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Chapter 5: Greater Sage-Grouse: General Use and Roost Site Occurrence with Pellet Counts as a Measure of Relative Abundance

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Abstract. Greater sage-grouse (*Centrocercus urophasianus*) have been declining both spatially and numerically throughout their range because of anthropogenic disturbance and loss and fragmentation of sagebrush (*Artemisia* spp.) habitats. Understanding how sage-grouse respond to these habitat alterations and disturbances, particularly the types of disturbances and extent at which they respond, is critical to designing management actions and prioritizing areas of conservation. To address these needs, we developed statistical models of the relationships between occurrence and abundance of greater sage-grouse and multi-scaled measures of vegetation, abiotic, and disturbance in the Wyoming Basins Ecoregional Assessment (WBEA) area. Sage-grouse occurrence was strongly related to the amount of sagebrush within 1 km for both roost site and general use locations. Roost sites were identified by presence of sage-grouse fecal pellet groups whereas general use locations had single pellets. Proximity to anthropogenic disturbance including energy development, power lines, and major roads was negatively associated with sage-grouse occurrence. Models of sage-grouse occurrence correctly predicted active lek locations with >75% accuracy. Our spatially explicit models identified areas of high occurrence probability in the WBEA area that can be used to delineate areas for conservation and refine existing conservation plans. These models can also facilitate identification of pathways and corridors important for maintenance of sage-grouse population connectivity.

Key words: abundance, anthropogenic disturbance, generalized ordered logistic regression, greater sage-grouse, habitat, occurrence.

Greater sage-grouse (sage-grouse hereafter, *Centrocercus urophasianus*) have undergone long-term declines throughout their range both spatially and numerically (Connelly and Braun 1997, Connelly et al. 2004, Garton et al. 2011). These declines have been attributed to the fragmentation and loss of sagebrush (*Artemisia* spp.) due to single and interacting effects of invasive grasses, fire, and increased human disturbances (Aldridge et al. 2008, Wisdom et al. 2011). As a result, sage-grouse were recently designated as a candidate species under the Endangered Species Act (U.S. Department of the Interior 2010); the biological data supported listing as endangered but immediate action was precluded by higher priorities. As a consequence, it is important to understand the environmental factors related to the distribution and abundance of sage-grouse both for management of current land uses but also for long-term conservation planning.

Sage-grouse have been studied extensively throughout their range (Schroeder et al. 1999, Connelly et al. 2004, Knick and Connelly 2011). Sage-grouse have extensive home ranges (up to 2,975 km^2; Connelly et al. 2000, 2004), and large expanses of sagebrush land cover are required to support viable populations (Patterson 1952, Wakkinen 1990, Connelly et al. 2000, Connelly et al. 2004). Wildfire (Connelly et al. 2000, Beck et al. 2009, Knick and Hanser

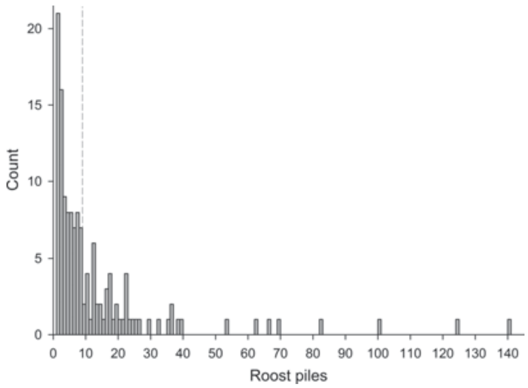

FIG. 5.1. Histogram of 137 survey blocks in the Wyoming Basins Ecoregional Assessment area surveyed for sage-grouse roost piles with >0 roost piles. Abundance at each survey block equates with total number of roost piles. Survey blocks with zero roost piles were classed as absent, survey blocks with 1-8 roost piles as low abundance, and >8 roost piles as high abundance. The dashed vertical line indicates the boundary between the low and high abundance classes.

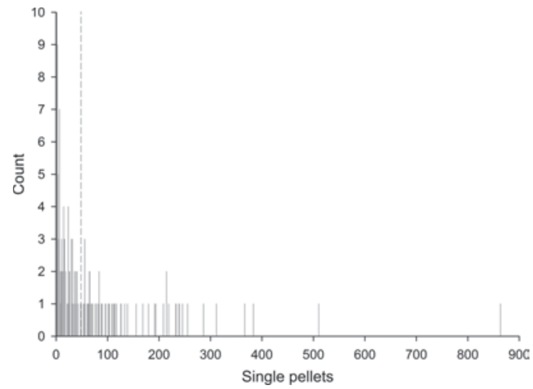

FIG. 5.2. Histogram of 149 survey blocks in the Wyoming Basins Ecoregional Assessment area surveyed for sage-grouse single pellets with >0 pellets. Abundance at each survey block equates with total number of single pellets. Survey blocks with zero pellets were classed as absent, 1-48 pellets as low abundance, and >48 pellets as high abundance. The dashed vertical line indicates the boundary between the low and high abundance classes.

2011), energy resource extraction (Naugle et al. 2011), and other anthropogenic infrastructure (Johnson et al. 2011) influence the distribution, movement patterns, and population trends of sage-grouse. However, habitat requirements and responses to disturbance may vary across spatial scales (Aldridge 2005, Aldridge and Boyce 2007, Walker et al. 2007, Carpenter et al. 2010, Connelly et al. 2011).

Knowledge of the response by sage-grouse populations to the multi-scale habitat and disturbance factors regulating their occurrence and abundance is needed for planning land use and conservation actions that mitigate these declines. Our objective was to develop spatially explicit models of occurrence and abundance for sage-grouse in the Wyoming Basins Ecoregional Assessment (WBEA) area. We conducted surveys throughout the WBEA area (Ch. 4) and used habitat and disturbance variables measured across multiple spatial scales to develop models of species occurrence and abundance. Such models may be particularly useful for assessing effects of proposed or future development across the WBEA on sage-grouse populations and aiding in the development of management practices to avoid or minimize these potential effects.

METHODS

Field Surveys

We conducted field surveys for sage-grouse between 6 July and 2 September, within 7.29-ha survey blocks (270 m x 270 m) sampled in 2005 and 2006 (Ch. 4). We used sage-grouse pellet-count surveys (Boyce 1981, Hanser and Knick 2011, Schroeder and Vander Haegen 2011) on each survey block walking parallel transects spaced 30 m apart (Fig. 4.2). We searched within 2 m of the walking transect to detect sage-grouse pellets. We did not assess detection rates for pellets; detectability along transects typically is high and detection of pellets does not vary dramatically between areas of different vegetation cover (Dahlgren et al. 2006). We counted roost piles (>1 pellet within a 30-cm diameter circle) and single pellets. To determine the average number of pellets per group across the entire study area, we counted total pellets within the first group

TABLE 5.1. Occurrence (abundance) of sage grouse pellets counted as single pellets and roost piles in relation to distance to road during 2005 and 2006 in the Wyoming Basins Ecoregional Assessment area.

Year	Survey block type	Single pellets	Roost piles	Occurrence (%)[a]
2005	On road[b]	32 (993)	28 (230)	54.1
	Near road[c]	22 (1,163)	18 (344)	46.0
	Far road[d]	17 (961)	18 (278)	39.6
	Total	71 (3,117)	64 (852)	47.2
2006	On road	30 (3,135)	28 (312)	55.0
	Near road	21 (2,782)	19 (213)	43.4
	Far road	27 (1,646)	26 (480)	58.8
	Total	78 (7,563)	73 (1,005)	52.4
Total	On road	62 (4,128)	56 (542)	54.5
	Near road	43 (3,945)	37 (557)	44.7
	Far road	44 (2,607)	44 (758)	49.5
	Total	149 (10,680)	137 (1,857)	49.8

[a] Percent occurrence based on number of survey blocks surveyed, by type, within each year. In 2005, 159 survey blocks were surveyed (58 on-road, 49 near-road, and 48 far-road) and in 2006, 164 were surveyed (63 on-road, 54 near-road, and 51 far-road) for a total of 323 survey blocks

[b] On-road survey blocks were centered on the road

[c] Near-road survey blocks were 0-0.75 km from the nearest road

[d] Far-road survey blocks were >0.75-3 km from the nearest road

encountered on each survey block. We used roost piles as an indicator of roost site locations and single pellets as a metric of general use (Dahlgren et al. 2006).

Abundance Categories

We classified abundance levels according to frequency histograms of study blocks versus number of roost piles or single pellets per survey block. Survey blocks with zero detections were categorized as absent. Histograms of survey blocks with roost piles counts > 0 (Fig. 5.1) and single pellet counts > 0 (Fig. 5.2) were used to categorize survey blocks into two abundance classes (low and high) of roost site and general use based on patterns in the frequency distribution.

Model Development

Variables considered in the selection of the sage-grouse models included the standard candidate predictor variables (Ch. 4) with the exclusion of mountain big sagebrush (*A. tridentata* ssp. *vaseyana*), precipitation, and the eight soil variables (pH, soil depth, salinity, clay, sand, silt, bulk density, and available water capacity). These variables were excluded because sage-grouse use a variety of different sagebrush habitats (Connelly et al. 2011) and are not directly influenced by precipitation or soil characteristics. We calculated descriptive statistics for all predictor variables within each abundance class for both roost sites and general use. We also determined the number of survey blocks with predictor variable values > 0 within each abundance class and excluded from model development all variables/extents with <20 survey blocks in a class (Ch. 4).

