Western North American Naturalist 82(2), © 2022, pp. 409–416

Predicting Columbian Sharp-tailed Grouse lek occurrence in Grand Teton National Park, Wyoming

Jonathan D. Lautenbach[1,*], John A. Stephenson[2], and Jeffrey L. Beck[1]

[1]*University of Wyoming, Department of Ecosystem Science and Management, Laramie, WY 82701*
[2]*Grand Teton National Park, Moose, WY 83012*

Abstract.—Many North American populations of lekking grouse have declined across their ranges, and understanding and evaluating population trajectories can assist in better managing these iconic species. Columbian Sharp-tailed Grouse (*Tympanuchus phasianellus columbianus*) is a subspecies of Sharp-tailed Grouse that has declined across its range in the Intermountain West over the past century. Management of this species primarily focuses on habitat around leks; therefore, knowing where Columbian Sharp-tailed Grouse leks occur is key to their conservation. We used a resource selection framework to predict lek occurrence in an area with multiple known leks in Carbon County, Wyoming. We used this model to predict lek occurrence in an area with only one known lek in Grand Teton National Park. Our model predicting lek locations in Carbon County was a strong predictor of lek occurrence in that area (r_s = 0.97), and when this model was projected onto Grand Teton National Park, the one known lek in the park was located in an area of very high probability for lek occurrence (>90% probability of lek occurrence). We also used this predictive surface to locate 1 unknown lek and 7 other locations in Grand Teton National Park used by Columbian Sharp-tailed Grouse as detected by fecal droppings, feathers, or birds flushed. Our methods demonstrated that a resource selection framework from one area can be used to predict lek and other occurrences in another area when these areas have similar vegetation compositions.

Resumen.—Muchas poblaciones norteamericanas de urogallos han disminuido en toda su área de distribución, la comprensión y evaluación de sus trayectorias poblacionales puede ayudar a gestionar mejor estas especies emblemáticas. El urogallo de cola afilada de Columbia (*Tympanuchus phasianellus columbianus*) es una subespecie de urogallo de cola afilada que ha disminuido en toda su área de distribución en el oeste intermontano durante el último siglo. La conservación de esta especie se centra principalmente en el hábitat alrededor de los leks. Por lo tanto, conocer la localización de los leks del urogallo de cola afilada de columbia es clave para su conservación. Utilizamos un marco de selección de recursos para predecir la presencia de leks en un área con múltiples leks conocidos en el condado de Carbon, Wyoming. Usamos este modelo para predecir la presencia de leks en un área con únicamente un lek conocido en el Parque Nacional Grand Teton. Nuestro modelo de predicción de la ubicación de lo leks en el condado de Carbon fue un fuerte predictor de la ocurrencia de leks en esa zona (r_s = 0.97) y cuando este modelo se proyectó en el Parque Nacional Grand Teton, el único lek conocido en el Parque estaba situado en una zona de muy alta probabilidad de ocurrencia de leks (>90% de probabilidad de ocurrencia de leks). De igual forma, utilizamos esta superficie de predicción para localizar un lek desconocido y otras siete zonas utilizadas por el urogallo de cola afilada de Columbia, en el Parque Nacional Grand Teton. Dichas zonas también fueron detectadas mediante la presencia de excrementos fecales, plumas o aves. Nuestros métodos demostraron que un marco de selección de recursos de un área puede utilizarse para predecir la presencia de leks y otros lugares en un área distinta, cuando estas áreas tienen composiciones de vegetación similares.

Understanding characteristics about species population dynamics is key to implementing management practices to conserve species (Williams et al. 2002, Nichols and Williams 2006, Marsh and Trenham 2008). This information is useful in determining where to implement management practices and the effects of prior management applications (Holling 1978, Williams et al. 2002). Population monitoring is conducted in multiple ways, from population counts via different methods to broad surveys (e.g., breeding bird surveys). For many lekking species, such as prairie grouse (*Tympanuchus* spp.), population monitoring is primarily accomplished through spring lek counts (Connelly et al. 2003, Hagen et al. 2004, Van Pelt et al. 2013, Hoffman et al. 2015). Leks are areas where males gather at communal display

*Corresponding author: jlauten1@uwyo.edu

JDL orcid.org/0000-0002-6466-5111 JAS orcid.org/0000-0002-7023-2195 JLB orcid.org/0000-0003-0236-7343

arenas to attract females. Human observers visit known lek locations, typically on multiple days throughout the lekking season, to count numbers of attending males; the maximum count of males is the sample statistic used to compute an average lek attendance index for population trend monitoring (Beck and Braun 1980, Connelly et al. 2003). For management decisions, lek locations are used to evaluate effects from management actions, especially in relation to surface disturbances such as oil and gas development and prescribed fire (Van Pelt et al. 2013, Hoffman et al. 2015). Therefore, without understanding where leks are, managers cannot accurately monitor population trends, nor can they properly manage for prairie grouse.

