Expected	G-Test	Observed	Expected	G-Test	Observed	Expected	G-Test	Observed	Expected	G-Test
Other	81.5	81.4	0.12	79.2	81.4	-2.19	72.0	81.4	-8.80	55.6	81.4	-21.18	67.2	81.4	-12.87	57.3	81.4	-20.12
Sagebrush habitat, 5–15% slope, south-to-west aspect	10.6	10.7	-0.08	11.8	10.7	1.17	17.9	10.7	9.26	30.5	10.7	31.98	16.6	10.7	7.35	27.1	10.7	25.13
Sagebrush habitat, 0–5% slope, south-to-west aspect	7.9	7.9	-0.04	9.0	7.9	1.18	10.0	7.9	2.39	13.9	7.9	7.80	16.2	7.9	11.56	15.7	7.9	10.68
Total			0.00			0.16			2.85			18.60			6.04			15.69
G			0.00			0.32			5.70			37.20			12.07			31.38
df			2			2			2			2			2			2
P			N/A			0.85			0.06			8.3E-09			2.4E-03			1.5E-07

Table 2. Sagebrush slope availability versus winter use by greater sage-grouse (*Centrocercus urophasianus*) on Parker Mountain, Utah, USA, 2008 to 2010.

	Use (locations per km²)																	
	0–.94			.94–2.55			2.55–3.39			3.39–4.41			4.41–5.53			5.53–6.66		
Slope	Observed	Expected	G-Test	Observed	Expected	G-Test	Observed	Expected	G-Test	Observed	Expected	G-Test	Observed	Expected	G-Test	Observed	Expected	G-Test
>15% sagebrush	12.4	12.3	0.15	7.5	12.3	-3.70	5.6	12.3	-4.38	6.1	12.3	-4.24	5.1	12.3	-4.47	4.8	12.3	-4.50
>5–15% sage-brush	42.6	42.8	-0.15	46.0	42.8	3.35	54.0	42.8	12.64	50.7	42.8	8.63	31.9	42.8	-9.38	42.4	42.8	-0.33
0–5% sagebrush	38.0	38.2	-0.23	45.2	38.2	7.58	39.6	38.2	1.40	43.2	38.2	5.28	63.1	38.2	31.62	52.8	38.2	17.10
Non-sagebrush slope	7.0	6.8	0.24	1.4	6.8	-2.19	0.8	6.8	-1.69	0.0	6.8	-3E–11	0.0	6.8	-3E–11	0.0	6.8	-3E–11
Total			0.01			5.03			7.97			9.67			17.77			12.27
G			0.01			10.07			15.94			19.33			35.54			24.54
df			3			3			3			3			3			3
P			N/A			0.02			1.2E-03			2.3E-04			9.4E-08			1.9E-05

of 38%, 43%, and 12% for sagebrush slopes (irrespective of orientation) ≤5%, 5 to 15%, and >15%, respectively.

Sagebrush habitats with 0 to 5% slope or >5 to 15% slopes and south-to-west aspects were used more than available at kernel density estimates above 3.39 locations/km² (Table 1). Sagebrush slopes >15% were used disproportionately less than available at kernel density estimates >2.55 locations/km² (Table 2). Sagebrush slopes 0 to 5% were used disproportionately more than available at kernel density estimates >4.4 locations/km² (Table 2).

Discussion

Doherty et al. (2008) reported that slope was an important topographic predictor of sage-grouse winter habitat use, with winter sage-grouse typically using slopes ≤5% (Eng and Schladweiler 1972, Beck 1977) on south to west facing aspects (Beck 1977). Hupp and Braun (1989) reported that Gunnison sage-grouse used drainages and slopes with south or west aspects during winter. Sage-grouse on Parker Mountain used sagebrush slopes ≤5% regardless of aspect and avoided sagebrush slopes >15% during the winter. Both ≤5% and >5-15% sagebrush slopes oriented south to west were used more than available. Juvenile sage-grouse on Parker Mountain used winter habitats similar to those described by Beck (1977) and Eng and Schladweiler (1972), as well as the Gunnison sage-grouse winter habitats described by Hupp and Braun (1989). However, juvenile sage-grouse on Parker Mountain also used steeper slopes (5 to 15%) which contradicts the findings of Eng and Schladweiler (1972) and Beck (1977). The use of moderately steep sagebrush slopes (5 to 15%) could be an artifact of the population's location at the southern extent of the species' range. Suitable sage-grouse sagebrush habitats at the southern extent of the species range (e.g., Parker Mountain) generally occur at high elevations with considerable topographic relief. Topography likely influences snowfall, accumulation, and drifting. These parameters control sagebrush availability and likely lead to our observed use of slopes by sage-grouse.