We used a hierarchical multi-stage modeling approach (Ch. 4) assessing all model subsets using generalized ordered logistic

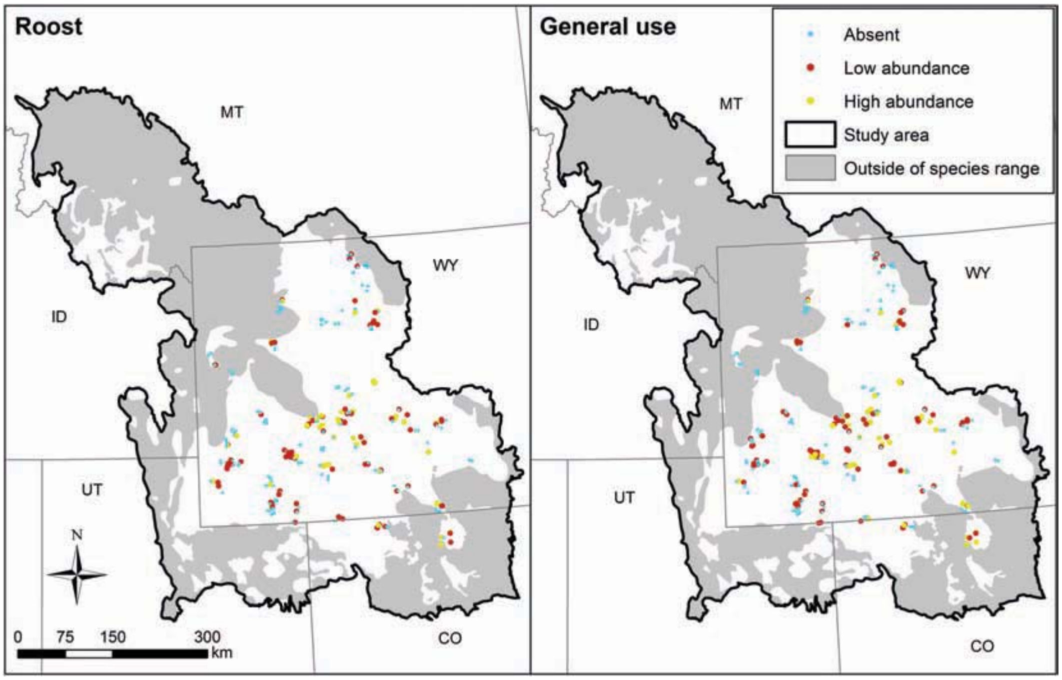

FIG. 5.3. Distribution of survey blocks in the Wyoming Basins Ecoregional Assessment area surveyed for sage-grouse pellets. Survey blocks were surveyed for both roost piles and single pellets. Roost piles were an indicator of roost locations and survey blocks were designated as absent (blue, zero roost piles), low abundance (red, 1-8 roost piles), or high abundance (yellow, >8 roost piles) for development of the roost model. Single pellets were used to develop the general habitat use model and survey blocks were designated as absent (blue, zero single pellets), low abundance (red, 1-48 single pellets), or high abundance (yellow, >48 single pellets). The gray shaded areas are outside the current range of sage-grouse (Schroeder et al. 2004).

regression (GOLOGIT2 within Stata 10.1, Stata Corporation, College Station, TX, USA; Williams 2006). We first examined scatterplots and histograms of sagebrush, NDVI, and abiotic variables to look for non-linearities and interactions. If visual inspection indicated a potential non-linearity or interaction, these functions were tested in subsequent modeling steps. We used Akaike's Information Criterion, corrected for small sample sizes (AIC_c), for model selection (Burnham and Anderson 2002). We first evaluated each sagebrush and NDVI variable and identified circular moving window radii (extent) and combination of sagebrush and NDVI variables that had the strongest relationship to sage-grouse occurrence. We used these selected sagebrush/NDVI variables as a base model and tested the relationship between sage-grouse occurrence/abundance and all spatial extents for each vegetation, abiotic, and disturbance variable to identify the best spatial extent for each variable using AIC_c values. We then allowed the best spatial extent for each variable to compete with all possible combinations of other variables within the same category to identify the AIC_c-best model. We limited the number of variables in all competing models to 10% of the sample size in the lowest frequency class (Hosmer and Lemeshow 2000). After identifying the AIC_c-best model within vegetation, abiotic, and disturbance categories, we allowed variables within these models to compete both within and across submodels to develop the best overall composite model, holding the sagebrush/NDVI base constant. In order to incorporate model uncertainty, we used

TABLE 5.2. Results of AIC_c-based model selection for sage-grouse roost site selection in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale sagebrush and NDVI using generalized ordered logistic regression; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC_c), change in AIC_c value from the top model (ΔAIC_c), and Akaike weight (w_i). Only models with $\Delta AIC_c < 2$ are presented in the table.

Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
1	$ALLSAGE_{1km}$	-294.43	3	594.93	0.00	0.10
2	$ALLSAGE_{1km}$ + $NDVI_{5km}$	-294.35	4	596.83	1.91	0.04
3	$ALLSAGE_{1km}$ + NDVI	-294.37	4	596.87	1.94	0.04
4	$ALLSAGE_{1km}$ + $NDVI_{3km}$	-294.38	4	596.88	1.95	0.04
5	$ALLSAGE_{1km}$ + $NDVI_{1km}$	-294.38	4	596.88	1.95	0.04
6	$ALLSAGE_{1km}$ + $NDVI_{270}$	-294.40	4	596.92	1.99	0.04

[a] Variable definitions provided in Table 4.2.

a weighted average of coefficients from models with a cumulative AIC_c weight of just ≥ 0.9 (Burnham and Anderson 2002) to create a composite model. Coefficients were set to zero when a model did not contain a particular variable. Accuracy of statistical models was evaluated with receiver operating characteristic (ROC) estimating the area under the curve (AUC, Metz 1978). We determined an optimal cutoff threshold for predicting the presence-absence of sage-grouse using a sensitivity-specificity equality approach (Liu et al. 2005) and applied this threshold to assess predictive capability for each model (Nielsen et al. 2004).

Spatial Application and Dose Response

We predicted species occurrence in a Geographic Information System (GIS) at a 90-m cell size using the final model coefficients in ArcGIS raster calculator (ESRI 2006). Final model predictions were binned into 10% probability classes for summary and display. Masks of non-sagebrush habitats (areas with <3% sagebrush habitat in a 5-km moving window) and those areas outside the known range of sage-grouse (Schroeder et al. 2004) were used to identify areas where predictions were either not possible or where it was not reasonable to extrapolate model predictions. Probability of occurrence maps were subsequently combined into a composite three-class abundance surface (absent, low, and high). The bin breakpoint separating absent from low/high abundance habitat was based on the sensitivity-specificity equality threshold to maximize prediction success for each model. Within low/high abundance habitat, the threshold was set at the point where the predicted probability of being high abundance habitat exceeded the probability of being low abundance habitat. This map allowed us to first assess the proportion of the WBEA area likely to contain sage-grouse, and then further delineate the WBEA into areas likely to support low or high abundance of sage-grouse.

Following development of both the roost and general use models, we plotted predicted probability of sage-grouse occurrence relative to changes in sagebrush quantity. This permitted us to assess levels of sagebrush required for sage-grouse presence, as well as to characterize response to losses or fragmentation of sagebrush habitat. We calculated these values using the Dose Response Calculator for ArcGIS tool (Hanser et al. 2011). We used the optimal cut-off threshold from the sensitivity-specificity analysis to identify the sagebrush threshold value above which the species was likely to occur.

TABLE 5.3. Evaluation statistics from AIC_c-based univariate model selection for sage-grouse roost site selection in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale vegetation, abiotic, and disturbance predictor variables (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC_c], change in AIC_c value from the top model [ΔAIC_c], and Akaike weight [w_i]). We ran generalized ordered logistic models with all sagebrush within 1 km as a base model for all variables tested. We used AIC_c to identify the spatial extent at which sage-grouse respond to individual variables.

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	$CFRST_{3km}$	-293.92	4	595.96	0.00	0.38
	$CFRST_{5km}$	-293.94	4	596.00	0.05	0.37
	$CFRST_{18km}$	-294.33	4	596.79	0.83	0.25
	$GRASS_{18km}$	-293.87	4	595.87	0.00	0.46
	$GRASS_{3km}$	-294.42	4	596.96	1.10	0.27
	$GRASS_{5km}$	-294.42	4	596.96	1.10	0.27
	MIX_{3km}	-291.57	4	591.26	0.00	0.73
	MIX_{5km}	-293.08	4	594.28	3.02	0.16
	MIX_{1km}	-294.05	4	596.22	4.96	0.06
	MIX_{18km}	-294.42	4	596.96	5.70	0.04
	RIP_{1km}	-290.75	4	589.63	0.00	0.67
	RIP_{540}	-292.05	4	592.22	2.60	0.18
	RIP_{5km}	-292.85	4	593.83	4.21	0.08
	RIP_{3km}	-293.33	4	594.78	5.15	0.05
	RIP_{18km}	-294.30	4	596.72	7.09	0.02
	$SALT_{18km}$	-294.39	4	596.91	0.00	0.34
	$SALT_{3km}$	-294.40	4	596.93	0.02	0.33
	$SALT_{5km}$	-294.40	4	596.93	0.02	0.33
	$EDGE_{5km}$	-292.95	4	594.02	0.00	0.48
	$CONTAG_{5km}$	-293.62	4	595.37	1.34	0.25
	$CONTAG_{3km}$	-294.18	4	596.49	2.47	0.14
	$EDGE_{3km}$	-294.27	4	596.67	2.65	0.13
Abiotic	CTI[b]	-292.09	5	594.36	0.00	0.61
	CTI	-293.58	4	595.29	0.92	0.39
	ELEV	-292.91	4	593.95	0.00	0.67
	ELEV[b]	-292.57	5	595.32	1.38	0.33
	$iH2Od_{250}$[c]	-293.96	4	596.04	0.00	0.37
	$iH2Od_{500}$[c]	-294.09	4	596.30	0.25	0.33
	$iH2Od_{1km}$[c]	-294.19	4	596.51	0.47	0.30
	$pH2Od_{250}$[c]	-292.41	4	592.95	0.00	0.52
	$pH2Od_{500}$[c]	-292.97	4	594.06	1.11	0.30
	$pH2Od_{1km}$[c]	-293.45	4	595.02	2.07	0.18
	SOLAR[b]	-290.24	5	590.67	0.00	0.96
	SOLAR	-294.33	4	596.78	6.12	0.04