Populations of Columbian Sharp-tailed Grouse (*T. phasianellus columbianus*; hereafter CSTG) have declined to about 10% of their historical distribution (Hoffman et al. 2015). The current distribution of CSTG occurs in suitable grassland and shrubland habitats of the Intermountain West including portions of British Columbia, Colorado, Idaho, Nevada, Utah, Washington, and Wyoming (Connelly et al. 2020, Mathews et al. 2021). Range-wide declines have led to CSTG being petitioned twice for listing under the U.S. Endangered Species Act (USDI 2000, 2006), and CSTG is currently listed as a species of greatest conservation need by the Wyoming Game and Fish Department (Wyoming State Wildlife Action Plan 2017).

Species distribution models use abundance or occurrence data to predict where a species and its habitat potentially occur (Guisan and Zimmerman 2000, Guisan and Thuiller 2005, Elith and Leathwick 2009). In particular, resource selection functions (RSFs) have been used to predict habitat for individual species within specific areas and outside these areas (Mladenoff and Sickley 1998, Boyce and McDonald 1999). These models compare known locations to unused or random locations on the landscape to predict habitat selection (Manly et al. 2002). Resource selection functions have been used to predict prairie grouse habitat and lek locations (Niemuth and Boyce 2004, Gregory et al. 2011, Hamilton and Manzer 2011, Smith et al. 2016, Plumb et al. 2019).

The primary goal of our research was to evaluate the landscape within Grand Teton National Park for potential CSTG lekking sites. Columbian Sharp-tailed Grouse were thought to be extirpated from Grand Teton National Park during the 1940s; however, during spring 2010, a single lek was located with 1–10 individuals attending each spring since it was discovered (J. Stephenson NPS unpublished data). Understanding whether there are additional leks within the Grand Teton National Park landscape will provide a better understanding of distribution, size, and growth for this population. Our research objectives were to (1) develop an RSF to identify habitat features influencing CSTG lek locations in Carbon County, Wyoming, and project this model onto a similar landscape in Grand Teton National Park, Wyoming, (2) identify areas within Grand Teton National Park that offer a high probability of CSTG lek occurrence, and (3) conduct a field survey to locate previously unidentified CSTG leks and areas of CSTG activity during the breeding season within Grand Teton National Park. For our first objective, we modeled the probability of lek occurrence in a landscape with multiple known leks and then projected that model onto the Grand Teton National Park landscape and used the one known lek to verify that this model showed potential to identify new leks. For our second objective, we used this model to identify areas with high potential for lek occurrence. For our final objective, we visited areas with high potential for leks and walked transects to identify new lek locations and areas of CSTG activity during the breeding season.

To better understand potential CSTG lek site distribution within Grand Teton National Park, we developed an RSF from used and available lek locations from a site with similar vegetation conditions in southwestern Carbon County, Wyoming (Fig. 1; Manly et al. 2002). Topography in southwestern Carbon County ranged from relatively flat at lower elevations to undulating hills at higher elevations, with an average elevation of 2293 m above sea level (range 1904 to 3124 m asl). Vegetation at this site was a mixture of sagebrush (*Artemisia* spp.) steppe (51.8%), mixed shrub (15.0%), grasslands (4.0%), conifer forests (7.0%), aspen (*Populus tremuloides*; 9.4%) forest, mixed conifer and aspen forest (9.0%), and other land cover types (e.g., water, roads, rocks, and developed areas; 3.8%). Topography in Grand Teton National Park ranged from low-elevation flats to undulating hills at mid-elevations,

