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Chapter 6: Detectability Adjusted Count Models of Songbird Abundance

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Abstract. Sagebrush (*Artemisia* spp.) steppe ecosystems have experienced recent changes resulting not only in the loss of habitat but also fragmentation and degradation of remaining habitats. As a result, sagebrush-obligate and sagebrush-associated songbird populations have experienced population declines over the past several decades. We examined landscape-scale responses in occupancy and abundance for six focal songbird species at 318 survey sites across the Wyoming Basins Ecoregional Assessment (WBEA) area. Occupancy and abundance models were fit for each species using datasets developed at multiple moving window extents to assess landscape-scale relationships between abiotic, habitat, and anthropogenic factors. Anthropogenic factors had less influence on species occupancy or abundance than abiotic and habitat factors. Sagebrush measures were strong predictors of occurrence for sagebrush-obligate species, such as Brewer's sparrows (*Spizella breweri*), sage sparrows (*Amphispiza belli*) and sage thrashers (*Oreoscoptes montanus*), as well as green-tailed towhees (*Pipilo chlorurus*), a species associated with mountain shrub communities. Occurrence for lark sparrows (*Chondestes grammacus*) and vesper sparrows (*Pooecetes gramineus*), considered shrub steppe-associated species, was also related to big sagebrush communities, but at large spatial extents. Although relationships between anthropogenic variables and occurrence were weak for most species, the consistent relationship with sagebrush habitat variables suggests direct habitat loss and not edge or additional fragmentation effects are causing declines in the avifauna examined in the WBEA area. Thus, natural and anthropogenic disturbances that result in loss of critical habitats are the biggest threats to these species. We applied our models spatially across the WBEA area to identify and prioritize key areas for conservation.

Key words: count-based models, energy development, habitat, occurrence, point counts, sagebrush, songbirds, Wyoming.

There is a growing body of research on habitat relationships for sagebrush (*Artemisia* spp.)-obligate birds at both local (Wiens and Rotenberry 1985, Vander Haegen et al. 2000, Erickson 2011) and landscape (Knick and Rotenberry 1995, 1997, 2000; Vander Haegen et al. 2000) scales. Relationships with anthropogenic developments, however, are less well understood (Rotenberry and Knick 1995, Braun et al. 2002, Inglefinger and Anderson 2004). Concerns over loss and degradation of sagebrush habitats have been raised for sagebrush-obligate songbirds because of population declines (Braun et al. 1976, Knick et al. 2003, Dobkin and Sauder 2004). However, consequences of current land-use activities on non-obligate or sagebrush-associated species are poorly understood because research addressing the effects of habitat loss and degradation is limited to a few species.

Oil and natural gas energy development and associated infrastructure, including roads, power lines, pumps, and water storage ponds all result in the loss and fragmentation of habitat (Walston et al. 2009, Ch. 3). This development has been rapidly increasing in recent decades with more wells proposed for development than are currently on the landscape (Naugle et al. 2011). Potential negative ecological consequences for songbirds due to energy development, beyond habitat loss and fragmentation, include: (1) disturbance due to increased noise levels associated with drilling, well operations, and vehicle traffic (Bayne et al. 2008); (2) subsidization of avian nest predators, such as common ravens (*Corvus corax*), through the creation of perches, nest sites, and increased refuse (Andrén 1992, Chalfoun et al. 2002, Bui et al. 2010); and (3) spread of exotic plants (Ch. 10, Knick et al. 2011). Indeed, localized negative effects of energy development on songbird abundance have recently been shown for sagebrush-obligate songbirds (Gilbert and Chalfoun 2011), but landscape scale assessments are lacking.

Ongoing development of energy resources in the Wyoming Basins Ecoregional Assessment (WBEA) area (Ch. 3) highlights the importance of understanding relationships between sagebrush-obligate and sagebrush-associated songbird abundance, current habitat conditions, and anthropogenic activities. Our objectives were two-fold: (1) determine whether anthropogenic disturbances, including energy development, affect occupancy and abundance for a suite of songbirds in sagebrush habitats across the WBEA area; and (2) develop spatially explicit empirical models of songbird occurrence and abundance using data from point count surveys to identify priority conservation areas in the WBEA area. We used count-based models (Hilbe 2007) while accounting for detectability (Buckland et al. 2009) for those species with sufficient observations (Ch. 4). Statistical models were developed for each species to assign habitat associations and gauge impacts of anthropogenic activities, as well as to map the distribution of species habitat for the sagebrush ecosystem across the WBEA area.

METHODS

Field Surveys

Survey blocks (7.29 ha) within the sagebrush ecosystem of the WBEA were chosen using a stratified sampling design (Ch. 4). Point counts were used to survey songbirds (Rosenstock et al. 2002); surveys were conducted at the center of each survey block. Each block was visited twice within a season, once in both May and June, in order to capture phenological differences between migratory species and to further reduce observer bias by switching observers between sampling periods. For each detected bird, we recorded observation type (visual, aural, or both) and estimated the distance to the individual using a laser range finder (Bushnell Yardage Pro Legend) to estimate detectability (Buckland et al. 2001, 2004). Point counts were conducted for 5 minutes at each survey block during calm (<12 km/hr winds) and rainless (light drizzle allowed) days. Counts began at sunrise, and on cold days, particularly following rain, point counts were conducted until 1100 hr (depending on the activity of the bird community). Counts were terminated at ~0900 hr on hot and sunny days. Once observers navigated to a point count using a hand-held global position system (Fig. 4.1), they remained quiet and still for 3 minutes before beginning the survey. Individual detections were mapped to avoid double counting of birds.

Prior to field visits, we selected 23 species of birds for possible inclusion in the assessment (Table 6.1). These included sagebrush-obligate species, such as Brewer's sparrow (*Spizella breweri*), sage sparrow (*Amphispiza belli*), and sage thrasher (*Oreoscoptes montanus*); sagebrush-associated species, such as western meadowlark (*Sturnella neglecta*), lark sparrow (*Chondestes grammacus*), and vesper sparrow (*Pooecetes gramineus*); grassland-associated species, such as savannah sparrow (*Passerculus sandwichensis*) and grasshopper sparrow (*Ammodramus savannarum*);

juniper (*Juniperus* spp.) and mountain shrub-associated species, such as gray flycatcher (*Empidonax wrightii*) and green-tailed towhee (*Pipilo chlorurus*); and synanthropic species (species associated with humans), such as European starling (*Sturnus vulgaris*), house sparrow (*Passer domesticus*), and corvids (e.g., black-billed magpie [*Pica hudsonia*], common raven [*Corvus corax*], and American crow [*Corvus brachyrhynchos*]).

Analytical Approaches

We used count-based generalized linear models (GLM) with a Poisson or negative binomial error distribution and a log-link function to model bird abundance (Hilbe 2007; Ch. 4). We included an offset term in the GLM to account for detectability (Buckland et al. 2009), whereby site-specific detectability for each species can be incorporated into the GLM after estimation in Program DISTANCE (Thomas et al. 2006). When count models could not be developed due to limitations in the number of observations (Ch. 4, Fig. 4.4), we modeled probability of occurrence using logistic regression (Hosmer and Lemeshow 2000). We describe these specific model building approaches in the general analytical methods presented in Chapter 4.

Detection probability

We used program DISTANCE 5.0 Release 2 (Thomas et al. 2006) to calculate detection probabilities for species with a minimum of 60 observations using distance estimates recorded for each individual detection (Ch. 4). We considered half-normal and hazard rate key functions using simple polynomial and cosine series expansions and an information theoretic approach (Burnham and Anderson 2002) to select the top model based on Akaike's Information Criterion (AIC). We right-truncated observations to remove large distance outliers and assessed overall model fit using standard goodness of fit tests and visual plots of the data (Thomas et al. 2006, 2010). We then used the Multiple Covariate Distance-Sampling engine (Thomas et al. 2006) to model detection probabilities by bird species using covariates. We considered covariates representing (1) observer effect (team or detection type [auditory versus visual]), (2) time (start time or Julian date), and (3) vegetation obstruction cover, based on a multiplicative index of local shrub height and cover measured at all sites (Ch. 4, Ch. 10). We identified the top model in each of the three categories using AIC and then evaluated candidate models, including all combinations of variables from top models. We predicted species density across all survey sites as a function of covariates in the top AIC-selected model.

Model development and selection

To model bird abundance (density), we developed a GLM for each species using observed counts as the response variable and an offset term that included detection probability (varied among sites) and effort (constant across sites) (Buckland et al. 2009). This approach allowed us to model observed counts while incorporating detectability differences to assess how covariates might affect bird density (birds/ha). We restricted raw counts for regression models based on the truncation distance identified in program DISTANCE (Buckland et al. 2001). When no detections for a given species occurred at a site, we applied the mean offset value for sites with detections (Buckland et al. 2009). Most count data are Poisson distributed, but a negative binomial distribution may be more appropriate when data are overdispersed (Hilbe 2007). Negative binomial regression models may account for excess zeros, but often a zero-inflated model (type of mixture model) is required to properly account for excess zeros in the dataset (Hilbe 2007). We evaluated different model structures, and assessed the fit of each using a Vuong test (Vuong 1989). We first conducted a Voung test using an

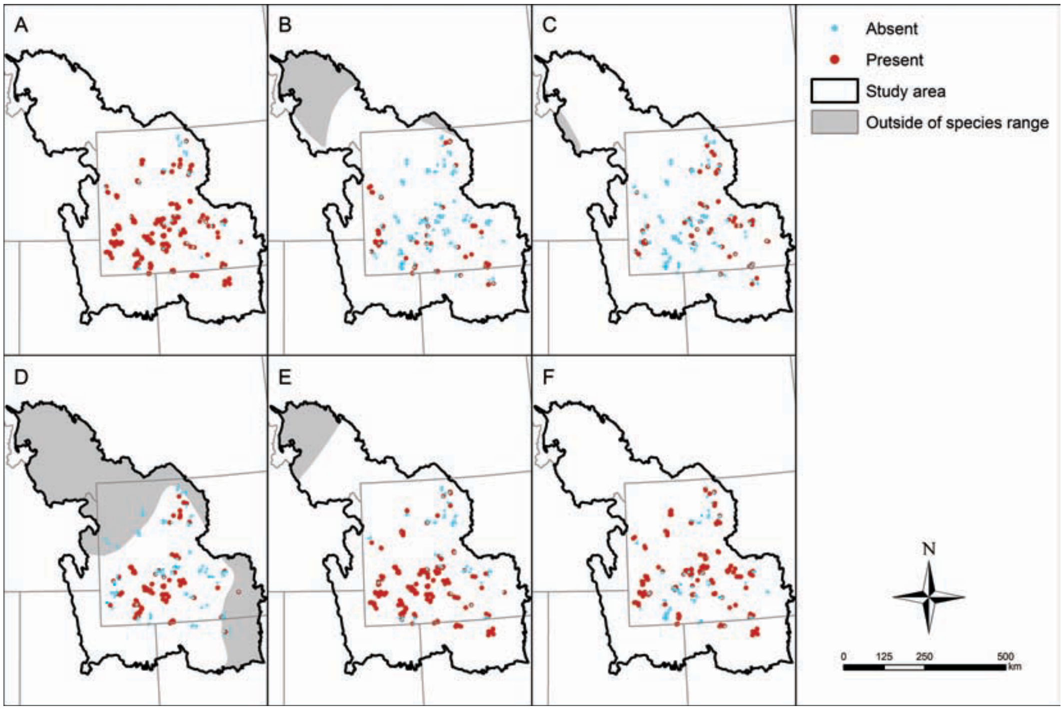

FIG. 6.1. Distribution of survey blocks in the Wyoming Basins Ecoregional Assessment area surveyed for Brewer's sparrow (A), green-tailed towhee (B), lark sparrow (C), sage sparrow (D), sage thrasher (E), and vesper sparrow (F). Survey blocks were designated as absent (blue, zero detections) and present (red) for model development. Grey shades indicate areas of the Wyoming Basins Ecoregional Assessment that are outside the range of each species.

intercept-only model to identify the most appropriate exponential model form: Poisson, negative binomial (NB), zero-inflated Poisson (ZIP), or zero-inflated negative binomial (ZINB). The top-selected model form was used to evaluate the sagebrush univariate variables (Ch. 4, see below). Where zero-inflated processes were warranted, we maintained candidate model forms for both count and inflated portions of the model; otherwise potential model combinations became too cumbersome to evaluate. Final count model predictions resulted in an estimate of abundance (density) that we report as birds/ha, which includes the joint model processes of occurrence and abundance. We present coefficient estimates for both processes; however, these estimates are dependent on the entire model.

We considered all variables in the standard candidate predictor set (Ch. 4, Table 4.2) for bird models with the exception of the eight soil-related variables (pH, salinity, bulk density, sand, silt, clay, soil depth, and available water capacity) and precipitation. Mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana;* moderately correlated with elevation and NDVI), was only considered for the green-tailed towhee. We also evaluated solar radiation and temperature (min or max) for inclusion in each bird species model when determined relevant. We calculated descriptive statistics for all predictor variables within presence/absence classes for each species, identifying survey blocks with predictor variable values > 0 within each abundance class and excluding variables/scales with <20 survey blocks in a class from model building. Correlated predictor variables were removed from potential analyses prior to model development (Ch. 4). In some cases, particularly with zero-inflated models, we ran into convergence issues for a few of the candidate models. In such cases, these models were dropped from consideration.

We followed a hierarchical multi-stage modeling approach where we assessed all model subsets using count-based GLMs or logistic regression occurrence models in Stata 10.1 (Stata Corporation, College Station, Texas, USA). We used Akaike's Information Criterion, corrected for small sample sizes (AIC_c), for model selection (Burnham and Anderson 2002). Our sampling design was stratified by sagebrush and productivity (NDVI, Ch. 4). Therefore, we first evaluated each sagebrush and NDVI variable and identified the circular moving window radius (extent) and combinations of sagebrush and NDVI variables that had the strongest relationship to species occurrence/abundance. Selected sagebrush/NDVI variables formed a base model for assessing all spatial extents for each variable within the vegetation, abiotic, and disturbance subgroups to identify the best spatial extent for each variable using AIC_c values. For each variable, we examined data using scatterplots and histograms to look for nonlinearities. Potential interactions were investigated between sagebrush and NDVI variables and included when appropriate. We then allowed selected spatial extents for each variable to compete with all possible combinations of other variables within the same category to identify the AIC_c-selected top model within that category. To avoid overfitting, we limited the number of variables in all competing models to 10% of the sample size in the lowest frequency class (presence or absence; 1 variable per 10 survey blocks in lowest class; Hosmer and Lemeshow 2000). All variables from the top model within vegetation, abiotic, and disturbance submodel categories were allowed to compete with variables both within and across submodels to identify the top overall composite model; the sagebrush/NDVI base model, however, was held constant for all subsequent models. We model-averaged coefficients from all models with a cumulative AIC_c weight of just ≥ 0.9 to incorporate model uncertainty and generate model averaged spatial predictions (Burnham and Anderson 2002). Coefficients were set to zero when a model did not contain a particular variable.

Accuracy of logistic regression occurrence models was evaluated with receiver operating characteristic (ROC) plots estimating the area under the curve (AUC, Metz 1978). We determined an optimal cutoff threshold for predicting presence-absence of each species (i.e., habitat or non-habitat) using a sensitivity-specificity equality approach (Liu et al. 2005) and applied this threshold to assess the predictive capacity for each model (Nielsen et al. 2004).

Spatial Application and Dose Response

We predicted species occurrence or abundance in a GIS at a 90-m resolution (pixel size) applying the final model-averaged coefficients in ArcGIS using the raster calculator function (ESRI 2006). For abundance (count) models, we predicted the count of individuals occurring within a 1-ha area, effectively making our predictions density estimates. Final model predictions were displayed in 10 equal-area density classes for count-based models or 10% probability classes when species occurrence (presence/absence) was modeled. A non-sagebrush habitat mask (areas with <3% sagebrush habitat in a 5-km moving window) was used to exclude areas without significant sagebrush habitat for prediction. Areas outside the known range of each species (Ch. 2; Ridgely et al. 2003) were also used to restrict prediction to the range of the species. Probability of occurrence maps were converted to binary presence/absence maps based on the sensitivity-specificity equality threshold to

TABLE 6.1. Survey results for 23 songbird species on 318 survey blocks during May and June of 2005 and 2006 in the Wyoming Basins Ecoregional Assessment area. Shown are number sites with occurrences (percent), aural detections (percent), total detections, and detection distance (m; $\bar{x}$ [SE]).

Species	Scientific Name	Occurrence # sites (%)	Total detections (% aural detection)		Total Detections Both Years	Detection distance (m; $\bar{x}$ [SE])	
			2005	2006		2005	2006
American crow	*Corvus brachyrhynchos*	3 (0.9)	1 (0)	11 (27)	7	100	165 (9)
Black-billed magpie	*Pica hudsonia*	24 (7.5)	20 (30)	24 (63)	38	184 (18)	218 (35)
Brewer's blackbird	*Euphagus cyanocephalus*	25 (7.9)	63 (14)	29 (37)	85	90 (7)	100 (9)
Brewer's sparrow[a]	*Spizella breweri*	236 (74.2)	429 (90)	383 (89)	818	81 (2)	85 (3)
Brown-headed cowbird	*Molothrus ater*	18 (5.7)	7 (17)	17 (1)	20	81 (29)	71 (9)
Common raven	*Corvus corax*	29 (9.1)	22 (36)	66 (71)	36	301 (40)	237 (33)
European starling	*Sturnus vulgaris*	2 (0.6)	0	5 (40)	5	na	100 (30)
Grasshopper sparrow	*Ammodramus savannarum*	10 (3.1)	1 (100)	14 (86)	14	80	58 (7)
Gray flycatcher	*Empidonax wrightii*	24 (7.5)	3 (0)	27 (89)	30	59 (39)	60 (7)
Green-tailed towhee[a]	*Pipilo chlorurus*	59 (18.6)	86 (83)	65 (89)	152	84 (4)	66 (4)
Horned lark	*Eremophila alpestris*	235 (73.9)	683 (67)	551 (71)	1,221	68 (1)	78 (2)
House sparrow	*Passer domesticus*	4 (1.3)	0	4 (100)	5	na	43 (6)
House finch	*Carpodacus mexicanus*	1 (0.3)	0	4 (100)	4	na	190 (0)
Lark sparrow[a]	*Chondestes gramnacus*	67 (21.1)	99 (88)	34 (82)	133	76 (3)	63 (9)
Lark bunting	*Calamospiza melanocorys*	28 (8.8)	48 (81)	4 (100)	52	86 (5)	103 (27)
Loggerhead shrike	*Lanius ludovicianus*	15 (4.7)	10 (30)	12 (75)	22	66 (19)	90 (12)
Rock wren	*Salpinctes obsoletus*	49 (15.4)	20 (90)	101 (95)	125	125 (13)	135 (9)
Sage sparrow[a]	*Amphispiza belli*	114 (35.8)	192 (84)	117 (93)	307	86 (3)	109 (6)
Sage thrasher[a]	*Oreoscoptes montanus*	199 (62.6)	191 (93)	230 (95)	421	108 (3)	121 (5)
Savannah sparrow	*Passerculus sandwichensis*	25 (7.9)	5 (100)	45 (73)	50	68 (16)	83 (8)
Vesper sparrow[a]	*Pooecetes gramineus*	168 (52.8)	277 (75)	229 (87)	512	81 (2)	87 (3)
Western meadowlark	*Sturnella neglecta*	143 (45.0)	356 (78)	180 (83)	537	97 (2)	105 (6)
White-crowned sparrow	*Zonotrichia leucophrys*	7 (2.2)	0	14 (57)	14	na	80 (9)

[a] Species for which models were developed

TABLE 6.2. Results of AIC_c-based model selection for Brewer's sparrow negative binomial abundance models in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale sagebrush and NDVI; 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 $\Delta AIC_c \leq 2$ are shown.

Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
1	$ABIGSAGE_{1km} + NDVI_{270} + NDVI_{270}^2$	-662.90	5	1336.18	0.00	0.07
2	$ABIGSAGE_{1km} + NDVI + NDVI^2$	-663.11	5	1336.41	0.23	0.06
3	$ABIGSAGE_{540} + NDVI_{270} + NDVI_{270}^2$	-663.24	5	1336.68	0.50	0.05
4	$ABIGSAGE_{540} + NDVI + NDVI^2$	-663.35	5	1336.89	0.71	0.05
5	$ABIGSAGE_{1km} + NDVI_{270}$	-664.48	4	1337.09	0.91	0.04
6	$ABIGSAGE_{1km} + NDVI$	-664.50	4	1337.13	0.95	0.04
7	$ABIGSAGE_{1km} + NDVI_{540} + NDVI_{540}^2$	-663.54	5	1337.27	1.08	0.04
8	$ABIGSAGE_{540} + NDVI_{540} + NDVI_{540}^2$	-663.69	5	1337.57	1.39	0.03
9	$ABIGSAGE_{1km} + NDVI_{540}$	-664.79	4	1337.71	1.53	0.03

[a] Variable definitions provided in Table 4.2

maximize prediction success for each model (Liu et al. 2005). For abundance models, we identified areas where predicted density exceeded that required to support ≥1 individual for each species, based on the largest recorded territory size (lowest density) required by each species, as reported in the "Spacing and Territoriality" section of the Birds of North America (BNA) species accounts (Poole 2005).

For each species, we plotted either density or predicted probability of occurrence relative to changes in sagebrush metrics to assess critical levels of sagebrush habitat required for a species to be present and characterize responses to loss or fragmentation of sagebrush habitat. We used the Dose Response Calculator for ArcGIS tool (Hanser et al. 2011) and plotted the occupancy threshold to identify the critical sagebrush requirement for species occupancy.

Model Evaluation

We evaluated model fit for species using independent data from the Breeding Bird Survey (BBS, Sauer et al. 2011) collected in 2005 and 2006, concurrent with our field sampling. The BBS data were not ideal because counts are conducted along roadsides rather than random transects. Although counts are conducted at discreet locations along a BBS route, the lack of availability of the specific coordinates required the use of aggregated summary data to compare to spatial model results. We used route-level (50 counts spaced 0.8 km apart along the 40-km route unadjusted for detectability) summaries for each of 96 BBS routes within the WBEA to compare summed counts with predicted species density or probability of occurrence averaged across the BBS route (mean of all pixel predictions within 200 m of the route). Model density/probability predictions should have a significant and positive correlation (Spearman Rho) with BBS counts (averaged over the two years).

RESULTS

Field Surveys

We sampled 318 survey blocks in both May and June during the 2005 or 2006 field season (n = 155 in 2005 and 163 in 2006; Table 6.1). Detections varied across species, with as many as 1,221 detections for horned lark (*Eremophila alpestris*) and as

TABLE 6.3. Evaluation statistics from AIC_c-based univariate model selection for Brewer's sparrow negative binomial abundance models 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 models with all big sagebrush (1-km radius) and NDVI (0.27-km radius; quadratic) variables as a base model for variables tested. We used AIC_c to sort models for each variable in ascending order to identify the extent at which Brewer's sparrows respond to individual variables.

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	$CFRST_{1km}$	-658.83	4	1,329.92	0.00	0.75
	$CFRST_{540}$	-660.14	4	1,332.54	2.62	0.20
	$CFRST_{270}$	-661.60	4	1,335.47	5.54	0.05
	$GRASS_{540}$	-659.91	4	1,332.09	0.00	0.29
	$GRASS_{5km}$	-660.19	4	1,332.66	0.56	0.22
	$GRASS_{3km}$	-660.45	4	1,333.17	1.08	0.17
	$GRASS_{1km}$	-660.54	4	1,333.34	1.25	0.16
	$GRASS_{270}$	-660.94	4	1,334.15	2.06	0.10
	$GRASS_{18km}$	-661.67	4	1,335.61	3.51	0.05
	MIX_{18km}	-659.40	4	1,331.07	0.00	0.47
	MIX_{5km}	-659.68	4	1,331.64	0.57	0.35
	MIX_{3km}	-661.18	4	1,334.63	3.56	0.08
	MIX_{1km}	-661.56	4	1,335.38	4.31	0.05
	MIX_{540}	-662.21	4	1,336.70	5.63	0.03
	MIX_{270}	-662.42	4	1,337.12	6.05	0.02
	RIP_{540}	-657.21	4	1,326.69	0.00	0.41
	RIP_{1km}	-657.32	4	1,326.91	0.22	0.37
	RIP_{270}	-658.06	4	1,328.39	1.70	0.18
	RIP_{3km}	-660.33	4	1,332.94	6.25	0.02
	RIP_{18km}	-660.37	4	1,333.00	6.32	0.02
	RIP_{5km}	-660.90	4	1,334.07	7.38	0.01
	$SALT_{18km}$	-662.47	4	1,337.20	0.00	0.23
	$SALT_{1km}$	-662.74	4	1,337.75	0.55	0.18
	$SALT_{3km}$	-662.89	4	1,338.05	0.84	0.15
	$SALT_{540}$	-662.90	4	1,338.08	0.87	0.15
	$SALT_{270}$	-662.94	4	1,338.15	0.95	0.14
	$SALT_{5km}$	-662.94	4	1,338.16	0.96	0.14
	$CONTAG_{5km}$	-661.62	4	1,335.51	0.00	0.35
	$PATCH_{3km}$	-661.88	4	1,336.04	0.53	0.27
	$PATCH_{5km}$	-662.21	4	1,336.69	1.18	0.19
	$EDGE_{5km}$	-662.88	4	1,338.03	2.53	0.10
	$CONTAG_{3km}$	-662.99	4	1,338.26	2.75	0.09

TABLE 6.3. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
Abiotic	CTI	-662.80	4	1,337.88	0.00	1.00
	$ELEV^{2b}$	-652.80	5	1,319.97	0.00	0.96
	ELEV	-657.12	4	1,326.51	6.54	0.04
	$iH2Od_{250}^{c}$	-662.18	4	1,336.63	0.00	0.36
	$iH2Od_{500}^{c}$	-662.19	4	1,336.66	0.02	0.36
	$iH2Od_{1km}^{c}$	-662.42	4	1,337.11	0.48	0.28
	$pH2Od_{1km}^{c}$	-662.88	4	1,338.04	0.00	0.36
	$pH2Od_{250}^{c}$	-662.98	4	1,338.24	0.20	0.32
	$pH2Od_{500}^{c}$	-662.99	4	1,338.26	0.22	0.32
	$SOLAR^{2b}$	-653.84	5	1,322.04	0.00	1.00
	SOLAR	-660.99	4	1,334.25	12.21	0.00
	TRI_{18km}	-650.01	4	1,312.28	0.00	0.81
	TRI_{5km}	-651.62	4	1,315.52	3.23	0.16
	TRI_{3km}	-654.29	4	1,320.85	8.57	0.01
	TRI_{1km}	-654.60	4	1,321.48	9.20	0.01
	TRI_{540}	-655.66	4	1,323.59	11.30	0.00
	TRI_{270}	-656.81	4	1,325.88	13.60	0.00
	TRI	-656.84	4	1,325.94	13.66	0.00
Disturbance	AG_{250}^{c}	-661.58	4	1,335.43	0.00	0.42
	AG_{500}^{c}	-661.77	4	1,335.80	0.37	0.35
	AG_{1km}^{c}	-662.22	4	1,336.71	1.27	0.22
	$MjRD_{250}^{c}$	-662.92	4	1,338.11	0.00	0.34
	$MjRD_{500}^{c}$	-662.94	4	1,338.15	0.04	0.34
	$MjRD_{1km}^{c}$	-662.99	4	1,338.26	0.15	0.32
	$PIPE_{1km}^{c}$	-662.44	4	1,337.15	0.00	0.46
	$PIPE_{500}^{c}$	-662.94	4	1,338.15	1.01	0.28
	$PIPE_{250}^{c}$	-662.96	4	1,338.20	1.05	0.27
	$POWER_{1km}^{c}$	-662.77	4	1,337.81	0.00	0.38
	$POWER_{250}^{c}$	-662.96	4	1,338.19	0.38	0.31
	$POWER_{500}^{c}$	-662.99	4	1,338.24	0.44	0.31
	$RDdens_{18km}$	-661.05	4	1,334.36	0.00	0.29
	$RDdens_{270}$	-661.88	4	1,336.03	1.66	0.13
	$2RD_{500}^{c}$	-661.99	4	1,336.25	1.89	0.11
	$2RD_{250}^{c}$	-662.02	4	1,336.30	1.94	0.11
	$2RD_{1km}^{c}$	-662.04	4	1,336.35	1.99	0.11
	$RDdens_{540}$	-662.07	4	1,336.40	2.04	0.10

TABLE 6.3. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
	$RDdens_{1km}$	-662.77	4	1,337.80	3.44	0.05
	$RDdens_{5km}$	-662.78	4	1,337.82	3.46	0.05
	$RDdens_{3km}$	-662.97	4	1,338.21	3.85	0.04
	$WELL_{250}$[c]	-661.96	4	1,336.19	0.00	0.46
	$WELL_{500}$[c]	-662.30	4	1,336.88	0.69	0.32
	$WELL_{1km}$[c]	-662.70	4	1,337.66	1.47	0.22

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

few as four detections for house finch (*Carpodacus mexicanus*; Table 6.1). Only eight species met our criteria with detection on >50 survey blocks (see Ch. 4; Fig. 6.1), including Brewer's sparrow, green-tailed towhee, horned lark, lark sparrow, sage sparrow, sage thrasher, vesper sparrow, and western meadowlark (Table 6.1). Models for the two grassland species, horned lark and western meadowlark, resulted in non-sensible spatial predictions, possibly as a result of our biased sampling design that targeted sagebrush habitats, and were therefore dropped from further consideration. Of the remaining six species modeled, Brewer's sparrow was most abundant, occurring on 74% of the 318 survey blocks (Table 6.1). Sage thrasher, vesper sparrow, and sage-sparrow were present at more than 1/3 of survey blocks (63%, 53%, and 36%, respectively), with lark sparrow (21%) and green-tailed towhee (19%) having the lowest occurrences of species we modeled (Table 6.1). Total detections across both survey years for modeled species ranged from 133 for lark sparrow to 818 for Brewer's sparrow (Table 6.1).

Detection Probability

Brewer's sparrow

A hazard rate model with a simple polynomial adjustment, 20-m grouping and aggregation of detections <40 m, combined with a truncation distance of 200 m, provided the best fit to the distance data for Brewer's sparrow ($\chi^2_5 = 4.069$, p = 0.54). This resulted in 799 detections being used at 232 of the 318 survey blocks. The top AIC-selected detection model included the base model with covariates for shrub index, observer group, detection type, and survey start time. All other models had ΔAIC values ranging from 1.33 to 72.5. A goodness of fit test could not be estimated for this top Brewer's sparrow model due to limited degrees of freedom. Brewer's sparrow detection probability was low (0.23; 95% CI = 0.22-0.26). The overall density estimate was 0.87 (95% CI = 0.77-0.98) birds/ha. Where present, mean Brewer's sparrow density was 1.19 birds/ha (range: 0.90-5.16).

Green-tailed towhee

The best distance model for green-tailed towhee was a hazard rate model with a simple polynomial adjustment and 25-m groupings. No truncation was required with the farthest detection at 174 m. We used 150 detections occurring at 59 of the 318 survey blocks for this model. The green-tailed towhee model with no covariates had good fit ($\chi^2_3 = 3.04$, p = 0.39), and based on AIC, outcompeted all other distance models fit with covariates; ΔAIC values ranged from 4.38 to 8.33. Detectability was 0.25 (95% CI = 0.20–

TABLE 6.4. Results of AIC_c-based submodel selection for Brewer's sparrow negative binomial abundance models 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 $\Delta AIC_c \leq 2$ are shown.

Category	Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	1	$ABIGSAGE_{1km} + NDVI_{270m} + NDVI_{270m}^2 + CFRST_{1km} + GRASS_{540m} + MIX_{18km} + RIP_{540m} + EDGE_{3km}$	-646.74	8	1,314.20	0.00	0.23
	2	$ABIGSAGE_{1km} + NDVI_{270m} + NDVI_{270m}^2 + CFRST_{1km} + GRASS_{540m} + MIX_{18km} + RIP_{540m} + EDGE_{3km} + SALT_{18km}$	-646.36	9	1,315.58	1.38	0.12
	3	$ABIGSAGE_{1km} + NDVI_{270m} + NDVI_{270m}^2 + CFRST_{1km} + GRASS_{540m} + MIX_{18km} + EDGE_{3km}$	-648.78	7	1,316.14	1.95	0.09
	4	$ABIGSAGE_{1km} + NDVI_{270m} + NDVI_{270m}^2 + CFRST_{1km} + GRASS_{540m} + RIP_{540m} + EDGE_{3km}$	-648.80	7	1,316.18	1.98	0.09
Abiotic	1	$ABIGSAGE_{1km} + NDVI_{270m} + NDVI_{270m}^2 + CTI + ELEV + ELEV^2 + iH2Od_{500} + SOLAR + SOLAR^2 + TRI_{18km}$	-635.23	10	1,295.48	0.00	0.24
	2	$ABIGSAGE_{1km} + NDVI_{270m} + NDVI_{270m}^2 + ELEV + ELEV^2 + pH2Od_{1km} + SOLAR + SOLAR^2 + TRI_{18km}$	-636.74	9	1,296.34	0.86	0.16
	3	$ABIGSAGE_{1km} + NDVI_{270m} + NDVI_{270m}^2 + ELEV + ELEV^2 + iH2Od_{500} + pH2Od_{1km} + SOLAR + SOLAR^2 + TRI_{18km}$	-635.90	10	1,296.83	1.35	0.12
	4	$ABIGSAGE_{1km} + NDVI_{270m} + NDVI_{270m}^2 + CTI + ELEV + ELEV^2 + SLOPE + SOLAR + SOLAR^2 + TRI_{18km}$	-636.03	10	1,297.09	1.61	0.11
	5	$ABIGSAGE_{1km} + NDVI_{270m} + NDVI_{270m}^2 + CTI + ELEV + ELEV^2 + iH2Od_{500} + pH2Od_{1km} + SOLAR + SOLAR^2 + TRI_{18km}$	-635.10	11	1,297.40	1.92	0.09
Disturbance	1	$ABIGSAGE_{1km} + NDVI_{270m} + NDVI_{270m}^2 + AG_{250} + RDdens_{18km}$	-659.16	5	1,332.68	0.00	0.11
	2	$ABIGSAGE_{1km} + NDVI_{270m} + NDVI_{270m}^2 + AG_{250} + RDdens_{18km} + WELL_{250}$	-658.65	6	1,333.76	1.08	0.06
	3	$ABIGSAGE_{1km} + NDVI_{270m} + NDVI_{270m}^2 + AG_{250} + POWER_{1km} + RDdens_{18km}$	-658.83	6	1,334.13	1.45	0.05
	4	$ABIGSAGE_{1km} + NDVI_{270m} + NDVI_{270m}^2 + AG_{250} + PIPE_{1km} + RDdens_{18km}$	-658.94	6	1,334.35	1.67	0.05
	5	$ABIGSAGE_{1km} + NDVI_{270m} + NDVI_{270m}^2 + RDdens_{18km}$	-661.05	4	1,334.36	1.68	0.05
	6	$ABIGSAGE_{1km} + NDVI_{270m} + NDVI_{270m}^2 + AG_{250} + MjRD_{250} + RDdens_{18km}$	-658.97	6	1,334.41	1.73	0.04

[a] Variable definitions provided in Table 4

TABLE 6.5. Results of AIC_c-based model selection for the combined Brewer's sparrow negative binomial abundance 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 shown with cumulative Akaike weight (w_i) just ≥ 0.9.