TABLE 5.3. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
	Tmin	-294.40	4	596.92	0.00	1.00
	TRI_{270}	-282.53	4	573.19	0.00	0.48
	TRI_{540}	-282.55	4	573.22	0.03	0.47
	TRI	-285.32	4	578.77	5.58	0.03
	TRI_{1km}	-285.59	4	579.30	6.11	0.02
	TRI_{3km}	-291.81	4	591.75	18.56	0.00
	TRI_{5km}	-292.71	4	593.55	20.36	0.00
	TRI_{18km}	-294.06	4	596.25	23.06	0.00
Disturbance	$AG_{1km}{}^{c}$	-294.14	4	596.41	0.00	0.39
	$AG_{500}{}^{c}$	-294.33	4	596.78	0.37	0.32
	$AG_{250}{}^{c}$	-294.41	4	596.95	0.54	0.29
	$MjRD_{1km}{}^{c}$	-290.38	4	588.89	0.00	0.45
	$MjRD_{500}{}^{c}$	-290.44	4	589.00	0.11	0.42
	$MjRD_{250}{}^{c}$	-291.65	4	591.44	2.55	0.13
	$PIPE_{500}{}^{c}$	-291.87	4	591.87	0.00	0.39
	$PIPE_{1km}{}^{c}$	-292.09	4	592.31	0.44	0.31
	$PIPE_{250}{}^{c}$	-292.12	4	592.36	0.49	0.30
	$POWER_{500}{}^{c}$	-289.46	4	587.05	0.00	0.43
	$POWER_{1km}{}^{c}$	-289.46	4	587.05	0.00	0.42
	$POWER_{250}{}^{c}$	-290.51	4	589.14	2.09	0.15
	$RDdens_{3km}$	-293.42	4	594.96	0.00	0.22
	$RDdens_{5km}$	-293.71	4	595.54	0.58	0.16
	$RDdens_{1km}$	-293.88	4	595.89	0.93	0.14
	$RDdens_{540}$	-294.39	4	596.90	1.94	0.08
	$RDdens_{18km}$	-294.43	4	596.98	2.02	0.08
	$RDdens_{270}$	-294.43	4	596.98	2.02	0.08
	$2RD_{250}{}^{c}$	-294.37	4	596.86	1.91	0.08
	$2RD_{1km}{}^{c}$	-294.40	4	596.93	1.97	0.08
	$2RD_{500}{}^{c}$	-294.43	4	596.98	2.02	0.08
	$WELL_{1km}{}^{c}$	-290.50	4	589.12	0.00	0.68
	$WELL_{500}{}^{c}$	-291.64	4	591.41	2.29	0.22
	$WELL_{250}{}^{c}$	-292.34	4	592.81	3.70	0.11

[a] Variable definitions provided in Table 4.2
[b] Quadratic function (variable + variable^2)
[c] Distance decay function ($e^{(\text{Euclidean distance from feature/-distance parameter})}$)

TABLE 5.4. Results of AIC_c-based submodel selection for sage-grouse roost site selection in the Wyoming Basins Ecoregional Assessment area; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC_c), change in AIC_c value from the top model (ΔAIC_c), and Akaike weight (w_i). Only models with $\Delta AIC_c < 2$ are shown.

Category	Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	1	$ALLSAGE_{1km} + CFRST_{3km} + MIX_{3km} + RIP_{1km} + EDGE_{5km}$	-283.71	7	581.78	0.00	0.24
	2	$ALLSAGE_{1km} + MIX_{3km} + RIP_{1km} + EDGE_{5km}$	-284.79	6	581.84	0.06	0.23
	3	$ALLSAGE_{1km} + MIX_{3km} + RIP_{1km} + EDGE_{5km} + SALT_{18km}$	-284.33	7	583.01	1.23	0.13
Abiotic	1	$ALLSAGE_{1km} + ELEV + Tmin + TRI_{270}$	-274.85	6	561.96	0.00	0.41
	2	$ALLSAGE_{1km} + ELEV + iH2Od_{250} + Tmin + TRI_{270}$	-274.32	7	563.00	1.05	0.24
	3	$ALLSAGE_{1km} + ELEV + pH2Od_{250} + Tmin + TRI_{270}$	-274.50	7	563.35	1.40	0.21
Disturbance	1	$ALLSAGE_{1km} + WELL_{1km} + MjRD_{1km} + POWER_{500}$	-282.50	6	577.27	0.00	0.33
	2	$ALLSAGE_{1km} + WELL_{1km} + MjRD_{1km} + POWER_{500} + PIPE_{1km}$	-282.29	7	578.94	1.67	0.15
	3	$ALLSAGE_{1km} + WELL_{1km} + MjRD_{1km} + POWER_{500} + AG_{1km}$	-282.30	7	578.95	1.69	0.14

[a] Variable definitions provided in Table 4.2

Model Evaluation

We evaluated roost and general use models using sage-grouse lek data obtained from the Wyoming Game and Fish lek count database (unpublished data on file). Although lek locations represent one portion of the annual life cycle of sage-grouse, these locations are generally in or adjacent to nesting habitats (Connelly et al. 2011). Standardized lek survey protocols (Connelly et al. 2003) and the point-based nature of lek counts provided an ideal data set for validating our models; lek data are often used to assess population trajectories because they represent abundance in a region (Fedy and Aldridge 2011, Garton et al. 2011). We evaluated model predictions by assessing the proportion of active leks that were correctly classified as low or high abundance areas, using the pixel value intersected with each lek site (point). We then compared observed proportion of lek locations in each probability bin against expected proportion of locations from the model, using regression analysis to evaluate model fit (Johnson et al. 2006). A model with good fit should have a high R^2 value, a slope not different from 1.0, and an intercept not different from zero (Johnson et al. 2006). We also compared predicted model probabilities within each 10% probability class to (1) mean maximum count of male sage-grouse (2003-2006) as an abundance metric and (2) proportion of total leks identified as inactive (counts with zero birds during the same time frame). Finally, we calculated the same metrics for the three abundance classes (absent, low, and high).

RESULTS

Field Surveys

We counted sage-grouse pellets on 323 survey blocks (n = 159 in 2005 and 164 in 2006). For both years combined, 50% of survey blocks contained single pellets or roost piles. Sage-grouse use generally was highest on on-road survey blocks, medium

TABLE 5.5. Results of AIC_c-based model selection for combined sage-grouse roost site selection models[a] in the Wyoming Basins Ecoregional Assessment area; the table also shows parameter estimates (beta [SE]) and evaluation statistics (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC_c], change in AIC_c value from the top model [ΔAIC_c], and cumulative Akaike weight [$\sum w_i$]). Models were developed from a combination of vegetation, abiotic and disturbance variables using generalized ordered logistic regression. The generalized ordered logistic regression models resulted in parallel lines with a separate intercept value for the low (Present) and high (High) abundance categories. Models shown with cumulative Akaike weight (w_i) of just ≥ 0.9.

Rank	Intercept	$ALLSAGE_{1km}$	RIP_{1km}	TRI_{270}	$MjRD_{1km}$	$POWER_{500}$
1	Present: -1.34 (0.65) High: -2.94 (0.67)	2.72 (0.71)	7.59 (2.39)	-0.05 (0.01)	-1.59 (0.59)	-2.19 (0.91)
2	Present: -3.54 (1.03) High: -5.14 (1.06)	2.45 (0.67)	7.23 (2.37)	-0.06 (0.01)	-1.97 (0.59)	
3	Present: -1.38 (0.66) High: -2.99 (0.67)	2.84 (0.72)	7.36 (2.37)	-0.05 (0.01)	-2.02 (0.59)	
4	Present: -3.75 (1.03) High: -5.35 (1.06)	2.62 (0.68)	7.25 (2.36)	-0.05 (0.01)		-2.73 (0.94)
5	Present: -4.78 (1.19) High: -6.39 (1.21)	2.36 (0.63)		-0.06 (0.01)	-2.04 (0.59)	
6	Present: -1.71 (0.65) High: -3.3 (0.67)	3.03 (0.73)	7.42 (2.37)	-0.05 (0.01)		-2.71 (0.92)
7	Present: -0.83 (0.6) High: -2.44 (0.62)	2.51 (0.67)		-0.05 (0.01)	-1.71 (0.59)	-2.2 (0.88)
8	Present: -3.09 (1.01) High: -4.69 (1.03)	2.21 (0.62)		-0.06 (0.01)	-1.62 (0.59)	-2.13 (0.9)
9	Present: -3.14 (1.03) High: -4.74 (1.05)	2.34 (0.63)		-0.06 (0.01)	-2.04 (0.59)	
10	Present: -4.87 (1.17) High: -6.47 (1.2)	2.48 (0.63)		-0.06 (0.01)		-2.76 (0.93)
11	Present: -1.6 (0.66) High: -3.19 (0.68)	2.69 (0.72)	8.13 (2.39)	-0.05 (0.01)	-1.92 (0.59)	
12	Present: -3.35 (1.02) High: -4.94 (1.04)	2.48 (0.64)		-0.05 (0.01)		-2.66 (0.91)
13	Present: -5.58 (1.2) High: -7.17 (1.23)	2.85 (0.69)	7.87 (2.37)	-0.06 (0.01)		
14	Present: -1.77 (0.7) High: -3.36 (0.71)	3.18 (0.78)	8.02 (2.40)	-0.06 (0.01)	-1.95 (0.59)	
15	Present: -1.89 (0.66) High: -3.47 (0.68)	2.87 (0.73)	8.20 (2.40)	-0.05 (0.01)		-2.7 (0.93)
16	Present: -3.78 (1.07) High: -5.38 (1.09)	2.13 (0.62)		-0.05 (0.01)	-1.92 (0.59)	
17	Present: -1.43 (0.65) High: -3.01 (0 .67)	2.70 (0.71)	7.63 (2.38)	-0.05 (0.01)	-1.93 (0.59)	

[a] Variable definitions provided in Table 4.2
[b] Coefficients and standard errors multiplied by 10^2

TABLE 5.5. Extended

ELEV[b]	$WELL_{500}$	Tmin	MIX_{3km}	$CFRST_{3km}$	LL	K	AIC_c	ΔAIC_c	$\sum w_i$
					-267.09	7	548.55	0.00	0.153
0.12 (0.04)					-267.23	7	548.82	0.27	0.287
	-1.97 (0.78)				-267.30	7	548.97	0.42	0.412
0.11 (0.04)					-267.79	7	549.95	1.4	0.488
0.23 (0.06)		0.24 (0.09)			-267.89	7	550.15	1.6	0.557
	-1.87 (0.78)				-267.94	7	550.25	1.71	0.622
	-2.11 (0.79)				-268.06	7	550.49	1.95	0.680
0.12 (0.04)					-268.28	7	550.92	2.38	0.727
0.12 (0.04)	-1.96 (0.77)				-268.29	7	550.94	2.39	0.773
0.22 (0.06)		0.23 (0.09)			-268.75	7	551.87	3.33	0.802
			16.86 (9.36)		-269.25	7	552.87	4.32	0.820
0.11 (0.04)	-1.85 (0.77)				-269.29	7	552.95	4.4	0.837
0.22 (0.06)		0.25 (0.09)			-269.41	7	553.19	4.64	0.852
				3.54 (1.95)	-269.48	7	553.32	4.77	0.866
			16.85 (9.27)		-269.51	7	553.38	4.83	0.880
0.14 (0.04)			20.02 (9.8)		-269.73	7	553.82	5.27	0.891
					-270.87	6	554.02	5.48	0.901

on far-road survey blocks, and lowest on near-road survey blocks (Table 5.1). Annual differences in occurrence were evident with the highest occurrence on on-road survey blocks in 2005 and far-road survey blocks in 2006. Total single pellet counts (general use model) were highest on on-road survey blocks, medium on near-road survey blocks, and lowest on far-road survey blocks. Total roost piles had the opposite relationship with the highest count at far-road survey blocks, medium at near-road survey blocks, and lowest at on-road survey blocks.