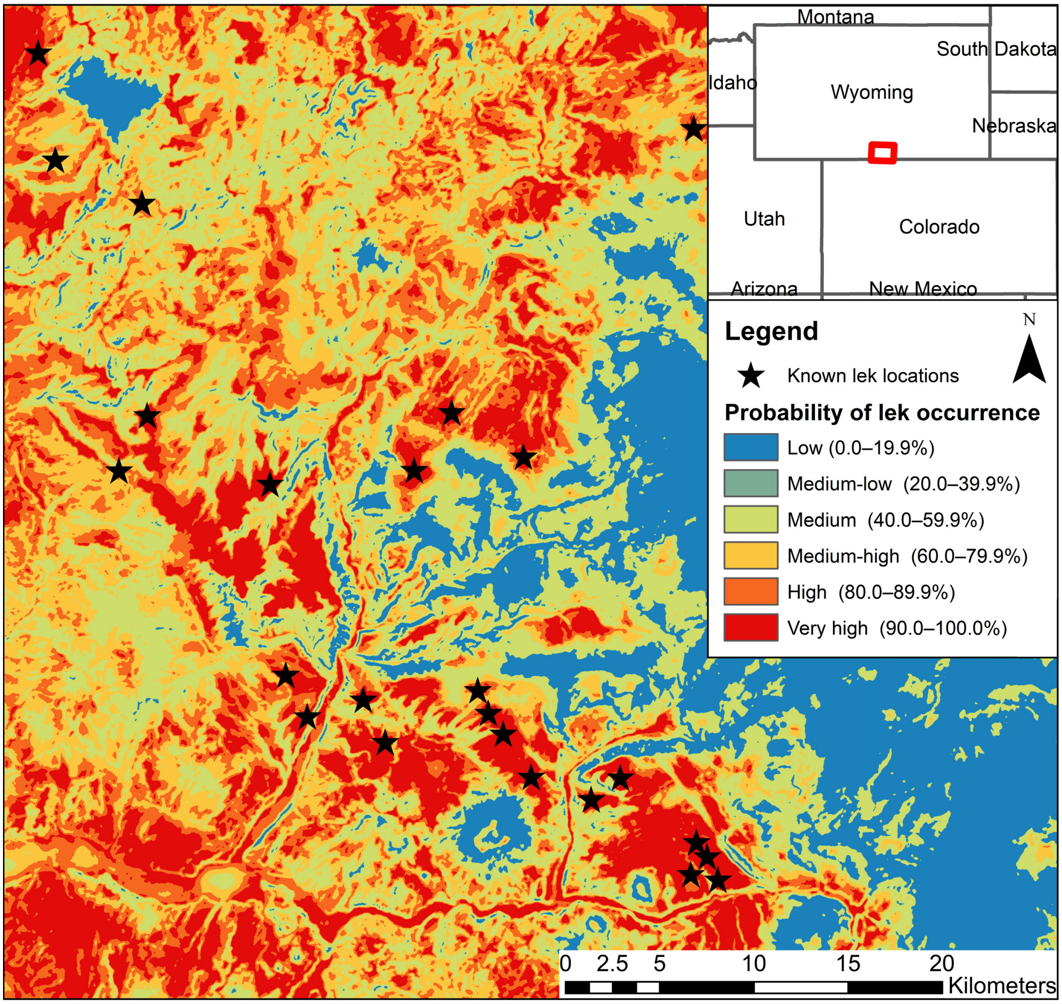

Fig. 1. Relative probability of Columbian Sharp-tailed Grouse lek occurrence within Carbon County, Wyoming, 2019. Stars represent known lek locations.

and steep mountains at higher elevations with a mean elevation of 2345 m above sea level (range 1927 to 4196 m asl). Vegetation within Grand Teton National Park consisted of sagebrush steppe (18.2%), mixed shrub (2.2%), grasslands (7.9%), conifer forests (23.5%), aspen forest (5.7%), mixed deciduous and conifer forests (10.7%), and other land cover types (e.g., water, rocks, developed areas; 31.8%).

To develop our RSF, we followed a procedure similar to Smith et al. (2016) and established baseline lek-site selection within southwestern Carbon County, Wyoming. In a geographical information system, we extracted vegetation and topographic features known and suspected to influence CSTG lek occurrence (Table 1; Klott and Lindzey 1989, Smith et al. 2016) at 24 known, active lek locations and 960 random points. We randomly generated 40 times the number of known active lek locations within the 99.9% fixed kernel of known lek locations to characterize the available landscape (Northrup et al. 2013). We obtained vegetation layers from the USDA Forest Service LANDFIRE Existing Vegetation Type (30-m resolution; USDA and USDI 2013) and topographic data from a 30-m digital elevation map (DEM; USGS 2011). From these data layers, we calculated 5 topographic variables from the DEM and 8 vegetation

TABLE 1. Variables used to develop a resource selection function to predict Columbian Sharp-tailed Grouse lek locations within Carbon County, Wyoming, and Grand Teton National Park, Teton County, Wyoming.

Variable	Description
Topographic	
TPI[a]	Mean topographic position index derived from 30-m digital elevation map (De Reu et al. 2013)
TRI[a]	Mean topographic ruggedness index derived from 30-m digital elevation map (Riley et al. 1999)
Slope[a]	Mean percent slope derived from 30-m digital elevation map (USGS 2011)
Aspect[a]	Mean aspect derived from 30-m digital elevation map (USGS 2011)
HLI[a]	Mean heat load index derived from 30-m digital elevation map (McCune and Keon 2002, McCune 2007)
Vegetation	
Aspen[b]	Total cover or distance to aspen (*Populus tremuloides*; USDA and USDI 2013)
Conifer[b]	Total cover or distance to any coniferous forest (USDA and USDI 2013)
Sagebrush[b]	Total cover or distance to any species of sagebrush (*Artemisia* sp.; USDA and USDI 2013)
Grasslands[b]	Total cover or distance to grasslands (USDA and USDI 2013)
Mixed forest[b]	Total cover or distance to mixed deciduous and coniferous forests (USDA and USDI 2013)
Mixed shrub[b]	Total cover or distance to mixed shrublands (USDA and USDI 2013)
Pinyon-juniper woodland[b]	Total cover or distance to pinyon-juniper (*Pinus* spp.–*Juniperus* spp.) woodlands (USDA and USDI 2013)
Forest (any type)[b]	Total cover or distance to any forest type (USDA and USDI 2013)
Anthropogenic	
Distance to roads[a]	Mean distance to linear roads including improved and unimproved roads (USDA and USDI 2013)
Development[b]	Total anthropogenic development (USDA and USDI 2013)