Rank	Intercept	$ABIGSAGE_{1km}$	$NDVI_{270}$	$NDVI_{270}^2$	ELEV[b]	ELEV[2c]	SOLAR	SOLAR[2d]	TRI_{18km}	$CFRST_{1km}$
1	-11.65 (4.03)	0.82 (0.36)	3.36 (3.51)	0.03 (4.09)	0.26 (0.20)	-0.42 (0.50)	0.09 (0.04)	-0.33 (0.14)	-0.02 (0.01)	-2.31 (1.22)
2	-11.49 (4.05)	0.57 (0.39)	2.91 (3.52)	0.39 (4.10)	0.23 (0.20)	-0.35 (0.50)	0.10 (0.04)	-0.35 (0.14)	-0.02 (0.01)	-2.45 (1.22)
3	-10.10 (3.87)	0.98 (0.34)	3.93 (3.49)	-0.73 (4.07)	0.22 (0.20)	-0.34 (0.50)	0.08 (0.04)	-0.29 (0.14)	-0.02 (0.01)	-2.09 (1.21)
4	-12.59 (4.03)	0.35 (0.37)	4.48 (3.40)	-1.11 (4.02)	0.28 (0.20)	-0.48 (0.50)	0.10 (0.04)	-0.37 (0.14)	-0.02 (0.01)	-2.78 (1.21)
5	-9.86 (3.88)	0.76 (0.38)	3.53 (3.50)	-0.42 (4.07)	0.19 (0.20)	-0.26 (0.50)	0.09 (0.04)	-0.31 (0.14)	-0.02 (0.01)	-2.22 (1.21)
6	-11.78 (4.01)	0.79 (0.36)	3.78 (3.51)	-0.87 (4.14)	0.29 (0.20)	-0.51 (0.50)	0.09 (0.04)	-0.32 (0.14)	-0.02 (0.01)	-2.05 (1.22)
7	-12.95 (4.01)	0.60 (0.34)	5.24 (3.38)	-1.75 (4.01)	0.32 (0.20)	-0.59 (0.49)	0.10 (0.04)	-0.35 (0.14)	-0.02 (0.01)	-2.65 (1.22)
8	-11.61 (4.02)	0.56 (0.39)	3.33 (3.52)	-0.46 (4.16)	0.26 (0.20)	-0.43 (0.51)	0.10 (0.04)	-0.34 (0.14)	-0.02 (0.01)	-2.21 (1.23)
9	-12.69 (4.00)	0.34 (0.37)	4.88 (3.40)	-1.96 (4.07)	0.31 (0.20)	-0.57 (0.50)	0.10 (0.04)	-0.36 (0.14)	-0.02 (0.01)	-2.51 (1.22)
10	-10.12 (3.85)	0.97 (0.34)	4.33 (3.50)	-1.56 (4.13)	0.24 (0.20)	-0.41 (0.50)	0.08 (0.04)	-0.28 (0.14)	-0.02 (0.01)	-1.86 (1.22)
11	-12.29 (3.75)	1.21 (0.32)	4.78 (3.46)	-2.42 (3.95)	0.33 (0.19)	-0.63 (0.47)	0.10 (0.04)	-0.34 (0.14)	-0.02 (0.01)	
12	-9.37 (3.90)	0.91 (0.34)	3.77 (3.48)	-0.44 (4.06)	0.20 (0.20)	-0.30 (0.50)	0.08 (0.04)	-0.28 (0.14)	-0.02 (0.01)	-2.30 (1.22)
13	-9.03 (3.91)	0.66 (0.38)	3.32 (3.49)	-0.07 (4.06)	0.16 (0.20)	-0.21 (0.50)	0.08 (0.04)	-0.30 (0.14)	-0.02 (0.01)	-2.46 (1.22)
14	-13.04 (3.98)	0.58 (0.33)	5.61 (3.38)	-2.65 (4.05)	0.35 (0.20)	-0.68 (0.50)	0.09 (0.04)	-0.33 (0.14)	-0.02 (0.01)	-2.36 (1.22)
15	-13.71 (3.91)	1.02 (0.33)	4.76 (3.46)	-2.79 (3.98)	0.39 (0.19)	-0.79 (0.48)	0.10 (0.04)	-0.36 (0.14)	-0.02 (0.01)	
16	-10.64 (4.10)	0.51 (0.40)	2.80 (3.50)	0.60 (4.08)	0.20 (0.20)	-0.30 (0.50)	0.09 (0.04)	-0.34 (0.14)	-0.02 (0.01)	-2.63 (1.23)
17	-12.02 (3.71)	1.16 (0.32)	5.17 (3.46)	-3.23 (3.98)	0.34 (0.19)	-0.67 (0.47)	0.09 (0.04)	-0.32 (0.14)	-0.02 (0.01)	
18	-11.62 (4.09)	0.29 (0.37)	4.29 (3.39)	-0.82 (4.01)	0.25 (0.20)	-0.43 (0.50)	0.10 (0.04)	-0.35 (0.14)	-0.02 (0.01)	-2.96 (1.22)
19	-10.93 (4.09)	0.78 (0.36)	3.28 (3.49)	0.20 (4.08)	0.24 (0.20)	-0.39 (0.50)	0.09 (0.04)	-0.32 (0.14)	-0.02 (0.01)	-2.45 (1.23)
20	-13.83 (3.96)	1.09 (0.33)	4.37 (3.47)	-1.93 (3.96)	0.37 (0.19)	-0.73 (0.47)	0.11 (0.04)	-0.38 (0.14)	-0.02 (0.01)	
21	-11.96 (4.06)	0.79 (0.36)	3.67 (3.53)	-0.33 (4.11)	0.27 (0.20)	-0.46 (0.50)	0.09 (0.04)	-0.33 (0.14)	-0.02 (0.01)	-2.26 (1.22)
22	-12.87 (4.04)	0.34 (0.37)	4.74 (3.40)	-1.43 (4.02)	0.29 (0.20)	-0.51 (0.50)	0.11 (0.04)	-0.37 (0.14)	-0.02 (0.01)	-2.69 (1.21)
23	-9.89 (3.86)	0.76 (0.38)	3.92 (3.52)	-1.19 (4.14)	0.21 (0.20)	-0.32 (0.50)	0.08 (0.04)	-0.30 (0.14)	-0.02 (0.01)	-2.00 (1.22)
24	-11.79 (4.07)	0.55 (0.39)	3.22 (3.54)	0.04 (4.12)	0.24 (0.20)	-0.38 (0.50)	0.10 (0.04)	-0.35 (0.14)	-0.02 (0.01)	-2.41 (1.22)
25	-10.40 (3.89)	0.96 (0.34)	4.25 (3.52)	-1.09 (4.09)	0.23 (0.20)	-0.37 (0.50)	0.08 (0.04)	-0.29 (0.14)	-0.02 (0.01)	-2.05 (1.21)
26	-12.24 (3.76)	1.03 (0.35)	4.46 (3.47)	-2.23 (3.95)	0.30 (0.19)	-0.57 (0.47)	0.10 (0.04)	-0.37 (0.14)	-0.02 (0.01)	
27	-11 (4.06)	0.74 (0.36)	3.70 (3.49)	-0.72 (4.13)	0.27 (0.20)	-0.48 (0.50)	0.09 (0.04)	-0.30 (0.14)	-0.02 (0.01)	-2.20 (1.23)
28	-9.35 (3.87)	0.89 (0.34)	4.18 (3.48)	-1.31 (4.11)	0.23 (0.20)	-0.37 (0.50)	0.07 (0.04)	-0.26 (0.13)	-0.02 (0.01)	-2.06 (1.23)
29	-13.23 (4.02)	0.59 (0.33)	5.50 (3.38)	-2.09 (4.01)	0.33 (0.20)	-0.62 (0.49)	0.10 (0.04)	-0.35 (0.14)	-0.02 (0.01)	-2.56 (1.21)
30	-11.68 (4.05)	0.28 (0.37)	4.69 (3.39)	-1.69 (4.06)	0.28 (0.20)	-0.51 (0.50)	0.10 (0.04)	-0.34 (0.14)	-0.02 (0.01)	-2.70 (1.22)
31	-3.96 (2.16)	0.96 (0.34)	4.80 (3.43)	-1.73 (3.98)	0.15 (0.19)	-0.16 (0.49)			-0.03 (0.01)	-2.80 (1.15)
32	-10.72 (4.07)	0.50 (0.40)	3.23 (3.51)	-0.28 (4.14)	0.23 (0.20)	-0.39 (0.51)	0.09 (0.04)	-0.32 (0.14)	-0.02 (0.01)	-2.39 (1.23)
33	-13.86 (3.97)	0.89 (0.36)	4.02 (3.48)	-1.72 (3.96)	0.34 (0.19)	-0.67 (0.47)	0.11 (0.04)	-0.41 (0.14)	-0.02 (0.01)	
34	-12.12 (4.08)	0.57 (0.34)	5.09 (3.37)	-1.52 (4.00)	0.30 (0.20)	-0.55 (0.49)	0.09 (0.04)	-0.33 (0.14)	-0.02 (0.01)	-2.80 (1.23)
35	-13.74 (3.93)	0.84 (0.36)	4.43 (3.47)	-2.57 (3.99)	0.37 (0.19)	-0.74 (0.48)	0.11 (0.04)	-0.39 (0.14)	-0.02 (0.01)	
36	-10.15 (3.91)	0.74 (0.38)	3.84 (3.53)	-0.77 (4.10)	0.20 (0.20)	-0.29 (0.50)	0.09 (0.04)	-0.31 (0.14)	-0.02 (0.01)	-2.17 (1.21)
37	-9.02 (3.88)	0.66 (0.38)	3.73 (3.50)	-0.89 (4.12)	0.19 (0.20)	-0.28 (0.50)	0.08 (0.04)	-0.28 (0.14)	-0.02 (0.01)	-2.24 (1.23)
38	-12.03 (4.03)	0.77 (0.36)	4.04 (3.53)	-1.15 (4.16)	0.30 (0.20)	-0.53 (0.51)	0.09 (0.04)	-0.32 (0.14)	-0.02 (0.01)	-2.02 (1.22)
39	-11.99 (3.72)	1.00 (0.35)	4.86 (3.47)	-3.02 (3.98)	0.32 (0.19)	-0.62 (0.47)	0.09 (0.04)	-0.34 (0.14)	-0.02 (0.01)	
40	-11.81 (4.09)	0.28 (0.37)	4.56 (3.39)	-1.16 (4.01)	0.26 (0.20)	-0.45 (0.50)	0.10 (0.04)	-0.35 (0.14)	-0.02 (0.01)	-2.88 (1.21)
41	-10.81 (3.90)	0.52 (0.36)	5.87 (3.36)	-2.73 (3.96)	0.24 (0.20)	-0.40 (0.50)	0.09 (0.04)	-0.32 (0.14)	-0.02 (0.01)	-2.58 (1.21)
42	-12.15 (4.04)	0.54 (0.34)	5.47 (3.37)	-2.43 (4.04)	0.33 (0.20)	-0.63 (0.50)	0.09 (0.04)	-0.32 (0.14)	-0.02 (0.01)	-2.52 (1.23)

TABLE 6.5. Extended

MIX_{18km}	RIP_{540m}	$RDdens_{18km}$	$GRASS_{540m}$	AG_{250}	$EDGE_{3km}$[b]	$iH2Od_{500}$	LL	K	AIC_c	ΔAIC_c	$\sum w_i$
-24.50 (7.98)	1.61 (0.92)	0.29 (0.18)					-625.58	12	1,280.56	0.00	0.028
-23.57 (8.00)	1.43 (0.92)	0.30 (0.18)	-1.07 (0.76)				-624.56	13	1,280.71	0.15	0.051
-23.34 (7.97)	1.96 (0.89)						-626.79	11	1,280.78	0.23	0.073
-24.96 (8.00)		0.37 (0.18)	-1.23 (0.76)				-625.78	12	1,280.94	0.38	0.094
-22.41 (7.98)	1.81 (0.90)		-1.01 (0.76)				-625.89	12	1,281.16	0.61	0.113
-24.10 (7.97)	1.55 (0.91)	0.31 (0.18)		1.13 (0.90)			-624.79	13	1,281.18	0.62	0.131
-26.26 (7.99)		0.37 (0.18)					-627.14	11	1,281.48	0.92	0.147
-23.27 (7.98)	1.39 (0.92)	0.32 (0.18)	-1.00 (0.76)	1.02 (0.90)			-623.91	14	1,281.63	1.07	0.162
-24.61 (7.98)		0.39 (0.18)	-1.15 (0.76)	1.08 (0.91)			-625.07	13	1,281.73	1.17	0.176
-22.90 (7.95)	1.93 (0.89)			0.99 (0.90)			-626.18	12	1,281.74	1.18	0.189
-24.42 (7.97)	2.17 (0.89)						-628.36	10	1,281.74	1.19	0.203
-22.11 (8.03)	1.87 (0.89)				-0.30 (0.28)		-626.20	12	1,281.79	1.24	0.217
-20.97 (8.05)	1.70 (0.90)		-1.09 (0.76)		-0.34 (0.28)		-625.14	13	1,281.88	1.32	0.230
-25.77 (7.98)		0.39 (0.18)		1.21 (0.91)			-626.25	12	1,281.90	1.34	0.243
-24.88 (7.98)	1.79 (0.90)	0.28 (0.18)		1.38 (0.90)			-626.26	12	1,281.92	1.36	0.255
-22.29 (8.08)	1.38 (0.92)	0.27 (0.19)	-1.13 (0.76)		-0.28 (0.28)		-624.07	14	1,281.95	1.39	0.268
-23.72 (7.96)	2.11 (0.88)			1.23 (0.89)			-627.39	11	1,281.97	1.42	0.280
-23.49 (8.10)		0.34 (0.18)	-1.29 (0.76)		-0.30 (0.28)		-625.21	13	1,282.00	1.45	0.292
-23.43 (8.07)	1.57 (0.91)	0.26 (0.19)			-0.24 (0.28)		-625.22	13	1,282.02	1.46	0.304
-25.51 (8.00)	1.89 (0.91)	0.25 (0.18)					-627.47	11	1,282.13	1.58	0.316
-24.50 (7.97)	1.50 (0.92)	0.29 (0.18)				0.14 (0.18)	-625.30	13	1,282.19	1.63	0.327
-24.85 (7.98)		0.37 (0.18)	-1.21 (0.76)			0.17 (0.18)	-625.32	13	1,282.23	1.67	0.338
-22.08 (7.97)	1.79 (0.89)		-0.94 (0.76)	0.89 (0.90)			-625.40	13	1,282.38	1.82	0.348
-23.57 (7.98)	1.33 (0.93)	0.30 (0.18)	-1.06 (0.76)			0.13 (0.18)	-624.29	14	1,282.39	1.83	0.358
-23.34 (7.96)	1.85 (0.90)					0.13 (0.18)	-626.52	12	1,282.42	1.86	0.368
-23.63 (7.99)	2.06 (0.89)		-0.90 (0.76)				-627.65	11	1,282.51	1.95	0.377
-22.92 (8.05)	1.51 (0.91)	0.28 (0.19)		1.17 (0.90)	-0.26 (0.28)		-624.36	14	1,282.52	1.97	0.387
-21.56 (8.02)	1.84 (0.89)			1.06 (0.89)	-0.32 (0.28)		-625.50	13	1,282.58	2.02	0.396
-26.12 (7.97)		0.36 (0.18)				0.18 (0.18)	-626.63	12	1,282.64	2.08	0.405
-23.06 (8.08)		0.36 (0.18)	-1.21 (0.76)	1.12 (0.90)	-0.32 (0.28)		-624.43	14	1,282.68	2.12	0.413
-22.81 (8.02)	2.02 (0.90)						-629.91	9	1,282.69	2.14	0.422
-21.92 (8.06)	1.34 (0.92)	0.29 (0.19)	-1.06 (0.76)	1.06 (0.90)	-0.29 (0.28)		-623.36	15	1,282.77	2.21	0.430
-24.72 (8.01)	1.76 (0.91)	0.25 (0.18)	-0.94 (0.77)				-626.69	12	1,282.77	2.21	0.438
-25.02 (8.09)		0.34 (0.18)			-0.26 (0.28)		-626.71	12	1,282.80	2.24	0.447
-24.20 (7.99)	1.67 (0.91)	0.28 (0.18)	-0.85 (0.76)	1.30 (0.90)			-625.62	13	1,282.83	2.27	0.455
-22.41 (7.97)	1.70 (0.91)		-1.00 (0.76)			0.13 (0.18)	-625.63	13	1,282.85	2.29	0.463
-20.56 (8.03)	1.68 (0.89)		-1.02 (0.76)	0.95 (0.89)	-0.36 (0.28)		-624.57	14	1,282.95	2.39	0.470
-24.12 (7.96)	1.46 (0.92)	0.31 (0.18)		1.08 (0.90)		0.12 (0.18)	-624.58	14	1,282.96	2.40	0.478
-23.05 (7.97)	2.01 (0.89)		-0.82 (0.76)	1.16 (0.89)			-626.80	12	1,282.99	2.44	0.485
-23.20 (8.07)		0.33 (0.18)	-1.27 (0.76)		-0.34 (0.28)	0.20 (0.18)	-624.60	14	1,283.01	2.45	0.493
-23.90 (8.03)			-1.20 (0.76)				-627.94	11	1,283.08	2.52	0.500
-24.42 (8.07)		0.36 (0.18)		1.25 (0.91)	-0.28 (0.28)		-625.75	13	1,283.08	2.53	0.507

TABLE 6.5. Continued

Rank	Intercept	$ABIGSAGE_{1km}$	$NDVI_{270}$	$NDVI_{270}^2$	$ELEV^b$	$ELEV^{2c}$	SOLAR	$SOLAR^{2d}$	TRI_{18km}	$CFRST_{1km}$
43	-9.65 (3.91)	0.88 (0.35)	4.13 (3.50)	-0.85 (4.07)	0.21 (0.20)	-0.33 (0.50)	0.08 (0.04)	-0.28 (0.14)	-0.02 (0.01)	-2.27 (1.22)
44	-12.92 (4.01)	0.34 (0.37)	5.09 (3.41)	-2.21 (4.07)	0.32 (0.20)	-0.58 (0.50)	0.10 (0.04)	-0.36 (0.14)	-0.02 (0.01)	-2.45 (1.22)
45	-12.57 (3.76)	1.19 (0.32)	5.11 (3.49)	-2.78 (3.97)	0.34 (0.19)	-0.66 (0.47)	0.10 (0.04)	-0.34 (0.14)	-0.02 (0.01)	
46	-4.26 (2.17)	0.94 (0.34)	5.15 (3.43)	-2.56 (4.03)	0.18 (0.19)	-0.24 (0.49)			-0.03 (0.01)	-2.53 (1.16)
47	-13.28 (3.99)	0.57 (0.33)	5.83 (3.38)	-2.90 (4.05)	0.36 (0.20)	-0.69 (0.50)	0.10 (0.04)	-0.34 (0.14)	-0.02 (0.01)	-2.30 (1.22)
48	-9.78 (3.92)	0.43 (0.36)	5.45 (3.35)	-2.16 (3.96)	0.21 (0.20)	-0.34 (0.50)	0.08 (0.04)	-0.31 (0.14)	-0.02 (0.01)	-2.84 (1.22)
49	-11.94 (3.75)	1.18 (0.32)	4.73 (3.45)	-2.34 (3.94)	0.32 (0.19)	-0.63 (0.46)	0.09 (0.04)	-0.34 (0.14)	-0.02 (0.01)	
50	-11.60 (3.71)	1.12 (0.32)	5.13 (3.45)	-3.19 (3.96)	0.34 (0.19)	-0.67 (0.47)	0.09 (0.04)	-0.32 (0.13)	-0.02 (0.01)	
51	-10.89 (4.11)	0.48 (0.40)	3.15 (3.52)	0.20 (4.10)	0.22 (0.20)	-0.33 (0.50)	0.09 (0.04)	-0.34 (0.14)	-0.02 (0.01)	-2.60 (1.23)
52	-11.86 (4.04)	0.54 (0.39)	3.58 (3.54)	-0.74 (4.17)	0.27 (0.20)	-0.46 (0.51)	0.10 (0.04)	-0.34 (0.14)	-0.02 (0.01)	-2.18 (1.22)
53	-11.18 (4.10)	0.74 (0.36)	3.63 (3.51)	-0.20 (4.10)	0.25 (0.20)	-0.42 (0.50)	0.09 (0.04)	-0.32 (0.14)	-0.02 (0.01)	-2.42 (1.23)
54	-11.21 (3.89)	0.77 (0.33)	6.60 (3.34)	-3.35 (3.95)	0.29 (0.20)	-0.52 (0.50)	0.08 (0.04)	-0.30 (0.14)	-0.03 (0.01)	-2.46 (1.22)
55	-3.50 (2.19)	0.88 (0.35)	4.64 (3.42)	-1.46 (3.97)	0.13 (0.19)	-0.13 (0.49)			-0.03 (0.01)	-3.01 (1.17)
56	-10.38 (3.87)	0.95 (0.34)	4.59 (3.52)	-1.84 (4.15)	0.25 (0.20)	-0.43 (0.50)	0.08 (0.04)	-0.28 (0.14)	-0.02 (0.01)	-1.83 (1.22)
57	-4.39 (2.19)	0.84 (0.36)	4.39 (3.44)	-1.19 (4.00)	0.18 (0.19)	-0.22 (0.49)			-0.03 (0.01)	-2.98 (1.16)
58	-13.97 (3.93)	0.99 (0.33)	5.03 (3.48)	-3.07 (4.00)	0.40 (0.19)	-0.81 (0.48)	0.10 (0.04)	-0.36 (0.14)	-0.02 (0.01)	
59	-14.13 (3.97)	1.06 (0.33)	4.70 (3.49)	-2.29 (3.98)	0.38 (0.19)	-0.76 (0.47)	0.11 (0.04)	-0.39 (0.14)	-0.02 (0.01)	
60	-12.27 (3.73)	1.14 (0.32)	5.43 (3.48)	-3.51 (4.00)	0.35 (0.19)	-0.70 (0.47)	0.09 (0.04)	-0.32 (0.14)	-0.02 (0.01)	
61	-13.26 (3.94)	1.00 (0.33)	4.77 (3.45)	-2.80 (3.97)	0.38 (0.19)	-0.78 (0.47)	0.10 (0.04)	-0.36 (0.14)	-0.02 (0.01)	
62	-15.58 (3.86)	0.81 (0.32)	7.09 (3.30)	-5.23 (3.84)	0.48 (0.19)	-1.04 (0.46)	0.11 (0.04)	-0.39 (0.14)	-0.02 (0.01)	
63	-12.31 (4.08)	0.55 (0.34)	5.37 (3.37)	-1.87 (4.00)	0.31 (0.20)	-0.57 (0.49)	0.09 (0.04)	-0.33 (0.14)	-0.02 (0.01)	-2.72 (1.22)
64	-4.78 (2.21)	0.81 (0.36)	4.73 (3.44)	-2.04 (4.04)	0.21 (0.20)	-0.32 (0.50)			-0.03 (0.01)	-2.71 (1.16)
65	-3.78 (2.19)	0.86 (0.35)	5.01 (3.42)	-2.32 (4.01)	0.16 (0.19)	-0.21 (0.49)			-0.03 (0.01)	-2.75 (1.17)
66	-3.52 (2.21)	0.79 (0.38)	4.56 (3.44)	-1.58 (3.98)	0.13 (0.20)	-0.10 (0.49)			-0.03 (0.01)	-2.94 (1.16)
67	-11.85 (4.05)	0.27 (0.37)	4.92 (3.39)	-1.95 (4.05)	0.29 (0.20)	-0.53 (0.50)	0.10 (0.04)	-0.34 (0.14)	-0.02 (0.01)	-2.64 (1.22)
68	-11.85 (3.76)	0.98 (0.35)	4.39 (3.46)	-2.14 (3.93)	0.30 (0.19)	-0.57 (0.47)	0.10 (0.04)	-0.36 (0.14)	-0.02 (0.01)	
69	-13.46 (3.99)	1.07 (0.33)	4.36 (3.46)	-1.91 (3.95)	0.36 (0.19)	-0.72 (0.47)	0.11 (0.04)	-0.38 (0.14)	-0.02 (0.01)	
70	-15.46 (3.87)	0.62 (0.35)	6.52 (3.33)	-4.76 (3.85)	0.45 (0.19)	-0.96 (0.47)	0.12 (0.04)	-0.42 (0.14)	-0.02 (0.01)	
71	-12.51 (3.77)	1.00 (0.35)	4.78 (3.49)	-2.58 (3.97)	0.31 (0.19)	-0.60 (0.47)	0.10 (0.04)	-0.37 (0.14)	-0.02 (0.01)	
72	-10.31 (3.91)	0.70 (0.33)	6.27 (3.33)	-2.87 (3.94)	0.26 (0.20)	-0.47 (0.49)	0.08 (0.04)	-0.29 (0.14)	-0.03 (0.01)	-2.69 (1.23)
73	-10.05 (3.93)	0.41 (0.36)	5.71 (3.34)	-2.48 (3.95)	0.22 (0.20)	-0.37 (0.50)	0.08 (0.04)	-0.31 (0.14)	-0.02 (0.01)	-2.76 (1.21)
74	-9.59 (3.88)	0.87 (0.34)	4.49 (3.50)	-1.64 (4.13)	0.24 (0.20)	-0.40 (0.50)	0.07 (0.04)	-0.27 (0.13)	-0.02 (0.01)	-2.05 (1.23)
75	-11.22 (4.07)	0.72 (0.36)	4.01 (3.51)	-1.05 (4.14)	0.28 (0.20)	-0.50 (0.50)	0.09 (0.04)	-0.30 (0.14)	-0.02 (0.01)	-2.18 (1.23)
76	-10.14 (3.88)	0.74 (0.38)	4.18 (3.54)	-1.47 (4.16)	0.22 (0.20)	-0.35 (0.51)	0.08 (0.04)	-0.30 (0.14)	-0.02 (0.01)	-1.97 (1.22)
77	-12.32 (4.04)	0.52 (0.34)	5.70 (3.36)	-2.70 (4.04)	0.34 (0.20)	-0.65 (0.50)	0.09 (0.04)	-0.32 (0.14)	-0.02 (0.01)	-2.46 (1.22)
78	-11.13 (3.91)	0.51 (0.36)	6.13 (3.36)	-3.05 (3.97)	0.26 (0.20)	-0.44 (0.50)	0.09 (0.04)	-0.32 (0.14)	-0.02 (0.01)	-2.49 (1.21)
79	-11.54 (3.72)	0.94 (0.35)	4.81 (3.46)	-2.97 (3.97)	0.31 (0.19)	-0.62 (0.47)	0.09 (0.04)	-0.34 (0.14)	-0.02 (0.01)	
80	-10.83 (3.88)	0.52 (0.36)	6.25 (3.37)	-3.51 (4.03)	0.27 (0.20)	-0.47 (0.50)	0.09 (0.04)	-0.31 (0.14)	-0.02 (0.01)	-2.35 (1.22)
81	-14.15 (3.99)	0.86 (0.37)	4.34 (3.50)	-2.07 (3.98)	0.36 (0.19)	-0.70 (0.48)	0.11 (0.04)	-0.41 (0.14)	-0.02 (0.01)	
82	-9.77 (3.89)	0.43 (0.36)	5.85 (3.35)	-2.98 (4.02)	0.24 (0.20)	-0.41 (0.50)	0.08 (0.04)	-0.29 (0.14)	-0.02 (0.01)	-2.61 (1.23)
83	-11.22 (3.86)	0.76 (0.33)	6.97 (3.34)	-4.18 (4.01)	0.31 (0.20)	-0.59 (0.50)	0.08 (0.04)	-0.29 (0.14)	-0.03 (0.01)	-2.21 (1.22)
84	-15.69 (3.93)	0.66 (0.35)	6.18 (3.34)	-3.95 (3.83)	0.43 (0.19)	-0.90 (0.46)	0.12 (0.04)	-0.44 (0.15)	-0.02 (0.01)	
85	-15.82 (3.91)	0.88 (0.32)	6.81 (3.32)	-4.42 (3.83)	0.46 (0.18)	-0.98 (0.46)	0.12 (0.04)	-0.42 (0.14)	-0.02 (0.01)	
86	-4.19 (2.19)	0.94 (0.34)	5.09 (3.46)	-2.07 (4.01)	0.17 (0.19)	-0.19 (0.49)			-0.03 (0.01)	-2.76 (1.15)
87	-2.97 (2.23)	0.69 (0.39)	4.37 (3.42)	-1.26 (3.97)	0.10 (0.19)	-0.05 (0.49)			-0.03 (0.01)	-3.20 (1.17)

TABLE 6.5. Extended

MIX_{18km}	RIP_{540m}	$RDdens_{18km}$	$GRASS_{540m}$	AG_{250}	$EDGE_{3km}$[b]	$iH2Od_{500}$	LL	K	AIC_c	ΔAIC_c	Σw_i
-21.98 (8.01)	1.73 (0.90)				-0.33 (0.28)	0.16 (0.18)	-625.80	13	1,283.19	2.63	0.514
-24.53 (7.97)		0.38 (0.18)	-1.13 (0.76)	1.01 (0.91)		0.16 (0.18)	-624.69	14	1,283.19	2.64	0.520
-24.39 (7.96)	2.05 (0.90)					0.15 (0.18)	-628.02	11	1,283.23	2.68	0.527
-22.32 (7.99)	1.99 (0.90)			1.12 (0.89)			-629.11	10	1,283.24	2.68	0.533
-25.67 (7.96)		0.38 (0.18)		1.14 (0.91)		0.16 (0.18)	-625.84	13	1,283.27	2.72	0.540
-22.10 (8.11)			-1.28 (0.76)		-0.39 (0.28)		-626.96	12	1,283.31	2.75	0.546
-23.62 (8.03)	2.13 (0.89)				-0.21 (0.27)		-628.06	11	1,283.32	2.76	0.552
-22.74 (8.01)	2.06 (0.88)			1.30 (0.89)	-0.25 (0.27)		-626.97	12	1,283.34	2.78	0.559
-22.16 (8.06)	1.25 (0.93)	0.27 (0.18)	-1.13 (0.76)		-0.31 (0.28)	0.16 (0.18)	-623.69	15	1,283.42	2.86	0.565
-23.29 (7.97)	1.30 (0.93)	0.32 (0.18)	-0.99 (0.76)	0.98 (0.90)		0.12 (0.18)	-623.70	15	1,283.44	2.88	0.571
-23.29 (8.05)	1.44 (0.92)	0.26 (0.18)			-0.27 (0.28)	0.16 (0.18)	-624.83	14	1,283.46	2.91	0.576
-25.19 (8.03)							-629.23	10	1,283.47	2.92	0.582
-21.50 (8.08)	1.93 (0.90)				-0.33 (0.28)		-629.23	10	1,283.48	2.92	0.588
-22.92 (7.95)	1.83 (0.90)			0.94 (0.90)		0.12 (0.18)	-625.96	13	1,283.51	2.95	0.594
-23.60 (8.03)	1.77 (0.92)	0.21 (0.18)					-629.26	10	1,283.54	2.98	0.600
-24.88 (7.97)	1.68 (0.91)	0.28 (0.18)		1.33 (0.90)		0.13 (0.18)	-626.01	13	1,283.60	3.05	0.605
-25.49 (7.99)	1.76 (0.92)	0.25 (0.18)				0.15 (0.18)	-627.11	12	1,283.61	3.06	0.610
-23.72 (7.95)	2.00 (0.89)			1.18 (0.89)		0.13 (0.18)	-627.14	12	1,283.66	3.10	0.616
-24.06 (8.06)	1.77 (0.90)	0.26 (0.19)		1.42 (0.90)	-0.19 (0.28)		-626.03	13	1,283.66	3.10	0.621
-27.02 (7.99)		0.37 (0.18)		1.53 (0.91)			-628.23	11	1,283.67	3.11	0.626
-24.68 (8.06)		0.33 (0.18)			-0.30 (0.28)	0.21 (0.18)	-626.05	13	1,283.69	3.14	0.632
-23.16 (8.00)	1.71 (0.92)	0.23 (0.18)		1.24 (0.89)			-628.29	11	1,283.77	3.22	0.637
-20.90 (8.05)	1.89 (0.89)			1.19 (0.88)	-0.35 (0.28)		-628.32	11	1,283.83	3.28	0.641
-22.11 (8.04)	1.91 (0.91)		-0.75 (0.76)				-629.41	10	1,283.85	3.29	0.646
-22.81 (8.06)		0.34 (0.18)	-1.19 (0.76)	1.05 (0.90)	-0.35 (0.28)	0.18 (0.18)	-623.92	15	1,283.88	3.33	0.651
-22.70 (8.05)	2.00 (0.89)		-0.94 (0.76)		-0.24 (0.27)		-627.28	12	1,283.95	3.39	0.656
-24.85 (8.08)	1.88 (0.91)	0.23 (0.19)			-0.15 (0.28)		-627.31	12	1,284.02	3.46	0.660
-26.04 (8.00)		0.37 (0.18)	-1.02 (0.76)	1.42 (0.91)			-627.32	12	1,284.02	3.47	0.665
-23.61 (7.98)	1.93 (0.90)		-0.89 (0.76)			0.15 (0.18)	-627.33	12	1,284.04	3.48	0.669
-23.61 (8.10)					-0.35 (0.28)		-628.43	11	1,284.06	3.51	0.673
-21.84 (8.08)			-1.26 (0.76)		-0.43 (0.28)	0.21 (0.18)	-626.24	13	1,284.07	3.52	0.678
-21.47 (8.00)	1.71 (0.90)			1.01 (0.89)	-0.35 (0.28)	0.15 (0.18)	-625.16	14	1,284.13	3.57	0.682
-22.82 (8.04)	1.39 (0.92)	0.28 (0.19)		1.12 (0.90)	-0.29 (0.28)	0.14 (0.18)	-624.05	15	1,284.13	3.58	0.686
-22.10 (7.96)	1.70 (0.90)		-0.94 (0.76)	0.84 (0.90)		0.12 (0.18)	-625.19	14	1,284.18	3.62	0.690
-24.14 (8.05)		0.34 (0.18)		1.18 (0.91)	-0.32 (0.28)	0.19 (0.18)	-625.20	14	1,284.21	3.66	0.694
-23.81 (8.01)			-1.17 (0.76)			0.18 (0.18)	-627.41	12	1,284.21	3.66	0.698
-21.97 (8.03)	1.94 (0.89)		-0.86 (0.76)	1.23 (0.89)	-0.27 (0.27)		-626.32	13	1,284.22	3.67	0.702
-23.56 (8.02)			-1.13 (0.76)	0.91 (0.91)			-627.43	12	1,284.24	3.69	0.706
-24.70 (8.00)	1.63 (0.92)	0.26 (0.18)	-0.93 (0.76)			0.15 (0.18)	-626.35	13	1,284.29	3.73	0.710
-21.65 (8.10)			-1.21 (0.76)	0.99 (0.90)	-0.41 (0.28)		-626.36	13	1,284.30	3.75	0.714
-24.70 (8.01)				1.04 (0.91)			-628.56	11	1,284.32	3.77	0.718
-26.71 (8.03)		0.34 (0.18)	-1.12 (0.77)				-628.56	11	1,284.32	3.77	0.721
-27.86 (8.02)		0.34 (0.18)					-629.66	10	1,284.35	3.79	0.725
-22.81 (8.01)	1.92 (0.91)					0.12 (0.18)	-629.68	10	1,284.38	3.83	0.729
-20.62 (8.10)	1.80 (0.91)		-0.84 (0.76)		-0.35 (0.28)		-623.05	16	1,284.38	3.83	0.733