We detected single pellets at 46.1% and roost piles at 42.4% of all sampled survey blocks. We counted 10,680 single pellets and 1,857 roost piles across both years. The maximum count at any given survey block was 864 single pellets and 141 roost piles. Based on the total pellet size within the first roost pile encountered on each survey block, mean (SE) group size per root pile was 23.0 (1.3) pellets (n = 137).

Abundance Categories

The frequency distribution illustrates patterns observed in abundance of sage-grouse pellets on survey block locations (Figs. 5.1 and 5.2). Survey blocks with zero roost pile detections were classified as absent whereas those with 1–8 roost piles were classified as low abundance, and those with >8 piles were assigned a high abundance value for modeling purposes (Fig. 5.3). Survey blocks were classified using a similar three class abundance scheme for single pellet detections; zero detection survey blocks were classified as absent, 1–48 single pellets as low abundance, and >48 single pellets as high abundance (Fig. 5.3).

Model Development

Eight predictor variables were excluded because they had <20 survey blocks with values > 0 in the least frequent abundance category (high) for both roost sites and general use. These variables included proportion of coniferous forest (0.27-, 0.54-, and 1-km radii), grassland (0.27 km), mixed shrubland (0.27 and 0.54 km), salt desert shrubland (0.27 km), and riparian (0.27 km). We excluded highly correlating variables ($r_s \geq 0.7$) from the candidate set in both models: sagebrush mean patch size (1 and 3 km), all sagebrush contagion (1 km), mean annual maximum temperature, and slope. Additional variables excluded from the roost model because of correlation included all sagebrush mean patch size (5 km) and all sagebrush edge density (1 km). Several variables caused instability in the generalized ordered logistic regression procedure and were removed from submodel development. These variables included salt desert shrubland (0.54, 1, 3, and 5 km), solar radiation, and 0.25-km distance decay from power lines for the general use model; and grassland (0.54 and 1 km) and salt desert shrubland (0.54 and 1 km) for the roost model.

Roost model

All sagebrush (*Artemisia* spp.) within 1 km ($ALLSAGE_{1km}$) was the only predictor variable in the AIC_c-selected top sagebrush/NDVI model when predicting roost site occurrence (Table 5.2). All models with $\Delta AIC_c \leq 2$ contained $ALLSAGE_{1km}$, as the sagebrush component, and NDVI at multiple spatial extents. There was 14.9% more $ALLSAGE_{1km}$ at high abundance roost sites (83.3%, SE = 2.38) and 14.6% more at low abundance use sites (83.0%, SE = 1.96) when compared with unused sites (68.5%, SE = 1.85; Appendix 5.1).

After assessing individual covariates (Table 5.3) within model subgroups, the top roost site vegetation submodel consisted of three land cover variables (riparian within 1 km [RIP_{1km}], conifer forest within 3 km [$CFRST_{3km}$], and mixed shrubland within 3 km [MIX_{3km}]) and all sagebrush edge density within 5 km ($EDGE_{5km}$), in addition to the sagebrush base model (Table 5.4). Important abiotic predictors of sage-grouse roost site locations included elevation (ELEV), topographic ruggedness within 0.27 km (TRI_{270}), and minimum yearly temperature (Tmin) (Table 5.4). Three disturbance factors, 1-km distance decay from interstates/major highways ($MjRD_{1km}$), 0.5-km distance decay from power lines ($POWER_{500}$), and 1-km distance decay from oil/gas wells ($WELL_{1km}$), were included in the top disturbance model (Table 5.4).

The AIC_c-selected top sage-grouse roost site model was a combination of vegetation, abiotic, and disturbance factors. Sage-grouse roost sites were positively associated with large expanses of sagebrush and riparian habitat and negatively associated with rugged terrain and proximity to major roads (interstates and major highways) and power lines (Table 5.5). However, the low Akaike weight ($w_i = 0.15$) indicated there were other suitable candidate models. An examination of variables in the other candidate models with a cumulative Akaike weight of just ≥ 0.9 indicated that sage-grouse roost site locations were positively associated with mixed shrubland, conifer forest, increased elevation, and higher minimum yearly temperatures, and negatively associated with proximity to oil/gas wells (Table 5.5). The final composite model-averaged linear predictors of occurrence for the low (Eq. 5.1) and high (Eq. 5.2) abundance categories are listed below.

$$Prob_{low} = 1 / (1 + (exp(-(-2.81 + 2.66 * ALLSAGE_{1km} + 5.15 * RIP_{1km} - 0.05 * TRI_{270} - 1.08 * MjRD_{1km} - 1.34 * POWER_{500} - 0.28* WELL_{1km} + 0.06 * Tmin + 0.0008 * ELEV + 4.45 * MIX_{3km} + 0.26 * CFRST_{3km)}))) \quad (5.1)$$

$$Prob_{high} = 1 / (1 + (exp(-(-4.40 + 2.66 * ALLSAGE_{1km} + 5.15 * RIP_{1km} - 0.05 * TRI_{270} - 1.08 * MjRD_{1km} - 1.34 * POWER_{500} - 0.28* WELL_{1km} + 0.06 * Tmin + 0.0008 * ELEV + 4.45 * MIX_{3km} + 0.26 * CFRST_{3km})))) \quad (5.2)$$

The AIC_c-selected top model had good accuracy in predicting both sage-grouse roost site presence (ROC AUC = 0.79) and high abundance roost site areas (ROC AUC = 0.74). The composite model of sage-grouse roost occurrence was an improvement over the top model with excellent model accuracy for presence (ROC AUC = 0.81) and good model accuracy for high density (ROC AUC = 0.78). Our model of sage-grouse roost occurrence had an optimal sensitivity-specificity equality threshold of 0.48 when determining presence/absence, which resulted in the correct classification of 74.7% of survey block locations.

General use model

All big sagebrush (*A. tridentata*) within 1 km ($ABIGSAGE_{1km}$) was the AIC_c-selected top sagebrush/NDVI model when predicting sage-grouse general use (Table 5.6). All models with $\Delta AIC_c < 2$ contained $ABIGSAGE_{1km}$ or $ALLSAGE_{1km}$, as the sagebrush component, and NDVI at all spatial extents. $ABIGSAGE_{1km}$ increased with increasing use class. There was 18.0% more $ABIGSAGE_{1km}$ at high abundance general use sites (83.8% SE = 1.83) and 13.2% more at low abundance general use sites (79.0% SE = 2.13) when compared with unused sites (65.8% SE = 1.88; Appendix 5.2).

After assessing individual covariates (Table 5.7) within model subgroups, the top general use vegetation submodel consisted of RIP_{1km}, MIX_{3km}, coniferous forest within 5 km ($CFRST_{5km}$) and all sagebrush edge density within 1 km ($EDGE_{1km}$), in addition to the sagebrush base model (Table 5.8). ELEV, TRI_{270}, and Tmin were selected as important abiotic predictors of sage-grouse general use locations (Table 5.8). Distance decay from three disturbance factors, $MjRD_{1km}$, $POWER_{500}$, and $WELL_{1km}$, were included in the top disturbance submodel (Table 5.8).

The AIC_c-selected top sage-grouse general use model was a combination of vegetation, abiotic, and disturbance factors. Sage-grouse general use was positively associated with large expanses of all big sagebrush and higher elevations and negatively associated with rugged terrain and proximity to interstates and major highways, power lines, and oil/gas wells (Table 5.9). Although the weight of evidence was high for the top model (w_i = 0.58), there were other suitable candidate models. An examination of variables in the other eight candidate models with cumulative Akaike weight of just ≥ 0.9 showed that sage-grouse general use was also positively associated with mixed shrubland and riparian land cover, and higher minimum yearly temperatures (Table 5.9). The final composite model-averaged linear predictor of occurrence for the low (Eq. 5.3) and high (Eq. 5.4) abundance categories are listed below.

$$Prob_{low} = 1 / (1 + (exp(-(-3.56 + 2.57 * ABIGSAGE_{1km} - 0.07 * TRI_{270} + 0.002 * ELEV - 1.75 * WELL_{1km} - 2.44 * MjRD_{1km} - 2.12 * POWER_{500} + 0.04 * Tmin + 0.25 * RIP_{1km} + 0.99 * MIX_{3km})))) \quad (5.3)$$

$$Prob_{high} = 1 / (1 + (exp(-(-5.26 + 2.57 * ABIGSAGE_{1km} - 0.07 * TRI_{270} + 0.002 * ELEV - 1.75 * WELL_{1km} - 2.44 * MjRD_{1km} - 2.12 * POWER_{500} + 0.04 * Tmin + 0.25 * RIP_{1km} + 0.99 * MIX_{3km})))) \quad (5.4)$$

The AIC_c-selected top model had excellent model accuracy predicting sage-grouse general use occurrence (ROC AUC = 0.82) and good accuracy when predicting high density general use areas (ROC AUC = 0.75). The composite model of sage-grouse general use occurrence had improved model accuracy compared to the top single model for both presence (ROC AUC = 0.83) and high density areas (ROC AUC = 0.81). Our model of sage-grouse general use had an optimal sensitivity and specificity equality threshold of 0.49 when determining presence/absence, which resulted in 75.2% survey blocks locations correctly classified.

Spatial Application and Dose Response

Sage-grouse roost site and general use occurrence was predicted to be highest in the central part of the WBEA area (Figs. 5.4, 5.5). We estimated that the WBEA contained approximately 52,979 km^2 (32.4%) of suitable sage-grouse roost habitat and 63,784 km^2 (39.2%) of suitable sage-grouse general use habitat, much of which was overlapping. Where sage-grouse were predicted to be present, high-quality habitat based on density of pellets was much smaller for both roosting (4,170 km^2; 7.9%; Fig. 5.6) and general use (16,760 km^2; 26.2%; Fig. 5.7). Sage-grouse were more likely to roost in areas with at least 88% (61% at +1SD) all sagebrush habitat within 1 km (Fig. 5.8) and general use areas with at least 81% (51% at +1SD) all big sagebrush habitat, also within 1 km (Fig. 5.9).

