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Chapter 9: Occurrence of Small Mammals: Deer Mice and the Challenge of Trapping Across Large Spatial Extents

Steven E. Hanser, Matthias Leu, Cameron L. Aldridge, Scott E. Nielsen, and Steven T. Knick

Abstract. Small mammal communities living in sagebrush (*Artemisia* spp.) may be sensitive to habitat isolation and invasion by exotic grass species. Yet there have been no spatially explicit models to improve our understanding of landscape-scale factors determining small mammal occurrence or abundance. We live-trapped small mammals at 186 locations in the Wyoming Basin Ecoregional Assessment area to develop species distribution (habitat) models for each species. Most small mammal species ($n = 14$) were trapped at a only few locations. As a result, we developed a small mammal model only for the deer mouse (*Peromyscus maniculatus*). Deer mice were associated with areas having moderately productive habitat as measured by Normalized Difference Vegetation Index (NDVI), increased grassland land cover, contagion of sagebrush land cover, and proximity to intermittent water. The proportion of big sagebrush (*Artemisia tridentata*) within 0.27 km, proportion of mixed shrubland within 5 km, soil clay content, and proximity to pipelines were inversely related to the occurrence of deer mice. Understanding habitat characteristics for deer mice helps our overall understanding of the ecological processes within sagebrush habitats because deer mice act as predator, prey, competitor, and disease reservoir. Development of the empirical data necessary for spatially explicit habitat modeling of small mammal distributions at large spatial extents requires an extensive trapping effort in order to obtain enough observations to construct models, calculate robust detectability estimates, and overcome issues such as trap shyness and population cycling.

Key words: anthropogenic disturbance, deer mouse, occurrence, *Peromyscus maniculatus*, small mammals.

Habitat fragmentation and loss (Soulé et al. 1992, Bentley et al. 2000, Debinski and Holt 2000) as well as anthropogenic activity (Oxley et al. 1974, Germaine et al. 2001, Yale-Conrey and Mills 2001) can influence dispersal, diversity, and abundance of small mammal populations (Dunsten and Fox 1996, Fitzgibbon 1997, Clark et al. 2001, Yale-Conrey and Mills 2001). Similar impacts have been documented for the small mammal community within the sagebrush (*Artemisia* spp.) steppe ecosystem (Dobkin and Sauder 2004, Hanser and Huntly 2006). In addition to these effects, cultivation (crested wheatgrass, *Agropyron cristatum*) or invasion (cheatgrass, *Bromus tectorum*) of exotic grasses within sagebrush ecosystems further alters the composition and abundance of the small mammal community (Reynolds 1980, Hanser and Huntly 2006). Anthropogenic disturbances can also increase predation rates on small mammals through the addition of perch and nest locations, as well as subsidization of synanthropic predators because of the presence of landfills and other anthropogenic food sources (Engel et al. 1992, Knight and Kawashima 1993, Steenhof et al. 1993, Kristan et al. 2004).

Most habitat studies on small mammals have examined the effects of local habitat factors (Dueser and Shugart 1978, Jorgensen 2004). Few have examined regional or landscape effects on small mammals (Orrock et al. 2000, Martin and McComb 2002), likely owing to the difficulty in es-

timating small mammal occurrence and abundance at large spatial extents and the lack of a systematic monitoring scheme, such as the Breeding Bird Survey (Pardieck and Sauer 2000).

Spatially explicit habitat models that predict and explain factors affecting occurrence and abundance of small mammals would be of substantial value for conservation planning purposes. Our objective was to develop spatially explicit models describing the occurrence and abundance of small mammal species in the Wyoming Basins Ecoregional Assessment (WBEA) area (Ch. 1). We live-trapped small mammals throughout the WBEA area and used Geographic Information System (GIS) derived multi-scale habitat and anthropogenic disturbance metrics to relate species occurrence to landscape factors.

METHODS

Field Surveys

We conducted small mammal trapping surveys between 6 July and 2 September in 2005 and 2006 using a random subset of 7.29-ha survey blocks ($n = 330$; Ch. 4 for a full explanation of overall study design and site selection). We randomly selected survey blocks stratified by road-distance class to achieve a balanced sampling design; however, logistic constraints led to an unbalanced sample.