TABLE 6.5. Continued

Rank	Intercept	$ABIGSAGE_{1km}$	$NDVI_{270}$	$NDVI_{270}^2$	$ELEV^b$	$ELEV^{2c}$	SOLAR	$SOLAR^{2d}$	TRI_{18km}	$CFRST_{1km}$
88	-11.54 (3.90)	0.76 (0.33)	6.86 (3.34)	-3.68 (3.95)	0.30 (0.20)	-0.55 (0.50)	0.08 (0.04)	-0.30 (0.14)	-0.03 (0.01)	-2.37 (1.21)
89	-13.25 (3.96)	0.81 (0.37)	4.43 (3.46)	-2.56 (3.98)	0.36 (0.19)	-0.73 (0.48)	0.11 (0.04)	-0.38 (0.14)	-0.02 (0.01)	
90	-9.26 (3.89)	0.63 (0.38)	4.04 (3.51)	-1.22 (4.14)	0.20 (0.20)	-0.31 (0.50)	0.08 (0.04)	-0.28 (0.14)	-0.02 (0.01)	-2.23 (1.23)
91	-13.99 (3.94)	0.82 (0.37)	4.70 (3.49)	-2.84 (4.00)	0.38 (0.19)	-0.76 (0.48)	0.11 (0.04)	-0.39 (0.14)	-0.02 (0.01)	
92	-13.44 (4.01)	0.87 (0.36)	4.00 (3.47)	-1.69 (3.95)	0.34 (0.19)	-0.66 (0.47)	0.11 (0.04)	-0.40 (0.14)	-0.02 (0.01)	
93	-3.85 (2.22)	0.79 (0.38)	4.93 (3.44)	-2.38 (4.03)	0.16 (0.20)	-0.18 (0.50)			-0.03 (0.01)	-2.68 (1.16)
94	-3.96 (2.23)	0.66 (0.40)	4.14 (3.45)	-1.01 (4.00)	0.15 (0.20)	-0.16 (0.50)			-0.03 (0.01)	-3.14 (1.17)
95	-12.20 (3.76)	1.14 (0.32)	5.10 (3.47)	-2.74 (3.95)	0.33 (0.19)	-0.66 (0.47)	0.09 (0.04)	-0.34 (0.14)	-0.02 (0.01)	
96	-3.93 (2.23)	0.79 (0.36)	4.30 (3.43)	-1.01 (3.99)	0.16 (0.19)	-0.19 (0.49)			-0.03 (0.01)	-3.15 (1.17)
97	-12.23 (3.74)	0.98 (0.35)	5.12 (3.49)	-3.29 (4.00)	0.33 (0.19)	-0.64 (0.47)	0.10 (0.04)	-0.34 (0.14)	-0.02 (0.01)	
98	-10.58 (3.92)	0.68 (0.33)	6.52 (3.32)	-3.19 (3.94)	0.27 (0.20)	-0.50 (0.49)	0.08 (0.04)	-0.29 (0.14)	-0.02 (0.01)	-2.61 (1.22)
99	-10.27 (3.88)	0.68 (0.33)	6.65 (3.33)	-3.73 (4.00)	0.29 (0.20)	-0.54 (0.50)	0.08 (0.04)	-0.27 (0.14)	-0.03 (0.01)	-2.43 (1.23)
100	-4.30 (2.24)	0.75 (0.36)	4.65 (3.42)	-1.88 (4.02)	0.19 (0.20)	-0.28 (0.50)			-0.03 (0.01)	-2.88 (1.17)
101	-15.78 (3.86)	0.80 (0.32)	7.29 (3.30)	-5.43 (3.83)	0.49 (0.19)	-1.05 (0.46)	0.11 (0.04)	-0.39 (0.14)	-0.02 (0.01)	
102	-11.84 (3.72)	1.09 (0.32)	5.45 (3.46)	-3.51 (3.98)	0.35 (0.19)	-0.70 (0.47)	0.09 (0.04)	-0.32 (0.13)	-0.02 (0.01)	
103	-3.73 (2.20)	0.85 (0.35)	5.00 (3.44)	-1.85 (3.99)	0.15 (0.19)	-0.16 (0.49)			-0.03 (0.01)	-2.99 (1.16)
104	-3.29 (2.24)	0.68 (0.39)	4.75 (3.42)	-2.10 (4.01)	0.13 (0.20)	-0.14 (0.50)			-0.03 (0.01)	-2.93 (1.18)
105	-4.44 (2.19)	0.93 (0.34)	5.39 (3.46)	-2.83 (4.05)	0.19 (0.20)	-0.26 (0.49)			-0.03 (0.01)	-2.51 (1.16)
106	-4.37 (2.25)	0.65 (0.39)	4.49 (3.45)	-1.84 (4.04)	0.19 (0.20)	-0.26 (0.50)			-0.03 (0.01)	-2.87 (1.17)
107	-5.31 (2.16)	0.61 (0.34)	6.46 (3.32)	-3.16 (3.92)	0.24 (0.19)	-0.39 (0.49)			-0.03 (0.01)	-3.39 (1.16)
108	-5.68 (2.18)	0.58 (0.34)	6.75 (3.31)	-4.00 (3.95)	0.28 (0.19)	-0.49 (0.49)			-0.03 (0.01)	-3.08 (1.16)
109	-16.05 (3.92)	0.86 (0.31)	7.06 (3.32)	-4.71 (3.82)	0.47 (0.18)	-1.00 (0.46)	0.12 (0.04)	-0.42 (0.14)	-0.02 (0.01)	
110	-13.48 (3.95)	0.97 (0.33)	5.07 (3.47)	-3.11 (3.99)	0.39 (0.19)	-0.81 (0.47)	0.10 (0.04)	-0.36 (0.14)	-0.02 (0.01)	
111	-4.61 (2.22)	0.82 (0.36)	4.68 (3.47)	-1.52 (4.03)	0.19 (0.20)	-0.25 (0.49)			-0.03 (0.01)	-2.94 (1.16)
112	-15.66 (3.88)	0.61 (0.34)	6.71 (3.32)	-4.96 (3.85)	0.46 (0.19)	-0.97 (0.47)	0.12 (0.04)	-0.42 (0.14)	-0.02 (0.01)	
113	-15.91 (3.93)	0.65 (0.35)	6.43 (3.34)	-4.24 (3.83)	0.44 (0.19)	-0.91 (0.46)	0.12 (0.04)	-0.44 (0.15)	-0.02 (0.01)	
114	-10.02 (3.90)	0.41 (0.36)	6.06 (3.35)	-3.22 (4.01)	0.25 (0.20)	-0.44 (0.50)	0.08 (0.04)	-0.29 (0.14)	-0.02 (0.01)	-2.55 (1.22)
115	-12.11 (3.77)	0.95 (0.36)	4.75 (3.48)	-2.53 (3.95)	0.31 (0.19)	-0.60 (0.47)	0.10 (0.04)	-0.36 (0.14)	-0.02 (0.01)	
116	-15.07 (3.90)	0.80 (0.32)	7.07 (3.29)	-5.20 (3.83)	0.47 (0.19)	-1.03 (0.46)	0.11 (0.04)	-0.38 (0.14)	-0.02 (0.01)	
117	-13.71 (4.00)	1.04 (0.33)	4.73 (3.48)	-2.30 (3.97)	0.37 (0.19)	-0.75 (0.47)	0.11 (0.04)	-0.38 (0.14)	-0.02 (0.01)	
118	-3.98 (2.21)	0.84 (0.35)	5.31 (3.44)	-2.64 (4.03)	0.17 (0.19)	-0.23 (0.49)			-0.03 (0.01)	-2.74 (1.17)
119	-11.52 (3.87)	0.75 (0.33)	7.19 (3.34)	-4.42 (4.01)	0.32 (0.20)	-0.61 (0.50)	0.08 (0.04)	-0.29 (0.14)	-0.03 (0.01)	-2.14 (1.22)
120	-3.41 (2.27)	0.58 (0.40)	4.02 (3.43)	-0.79 (3.99)	0.13 (0.20)	-0.11 (0.50)			-0.03 (0.01)	-3.34 (1.18)
121	-11.13 (3.89)	0.52 (0.36)	6.46 (3.37)	-3.75 (4.03)	0.28 (0.20)	-0.50 (0.50)	0.09 (0.04)	-0.31 (0.14)	-0.02 (0.01)	-2.28 (1.22)
122	-10.51 (3.88)	0.66 (0.33)	6.86 (3.32)	-3.98 (3.99)	0.30 (0.20)	-0.56 (0.50)	0.08 (0.04)	-0.27 (0.14)	-0.02 (0.01)	-2.37 (1.23)
123	-14.90 (3.91)	0.59 (0.35)	6.48 (3.31)	-4.72 (3.83)	0.44 (0.19)	-0.94 (0.47)	0.11 (0.04)	-0.41 (0.14)	-0.02 (0.01)	
124	-13.67 (3.71)	0.97 (0.31)	8.28 (3.27)	-6.48 (3.80)	0.44 (0.18)	-0.94 (0.46)	0.09 (0.04)	-0.34 (0.14)	-0.03 (0.01)	
125	-3.75 (2.23)	0.77 (0.38)	4.85 (3.46)	-1.91 (4.01)	0.14 (0.20)	-0.13 (0.50)			-0.03 (0.01)	-2.90 (1.16)
126	-4.70 (2.21)	0.41 (0.37)	5.97 (3.33)	-2.76 (3.92)	0.21 (0.20)	-0.30 (0.49)			-0.03 (0.01)	-3.55 (1.16)
127	-4.95 (2.23)	0.79 (0.36)	4.97 (3.46)	-2.30 (4.06)	0.22 (0.20)	-0.34 (0.50)			-0.03 (0.01)	-2.69 (1.16)
128	-4.86 (2.15)	0.74 (0.33)	7.52 (3.28)	-4.41 (3.86)	0.22 (0.19)	-0.34 (0.49)			-0.03 (0.01)	-3.20 (1.15)
129	-14.01 (3.75)	1.02 (0.31)	7.96 (3.28)	-5.70 (3.78)	0.42 (0.18)	-0.90 (0.46)	0.10 (0.04)	-0.37 (0.14)	-0.02 (0.01)	
130	-13.83 (3.76)	0.80 (0.34)	7.34 (3.30)	-5.24 (3.79)	0.39 (0.19)	-0.81 (0.46)	0.11 (0.04)	-0.39 (0.14)	-0.02 (0.01)	
131	-11.78 (3.73)	0.91 (0.35)	5.12 (3.47)	-3.29 (3.98)	0.33 (0.19)	-0.64 (0.47)	0.09 (0.04)	-0.34 (0.14)	-0.02 (0.01)	
132	-5.12 (2.21)	0.53 (0.34)	6.58 (3.30)	-3.75 (3.94)	0.25 (0.19)	-0.44 (0.49)			-0.03 (0.01)	-3.26 (1.17)

TABLE 6.5. Extended

MIX_{18km}	RIP_{540m}	$RDdens_{18km}$	$GRASS_{540m}$	AG_{250}	$EDGE_{3km}$ [b]	$iH2Od_{500}$	LL	K	AIC_c	ΔAIC_c	Σw_i
-25.07 (8.00)						0.19 (0.18)	-628.60	11	1,284.40	3.85	0.736
-23.28 (8.07)	1.64 (0.91)	0.26 (0.19)	-0.89 (0.76)	1.35 (0.89)	-0.21 (0.28)		-628.64	11	1,284.48	3.92	0.740
-20.46 (8.02)	1.55 (0.90)		-1.02 (0.76)	0.90 (0.89)	-0.38 (0.28)	0.15 (0.18)	-625.34	14	1,284.48	3.93	0.743
-24.21 (7.98)	1.56 (0.92)	0.28 (0.18)	-0.85 (0.76)	1.25 (0.90)		0.13 (0.18)	-624.23	15	1,284.51	3.95	0.747
-23.94 (8.09)	1.74 (0.91)	0.23 (0.19)	-0.97 (0.76)		-0.18 (0.28)		-625.37	14	1,284.54	3.98	0.750
-21.72 (8.01)	1.89 (0.90)		-0.68 (0.76)	1.06 (0.89)			-626.49	13	1,284.56	4.01	0.754
-22.89 (8.05)	1.65 (0.93)	0.21 (0.18)	-0.79 (0.76)				-628.70	11	1,284.60	4.04	0.757
-23.46 (8.01)	1.98 (0.90)				-0.25 (0.28)	0.17 (0.18)	-628.71	11	1,284.62	4.06	0.760
-22.35 (8.11)	1.72 (0.92)	0.18 (0.18)			-0.29 (0.28)		-627.62	12	1,284.62	4.07	0.764
-23.06 (7.96)	1.90 (0.90)		-0.81 (0.76)	1.10 (0.89)		0.13 (0.18)	-628.73	11	1,284.65	4.09	0.767
-23.31 (8.07)					-0.39 (0.28)	0.22 (0.18)	-626.55	13	1,284.70	4.14	0.770
-23.00 (8.09)				1.12 (0.90)	-0.38 (0.28)		-627.66	12	1,284.71	4.15	0.773
-21.82 (8.08)	1.65 (0.91)	0.21 (0.18)		1.28 (0.89)	-0.31 (0.28)		-627.66	12	1,284.71	4.16	0.776
-26.87 (7.97)		0.36 (0.18)		1.44 (0.91)		0.18 (0.18)	-627.68	12	1,284.74	4.18	0.779
-22.64 (8.00)	1.92 (0.89)			1.25 (0.89)	-0.28 (0.28)	0.15 (0.18)	-627.72	12	1,284.82	4.26	0.782
-21.38 (8.06)	1.79 (0.91)				-0.36 (0.28)	0.16 (0.18)	-626.62	13	1,284.84	4.28	0.785
-20.14 (8.08)	1.77 (0.90)		-0.76 (0.76)	1.12 (0.88)	-0.37 (0.28)		-628.86	11	1,284.92	4.37	0.788
-22.34 (7.98)	1.90 (0.91)			1.08 (0.89)		0.11 (0.18)	-627.80	12	1,284.98	4.43	0.791
-22.55 (8.02)	1.60 (0.92)	0.24 (0.18)	-0.71 (0.76)	1.17 (0.89)			-628.93	11	1,285.07	4.51	0.793
-25.45 (8.06)		0.29 (0.18)					-627.84	12	1,285.07	4.51	0.796
-24.92 (8.03)		0.32 (0.18)		1.32 (0.90)			-631.12	9	1,285.10	4.54	0.799
-27.64 (7.99)		0.33 (0.18)				0.21 (0.18)	-630.04	10	1,285.10	4.55	0.801
-23.94 (8.05)	1.64 (0.91)	0.25 (0.19)		1.37 (0.90)	-0.22 (0.28)	0.15 (0.18)	-628.98	11	1,285.16	4.60	0.804
-23.59 (8.02)	1.67 (0.93)	0.21 (0.18)				0.12 (0.18)	-625.70	14	1,285.21	4.66	0.806
-25.91 (7.98)		0.36 (0.18)	-1.00 (0.76)	1.34 (0.91)		0.18 (0.18)	-629.02	11	1,285.25	4.69	0.809
-26.52 (8.01)		0.33 (0.18)	-1.09 (0.76)			0.20 (0.18)	-626.83	13	1,285.25	4.69	0.811
-21.43 (8.07)			-1.19 (0.76)	0.92 (0.90)	-0.44 (0.28)	0.20 (0.18)	-627.93	12	1,285.25	4.69	0.813
-22.55 (8.03)	1.85 (0.90)		-0.94 (0.76)		-0.27 (0.28)	0.17 (0.18)	-625.72	14	1,285.25	4.70	0.816
-26.09 (8.08)		0.34 (0.18)		1.57 (0.91)	-0.20 (0.28)		-626.84	13	1,285.27	4.71	0.818
-24.68 (8.07)	1.74 (0.92)	0.22 (0.19)			-0.19 (0.28)	0.17 (0.18)	-627.97	12	1,285.33	4.77	0.821
-20.82 (8.04)	1.77 (0.90)			1.14 (0.88)	-0.38 (0.28)	0.14 (0.18)	-626.88	13	1,285.36	4.80	0.823
-24.63 (7.99)				0.97 (0.91)		0.18 (0.18)	-628.03	12	1,285.44	4.89	0.825
-21.47 (8.13)	1.58 (0.93)	0.19 (0.18)	-0.86 (0.76)		-0.32 (0.28)		-628.07	12	1,285.52	4.97	0.827
-23.49 (8.00)			-1.11 (0.76)	0.85 (0.91)		0.17 (0.18)	-628.07	12	1,285.53	4.97	0.829
-22.76 (8.06)				1.04 (0.90)	-0.41 (0.28)	0.21 (0.18)	-626.98	13	1,285.54	4.98	0.831
-24.99 (8.09)		0.34 (0.18)	-1.05 (0.76)	1.47 (0.91)	-0.23 (0.28)		-626.99	13	1,285.58	5.02	0.833
-25.94 (8.02)				1.34 (0.90)			-626.99	13	1,285.58	5.02	0.835
-22.12 (8.03)	1.81 (0.92)		-0.74 (0.76)			0.12 (0.18)	-630.28	10	1,285.58	5.03	0.837
-24.42 (8.08)		0.29 (0.18)	-0.96 (0.76)				-629.19	11	1,285.58	5.03	0.839
-23.17 (7.99)	1.62 (0.93)	0.23 (0.18)		1.20 (0.89)		0.11 (0.18)	-630.30	10	1,285.62	5.06	0.841
-24.67 (8.08)							-628.12	12	1,285.62	5.07	0.843
-26.78 (8.04)							-632.46	8	1,285.64	5.08	0.845
-25.64 (8.05)			-1.10 (0.77)				-631.40	9	1,285.65	5.10	0.847
-21.86 (8.02)	1.80 (0.90)		-0.86 (0.76)	1.17 (0.89)	-0.30 (0.28)	0.15 (0.18)	-630.34	10	1,285.71	5.15	0.849
-23.36 (8.12)		0.28 (0.18)		1.36 (0.90)	-0.34 (0.28)		-625.96	14	1,285.73	5.18	0.851

TABLE 6.5. Continued

Rank	Intercept	$ABIGSAGE_{1km}$	$NDVI_{270}$	$NDVI_{270}^2$	$ELEV^b$	$ELEV^{2c}$	SOLAR	$SOLAR^{2d}$	TRI_{18km}	$CFRST_{1km}$
133	-3.81 (2.29)	0.57 (0.40)	4.39 (3.43)	-1.65 (4.03)	0.17 (0.20)	-0.21 (0.50)			-0.03 (0.01)	-3.07 (1.18)
134	-3.21 (2.25)	0.66 (0.39)	4.72 (3.44)	-1.65 (3.99)	0.12 (0.20)	-0.08 (0.49)			-0.03 (0.01)	-3.17 (1.17)
135	-5.10 (2.23)	0.40 (0.37)	6.29 (3.33)	-3.59 (3.96)	0.24 (0.20)	-0.40 (0.50)			-0.03 (0.01)	-3.26 (1.16)
136	-13.68 (4.01)	0.83 (0.37)	4.37 (3.49)	-2.08 (3.97)	0.35 (0.19)	-0.69 (0.47)	0.11 (0.04)	-0.40 (0.14)	-0.02 (0.01)	
137	-4.27 (2.18)	0.66 (0.33)	7.19 (3.26)	-3.93 (3.86)	0.19 (0.19)	-0.29 (0.49)			-0.03 (0.01)	-3.43 (1.17)
138	-13.52 (3.72)	0.78 (0.34)	7.70 (3.30)	-6.01 (3.82)	0.41 (0.19)	-0.85 (0.47)	0.10 (0.04)	-0.37 (0.14)	-0.02 (0.01)	
139	-4.77 (2.20)	0.56 (0.34)	6.29 (3.31)	-2.89 (3.91)	0.22 (0.19)	-0.35 (0.49)			-0.03 (0.01)	-3.56 (1.17)
140	-15.21 (3.97)	0.64 (0.35)	6.14 (3.33)	-3.89 (3.82)	0.42 (0.19)	-0.88 (0.46)	0.12 (0.04)	-0.44 (0.15)	-0.02 (0.01)	
141	-13.46 (3.97)	0.78 (0.37)	4.73 (3.48)	-2.88 (3.99)	0.37 (0.19)	-0.75 (0.48)	0.11 (0.04)	-0.38 (0.14)	-0.02 (0.01)	
142	-5.15 (2.16)	0.73 (0.33)	7.85 (3.28)	-5.24 (3.91)	0.25 (0.19)	-0.42 (0.49)			-0.03 (0.01)	-2.92 (1.16)
143	-4.15 (2.24)	0.76 (0.36)	4.65 (3.45)	-1.40 (4.01)	0.17 (0.20)	-0.21 (0.49)			-0.03 (0.01)	-3.12 (1.17)
144	-15.41 (3.96)	0.87 (0.32)	6.78 (3.31)	-4.38 (3.82)	0.45 (0.18)	-0.97 (0.46)	0.11 (0.04)	-0.41 (0.14)	-0.02 (0.01)	
145	-4.54 (2.19)	0.65 (0.33)	7.53 (3.26)	-4.79 (3.90)	0.22 (0.19)	-0.37 (0.49)			-0.03 (0.01)	-3.14 (1.17)
146	-4.24 (2.20)	0.54 (0.36)	7.03 (3.29)	-4.02 (3.87)	0.18 (0.20)	-0.25 (0.49)			-0.03 (0.01)	-3.36 (1.15)
147	-3.55 (2.24)	0.44 (0.37)	6.63 (3.28)	-3.47 (3.86)	0.15 (0.20)	-0.18 (0.49)			-0.03 (0.01)	-3.62 (1.16)
148	-8.37 (3.93)	0.59 (0.39)	2.50 (3.55)	0.94 (4.13)	0.12 (0.20)	-0.07 (0.50)	0.08 (0.04)	-0.29 (0.14)	-0.02 (0.01)	-2.81 (1.24)
149	-4.06 (2.26)	0.34 (0.37)	5.75 (3.32)	-2.45 (3.91)	0.18 (0.20)	-0.24 (0.49)			-0.03 (0.01)	-3.75 (1.17)
150	-15.19 (3.90)	0.77 (0.32)	7.29 (3.29)	-5.42 (3.82)	0.48 (0.18)	-1.03 (0.46)	0.11 (0.04)	-0.38 (0.14)	-0.02 (0.01)	
151	-5.75 (2.06)	1.24 (0.32)	6.49 (3.39)	-5.19 (3.86)	0.31 (0.19)	-0.58 (0.47)			-0.03 (0.01)	
152	-14.27 (3.75)	0.99 (0.31)	8.20 (3.28)	-5.98 (3.78)	0.43 (0.18)	-0.91 (0.46)	0.10 (0.04)	-0.37 (0.14)	-0.02 (0.01)	
153	-5.54 (2.18)	0.60 (0.34)	6.72 (3.32)	-3.49 (3.92)	0.26 (0.19)	-0.42 (0.49)			-0.03 (0.01)	-3.30 (1.16)
154	-4.18 (2.26)	0.64 (0.40)	4.42 (3.47)	-1.33 (4.03)	0.17 (0.20)	-0.19 (0.50)			-0.03 (0.01)	-3.10 (1.17)
155	-4.48 (2.25)	0.73 (0.36)	4.95 (3.44)	-2.19 (4.04)	0.20 (0.20)	-0.30 (0.50)			-0.03 (0.01)	-2.87 (1.17)
156	-4.45 (2.27)	0.33 (0.37)	6.08 (3.31)	-3.29 (3.95)	0.21 (0.20)	-0.34 (0.50)			-0.03 (0.01)	-3.46 (1.17)
157	-4.03 (2.24)	0.78 (0.38)	5.16 (3.47)	-2.64 (4.06)	0.17 (0.20)	-0.20 (0.50)			-0.03 (0.01)	-2.66 (1.16)
158	-14.08 (3.76)	0.78 (0.34)	7.58 (3.30)	-5.51 (3.79)	0.40 (0.19)	-0.83 (0.46)	0.11 (0.04)	-0.39 (0.14)	-0.02 (0.01)	
159	-5.87 (2.19)	0.58 (0.34)	6.97 (3.31)	-4.25 (3.95)	0.29 (0.19)	-0.51 (0.49)			-0.03 (0.01)	-3.02 (1.16)
160	-13.92 (3.71)	0.95 (0.31)	8.47 (3.27)	-6.68 (3.80)	0.45 (0.18)	-0.95 (0.46)	0.10 (0.04)	-0.34 (0.14)	-0.02 (0.01)	
161	-15.02 (3.91)	0.58 (0.34)	6.69 (3.31)	-4.94 (3.83)	0.45 (0.19)	-0.95 (0.46)	0.11 (0.04)	-0.41 (0.14)	-0.02 (0.01)	
162	-3.49 (2.26)	0.66 (0.39)	5.05 (3.44)	-2.42 (4.03)	0.14 (0.20)	-0.16 (0.50)			-0.03 (0.01)	-2.92 (1.17)
163	-13.13 (3.71)	0.93 (0.31)	8.14 (3.26)	-6.32 (3.79)	0.43 (0.18)	-0.93 (0.46)	0.09 (0.04)	-0.34 (0.14)	-0.02 (0.01)	
164	-9.40 (3.92)	0.71 (0.38)	2.68 (3.57)	0.59 (4.15)	0.14 (0.20)	-0.11 (0.51)	0.08 (0.04)	-0.30 (0.14)	-0.02 (0.01)	-2.51 (1.23)
165	-4.52 (2.19)	0.64 (0.33)	7.45 (3.26)	-4.26 (3.85)	0.21 (0.19)	-0.32 (0.49)			-0.03 (0.01)	-3.35 (1.16)
166	-3.86 (2.24)	0.44 (0.37)	6.99 (3.28)	-4.31 (3.91)	0.18 (0.20)	-0.27 (0.50)			-0.03 (0.01)	-3.35 (1.17)
167	-5.13 (2.17)	0.73 (0.33)	7.78 (3.28)	-4.73 (3.87)	0.23 (0.19)	-0.37 (0.49)			-0.03 (0.01)	-3.11 (1.15)
168	-10.94 (4.08)	0.47 (0.40)	3.53 (3.52)	-0.60 (4.15)	0.24 (0.20)	-0.41 (0.51)	0.09 (0.04)	-0.33 (0.14)	-0.02 (0.01)	-2.37 (1.23)

[a] Variable definitions provided in Table 4.2
[b] Coefficients and standard errors multiplied by 10^2
[c] Coefficients and standard errors multiplied by 10^6
[d] Coefficients and standard errors multiplied by 10^3

TABLE 6.5. Extended

MIX_{18km}	RIP_{540m}	$RDdens_{18km}$	$GRASS_{540m}$	AG_{250}	$EDGE_{3km}$[b]	$iH2Od_{500}$	LL	K	AIC_c	ΔAIC_c	Σw_i
-21.06 (8.10)	1.53 (0.92)	0.21 (0.18)	-0.78 (0.76)	1.21 (0.88)	-0.33 (0.28)		-629.32	11	1,285.84	5.28	0.853
-20.51 (8.09)	1.66 (0.92)		-0.83 (0.76)		-0.39 (0.28)	0.15 (0.18)	-627.13	13	1,285.86	5.30	0.855
-24.02 (8.04)		0.31 (0.18)	-0.88 (0.76)	1.23 (0.90)			-628.25	12	1,285.88	5.33	0.856
-23.77 (8.08)	1.60 (0.92)	0.23 (0.19)	-0.97 (0.76)		-0.21 (0.28)	0.17 (0.18)	-629.36	11	1,285.91	5.35	0.858
-22.99 (8.16)					-0.38 (0.28)		-626.06	14	1,285.92	5.37	0.860
-24.97 (8.03)			-1.01 (0.77)	1.24 (0.90)			-631.55	9	1,285.96	5.41	0.861
-23.98 (8.15)		0.26 (0.18)			-0.32 (0.28)		-629.39	11	1,285.98	5.42	0.863
-25.82 (8.12)		0.32 (0.18)	-1.15 (0.77)		-0.19 (0.28)		-630.49	10	1,286.00	5.44	0.865
-23.16 (8.06)	1.52 (0.92)	0.26 (0.19)	-0.89 (0.76)	1.30 (0.90)	-0.24 (0.28)	0.15 (0.18)	-628.33	12	1,286.04	5.48	0.866
-24.13 (8.06)				1.17 (0.90)			-625.00	15	1,286.05	5.49	0.868
-22.22 (8.09)	1.59 (0.93)	0.18 (0.18)			-0.32 (0.28)	0.15 (0.18)	-631.61	9	1,286.08	5.53	0.870
-27.12 (8.11)		0.32 (0.18)			-0.17 (0.28)		-628.38	12	1,286.14	5.59	0.871
-22.33 (8.14)				1.24 (0.89)	-0.40 (0.28)		-629.49	11	1,286.18	5.62	0.873
-23.65 (8.10)			-0.95 (0.76)				-630.58	10	1,286.18	5.63	0.874
-21.76 (8.18)			-1.03 (0.76)		-0.41 (0.28)		-631.66	9	1,286.19	5.63	0.876
	1.88 (0.92)		-1.29 (0.77)		-0.45 (0.28)		-630.60	10	1,286.22	5.66	0.877
-22.76 (8.17)		0.26 (0.18)	-1.03 (0.76)		-0.35 (0.28)		-628.44	12	1,286.26	5.70	0.879
-25.75 (8.06)		0.33 (0.18)		1.49 (0.91)	-0.24 (0.28)	0.20 (0.18)	-629.54	11	1,286.28	5.72	0.880
-23.36 (8.02)	2.30 (0.89)			1.48 (0.88)			-627.34	13	1,286.28	5.72	0.881
-26.58 (8.01)						0.22 (0.18)	-631.72	9	1,286.29	5.74	0.883
-25.32 (8.04)		0.28 (0.18)				0.17 (0.18)	-630.65	10	1,286.32	5.77	0.884
-22.89 (8.04)	1.55 (0.94)	0.21 (0.18)	-0.77 (0.76)			0.12 (0.18)	-630.65	10	1,286.32	5.77	0.886
-21.72 (8.06)	1.54 (0.92)	0.20 (0.18)		1.23 (0.89)	-0.34 (0.28)	0.13 (0.18)	-628.49	12	1,286.37	5.81	0.887
-22.28 (8.14)		0.28 (0.18)	-0.95 (0.76)	1.27 (0.89)	-0.36 (0.28)		-627.41	13	1,286.40	5.85	0.888
-21.74 (8.01)	1.81 (0.91)		-0.67 (0.76)	1.02 (0.89)		0.10 (0.18)	-628.52	12	1,286.42	5.87	0.890
-25.48 (8.02)			-1.07 (0.77)			0.21 (0.18)	-628.53	12	1,286.45	5.90	0.891
-24.83 (8.01)		0.31 (0.18)		1.26 (0.90)		0.15 (0.18)	-629.65	11	1,286.50	5.95	0.892
-25.81 (8.00)				1.25 (0.91)		0.20 (0.18)	-629.68	11	1,286.55	5.99	0.894
-24.67 (8.07)		0.33 (0.18)	-1.04 (0.76)	1.39 (0.91)	-0.26 (0.28)	0.20 (0.18)	-629.68	11	1,286.56	6.01	0.895
-20.06 (8.06)	1.65 (0.91)		-0.76 (0.76)	1.07 (0.88)	-0.40 (0.28)	0.14 (0.18)	-626.39	14	1,286.58	6.03	0.896
-24.68 (8.10)				1.43 (0.90)	-0.30 (0.28)		-627.51	13	1,286.61	6.05	0.897
	2.05 (0.92)		-1.20 (0.77)				-629.72	11	1,286.64	6.09	0.899
-22.71 (8.13)					-0.42 (0.28)	0.22 (0.18)	-629.72	11	1,286.64	6.09	0.900
-21.25 (8.15)			-0.96 (0.76)	1.15 (0.89)	-0.43 (0.28)		-630.82	10	1,286.67	6.11	0.901
-24.56 (8.06)						0.19 (0.18)	-629.76	11	1,286.72	6.16	0.902
-21.81 (8.05)	1.22 (0.92)	0.28 (0.18)	-1.06 (0.76)	1.01 (0.90)	-0.32 (0.28)	0.14 (0.18)	-631.93	9	1,286.72	6.16	0.903

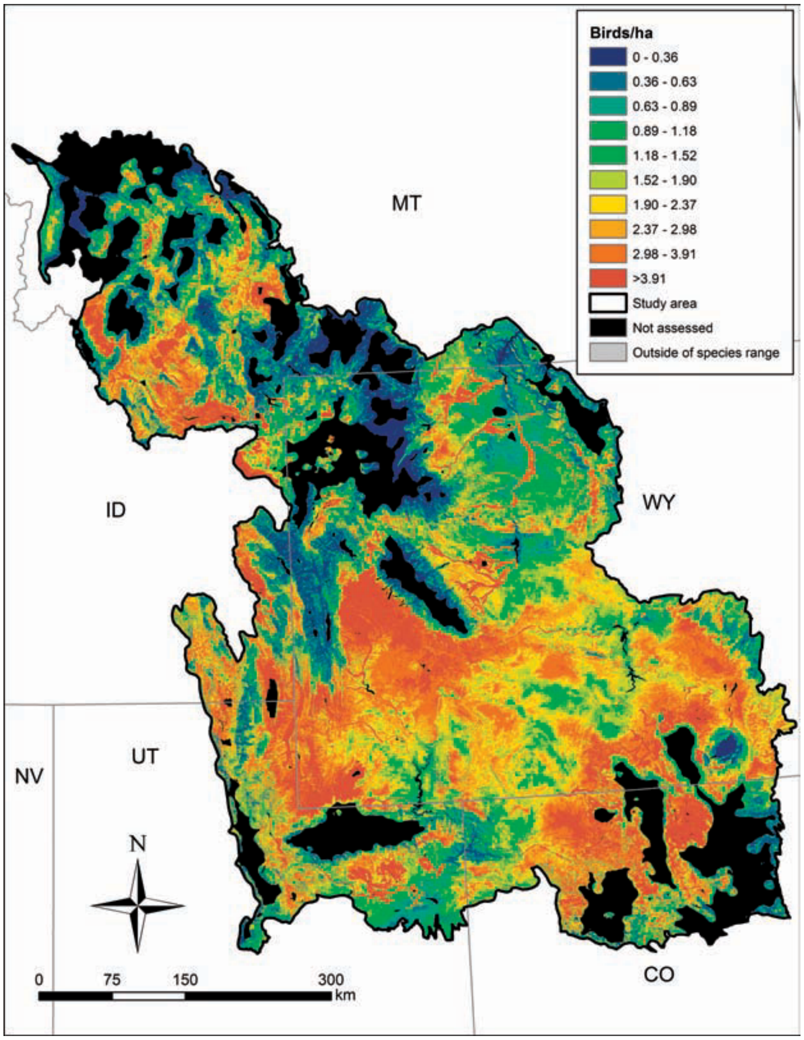

FIG. 6.2. Predicted density estimates (birds/ha) for Brewer's sparrow in the Wyoming Basins Ecoregional Assessment area. Black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water). Based on the largest territory sizes required to support one Brewer's sparrow, the lowest density that could support a viable territory is 0.42 birds/ha. We infer that spatial predictions above this threshold predict occupied patches.

0.33), and the global density was estimated at 0.10 birds/ha (95% CI = 0.07–0.12). Plot level density estimates could not be developed for many sites because of single detections at many survey blocks.

Lark sparrow

A hazard rate model with a simple polynomial adjustment and 25-m groupings combined with a truncation distance of 175 m provided the best fit to the distance data for lark sparrow ($\chi^2_4 = 4.96$, p = 0.29). We used 132 detections at 67 of the 318 survey blocks for this model. The top AIC-selected detection model included the base model with covariates for shrub index and survey start time. The top AIC-selected lark sparrow model had reasonable fit ($\chi^2_2 = 5.97$, p = 0.05) and outcompeted all other covariate distance models; ΔAIC values

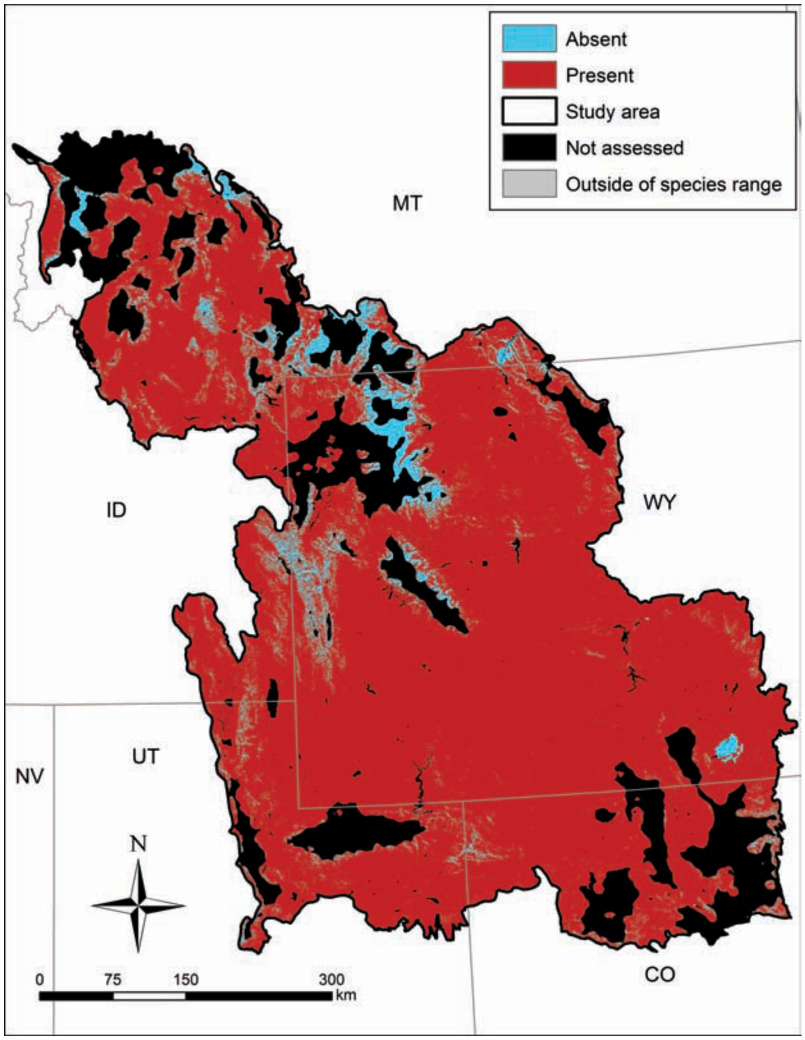

FIG. 6.3. Distribution of Brewer's sparrow in the Wyoming Basins Ecoregional Assessment area based on a threshold of (0.42 birds/ha), the largest territory sizes required to support one Brewer's sparrow. Semi-transparent grey shaded areas are outside the range of Brewer's sparrow and black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water).

ranged from 1.02 to 8.46. Detectability was 0.27 (95% CI = 0.23–0.32) with an overall density estimate of 0.16 (95% CI = 0.12–0.20) birds/ha. Where present, mean lark sparrow density was 0.76 (range: 0.20–2.95) birds/ha.

Sage sparrow

A hazard rate model with a simple polynomial adjustment, and 20-m grouping and aggregation of detections <40 m, combined with a truncation distance of 220 m provided the best fit to the distance data for sage sparrow. We used 299 detections at 114 of the 318 survey blocks for this model. The sage sparrow model with no covariates had reasonable fit (χ^2_5 = 10.47, p = 0.06), and based on AIC, outcompeted all other distance models fit with covariates; ΔAIC values ranged from 11.75 to 21.73. Detect-

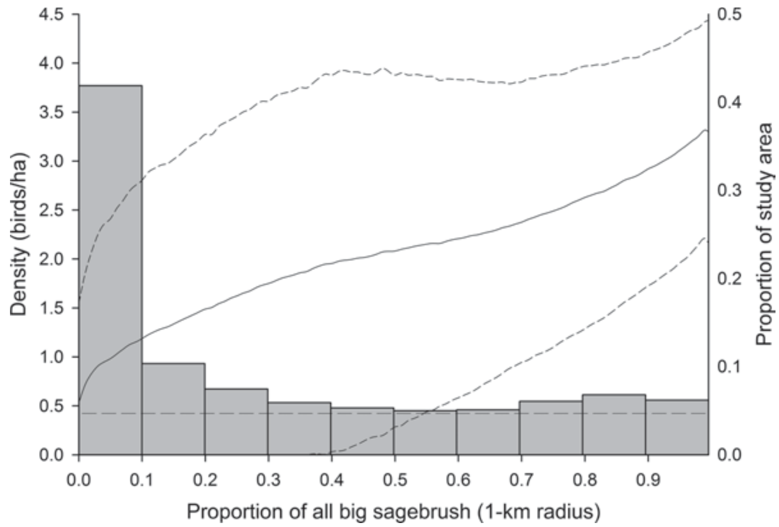

FIG. 6.4. Brewer's sparrow predicted densities within the Wyoming Basins Ecoregional Assessment area in relation to proportion of all big sagebrush (*Artemisia tridentata* spp.) within a 1-km radius. Mean density (black line, ± 1 SD [dashed lines]) values were calculated in each one percent increment of all big sagebrush within a 1-km radius. Range of predicted densities relate to the observed range of sagebrush at study site locations. The dashed horizontal line represents the lowest density that could support a viable territory (0.42 birds/ha), above which we infer patches to be occupied. Histogram values represent the proportion of the total study area in each 10 percent segment of all big sagebrush within 1 km.

ability was 0.27 (95% CI = 0.22–0.33) with an overall density estimate of 0.12 birds/ha (95% CI = 0.10–0.14) birds. Where present, mean sage sparrow density was 0.32 (range: 0.12–0.99) birds/ha.

Sage thrasher

A hazard rate model with a simple polynomial adjustment and 50-m grouping combined with a truncation distance of 450 m provided the best fit to the distance data for sage thrasher ($\chi^2_6 = 6.18$, $p = 0.40$). We used 420 detections at 199 of the 318 survey blocks for this model. The top AIC-selected detection model included the base model with a covariate for shrub index. All other models had ΔAIC values ranging from 1.33–72.5. The top AIC-selected sage thrasher model with one covariate had reasonable fit ($\chi^2_5 = 10.89$, $p = 0.05$); ΔAIC values ranged from 1.97 to 9.13. Detectability for sage thrasher was the lowest for all species modeled at 0.09 (95% CI = 0.08–0.10) with an overall density estimate of 0.23 (95% CI = 0.21–0.25) birds/ha. Where present, mean sage thrasher density was 0.36 (range: 0.17–1.03) birds /ha.