[a]Evaluated at the point scale (30 m) and averaged value within 100, 500, and 2000 m
[b]Evaluated distance to this land cover type at the point scale (30 m) and average distance to within 100, 500, and 2000 m and proportion of area within 100, 500, and 2000 m

variables and anthropogenic variables from LANDFIRE data (Table 1). For variables derived from LANDFIRE data, we reclassified all the classes that contained labels similar to our variable names (e.g., all species of sagebrush were reclassified into our sagebrush layer, all conifer forest types except pinyon-juniper [*Pinus* spp.–*Juniperus* spp.] were reclassified into the conifer class, and so forth). To identify the scale at which CSTG leks occurred, we calculated average vegetation and topographic values within 100, 500, and 2000 m of each pixel using a moving window analysis. We used these distances because features within 100 and 500 m of a lek influence specific lek locations and most breeding activity occurs within 2000 m of leks (Connelly et al. 2020); these distances have been used in previous studies of lek occurrence (e.g., Smith et al. 2016). For vegetation variables we used 2 metrics: (1) average distance to nearest patch of vegetation type of interest at the pixel, 100-m, 500-m, and 2000-m scales and (2) percent cover of vegetation type of interest within 100, 500, and 2000 m of each pixel.

We used the vegetation and topographic variables to identify how CSTG were selecting lek sites relative to these features. We compared linear and quadratic models of each vegetation and topographic variable to identify the relationship (linear or quadratic) and scale of each variable relative to selection. We ranked models with Akaike's information criterion for small samples (AICc) and considered the model with the lowest AICc to be the best model and included this variable in our top model (Burnham and Anderson 2002). If the null model was our top model for any variable, we did not include that variable in our final prediction model. Once we identified the scale and relationship variable, we removed correlated variables ($|r| > 0.6$). We then used noncorrelated variables in a binomial logistic regression to predict lek site selection in Carbon County, Wyoming. We used a 5-fold cross validation to evaluate goodness-of-fit of our top model (Boyce et al. 2002). Once this model was validated, we projected this model onto the Grand Teton National Park landscape. Prediction models for Carbon County, Wyoming, and Grand Teton National Park, Wyoming, were binned into 6 classes: low (0.0% to 19.9%), medium-low (20.0% to 39.9%), medium (40.0% to

TABLE 2. Parameter estimates (with 95% confidence limits) for variables included in our top model predicting Columbian Sharp-tailed Grouse lek occurrence in Carbon County, Wyoming. Vegetation cover data were derived from LANDFIRE (USDA and USDI 2013) with similar areas reclassified (e.g., all sagebrush layers were reclassified into the sagebrush category), and slope was derived from a digital elevation model (USGS 2011).

Parameter	Estimate	95% CI Lower	95% CI Upper
$Aspen_{500}$[a]	−0.193	−1.871	0.853
$Conifer_{100}$[b]	−0.414	−2.065	0.609
Distance to grass[c]	−0.947	−1.974	−0.163
Distance to $sagebrush_{500}$[d]	−1.622	−3.436	−0.402
Mixed $forest_{500}$[e]	−1.198	−3.335	0.242
Mixed $shrub_{2000}$[f]	0.942	0.500	1.421
$Slope_{100}$[g]	−2.681	−4.252	−1.448

[a]$Aspen_{500}$ is average aspen cover within 500 m.
[b]$Conifer_{100}$ is average conifer cover within 100 m.
[c]Distance to grass is the Euclidian distance to the nearest patch of grass.
[d]Distance to $sagebrush_{500}$ is average distance to any species of sagebrush within 500 m.
[e]Mixed $forest_{500}$ is average cover of mixed conifer-deciduous forest within 500 m.
[f]Mixed $shrub_{2000}$ is average cover of mixed shrub within 2000 m.
[g]$Slope_{100}$ is average slope within 100 m.

59.9%), medium-high (60.0% to 79.9%), high (80.0% to 89.9%), and very high (90.0% to 100%) probability of lek occurrence. We conducted all analyses in R statistical software (R Development Core Team 2019).