We used a three-day schedule for small mammal trapping. On day one, we walked to the center point of the survey block and selected a random direction for the first trapping transect (0.25-km long). We placed one Sherman live trap (23 x 8 x 9 cm; H. B. Sherman Traps, Inc., Tallahassee, Florida) every 10 m along the transect, in a shaded location, if possible. Traps were baited with peanut butter and rolled oats and were locked open using wooden popsicle sticks for the pre-bait period (one night). After the first transect was established, we moved 15 m to a random side (left or right) of the first transect and

placed the second transect parallel to the first, using the same trap spacing. If a survey block was centered on a road, the starting point was moved to a randomly selected side of the road at the ecotone between the road and the road verge. We then selected a random direction $<180^\circ$ to avoid crossing roads.

On day two, we traveled to the next trap location and followed the procedures of day one for trap setting. In the evening we returned to the initial survey block location where traps had been pre-baited the previous night. We checked traps to ensure that they were baited, placed cotton in each trap for bedding, and set the traps.

On the morning of day three, we checked each trap line at the initial survey block, removed captured animals, identified individuals to species, and released each animal in place. Once animals were processed we collected traps and moved to the next sampling site and followed day one procedures for setting up the trap plots. In the evening we traveled back to the location where the traps had been pre-baited the previous night and followed protocols of day two. All trapping protocols were approved by the Animal Care and Use Committee (ACUC) of Boise State University (ACUC approval number 692-05-007).

Abundance Categories

We classified abundance levels according to three abundance classes for each species that met the criteria for abundance modeling, a minimum of 100 occurrences and an abundance metric (Ch. 4). Survey blocks with zero detections were categorized as absent. Histograms of survey blocks with counts > 0 were used to categorize survey blocks into two abundance classes (low and high) based on patterns in the frequency distribution.

Model Selection

Variables included in the model selection process included the standard candidate predictor set (Table 4.2) with the exclusion

of mountain sagebrush (*A. tridentata* ssp. *vaseyana*), mean annual maximum temperature, precipitation, and three soil variables (pH, salinity, and available water capacity). We calculated descriptive statistics for all predictor variables within presence/absence or abundance classes for each species. We excluded predictor variables with <20 survey blocks within each abundance class with values > 0 and examined correlation of predictor variables prior to analysis (Ch. 4).

We followed a hierarchical multi-stage modeling approach (Ch. 4) assessing all model subsets using logistic, generalized ordered logistic, or count-based regression. We first examined scatter plots and histograms of sagebrush, NDVI, and abiotic variables to look for non-linearities and interactions. If visual inspection indicated a potential non-linearity or interaction, we included these terms in subsequent modeling steps. We used Akaike's Information Criterion, corrected for small sample sizes (AIC_c), for model selection (Burnham and Anderson 2002). We first evaluated each sagebrush and NDVI variable and identified circular moving window radius (extent) and combination of sagebrush and NDVI variables that had the strongest relationship with small mammal occurrence. We used these selected sagebrush/NDVI variables as a base model and tested the relationship between small mammal occurrence and vegetation, abiotic, and disturbance variables to identify the best spatial extent for each additional variable assessed using AIC_c values. We then allowed the best spatial extent for each variable to compete with all possible combinations of other variables within the same category to identify the AIC_c -selected best model. We limited the number of variables in all competing models to 10% of the sample size in the lowest frequency class due to sample size limitations in generalized ordered logistic and logistic regression models (Hosmer and Lemeshow 2000). After identifying the AIC_c -selected best model within vegetation, abiotic, and disturbance categories, we allowed the vari-

ables within these top models to compete both within and across submodels, to develop the best overall composite model, again retaining the sagebrush/NDVI base in all candidate models. In order to incorporate model uncertainty, we created a final composite model using the weighted average of coefficients from models with a cumulative AIC_c weight of just ≥ 0.9 (Burnham and Anderson 2002). Coefficients were set to zero when a model did not contain a particular variable. Accuracy of logistic regression models were evaluated with receiver operating characteristic (ROC) by 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). All statistical analyses were conducted using STATA 10.1 (Stata Corporation, College Station, Texas, USA).