Model Evaluation

Our final composite models of sage-grouse occurrence correctly classified active sage-grouse lek locations as occurrence locations with 75.2% accuracy for the roost site model and 79.5% for the general use model. Both models also validated well with slope of observed versus expected values not differing from 1.0, the intercept not differing from zero for roosting (slope = 1.31, 95% CI = 0.15-2.47; intercept = -0.03, 95% CI = -0.16-0.99; r_s = 0.92, $p < 0.001$) and general use (slope = 1.73, 95% CI=-0.45-3.01; intercept = -0.07, 95% CI = -0.21-0.64; r_s = 0.77 p = 0.009). The mean maximum count (2003-2006) of sage-grouse at active leks increased, and the percentage of inactive leks decreased, with increasing predicted probability of occurrence for both roost and general use models (Figs. 5.10, 5.11). When probability of occurrence was transformed into three abundance classes this same relationship

TABLE 5.6. Results of AIC_c-based model selection for sage-grouse general use in the Wyoming Basins Ecoregional Assessment area.in relation to multi-scale sagebrush and NDVI using generalized ordered logistic regression; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC_c), change in AIC_c value from the top model (ΔAIC_c), and Akaike weight (w_i). Only models with $\Delta AIC_c < 2$ are shown.

Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
1	$ABIGSAGE_{1km}$	-303.43	3	612.93	0.00	0.05
2	$ABIGSAGE_{1km} + NDVI_{3km}$	-302.41	4	612.95	0.02	0.05
3	$ABIGSAGE_{1km} + NDVI_{5km}$	-302.42	4	612.96	0.04	0.05
4	$ABIGSAGE_{1km} + NDVI_{540}$	-302.80	4	613.72	0.80	0.03
5	$ALLSAGE_{1km} + NDVI_{3km}$	-302.80	4	613.73	0.81	0.03
6	$ALLSAGE_{1km} + NDVI_{5km}$	-302.81	4	613.74	0.81	0.03
7	$ABIGSAGE_{1km} + NDVI_{1km} + NDVI_{1km}^2$	-299.74	7	613.84	0.91	0.03
8	$ABIGSAGE_{1km} + NDVI_{1km}$	-302.86	4	613.85	0.92	0.03
9	$ABIGSAGE_{1km} + NDVI_{270}$	-302.87	4	613.86	0.94	0.03
10	$ALLSAGE_{1km}$	-303.92	3	613.91	0.98	0.03
11	$ABIGSAGE_{1km} + NDVI_{18km}$	-302.96	4	614.05	1.12	0.03
12	$ABIGSAGE_{1km} + NDVI$	-302.98	4	614.09	1.16	0.03
13	$ABIGSAGE_{1km} + NDVI + NDVI^2$	-301.99	5	614.17	1.24	0.02
14	$ABIGSAGE_{1km} + NDVI_{270} + NDVI_{270}^2$	-302.16	5	614.51	1.59	0.02
15	$ALLSAGE_{1km} + NDVI_{540}$	-303.20	4	614.52	1.60	0.02
16	$ALLSAGE_{1km} + NDVI_{18km}$	-303.23	4	614.58	1.65	0.02
17	$ALLSAGE_{1km} + NDVI_{1km}$	-303.28	4	614.68	1.75	0.02
18	$ALLSAGE_{1km} + NDVI_{270}$	-303.28	4	614.69	1.76	0.02
19	$ABIGSAGE_{1km} + NDVI_{540} + NDVI_{540}^2$	-302.28	5	614.76	1.83	0.02
20	$ABIGSAGE_{1km} + NDVI_{18km} + NDVI_{18km}^2$	-300.21	7	614.77	1.84	0.02
21	$ALLSAGE_{1km} + NDVI_{18km} + NDVI_{18km}^2$	-300.28	7	614.91	1.98	0.02

[a] Variable definitions provided in Table 4.2

held true for the predicted density classes (Tables 5.10, 5.11), suggesting both our low and high density models captured trends in lek attendance by sage-grouse.

DISCUSSION

Sage-grouse occurrence was variable throughout the known range in the WBEA area (Schroeder et al. 2004), with the highest probabilities of occurrence throughout central Wyoming. Models describing sage-grouse general use and roost sites had strong positive relationships with the amount of sagebrush habitat within a 1-km radius; this spatial scale is similar to winter habitats selected in Wyoming (1.13-km radius; Doherty et al. 2008) and nest, brood, and winter habitat selection in Alberta (0.564-km radius; Aldridge and Boyce 2007, Carpenter et al. 2010). Amount of sagebrush habitat surrounding lek locations is an important determinant of lek population trend (Johnson et al. 2011). Sage-grouse select intact sagebrush landscapes that may provide protection against predation and enhance nesting success (Aldridge and Boyce 2007), thus contrib-

TABLE 5.7. Evaluation statistics from AIC_c-based univariate model selection for sage-grouse general use in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale vegetation, abiotic, and disturbance predictor variables (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC_c], change in AIC_c value from the top model [ΔAIC_c], and Akaike weight [w_i]). We ran generalized ordered logistic regression models with the all big sagebrush (1-km radius) variable as a base model for all variables tested. We used AIC_c to identify the spatial extent at which sage-grouse respond to individual variables.

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	$CFRST_{5km}$	-302.36	4	612.97	0.00	0.35
	$CFRST_{3km}$	-302.37	4	613.00	0.03	0.35
	$CFRST_{1km}$	-302.97	4	614.19	1.22	0.19
	$CFRST_{18km}$	-303.56	4	615.37	2.40	0.11
	$GRASS_{18km}$	-302.33	4	612.92	0.00	0.40
	$GRASS_{540}$	-303.07	4	614.39	1.47	0.19
	$GRASS_{3km}$	-303.35	4	614.95	2.03	0.14
	$GRASS_{5km}$	-303.37	4	615.00	2.08	0.14
	$GRASS_{1km}$	-303.54	4	615.32	2.40	0.12
	MIX_{3km}	-301.84	4	611.93	0.00	0.46
	MIX_{540}	-302.62	4	613.49	1.56	0.21
	MIX_{5km}	-302.88	4	614.02	2.09	0.16
	MIX_{1km}	-303.45	4	615.14	3.21	0.09
	MIX_{18km}	-303.61	4	615.47	3.54	0.08
	RIP_{1km}	-302.01	4	612.27	0.00	0.39
	RIP_{540}	-302.72	4	613.70	1.43	0.19
	RIP_{5km}	-302.80	4	613.85	1.58	0.17
	RIP_{3km}	-302.84	4	613.93	1.66	0.17
	RIP_{18km}	-303.54	4	615.33	3.06	0.08
	$EDGE_{1km}$	-300.52	4	609.28	0.00	0.66
	$EDGE_{5km}$	-302.16	4	612.57	3.29	0.13
	$EDGE_{3km}$	-301.61	5	613.60	4.32	0.08
	$PATCH_{5km}$	-302.88	4	614.01	4.73	0.06
	$CONTAG_{5km}$	-303.12	4	614.48	5.20	0.05
	$CONTAG_{3km}$	-303.56	4	615.37	6.09	0.03
	$SALT_{18km}$	-301.95	5	614.28	0.00	1.00
Abiotic	CTI[b]	-299.77	5	609.93	0.00	0.87
	CTI	-302.71	4	613.66	3.73	0.13
	ELEV	-301.14	4	610.53	0.00	1.00
	$pH2Od_{250}$[c]	-302.45	4	613.15	0.00	0.35
	$pH2Od_{500}$[c]	-302.48	4	613.21	0.05	0.34
	$pH2Od_{1km}$[c]	-302.57	4	613.40	0.25	0.31
	$iH2Od_{250}$[c]	-302.86	4	613.98	0.00	0.43

TABLE 5.7. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
	$iH2Od_{500}$[c]	-303.14	4	614.54	0.56	0.32
	$iH2Od_{1km}$[c]	-303.42	4	615.08	1.10	0.25
	Tmin	-303.49	4	615.23	0.00	1.00
	TRI_{270}	-287.69	4	583.62	0.00	0.34
	TRI_{540}	-287.69	4	583.64	0.02	0.34
	TRI_{270}[b]	-287.60	5	585.59	1.96	0.13
	TRI_{540}[b]	-287.68	5	585.75	2.12	0.12
	TRI	-289.85	4	587.95	4.32	0.04
	TRI_{1km}	-290.52	4	589.29	5.67	0.02
	TRI[b]	-289.74	5	589.87	6.24	0.01
	TRI_{1km}[b]	-290.52	5	591.42	7.79	0.01
	TRI_{3km}	-297.70	4	603.65	20.02	0.00
	TRI_{3km}[b]	-297.19	5	604.77	21.14	0.00
	TRI_{5km}	-298.81	4	605.88	22.25	0.00
	TRI_{5km}[b]	-298.41	5	607.19	23.57	0.00
	TRI_{18km}	-301.69	4	611.63	28.01	0.00
	TRI_{18km}[b]	-301.66	5	613.69	30.07	0.00
Disturbance	AG_{1km}[c]	-302.93	4	614.11	0.00	0.46
	AG_{500}[c]	-303.35	4	614.95	0.84	0.30
	AG_{250}[c]	-303.57	4	615.39	1.28	0.24
	$PIPE_{1km}$[c]	-300.90	4	610.05	0.00	0.48
	$PIPE_{500}$[c]	-301.26	4	610.78	0.73	0.33
	$PIPE_{250}$[c]	-301.82	4	611.88	1.83	0.19
	$POWER_{500}$[c]	-297.32	4	602.88	0.00	0.59
	$POWER_{1km}$[c]	-297.67	4	603.58	0.70	0.41
	$MjRD_{1km}$[c]	-296.24	4	600.73	0.00	0.67
	$MjRD_{500}$[c]	-297.12	4	602.49	1.75	0.28
	$MjRD_{250}$[c]	-298.91	4	606.07	5.33	0.05
	$RDdens_{3km}$	-300.43	4	609.11	0.00	0.42
	$RDdens_{5km}$	-300.93	4	610.11	1.00	0.26
	$RDdens_{1km}$	-301.61	4	611.47	2.36	0.13
	$2RD_{250}$[c]	-301.36	5	613.11	4.00	0.06
	$2RD_{500}$[c]	-301.63	5	613.63	4.52	0.04
	$RDdens_{540}$	-303.19	4	614.64	5.53	0.03
	$RDdens_{270}$	-303.26	4	614.78	5.67	0.02

TABLE 5.7. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
	$RDdens_{18km}$	-303.28	4	614.81	5.70	0.02
	$2RD_{1km}^{c}$	-303.60	4	615.46	6.35	0.02
	$WELL_{1km}^{c}$	-298.69	4	605.63	0.00	0.67
	$WELL_{500}^{c}$	-299.74	4	607.73	2.11	0.23
	$WELL_{250}^{c}$	-300.65	4	609.55	3.92	0.09

[a] Variable definitions provided in Table 4.2
[b] Quadratic function (variable + variable^2)
[c] Distance decay function ($e^{(\text{Euclidian distance from feature/-distance parameter})}$)

uting to increased recruitment and population trends based on attendance at leks.