To apply our model to the Grand Teton National Park landscape to locate new leks, we generated 50 random points within areas of high-to-very-high probability of lek occurrence (>80%) within the park, assuming these areas would be where we would most likely observe CSTG activity. We used each random point as the start- or midpoint of a 1000-m transect, which included points spaced every 250 m where we listened and scanned for possible leks for 3 minutes before walking to the next point. To minimize overlap of transects, we generated points that were ≥1000 m apart and oriented transects north–south. We found that this transect arrangement focused our search area to 500 m where we could most optimally visually or aurally detect CSTG leks (J.D. Lautenbach personal observation). We conducted transect surveys during morning hours (05:30–09:30) from 1 May to 13 May 2021. We only used points along transects as midpoints if there was an obstacle that prevented the continuation of a transect (e.g., a river) or if the transect would have entered an area with low probability of lek occurrence (e.g., a forest). In addition to aural and visual searching for leks along transects, we also noted any sign that CSTG were present, which included CSTG fecal droppings or feathers or flushing a CSTG.

Our top model predicting lek occurrence within Carbon County indicated that CSTG leks were on average closer to areas of grass cover (β = −0.95, 95% CI −1.97 to −0.16) and closer to sagebrush within 500 m (β = −1.62, 95% CI −3.436 to −0.40). Leks were also located in areas with more mixed shrub cover within 2000 m (β = 0.94, 95% CI 0.50 to 1.42) and in areas with lower slopes within 100 m (β = −2.68, 95% CI −4.25 to −1.45; Table 2). The top model also included mean aspen cover within 500 m, mean conifer cover within 100 m, and mean mixed forest cover within 500 m; however, these covariates did not have significant betas, as indicated by 95% confidence intervals overlapping zero (Table 2). We used the top model to generate a predictive surface within Carbon County (Fig. 1). Cross-validation indicated that our top model was a strong, positive predictor for CSTG lek occurrence in Carbon County (r_s = 0.97). We then projected this model onto the landscape within Grand Teton National Park, Wyoming (Fig. 2). The one known lek from the park was located in an area with very high probability of lek occurrence (>90% probability of lek occurrence), indicating that our model was supportive of predicting lek locations within Grand Teton National Park.

During 1 May to 13 May 2021, due to logistical constraints, we visited 29 of the 50 randomly generated points and surveyed 144 points and 29 km along transects connecting points within potential CSTG habitat in Grand Teton National Park. Along these transects, we located 1 previously unidentified CSTG lek, identified 6 areas with CSTG fecal droppings or feathers, and flushed 1 CSTG in an area with no known leks in Grand Teton National Park (Fig. 2). We randomly encountered each of these detections along transects during our surveys. The new CSTG lek that we located was in an area predicted to have a high probability of lek occurrence (88.0% probability of occurrence; Fig. 2). Additionally, fecal droppings, feathers, and flush locations were also found in areas of high-to-very-high probability of lek occurrence (mean probability of lek occurrence = 93.6%, range 87.0% to 97.0%; Fig. 2).