Spatial Application and Dose Response

We predicted species occurrence in a GIS at a 90-m cell size using the final model coefficients in ArcGIS raster calculator (ESRI 2006). Final model predictions were binned into 10% probability classes for summary and display purposes. Masks of non-sagebrush habitats (areas <3% sagebrush habitat in a 5-km moving window) and those areas outside the known range of each species (Patterson et al. 2003) were used to exclude areas where predictions were either not possible for the species or where extrapolations occurred with high uncertainty. Probability of occurrence maps were subsequently converted to binary presence/absence maps based on the sensitivity-specificity equality threshold to maximize prediction success for each model (Liu et al. 2005). Where applicable, probability of occurrence output from generalized ordered logistic regression models were combined into a composite three

class abundance surface, including absent, low, and high abundance. The bin breakpoint separating absent from low/high abundance habitat was based on the sensitivity-specificity equality threshold to maximize prediction success for each model in the ordered logistic process. Within low/high abundance habitat, the threshold was set where the predicted probability of being high abundance habitat exceeded the probability of being low abundance habitat. These maps allowed us to assess the proportion of the WBEA area containing habitat likely to support individuals (presence/absence) and, where data permitted, to separate occurrence into areas capable of supporting low versus high abundances of a species.

Following development of species models, we plotted predicted probability of occurrence relative to changes in sagebrush metrics to assess critical levels of sagebrush required for a species to be present and to characterize response to losses or fragmentation of sagebrush habitat. We calculated these values using the Dose Response Calculator for ArcGIS (Hanser et al. 2011). We used the optimal cut-off threshold to identify the sagebrush threshold value above which the species was likely to occur.

RESULTS

Field Surveys

We surveyed small mammals at 186 of 330 survey blocks (77 in 2005 and 109 in 2006), of which 59 (25 in 2005, 34 in 2006) were on-road survey blocks, 70 (29 in 2005 and 41 in 2006) were near-road (0–750 m) survey blocks, and 57 (23 in 2005 and 34 in 2006) were far-road (>750 m) survey blocks.

We captured 1,533 individuals over 9,300 total trap-nights and identified 15 species, including bushy-tailed woodrat (*Neotoma cinerea*), deer mouse (*Peromyscus maniculatus*), desert cottontail (*Sylvilagus audubonii*), golden-mantled ground squirrel (*Spermophilus lateralis*), Great Basin

pocket mouse (*Perognathus parvus*), least chipmunk (*Tamias minimus*), montane vole (*Microtus montanus*), northern grasshopper mouse (*Onychomys leucogaster*), olive-backed pocket mouse (*Perognathus fasciatus*), Ord's kangaroo rat (*Dipodomys ordii*), sagebrush vole (*Lemmiscus curtatus*), thirteen-lined ground squirrel (*Spermophilus tridecemlineatus*), Uinta ground squirrel (*Spermophilus armatus*), western harvest mouse (*Reithrodontomys megalotis*), and Wyoming ground squirrel (*Spermophilus elegans*) (Table 9.1). For 58 (31.2%) survey blocks, no small mammals were captured. The most common species was the deer mouse, occurring on 124 (66.6%) survey blocks and comprising 83% of all captures (Fig. 9.1). Average capture rate of deer mice across all survey blocks was 13.7 individuals per 100 trap nights. The second most common species captured was the least chipmunk, which occurred at 39 (21.0%) survey blocks, with 87 total captures (0.9 individuals per 100 trap nights). Both Ord's kangaroo rat and northern grasshopper mouse occurred on >20 survey blocks. The other 11 species were captured infrequently (30% captured only once). Only four sagebrush voles were captured.

Abundance Categories and Detection

The deer mouse was the only species for which we had a sufficient sample size (>50 occurrence survey blocks) to develop a species occurrence model (but see Ch. 7 for the least chipmunk). No apparent breaks were found in histograms of deer mouse abundance (Fig. 9.2). We therefore used a logistic regression modeling approach to model presence/absence. Count-based regression models were also avoided since we lacked data necessary to determine survey block-level capture probabilities.