Sage-grouse also were more likely to occur in areas near riparian zones. Riparian habitats provide higher cover and diversity of forbs and insects that are important for sage-grouse broods (Drut et al. 1994a, 1994b; Johnson and Boyce 1991; Sveum et al. 1998), and lek population trends in the Wyoming Basin sage-grouse management zone exhibited a positive association with increased riparian habitat (Johnson et al. 2011). This relationship is most likely related to mesic habitats characterized by landscape-scale measures of riparian habitat. Riparian habitat can be more risky for sage-grouse broods because chicks experience reduced survival in this habitat type (Aldridge and Boyce 2007). The association of sage-grouse with mixed shrubland and conifer forest land cover within a 3-km radius may be due to the proximity of these habitat types to favorable conditions or conditions within the habitat type itself. Sage-grouse use shrubs in the mixed shrubland land cover (i.e., rabbitbrush [*Chrysothamnus* spp. and *Ericameria* spp.] and horsebrush [*Tetradymia* spp.]) as both nesting and hiding cover, and birds may also occupy sagebrush habitat with some conifer nearby (Connelly et al. 2011). However, the effect of conifer in our roost site model was weak, only occurring in one of the 17 models in the top AIC_c-selected set ($w_i = 0.02$, Table 5.5).

Sage-grouse avoided areas with rugged terrain in our study area, selecting for flat valleys and rolling hills with low topographic ruggedness, which is typical of sage-grouse habitat (Eng and Schladweiler 1972, Connelly et al. 1991, Gregg et al. 1994). Sage-grouse seek out habitats with less rugged terrain during winter (Beck 1977, Doherty et al. 2008, Carpenter et al. 2010) and avoid rugged terrain for nesting habitat in central Wyoming (Jensen 2006).

Sage-grouse were more likely to occur at higher elevations in the Wyoming Basins, which may be related to seasonal movements where birds track vegetation phenology and use habitats with increased forb availability at higher elevations throughout summer (Klebenow 1969, Wallestad 1971, Connelly et al. 2011). Sage-grouse occurrence increased in warmer areas as identified by higher minimum temperatures. Sage-grouse require access to sagebrush exposed above snow for food and shelter (Connelly et al. 2011). South or southwest-facing aspects and windswept ridges or draws and swales (Beck 1977, Crawford et al. 2004) are common habitat characteristics of sage-grouse winter habitat. South and southwest-facing aspects often have high-

Table 5.8. Results of AIC_c-based submodel selection for sage-grouse general use in the Wyoming Basins Ecoregional Assessment area; the table also shows log-likelihood (LL), number of parameters (K), Akaike's Information Criterion corrected for small sample sizes (AIC_c), change in AIC_c value from the top model (ΔAIC_c), and Akaike weight (w_i). Only models with $\Delta AIC_c < 2$ are shown.

Category	Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	1	$ABIGSAGE_{1km} + EDGE_{1km} + CFRST_{5km} + MIX_{3km} + RIP_{1km}$	-293.71	7	601.78	0.00	0.15
	2	$ABIGSAGE_{1km} + EDGE_{1km} + CFRST_{5km} + MIX_{3km} + RIP_{1km} + SALT_{18km}$	-291.78	9	602.13	0.35	0.13
	3	$ABIGSAGE_{1km} + EDGE_{1km} + MIX_{3km} + RIP_{1km} + SALT_{18km}$	-293.05	8	602.55	0.77	0.10
	4	$ABIGSAGE_{1km} + EDGE_{1km} + MIX_{3km} + RIP_{1km}$	-295.63	6	603.53	1.75	0.06
	5	$ABIGSAGE_{1km} + EDGE_{1km} + CFRST_{5km} + GRASS_{18km} + MIX_{3km} + RIP_{1km}$	-293.56	8	603.57	1.79	0.06
	6	$ABIGSAGE_{1km} + EDGE_{1km} + CFRST_{5km} + MIX_{3km}$	-295.73	6	603.72	1.94	0.06
Abiotic	1	$ABIGSAGE_{1km} + Tmin + TRI_{270} + ELEV$	-279.19	6	570.64	0.00	0.25
	2	$ABIGSAGE_{1km} + Tmin + TRI_{270} + ELEV + iH2Od_{250}$	-278.54	7	571.43	0.79	0.17
	3	$ABIGSAGE_{1km} + TRI_{270} + ELEV$	-281.05	5	572.30	1.66	0.11
	4	$ABIGSAGE_{1km} + Tmin + TRI_{270} + ELEV + pH2Od_{250}$	-279.13	7	572.62	1.98	0.09
Disturbance	1	$ABIGSAGE_{1km} + WELL_{1km} + MjRD_{1km} + POWER_{500}$	-286.46	6	585.18	0.00	0.28
	2	$ABIGSAGE_{1km} + WELL_{1km} + MjRD_{1km} + POWER_{500} + AG_{1km}$	-285.91	7	586.16	0.98	0.17
	3	$ABIGSAGE_{1km} + WELL_{1km} + MjRD_{1km} + POWER_{500} + PIPE_{1km}$	-286.09	7	586.52	1.34	0.14
	4	$ABIGSAGE_{1km} + WELL_{1km} + MjRD_{1km} + RDdens_{3km} + POWER_{500}$	-286.18	7	586.72	1.54	0.13

[a] Variable definitions provided in Table 4.2

TABLE 5.9. Results of AIC_c-based model selection for combined sage-grouse general use models[a] in the Wyoming Basins Ecoregional Assessment area.; the table also shows parameter estimates (beta [SE]) and evaluation statistics (log-likelihood [LL], number of parameters [K], Akaike's Information Criterion corrected for small sample sizes [AIC_c], change in AIC_c value from the top model [ΔAIC_c], and cumulative Akaike weight [Σw_i]). Models were developed from a combination of vegetation, abiotic and disturbance variables using generalized ordered logistic regression. The generalized ordered logistic regression models resulted in parallel lines with a separate intercept value for the low (Present) and high (High) abundance categories. Models shown with cumulative Akaike weight (w_i) of just ≥ 0.9.

Rank	Intercept	$ABIGSAGE_{1km}$	TRI_{270}	ELEV[b]	$MjRD_{1km}$	$POWER_{500}$
1	Present: -3.24 (1.03) High: -4.95 (1.05)	2.58 (0.62)	-0.07 (0.01)	0.14 (0.04)	-2.40 (0.62)	-2.51 (0.97)
2	Present: -4.63 (1.17) High: -6.32 (1.2)	2.54 (0.61)	-0.07 (0.01)	0.24 (0.06)	-2.35 (0.62)	-2.52 (1.00)
3	Present: -4.51 (1.19) High: -6.2 (1.21)	2.65 (0.62)	-0.07 (0.01)	0.23 (0.06)	-2.82 (0.62)	
4	Present: -3.83 (1.07) High: -5.52 (1.1)	2.49 (0.62)	-0.07 (0.01)	0.17 (0.04)	-2.73 (0.62)	
5	Present: -3.64 (1.03) High: -5.32 (1.06)	2.63 (0.64)	-0.07 (0.01)	0.15 (0.04)	-2.25 (0.61)	-2.54 (1.00)
6	Present: -3.64 (1.04) High: -5.32 (1.07)	2.75 (0.65)	-0.07 (0.01)	0.15 (0.04)	-2.75 (0.63)	
7	Present: -3.76 (1.06) High: -5.45 (1.08)	2.36 (0.61)	-0.07 (0.01)	0.16 (0.04)	-2.24 (0.61)	-2.5 (0.99)
8	Present: -3.4 (1.03) High: -5.08 (1.05)	2.53 (0.62)	-0.07 (0.01)	0.15 (0.04)	-2.76 (0.62)	
9	Present: -3.38 (1.02) High: -5.06 (1.04)	2.40 (0.61)	-0.07 (0.01)	0.15 (0.04)	-2.27 (0.61)	-2.49 (0.98)

[a] Variable definitions provided in Table 4.2
[b] Coefficients and standard errors multiplied by 10^2

er temperatures due to solar radiation. Although we tested solar radiation as a predictor, temperature (modeled from Doggett et al. 2004) incorporates additional environmental characteristics and therefore may better capture local variation than solar radiation alone.

Sage-grouse occurrence was negatively affected by anthropogenic features. Areas near interstates and major highways, power lines, and oil and gas well locations had lower probability of sage-grouse occurrence (roost and general use). Direct and indirect effects of roads negatively affect both distribution and abundance of sage-grouse (Lyon and Anderson 2003, Connelly et al. 2004, Holloran and Anderson 2005, Aldridge and Boyce 2007). Sage-grouse no longer occupied leks within 2 km of Interstate 80 in Wyoming; leks within 7.5 km of the interstate had greater rates of population decline (based on lek attendance) than leks between 7.5 and 15 km of the interstate (Connelly et al. 2004). At range-wide scales, lek count trends were lower on leks with >20 linear km of interstate, federal, or state highways within 18 km (Johnson et al. 2011). Ef-

TABLE 5.9. Extended

$WELL_{1km}$	Tmin	MIX_{3km}	RIP_{1km}	LL	K	AIC_c	ΔAIC_c	$\sum w_i$
-2.24 (0.80)				-261.08	8	538.62	0.00	0.577
	0.20 (0.09)			-262.72	8	541.91	3.29	0.688
-2.00 (0.79)	0.17 (0.09)			-263.35	8	543.17	4.55	0.748
-2.24 (0.79)		16.19 (9.72)		-263.95	8	544.35	5.73	0.781
			3.88 (2.29)	-263.99	8	544.45	5.84	0.812
-2.16 (0.79)			3.71 (2.29)	-264.07	8	544.59	5.97	0.841
		14.72 (9.59)		-264.23	8	544.91	6.29	0.866
-2.18 (0.79)				-265.37	7	545.09	6.47	0.888
				-265.42	7	545.19	6.58	0.910

fects of oil and gas development on sage-grouse have been extensively investigated in Wyoming (Lyon 2000, Braun et al. 2002, Lyon and Anderson 2003, Holloran 2005, Walker et al. 2007, Doherty et al. 2008) and Alberta (Braun et al. 2002, Aldridge and Boyce 2007, Carpenter et al. 2010). Maximum counts of males/lek within 3.2 km of a drilling rig declined 32%, compared to a 2% decline on areas >6.5 km from a rig (Holloran and Anderson 2005). Any drilling <6.5 km from a sage-grouse lek could have indirect (noise disturbance) or direct (mortality) negative effects on sage-grouse populations. In the Powder River Basin, sage-grouse declined 82% within gas fields compared to 12% outside (Naugle et al. 2011). Sage-grouse had lower nest initiation rates and moved longer distances from the lek to nesting sites for hens from "disturbed leks" (leks ≤3 km of a well pad or road) compared to hens from control leks (leks >3 km away from pad or road) in southwestern Wyoming (Lyon and Anderson (2003). The longer movements from disturbed leks may have been a response to light (<12 vehicles/day) traffic at these sites during the breeding season.