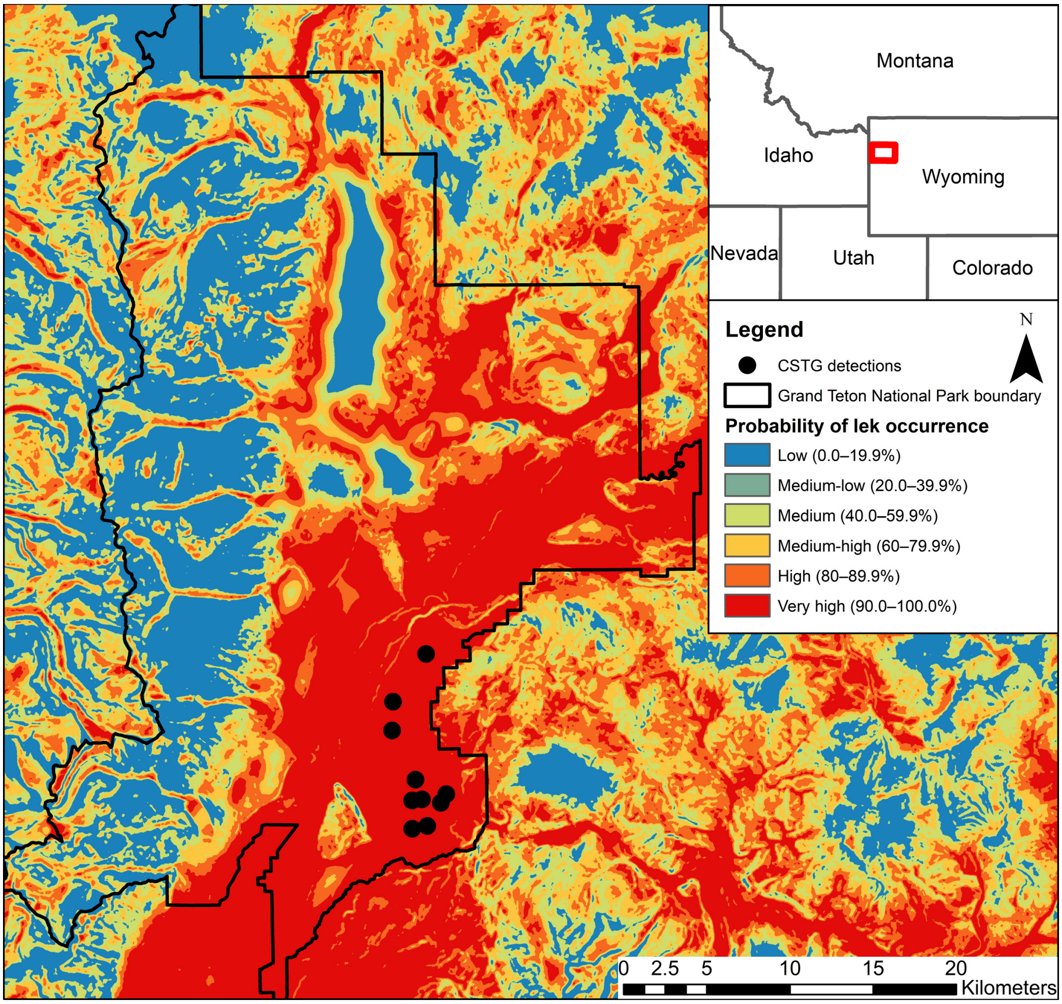

Fig. 2. Relative probability of Columbian Sharp-tailed Grouse (CSTG) lek occurrence within Grand Teton Nation Park, Wyoming. Probability surface based on a resource selection model generated within Carbon County, Wyoming. Filled circles represent detection locations of Columbian Sharp-tailed Grouse (fecal droppings, feathers, or flushed individual grouse), a lek first detected in 2010, and a new lek detected in May 2021.

Understanding where CSTG leks occur is important for determining where to implement management. We developed an RSF in an offsite study area in Carbon County, Wyoming, based on similar vegetation and topographic characteristics found in Grand Teton National Park in Teton County, Wyoming, to project the probability of lek occurrence within this novel area. By applying our model to potential CSTG habitat in Grand Teton National Park, we located one unknown lek and identified other areas of CSTG use. The new lek that we located was 1.6 km from the known lek, which is a distance greater than the 1.0-km cutoff for designating an independent lek (Schroeder et al. 2000). This suggests that there are now 2 active leks in the park. Attendance at the previously known lek has varied from 1 to 10 individuals since its discovery in 2010 (J. Stephenson, NPS unpublished data); identification of the new lek that contained 94% (15 of 16) of the male population in 2021 will aid park staff in monitoring this small CSTG population to enable them to make more informed management decisions in the future.

Though the relative cover percentages of vegetation types in our 2 study areas were similar, lek locations in Grand Teton National Park might not follow the same landscape pattern as CSTG leks in Carbon County, Wyoming. Studies on the transferability of species distribution models to different study systems have found that species distribution models do not always accurately predict species presence in areas outside the original area modeled (Randin et al. 2006, Torres et al. 2015, Huang and Frimpong 2016), but this outcome can depend on species (Randin et al. 2006). Our model predicted CSTG leks in Grand Teton National Park with some accuracy; however, more data would be useful in better evaluating our predictive model. Our model has utility in locating more leks within Grand Teton National Park and surrounding areas outside the park. In turn, if more leks are located, a new model based on the leks within the park could be developed to better predict leks in that area.

Our framework demonstrates that CSTG occupying areas with similar vegetation and topographic characteristics may be used to develop models to predict lek locations in areas with fewer known leks where modeling is not feasible. Species distribution models, such as resource selection functions, have been used to better understand prairie grouse lek occurrence (Niemuth and Boyce 2004, Gregory et al. 2011, Hovick et al. 2015) and to locate new prairie grouse leks (Hamilton and Manzer 2011, Smith et al. 2016); however, these studies located leks within the original area of interest. The method we employed shows great potential in predicting lek occurrence for other lekking grouse species (Greater Sage-Grouse [*Centrocercus urophasianus*], Gunnison Sage-Grouse [*C. minimus*], Greater Prairie-Chicken [*T. cupido*], and Lesser Prairie-Chicken [*T. pallidicinctus*]), all of which have declining populations across their ranges.

ACKNOWLEDGMENTS

We thank the Meg and Bert Raynes Wildlife Fund for providing funding to support our field research. We also thank Sarah Hegg and Lindsey Dreger with the National Park Service for their help conducting fieldwork in Grand Teton National Park. Research in Grand Teton National Park was conducted under permit number GRTE-2021-SCI-0008.