Model Selection

We excluded four variables from the total pool of *a priori* predictor variables because they contained values > 0 on <20

TABLE 9.1. Summary of small mammal trapping during 6 July through 2 September of 2005 and 2006 including total individuals captured (number of occurrence survey blocks) by survey block type in the Wyoming Basins Ecoregional Assessment area.

Common name	Scientific name	On road	Near road	Far road	Total
Bushy-tailed woodrat	<i>Neotoma cinerea</i>	3 (2)	4 (3)	1 (1)	8 (6)
Deer mouse	<i>Peromyscus maniculatus</i>	391 (38)	490 (51)	393 (35)	1,274 (124)
Desert cottontail	<i>Sylvilagus audubonii</i>	0 (0)	1 (1)	0 (0)	1 (1)
Golden-mantled ground squirrel	<i>Spermophilus lateralis</i>	0 (0)	1 (1)	2 (1)	3 (2)
Great Basin pocket mouse	<i>Perognathus parvus</i>	0 (0)	1 (1)	0 (0)	1 (1)
Least chipmunk	<i>Tamias minimus</i>	27 (11)	29 (16)	31 (12)	87 (39)
Montane vole	<i>Microtus montanus</i>	0 (0)	3 (3)	0 (0)	3 (3)
Northern grasshopper mouse	<i>Onychomys leucogaster</i>	13 (9)	12 (7)	8 (8)	33 (24)
Olive-backed pocket mouse	<i>Perognathus fasciatus</i>	2 (1)	4 (4)	5 (5)	11 (10)
Ord's kangaroo rat	<i>Dipodomys ordii</i>	36 (9)	24 (7)	21 (4)	81 (20)
Sagebrush vole	<i>Lemmiscus curtatus</i>	0 (0)	2 (2)	2 (1)	4 (3)
Thirteen-lined ground squirrel	<i>Spermophilus tridecemlineatus</i>	4 (3)	9 (4)	8 (3)	21 (10)
Uinta ground squirrel	<i>Spermophilus armatus</i>	0 (0)	1 (1)	0 (0)	1 (1)
Western harvest mouse	<i>Reithrodontomys megalotis</i>	2 (1)	0 (0)	2 (1)	4 (2)
Wyoming ground squirrel	<i>Spermophilus elegans</i>	0 (0)	0 (0)	1 (1)	1 (1)

survey blocks. These variables were proportion of coniferous forest (0.27- and 0.54-km radii), mixed shrub (0.27 km), and riparian (0.27 km). Mean sagebrush patch size (1 km), slope, soil bulk density, and soil silt content were removed because of collinearity with other variables that were more biologically relevant.

The AIC_c-selected best sagebrush/NDVI model consisted of all big sagebrush (*A. tridentata*) within 0.27 km (ABIGSAGE₂₇₀) and a non-linear quadratic form of NDVI within 0.27 km (NDVI₂₇₀ * NDVI₂₇₀²) (Table 9.2). The other 19 models with $\Delta AIC_c \leq 2$ contained local measures of sagebrush in combination with NDVI in quadratic form, as well as sagebrush/NDVI interactions. Within a 0.27-km radius, there was 3.5% more all

big sagebrush habitat at absent survey blocks (80.7%, SE = 2.3) than at presence survey blocks (77.14%, SE = 2.1) (Appendix 9.1).