Beck (1977) found that nearly 80% of use occurred on areas comprising <7% of the total area. Similar to findings by Beck (1977), Parker Mountain winter-use areas, kernel density estimates of >0.94 locations/km² accounted for only 3% (2,910 ha) of the available habitat. Carpenter et al. (2010) reported that 72% of model validation locations occurred in the highest quality wintering areas, which accounted for only 13% of the study area. Highly disproportionate use of specific rare habitats led Doherty et al. (2008) to conclude that impacts to wintering habitats could have substantial negative effects on sage-grouse populations. Braun et al. (1977) recommended that no manipulation of sagebrush take place in any important winter areas known (within 10 years) to support sage-grouse.

Most of the winter locations obtained were on lands managed by SITLA. The SITLA lands are located at higher elevations in the study area, while those managed by the BLM are lower in elevation. This may be particularly important during above normal snowfall years. Over both years of our study, 21% of winter locations occurred on BLM lands. In 2009, January to March had below average snowfall, and only 3% of winter locations were recorded on BLM land. In January to March 2010, with above average snowfall, 32% of locations were recorded on BLM land (Figure 1).

More research is needed to examine the specific sagebrush species used by sage-grouse during winter. Although sagebrush is crucial to sage-grouse winter diet, selection of sites also could be tied to avoidance of predation or to thermoregulation. The SWReGAP could not accurately differentiate between mountain big and black sagebrush species on Parker Mountain. Consequently, this study was unable to evaluate parameters surrounding each species of sagebrush. The addition of habitat-specific parameters in future models could increase their utility. Sagebrush cover has been identified as an important parameter for winter habitat (Eng and Schlaweiler 1972, Doherty et al. 2008) and could be a useful parameter in future models.

Management implications

Sagebrush habitat should be protected at lower elevation sites with slopes ≤5% regardless of aspect and slopes >5 to 15% that were south-to-west in aspect. Identification and protection of wintering areas are critical. Although large expanses of habitat may be available, sage-grouse have been shown to use a small subset of available habitat. Additionally, there could be some degree of site fidelity to wintering areas (Eng and Schladweiler 1972, Berry and Eng 1985, Connelly et al. 1988). Some wintering areas may not be utilized in typical years but may become critical in severe winters. In this study, use of low-elevation lands managed by the BLM went from 3% in a low snowfall year to 32.1% in a high snowfall year. These lower elevation sites may be critical refuges in severe winters and should be managed accordingly to ensure their availability. Sage-grouse winter survival is high (see Connelly et al. 2004) and individuals typically gain weight over winter (Beck and Braun 1978). Consequently, reduced winter survival or pre-breeding body condition due to loss or degradation of wintering habitats would be expected to have large impacts on populations. Land management treatments typically are conducted at lower elevations to open, dense stands of sagebrush cover to increase big game winter or livestock early-season forage. These treatments, however, could adversely impact sage-grouse (Connelly et al. 2004). Prior to initiating land management treatments in lower elevation sagebrush areas in occupied sage-grouse habitats, managers should consider seasonal population movements relative to annual weather variation.