LITERATURE CITED

BECK, T.D.I., AND C.E. BRAUN. 1980. The strutting ground count: variation, traditionalism, management needs. Proceedings of the Western Association of Fish and Wildlife Agencies 60:558–566.

BOYCE, M.S., AND L.L. MCDONALD. 1999. Relating populations to habitats using resource selection functions. Trends in Ecology and Evolution 14:268–272.

BOYCE, M.S., P.R. VERNIER, S.E. NIELSEN, AND F.K.A. SCHMIEGELOW. 2002. Evaluating resource selection functions. Ecological Modeling 157:281–300.

BURNHAM, K.P., AND D.R. ANDERSON. 2002. Model selection and multimodel inference: a practical information-theoretic approach. 2nd edition. Springer-Verlag, New York, NY.

CONNELLY, J.W., M.W. GRATSON, AND K.P. REESE. 2020. Sharp-tailed Grouse (*Tympanuchus phasianellus*), version 1.0. *In*: A.F. Poole and F.B. Gill, editors, Birds of the World. Cornell Lab of Ornithology, Ithaca, NY. https://doi.org/10.2173/bna.354

CONNELLY, J.W., K.P. REESE, AND M.A. SCHROEDER. 2003. Monitoring of Greater Sage-Grouse habitats and populations. Station Bulletin 80, College of Natural Resources Experiment Station, Moscow, ID.

DE REU, J., J. BOURGEOIS, M. BATS, A. ZWERTVAEGHER, V. GELORINI, P. DE SMEDT, W. CHU, M. ANTROP, P. DE MAEYER, P. FINKE, ET AL. 2013. Application of the topographic position index to heterogeneous landscapes. Geomorphology 186:39–49.

ELITH, J., AND J.R. LEATHWICK. 2009. Species distribution models: ecological explanation and prediction across space and time. Annual Review of Ecology, Evolution and Systematics 40:677–697.

GREGORY, A.J., L.B. MCNEW, T.J. PREBYL, S.M. WISELY, AND B.K. SANDERCOCK. 2011. Hierarchical modeling of lek habitats of Greater Prairie-Chickens. Studies in Avian Biology 39:21–32.

GUISAN, A., AND W. THUILLER. 2005. Predicting species distribution: offering more than simple habitat models. Ecology Letters 8:993–1009.

GUISAN, A., AND N.E. ZIMMERMANN. 2000. Predictive habitat distribution models in ecology. Ecological Modelling 135:147–186.

HAGEN, C.A., B.E. JAMISON, K.M. GIESEN, AND T.Z. RILEY. 2004. Guidelines for managing Lesser Prairie-Chicken populations and their habitats. Wildlife Society Bulletin 32:69–82.

HAMILTON, S., AND D. MANZER. 2011. Estimating lek occurrence and density for Sharp-tailed Grouse. Studies in Avian Biology 39:21–32.

HOFFMAN, R.W., K.A. GRIFFIN, J.M. KNETTER, M.A. SCHROEDER, A.D. APA, J.D. ROBINSON, S.P. ESPINOSA, T.J. CHRISTIANSEN, R.D. NORTHRUP, D.A. BUDEAU, AND M.J. CHUTTER. 2015. Guidelines for the management of Columbian Sharp-tailed Grouse populations and their habitats. Sage and Columbian Sharp-tailed Grouse Technical Committee, Western Association of Fish and Wildlife Agencies, Cheyenne, WY.

HOLLING, C.S., EDITOR. 1978. Adaptive environmental assessment and management. John Wiley & Sons, London, England.

HOVICK, T.J., D.K. DAHLGREN, M. PAPE , R.D. ELMORE, AND J.C. PITMAN. 2015. Predicting Greater Prairie-Chicken lek site suitability to inform conservation actions. PLOS ONE 10:e0137021.

HUANG, J., AND E.A. FRIMPONG. 2016. Limited transferability of stream-fish distribution models among river catchments: reasons and implications. Freshwater Biology 61:729–744.

KLOTT, J.H., AND F.G. LINDZEY. 1989. Comparison of sage grouse and Sharp-tailed Grouse leks in south central Wyoming. Great Basin Naturalist 49:275–277.

MANLY, B.F., L.L. MCDONALD, D.L. THOMAS, T.L. MCDONALD, AND W.P. ERICKSON. 2002. Resource selection by animals: statistical design and analysis for field studies. Chapman and Hall, London, United Kingdom.

MARSH, D.M., AND P.C. TRENHAM. 2008. Current trends in plant and animal population monitoring. Conservation Biology 22:647–655.

MATHEWS, S.R., P.S. COATES, B.G. PROCHAZKA, S.P. ESPINOSA, AND D.J. DELEHANTY. 2021. Offspring of translocated individuals drive the successful reintroduction of Columbian Sharp-tailed Grouse in Nevada, USA. Ornithological Applications 123:1–17.