Vesper sparrow

A hazard rate model with a simple polynomial adjustment, 25-m grouping and aggregation of detections <50 m, combined with a truncation distance of 240 m provided the best fit to the distance data for vesper sparrow ($\chi^2_5 = 7.53$, $p = 0.18$). This resulted in 509 detections being used at 167 of the 318 survey blocks. The top AIC-selected detection model included covariates for shrub index, observer group, detection type, and Julian date of survey. All other models had ΔAIC values ranging from 4.56 to 35.74. A goodness of fit test could not be generated for the top vesper sparrow model due to limited degrees of freedom. Detection probability was 0.16 (95% CI = 0.15–0.18) with an overall density estimate of 0.54 (95% CI = 0.46–0.62) birds/ha. Where present, mean vesper sparrow density was 1.04 (range: 0.16–3.04) birds/ha.

TABLE 6.6. Results of AIC_c-based model selection for green-tailed towhee occurrence models in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale sagebrush and NDVI; 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 $\Delta AIC_c \leq 2$ are shown.

Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
1	$MTNSAGE_{5km}$ + $NDVI_{5km}$	-126.27	3	258.70	0.00	0.09
2	$MTNSAGE_{3km}$ + $NDVI_{5km}$	-126.46	3	259.08	0.38	0.07
3	$ABIGSAGE_{5km}$ + $NDVI_{5km}$	-126.72	3	259.58	0.88	0.06
4	$MTNSAGE_{5km}$ + $NDVI_{3km}$	-126.98	3	260.12	1.42	0.04
5	$MTNSAGE_{270}$ + $NDVI_{5km}$	-127.06	3	260.28	1.58	0.04
6	$MTNSAGE_{3km}$ + $NDVI_{3km}$	-127.11	3	260.37	1.66	0.04
7	$ABIGSAGE_{3km}$ + $NDVI_{5km}$	-127.11	3	260.37	1.67	0.04
8	$ALLSAGE_{5km}$ + $NDVI_{5km}$	-127.12	3	260.39	1.69	0.04
9	$MTNSAGE_{540}$ + $NDVI_{5km}$	-127.17	3	260.50	1.80	0.04

[a] Variable definitions provided in Table 4.2

Model Selection, Spatial Application, Dose Response, and Evaluation

Brewer's sparrow

Two variables were excluded from the *a priori* candidate set of variables for Brewer's sparrow abundance models, conifer forest (0.27-km radius) and mixed shrubland (0.27 km), because these habitats were present on only 20 or fewer survey blocks. Also, we did not consider temperature variables for this species, but did consider solar radiation. Several remaining variables were dropped, including many of the sagebrush contagion, patch, and edge variables, because they were correlated with other sagebrush variables. We considered NDVI as a non-linearity at all scales but non-linearities were not evident for any sagebrush variable. Interactions between sagebrush and NDVI variables were not considered.

Initial exploration of the count data without covariates suggested that a zero-inflated negative binomial may be most appropriate. However, inclusion of sagebrush and NDVI covariates with the offset term using a negative binomial model (without zero-inflation) had a better fit to the data (z = 0.94, p = 0.17) and was used to fit the sagebrush/NDVI base models. The top AIC_c-selected sagebrush/NDVI model consisted of all big sagebrush (*A. tridentata*) within 1 km ($ABIGSAGE_{1km}$) and NDVI as a quadratic within 0.27 km ($NDVI_{270} + NDVI_{270}^2$), which had low support (w_i = 0.07; Table 6.2). Use locations averaged 9.3% more big sagebrush habitat than absence locations (Appendix 6.1). Using this sagebrush/NDVI base model to evaluate individual multi-scale covariates (Table 6.3), the top vegetation submodel consisted of conifer forest within 1 km ($CFRST_{1km}$), grassland within 0.54 km ($GRASS_{540m}$), mixed shrubland within 18 km (MIX_{18km}), riparian within 0.54 km (RIP_{540}), and all sagebrush edge density within 3 km ($EDGE_{3km}$; Table 6.4). The top AIC_c-selected abiotic model consisted of Compound Topographic Index (CTI), elevation as a quadratic (ELEV + $ELEV^2$), 0.5-km distance decay from intermittent water ($iH2Od_{500}$), solar radiation as a quadratic (SOLAR + $SOLAR^2$), and topographic ruggedness within 18 km (TRI_{18km}; Table 6.4). Decay distance (0.25 km) to agricultural land (AG_{250}) and density of all roads within 18 km ($RDdens_{18km}$) were

TABLE 6.7. Evaluation statistics from AIC_c-based univariate model selection for green-tailed towhee occurrence models 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 models with mountain sagebrush (5-km radius) and NDVI (5-km radius) variables as a base model for variables tested. We used AIC_c to sort models for each variable in ascending order to identify the extent at which green-tailed towhees respond to individual variables.

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	$CFRST_{540}$	-125.61	4	259.36	0.00	0.41
	$CFRST_{1km}$	-125.80	4	259.73	0.38	0.34
	$CFRST_{270}$	-126.15	4	260.43	1.07	0.24
	$GRASS_{5km}$	-124.88	4	257.88	0.00	0.25
	$GRASS_{3km}$	-125.07	4	258.27	0.39	0.20
	$GRASS_{1km}$	-125.20	4	258.53	0.65	0.18
	$GRASS_{270}$	-125.41	4	258.94	1.06	0.15
	$GRASS_{540}$	-125.42	4	258.98	1.10	0.14
	$GRASS_{18km}$	-126.10	4	260.32	2.44	0.07
	MIX_{270}	-125.21	4	258.54	0.00	0.31
	MIX_{3km}	-125.66	4	259.44	0.90	0.20
	MIX_{540}	-125.99	4	260.11	1.57	0.14
	MIX_{5km}	-126.00	4	260.13	1.59	0.14
	MIX_{1km}	-126.22	4	260.56	2.01	0.11
	MIX_{18km}	-126.26	4	260.64	2.10	0.11
	RIP_{3km}	-125.78	4	259.69	0.00	0.24
	RIP_{5km}	-126.19	4	260.51	0.83	0.16
	RIP_{18km}	-126.21	4	260.54	0.85	0.16
	RIP_{270}	-126.26	4	260.64	0.95	0.15
	RIP_{540}	-126.26	4	260.65	0.96	0.15
	RIP_{1km}	-126.27	4	260.67	0.98	0.15
	$SALT_{18km}$	-125.73	4	259.58	0.00	0.23
	$SALT_{270}$	-125.87	4	259.87	0.29	0.20
	$SALT_{540m}$	-126.13	4	260.38	0.80	0.15
	$SALT_{5km}$	-126.16	4	260.44	0.86	0.15
	$SALT_{1km}$	-126.16	4	260.45	0.87	0.15
	$SALT_{3km}$	-126.26	4	260.65	1.07	0.13
	$PATCH_{1km}$	-124.71	4	257.55	0.00	0.31
	$EDGE_{5km}$	-125.32	4	258.78	1.23	0.17
	$CONTAG_{3km}$	-125.92	4	259.96	2.41	0.09
	$EDGE_{3km}$	-125.95	4	260.04	2.49	0.09
	$EDGE_{1km}$	-126.13	4	260.38	2.83	0.07
	$PATCH_{3km}$	-126.17	4	260.46	2.91	0.07

TABLE 6.7. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
	$PATCH_{5km}$	-126.22	4	260.57	3.03	0.07
	$CONTAG_{1km}$	-126.27	4	260.67	3.12	0.06
	$CONTAG_{5km}$	-126.27	4	260.67	3.12	0.06
Abiotic	CTI	-126.14	4	260.41	0.00	1.00
	ELEV	-126.27	4	260.67	0.00	1.00
	$iH2Od_{1km}$[b]	-125.52	4	259.16	0.00	0.48
	$iH2Od_{500}$[b]	-126.01	4	260.14	0.98	0.29
	$iH2Od_{250}$[b]	-126.25	4	260.63	1.47	0.23
	$pH2Od_{1km}$[b]	-126.10	4	260.33	0.00	0.35
	$pH2Od_{250}$[b]	-126.12	4	260.37	0.04	0.34
	$pH2Od_{250}$[b]	-126.22	4	260.56	0.23	0.31
	SOLAR	-125.67	4	259.47	0.00	1.00
	TRI_{270}	-123.36	4	254.86	0.00	0.45
	TRI	-124.31	4	256.76	1.90	0.17
	TRI_{540}	-124.36	4	256.84	1.98	0.17
	TRI_{1km}	-124.96	4	258.05	3.20	0.09
	TRI_{5km}	-125.47	4	259.06	4.20	0.05
	TRI_{3km}	-125.67	4	259.47	4.61	0.04
	TRI_{18km}	-126.21	4	260.55	5.69	0.03
Disturbance	AG_{250}[b]	-125.72	4	259.56	0.00	0.44
	AG_{500}[b]	-126.12	4	260.37	0.81	0.30
	AG_{1km}[b]	-126.25	4	260.63	1.07	0.26
	$MjRD_{1km}$[b]	-124.82	4	257.76	0.00	0.38
	$MjRD_{500}$[b]	-124.91	4	257.96	0.20	0.34
	$MjRD_{250}$[b]	-125.13	4	258.39	0.63	0.28
	$PIPE_{250}$[b]	-125.49	4	259.11	0.00	0.37
	$PIPE_{500}$[b]	-125.63	4	259.38	0.27	0.33
	$PIPE_{1km}$[b]	-125.71	4	259.54	0.43	0.30
	$POWER_{1km}$[b]	-126.08	4	260.29	0.00	0.36
	$POWER_{500}$[b]	-126.16	4	260.44	0.15	0.34
	$POWER_{250}$[b]	-126.27	4	260.68	0.38	0.30
	$RDdens_{540}$	-125.56	4	259.25	0.00	0.17
	$2RD_{250}$[b]	-125.80	4	259.72	0.47	0.14
	$2RD_{500}$[b]	-125.91	4	259.95	0.70	0.12
	$RDdens_{270}$	-126.03	4	260.19	0.94	0.11
	$2RD_{1km}$[b]	-126.06	4	260.25	1.00	0.11

TABLE 6.7. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
	$RDdens_{18km}$	-126.19	4	260.51	1.26	0.09
	$RDdens_{5km}$	-126.23	4	260.59	1.34	0.09
	$RDdens_{1km}$	-126.27	4	260.67	1.42	0.09
	$RDdens_{3km}$	-126.27	4	260.67	1.42	0.09
	$WELL_{1km}$[b]	-125.41	4	258.94	0.00	0.51
	$WELL_{500}$[b]	-126.02	4	260.17	1.23	0.28
	$WELL_{250}$[b]	-126.27	4	260.66	1.72	0.22

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

included in the top disturbance submodel (Table 6.4).

The top AIC_c-selected Brewer's sparrow abundance model combined vegetation, abiotic, and disturbance factors (Table 6.5). Brewer's sparrow abundance was positively associated with proportion of big sagebrush, more productive habitats (positive and increasing quadratic function), moderate elevations, proportion of riparian land cover, and road densities (at large scales; Table 6.5). Lower abundance was associated with high solar radiation, more rugged terrain, and proportion of both conifer forest and mixed shrubland (Table 6.5). However, the weight of evidence for the top model was low (w_i = 0.03), with 168 candidate models occurring within the cumulative Akaike weight of just ≥ 0.9 (Table 6.5). Other models indicated Brewer's sparrow abundance increased with proportion of agricultural land and with proximity to intermittent water sources but decreased with proportion of grassland and sagebrush edge density (Table 6.5). The final model-averaged abundance model was:

$$\text{Density} = \exp(-9.42 + 0.63 * ABIGSAGE_{1km} + 3.77 * NDVI_{270} -1.30 * NDVI_{270}^2 + 0.0023 * ELEV - 0.41 * ELEV^2 + 0.073 * SOLAR - 0.00026 * SOLAR^2 - 0.02 * TRI_{18km} - 1.59 * CFRST_{1km} - 20.04 * MIX_{18km} + 1.05 * RIP_{540} + 0.15 * RDdens_{18km} - 0.41 * GRASS_{540} + 0.39 * AG_{250} - 0.08 * EDGE_{3km} + 0.03 * iH2Od_{500} + 1.07) \quad (6.1)$$

The mean offset for the survey blocks is represented by the final constant in the model (1.07).

The final model-averaged Brewer's sparrow abundance model predicted mean densities that were significantly and positively correlated with independent count data from 96 BBS routes (r_s = 0.54, $p < 0.001$). When applied spatially, the low elevation areas dominated by sagebrush habitats in the southwestern, southcentral, and northwestern portions of the WBEA area were predicted to support high densities of Brewer's sparrow (Fig. 6.2). Based on the lowest density that could support a Brewer's sparrow territory (0.42 birds/ha; Fig. 6.2), 87.7% of the area (302,891 km^2) of the Wyoming Basins was predicted to contain enough resources to support breeding Brewer's sparrows (Fig. 6.3). Brewer's sparrow densities increased linearly from 0.5 to 3.0 birds/ha as proportion of all big sagebrush in a 1-km radius increased from 0.0

TABLE 6.8. Results of AIC_c-based submodel selection for green-tailed towhee occurrence models 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 $\Delta AIC_c \leq 2$ are shown.

Category	Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	1	$MTNSAGE_{5km} + NDVI_{5km} + MIX_{270m} + PATCH_{1km}$	-123.61	5	257.41	0.00	0.04
	2	$MTNSAGE_{5km} + NDVI_{5km} + PATCH_{1km}$	-124.71	4	257.55	0.14	0.04
	3	$MTNSAGE_{5km} + NDVI_{5km} + GRASS_{5km} + MIX_{270m}$	-123.79	5	257.78	0.37	0.04
	4	$MTNSAGE_{5km} + NDVI_{5km} + GRASS_{5km}$	-124.88	4	257.88	0.48	0.04
	5	$MTNSAGE_{5km} + NDVI_{5km} + MIX_{270m} + RIP_{3km} + PATCH_{1km}$	-122.96	6	258.19	0.78	0.03
	6	$MTNSAGE_{5km} + NDVI_{5km} + RIP_{3km} + PATCH_{1km}$	-124.04	5	258.27	0.86	0.03
	7	$MTNSAGE_{5km} + NDVI_{5km} + GRASS_{5km} + MIX_{270m} + PATCH_{1km}$	-123.14	6	258.54	1.14	0.03
	8	$MTNSAGE_{5km} + NDVI_{5km} + MIX_{270m}$	-125.21	4	258.54	1.14	0.03
	9	$MTNSAGE_{5km} + NDVI_{5km} + GRASS_{5km} + SALT_{18km}$	-124.20	5	258.58	1.18	0.02
	10	$MTNSAGE_{5km} + NDVI_{5km} + GRASS_{5km} + MIX_{270m} + SALT_{18km}$	-123.16	6	258.59	1.18	0.02
	11	$MTNSAGE_{5km} + NDVI_{5km}$	-126.27	3	258.62	1.22	0.02
	12	$MTNSAGE_{5km} + NDVI_{5km} + CFRST_{540m} + GRASS_{5km} + MIX_{270m}$	-123.18	6	258.63	1.23	0.02
	13	$MTNSAGE_{5km} + NDVI_{5km} + GRASS_{5km} + PATCH_{1km}$	-124.23	5	258.65	1.24	0.02
	14	$MTNSAGE_{5km} + NDVI_{5km} + CFRST_{540m} + GRASS_{5km}$	-124.23	5	258.66	1.25	0.02
	15	$MTNSAGE_{5km} + NDVI_{5km} + MIX_{270m} + PATCH_{1km} + SALT_{18km}$	-123.31	6	258.89	1.49	0.02
	16	$MTNSAGE_{5km} + NDVI_{5km} + PATCH_{1km} + SALT_{18km}$	-124.39	5	258.96	1.56	0.02
	17	$MTNSAGE_{5km} + NDVI_{5km} + CFRST_{540m} + MIX_{270m} + PATCH_{1km}$	-123.38	6	259.02	1.61	0.02
	18	$MTNSAGE_{5km} + NDVI_{5km} + GRASS_{5km} + MIX_{270m} + RIP_{3km}$	-123.40	6	259.06	1.66	0.02
	19	$MTNSAGE_{5km} + NDVI_{5km} + CFRST_{540m} + PATCH_{1km}$	-124.45	5	259.09	1.68	0.02
	20	$MTNSAGE_{5km} + NDVI_{5km} + GRASS_{5km} + RIP_{3km}$	-124.47	5	259.12	1.72	0.02
	21	$MTNSAGE_{5km} + NDVI_{5km} + CFRST_{540m} + GRASS_{5km} + SALT_{18km}$	-123.43	6	259.14	1.73	0.02
	22	$MTNSAGE_{5km} + NDVI_{5km} + CFRST_{540m} + GRASS_{5km} + MIX_{270m} + SALT_{18km}$	-122.44	7	259.25	1.84	0.02
	23	$MTNSAGE_{5km} + NDVI_{5km} + CFRST_{540m} + MIX_{270m}$	-124.58	5	259.34	1.94	0.02
	24	$MTNSAGE_{5km} + NDVI_{5km} + CFRST_{540m}$	-125.61	4	259.36	1.95	0.02
Abiotic	1	$MTNSAGE_{5km} + NDVI_{5km} + SOLAR + TRI_{270}$	-121.90	5	254.00	0.00	0.09

TABLE 6.8. Continued

Category	Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
	2	$MTNSAGE_{5km} + NDVI_{5km} + pH2Od_{1km} + SOLAR + TRI_{270}$	-120.98	6	254.24	0.24	0.08
	3	$MTNSAGE_{5km} + NDVI_{5km} + iH2Od_{1km} + SOLAR + TRI_{270}$	-121.02	6	254.31	0.31	0.08
	4	$MTNSAGE_{5km} + NDVI_{5km} + TRI_{270}$	-123.36	4	254.86	0.86	0.06
	5	$MTNSAGE_{5km} + NDVI_{5km} + iH2Od_{1km} + TRI_{270}$	-122.41	5	255.01	1.01	0.06
	6	$MTNSAGE_{5km} + NDVI_{5km} + iH2Od_{1km} + pH2Od_{1km} + SOLAR + TRI_{270}$	-120.52	7	255.40	1.40	0.05
	7	$MTNSAGE_{5km} + NDVI_{5km} + CTI + SOLAR + TRI_{270}$	-121.69	6	255.66	1.66	0.04
	8	$MTNSAGE_{5km} + NDVI_{5km} + pH2Od_{1km} + TRI_{270}$	-122.81	5	255.81	1.82	0.04
	9	$MTNSAGE_{5km} + NDVI_{5km} + CTI + pH2Od_{1km} + SOLAR + TRI_{270}$	-120.75	7	255.86	1.86	0.04
Disturbance	1	$MTNSAGE_{5km} + NDVI_{5km} + MjRD_{1km}$	-124.82	4	257.76	0.00	0.06
	2	$MTNSAGE_{5km} + NDVI_{5km} + MjRD_{1km} + WELL_{1km}$	-123.80	5	257.79	0.03	0.06
	3	$MTNSAGE_{5km} + NDVI_{5km}$	-126.27	3	258.62	0.86	0.04
	4	$MTNSAGE_{5km} + NDVI_{5km} + MjRD_{1km} + RDdens_{540}$	-124.23	5	258.65	0.89	0.04
	5	$MTNSAGE_{5km} + NDVI_{5km} + WELL_{1km}$	-125.41	4	258.94	1.18	0.03
	6	$MTNSAGE_{5km} + NDVI_{5km} + PIPE_{250}$	-125.49	4	259.11	1.35	0.03
	7	$MTNSAGE_{5km} + NDVI_{5km} + MjRD_{1km} + PIPE_{250}$	-124.50	5	259.19	1.43	0.03
	8	$MTNSAGE_{5km} + NDVI_{5km} + AG_{250} + MjRD_{1km}$	-124.51	5	259.21	1.45	0.03
	9	$MTNSAGE_{5km} + NDVI_{5km} + RDdens_{540}$	-125.56	4	259.25	1.49	0.03
	10	$MTNSAGE_{5km} + NDVI_{5km} + MjRD_{1km} + RDdens_{540} + WELL_{1km}$	-123.51	6	259.28	1.52	0.03
	11	$MTNSAGE_{5km} + NDVI_{5km} + AG_{250} + MjRD_{1km} + WELL_{1km}$	-123.53	6	259.33	1.57	0.03
	12	$MTNSAGE_{5km} + NDVI_{5km} + AG_{250}$	-125.72	4	259.56	1.80	0.02
	13	$MTNSAGE_{5km} + NDVI_{5km} + MjRD_{1km} + PIPE_{250} + WELL_{1km}$	-123.66	6	259.58	1.83	0.02

[a] Variable definitions provided in Table 4.2

to 1.0 and densities exceeded the occurrence threshold across the entire range of values (Fig. 6.4).

Green-tailed towhee

Seven variables were excluded from the *a priori* candidate set of variables for green-tailed towhee models because they were represented in fewer than 20 survey blocks. These included conifer forest (0.27 km), mixed shrubland (0.27 km, 0.54 km, 1 km), riparian (0.27 km), and salt-desert shrubland (0.27 km, 0.54 km). We did not consider temperature variables for this species but did consider solar radiation and mountain big sagebrush. Slope and several of the conifer forest variables were correlated with other variables and were dropped. Non-linearities were not evident for NDVI or sagebrush variables, and we did not consider interactions between sagebrush and NDVI variables.

Initial exploration of the count data with covariates revealed major issues of non-convergence with count-base models. This was due to the limited number of survey blocks where site-specific density estimates for the offset term could be derived because of small sample sizes (only 59 presences) and single detections at many survey blocks. Therefore, we only modeled probability of occurrence for green-tailed towhee. The top AIC_c-selected sagebrush/NDVI logistic regression model consisted of mountain sagebrush within 5 km ($MTNSAGE_{1km}$) and NDVI within 5 km ($NDVI_{5km}$; Table 6.6). Use locations averaged 15.4% more mountain sagebrush habitat than absence locations (Appendix 6.2). Using this base model to evaluate individual multi-scale covariates (Table 6.7), the top vegetation submodel consisted of mixed shrubland within 0.27 km (MIX_{270}) and mean patch size of sagebrush within 1km ($PATCH_{1km}$); Table 6.8). The top AIC_c-selected abiotic model consisted of 1-km decay distance from permanent water ($pH2Od_{250}$), solar radiation, and topographic ruggedness within

TABLE 6.9. Results of AIC_c-based model selection for the combined green-tailed towhee occurrence 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 shown with cumulative Akaike weight (w_i) just ≥ 0.9.

Rank	Intercept	$MTNSAGE_{5km}$	$NDVI_{5km}$	SOLAR	TRI_{270}	$PATCH_{1km}$[b]	$MjRD_{1km}$	MIX_{270m}	LL	K	AIC_c	ΔAIC_c	$\sum w_i$
1	-3.64 (1.50)	0.86 (0.81)	7.14 (1.67)	-0.02 (0.01)	0.03 (0.01)	0.53 (0.21)			-118.26	6	248.79	0.00	0.173
2	-3.57 (1.51)	0.75 (0.81)	7.01 (1.68)	-0.02 (0.01)	0.03 (0.01)	0.53 (0.21)		-27.34 (28.01)	-117.28	7	248.93	0.14	0.334
3	-3.81 (1.51)	0.86 (0.81)	7.32 (1.68)	-0.01 (0.01)	0.03 (0.01)	0.52 (0.21)	-0.97 (0.86)		-117.57	7	249.51	0.73	0.455
4	-5.64 (0.92)	0.91 (0.80)	6.34 (1.62)		0.03 (0.01)	0.52 (0.21)		-29.28 (28.54)	-118.69	6	249.65	0.86	0.567
5	-5.78 (0.92)	1.04 (0.79)	6.47 (1.61)		0.03 (0.01)	0.53 (0.21)			-119.76	5	249.71	0.93	0.676
6	-5.7 (0.92)	1.03 (0.8)	6.77 (1.63)		0.03 (0.01)	0.51 (0.21)	-1.19 (0.87)		-118.74	6	249.75	0.96	0.783
7	-5.56 (0.92)	0.91 (0.8)	6.62 (1.64)		0.03 (0.01)	0.50 (0.21)	-1.15 (0.87)	-27.59 (28.02)	-117.72	7	249.80	1.01	0.887
8	-1.96 (1.27)	1.72 (0.73)	5.24 (1.44)	-0.02 (0.01)	0.02 (0.01)				-121.90	5	254.00	5.21	0.900
9	-1.88 (1.28)	1.59 (0.74)	5.10 (1.45)	-0.02 (0.01)	0.03 (0.01)			-28.89 (27.79)	-120.87	6	254.00	5.22	0.912

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

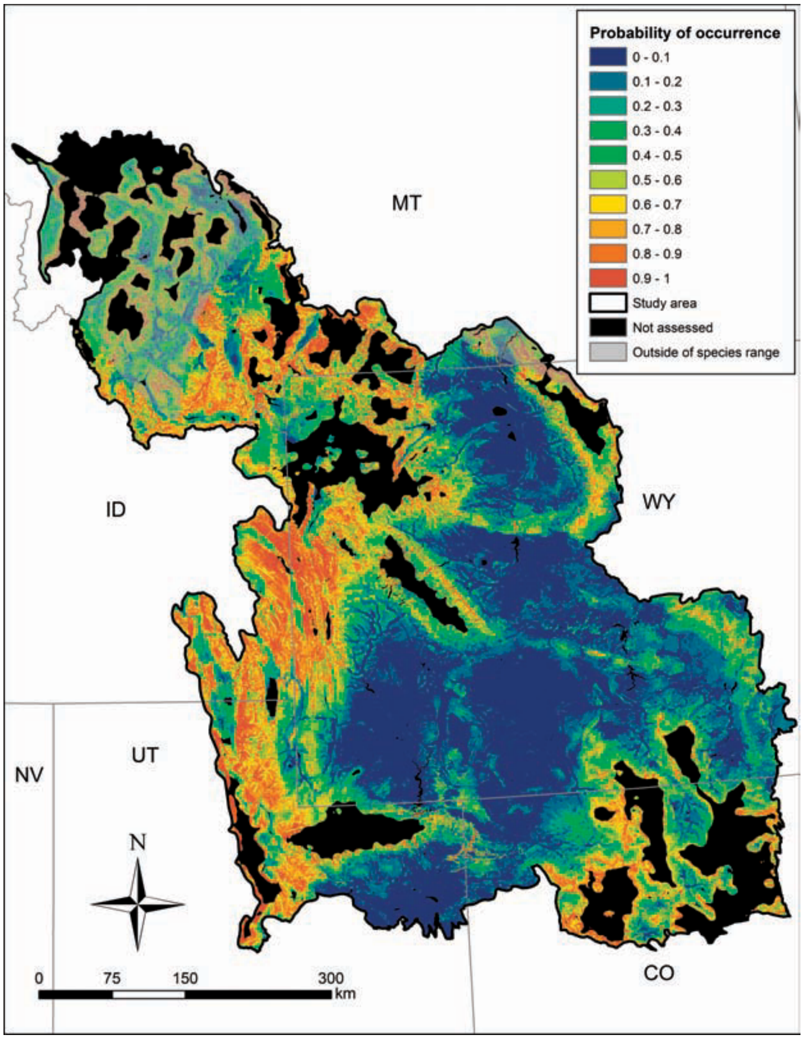

FIG. 6.5. Predicted occurrence (probability) for green-tailed towhee in the Wyoming Basins Ecoregional Assessment area. Semi-transparent grey shaded areas are outside the range of the green-tailed towhee and black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water). Based on the optimal classification, the lowest probability where the occurrence of green-tailed towhee is predicted is 0.17. We infer that spatial predictions above this threshold predict occupied patches.

0.27 km (TRI_{270}; Table 6.8). Decay distance (1 km) from interstate/federal and state highways ($MjRD_{1km}$) was the only variable in the top disturbance submodel (Table 6.8).

The top AIC_c-selected occurrence model for green-tailed towhees combined vegetation, abiotic, and disturbance factors (Table 6.9). Green-tailed towhees selected more productive areas with a greater proportion of mountain sagebrush with larger patches of sagebrush and more rugged terrain, but avoided areas with increased solar radiation (Table 6.9). The weight of evidence for the top model was low (w_i = 0.17), with 7 other candidate models occurring within the cumulative Akaike weight of just ≥ 0.9 (Table 6.9). Other models indicated green-tailed towhees showed weak (large coefficient SEs) avoidance of mixed

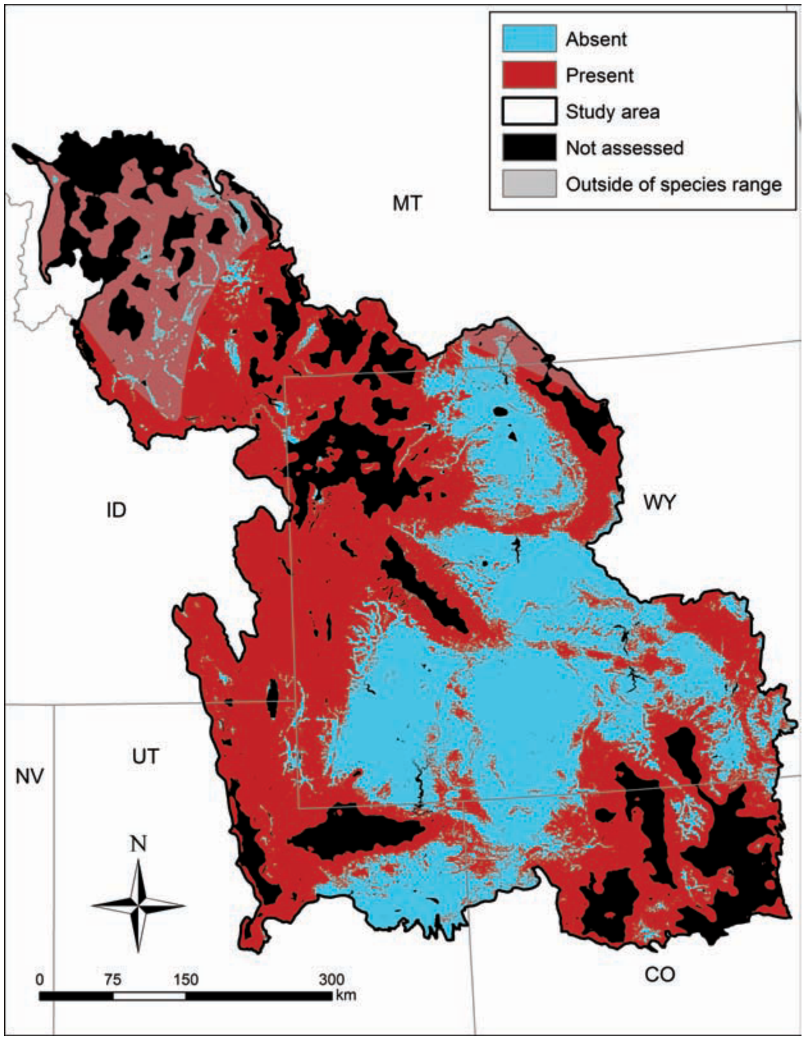

FIG. 6.6. Distribution of green-tailed towhee in the Wyoming Basins Ecoregional Assessment area based on an optimal probability cutoff threshold of 0.17. Semi-transparent grey shaded areas are outside the range of green-tailed towhee and black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water).

shrubland and areas close to interstate highways (Table 6.9). The final model-averaged occurrence model was:

$$Prob = 1 / (1 + (exp(-(-4.56 + 0.92 * MTNSAGE_{5km} + 6.80 * NDVI_{5km} - 0.01 * SOLAR + 0.03 * TRI_{270} + 0.01 * PATCH_{1km} - 0.40 * MjRD_{1km} - 12.00 * MIX_{270})))) \quad (6.2)$$

When applied spatially, the final model-averaged occurrence model for green-tailed towhees predicted the greatest occurrence at higher elevations along the western portion of the WBEA area and in more mountainous shrub habitats containing mountain sagebrush (Fig. 6.5). The final composite green-tailed towhee model had good accuracy (ROC AUC = 0.82 ± 0.03) when predicting green-tailed

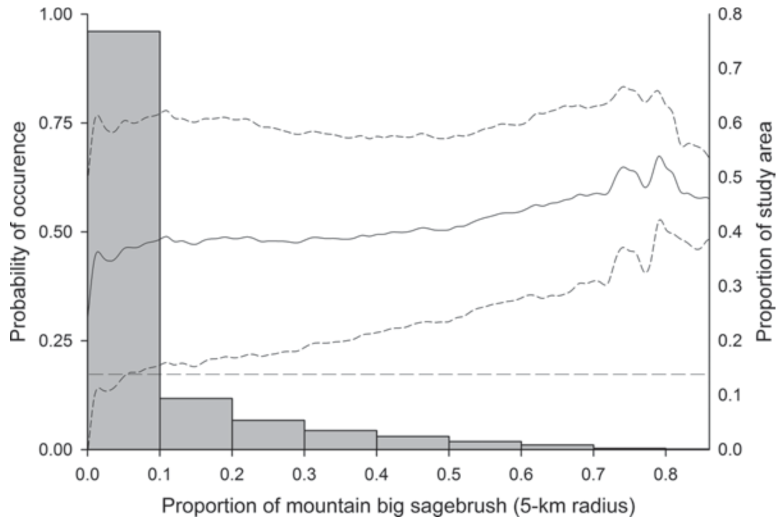

FIG. 6.7. Green-tailed towhee predicted occurrence within the Wyoming Basins Ecoregional Assessment area in relation to proportion of mountain sagebrush (*Artemisia tridentata* ssp. *vaseyana*.) within a 5-km radius. Mean density (black line, ± 1 SD [dashed lines]) values were calculated in each one percent increment of mountain sagebrush within a 5-km radius moving window. Range of predicted densities relate to the observed range of mountain sagebrush at study site locations. The dashed horizontal line represents the probability above which green-tailed towhee is predicted to occur (0.17). Histogram values represent the proportion of the total study area in each 10% segment of mountain sagebrush within 5 km.

towhee presence. This was comparable to the accuracy of the top AIC_c-selected model (ROC AUC = 0.82 ± 0.03). Based on the optimal probability threshold classification cut-point (0.17; Fig. 6.5), this model had an overall classification accuracy of 73.9%. Using this cutoff threshold, 67.5% of the WBEA area (230,078 km^2) was predicted to support green-tailed towhee occurrence (Fig. 6.6). Probability of occurrence increased linearly (although weak) from ~0.45 to ~0.60 as the proportion of mountain big sagebrush habitat increased within a 5-km radius from 0 to 0.8, and green-tailed towhees were likely to occur across the entire range of mountain big sagebrush habitat values (Fig. 6.7). The final green-tailed towhee model predicted probabilities of occurrence that were significantly and positively correlated (although weakly) with independent count data from 96 BBS routes ($r_s = 0.21$, $p = 0.04$).

Lark sparrow

Five variables were excluded from the *a priori* candidate set of variables for lark sparrow abundance models because they

TABLE 6.10. Results of AIC_c-based model selection for lark sparrow zero-inflated negative binomial abundance models in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale sagebrush and NDVI; 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 $\Delta AIC_c \leq 2$ are shown.

Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
1	$ABIGSAGE_{18km} + NDVI_{18km}$	-235.68	7	486.07	0.00	0.59

[a] Variable definitions provided in Table 4.2

TABLE 6.11. Evaluation statistics from AIC_c-based univariate model selection for lark sparrow zero-inflated negative binomial abundance models 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 models with mountain sagebrush (5-km radius) and NDVI (5-km radius) variables as a base model for variables tested. We used AIC_c to sort models for each variable in ascending order to identify the extent at which lark sparrows respond to individual variables.