Acknowledgments

J. W. Connelly provided his valuable expertise into the dynamics of sage-grouse. R. W. Dimmick provided valuable project guidance. Additionally, G. Caudill, J. Tarwater, and A. Wiley all provided critical help in the field. A. Taft and J. Lamb provided their extensive knowledge of the local areas. E. Leone and R. S. Butryn provided valuable expertise and commentary. Two anonymous reviewers provided constructive comments that improved the manuscript. Funding for this study was provided by Utah State University Quinney Fellowship, College of Natural Resources, Jessie and S. J. Quinney Foundations, Quinney Professorship for Wildlife Conflict Management, Jack H. Berryman Institute for Wildlife Damage, Utah Division of Wildlife Resources and Utah State University Extension.

Literature cited

Beck, T. D. 1977. Sage-grouse flock characteristics and habitat selection in winter. Journal of Wildlife Management 41:18–26.

Beck, T. D., and C. E. Braun. 1978. Weights of Colorado sage-grouse. Condor 80:241–243.

Beck, T. D., R. B. Gill, and C. E. Braun. 1975. Sex and age determination of sage-grouse from wing characteristics. Colorado Division of Game, Fish and Parks, Outdoor Facts, Game Information Leaflet 49, Denver, Colorado, USA.

Berry, J. D., and R. L. Eng. 1985. Interseasonal movements and fidelity to seasonal use areas by female sage grouse. Journal of Wildlife Management 49:237–240.

Braun, C. E., T. Britt, and R. O. Wallestad. 1977. Maintenance of sage grouse habitats. Wildlife Society Bulletin 5:99–106.

Burke, I. C., W. A. Reiners, and R. K. Olson. 1989. Topographic control of vegetation in a mountain big sagebrush steppe. Vegetatio 84:77–86.

Burkepile, N. A., J. W. Connelly, D. W. Stanley, and K. P. Reese. 2002. Attachment of radiotransmitters to one-day-old sage-grouse chicks. Wildlife Society Bulletin 30:93–96.

Carpenter, J., C. Aldridge, and M. S. Boyce. 2010. Sage-grouse habitat selection during winter in Alberta. Journal of Wildlife Management 74:1806–1814.

Caudill, D. 2011. Factors affecting greater sage-grouse (*Centrocercus urophasianus*) survival and movement in south-central Utah. Thesis, Utah State University, Logan, Utah, USA.

Connelly, J. W., H. W. Browers, and R. J. Gates. 1988. Seasonal movements of sage-grouse in southeastern Idaho. Journal of Wildlife Management 52:116–122.

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, USA.

Connelly, J. W., K. P. Reese, and M.A. Schroeder. 2003. Monitoring of greater sage-grouse habitats and populations. Idaho Forest, Wildlife and Range Experiment Station Bulletin 80, College of Natural Resources, University of Idaho, Moscow, Idaho, USA.

Dalke, P. D., D. B. Pyrah, D. C. Stanton, J. E. Crawford, and E. F. Schlatterer. 1963. Ecology, productivity, and management of sage-grouse in Idaho. Journal of Wildlife Management 27:811–841.

Doherty, K. E., D. E. Naugle, B. L. Walker, and J. M. Graham. 2008. Greater sage-grouse winter habitat selection and energy development. Journal of Wildlife Management 72:187–195.

Eng, R. L., and P. Schladweiler. 1972. Sage-grouse winter movements and habitat use in central Montana. Journal of Wildlife Management 36:141–146.

Giesen, K. M., T. J. Schoenberg, and C. E. Braun. 1982. Methods for trapping sage grouse in Colorado. Wildlife Society Bulletin 10:224–231.

Horne, J. S., and Edward O. G. 2009. Animal Space Use 1.3 <http://www.cnr.uidaho.edu/population_ecology/animal_space_use>. Accessed August 27, 2013.

Hupp, J. W., and C. E. Braun. 1989. Topographic distribution of sage-grouse foraging in winter. Journal of Wildlife Management 53:823–829.

Jaynes, R. A. 1982. Inventory and analysis of rangeland resources of the state land block on Parker Mountain, Utah. Center for Remote Sensing and Cartography, Report 82-6, Salt Lake City, Utah, USA.

Mech, L. D. 1983. Handbook of animal radio-tracking. University of Minnesota Press, Minneapolis, Minnesota, USA.