MCCUNE, B. 2007. Improved estimates of incident radiation and heat load using non-parametric regression against topographic variables. Journal of Vegetation Science 18:751–754.

MCCUNE, B., AND D. KEON. 2002. Equations for potential annual direct incident radiation and heat load index. Journal of Vegetation Science 13:603–606.

MLADENOFF, D.J., AND T.A. SICKLEY. 1998. Assessing potential gray wolf restoration in the northeastern United States: a spatial prediction of favorable habitat and potential population levels. Journal of Wildlife Management 62:1–10.

NICHOLS, J.D., AND B.K. WILLIAMS. 2006. Monitoring for conservation. Trends in Ecology and Evolution 21: 668–673.

NIEMUTH, N.D., AND M.S. BOYCE. 2004. Influence of landscape composition on Sharp-tailed Grouse lek location and attendance in Wisconsin pine barrens. Écoscience 11:209–217.

NORTHRUP, J.M., M.B. HOOTEN, C.R. ANDERSON, AND G. WITTEMYER JR. 2013. Practical guidance on characterizing availability in resource selection functions under a use-availability design. Ecology 94:1456–1463.

PLUMB, R.T., J.M. LAUTENBACH, S.G. ROBINSON, D.A. HAUKOS, V.L. WINDER, C.A. HAGEN, D.S. SULLINS, J.C. PITMAN, AND D.K. DAHLGREN. 2019. Lesser Prairie-Chicken space use in relation to anthropogenic structures. Journal of Wildlife Management 83:216–230.

RANDIN, C.F., T. DIRNBÖCK, S. DULLINGER, N.E. ZIMMERMANN, M. ZAPPA, AND A. GUISAN. 2006. Are niche-based species distribution models transferable in space? Journal of Biogeography 33:1689–1703.

R DEVELOPMENT CORE TEAM. 2019. R: environment and language for statistical computing. Version 3.6.1. R Foundation for Statistical Computing, Vienna, Austria.

RILEY, S.J., S.D. DEGLORIA, AND R. ELLIOT. 1999. A terrain ruggedness index that quantifies topographic heterogeneity. Intermountain Journal of Sciences 5: 23–27.

SCHROEDER, M.A., D.W. HAYS, M.A. MURPHY, AND D.J. PIERCE. 2000. Changes in the distribution and abundance of Columbian Sharp-tailed Grouse in Washington. Northwestern Naturalist 81:95–103.

SMITH, K.T., J.L. BECK, T.W. MONG, AND F.C. BLOMQUIST. 2016. Identification of Columbian Sharp-tailed Grouse lek sites in south-central Wyoming. Western North American Naturalist 76:135–141.

TORRES, L.G., P.J.H. SUTTON, D.R. THOMPSON, K. DELORD, H. WEIMERSKIRCH, P.M. SAGAR, E. SOMMER, B.J. DILLEY, P.G. RYAN, AND R.A. PHILLIPS. 2015. Poor transferability of species distribution models for a pelagic predator, the Grey Petrel, indicates contrasting habitat preferences across ocean basins. PLOS ONE 10:e0120014.

[USDA AND USDI] UNITED STATES DEPARTMENT OF AGRICULTURE AND UNITED STATES DEPARTMENT OF THE INTERIOR. 2013. Landfire: landscape fire and resource management planning tool. http://www.landfire.gov

[USDI] UNITED STATES DEPARTMENT OF THE INTERIOR. 2000. Endangered and threatened wildlife and plants; 12-month finding for a petition to list the Columbian Sharp-tailed Grouse as threatened. Federal Register 65:60391–60396.

[USDI] UNITED STATES DEPARTMENT OF THE INTERIOR. 2006. Endangered and threatened wildlife and plants; 90-day finding on a petition to list the Columbian Sharp-tailed Grouse as threatened or endangered. Federal Register 71:67318–67325.

[USGS] UNITED STATES GEOLOGICAL SURVEY. 2011. Seamless Data Warehouse. http://seamless.usgs.gov/

VAN PELT, W.E., S. KYLE, J. PITMAN, D. KLUTE, G. BEAUPREZ, D. SCHOELING, A. JANUS, AND J. HAUFLER. 2013. The Lesser Prairie-Chicken range-wide conservation plan. Western Association of Fish and Wildlife Agencies, Cheyenne, WY.

WILLIAMS, B.K., J.D. NICHOLS, AND M.J. CONROY. 2002. Analysis and management of animal populations. Academic Press, San Diego, CA.

WYOMING STATE WILDLIFE ACTION PLAN. 2017. Wyoming species of greatest conservation need. Wyoming Game and Fish Department, Cheyenne, WY.

Received 19 January 2022
Revised 28 February 2022
Accepted 7 March 2022
Published online 20 June 2022