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	$CFRST_{1km}$	-233.55	9	486.27	0.00	1.00
	$GRASS_{5km}$	-233.91	9	487.00	0.00	0.29
	$GRASS_{3km}$	-234.24	9	487.66	0.66	0.21
	$GRASS_{270}$	-234.66	9	488.49	1.49	0.14
	$GRASS_{540}$	-234.66	9	488.49	1.50	0.13
	$GRASS_{1km}$	-234.71	9	488.59	1.60	0.13
	$GRASS_{18km}$	-234.87	9	488.90	1.91	0.11
	MIX_{1km}	-232.13	9	483.43	0.00	1.00
	MIX_{18km}	-240.04	9	499.24	15.82	0.00
	MIX_{5km}	-242.41	9	504.00	20.57	0.00
	MIX_{3km}	-244.41	9	507.99	24.56	0.00
	RIP_{18km}	-226.33	9	471.83	0.00	0.73
	RIP_{5km}	-227.35	9	473.87	2.04	0.26
	RIP_{3km}	-231.91	9	482.99	11.16	0.00
	RIP_{1km}	-234.57	9	488.30	16.48	0.00
	RIP_{540}	-235.62	9	490.41	18.59	0.00
	RIP_{270}	-235.63	9	490.44	18.61	0.00
	$SALT_{1km}$	-247.87	9	514.91	0.00	0.67
	$SALT_{540}$	-248.60	9	516.36	1.45	0.33
	$CONTAG_{5km}$	-661.62	4	1,335.51	0.00	0.35
	$PATCH_{3km}$	-661.88	4	1,336.04	0.53	0.27
	$PATCH_{5km}$	-662.21	4	1,336.69	1.18	0.19
	$EDGE_{5km}$	-662.88	4	1,338.03	2.53	0.10
	$CONTAG_{3km}$	-662.99	4	1,338.26	2.75	0.09
Abiotic	CTI	-234.53	9	488.22	0.00	0.88
	CTI[2b]	-234.26	11	492.24	4.01	0.12
	ELEV	-232.48	9	484.13	0.00	1.00
	ELEV[2b]	-240.20	11	504.14	20.01	0.00
	$iH2Od_{250}$[c]	-235.13	9	489.42	0.00	0.41
	$iH2Od_{1km}$[c]	-235.43	9	490.03	0.61	0.30
	$iH2Od_{500}$[c]	-235.44	9	490.05	0.62	0.30
	$pH2Od_{1km}$[c]	-234.09	9	487.35	0.00	0.53
	$pH2Od_{250}$[c]	-234.66	9	488.48	1.13	0.30

TABLE 6.11. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
	$pH2Od_{250}$[c]	-235.25	9	489.67	2.32	0.17
	SOLAR	-235.21	9	489.60	0.00	0.91
	$SOLAR^{2b}$	-235.22	11	494.16	4.56	0.09
	TRI_{3km}^{2b}	-231.03	11	485.79	0.00	0.49
	TRI_{5km}	-234.74	9	488.65	2.86	0.12
	TRI_{5km}^{2b}	-232.71	11	489.15	3.36	0.09
	TRI_{3km}	-235.01	9	489.19	3.40	0.09
	TRI_{1km}	-235.38	9	489.92	4.14	0.06
	TRI	-235.56	9	490.29	4.51	0.05
	TRI_{540}	-235.61	9	490.40	4.61	0.05
	TRI_{270}	-235.67	9	490.52	4.73	0.05
	TRI_{1km}^{2b}	-242.57	11	508.86	23.07	0.00
	TRI^{2b}	-244.93	11	513.59	27.80	0.00
	TRI_{270}^{2b}	-244.95	11	513.63	27.84	0.00
Disturbance	AG_{1km}[c]	-232.70	9	484.56	0.00	1.00
	AG_{500}[c]	-247.58	9	514.32	29.76	0.00
	AG_{250}[c]	-248.19	9	515.54	30.98	0.00
	$MjRD_{250}$[c]	-246.49	9	512.16	0.00	0.46
	$MjRD_{500}$[c]	-246.97	9	513.10	0.94	0.29
	$MjRD_{1km}$[c]	-247.09	9	513.36	1.20	0.25
	$PIPE_{1km}$[c]	-235.58	9	490.33	0.00	0.34
	$PIPE_{500}$[c]	-235.59	9	490.35	0.03	0.34
	$PIPE_{250}$[c]	-235.66	9	490.50	0.17	0.32
	$POWER_{1km}$[c]	-234.28	9	487.73	0.00	0.52
	$POWER_{500}$[c]	-234.94	9	489.05	1.32	0.27
	$POWER_{250}$[c]	-235.14	9	489.45	1.72	0.22
	$RDdens_{540}$	-234.01	9	487.20	0.00	0.22
	$RDdens_{270}$	-234.02	9	487.20	0.00	0.22
	$2RD_{500}$[c]	-234.75	9	488.67	1.47	0.11
	$2RD_{250}$[c]	-234.78	9	488.72	1.52	0.10
	$2RD_{1km}$[c]	-234.92	9	489.00	1.80	0.09
	$RDdens_{18km}$	-235.08	9	489.33	2.14	0.08
	$RDdens_{5km}$	-235.32	9	489.82	2.62	0.06
	$RDdens_{3km}$	-235.33	9	489.83	2.63	0.06
	$RDdens_{1km}$	-235.41	9	489.98	2.79	0.06
	$WELL_{1km}$[c]	-233.94	9	487.04	0.00	0.64

TABLE 6.11. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
	$WELL_{500}$[c]	-234.99	9	489.14	2.10	0.22
	$WELL_{250}$[c]	-235.50	9	490.16	3.12	0.13

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

were represented in 20 or fewer survey blocks. These variables included conifer forest (0.27 km, 0.54 km), mixed shrubland (0.27 km, 0.54 km), and salt-desert shrubland (0.27 km). We did not consider temperature variables but did assess solar radiation. Several remaining variables were dropped due to correlation, such as slope, some conifer forest variables, and some salt-desert shrubland variables. We considered non-linear responses of lark sparrow to NDVI, but not for sagebrush because non-linearities were not evident. Interactions between sagebrush and NDVI variables were not apparent and thus not considered.

Initial exploration of the count data without covariates suggested that a zero-inflated negative binomial may be the most appropriate model. This was confirmed by comparing fit with sagebrush and NDVI covariates between a zero inflated to a standard negative binomial model (without zero-inflation; z = 3.17, p < 0.001). The zero-inflated model was used to fit the sagebrush/NDVI base models. The top AIC_c-selected sagebrush/NDVI model consisted of all big sagebrush within 18 km ($ABIGSAGE_{18km}$) and NDVI within 18 km ($NDVI_{18km}$; Table 6.10). Use locations averaged 2.8% more all big sagebrush habitat than absence locations (Appendix 6.3). Using this base model to evaluate and select individual covariates (Table 6.11), the top vegetation submodel consisted of conifer forest within 1 km ($CFRST_{1km}$), mixed shrubland within 1 km (MIX_{1km}), and riparian within 18 km (RIP_{18km}; Table 6.12). The top AIC_c-selected abiotic model consisted of only elevation as a quadratic ($ELEV + ELEV^2$; Table 6.12). Decay distance (1 km) to agricultural land (AG_{1km}) and 1-km decay distance to oil and gas wells ($WELL_{1km}$) were included in the top disturbance submodel (Table 6.12).

The top AIC_c-selected lark sparrow occurrence portion of the zero-inflated abundance model was a combination of vegetation and disturbance factors (Table 6.13). Lark sparrow occurrence was negatively associated with proportion of all big sagebrush, conifer forest, proportion of riparian land cover, and proportion of agricultural land, but positively associated with productive habitats, proportion of mixed shrubland, and proportion of agricultural land (Table 6.13a). Despite avoidance of sagebrush in the occurrence model, abundance was positively associated with proportion of big sagebrush, conifer forest, proportion of mixed shrubland, and proportion of riparian land cover (Table 6.13b). However, relationships were weak for most variables except sagebrush. Weight of evidence for the top model was moderate (w_i = 0.25), with 12 candidate models occurring within the cumulative Akaike weight of just ≥ 0.9 (Table 6.13). Other models indicated positive but weak relationships between proximity to wells (decay) and elevation (note coefficient instability across models) with lark sparrow occurrence (Table 6.13a). Abundance, however, declined with proximity to energy wells and higher elevation sites (both

TABLE 6.12. Results of AIC_c-based submodel selection for lark sparrow zero-inflated negative binomial abundance models 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 $\Delta AIC_c \leq 2$ are shown.

Category	Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	1	$ABIGSAGE_{18km} + NDVI_{18km} + CFRST_{1km} + MIX_{1km} + RIP_{18km}$	-218.94	13	465.09	0.00	0.39
	2	$ABIGSAGE_{18km} + NDVI_{18km} + MIX_{1km} + RIP_{18km}$	-221.45	11	465.75	0.67	0.28
Abiotic	1	$ABIGSAGE_{18km} + NDVI_{18km} + ELEV$	-232.48	9	483.54	0	0.17
	2	$ABIGSAGE_{18km} + NDVI_{18km} + CTI + ELEV + pH2Od_{1km} + TRI_{3km} + TRI_{3km}^2$	-223.81	17	483.66	0.11	0.16
	3	$ABIGSAGE_{18km} + NDVI_{18km} + pH2Od_{1km} + TRI_{3km} + TRI_{3km}^2$	-228.39	13	483.98	0.43	0.14
	4	$ABIGSAGE_{18km} + NDVI_{18km} + TRI_{3km} + TRI_{3km}^2$	-231.03	11	484.93	1.38	0.09
	5	$ABIGSAGE_{18km} + NDVI_{18km} + CTI + pH2Od_{1km} + TRI_{3km} + TRI_{3km}^2$	-226.95	15	485.48	1.94	0.07
Disturbance	1	$ABIGSAGE_{18km} + NDVI_{18km} + AG_{1km} + WELL_{1km}$	-226.22	11	0.00	0.00	0.55
	2	$ABIGSAGE_{18km} + NDVI_{18km} + AG_{1km} + RDdens_{540} + WELL_{1km}$	-224.95	13	1.46	1.80	0.22

[a] Variable definitions provided in Table 4.2

weak effects; Table 6.13b). The final model averaged abundance model was:

$$Density = 1 / (1 + (exp(-(-90.22 - 42.87 * ABIGSAGE_{18km} + 495.94 * NDVI_{18km} - 255.25 * CFRST_{1km} + 270.14 * MIX_{1km} - 400.67 * RIP_{18km} - 15.92 * AG_{1km} + 5.38 * WELL_{1km} - 0.00068 * ELEV)))) * exp(-2.50 + 3.14 * ABIGSAGE_{18km} - 2.34 * NDVI_{18km} + 3.06 * CFRST_{1km} + 1.42 * MIX_{1km} + 2.98 * RIP_{18km} + 0.15 * AG_{1km} - 0.43 * WELL_{1km} - 0.00014 * ELEV + 0.96) \quad (7.3)$$

The mean offset for the survey blocks is represented by the final constant in the model (0.96).

The final model-averaged lark sparrow abundance model had weak correlation with independent count data from 96 BBS routes ($r_s = 0.08$, $p = 0.45$). When applied spatially, moderate elevation sagebrush habitats across the WBEA area had the highest predicted densities of lark sparrow (Fig. 6.8). Based on the lowest density that could support a lark sparrow territory (0.17 birds/ha; Fig. 6.8), 60.5% of the Wyoming Basins (209,010 km^2) was predicted to support breeding lark sparrows (Fig. 6.9). Lark sparrow showed gradual but linear increases in density, with birds/ha increasing from 0.25 to 0.75 as proportion of all big sagebrush habitat across a 18-km radius area increased from about 0 to 0.8 (Fig. 6.10). Although lark sparrow occurrence was likely across the entire range of all big sagebrush habitat values, a threshold occurred when the proportion of all big sagebrush habitat exceeded 50% of a large landscape (18 km), where abundance of lark sparrow increased (Fig. 6.10).

Sage sparrow

Five variables were excluded from the *a priori* candidate set of variables for sage sparrow abundance models because they occurred on fewer than 20 survey blocks.

These variables included conifer forest (0.27 km, 0.54 km, 1 km), mixed shrubland (0.27 km), and riparian (0.27 km). We did not consider temperature variables for this species but did consider solar radiation. Again, several additional variables were removed from consideration due to correlations with other variables. We considered NDVI as a non-linearity at all scales but non-linearities were not evident for any sagebrush variable. Interactions between sagebrush and NDVI variables were also evaluated as competing models.

Initial exploration of the count data without covariates suggested that a zero-inflated Poisson model was most appropriate. The top AIC_c-selected sagebrush/NDVI model consisted of all sagebrush within 18 km ($ALLGSAGE_{18km}$) and NDVI as a quadratic within 18 km ($NDVI_{18km} + NDVI_{18km}^2$), which had low support (w_i = 0.15; Table 6.14). When fit with these base covariates, a Vuong test confirmed that the zero-inflated Poisson model had better fit over the Poisson model ($z = 4.7$, $p < 0.001$). Use locations averaged 6.1% more all sagebrush habitat than absence locations (Appendix 6.4). Using the base model to evaluate and select individual covariates (Table 6.15), the top vegetation submodel consisted of grassland within 3 km ($GRASS_{3km}$), mixed shrubland within 5 km (MIX_{5km}), riparian within 1 km (RIP_{1km}), sagebrush contagion within 3 km ($CONTAG_{3km}$), and salt-desert shrubland within 1 km ($SALT_{1km}$; Table 6.16). The top AIC_c-selected abiotic model had only the addition of topographic ruggedness within 5 km (TRI_{5km}; Table 6.16). Road density within 18 km ($RDdens_{18km}$), and 0.25-km decay distance to oil and gas wells ($WELL_{250}$) were included in the top disturbance submodel (Table 6.16).

The top AIC_c-selected sage sparrow occurrence portion of the zero-inflated abundance model combined vegetation, abiotic, and disturbance factors (Table 6.17). Despite presence locations containing a greater proportion (18 km) of all sagebrush ($\bar{x}$ = 0.68 ± 0.01) compared to absence locations ($\bar{x}$ = 0.63 ± 0.01; Appendix 6.4), the occurrence portion of the sage sparrow model appeared negatively associated with proportion of all sagebrush habitat. Occurrence was also correlated with greater proportion of riparian land cover (weak effect) and salt-desert shrubland, increased contagion of sagebrush, proximity to oil and gas wells (weak effect), and areas with greater overall road density (Table 6.17). However, sage sparrows avoided areas with rugged terrain or higher proportions of mixed shrubland (Table 6.17). Sage sparrow abundance was associated with lower proportions of all sagebrush, lower vegetation productivity, as well as lower proportions of mixed shrubland, riparian, and salt-desert shrubland habitats, higher sagebrush contagion, more rugged terrain, lower road densities, and areas closer to oil and gas wells (Table 6.17). However, most effects, except for sagebrush, NDVI, and wells, were weak (large SEs; Table 6.17). Weight of evidence for the top model was moderate (w_i = 0.30), with 10 candidate models occurring within the cumulative Akaike weight of just ≥ 0.9 (Table 6.17). These 10 models contained a subset of the variables in the top model, with the only additional covariate in some models being negative for occurrence and abundance of grasslands, although the effect was very weak (see SEs; Table 6.17). The final model averaged abundance model was

$$\begin{aligned} Density = {} & 1 / (1 + (exp(-(15.90 - 9.46 * ALLSAGE_{18km} - 54.46 * NDVI_{18km} + 48.79 * NDVI_{18km}^2 - 86.06 * MIX_{5km} + \\ & 1.22 * RIP_{1km} + 0.055 * CONTAG_{3km} + 9.18 * SALT_{1km} - 0.08 * TRI_{5km} + 1.52 * RDdens_{18km} + 4.68 * WELL_{250} - 1.49 * \\ & GRASS_{3km})))) * exp(1.29 - 2.32 * ALLSAGE_{18km} + 2.51 * NDVI_{18km} - 11.45 * NDVI_{18km}^2 - 19.58 * MIX_{5km} - 3.63 * RIP_{1km} - 0.0008 * \\ & CONTAG_{3km} - 0.97 * SALT_{1km} - 0.01 * TRI_{5km} - 0.31 * RDdens_{18km} + 1.70 * WELL_{250} - 0.27 * GRASS_{3km} + 2.09) \end{aligned} \tag{7.4}$$

TABLE 6.13. Results of AIC_c-based model selection for the combined lark sparrow zero-inflated negative binomial abundance 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 shown with cumulative Akaike weight (w_i) of just ≥ 0.9. Section (A) includes the inflate portion of the model capturing presence-absence (occurrence), whereas section (B) includes the count (abundance) portion of the model.

Rank	Intercept	$ABIGSAGE_{18km}$	$NDVI_{18km}$	$CFRST_{1km}$	MIX_{1km}	RIP_{18km}
(A) Occurrence						
1	-105.93 (56.11)	-45.77 (26.19)	563.68 (296.09)	-402.10 (217.34)	335.91 (226.86)	-462.49 (260.39)
2	-110.67 (63.34)	-45.40 (25.44)	581.35 (323.99)	-395.47 (222.94)	376.71 (273.49)	-489.19 (289.98)
3	-101.64 (55.81)	-42.39 (21.58)	534.21 (279.98)		366.67 (242.66)	-446.10 (250.70)
4	-97.75 (63.85)	-44.78 (31.34)	520.97 (333.91)	-363.35 (243.22)	356.56 (279.81)	-403.41 (294.23)
5	-52.90 (26.02)	-36.84 (15.08)	316.34 (135.42)	-235.80 (99.86)		-262.74 (127.10)
6	-101.20 (55.60)	-45.18 (24.65)	542.95 (291.51)		303.60 (182.34)	-443.13 (258.29)
7	-15.19 (12.71)	-41.97 (17.89)	305.60 (127.42)			-149.94 (66.22)
8	-52.68 (26.05)	-34.18 (13.69)	318.42 (140.24)	-232.57 (102.52)		-261.60 (129.41)
9	-49.78 (18.97)	-32.43 (13.34)	295.24 (100.63)	-210.77 (73.35)		-217.52 (88.78)
10	-48.86 (20.35)	-33.22 (14.24)	296.92 (104.19)	-212.99 (75.61)		-222.02 (92.61)
11	-88.40 (53.02)	-41.20 (21.77)	468.85 (247.29)		360.44 (251.82)	-353.16 (211.33)
12	-110.95 (74.20)	-46.29 (29.18)	582.61 (374.59)	-395.72 (249.90)	401.19 (372.20)	-482.52 (325.96)
13	-103.32 (60.96)	-44.24 (23.05)	542.89 (299.39)		403.43 (304.02)	-443.10 (262.11)
(B) Abundance						
1	-2.52 (1.24)	2.99 (1.23)	-2.94 (2.14)	4.08 (2.54)	1.75 (6.02)	3.47 (5.08)
2	-2.59 (1.27)	2.95 (1.23)	-2.58 (2.04)	3.81 (2.57)	1.97 (6.17)	2.45 (5.14)
3	-2.72 (1.26)	2.72 (1.16)	-1.59 (1.86)		2.25 (6.27)	1.71 (5.14)
4	-2.40 (1.27)	3.07 (1.24)	-3.38 (2.21)	3.99 (2.54)	1.38 (5.99)	3.55 (5.07)
5	-2.28 (1.25)	4.47 (1.39)	-0.45 (2.47)	5.58 (2.62)		3.49 (5.04)
6	-2.71 (1.25)	2.74 (1.16)	-1.66 (1.95)		2.28 (6.21)	2.11 (5.10)
7	-2.18 (1.23)	3.82 (1.26)	-1.29 (2.43)			4.23 (4.87)
8	-2.58 (1.23)	3.17 (1.24)	-3.02 (2.16)	4.23 (2.55)		3.37 (5.04)
9	-2.33 (1.23)	3.22 (1.22)	-3.78 (2.19)	4.12 (2.53)		3.43 (5.04)
10	-2.05 (1.24)	4.30 (1.36)	-1.40 (2.48)	5.27 (2.60)		3.27 (4.98)
11	-2.51 (1.28)	2.83 (1.17)	-2.38 (2.11)		1.68 (6.10)	2.56 (5.28)
12	-2.51 (1.27)	2.90 (1.24)	-2.59 (2.03)	3.62 (2.56)	1.63 (6.18)	2.58 (5.15)
13	-2.63 (1.27)	2.71 (1.16)	-1.68 (1.86)		1.81 (6.26)	1.91 (5.14)

[a] Variable definitions provided in Table 4.2
[b] Coefficients and standard errors multiplied by 10^3

TABLE 6.13. Extended

AG_{1km}	$WELL_{1km}$	ELEV[b]	LL	K	AIC_c	ΔAIC_c	$\sum w_i$
-21.18 (12.63)			-216.15	15	463.89	0.00	0.25
			-218.94	13	465.09	1.19	0.14
			-221.45	11	465.75	1.86	0.10
-25.66 (15.50)	8.70 (7.05)		-215.17	17	466.38	2.49	0.07
-13.52 (6.49)		1.40 (3.78)	-217.40	15	466.38	2.49	0.07
-19.97 (11.89)			-219.86	13	466.91	3.02	0.06
-65.38 (29.54)	73.79 (30.97)	-15.73 (8.34)	-217.87	15	467.33	3.44	0.05
-13.64 (6.72)			-220.11	13	467.43	3.53	0.04
-17.60 (7.04)	6.66 (5.33)		-218.41	15	468.41	4.52	0.03
-17.42 (7.23)	6.50 (5.53)	-0.26 (3.87)	-216.21	17	468.46	4.57	0.03
-25.57 (15.74)	11.40 (10.54)		-218.49	15	468.56	4.67	0.02
	4.99 (14.05)		-218.49	15	468.58	4.68	0.02
	6.42 (9.83)		-220.76	13	468.72	4.83	0.02
0.04 (0.77)			-216.15	15	463.89	0.00	0.25
			-218.94	13	465.09	1.19	0.14
			-221.45	11	465.75	1.86	0.10
0.42 (0.82)	-1.16 (1.01)		-215.17	17	466.38	2.49	0.07
-0.11 (0.77)		-1.03 (0.45)	-217.40	15	466.38	2.49	0.07
-0.03 (0.75)			-219.86	13	466.91	3.02	0.06
1.42 (0.87)	-3.18 (1.00)	-0.72 (0.44)	-217.87	15	467.33	3.44	0.05
0.08 (0.77)			-220.11	13	467.43	3.53	0.04
0.61 (0.86)	-1.46 (1.14)		-218.41	15	468.41	4.52	0.03
0.35 (0.85)	-1.21 (1.11)	-0.91 (0.44)	-216.21	17	468.46	4.57	0.03
0.50 (0.91)	-1.49 (1.20)		-218.49	15	468.56	4.67	0.02
	-1.01 (0.96)		-218.49	15	468.58	4.68	0.02
	-1.14 (0.94)		-220.76	13	468.72	4.83	0.02

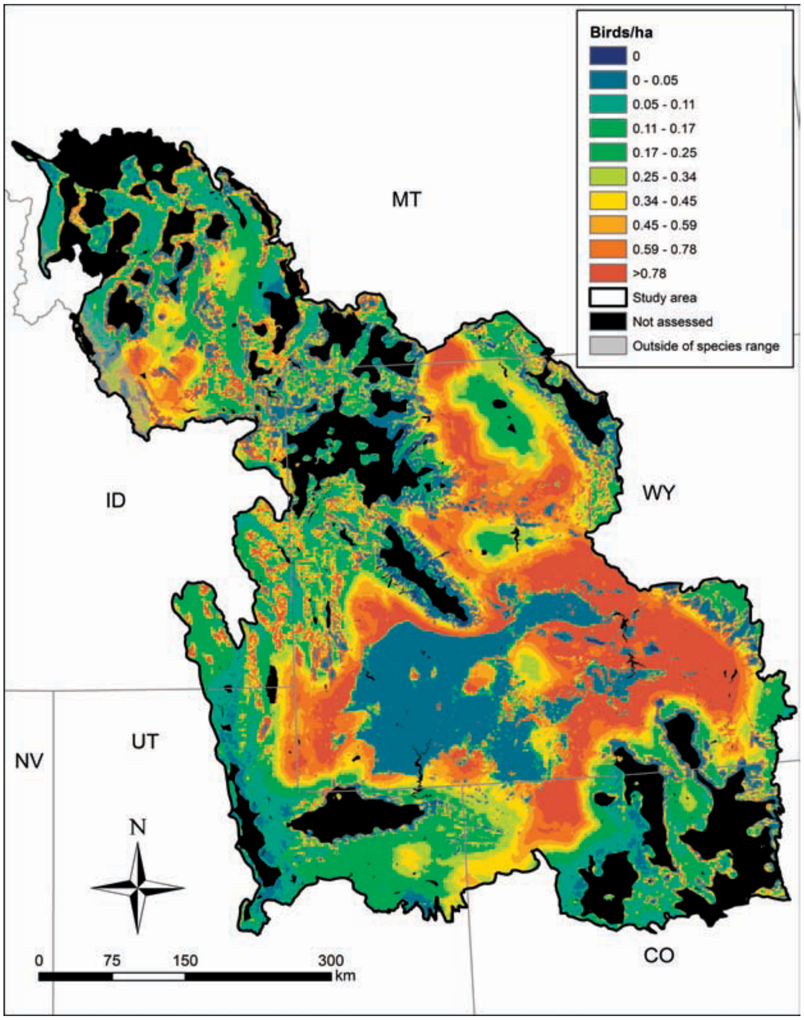

FIG. 6.8. Predicted density estimates (birds/ha) for lark sparrow in the Wyoming Basins Ecoregional Assessment area. Black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water). Based on the largest territory sizes required to support one lark sparrow, the lowest density that could support a viable territory is 0.17 birds/ha. We infer that spatial predictions above this threshold predict occupied patches.

The mean offset for the survey blocks is represented by the final constant in the model (2.09).

The final model-averaged abundance model for sage sparrow accurately predicted independent count data from 96 BBS routes ($r_s = 0.57$, $p < 0.001$). When applied spatially across the WBEA area within the range of the species, sage sparrow densities were predicted to be highest in lower elevation shrublands, with low densities in more productive high-elevation sites (Fig. 6.11). A negative relationship between abundance and road density was seen in some areas, with road areas having lower predicted bird density than the surrounding landscape matrix (Fig. 6.11). Based on the lowest density that could support a sage sparrow territory (0.14 birds/ha; Fig. 6.11), 49.0% of the Wyoming Basins (169,300 km^2) was predicted to support breeding sage sparrows (Fig. 6.12). Despite the apparent avoidance of sagebrush based on model covariates (negative oc-

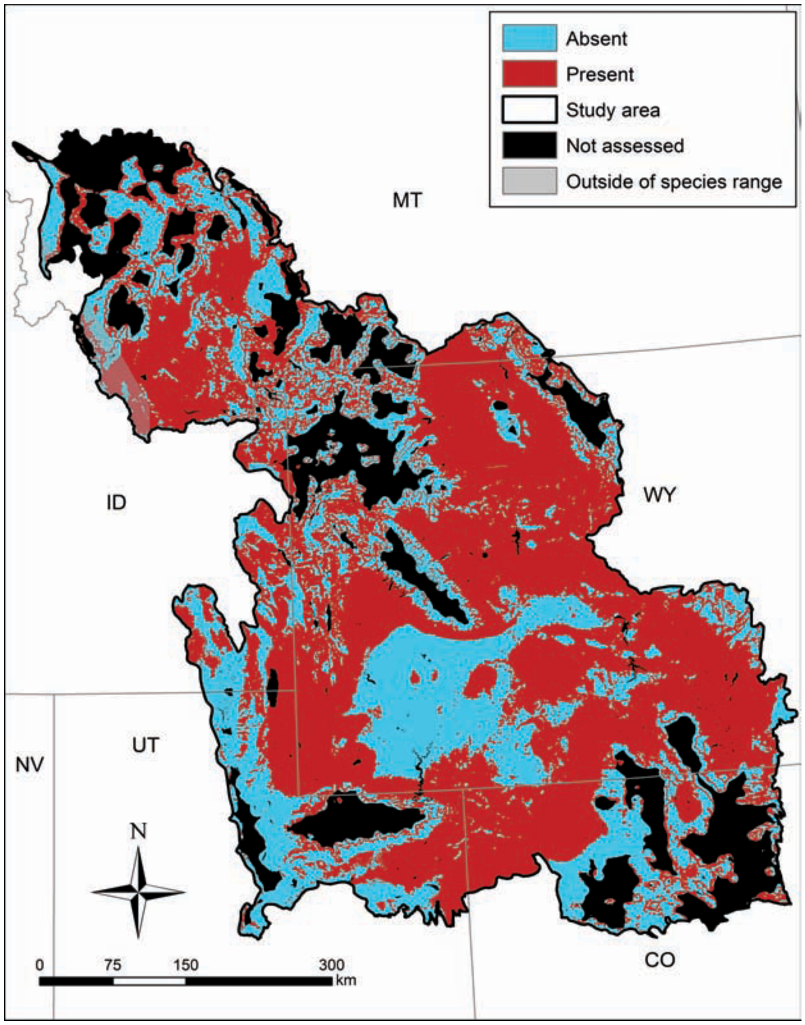

FIG. 6.9. Distribution of lark sparrow in the Wyoming Basins Ecoregional Assessment area based on a threshold of (0.17 birds/ha), the largest territory sizes required to support one lark sparrow. Semi-transparent grey shaded areas are outside the range of lark sparrow and black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water).

currence and abundance relationship with $ALLSAGE_{18km}$; Table 6.17), predicted sage sparrow densities assessed across the WBEA area were low (<0.5 birds/ha) when sagebrush land cover (all species) fell below approximately 20% of a large 18-km radius, but densities only increased slightly (up to 0.75 birds/ha) when sagebrush land cover increased (Fig. 6.13). Sage sparrows exceeded the threshold density for occurrence across the range of all sagebrush values (Fig. 6.13).

Sage thrasher

Two variables were excluded from the *a priori* candidate set of variables for sage thrasher abundance models because they were represented at fewer than 20 survey blocks for either presences or absences. These included conifer forest (0.27 km) and mixed shrubland (0.27 km). We did not consider temperature variables for this species, but did consider solar radiation. Several additional variables were removed

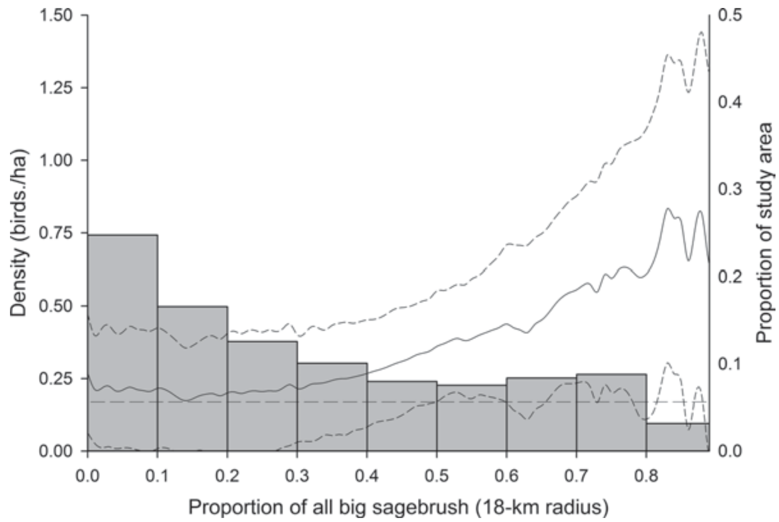

FIG. 6.10. Lark sparrow predicted densities within the Wyoming Basins Ecoregional Assessment area in relation to proportion of all big sagebrush (*Artemisia tridentata*) within an 18-km radius. Mean density (black line, ± 1 SD [dashed lines]) values were calculated in each one percent increment of all big sagebrush within a 1-km radius moving window. Range of predicted densities relate to the observed range of sagebrush at study site locations. The dashed horizontal line represents the lowest density that could support a viable territory (0.17 birds/ha), above which we infer patches to be occupied. Histogram values represent the proportion of the total study area in each 10% segment of all big sagebrush within 18 km.

from consideration due to correlations with other variables. We considered non-linear responses in sage thrasher to NDVI but not for any sagebrush variable. Interactions between sagebrush and NDVI variables were not evident and thus not evaluated as competing models.

Initial exploration of count data without covariates suggested that a zero-inflated Poisson model was most appropriate. The top AIC_c-selected sagebrush/NDVI model consisted of all big sagebrush within 0.27 km ($ABIGSAGE_{270}$) and NDVI as a quadratic within 18 km ($NDVI_{18km} + NDVI_{18km}^2$), which had low support (w_i = 0.09; Table 6.18). When fit with these base covariates, a Vuong test confirmed that the zero-inflated Poisson model had better fit than the Poisson model without zero-inflation (z = 2.81, p < 0.01). Use locations averaged 15.8% more big sagebrush habitat than absence locations (Appendix 6.5). Using the base model to evaluate and select individual

TABLE 6.14. Results of AIC_c-based model selection for sage sparrow zero-inflated Poisson abundance models in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale sagebrush and NDVI; 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 ΔAIC_c ≤ 2 are shown.

Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
1	$ALLSAGE_{18km} + NDVI_{18km} + NDVI_{18km}^2$	-335.92	8	688.30	0.00	0.15
2	$ABIGSAGE_{18km} + NDVI_{18km} + NDVI_{18km}^2$	-336.74	8	689.95	1.65	0.06

[a] Variable definitions provided in Table 4.2

TABLE 6.15. Evaluation statistics from AIC_c-based univariate model selection for sage sparrow zero-inflated Poisson abundance models 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 models with all sagebrush (18-km radius) and NDVI (18-km radius; quadratic) variables as a base model for variables tested. We used AIC_c to sort models for each variable in ascending order to identify the extent at which sage sparrows respond to individual variables.

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	$CFRST_{1km}$	-334.92	10	690.56	0.00	0.50
	$CFRST_{540m}$	-335.57	10	691.86	1.30	0.26
	$CFRST_{270m}$	-335.71	10	692.13	1.57	0.23
	$GRASS_{3km}$	-326.55	10	673.81	0.00	0.55
	$GRASS_{5km}$	-326.76	10	674.23	0.42	0.44
	$GRASS_{1km}$	-330.88	10	682.47	8.66	0.01
	$GRASS_{540m}$	-332.49	10	685.69	11.89	0.00
	$GRASS_{18km}$	-333.86	10	688.43	14.62	0.00
	$GRASS_{270m}$	-333.96	10	688.64	14.84	0.00
	MIX_{5km}	-327.32	10	675.36	0.00	0.34
	MIX_{3km}	-327.39	10	675.50	0.14	0.32
	MIX_{18km}	-327.49	10	675.70	0.34	0.29
	MIX_{270m}	-329.71	10	680.15	4.79	0.03
	MIX_{540m}	-331.10	10	682.92	7.56	0.01
	MIX_{1km}	-331.18	10	683.08	7.72	0.01
	RIP_{1km}	-332.07	10	684.86	0.00	0.43
	RIP_{540m}	-332.17	10	685.07	0.21	0.39
	RIP_{5km}	-333.69	10	688.10	3.24	0.08
	RIP_{3km}	-334.16	10	689.04	4.18	0.05
	RIP_{270}	-334.54	10	689.80	4.94	0.04
	RIP_{18km}	-335.73	10	692.19	7.33	0.01
	$SALT_{1km}$	-332.34	10	685.40	0.00	0.56
	$SALT_{270}$	-333.21	10	687.14	1.73	0.24
	$SALT_{540m}$	-333.38	10	687.48	2.08	0.20
	$CONTAG_{3km}$	-327.14	10	675.00	0.00	0.91
	$EDGE_{3km}$	-329.72	10	680.16	5.16	0.07
	$EDGE_{5km}$	-332.13	10	684.97	9.97	0.01
	$CONTAG_{5km}$	-332.56	10	685.84	10.84	0.00
	$PATCH_{1km}$	-332.59	10	685.90	10.90	0.00
	$CONTAG_{1km}$	-333.25	10	687.21	12.21	0.00
	$EDGE_{1km}$	-333.99	10	688.70	13.69	0.00
	$PATCH_{3km}$	-334.69	10	690.09	15.09	0.00

TABLE 6.15. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
Abiotic	CTI	-335.39	10	691.49	0.00	0.53
	CTI^{2b}	-333.36	12	691.75	0.26	0.47
	ELEV	-335.54	10	691.79	0.00	0.81
	$ELEV^{2b}$	-334.84	12	694.69	2.90	0.19
	$iH2Od_{1km}^{c}$	-334.09	10	688.89	0.00	0.46
	$iH2Od_{500}^{c}$	-334.38	10	689.47	0.57	0.35
	$iH2Od_{250}^{c}$	-334.95	10	690.62	1.72	0.19
	$pH2Od_{1km}^{c}$	-334.43	10	689.58	0.00	0.43
	$pH2Od_{250}^{c}$	-334.79	10	690.30	0.72	0.30
	$pH2Od_{250}^{c}$	-334.88	10	690.47	0.89	0.27
	SLOPE	-335.50	10	691.72	0.00	0.84
	$SLOPE^{2b}$	-335.04	12	695.11	3.39	0.16
	TRI_{5km}	-327.31	10	675.34	0.00	0.63
	TRI_{5km}^{2b}	-325.93	12	676.88	1.54	0.29
	TRI_{3km}	-329.54	10	679.80	4.46	0.07
	TRI_{3km}^{2b}	-329.16	12	683.34	8.00	0.01
	TRI_{1km}	-332.88	10	686.47	11.13	0.00
	TRI_{1km}^{2b}	-331.69	12	688.41	13.07	0.00
	TRI_{540}	-334.20	10	689.12	13.78	0.00
	TRI_{270}	-334.51	10	689.75	14.41	0.00
	TRI_{540}^{2b}	-332.83	12	690.69	15.35	0.00
	TRI_{270}^{2b}	-332.99	12	691.00	15.66	0.00
	TRI	-335.35	10	691.41	16.07	0.00
	TRI^{2b}	-335.05	12	695.13	19.79	0.00
Disturbance	AG_{500}^{c}	-335.74	10	692.19	0.00	0.36
	AG_{250}^{c}	-335.81	10	692.33	0.13	0.33
	AG_{1km}^{c}	-335.88	10	692.48	0.28	0.31
	$MjRD_{1km}^{c}$	-335.77	10	692.25	0.00	0.34
	$MjRD_{250}^{c}$	-335.77	10	692.26	0.02	0.33
	$MjRD_{500}^{c}$	-335.78	10	692.27	0.02	0.33
	$PIPE_{250}^{c}$	-334.95	10	690.62	0.00	0.45
	$PIPE_{500}^{c}$	-335.38	10	691.47	0.85	0.30
	$PIPE_{1km}^{c}$	-335.54	10	691.80	1.18	0.25
	$POWER_{250}^{c}$	-335.65	10	692.02	0.00	0.37
	$POWER_{500}^{c}$	-335.76	10	692.23	0.22	0.33
	$POWER_{1km}^{c}$	-335.87	10	692.45	0.43	0.30

TABLE 6.15. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
	$RDdens_{18km}$	-329.33	10	679.38	0.00	0.77
	$RDdens_{5km}$	-330.92	10	682.56	3.18	0.16
	$RDdens_{3km}$	-331.80	10	684.32	4.93	0.07
	$RDdens_{1km}$	-334.98	10	690.68	11.30	0.00
	$RDdens_{270}$	-335.59	10	691.89	12.50	0.00
	$2RD_{250}$[c]	-335.71	10	692.14	12.76	0.00
	$RDdens_{540}$	-335.72	10	692.15	12.77	0.00
	$2RD_{500}$[c]	-335.89	10	692.49	13.11	0.00
	$2RD_{1km}$[c]	-335.91	10	692.55	13.16	0.00
	$WELL_{250}$[c]	-331.34	10	683.39	0.00	0.55
	$WELL_{500}$[c]	-332.04	10	684.80	1.41	0.27
	$WELL_{1km}$[c]	-332.47	10	685.66	2.28	0.18

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

covariates (Table 6.19), the top vegetation submodel consisted of conifer forest within 1 km ($CFRST_{1km}$), mixed shrubland within 18 km (MIX_{18km}), riparian within 1 km (RIP_{1km}), and all sagebrush edge density within 5 km ($EDGE_{5km}$; Table 6.20). The top AIC_c-selected abiotic model included the addition of elevation (ELEV), 0.25-km decay distance to intermittent water ($iH2Od_{250}$), and topographic ruggedness within 1 km (TRI_{1km}; Table 6.20). Decay distance to secondary roads ($2RD_{1km}$) was the only variable included in the top disturbance submodel, which had low support (w_i = 0.13; Table 6.20).