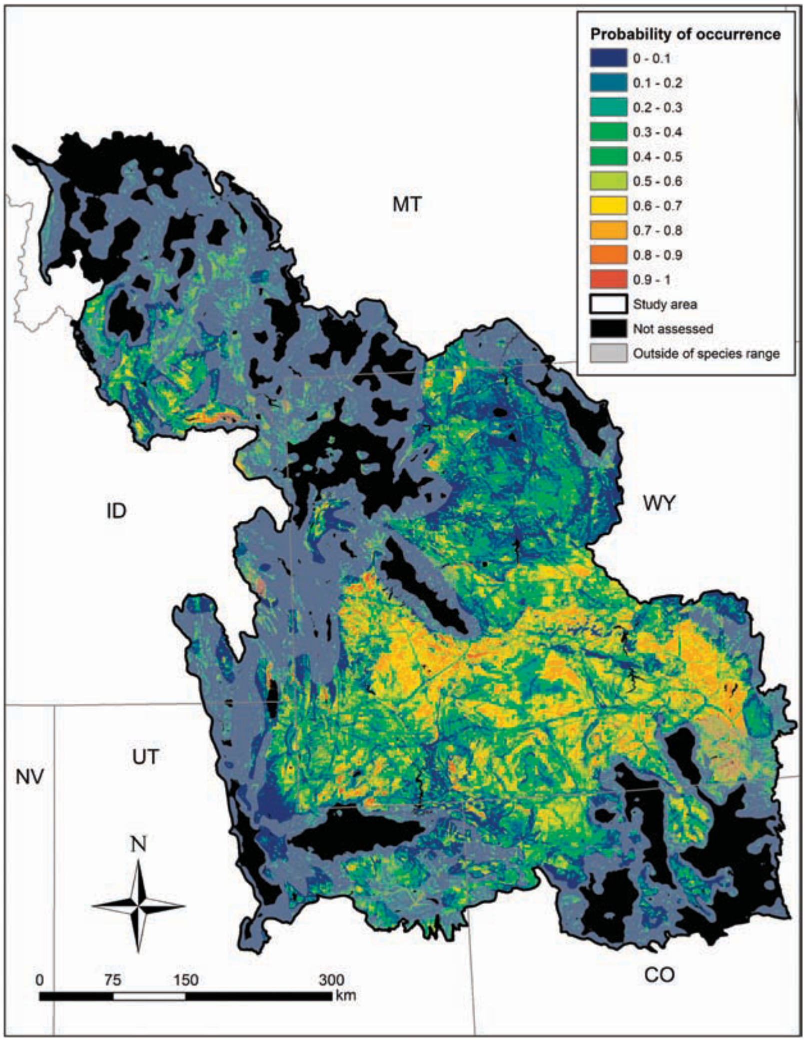

FIG. 5.4. Probability of sage-grouse roost site occurrence in the Wyoming Basins Ecoregional Assessment area. Semi-transparent grey shaded areas are outside the current range of sage-grouse (Schroeder et al. 2004) and black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water). Sage-grouse roost sites are likely to occur in areas with probability > 0.48.

In the Powder River Basin of Wyoming/ Montana, all leks <200 m from active oil and gas wells were abandoned (Braun et al. 2002). Sage-grouse within the Powder River Basin also avoided coal bed methane (CBM) developments (4-km^2 scale) when selecting winter habitat (Doherty et al. 2008), and attendance at leks within CBM developments was 46% lower than outside from 2002 to 2005 (Walker et al. 2007). In guidelines for mitigation related to oil and gas activity, the Wyoming Game and Fish Department (2004) suggested that oil and gas development at >16 wells or >80 acres (0.32 km^2) of disturbance per section (2.56 km^2) in sage-grouse nesting and early brood-rearing habitat would constitute an "extreme" impact. A density of 1-4 well locations per section (1–4 wells/2.56 km^2), or <20 acres/section (0.08 km^2/2.56 km^2) of disturbance, was deemed a moderate impact. In Alberta, a density

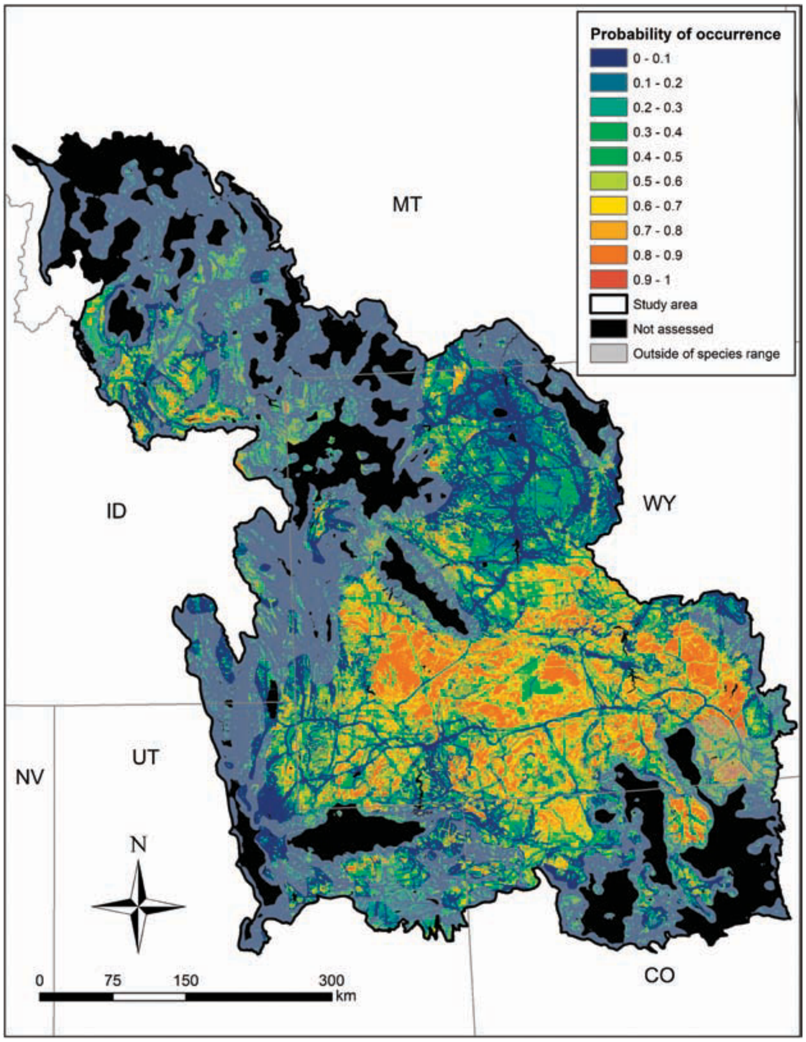

FIG. 5.5. Probability of sage-grouse general use in the Wyoming Basins Ecoregional Assessment area. Semi-transparent grey shaded areas are outside the current range of sage-grouse (Schroeder et al. 2004) and black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water). Sage-grouse general use is likely to occur in areas with probability > 0.49.

of 3 wells/km^2 was associated with steep declines in sage-grouse lek attendance (Braun et al. 2002). Birds in this population avoided energy developments within a minimum of 564 m from habitats during nesting, brood-rearing, and wintering; and increased development was correlated with reduced chick survival (Aldridge and Boyce 2007, Carpenter et al. 2010).

Interstates and major highways, power lines, and oil and gas well locations, all of which were avoided by sage-grouse in our study, are of particular importance to sage-grouse conservation given the ongoing development of energy resources within the Wyoming Basins (Ch. 3, Knick et al. 2011, Naugle et al. 2011). Future planning and assessments can use the strength of these measured responses of sage-grouse to the proximity of individual disturbance factors or the density of developments to avoid disruption of exist-

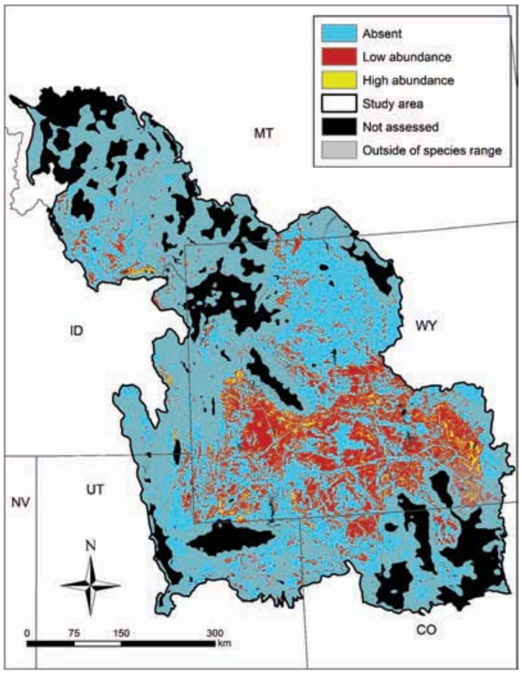

FIG. 5.6. Predicted absent, low, and high abundance sage-grouse roost site areas in the Wyoming Basins Ecoregional Assessment area. Sage-grouse were predicted to occur in areas with a probability above the sensitivity-specificity equality threshold (0.48). Within low/high abundance habitat, the threshold was set at the point where the predicted probability of being high abundance habitat exceeded the probability of being low abundance habitat. Semi-transparent grey shaded areas are outside the current range of sage-grouse (Schroeder et al. 2004) and black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water).