Mohr, C. O. 1947. Table of equivalent populations of North American small mammals. American Midland Naturalist 37:223–249.

Parker Mountain Adaptive Resource Management Local Working Group. 2006. Parker Mountain Greater Sage-grouse (*Centrocercus urophasianus*) Local Conservation Plan. Utah State University Extension, Jack H. Berryman Institute, and Utah Division of Wildlife Resources, Salt Lake City, Utah, USA.

Patterson, R. L. 1952. The sage-grouse in Wyoming. Sage Books, Denver, Colorado, USA.

Schroeder, M. A., C. L. Aldridge, A. D. Apa, J. R. Bohne, C. E. Braun, S. D. Bunnell, J. W. Connelly, P. A. Deibert, S. C. Gardner, M. A. Hillard, G. D. Kobriger, S. M. McAdam, C. W. McCarthy, J. J. McCarthy, D. L. Mitchell, E. V. Rickerson, and S. J. Stiver. 2004. Distribution of sage-grouse in North America. Condor 106:363–376.

Springer, J. T. 1979. Some sources of bias and sampling error in radio triangulation. Journal of Wildlife Management 43:926–935.

Thirgood, S. J., S. M. Redpath, P. J. Hudson, M. M. Hurley, and N. J. Aebischer. 1995. Effects of necklace radio transmitters on survival and breeding success of red grouse *Lagopus lagopus scoticus*. Wildlife Biology 1:121–126.

U.S. Geological Survey. 2004. Provisional digital land cover map for the southwestern United States. Version 1.0. U.S. Geological Survey, National Gap Analysis Program, Reston, Virginia, USA.

Wakkinen, W. L., K. P. Reese, J. W. Connelly, and R. A. Fischer. 1992. An improved spotlighting technique for capturing sage grouse. Wildlife Society Bulletin 20:425–426.

Wallestad, R. O. 1975. Life history and habitat requirements of sage-grouse in central Montana. Montana Department of Fish and Game Bulletin, Helena, Montana, USA.

Danny Caudill is the Upland Gamebird Research Biologist for the Florida Fish and Wildlife Conservation Commission at the Fish and Wildlife Research Institute in Gainesville, FL. He received a B.S. degree in Wildlife and Fisheries Sciences from the University of Tennessee and a M.S. degree in Wildlife Biology from Utah State University.

Terry A. Messmer is a professor and extension wildlife specialist in the Department of Wildland Resources, Utah State University (USU), where he is the director of the Jack H. Berryman Institute. He holds the Quinney Professorship of Wildlife Conflict Management in USU's Quiney College of Natural Resources, and he is the director of USU's Utah Community-Based Conservation Program (CBCP). He received a B.S. degree in fisheries and wildlife management and in biology from the University of North Dakota–Grand Forks, an M.S. degree in regional and community planning and a Ph.D. degree in animal and range science from North Dakota State University–Fargo. His research, teaching, and extension activities include identification, implementation, and evaluation of conservation strategies, technologies, and partnerships that can benefit agriculture, wildlife, and resource stakeholders. As CBCP director, he, his staff, and graduate students work closely with Utah's sage-grouse local working groups to identify, implement, and evaluate the effects of management actions on sage-grouse conservation. He has served as the major professor for over 25 graduate students (five Ph.D. and twenty M.S.) studying sage-grouse ecology in Utah. He is the past editor-in-chief of The Wildlife Society Bulletin, and is currently an associate editor for both the Journal of Wildlife Management and the Wildlife Society Bulletin.

Brent Bibles is an associate professor of wildlife biology at Unity College. He received a B.S. degree in fisheries and wildlife from Utah State University and M.S. and Ph.D. degrees in wildlife and fisheries sciences from the University of Arizona.

Michael R. Guttery is a post doctoral research assistant in the Department of Forest and Wildlife Ecology at the University of Wisconsin–Madison. He received a B.S. degree from the University of Tennessee–Martin, an M.S. degree from Mississippi State University, and a Ph.D. degree from Utah State University.