The top AIC_c-selected zero-inflated abundance model for sage thrashers combined vegetation and abiotic factors (Table 6.20). Sage thrasher occurrence was positively associated with proportion of all sagebrush habitat (Table 6.21). Presence was greatest at high elevation sites (containing higher vegetation productivity), in proximity to intermittent water, and was weakly associated with proportion of conifer forest and mean sagebrush edge density (Table 6.21). Sage thrashers avoided areas with more rugged terrain, as well as grassland and mixed shrubland habitats, although only the latter had a strong effect (Table 6.21). Sage thrasher abundance was associated with greater proportions of all big sagebrush and vegetation productivity at higher elevations but decreased as the proportion of conifer forest increased and terrain became more rugged (Table 6.21). Effects of proximity to intermittent water, grassland, mixed shrubland, and edge habitat were generally negatively correlated with abundance, but all had a weak influence on the final model (see SEs and unstable coefficients across models; Table 6.21). Weight of evidence for the top model was low (w_i = 0.15), with 24 total candidate models occurring within the cumulative Akaike weight of just ≥ 0.9 (Table 6.21). These 24 models each contained a subset of the variables in the top model, with some having the addition of riparian land cover or decay distance to secondary roads, although

TABLE 6.16. Results of AIC_c-based submodel selection for sage sparrow zero-inflated Poisson abundance models 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 $\Delta AIC_c \leq 2$ are shown.

Category	Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	1	$ALLSAGE_{18km} + NDVI_{18km} + NDVI_{18km}^2 + GRASS_{3km} + MIX_{5km} + RIP_{1km} + CONTAG_{3km} + SALT_{1km}$	-303.27	18	644.82	0.00	0.42
	2	$ALLSAGE_{18km} + NDVI_{18km} + NDVI_{18km}^2 + GRASS_{3km} + MIX_{5km} + RIP_{1km} + CONTAG_{3km}$	-306.29	16	646.39	1.57	0.19
Abiotic	1	$ALLSAGE_{18km} + NDVI_{18km} + NDVI_{18km}^2 + TRI_{5km}$	-327.31	10	675.34	0.00	0.20
	2	$ALLSAGE_{18km} + NDVI_{18km} + NDVI_{18km}^2 + TRI_{5km} + iH2Od_{1km}$	-325.30	12	675.62	0.28	0.18
	3	$ALLSAGE_{18km} + NDVI_{18km} + NDVI_{18km}^2 + TRI_{5km} + CTI$	-326.01	12	677.04	1.70	0.09
	4	$ALLSAGE_{18km} + NDVI_{18km} + NDVI_{18km}^2 + TRI_{5km} + CTI + iH2Od_{1km}$	-323.91	14	677.21	1.87	0.08
	5	$ALLSAGE_{18km} + NDVI_{18km} + NDVI_{18km}^2 + TRI_{5km} + SLOPE$	-326.11	12	677.25	1.91	0.08
Disturbance	1	$ALLSAGE_{18km} + NDVI_{18km} + NDVI_{18km}^2 + RDdens_{18km} + WELL_{250}$	-325.13	12	675.27	0.00	0.34
	2	$ALLSAGE_{18km} + NDVI_{18km} + NDVI_{18km}^2 + PIPE_{250} + RDdens_{18km} + WELL_{250}$	-323.70	14	676.78	1.51	0.16

[a] Variable definitions provided in Table 4.2

contribution of each to the model was weak (see large SEs; Table 6.21a,b). The final model averaged abundance model was:

(7.5)

$$Density = 1 / (1 + (exp(-(-0.79 + 5.11 * ABIGSAGE_{270} - 60.52 * NDVI_{18km} + 51.08 * NDVI_{18km}^2 + 0.00653 * ELEV + 2.54 * iH2Od_{250} - 0.04 * TRI_{1km} + 50.35 * CFRST_{1km} - 6.51 * GRASS_{270} - 159.79 * MIX_{18km} + 0.02 * EDGE_{5km} + 4.15 * RIP_{1km} - 0.22 * 2RD_{1km})))) * exp(-2.33 + 0.27 * ABIGSAGE_{270} - 0.85 * NDVI_{18km} + 2.06 * NDVI_{18km}^2 + 0.61 * ELEV + 0.00034 * iH2Od_{250} - 0.02 * TRI_{1km} + -5.93 * CFRST_{1km} - 1.22 * GRASS_{270} - 5.92 * MIX_{18km} + 0.0002 * EDGE_{5km} + 0.14 * RIP_{1km} + 0.03 * 2RD_{1km} + 1.77)$$

The mean offset for the survey blocks is represented by the final constant in the model (1.77).

The final model-averaged abundance model for sage thrasher accurately predicted independent count data from 96 BBS routes ($r_s = 0.65$, $p < 0.01$). When applied spatially across the WBEA area within the range of the species, sage thrasher densities were predicted to be highest in sagebrush habitats with high productivity but not higher elevation conifer forests or more productive high elevation sites (Fig. 6.14). Avoidance of grassland areas within the WBEA area was also apparent (Fig. 6.14). Based on the lowest density that could support a sage thrasher territory (0.59 birds/ha; Fig. 6.14), only 31.6% of the Wyoming Basins (109,054 km^2) was predicted to support breeding sage thrashers (Fig. 6.15). Predicted sage thrasher densities assessed across WBEA area increased from 0.1 to 1.5 birds/ha as the proportion of all big sagebrush (0.27 km) increased from 0 to 1.0 (Fig. 6.16). Based on the density threshold, landscapes containing >50% all big sagebrush land cover were likely to support sage thrashers (Fig. 6.16).

Vesper sparrow

Only one variable, mixed shrubland (0.27 km), was excluded from the *a priori* candidate set of variables for vesper sparrow abundance models because they were represented on fewer than 20 survey blocks for presences or absences. We did not consider temperature variables or solar radiation for this species. Several additional variables were removed from consideration due to correlations with other variables. We considered NDVI as a non-linearity at all scales, but non-linearities were not evident for any sagebrush variable. Interactions between sagebrush and NDVI variables were also evaluated as competing models.

Initial exploration of the count data without covariates suggested that a zero-inflated negative binomial was most appropriate. The top AIC_c-selected sagebrush/NDVI model consisted of big sagebrush (*A. t.* ssp. *wyomingensis*, *A. t.* spp. *tridentata*) within 18 km ($BIGSAGE_{18km}$) and NDVI within 3 km ($NDVI_{3km}$) with a sagebrush/NDVI interaction ($BIGSAGE_{18km} * NDVI_{3km}$), which had moderate support ($w_i = 0.27$; Table 6.22). When fit with these base covariates, a Vuong test confirmed that the zero-inflated negative binomial model had better fit over the negative binomial model without zero-inflation ($z = 4.67$, $p < 0.001$). Use locations averaged 5.9% less big sagebrush habitat than absence locations (Appendix 6.6). Using the base model for vesper sparrow (Table 6.23), the top vegetation submodel consisted of conifer forest within 0.54 km ($CFRST_{540}$), mixed shrubland within 3 km (MIX_{3km}), riparian within 18 km (RIP_{18km}), and salt-desert shrubland within 0.27 km ($SALT_{270}$; Table 6.24). The top AIC_c-selected abiotic included the addition of elevation as a quadratic ($ELEV + ELEV^2$) and topographic ruggedness as a quadratic within 0.27 km ($TRI_{270} + TRI_{270}^2$; Table 6.24). Decay distance (1 km) to pipeline ($PIPE_{1km}$) and density of all roads within 3 km ($RDdens_{3km}$) were the only two variables included in the top disturbance submodel (Table 6.24).

The top AIC_c-selected vesper sparrow zero-inflated abundance model was a combination of vegetation and disturbance factors (Table 6.25). Vesper sparrow occurrence was positively associated with proportion of all sagebrush habitat and vegetation productivity (Table 6.25). However, the large negative interaction term suggested that productive sagebrush sites, specifically, were avoided (Table 6.25). The top model also suggested selection for mixed shrubland and avoidance of conifer forest and proximity to pipelines (Table 6.25). Riparian, salt-desert shrubland and density of all roads were weak contributors to the top model (see coefficient SEs and instability of estimates; Table 6.25). Vesper sparrow abundance decreased with proportion of big sagebrush land cover, but increased with vegetation productivity (Table 6.25). The positive interaction term between these variables suggested that abundance increased with increasing proportions of productive big sagebrush habitat, which is opposite of the occurrence portion of the model (Table 6.25). Vesper sparrow abundance decreased with salt-desert shrubland (Table 6.25). As with the occurrence portion, several variables were weak contributors, including conifer forest, mixed shrubland, riparian, proximity to piplines, and density of roads (large coefficient SEs; Table 6.25). Weight of evidence for the top model was low ($w_i = 0.20$), with 20 total candidate models occurring within the cumulative Akaike weight of just ≥ 0.9 (Table 6.25). These 20 models each contained a subset of the variables in the top model, with some having the addition of the two abiotic variables, topographic ruggedness and elevation (Table 6.25). Both these variables showed generally positive but decreasing quadratic relationships, suggesting occurrence and abundance were highest with moderate terrain ruggedness and mid-elevations, but the contribution of each variable to the model was weak (large SEs and

TABLE 6.17. Results of AIC_c-based model selection for the combined sage sparrow zero-inflated Poisson abundance 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 shown with cumulative Akaike weight (w_i) of just ≥ 0.9. Section (A) includes the inflate portion of the model capturing presence-absence (occurrence), whereas Section (B) includes the count (abundance) portion of the model.

Rank	Intercept	$ALLSAGE_{18km}$	$NDVI_{18km}$	$NDVI_{18km}^2$	MIX_{5km}	RIP_{1km}	$CONTAG_{3km}$[b]
(A) Occurrence							
1	16.26 (3.68)	-9.94 (2.90)	-59.85 (21.64)	55.62 (29.96)	-105.65 (37.64)	1.44 (7.28)	5.49 (1.71)
2	16.19 (3.50)	-9.92 (2.76)	-59.47 (20.40)	54.19 (27.35)	-100.81 (35.37)		5.61 (1.58)
3	14.46 (3.53)	-8.20 (2.58)	-41.47 (19.54)	35.22 (26.07)	-53.02 (78.88)	4.64 (7.42)	5.77 (1.66)
4	16.82 (3.82)	-9.90 (2.90)	-59.37 (21.99)	53.70 (29.87)	-100.44 (36.42)	0.35 (7.10)	4.89 (1.73)
5	13.71 (3.15)	-8.10 (2.51)	-38.46 (16.99)	30.55 (22.36)	-59.14 (65.15)		5.94 (1.51)
6	16.38 (3.88)	-8.74 (2.71)	-46.83 (20.10)	38.96 (26.15)	-35.38 (72.36)	2.41 (7.17)	5.21 (1.64)
7	16.94 (3.72)	-10.03 (2.76)	-59.54 (21.23)	52.98 (28.22)	-96.43 (34.35)		5.10 (1.61)
8	15.85 (3.71)	-8.79 (2.57)	-44.90 (18.74)	35.71 (23.78)	-39.51 (69.51)		5.52 (1.56)
9	16.07 (3.53)	-9.81 (2.81)	-60.79 (20.38)	55.76 (27.66)	-90.24 (39.69)	-0.58 (6.42)	5.50 (1.64)
10	16.09 (3.41)	-9.91 (2.69)	-60.27 (19.74)	54.26 (26.25)	-86.03 (37.27)		5.63 (1.55)
(B) Abundance							
1	0.89 (1.36)	-2.26 (0.76)	4.93 (9.40)	-14.71 (13.92)	-12.31 (24.33)	-5.73 (3.04)	0.07 (0.41)
2	1.07 (1.33)	-2.39 (0.76)	5.04 (9.33)	-14.27 (13.72)	-9.39 (24.82)		0.07 (0.41)
3	1.54 (1.22)	-2.32 (0.84)	-0.60 (8.30)	-7.87 (12.87)	-38.27 (38.07)	-6.33 (3.00)	-0.32 (0.35)
4	1.36 (1.54)	-2.27 (0.76)	2.41 (10.17)	-11.51 (14.67)	-10.15 (25.93)	-5.60 (3.01)	0.02 (0.41)
5	2.01 (1.17)	-2.38 (0.86)	-2.84 (7.98)	-4.33 (12.30)	-32.44 (35.45)		-0.42 (0.34)
6	1.91 (1.36)	-2.42 (0.80)	-1.86 (8.48)	-6.30 (12.78)	-43.38 (28.84)	-6.09 (2.95)	-0.37 (0.33)
7	1.45 (1.53)	-2.39 (0.76)	2.95 (10.21)	-11.63 (14.67)	-6.82 (26.49)		0.04 (0.41)
8	2.32 (1.33)	-2.54 (0.81)	-3.63 (8.41)	-3.46 (12.57)	-39.20 (30.31)		-0.45 (0.33)
9	1.06 (1.37)	-1.87 (0.77)	1.61 (9.39)	-10.09 (13.89)	-29.13 (22.87)	-4.91 (2.75)	-0.32 (0.39)
10	1.24 (1.35)	-1.99 (0.77)	1.57 (9.44)	-9.53 (13.91)	-25.35 (22.86)		-0.31 (0.39)

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

coefficient instabilities across models; Table 6.25). The final model-averaged abundance model was

$$Density = 1 / (1 + (Exp(-(-123.81 + 142.3 * BIGSAGE_{18k} + 369.72 * NDVI_{3km} - 478.87 * BIGSAGE_{18k} * NDVI_{3km} - 141.52 * CFRST_{540} + 60.87 * MIX_{3km} - 19.94 * RIP_{18km} + 2.39 * SALT_{270} - 2.95 * PIPE_{1km} + 0.18 * RDdens_{3km} - 0.11 * TRI_{270} + 0.0020 * TRI_{270}^2 + 0.02 * ELEV - 0.000006 * ELEV^2))) * Exp(-2.46 - 2.08 * BIGSAGE_{18k} + 0.49 * NDVI_{3km} + 6.32 * BIGSAGE_{18k} * NDVI_{3km} - 1.09 * CFRST_{540} + 8.53 * MIX_{3km} + 7.23 * RIP_{18km} - 3.85 * SALT_{270} - 0.10 * PIPE_{1km} + 0.12 * RDdens_{3km} - 0.000078 * TRI_{270} - 0.000079 * TRI_{270}^2 + 0.0015 * ELEV - 0.00000037 * ELEV^2 + 1.05) \quad (7.6)$$

TABLE 6.17. Extended

$SALT_{1km}$	TRI_{5km}[b]	$RDdens_{18km}$	$WELL_{250}$	$GRASS_{3km}$	LL	K	AIC_c	ΔAIC_c	$\sum w_i$
9.46 (3.61)	-8.78 (2.92)	2.27 (0.99)	3.39 (3.54)		-291.61	22	630.65	0.00	0.30
9.52 (3.56)	-7.98 (2.65)	2.14 (0.95)	3.87 (3.55)		-294.40	20	631.62	0.98	0.19
9.49 (3.58)	-9.59 (2.80)		7.70 (4.77)		-294.94	20	632.71	2.06	0.11
8.80 (3.80)	-7.72 (3.00)	2.04 (1.00)	3.45 (3.50)	-4.99 (5.51)	-290.71	24	633.52	2.88	0.07
9.05 (3.42)	-8.22 (2.66)		7.49 (4.28)		-297.66	18	633.61	2.97	0.07
8.09 (3.73)	-8.04 (2.85)		7.56 (4.03)	-8.29 (5.71)	-293.19	22	633.80	3.15	0.06
8.93 (3.72)	-7.06 (2.72)	1.90 (0.98)	3.91 (3.51)	-4.92 (5.20)	-293.59	22	634.61	3.96	0.04
7.91 (3.58)	-7.09 (2.63)		7.56 (4.00)	-7.67 (5.49)	-296.07	20	634.98	4.33	0.03
8.52 (3.33)	-7.64 (2.68)	2.38 (0.90)			-296.79	20	636.41	5.76	0.02
8.57 (3.27)	-7.08 (2.52)	2.22 (0.89)			-299.40	18	637.08	6.43	0.01
-0.93 (0.56)	-0.48 (1.09)	-0.43 (0.31)	1.96 (0.64)		-291.61	22	630.65	0.00	0.30
-0.88 (0.55)	-1.28 (1.03)	-0.52 (0.31)	1.85 (0.63)		-294.40	20	631.62	0.98	0.19
-1.03 (0.55)	-0.27 (1.16)		1.52 (0.61)		-294.94	20	632.71	2.06	0.11
-1.05 (0.57)	-0.46 (1.11)	-0.40 (0.31)	1.87 (0.64)	-1.32 (1.83)	-290.71	24	633.52	2.88	0.07
-1.01 (0.54)	-1.36 (1.17)		1.34 (0.58)		-297.66	18	633.61	2.97	0.07
-1.10 (0.56)	-0.20 (1.11)		1.43 (0.58)	-1.15 (1.79)	-293.19	22	633.80	3.15	0.06
-0.97 (0.57)	-1.27 (1.03	-0.50 (0.31)	1.78 (0.63)	-1.08 (1.86)	-293.59	22	634.61	3.96	0.04
-1.07 (0.56)	-1.17 (1.07)		1.27 (0.57)	-0.98 (1.83)	-296.07	20	634.98	4.33	0.03
-1.02 (0.56)	-0.65 (1.11)	-0.14 (0.29)			-296.79	20	636.41	5.76	0.02
-0.96 (0.55)	-1.37 (1.06)	-0.22 (0.30)			-299.40	18	637.08	6.43	0.01

The mean offset for the survey blocks is represented by the final constant in the model (1.05).

The final model-averaged abundance model for vesper sparrows accurately predicted independent count data from 96 BBS routes ($r_s = 0.52$, $p < 0.01$). When applied spatially across the WBEA within the range of the species, vesper sparrow densities were predicted to be highest in sagebrush habitats with higher productivity and lowest in more xeric shrubland communities (Fig. 6.17). Avoidance of higher elevation sites associated with conifer forests was also evident (Fig. 6.17). Based on the lowest density that could support a vesper sparrow territory (0.12 birds/ha; Fig. 6.17), 74.8% of the Wyoming Basins (292,896 km^2) was predicted to contain enough resources to support breeding

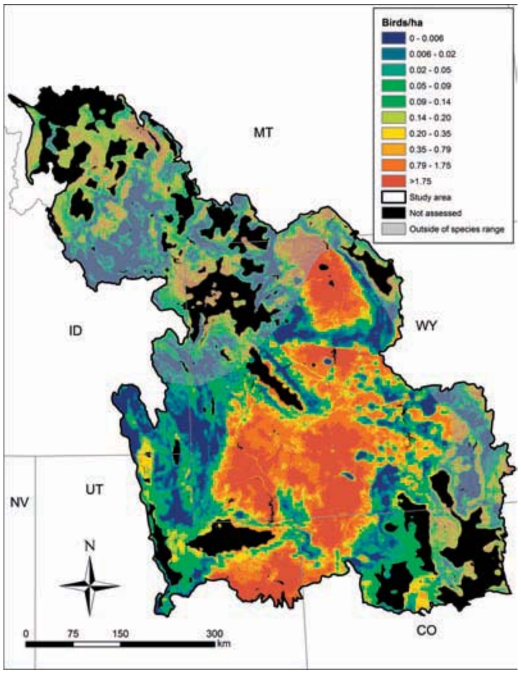

FIG. 6.11. Predicted density estimates (birds/ha) for sage sparrow in the Wyoming Basins Ecoregional Assessment area. Black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water). Based on the largest territory sizes required to support one sage sparrow, the lowest density that could support a viable territory is 0.14 birds/ha. We infer that spatial predictions above this threshold predict occupied patches.

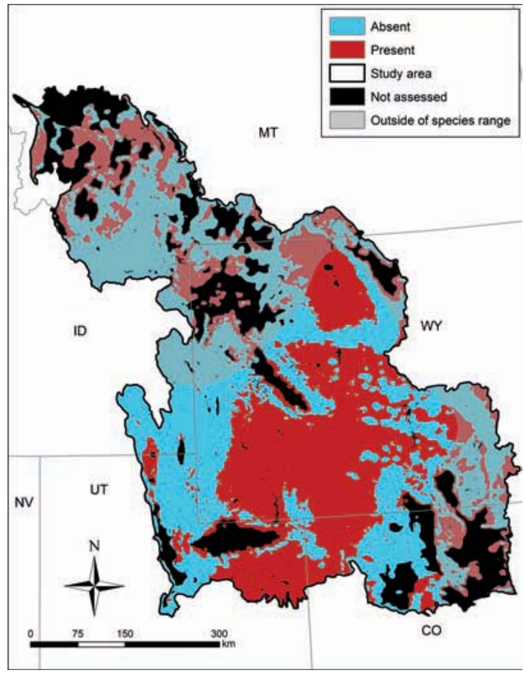

FIG. 6.12. Distribution of sage sparrow in the Wyoming Basins Ecoregional Assessment area based on a threshold of (0.14 birds/ha), the largest territory size required to support one sage sparrow. Semi-transparent grey shaded areas are outside the range of sage sparrow and black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water).

vesper sparrows (Fig. 6.18). Predicted vesper sparrow densities assessed across the WBEA area increased from 1 birds/ha to between 1.5-3 birds/ha when the proportion of big sagebrush (18 km) was between 0.1 and 0.75, and decreased back to 1 bird/ha as proportion of sagebrush increased to 1.0 with densities exceeding the occurrence threshold across the entire range of big sagebrush values (Fig. 6.19). However, based on the landscape summarized as a whole (Fig. 6.19), vesper sparrow density was not strongly correlated with sagebrush habitat across the WBEA area. Most areas were predicted to have enough habitat to support at least 1 birds/ha (Fig. 6.17, Fig. 6.18, Fig. 6.19).

DISCUSSION

Increasing our knowledge of how sagebrush-associated species respond to the distribution of environmental factors is important to improve our efforts at conservation and management of these species. We found strong relationships between habitat and abiotic factors and occurrence and abundance of selected bird species. Brewer's sparrows, green-tailed towhees, lark sparrows, sage sparrows, and sage thrashers all had positive relationships with sagebrush of some variety, reinforcing the importance of key sagebrush or shrubland vegetation structure components to these birds. The scale at which each of these species responded to

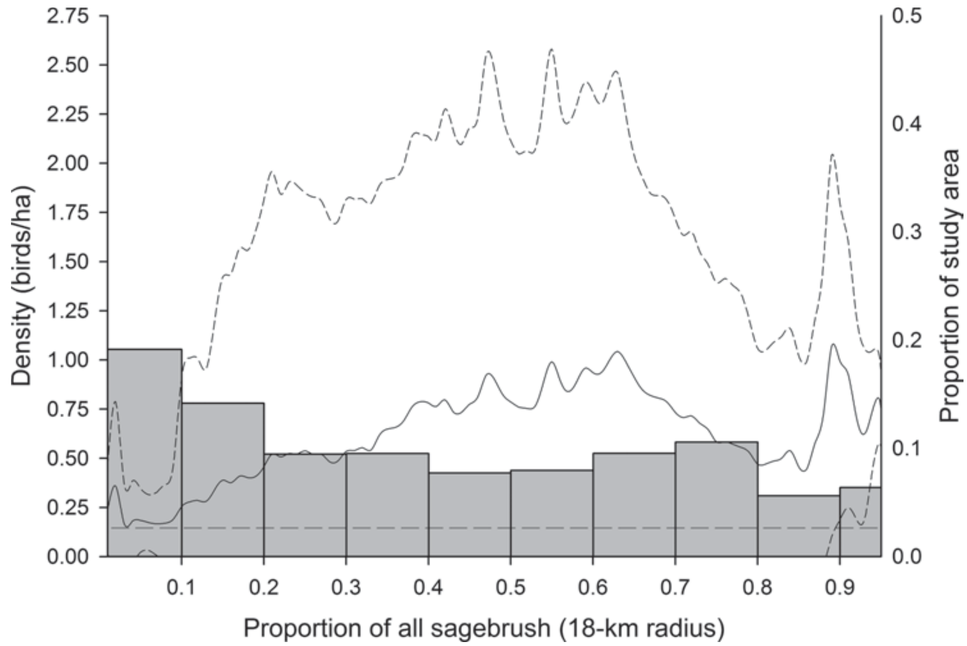

FIG. 6.13. Sage sparrow predicted densities within the Wyoming Basins Ecoregional Assessment area in relation to proportion of all sagebrush (*Artemisia* spp.) within an 18-km radius. Mean density (black line, ± 1 SD [dashed lines]) values were calculated in each one percent increment of all sagebrush within a 1-km radius moving window. Range of predicted densities relate to the observed range of sagebrush at study site locations. The dashed horizontal line represents the lowest density that could support a viable territory (0.14 birds/ha), above which we infer patches to be occupied. Histogram values represent the proportion of the total study area in each 10% segment of all sagebrush within 1 km.

TABLE 6.18. Results of AIC_c-based model selection for sage thrasher zero-inflated Poisson abundance models in relation to multi-scale sagebrush and NDVI 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 $\Delta AIC_c \leq 2$ are shown.

Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
1	$ABIGSAGE_{270} + NDVI_{18km} + NDVI_{18km}^2$	-457.15	8	930.77	0.00	0.09
2	$ABIGSAGE_{540} + NDVI_{18km} + NDVI_{18km}^2$	-457.40	8	931.26	0.49	0.07
3	$ABIGSAGE_{270} + NDVI_{18km}$	-459.51	6	931.30	0.53	0.07
4	$ABIGSAGE_{270} + NDVI_{5km}$	-459.58	6	931.43	0.67	0.07
5	$ALLSAGE_{540} + NDVI_{18km} + NDVI_{18km}^2$	-457.52	8	931.51	0.74	0.06
6	$ABIGSAGE_{540} + NDVI_{18km}$	-460.06	6	932.40	1.63	0.04
7	$ABIGSAGE_{270} + NDVI_{3km}$	-460.10	6	932.47	1.70	0.04
8	$ABIGSAGE_{540} + NDVI_{5km}$	-460.12	6	932.51	1.74	0.04
9	$ABIGSAGE_{270} + NDVI_{1km}$	-460.20	6	932.66	1.90	0.04

[a] Variable definitions provided in Table 4.2

TABLE 6.19. Evaluation statistics from AIC_c-based univariate model selection for sage thrasher zero-inflated Poisson abundance models 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 models with all big sagebrush (0.27-km radius) and NDVI (18-km radius; quadratic) variables as a base model for variables tested. We used AIC_c to sort models for each variable in ascending order to identify the extent at which sage thrashers respond to individual variables.

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	$CFRST_{1km}$	-442.90	10	906.51	0.00	0.56
	$CFRST_{3km}$	-443.19	10	907.09	0.58	0.42
	$CFRST_{540}$	-446.18	10	913.09	6.57	0.02
	$CFRST_{18km}$	-452.69	10	926.09	19.58	0.00
	$CFRST_{270}$	-456.40	10	933.52	27.01	0.00
	$GRASS_{270}$	-442.86	10	906.43	0.00	1.00
	$GRASS_{540}$	-449.46	10	919.63	13.20	0.00
	$GRASS_{1km}$	-450.75	10	922.22	15.79	0.00
	$GRASS_{3km}$	-450.76	10	922.24	15.81	0.00
	$GRASS_{5km}$	-451.15	10	923.01	16.58	0.00
	$GRASS_{18km}$	-451.50	10	923.72	17.29	0.00
	MIX_{18km}	-446.13	10	912.97	0.00	0.95
	MIX_{5km}	-449.23	10	919.17	6.20	0.04
	MIX_{1km}	-450.96	10	922.64	9.67	0.01
	MIX_{3km}	-451.94	10	924.59	11.62	0.00
	MIX_{540}	-453.66	10	928.04	15.07	0.00
	MIX_{270}	-455.13	10	930.98	18.01	0.00
	RIP_{1km}	-434.96	10	890.63	0.00	1.00
	RIP_{540}	-453.64	10	928.00	37.37	0.00
	RIP_{270}	-454.37	10	929.46	38.82	0.00
	RIP_{3km}	-454.54	10	929.81	39.17	0.00
	RIP_{18km}	-455.57	10	931.87	41.23	0.00
	RIP_{5km}	-455.96	10	932.64	42.01	0.00
	$SALT_{270}$	-456.51	10	933.74	0.00	0.31
	$SALT_{540}$	-456.75	10	934.21	0.46	0.24
	$SALT_{3km}$	-456.78	10	934.28	0.53	0.24
	$SALT_{1km}$	-456.88	10	934.47	0.72	0.21
	$EDGE_{5km}$	-445.76	10	912.23	0.00	0.73
	$CONTAG_{5km}$	-446.84	10	914.39	2.16	0.25
	$CONTAG_{3km}$	-449.16	10	919.03	6.80	0.02
	$EDGE_{3km}$	-451.05	10	922.81	10.59	0.00
	$EDGE_{1km}$	-454.10	10	928.92	16.69	0.00
	$CONTAG_{1km}$	-455.49	10	931.70	19.47	0.00

TABLE 6.19. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
	$PATCH_{1km}$	-456.21	10	933.13	20.91	0.00
	$PATCH_{5km}$	-456.39	10	933.50	21.28	0.00
	$PATCH_{3km}$	-457.13	10	934.97	22.75	0.00
Abiotic	CTI	-456.50	10	933.71	0.00	0.86
	CTI^{2b}	-456.19	12	937.40	3.70	0.14
	ELEV	-428.41	10	877.54	0.00	0.58
	$ELEV^{2b}$	-426.58	12	878.18	0.64	0.42
	$iH2Od_{250}^{c}$	-454.82	10	930.35	0.00	0.47
	$iH2Od_{500}^{c}$	-455.23	10	931.18	0.83	0.31
	$iH2Od_{1km}^{c}$	-455.61	10	931.94	1.59	0.21
	$pH2Od_{1km}^{c}$	-454.97	10	930.66	0.00	0.49
	$pH2Od_{250}^{c}$	-455.36	10	931.43	0.76	0.33
	$pH2Od_{250}^{c}$	-456.00	10	932.71	2.05	0.18
	SOLAR	-450.25	10	921.22	0.00	0.50
	$SOLAR^{2b}$	-448.11	12	921.23	0.01	0.50
	TRI_{1km}	-439.00	10	898.72	0.00	0.41
	TRI_{5km}	-439.46	10	899.63	0.91	0.26
	TRI_{540}	-439.52	10	899.75	1.04	0.24
	TRI_{3km}	-440.69	10	902.11	3.39	0.08
	TRI_{270}	-442.62	10	905.96	7.25	0.01
	TRI	-446.60	10	913.91	15.19	0.00
	TRI_{18km}	-448.16	10	917.04	18.32	0.00
Disturbance	AG_{250}^{c}	-455.29	10	931.30	0.00	0.66
	AG_{500}^{c}	-456.41	10	933.53	2.23	0.22
	AG_{1km}^{c}	-456.94	10	934.59	3.29	0.13
	$MjRD_{1km}^{c}$	-456.61	10	933.93	0.00	0.38
	$MjRD_{500}^{c}$	-456.79	10	934.30	0.37	0.31
	$MjRD_{250}^{c}$	-456.82	10	934.35	0.42	0.31
	$PIPE_{250}^{c}$	-456.32	10	933.35	0.00	0.51
	$PIPE_{500}^{c}$	-456.96	10	934.63	1.28	0.27
	$PIPE_{1km}^{c}$	-457.13	10	934.98	1.63	0.22
	$POWER_{1km}$	-456.31	10	933.34	0.00	0.43
	$POWER_{250}$	-456.54	10	933.80	0.46	0.34
	$POWER_{500}$	-456.93	10	934.57	1.23	0.23
	$2RD_{1km}^{c}$	-454.95	10	930.61	0.00	0.21
	$2RD_{500}^{c}$	-454.99	10	930.70	0.09	0.20

TABLE 6.19. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
	$RDdens_{18km}$	-455.12	10	930.96	0.35	0.18
	$2RD_{250}{}^{c}$	-455.25	10	931.22	0.61	0.15
	$RDdens_{270}$	-455.58	10	931.88	1.27	0.11
	$RDdens_{540}$	-456.38	10	933.48	2.87	0.05
	$RDdens_{3km}$	-456.65	10	934.01	3.40	0.04
	$RDdens_{1km}$	-456.67	10	934.06	3.45	0.04
	$RDdens_{5km}$	-456.98	10	934.67	4.06	0.03
	$WELL_{250}{}^{c}$	-456.40	10	933.52	0.00	0.35
	$WELL_{500}{}^{c}$	-456.41	10	933.54	0.02	0.35
	$WELL_{1km}{}^{c}$	-456.53	10	933.79	0.27	0.31

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

sagebrush and the other environmental factors varied widely. These scales were well beyond the typical home range of each species. Although we developed spatially explicit models by selecting a single scale for each GIS derived variable, it is important to understand that these species are influenced simultaneously by habitat factors at multiple spatial scales, including local vegetation cover (Knick et al. 2008, Erickson 2011, Hanser and Knick 2011). The strong relationships with the quantity and configuration of sagebrush, as well as other habitat variables, reiterates the importance of minimizing reductions in these habitats, either natural or human caused, if species are to be maintained (Braun et al. 1976, Knopf 1996, Wiens and Rotenberry 1985, Knick and Rotenberry 1995, Knick et al. 2003). Two species, Brewer's sparrows and sage thrashers, were common at sampled sites, suggesting that even if declines in these species have occurred (Sauer et al. 2003) or continue to occur, these species are likely to persist across at least some locations within the Wyoming Basins, based on the current distribution of sagebrush habitat. However, our models predict only Brewer's sparrows are likely to occur at suitable densities across the majority of the Wyoming Basins (87.7% above density threshold), whereas sage thrashers are predicted to occur in only 31.6% of the area, the lowest of any species modeled, despite being a sagebrush-obligate species. The sage thrasher and other species with lower detection rates (sage sparrow, lark sparrow, and green-tailed towhee) could be more sensitive to future losses of habitat, which might also suggest slower recovery for these species following disturbance. The minimum density estimates we obtained for individual species from DISTANCE (Thomas et al. 2006) were comparable to density thresholds derived from the largest known territory sizes for each species (Poole 2005), suggesting the count response data modeled with offsets and thresholds applied to binary maps capture biologically plausible density estimates. Indeed, most models accurately predicted independent BBS count data, despite differences in data collection and the broad areas assessed along BBS routes. Below, we discuss the key factors

TABLE 6.20. Results of AIC_c-based submodel selection for sage thrasher zero-inflated Poisson abundance models 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 $\Delta AIC_c \leq 2$ are shown.

Category	Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	1	$ABIGSAGE_{270} + NDVI_{18km} + NDVI_{18km}^2 + CFRST_{1km} + GRASS_{270m} + MIX_{18km} + RIP_{1km} + EDGE_{5km}$	-411.18	18	860.65	0.00	0.25
	2	$ABIGSAGE_{270} + NDVI_{18km} + NDVI_{18km}^2 + CFRST_{1km} + GRASS_{270m} + MIX_{18km} + RIP_{1km}$	-413.49	16	860.78	0.13	0.23
	3	$ABIGSAGE_{270} + NDVI_{18km} + NDVI_{18km}^2 + CFRST_{1km} + MIX_{18km} + RIP_{1km} + EDGE_{5km} + SALT_{270}$	-411.82	18	861.93	1.29	0.13
	4	$ABIGSAGE_{270} + NDVI_{18km} + NDVI_{18km}^2 + CFRST_{1km} + MIX_{18km} + RIP_{1km} + EDGE_{5km}$	-414.25	16	862.31	1.67	0.11
	5	$ABIGSAGE_{270} + NDVI_{18km} + NDVI_{18km}^2 + CFRST_{1km} + GRASS_{270m} + MIX_{18km} + RIP_{1km} + EDGE_{5km} + SALT_{270}$	-409.88	20	862.59	1.94	0.09
Abiotic	1	$ABIGSAGE_{270} + NDVI_{18km} + NDVI_{18km}^2 + ELEV + iH2Od_{250} + TRI_{1km}$	-413.73	14	856.85	0.00	0.54
	2	$ABIGSAGE_{270} + NDVI_{18km} + NDVI_{18km}^2 + ELEV + iH2Od_{250} + SOLAR + TRI_{1km}$	-411.99	16	857.79	0.94	0.34
Disturbance	1	$ABIGSAGE_{270} + NDVI_{18km} + NDVI_{18km}^2 + 2RD_{1km}$	-454.95	10	930.61	0.00	0.13
	2	$ABIGSAGE_{270} + NDVI_{18km} + NDVI_{18km}^2 + AG_{250}$	-455.29	10	931.30	0.69	0.09
	3	$ABIGSAGE_{270} + NDVI_{18km} + NDVI_{18km}^2 + POWER_{1km} + 2RD_{1km}$	-453.66	12	932.34	1.73	0.05
	4	$ABIGSAGE_{270} + NDVI_{18km} + NDVI_{18km}^2 + AG_{250} + WELL_{250}$	-453.71	12	932.44	1.83	0.05
	5	$ABIGSAGE_{270} + NDVI_{18km} + NDVI_{18km}^2 + AG_{250} + 2RD_{1km}$	-453.72	12	932.45	1.84	0.05

[a] Variable definitions provided in Table 4.2

TABLE 6.21. Results of AIC_c-based model selection for the combined sage thrasher zero-inflated Poisson abundance models in the Wyoming Basins Ecoregional Assessment area; the table also shows parameter estimates[a] (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 shown with cumulative Akaike weight (w_i) of just ≥ 0.9. Section (A) includes the inflate portion of the model capturing presence-absence, whereas section (B) includes the count portion of the model.