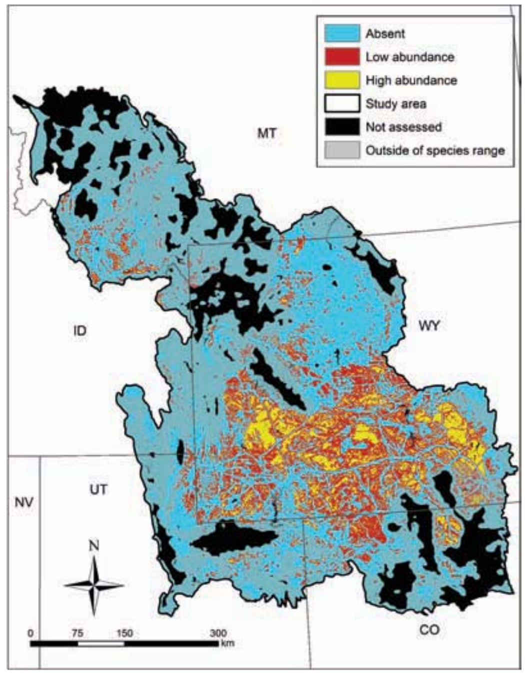

FIG. 5.7. Predicted absent, low, and high abundance sage-grouse general use areas in the Wyoming Basins Ecoregional Assessment area. Sage-grouse were predicted to occur in areas with probability above the sensitivity-specificity equality threshold (0.49). Within low/high abundance habitat, the threshold was set at the point where the predicted probability of being high abundance habitat exceeded the probability of being low abundance habitat. Semi-transparent grey shaded areas are outside the current range of sage-grouse (Schroeder et al. 2004) and black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water).

ing high quality habitats and inform sighting and mitigation efforts.

Our models of sage-grouse probability of occurrence/abundance, based on pellet count surveys, correctly classified habitat as occupied at >75% of active leks in Wyoming. Variables in these models were based on relatively large-scale effects, potentially capturing habitat surrounding leks. As predicted probability of occurrence and abundance increased in our models, the number of male sage-grouse at active leks increased and the proportion of inactive leks decreased, suggesting that our models captured multi-seasonal habitat use patterns associated with individual lek sites. The ordered logistic regression probability of occurrence models accurately identified key sage-grouse habitat across large landscapes and also provided important information on abundance (Nielsen et al. 2005), allowing for more refined management planning.

Our spatially explicit models predicting roost and general use can be used in efforts to conserve and improve habitat for sage-grouse within the WBEA area. Current mapping efforts to identify core areas (Doherty et al. 2011) of sage-grouse populations within the region may be improved or refined through an examination of over-

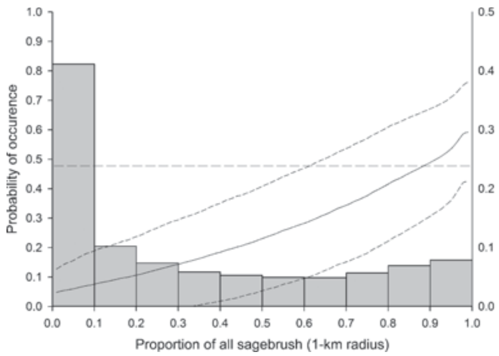

FIG. 5.8. Predicted probability of occurrence for greater sage-grouse roost locations within the Wyoming Basins Ecoregional Assessment area based on proportion of all sagebrush (*Artemisia* spp.) at a 1 km radius moving window. Mean probability of occurrence (±1 SD) values were calculated in each one percent increment of all sagebrush within a 1-km radius moving window. Range of predictions relate to the observed range of sagebrush at study site locations. The dashed horizontal line represents the optimal cutoff threshold (0.48) above which occurrence is predicted. Histogram values represent the proportion of the total study area in each 10 % segment of all sagebrush with 1 km.

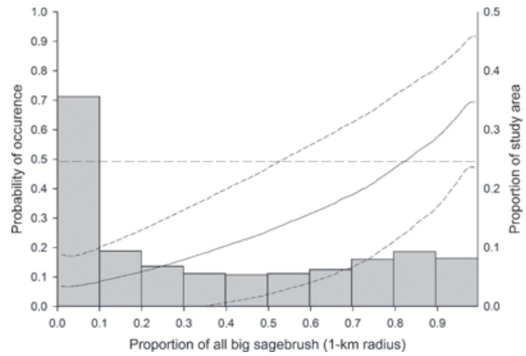

FIG. 5.9. Predicted probability of occurrence for greater sage-grouse general use locations within the Wyoming Basins Ecoregional Assessment area based on proportion of all big sagebrush (*Artemisia tridentata*) at a 1-km radius moving window. Range of predictions relate to the observed range of sagebrush at study site locations. Probability values are the mean predicted values in each one percent increment of all big sagebrush within a 1 km radius moving window. Dashed line represents the optimal cutoff threshold (0.49) above which occurrence is predicted. Histogram values represent the proportion of the total study area in each 10% segment of all big sagebrush within 1 km.

lap between core areas and our models of year-round occurrence probability and abundance; core areas are currently based only on breeding density. Our models can identify habitat conditions within the existing core areas, highlight high-quality habitats on the periphery of existing core areas that could be considered for protection, and identify high-quality habitat not currently included in a designated core area. This spatially explicit knowledge of existing sage-grouse distribution can help inform and prioritize areas for application of future conservation and management actions in the region (Aldridge et al. 2008, Meinke et al. 2009) and thus maximize the effectiveness of limited but precious conservation resources.

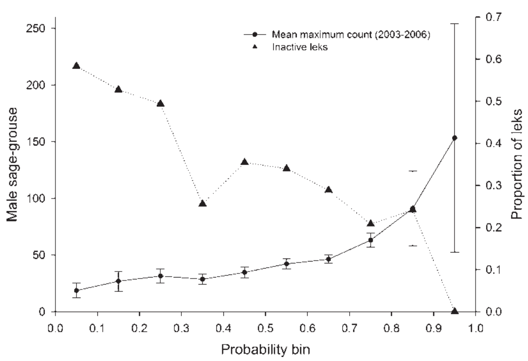

FIG. 5.10. Mean (±95% CI) maximum count (2003–2006) of male sage-grouse at active lek locations and proportion of inactive leks in Wyoming by probability bin in each 10% probability of occurrence bin for the Wyoming Basins Ecoregional Assessment roost model.

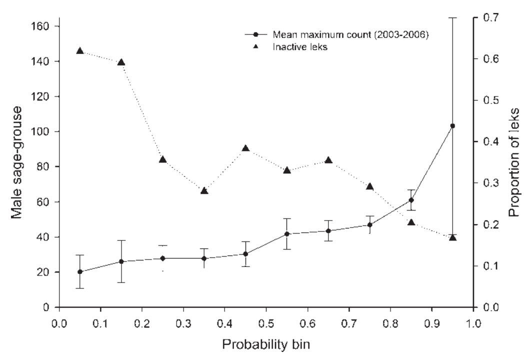

FIG. 5.11. Mean (±95% CI) maximum count (2003–2006) of male sage-grouse at active lek locations and proportion of inactive leks in Wyoming by probability bin in each 10% probability of occurrence bin for the Wyoming Basins Ecoregional Assessment general use model.

TABLE 5.10. Evaluation results for the sage-grouse roost site selection model in relation to lek characteristics in Wyoming including the number of active leks, total leks, extirpated leks (%), and mean count (SD).

	Leks			Count
Class	Active	Total	Extirpated (%)	$\bar{x}$ (SD)
Absent	287	459	37.47	19.16 (27.66)
Low	728	1,037	29.79	34.44 (44.98)
High	140	170	17.64	57.11 (64.08)

TABLE 5.11. Evaluation results for the sage-grouse general use model in relation to lek characteristics in Wyoming including the number of active leks, total leks, extirpated leks (%), and mean count (SD).

	Leks			Count
Class	Active	Total	Extirpated (%)	$\bar{x}$ (SD)
Absent	237	388	38.92	17.57 (26.26)
Low	487	722	32.55	29.75 (40.46)
High	431	556	22.48	46.61 (55.01)

Our regional models may also help identify pathways and corridors between priority areas important for maintaining population connectivity (Aldridge and Boyce 2007, Knick and Hanser 2011). Small isolated populations at the periphery of the sage-grouse distribution are at greater risk for extirpation than those within the core distribution (Aldridge et al. 2008, Wisdom et al. 2011). The explicit protection of areas such as those espoused by the core areas concept (Doherty et al. 2011) may institutionalize a disjunct or isolated view of sage-grouse populations in the region. Institutionalization of this type of population structure may be problematic to long-term conservation of this species because breeding habitats (leks) with lower connectivity inherently have a lower likelihood of persistence (Knick and Hanser 2011). Therefore, it is important to address issues of connectivity both within and between priority areas. Our models provide a means by which to identify areas that may currently serve as important connections between populations and areas that, if targeted for habitat improvements, could serve to improve connectivity.

Our sampling design and modeling approach provides a baseline for monitoring sage-grouse habitat use within the WBEA. The pellet survey technique used to develop these models is a rapid assessment and requires minimal training of field crews. The ability for surveys to be conducted year-round makes this a valuable field technique when conducting large landscape-scale studies and could be easily applied within other ecoregional assessments. Use of this survey methodology coupled with spatially explicit models will facilitate future research and monitoring of habitat-use by sage-grouse throughout its range.

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APPENDIX 5.1

Descriptive statistics for explanatory variables used to model sage-grouse roost occurrence in the Wyoming Basins Ecoregional Assessment area. Variables are summarized by occurrence class, and statistics include mean ($\bar{x}$), standard error (SE), lower (L95) and upper (U95) 95% confidence interval, and minimum (Min) and maximum (Max) value. This appendix is archived electronically and can be downloaded at the following URL: http://sagemap.wr.usgs.gov/wbea.aspx.

APPENDIX 5.2

Descriptive statistics for explanatory variables used to model sage-grouse general use occurrence in the Wyoming Basins Ecoregional Assessment area. Variables are summarized by occurrence class, and statistics include mean ($\bar{x}$), standard error (SE), lower (L95) and upper (U95) 95% confidence interval, and minimum (Min) and maximum (Max) value. This appendix is archived electronically and can be downloaded at the following URL: http://sagemap.wr.usgs.gov/wbea.aspx.