Rank	Intercept	$ABIGSAGE_{270}$	$NDVI_{18km}$	$NDVI_{18km}^2$	ELEV[b]	$iH2Od_{250}$	TRI_{1km}	$CFRST_{1km}$
(A) Occurrence								
1	-8.83 (7.90)	7.55 (2.84)	-56.56 (29.29)	41.18 (30.68)	8.38 (1.93)	4.37 (1.81)	-0.06 (0.04)	68.76 (37.25)
2	0.74 (5.65)	4.72 (2.51)	-62.23 (30.95)	50.39 (32.15)	6.41 (1.51)	3.76 (2.25)	-0.03 (0.04)	49.87 (30.49)
3	1.27 (4.97)	1.91 (2.44)	-43.78 (21.32)	33.53 (24.24)	5.48 (1.18)		-0.04 (0.03)	39.34 (35.76)
4	0.27 (4.07)	3.71 (1.87)	-47.28 (17.76)	37.17 (19.18)	5.39 (1.10)		-0.04 (0.03)	36.60 (20.71)
5	-0.91 (4.59)	5.75 (2.23)	-58.84 (25.39)	45.11 (25.27)	6.57 (1.50)	3.77 (1.98)	-0.03 (0.03)	56.12 (27.85)
6	-0.34 (5.00)	5.20 (2.81)	-58.92 (28.66)	46.78 (27.85)	6.31 (1.67)	3.28 (2.91)	-0.03 (0.03)	49.79 (29.08)
7	-7.69 (7.82)	7.81 (2.88)	-57.31 (29.96)	41.30 (31.82)	8.47 (2.03)	4.64 (1.74)	-0.07 (0.04)	71.95 (42.88)
8	-1.28 (3.61)	4.83 (1.71)	-44.83 (16.72)	33.48 (17.85)	5.43 (1.09)		-0.04 (0.02)	42.88 (20.07)
9	1.58 (5.04)	4.13 (2.24)	-56.64 (26.27)	44.87 (27.94)	6.15 (1.31)	3.65 (1.81)	-0.03 (0.03)	49.86 (33.54)
10	-10.82 (8.99)	8.01 (3.04)	-49.10 (29.74)	33.32 (31.33)	8.26 (2.01)	4.06 (2.01)	-0.07 (0.04)	68.72 (35.79)
11	-1.58 (4.39)	6.30 (2.55)	-58.34 (25.65)	44.58 (24.42)	6.51 (1.67)	3.44 (2.48)	-0.04 (0.03)	56.16 (26.69)
12	-2.10 (11.16)	2.48 (3.86)	-38.92 (25.76)	28.47 (28.63)	6.00 (1.53)		-0.05 (0.03)	41.82 (35.69)
13	-0.86 (3.84)	3.85 (1.62)	-41.41 (17.72)	30.49 (19.32)	5.35 (1.03)		-0.04 (0.03)	40.97 (23.42)
14	2.24 (5.14)	1.70 (2.31)	-44.32 (21.27)	34.12 (24.26)	5.37 (1.14)		-0.04 (0.03)	39.07 (38.02)
15	-7.13 (6.94)	7.11 (2.40)	-50.60 (24.90)	35.37 (25.56)	7.49 (1.69)	3.82 (1.61)	-0.05 (0.03)	63.04 (27.74)
16	-0.35 (4.38)	5.31 (1.86)	-53.67 (23.22)	40.50 (23.89)	6.26 (1.31)	3.64 (1.65)	-0.04 (0.03)	53.69 (28.00)
17	16.05 (14.00)	3.34 (2.98)	-91.16 (44.49)	75.80 (41.44)	5.39 (1.27)		-0.02 (0.03)	46.28 (25.60)
18	1.63 (4.27)	3.81 (1.91)	-48.15 (17.61)	38.21 (18.98)	5.14 (1.08)		-0.05 (0.03)	34.52 (20.99)
19	1.14 (4.54)	5.07 (2.08)	-55.79 (21.91)	44.32 (22.62)	5.96 (1.29)	3.34 (1.89)	-0.04 (0.03)	45.98 (25.97)
20	40.67 (18.25)	7.85 (2.17)	-291.08 (112.67)	386.89 (161.48)	3.78 (1.14)		-0.02 (0.03)	
21	-9.60 (9.04)	8.62 (3.05)	-49.46 (29.95)	33.47 (31.81)	8.37 (2.21)	4.47 (1.93)	-0.08 (0.05)	67.77 (39.16)
22	-0.41 (4.03)	6.07 (1.82)	-53.34 (20.25)	40.57 (20.75)	6.09 (1.27)	3.37 (1.71)	-0.05 (0.03)	51.01 (23.06)
23	50.69 (31.06)	6.47 (2.61)	-380.09 (189.36)	536.67 (287.32)	4.80 (2.10)	2.71 (4.13)	0.01 (0.04)	-58.82 (38.34)
24	10.22 (10.65)	1.89 (3.06)	-62.60 (32.42)	47.23 (32.68)	5.34 (1.25)		-0.03 (0.03)	57.23 (50.72)
(B) Abundance								
1	-2.52 (1.06)	0.20 (0.35)	-1.21 (3.76)	2.33 (4.31)	0.79 (0.39)	0.01 (0.18)	-0.02 (0.01)	-5.75 (2.01)
2	-2.20 (0.90)	0.18 (0.34)	-0.68 (3.54)	1.85 (4.12)	0.60 (0.40)	-0.01 (0.18)	-0.02 (0.01)	-5.84 (2.00)
3	-1.97 (0.85)	0.34 (0.36)	-0.75 (3.48)	2.13 (4.03)	0.41 (0.38)		-0.01 (0.01)	-6.10 (2.06)
4	-1.94 (0.85)	0.24 (0.37)	-1.27 (3.60)	2.69 (4.18)	0.48 (0.39)		-0.01 (0.01)	-6.28 (2.06)
5	-2.50 (0.82)	0.31 (0.33)	-0.23 (3.46)	1.37 (3.98)	0.63 (0.39)	-0.01 (0.18)	-0.02 (0.01)	-6.21 (1.99)
6	-2.13 (0.88)	0.18 (0.36)	-1.27 (3.68)	2.54 (4.24)	0.61 (0.40)	0.00 (0.19)	-0.02 (0.01)	-6.00 (2.02)
7	-2.52 (1.05)	0.20 (0.35)	-1.92 (3.72)	3.25 (4.29)	0.79 (0.37)	0.00 (0.18)	-0.02 (0.01)	-6.08 (2.05)
8	-2.16 (0.80)	0.36 (0.37)	-0.89 (3.57)	2.27 (4.11)	0.48 (0.38)		-0.02 (0.01)	-6.54 (2.07)

TABLE 6.21. Extended

$GRASS_{270m}$	MIX_{18km}	$EDGE_{5km}^{c}$	RIP_{1km}	$2RD_{1km}$	LL	K	AIC_c	ΔAIC_c	$\sum w_i$
-12.83 (6.95)	-204.14 (57.63)	8.42 (4.32)			-393.38	22	834.18	0.00	0.147
-6.20 (5.14)	-164.68 (49.75)				-395.70	20	834.24	0.05	0.289
-7.47 (5.71)	-129.78 (33.55)				-398.30	18	834.90	0.71	0.392
-5.62 (4.45)	-122.51 (34.12)		12.79 (8.57)		-396.42	20	835.67	1.49	0.462
	-170.62 (50.51)				-398.75	18	835.79	1.61	0.527
-5.05 (4.81)	-151.50 (49.97)		9.18 (9.32)		-394.73	22	836.88	2.70	0.565
-14.52 (7.20)	-216.84 (60.34)	8.87 (4.32)		-1.63 (1.54)	-392.42	24	836.93	2.75	0.602
	-122.75 (33.62)		12.12 (7.09)		-399.50	18	837.29	3.11	0.633
-7.23 (5.07)	-169.28 (46.28)			-1.34 (1.37)	-394.95	22	837.34	3.16	0.663
-11.35 (7.18)	-191.11 (57.49)	8.53 (4.89)	8.50 (10.97)		-392.66	24	837.41	3.22	0.693
	-158.32 (50.94)		8.85 (7.45)		-397.31	20	837.45	3.27	0.721
-8.32 (6.08)	-130.40 (35.81)	2.18 (6.79)			-397.39	20	837.61	3.43	0.748
	-128.94 (32.34)				-401.91	16	837.64	3.45	0.774
-8.35 (5.86)	-132.25 (33.87)			-0.56 (1.27)	-397.79	20	838.42	4.23	0.791
	-188.30 (52.92)	4.71 (3.72)			-397.92	20	838.67	4.48	0.807
	-172.16 (46.24)			-1.11 (1.22)	-398.10	20	839.02	4.84	0.820
	-110.40 (48.71)	-11.13 (7.47)	16.71 (8.71)		-398.12	20	839.08	4.89	0.833
-6.08 (4.52)	-127.08 (34.51)		14.45 (9.67)	-0.97 (1.32)	-395.85	22	839.14	4.95	0.845
-5.76 (4.69)	-160.89 (45.26)		12.54 (10.10)	-1.90 (1.40)	-393.55	24	839.20	5.02	0.857
	-138.20 (45.75)		32.09 (13.02)		-402.71	16	839.22	5.04	0.869
-12.86 (7.31)	-205.12 (59.35)	9.02 (5.00)	12.10 (12.79)	-2.31 (1.69)	-391.33	26	839.48	5.30	0.879
	-164.77 (44.57)		12.16 (8.09)	-1.89 (1.31)	-396.06	22	839.56	5.38	0.889
-5.62 (5.46)			48.58 (30.20)		-398.38	20	839.59	5.40	0.899
	-123.80 (43.57)	-8.10 (6.52)			-400.95	18	840.19	6.01	0.906
-1.64 (1.28)	-2.65 (8.85)	-0.02 (0.51)			-393.38	22	834.18	0.00	0.147
-1.82 (1.30)	-7.13 (10.67)				-395.70	20	834.24	0.05	0.289
-1.53 (1.31)	-7.51 (10.27)				-398.30	18	834.90	0.71	0.392
-1.49 (1.32)	-7.00 (10.37)		0.38 (1.04)		-396.42	20	835.67	1.49	0.462
	-7.37 (10.52)				-398.75	18	835.79	1.61	0.527
-1.75 (1.33)	-7.32 (11.84)		0.42 (1.03)		-394.73	22	836.88	2.70	0.565
-1.42 (1.28)	-2.22 (8.67)	-0.09 (0.50)		0.23 (0.21)	-392.42	24	836.93	2.75	0.602
	-6.70 (10.38)		0.56 (1.03)		-399.50	18	837.29	3.11	0.633

TABLE 6.21. Continued

Rank	Intercept	$ABIGSAGE_{270}$	$NDVI_{18km}$	$NDVI_{18km}^2$	ELEV[b]	$iH2Od_{250}$	TRI_{1km}	$CFRST_{1km}$
9	-2.33 (0.87)	0.22 (0.34)	-1.05 (3.48)	2.39 (4.06)	0.59 (0.38)	-0.01 (0.18)	-0.02 (0.01)	-6.09 (2.04)
10	-2.46 (1.06)	0.22 (0.37)	-1.95 (3.95)	3.15 (4.50)	0.82 (0.40)	0.02 (0.18)	-0.02 (0.01)	-5.82 (2.03)
11	-2.42 (0.82)	0.33 (0.34)	-0.95 (3.61)	2.21 (4.14)	0.64 (0.39)	0.00 (0.18)	-0.02 (0.01)	-6.31 (2.02)
12	-2.58 (1.18)	0.46 (0.52)	0.54 (4.20)	0.69 (4.71)	0.46 (0.43)		-0.02 (0.01)	-5.64 (2.13)
13	-2.21 (0.80)	0.38 (0.36)	-0.02 (3.43)	1.32 (3.95)	0.43 (0.38)		-0.02 (0.01)	-6.38 (2.04)
14	-2.13 (0.86)	0.35 (0.35)	-1.17 (3.48)	2.69 (4.04)	0.43 (0.38)		-0.01 (0.01)	-6.32 (2.10)
15	-2.70 (1.05)	0.33 (0.36)	-0.33 (3.75)	1.44 (4.28)	0.73 (0.39)	0.00 (0.18)	-0.02 (0.01)	-6.08 (2.02)
16	-2.58 (0.81)	0.31 (0.33)	-0.53 (3.42)	1.82 (3.96)	0.62 (0.38)	-0.02 (0.18)	-0.02 (0.01)	-6.41 (2.02)
17	-3.23 (1.02)	0.89 (0.44)	0.42 (3.82)	0.83 (4.36)	0.48 (0.37)		-0.02 (0.01)	-5.67 (2.16)
18	-2.13 (0.86)	0.23 (0.37)	-1.62 (3.61)	3.15 (4.19)	0.52 (0.39)		-0.01 (0.01)	-6.52 (2.08)
19	-2.29 (0.86)	0.18 (0.36)	-1.47 (3.56)	2.88 (4.13)	0.62 (0.38)	-0.01 (0.18)	-0.02 (0.01)	-6.29 (2.05)
20	-3.38 (0.77)	0.65 (0.31)	2.47 (3.43)	-3.55 (3.91)	0.78 (0.38)		-0.02 (0.01)	
21	-2.45 (1.05)	0.19 (0.37)	-2.57 (3.89)	3.96 (4.45)	0.81 (0.38)	0.01 (0.18)	-0.02 (0.01)	-6.19 (2.06)
22	-2.53 (0.80)	0.28 (0.34)	-1.09 (3.52)	2.48 (4.06)	0.64 (0.37)	-0.01 (0.18)	-0.02 (0.01)	-6.59 (2.04)
23	-3.10 (0.87)	0.18 (0.34)	-0.18 (4.04)	0.09 (4.56)	1.00 (0.51)	0.04 (0.19)	-0.02 (0.01)	-3.41 (1.99)
24	-3.24 (1.01)	0.85 (0.41)	1.26 (3.81)	-0.12 (4.30)	0.44 (0.38)		-0.02 (0.01)	-5.60 (2.11)

[a] Variable definitions provided in Table 4.2
[b] Coefficient and standard error multiplied by 10^3
[c] Coefficient and standard error multiplied by 10^2

influencing abundance or occurrence of each bird species assessed across the WBEA area.

Brewer's Sparrow

Brewer's sparrow, the most common species modeled, was predicted to occur at moderate densities throughout much of the Wyoming Basins sagebrush habitat, especially in southwestern Wyoming. Brewer's sparrow density was positively associated with all big sagebrush at a moderate scale. An association with sagebrush was expected, with previous research demonstrating that Brewer's sparrows are often the most abundant bird species in sagebrush habitats (Wiens and Rotenberry 1981). Abundance of sagebrush at the landscape, territory, and nesting patch scale has been linked to Brewer's sparrow habitat selection and fitness (Chalfoun and Martin 2007), with large-scale habitat fragmentation thought to be responsible for declines observed in Breeding Bird Survey data (Rotenberry 1998). Brewer's sparrows in the Wyoming Basins illustrated this sensitivity to increased fragmentation with reduced densities in areas of increased sagebrush edge density. Expansion of energy development in the region and the subsequent fragmentation (Ch. 3) could result in reductions in Brewer's sparrow abundance; reductions have been shown at more local scales in Wyoming (Gilbert and Chalfoun 2011). Other factors predicting abundance of Brewer's sparrows in the Wyoming Basins included an association with moderate site productivity at higher (mid-range) elevations with less rugged terrain, describing the sagebrush plateaus of southwest Wyoming as well as riparian areas. Brewer's sparrows occur in ripar-

TABLE 6.21. Extended

$GRASS_{270m}$	MIX_{18km}	$EDGE_{5km}{}^{c}$	RIP_{1km}	$2RD_{1km}$	LL	K	AIC_c	ΔAIC_c	$\sum w_i$
-1.55 (1.32)	-5.10 (9.73)			0.21 (0.22)	-394.95	22	837.34	3.16	0.663
-1.58 (1.30)	-2.59 (9.05)	-0.05 (0.52)	0.45 (1.02)		-392.66	24	837.41	3.22	0.693
	-7.36 (11.55)		0.65 (1.02)		-397.31	20	837.45	3.27	0.721
-1.72 (1.37)	-6.68 (12.43)	0.44 (0.89)			-397.39	20	837.61	3.43	0.748
	-6.73 (9.97)				-401.91	16	837.64	3.45	0.774
-1.37 (1.32)	-6.81 (10.07)			0.22 (0.22)	-397.79	20	838.42	4.23	0.791
	-3.20 (9.19)	-0.01 (0.53)			-397.92	20	838.67	4.48	0.807
	-5.30 (9.75)			0.20 (0.22)	-398.10	20	839.02	4.84	0.820
	-18.51 (9.43)	0.92 (0.48)	0.97 (1.04)		-398.12	20	839.08	4.89	0.833
-1.31 (1.32)	-6.16 (10.07)		0.20 (1.05)	0.21 (0.22)	-395.85	22	839.14	4.95	0.845
-1.48 (1.32)	-4.86 (9.90)		0.22 (1.04)	0.22 (0.22)	-393.55	24	839.20	5.02	0.857
	-4.18 (9.15)		0.63 (1.00)		-402.71	16	839.22	5.04	0.869
-1.34 (1.29)	-2.44 (8.94)	-0.13 (0.51)	0.29 (1.03)	0.22 (0.21)	-391.33	26	839.48	5.30	0.879
	-4.52 (9.76)		0.41 (1.03)	0.22 (0.22)	-396.06	22	839.56	5.38	0.889
-1.67 (1.35)			0.26 (1.01)		-398.38	20	839.59	5.40	0.899
	-18.23 (10.41)	0.90 (0.48)			-400.95	18	840.19	6.01	0.906

ian habitat in the Great Basin (Dobkin and Rich 1998) and have highest densities within 500 m of riparian habitat in Arizona (Szaro and Jakle 1985). Brewer's sparrow densities in the WBEA area decreased with increases in conifer forest at local scales and mixed shrubland at landscape scales. When selecting foraging patches, Brewer's sparrows preferentially use patches dominated by sagebrush over yellow (*Chrysothamnus viscidiflorous*) and gray (*Ericameria nauseosus*) rabbitbrush (Rotenberry and Wiens 1998); both rabbitbrush species are primary components of the mixed shrubland land cover type in the Wyoming Basins. Brewer's sparrows are shrubland-associated birds, so the decrease in abundance we found in relation to conifer forest was expected.

No significant impact was observed between local anthropogenic factors and the abundance of Brewer's sparrow in the WBEA area. Likewise, Rotenberry and Knick (1995) found no measurable effect of 2-track roads on the presence of Brewer's sparrow in southwest Idaho. However, Ingelfinger and Anderson (2004) demonstrated a reduction in Brewer's sparrow abundance of up to 50% along low traffic volume roads (within 100 m and up to 697 cars/day) associated with natural gas developments in Wyoming. The 100-m zone tested by Ingelfinger and Anderson (2004) was not always significant for all energy roads, suggesting that impacts are highly variable. Similarly, Brewer's sparrow abundance, on average, decreased at three local oil fields assessed in southwestern Wyoming, although the response varied across sites, with no declines at one older oil field (Gilbert and Chalfoun 2011). The large spatial extent

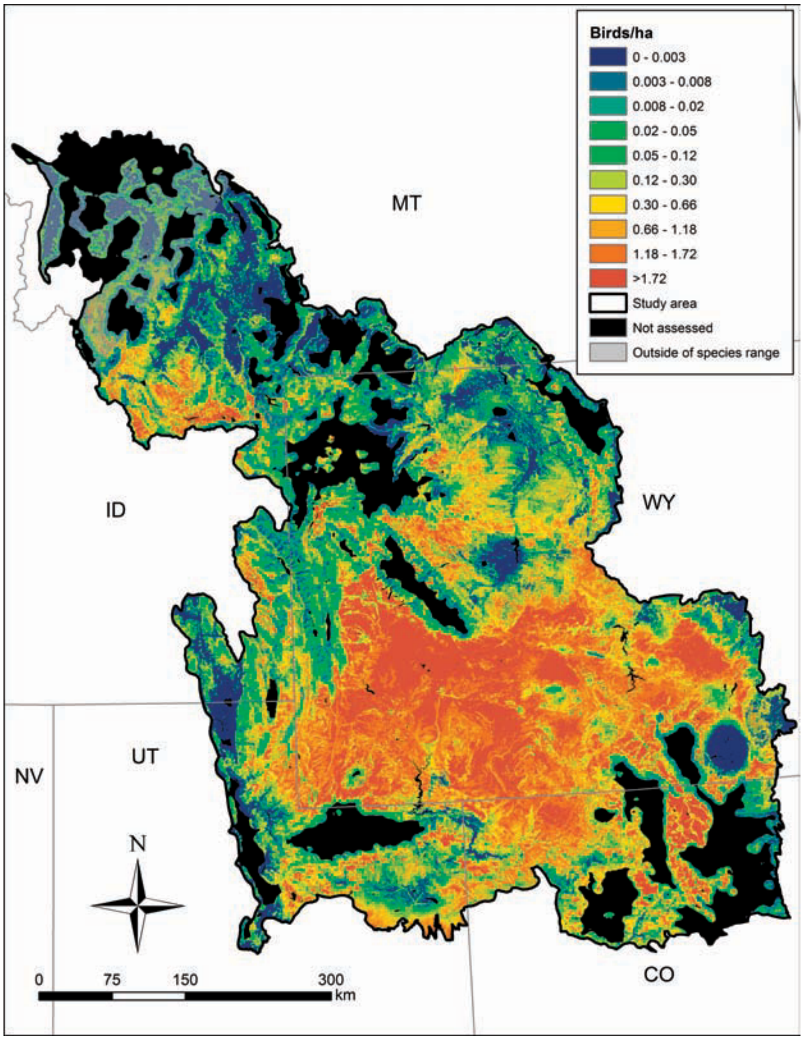

FIG. 6.14. Predicted density estimates (birds/ha) for sage thrasher in the Wyoming Basins Ecoregional Assessment area. Semi-transparent grey shaded areas are outside the range of the sage thrasher and black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water). Based on the largest territory sizes required to support one sage thrasher, the lowest density that could support a viable territory is 0.59 birds/ha. We infer that spatial predictions above this threshold predict occupied patches.

of our analyses across the WBEA area may have limited our ability to capture these more localized effects but provides insights to patterns across the region.

Green-tailed towhee

Green-tailed towhees are common throughout their range and, in general, populations have remained relatively stable since 1961 (Hejl 1994, Knopf 1994, Dobbs et al. 1998). However, biological and habitat relationships are less well understood because of the species' secretive nature (Dobbs et al. 1998). Accordingly, we had low detection rates (18.6% of plots) and low probability of detection (25%) for green-tailed towhees. Nevertheless, our model had good accuracy and reasonable classification success in predicting occurrence of green-tailed towhees.

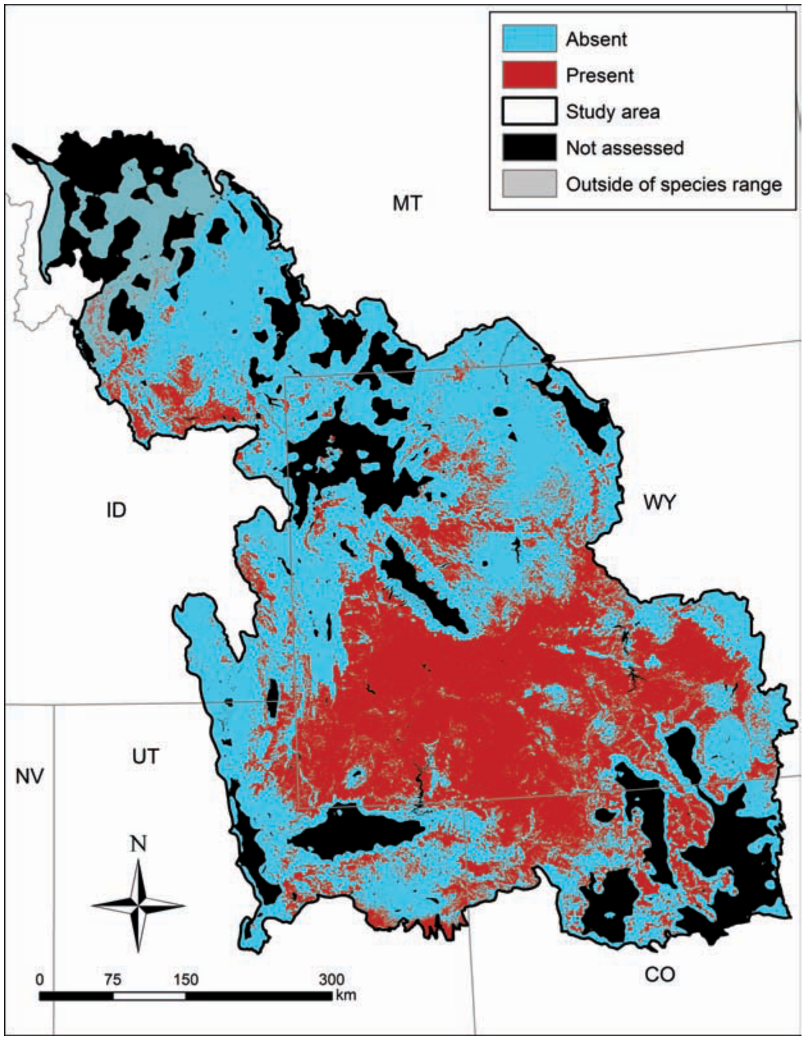

FIG 6.15. Distribution of sage thrasher in the Wyoming Basins Ecoregional Assessment area based on a threshold of (0.59 birds/ha), the largest territory size required to support one sage thrasher. Semi-transparent grey shaded areas are outside the range of sage thrasher and black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water).

Green-tailed towhees prefer a diverse mix of shrub species and are often associated with shrub steppe habitats and communities dominated by sagebrush or interspersed with pinyon (*Pinus* spp.)-juniper (Wiens and Rotenberry 1981, Sedgwick 1987, Knopf et al., 1990, Dobbs et al. 1998) as well as with heterogeneous habitats with no single dominant shrub (Berry and Bock 1998). Mapped occurrence of green-tailed towhees in the WBEA area was greatest along edges of sagebrush habitats, supporting other research indicating that ecotones between sagebrush and other shrubs or trees are ideal habitat for this species (Knopf et al. 1990). Although we found no relationship with forested habitats, occurrence was associated with a greater proportion of mountain big sagebrush at a moderate (5 km) extent. Species-diverse

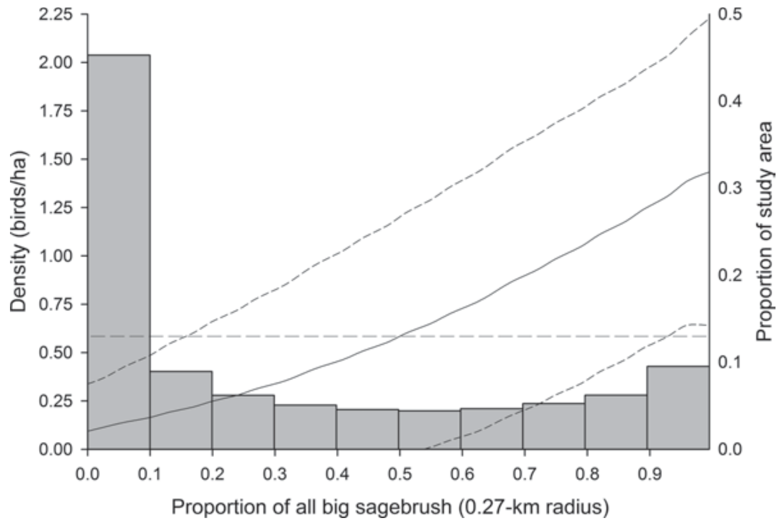

FIG. 6.16. Sage thrasher predicted densities within the Wyoming Basins Ecoregional Assessment area in relation to proportion of all big sagebrush (*Artemisia tridentata*) within a 0.27-km radius. Mean density (black line, ± 1 SD [dashed lines]) values were calculated in each one percent increment of all big sagebrush within a 0.27-km radius moving window. Range of predicted densities relate to the observed range of sagebrush at study site locations. The dashed horizontal line represents the lowest density that could support a viable territory (0.59 birds/ha), above which we infer patches to be occupied. Histogram values represent the proportion of the total study area in each 10% segment of all big sagebrush within 0.27 km.

shrub habitats were important green-tailed towhee habitat in Colorado at local patch scales but not at landscape scales (Berry and Bock 1998). Landscape fragmentation might not be an issue for birds, such as green-tailed towhees, which evolved in foothills shrub communities that are naturally fragmented (Berry and Bock 1998). We found higher occurrence in habitats with more rugged topography but larger mean patch size of sagebrush, suggesting heterogeneity of habitats may be important to green-tailed towhees, even within large patches of sagebrush habitat. Within shrub steppe habitats, vigor and heterogeneity of shrubs within a patch is important for nesting habitat (Knopf et al. 1990, Berry and Bock 1998). Similarly, occurrence of green-tailed towhees in the WBEA area was positively correlated within maximum NDVI values. These more productive habitats likely support a greater diversity of

TABLE 6.22. Results of AIC_c-based model selection for vesper sparrow zero-inflated negative binomial abundance models in relation to multi-scale sagebrush and NDVI 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 $\Delta AIC_c \leq 2$ are shown.

Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
1	$BIGSAGE_{18km}$ + $NDVI_{3km}$ + ($BIGSAGE_{18km}$ * $NDVI_{3km}$)	-503.24	9	1,025.06	0.00	0.27
2	$BIGSAGE_{18km}$ + $NDVI_{5km}$ + $NDVI_{5km}$2	-503.98	9	1,026.55	1.48	0.13

[a] Variable definitions provided in Table 4.2

TABLE 6.23. Evaluation statistics from AIC_c-based univariate model selection for vesper sparrow zero-inflated inflated negative binomial abundance models 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 models with big sagebrush (18-km radius), NDVI (3-km radius), and the big sagebrush NDVI interaction term variables as a base model for variables tested. We used AIC_c to sort models for each variable in ascending order to identify the extent at which vesper sparrow respond to individual variables.

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	$CFRST_{540m}$	-494.65	11	1,012.17	0.00	0.86
	$CFRST_{1km}$	-496.52	11	1,015.90	3.73	0.13
	$CFRST_{270m}$	-500.30	11	1,023.47	11.30	0.00
	$GRASS_{1km}$	-502.07	11	1,026.99	0.00	0.22
	$GRASS_{3km}$	-502.19	11	1,027.24	0.25	0.20
	$GRASS_{540m}$	-502.23	11	1,027.32	0.33	0.19
	$GRASS_{5km}$	-502.35	11	1,027.57	0.57	0.17
	$GRASS_{270m}$	-502.52	11	1,027.90	0.90	0.14
	$GRASS_{18km}$	-503.06	11	1,028.98	1.99	0.08
	MIX_{3km}	-498.00	11	1,018.85	0.00	0.42
	MIX_{5km}	-498.53	11	1,019.93	1.08	0.25
	MIX_{18km}	-498.70	11	1,020.27	1.41	0.21
	MIX_{540m}	-499.76	11	1,022.38	3.53	0.07
	MIX_{1km}	-500.46	11	1,023.79	4.94	0.04
	MIX_{270m}	-501.54	11	1,025.94	7.09	0.01
	RIP_{18km}	-495.93	11	1,014.73	0.00	0.52
	RIP_{5km}	-496.96	11	1,016.78	2.06	0.18
	RIP_{540m}	-497.25	11	1,017.35	2.63	0.14
	RIP_{1km}	-497.27	11	1,017.40	2.67	0.14
	RIP_{3km}	-499.45	11	1,021.76	7.03	0.02
	RIP_{270m}	-499.89	11	1,022.65	7.93	0.01
	$SALT_{270}$	-496.83	11	1,016.52	0.00	0.72
	$SALT_{1km}$	-498.00	11	1,018.86	2.34	0.22
	$SALT_{540m}$	-499.38	11	1,021.63	5.11	0.06
	$PATCH_{1km}$	-500.17	11	1,023.20	0.00	0.35
	$CONTAG_{3km}$	-500.43	11	1,023.72	0.52	0.27
	$EDGE_{3km}$	-500.91	11	1,024.67	1.47	0.17
	$PATCH_{3km}$	-501.68	11	1,026.22	3.02	0.08
	$CONTAG_{5km}$	-502.38	11	1,027.63	4.42	0.04
	$EDGE_{5km}$	-502.60	11	1,028.07	4.87	0.03
	$CONTAG_{1km}$	-502.67	11	1,028.21	5.01	0.03
	$EDGE_{1km}$	-502.98	11	1,028.82	5.62	0.02
	$PATCH_{5km}$	-503.17	11	1,029.21	6.00	0.02
	$PATCH_{1km}$	-500.17	11	1,023.20	0.00	0.35

TABLE 6.23. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
Abiotic	CTI^{2b}	-496.81	13	1,020.83	0.00	0.75
	CTI	-500.08	11	1,023.02	2.20	0.25
	$ELEV^{2b}$	-495.44	13	1,018.08	0.00	1.00
	ELEV	-503.22	11	1,029.31	11.23	0.00
	$iH2Od_{1km}^{c}$	-502.90	11	1,028.66	0.00	0.35
	$iH2Od_{250}^{c}$	-502.94	11	1,028.74	0.08	0.33
	$iH2Od_{500}^{c}$	-502.97	11	1,028.80	0.14	0.32
	$pH2Od_{1km}^{c}$	-502.19	11	1,027.23	0.00	0.41
	$pH2Od_{250}^{c}$	-502.42	11	1,027.71	0.48	0.32
	$pH2Od_{250}^{c}$	-502.61	11	1,028.08	0.85	0.27
	TRI_{270}^{2b}	-492.70	13	1,012.60	0.00	0.38
	TRI_{270}	-495.77	11	1,014.40	1.80	0.16
	TRI_{5km}^{2b}	-493.90	13	1,015.00	2.40	0.12
	TRI_{3km}^{2b}	-494.29	13	1,015.77	3.17	0.08
	TRI_{540}^{2b}	-494.43	13	1,016.06	3.46	0.07
	TRI^{2b}	-494.77	13	1,016.73	4.13	0.05
	TRI_{540}	-496.96	11	1,016.78	4.17	0.05
	TRI_{1km}^{2b}	-494.85	13	1,016.91	4.30	0.04
	TRI_{1km}	-497.53	11	1,017.92	5.32	0.03
	TRI	-497.54	11	1,017.93	5.33	0.03
	TRI_{3km}	-500.40	11	1,023.66	11.06	0.00
	TRI_{5km}	-501.03	11	1,024.93	12.33	0.00
Disturbance	AG_{250}^{c}	-501.54	11	1,025.95	0.00	0.52
	AG_{500}^{c}	-502.26	11	1,027.39	1.44	0.25
	AG_{1km}^{c}	-502.34	11	1,027.55	1.60	0.23
	$MjRD_{1km}^{c}$	-500.30	11	1,023.47	0.00	0.68
	$MjRD_{500}^{c}$	-501.56	11	1,025.98	2.51	0.19
	$MjRD_{250}^{c}$	-502.04	11	1,026.95	3.48	0.12
	$PIPE_{1km}^{c}$	-496.41	11	1,015.69	0.00	0.97
	$PIPE_{500}^{c}$	-500.28	11	1,023.42	7.72	0.02
	$PIPE_{250}^{c}$	-501.29	11	1,025.45	9.76	0.01
	$POWER_{1km}^{c}$	-501.62	11	1,026.11	0.00	0.66
	$POWER_{500}^{c}$	-502.97	11	1,028.79	2.69	0.17
	$POWER_{250}^{c}$	-502.99	11	1,028.84	2.73	0.17
	$RDdens_{3km}$	-499.07	11	1,021.01	0.00	0.41
	$RDdens_{5km}$	-499.93	11	1,022.72	1.71	0.17
	$RDdens_{270}$	-499.98	11	1,022.81	1.80	0.17

TABLE 6.23. Continued

Category	Variable[a]	LL	K	AIC_c	ΔAIC_c	w_i
	$2RD_{250}$[c]	-500.72	11	1,024.29	3.28	0.08
	$RDdens_{540}$	-500.98	11	1,024.82	3.80	0.06
	$2RD_{500}$[c]	-501.21	11	1,025.29	4.27	0.05
	$RDdens_{1km}$	-501.68	11	1,026.22	5.21	0.03
	$2RD_{1km}$[c]	-501.70	11	1,026.27	5.26	0.03
	$RDdens_{18km}$	-502.95	11	1,028.77	7.76	0.01
	$WELL_{1km}$[c]	-503.16	11	1,029.18	0.00	0.35
	$WELL_{250}$[c]	-503.21	11	1,029.29	0.10	0.33
	$WELL_{500}$[c]	-503.23	11	1,029.31	0.13	0.32

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

shrub species and structural variation within mountain shrub communities, which are important for breeding and nesting habitat for green-tailed towhees (Braun et al. 1976, Knopf et al. 1990, Dobbs et al. 1998).

Braun et al. (1976) suggested that long-term loss and destruction of sagebrush habitat negatively impacts green-tailed towhees. Other than reviews of the potential effects of fragmentation and loss of shrub steppe habitats (Braun et al. 1976, Knopf et al. 1990), no recorded research has specifically addressed the impacts of anthropogenic disturbances on green-tailed towhee populations. Green-tailed towhees were one of the few species for which we found an avoidance of human features, although the effect was not very strong. Green-tailed towhees avoided habitat in proximity to major (interstate and state/federal highways) roads, suggesting that cumulative anthropogenic developments may have negative consequences for populations, although these types of disturbance are less common in higher elevation mountain sagebrush communities. Further research directly assessing the consequences of human developments on green-tailed towhee populations is needed, especially given increasing rates of development for human habitation and recreational use at the sagebrush-conifer ecotone, where this species commonly occurs, and the increasing rates and extents of energy developments throughout sagebrush ecosystems.

Lark sparrow

Lark sparrows in western North America have remained relatively stable on BBS routes since surveys began in 1966 (Martin and Parrish 2000, Sauer et al. 2003). Although few habitat studies have been conducted for this species, birds tend to be found at ecotone boundaries in more open grassland or shrub steppe habitats adjacent to forest (pinyon-juniper) edges, although agricultural fields and roadside edges may also be selected (Knopf 1996, Martin and Parrish 2000). Our model predicted lark sparrows to occur in the grass dominated regions in the eastern and southern portions of the WBEA area, even though grassland did not enter into the model as a predictor. However, this may simply be an artifact of our sampling design targeting sagebrush habitats. Lark sparrow density was greatest in large landscapes containing a great-

TABLE 6.24. Results of AIC_c-based submodel selection for vesper sparrow zero-inflated inflated negative binomial abundance models 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 $\Delta AIC_c \leq 2$ are shown.

Category	Rank	Model[a]	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	1	$BIGSAGE_{18km} + NDVI_{3km} + (BIGSAGE_{18km} * NDVI_{3km}) + CFRST_{540m} + MIX_{3km} + RIP_{18km} + SALT_{270}$	-476.32	17	988.68	0.00	0.70
Abiotic	1	$BIGSAGE_{18km} + NDVI_{3km} + (BIGSAGE_{18km} * NDVI_{3km}) + ELEV + ELEV^2 + TRI_{270} + TRI_{270}{}^2$	-482.54	17	1,001.11	0.00	0.69
Disturbance	1	$BIGSAGE_{18km} + NDVI_{3km} + (BIGSAGE_{18km} * NDVI_{3km}) + PIPE_{1km} + RDdens_{3km}$	-492.45	13	1,012.09	0.00	0.25
	2	$BIGSAGE_{18km} + NDVI_{3km} + (BIGSAGE_{18km} * NDVI_{3km}) + AG_{250} + PIPE_{1km} + RDdens_{3km}$	-490.60	15	1,012.78	0.69	0.17
	3	$BIGSAGE_{18km} + NDVI_{3km} + (BIGSAGE_{18km} * NDVI_{3km}) + AG_{250} + PIPE_{1km} + RDdens_{3km} + WELL_{1km}$	-488.95	17	1,013.95	1.85	0.10

[a] Variable definitions provided in Table 4.2

er proportion of all big sagebrush, as well as mixed shrubs. Additionally, these birds showed moderate avoidance of conifer forest; but when present in sagebrush landscapes, abundance increased in the presence of coniferous forest, although the effect was small. This is consistent with other studies that have shown selection for desert-shrub and juniper-sagebrush mixed shrub communities (Knopf 1996, Martin and Parrish 2000). Occurrence of lark sparrows was correlated with greater vegetation productivity (higher maximum NDVI values) in the WBEA area, particularly within sagebrush habitats, but once present in these habitats, NDVI had little effect on abundance. These findings suggest that lark sparrows select denser structural cover within shrub steppe communities, consistent with research elsewhere (Martin and Parrish 2000).

No previous studies have addressed the response of lark sparrows to anthropogenic developments. We found only marginal response to proximity to wells and agricultural land for both occurrence and abundance. Given these responses and the fact that lark sparrow populations are currently stable, we suggest that lark sparrows will persist within the Wyoming Basins into the foreseeable future.

Sage sparrow

Sage sparrow density was predicted to be the highest across the central portion of the WBEA area, with high densities occurring within sagebrush habitats in southwest Wyoming and northeastern Utah, and those in northern Wyoming associated with the Bighorn River basin. The occurrence portion of the zero-inflated Poisson count model explained most of the variation in the model (based on log-likelihood estimates), suggesting presence-absence relationships were overwhelming. Despite having small home ranges (0.65 to 7.06 ha; Rich 1980, Reynolds 1981, Wiens and Rotenberry 1985), we found sage sparrow habitat associations at large spatial scales.

Survey blocks where sage sparrows were detected had ~5% more sagebrush habitat, but our count-based density model suggested a negative relationship with both the occurrence and abundance of all sagebrush. At first, this result was counterintuitive, but responses to other variables, such as increased occurrence with both lower productivity at a large spatial scale and increased proportion salt-desert shrubland at a moderate scale, likely counteracted these effects; abundance appears unaffected by productivity or proportion of salt-desert shrubland (large coefficient SEs). The dose response curve illustrates that predicted sage sparrow density across the WBEA area increased with proportion of sagebrush, with highest predicted densities occurring in large landscapes containing more than ~40% sagebrush land cover, despite the negative model coefficients. Configuration of sagebrush was also important. When contagion of sagebrush habitat increased, sage sparrows were more likely to occur; effects on abundance were again limited. This landscape-scale association with sagebrush is consistent with previous research (Wiens and Rotenberry 1981, Knick and Rotenberry 1995, Vander Haegen et al. 2000). Because sage sparrows also select open shrubland sites with patchy shrub distributions (Rich 1978, Rotenberry and Wiens 1978, Wiens and Rotenberry 1981, Smith et al. 1984, Wiens 1985), the observed relationship with salt-desert shrubland is consistent with previous research. Also consistent with previous research is the negative relationship between mixed shrub habitat and sage sparrow abundance, because sage sparrows preferentially forage in patches of sagebrush over yellow rabbitbrush (Rotenberry and Wiens 1998).

Rotenberry and Knick (1995) found no relationship between measured anthropogenic factors and the occurrence of sage sparrows, although this may not reflect demographic processes (Misenhelter and Rotenberry 2000, Bock and Jones 2004) or recent, broad-scale ecosystem changes (Bradley et al. 2006). Introduced invasive alien plants, particularly cheatgrass (*Bromus tectorum*), which can lead to altered fire frequencies and loss of sagebrush, can displace sage sparrows (Wiens 1985, Rogers et al. 1988). Mechanical or chemical removal of sagebrush also leads to degradation of sage sparrow habitat through similar structural changes (Braun et al. 1976, Wiens and Rotenberry 1985, Wiens et al. 1986, Rogers et al. 1988). However, we found limited responses of sage sparrows to anthropogenic features, which included road density and proximity to oil and gas wells. Although abundance of sage sparrows was effectively independent of roads (large coefficient SEs), occurrence was negatively impacted by high road densities. Ingelfinger and Anderson (2004) found reductions in abundance of sage sparrows of up to 76% along low traffic volume roads (within 100 m and up to 697 cars/day) associated with natural gas developments in Wyoming. The 100-m zone tested, however, was not always significant for all energy haul roads, suggesting that impacts are highly variable and other factors may be important. Similarly, Gilbert and Chalfoun (2011) found reductions in sage sparrow abundance with increasing well density in three oil fields in Wyoming, although relationships were only significant at one of these sites. The reductions in sage sparrow abundance that we observed with greater road densities coupled with continued landscape-scale loss of sagebrush and associated habitats from development are likely to result in declining sage sparrow occurrence and density with increasing human activities.

Sage thrasher

Sage thrashers were predicted to occur throughout much of the WBEA study area, with the highest densities occurring throughout southcentral Wyoming. Sage thrashers were positively associated with all big sagebrush vegetation at moderate

TABLE 6.25. Results of AIC_c-based model selection for the combined vesper sparrow zero-inflated inflated negative binomial abundance models 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 shown with cumulative Akaike weight (w_i) of just ≥ 0.9. Section (A) includes the inflate portion of the model capturing presence-absence, whereas Section (B) includes the count portion of the model.

Rank	Intercept	$BIGSAGE_{18km}$	$NDVI_{3km}$	$BIGSAGE_{18km}$ * $NDVI_{3km}$	$CFRST_{540m}$	MIX_{3km}	RIP_{18km}
(A) Occurrence							
1	-90.04 (27.87)	131.77 (42.41)	311.45 (96.31)	-445.78 (142.04)	-132.39 (40.00)	73.23 (51.09)	-25.67 (16.19)
2	-96.44 (31.59)	140.96 (48.29)	326.05 (104.63)	-471.98 (157.91)	-133.61 (41.51)	71.85 (54.17)	-24.31 (15.79)
3	-87.02 (25.81)	126.85 (39.12)	305.55 (90.96)	-432.59 (132.92)	-131.87 (38.31)	76 (48.86)	-25.68 (16.09)
4	-87.49 (27.70)	127.06 (41.92)	304.99 (95.81)	-431.85 (140.97)	-131.28 (40.32)	79.63 (50.90)	-24.53 (16.25)
5	-189.12 (157.24)	124.72 (104.81)	439.69 (354.19)	-465.16 (369.43)	-269.79 (214.96)	38.88 (66.29)	
6	-233.20 (109.35)	154.40 (75.15)	537.09 (246.45)	-569.28 (266.10)	-327.73 (147.78)		
7	-311.33 (124.75)	263.15 (129.42)	794.60 (356.51)	-802.06 (407.83)		57.51 (179.57)	
8	-90.97 (25.51)	132.02 (38.54)	311.83 (87.79)	-444.60 (129.12)	-132.00 (36.46)	68.75 (47.06)	-21.55 (14.36)
9	-96.58 (29.32)	140.42 (44.68)	325.71 (96.53)	-469.62 (145.92)	-132.51 (37.89)	62.64 (45.72)	-21.07 (14.27)
10	-111.93 (52.99)	164.66 (81.70)	366.08 (167.84)	-539.16 (261.01)	-144.99 (60.81)	77.23 (72.90)	
11	-328.31 (118.78)	280.20 (123.43)	849.78 (330.41)	-850.11 (394.60)			
12	-136.20 (33.97)	157.87 (38.98)	393.45 (94.71)	-551.97 (135.78)	-163.49 (38.77)		-42.14 (15.95)
13	-71.04 (20.80)	100.51 (31.37)	247.75 (73.57)	-343.06 (107.45)	-107.72 (30.86)	63.21 (36.66)	-17.70 (15.20)
14	-70.27 (20.73)	99.22 (31.18)	242.70 (72.76)	-337.49 (106.29)	-104.67 (30.41)	60.71 (35.43)	-16.69 (14.84)
15	-133.17 (34.25)	156.33 (39.74)	385.74 (95.99)	-544.24 (137.84)	-159.23 (39.37)		-40.71 (15.83)
16	-213.94 (102.49)	146.35 (70.13)	507.09 (243.87)	-537.50 (256.31)	-311.76 (152.58)	68.89 (86.28)	
17	-214.74 (87.34)	96.47 (59.60)	385.67 (169.76)	-274.09 (194.68)			
18	-82.16 (37.05)	118.42 (56.93)	277.37 (119.70)	-394.83 (180.86)	-116.96 (47.10)	81.28 (53.38)	
19	-245.26 (147.07)	187.38 (126.13)	609.49 (368.56)	-624.78 (433.10)	-348.06 (213.89)		-62.03 (39.86)
20	-195.38 (89.15)	95.40 (60.16)	365.05 (171.61)	-277.33 (196.25)		52.63 (94.93)	
(B) Abundance							
1	-1.31 (0.65)	-1.91 (1.08)	0.51 (1.13)	7.05 (2.90)	-1.53 (1.38)	10.09 (4.61)	9.31 (3.02)
2	-1.08 (0.72)	-2.04 (1.19)	0.90 (1.18)	6.27 (3.08)	-1.17 (1.38)	9.88 (4.62)	8.66 (3.03)
3	-1.10 (0.63)	-1.80 (1.09)	0.47 (1.13)	6.90 (2.92)	-1.64 (1.38)	9.63 (4.62)	10.36 (2.98)
4	-1.00 (0.69)	-1.62 (1.16)	1.01 (1.16)	5.44 (3.05)	-1.20 (1.37)	9.04 (4.57)	9.89 (2.95)
5	-6.26 (2.86)	-2.24 (1.54)	0.04 (1.26)	4.64 (3.54)	-0.02 (1.66)	9.26 (5.33)	
6	-5.65 (2.70)	-2.09 (1.29)	0.09 (1.25)	4.26 (3.29)	0.16 (1.70)		
7	-7.92 (2.48)	-3.20 (1.18)	-0.18 (1.17)	5.26 (3.00)		10.85 (4.84)	
8	-1.43 (0.66)	-2.17 (1.09)	0.58 (1.15)	7.76 (2.95)	-1.47 (1.41)	10.54 (4.68)	10.23 (3.07)
9	-1.24 (0.73)	-2.27 (1.20)	0.98 (1.20)	6.95 (3.15)	-1.16 (1.41)	10.43 (4.69)	9.64 (3.08)
10	-0.14 (0.67)	-3.10 (1.18)	0.23 (1.22)	7.29 (3.22)	-1.83 (1.45)	9.76 (4.99)	
11	-7.74 (2.44)	-2.83 (1.18)	0.02 (1.18)	4.56 (3.02)			

TABLE 6.25. Extended

SALT$_{270}$	PIPE$_{1km}$	RDdens$_{3km}$	TRI$_{270}$[b]	TRI$_{270}^{2b}$	ELEV[a]	ELEV^{2c}	LL	K	AIC$_c$	ΔAIC$_c$	Σw_i
-0.44 (3.50)	-3.02 (1.32)	0.52 (0.53)					-469.45	21	984.02	0.00	0.201
0.12 (3.63)	-3.40 (1.55)	0.85 (0.63)	10.13 (6.81)	-0.21 (0.11)			-464.88	25	984.22	0.19	0.384
-0.67 (3.48)	-2.63 (1.13)						-472.17	19	984.89	0.86	0.515
-0.16 (3.62)	-2.60 (1.17)		2.74 (7.17)	-0.04 (0.13)			-468.61	23	986.97	2.94	0.561
17.09 (18.94)			-33.24 (23.79)	0.40 (0.36)	8.18 (6.87)	-0.22 (0.18)	-468.67	23	987.10	3.07	0.604
22.65 (15.59)			-39.11 (19.1)	0.49 (0.31)	10.12 (4.87)	-0.27 (0.13)	-471.09	21	987.30	3.28	0.643
	-9.03 (4.88)	-2.73 (1.48)	-113.6 (52.7)	2.36 (1.07)	11.05 (4.33)	-0.33 (0.13)	-468.88	23	987.52	3.50	0.678
	-3.11 (1.24)	0.65 (0.54)					-473.79	19	988.13	4.10	0.704
	-3.51 (1.50)	0.97 (0.65)	8.44 (6.78)	-0.20 (0.11)			-469.23	23	988.22	4.20	0.729
1.05 (3.83)	-4.73 (2.91)	1.31 (1.40)	13.55 (12.19)	-0.28 (0.27)			-469.33	23	988.41	4.39	0.751
	-9.67 (4.50)	-2.87 (1.47)	-125.73 (45.09)	2.59 (0.93)	11.48 (4.25)	-0.34 (0.12)	-471.75	21	988.61	4.59	0.771
-1.15 (3.40)	-2.52 (1.09)				3.17 (1.58)	-0.09 (0.04)	-471.76	21	988.64	4.62	0.791
1.11 (3.67)							-476.32	17	988.68	4.66	0.811
1.52 (3.67)		0.29 (0.40)					-474.18	19	988.91	4.89	0.828
-0.88 (3.40)	-2.69 (1.13)	0.29 (0.48)			2.98 (1.61)	-0.08 (0.04)	-469.73	23	989.22	5.19	0.843
		-1.10 (0.77)	-32.93 (16.05)	0.42 (0.26)	9.06 (4.58)	-0.24 (0.12)	-469.92	23	989.60	5.58	0.856
30.61 (16.42)				1.76 (0.78)		-0.31 (0.14)	-474.54	19	989.63	5.61	0.868
1.19 (3.79)	-3.12 (2.11)	0.51 (0.82)	-81.06 (33.61)		11.6 (5.17)		-474.57	19	989.69	5.67	0.880
	-4.73 (3.38)	-1.49 (1.16)		1.19 (0.67)		-0.27 (0.17)	-467.65	25	989.76	5.73	0.891
26.27 (15.48)			-63.95 (32.01)	1.60 (0.80)	9.66 (5.98)	-0.27 (0.14)	-472.43	21	989.98	5.95	0.901

-4.12 (1.73)	-0.10 (0.27)	0.16 (0.09)	-75.12 (35.09)				-469.45	21	984.02	0.00	0.201
-4.13 (1.67)	-0.15 (0.27)	0.17 (0.09)	-0.63 (1.26)	-0.01 (0.01)			-464.88	25	984.22	0.19	0.384
-4.31 (1.76)	-0.12 (0.28)						-472.17	19	984.89	0.86	0.515
-4.42 (1.73)	-0.17 (0.27)		-0.23 (1.25)	-0.01 (0.01)			-468.61	23	986.97	2.94	0.561
-5.72 (1.52)			1.53 (1.54)	-0.03 (0.02)	0.61 (0.26)	-0.01 (0.01)	-468.67	23	987.10	3.07	0.604
-6.00 (1.51)			1.12 (1.31)	-0.03 (0.02)	0.57 (0.25)	-0.01 (0.01)	-471.09	21	987.30	3.28	0.643
	-0.08 (0.28)	0.29 (0.09)	0.27 (1.33)	-0.03 (0.02)	0.77 (0.23)	-0.02 (0.01)	-468.88	23	987.52	3.50	0.678
	-0.13 (0.28)	0.17 (0.09)					-473.79	19	988.13	4.10	0.704
	-0.17 (0.28)	0.18 (0.09)	-0.50 (1.30)	-0.01 (0.01)			-469.23	23	988.22	4.20	0.729
-4.52 (1.65)	-0.04 (0.28)	0.22 (0.09)	-0.70 (1.29)	-0.01 (0.01)			-469.33	23	988.41	4.39	0.751
	-0.03 (0.28)	0.29 (0.10)	0.04 (1.34)	-0.02 (0.02)	0.76 (0.23)	-0.02 (0.01)	-471.75	21	988.61	4.59	0.771

TABLE 6.25. Continued

Rank	Intercept	$BIGSAGE_{18km}$	$NDVI_{3km}$	$BIGSAGE_{18km}$ * $NDVI_{3km}$	$CFRST_{540m}$	MIX_{3km}	RIP_{18km}
12	-6.40 (2.45)	-2.32 (1.18)	-0.08 (1.17)	8.22 (3.03)	-0.24 (1.53)		8.98 (3.01)
13	-1.17 (0.63)	-1.52 (1.07)	0.59 (1.12)	6.29 (2.92)	-1.60 (1.36)	8.57 (4.55)	10.33 (2.97)
14	-1.39 (0.64)	-1.53 (1.06)	0.65 (1.12)	6.27 (2.90)	-1.49 (1.35)	8.75 (4.51)	9.35 (2.99)
15	-6.44 (2.44)	-2.29 (1.17)	0.01 (1.17)	8.12 (3.00)	-0.23 (1.51)		8.01 (3.02)
16	-8.10 (2.56)	-2.30 (1.27)	0.58 (1.25)	5.00 (3.28)	0.00 (1.68)	10.53 (4.86)	
17	-4.61 (2.51)	-2.79 (1.20)	-0.60 (1.15)	4.01 (3.08)			
18	-0.36 (0.64)	-2.66 (1.30)	-0.18 (1.18)	7.36 (3.28)	-2.20 (1.42)	8.79 (5.37)	
19	-7.58 (2.42)	-1.40 (1.29)	1.23 (1.29)	3.29 (3.16)	-0.04 (1.66)		7.23 (3.12)
20	-5.10 (2.51)	-3.07 (1.23)	-0.75 (1.15)	4.61 (3.13)		9.06 (4.97)	

[a] Variable definitions provided in Table 4.2
[b] Coefficients and standard errors multiplied by 10^2
[c] Coefficients and standard errors multiplied by 10^4

scales, consistent with previous research (Petersen and Best 1991, Knick and Rotenberry 1995, Erickson 2011). Based on our model, habitats containing >50% big sagebrush land cover provide suitable habitat for sage thrashers. Although the quantity of sagebrush was important, we did not find an influence of sagebrush configuration on either presence or abundance of sage thrashers across the WBEA area. Previous studies in Idaho found that sagebrush configuration and increased sagebrush cover are important factors influencing sage thrasher habitat, and probability of site occupancy increased with patch size and habitat similarity within a 1-km radius (Knick and Rotenberry 1995, 1997). These results suggest that any fragmentation of sagebrush habitats may be important in determining habitat quality for sage thrashers. Compared to other areas of the western U.S., many sampled sagebrush habitats in the Wyoming Basins are extensive, suggesting that configuration of sagebrush may not currently be limiting but may become more important when landscape cover of sagebrush habitat is reduced.

Sage thrashers avoided areas with increased proportion of mixed shrubland, and abundance decreased with increasing amounts of conifer forest. This was not surprising for a sagebrush-obligate species to avoid non-sagebrush habitat types, particularly the conifer forest type with dramatic differences in ecosystem structure and function. Both occurrence and abundance were greatest in areas with low topographic ruggedness, suggesting larger patches of flat and contiguous habitat (sagebrush) represent high-quality habitat for sage thrasher. In addition, proximity to intermittent water sources and increases in riparian habitat increased sage thrasher occurrence, and increased vegetation productivity resulted in increased sage thrasher density. These results are comparable to other work in Wyoming, where increased soil moisture and vegetation productivity enhanced sage thrasher densities (Erickson 2011).

No obvious anthropogenic impacts were identified in our assessment, suggesting that sage thrasher abundance in the Wyoming Basins was related more to habitat factors than land use. Previous assessments of local road impacts also suggest little to no impact to the occurrence or abundance of sage thrashers (Knick and Rotenberry 1995, Ingelfinger and Anderson 2004),

TABLE 6.25. Extended

$SALT_{270}$	$PIPE_{1km}$	$RDdens_{3km}$	$TRI_{270}{}^{b}$	$TRI_{270}{}^{2b}$	$ELEV^{*}$	$ELEV^{2c}$	LL	K	AIC_c	ΔAIC_c	Σw_i
-4.11 (1.75)	-0.07 (0.28)				0.56 (0.24)	-0.01 (0.01)	-471.76	21	988.64	4.62	0.791
-5.18 (1.74)							-476.32	17	988.68	4.66	0.811
-5.10 (1.72)		0.15 (0.09)					-474.18	19	988.91	4.89	0.828
-4.00 (1.74)	-0.06 (0.27)	0.15 (0.09)			0.53 (0.24)	-0.01 (0.01)	-469.73	23	989.22	5.19	0.843
		0.28 (0.09)	1.68 (1.29)	-0.04 (0.02)	0.69 (0.25)	-0.02 (0.01)	-469.92	23	989.60	5.58	0.856
-6.46 (1.53)			-0.28 (1.27)	-0.02 (0.02)	0.57 (0.23)	-0.01 (0.01)	-474.54	19	989.63	5.61	0.868
-4.79 (1.82)	0.02 (0.29)	0.21 (0.09)					-474.57	19	989.69	5.67	0.880
	-0.06 (0.28)	0.26 (0.10)	0.78 (1.37)	-0.03 (0.02)	0.59 (0.24)	-0.01 (0.01)	-467.65	25	989.76	5.73	0.891
-6.23 (1.51)			0.02 (1.28)	-0.02 (0.02)	0.61 (0.23)	-0.02 (0.01)	-472.43	21	989.98	5.95	0.901

and more recent work in Wyoming found no significant relationships between sage thrasher abundance and well density (Gilbert and Chalfoun 2011). Regardless of the neutral direct responses to anthropogenic activities, landscape-scale loss of sagebrush is expected to result in reductions in sage thrasher habitat, which has also been suggested to have greater impacts on sage thrashers because of their larger territory size requirements (Reynolds 1981, Reynolds et al. 1999, Erickson 2011).

Vesper sparrow

Occurrence of vesper sparrows was strongly correlated with the quantity of big sagebrush at large scales. Vesper sparrows are moderate habitat generalists (Jones and Cornely 2002), often associated with short or sparse vegetation cover occurring in open areas such as grasslands or those within shrub steppe habitats (Rotenberry and Wiens 1980, Kantrud and Kologiski 1983). Accordingly, predicted occurrence was greatest in the grassland-shrub interface in the eastern portions of the WBEA area with moderate occurrence in the sagebrush dominated Upper Green River Basin in southwest Wyoming. Vesper sparrows avoid tall and dense vegetation but select for increased structural complexity provided by sagebrush or other shrubs (Dechant et al. 2003). We found abundance of vesper sparrows increased with greater portions of mixed shrubland at large scales but decreased with less productive salt desert shrub communities. Occurrence has been positively correlated with cover of yellow rabbitbrush and antelope bitterbrush (*Purshia tridentata*) (Wiens and Rotenberry 1981), both of which are contained within our mixed shrub habitat class. Vesper sparrows occur at greater densities in montane shrub sites where meadows provide abundant forbs (Rotenberry and Wiens 1980). Similarly, we found occurrence to increase with habitat productivity, although sagebrush sites with high productivity were avoided (negative interaction term). However, when present, abundance increased when higher elevation sagebrush habitats had greater productivity (positive interaction term), although strong avoidance of conifer forests was evident. These relationships likely capture vesper sparrows selection for forb-rich habitats within more structural and heterogeneous shrub communities (Rotenberry and Wiens 1980). Accordingly, increased drought condi-

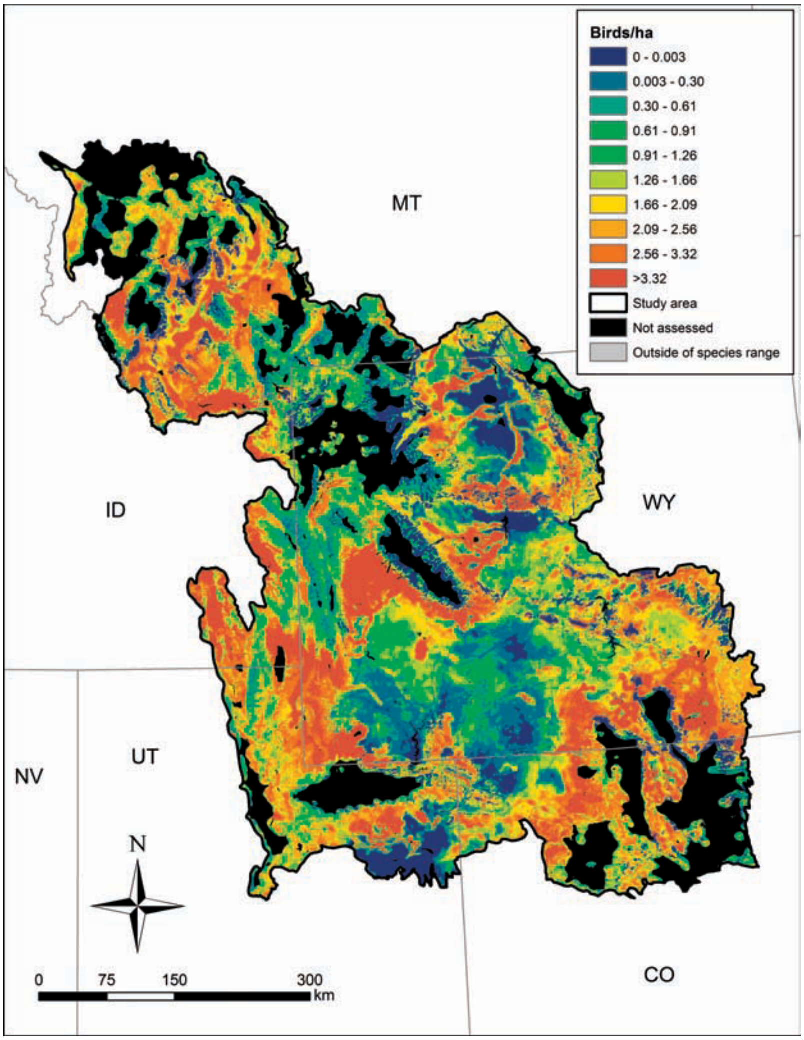

FIG. 6.17. Predicted density estimates (birds/ha) for vesper sparrow in the Wyoming Basins Ecoregional Assessment area. Black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water). Based on the largest territory sizes required to support one vesper sparrow, the lowest density that could support a viable territory is 0.12 birds/ha. We infer that spatial predictions above this threshold predict occupied patches.

tions may be important factors reducing habitat suitability for vesper sparrows (George et al. 1992).

Relationships with anthropogenic developments have rarely been assessed for vesper sparrows. However, the only significant anthropogenic response in the WBEA area was avoidance of habitats in proximity to pipelines. This avoidance may be a function of construction efforts which result in the loss of sagebrush cover and revegetation efforts on pipeline rights-of-way, ultimately leading to exotic grasslands (Booth and Cox 2009). In a recent study assessing songbird density at three oil fields in Wyoming, Gilbert and Chalfoun (2011) found no significant relationship between vesper sparrow abundance and well density. Vesper sparrows avoided urbanized landscapes in Colorado, and had

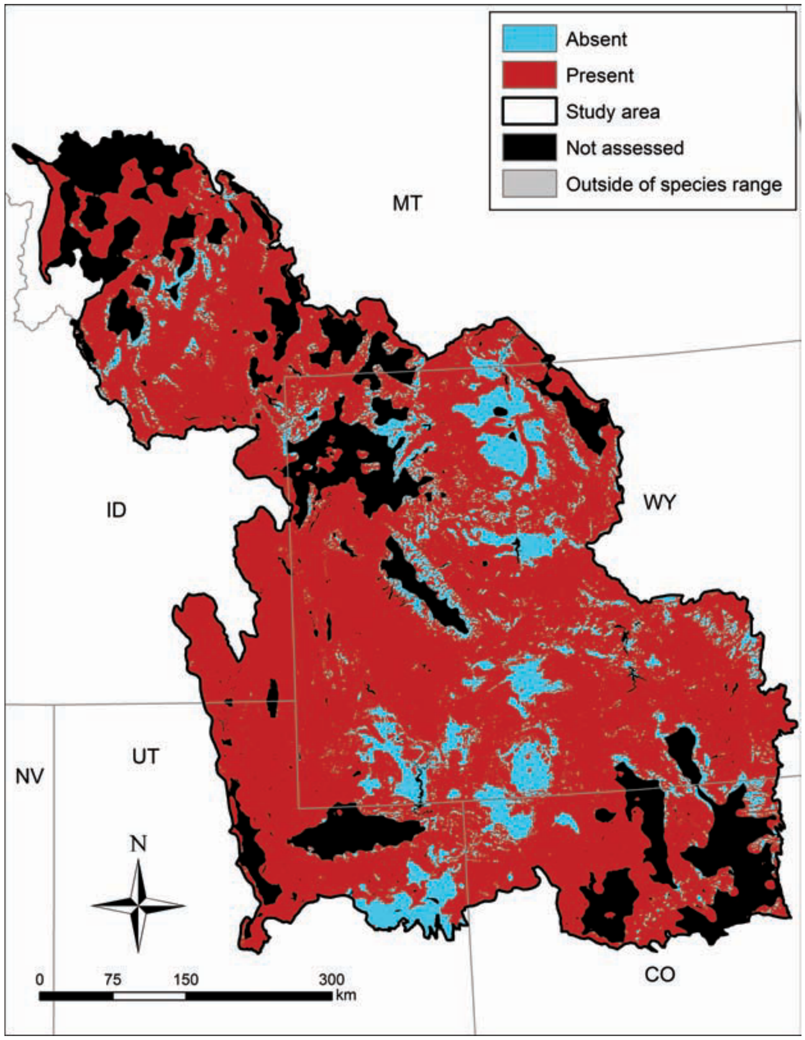

FIG 6.18. Distribution of vesper sparrow in the Wyoming Basins Ecoregional Assessment area based on a threshold of (0.12 birds/ha), the largest territory size required to support one vesper sparrow. Black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water).

greater abundance in more interior habitat locations (Bock et al. 1999, Jones and Bock 2002). Schaid et al. (1983) found that populations of vesper sparrows declined in proximity to mining operations, with effects lasting beyond reclamation activities, likely due to the direct loss of sagebrush. Although direct effects of human disturbance on the occurrence or abundance of vesper sparrows was limited in our study, loss of sagebrush and shrub steppe habitats could have lasting effects on populations of vesper sparrows within the Wyoming Basins.

CONCLUSIONS

Our models identified key habitat relationships for six songbird species of concern that depend on sagebrush habi-

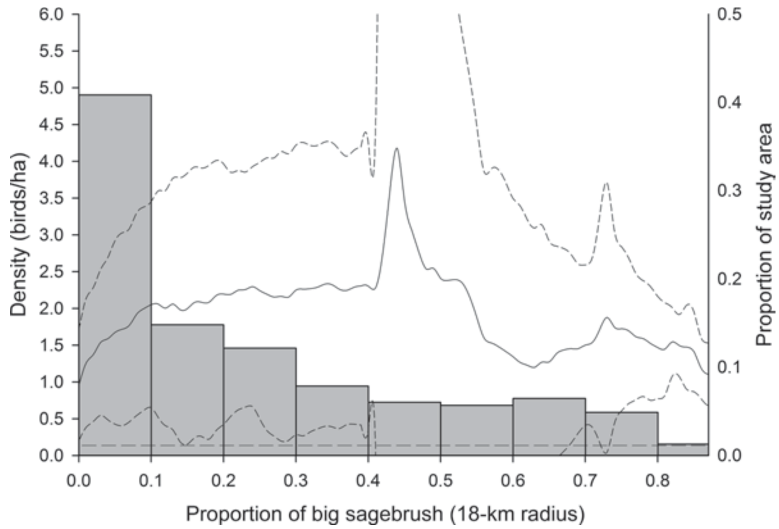

FIG. 6.19. Vesper sparrow predicted densities within the Wyoming Basins Ecoregional Assessment area in relation to proportion of big sagebrush (*Artemisia tridentata* spp.) within an 18-km radius. Mean density (black line, ± 1 SD [dashed lines]) values were calculated in each one percent increment of big sagebrush within an 18-km radius moving window. Range of predicted densities relate to the observed range of sagebrush at study site locations. The dashed horizontal line represents the lowest density that could support a viable territory (0.12 birds/ha), above which we infer patches to be occupied. Histogram values represent the proportion of the total study area in each 10% segment of big sagebrush within 18 km.

tats. These relationships were biologically intuitive, and in most cases, represent the first such landscape-level assessment for each species. The majority of songbird species examined across the WBEA area had positive relationships between occurrence and/or abundance and the quantity, and to a lesser extent, the configuration, of sagebrush habitats across the range of spatial extents (0.27-km to 18-km radii). The limited response of songbirds to anthropogenic disturbances aligns with previous findings in these systems (Knick and Rotenberry 1995, Rotenberry and Knick 1995, Ingelfinger and Anderson 2004, Gilbert and Chalfoun 2011) and should not be interpreted as a lack of response to anthropogenic developments. Time since disturbance, type of development, and activities associated with developments can mask direct effects on songbirds (Ingelfinger and Anderson 2004, Gilbert and Chalfoun 2011), and we were unable to incorporate a time component into our analysis of human disturbance factors. We also likely had low statistical power to detect changes in bird abundance as a function of human disturbance because our surveys were designed to sample both disturbance and habitat gradients across the broad extent of the entire WBEA area. We suggest that repeated, long-term monitoring of a selected subset of sites currently experiencing or expected to experience increased human disturbance in the future (see Gilbert and Chalfoun 2011, Erickson 2011), as well as control sites for comparison where human disturbances have been and are likely to continue to be minimal, be conducted to fully assess long-term impacts of landscape change to key sagebrush species of conservation concern. Moreover, assessment of fitness (nest success, fledging success, adult survival) may be necessary to fully understand influences of human disturbances and habitat conditions (Misenhelter and Rotenberry 2000, Bock and Jones 2004, Chalfoun and Martin 2007), although density may prove suitable for more targeted studies (Erickson 2011). Although we found limited or weak direct effects of human disturbance on the occurrence or abundance of six songbird species, loss of shrub steppe habitats could have lasting effects on songbird populations, reducing their future persistence within the Wyoming Basins.

Although sample sizes were low for some species, and relationships between abundance/occurrence and some predictor variables were weak, our approach of incorporating detectability directly into count-based GLMs with an offset term (Buckland et al. 2009) improved our ability to model species-resource relationships. However, some limitations were evident with this modeling approach, such as our inability to incorporate detectability for the green-tailed towhee model, a species for which we could only model occurrence. For count-based models, application of a mean offset to sites with no detections (Buckland et al. 2009) may introduce biases into models where a limited sample of detections exists for a given species. Similarly, we had to apply a mean offset to all pixels in order to apply models spatially, which may mask some true relationships in predicted maps. However, our models generally predicted 'raw' (uncorrected for detectability) count data collected in 2005 and 2006 along BSS routes. Count data summarized across entire 40-km routes validated our models and confirmed their utility as management tools. Two models (green-tailed towhee and lark sparrow) did not correlate with BBS data very well. These two species had a low number of survey blocks with detections that possibly limited our ability to accurately model their distribution and abundance. Despite those limitations, reasonable predictor variables were selected and the spatial application of the final models (maps) captured expected distributions across the WBEA area.

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APPENDIX 6.1

Descriptive statistics for explanatory variables used to model Brewer's sparrow abundance. 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 6.2

Descriptive statistics for explanatory variables used to model green-tailed towhee abundance. 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 6.3

Descriptive statistics for explanatory variables used to model lark sparrow abundance. 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 6.4

Descriptive statistics for explanatory variables used to model sage sparrow abundance. 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 6.5

Descriptive statistics for explanatory variables used to model sage thrasher. 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 6.6

Descriptive statistics for explanatory variables used to model vesper sparrow abundance. 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.