After assessing individual multi-scale covariates (Table 9.3) and developing sub-models, the AIC_c-selected vegetation sub-model for deer mice included grassland within 18 km (GRASSLAND_{18km}), mixed shrubland within 5 km (MIX_{5km}), and all sagebrush contagion within 3 km (CONTAG_{3km}), in addition to the sagebrush/NDVI base model (Table 9.4). Soil clay content (CLAY) in quadratic form and 1-km distance decay from intermittent water (iH2O_{d1km}) were selected as important abiotic predictors of deer mouse occurrence (Table 9.4). Only one disturbance factor, 1-km distance decay from pipelines

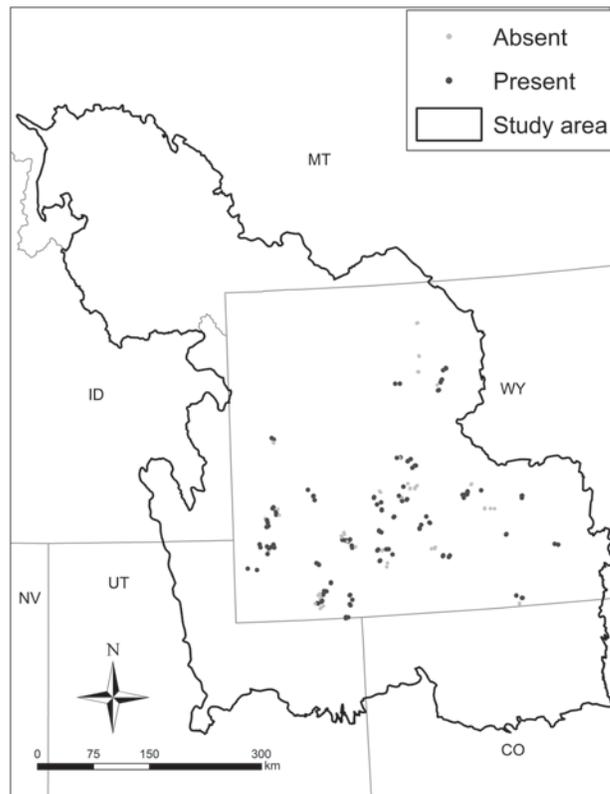


FIG. 9.1. Distribution of survey blocks surveyed for deer mice within the Wyoming Basins Ecoregional Assessment area. Survey blocks were designated as absent (black, zero detections) or present (gray) for model development.

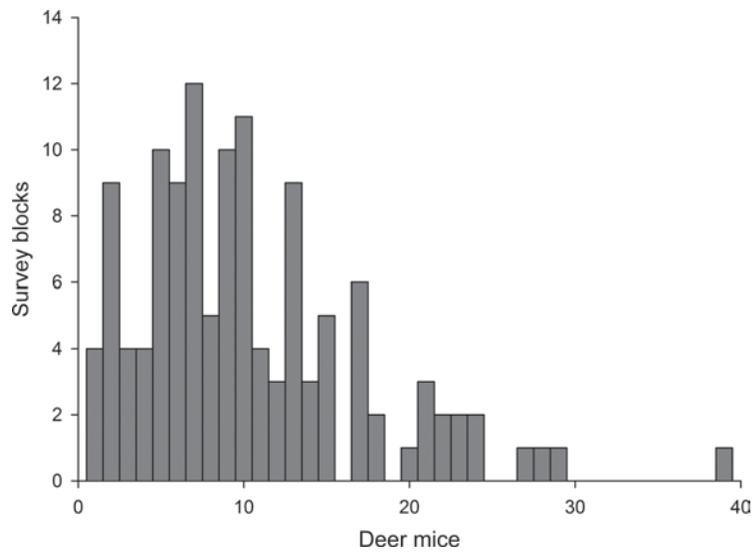


FIG. 9.2. A histogram of 124 survey blocks surveyed for deer mice in the Wyoming Basins Ecoregional Assessment area where number of individuals was > 0. Abundance at each survey block is represented by total number of individuals captured.

TABLE 9.2. Results of AIC_c-based model selection for deer mouse occurrence in the Wyoming Basins Ecoregional Assessment area in relation to multi-scale sagebrush and NDVI variables; 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 (Δ AIC_c), and Akaike weight (w_i). Only models with Δ AIC_c \leq 2 are shown.

Number	Model ^a	LL	K	AIC _c	Δ AIC _c	w_i
1	ABIGSAGE ₂₇₀ + NDVI ₂₇₀ + NDVI ₂₇₀ ²	-111.56	4	231.34	0.00	0.04
2	ALLSAGE ₂₇₀ + NDVI ₂₇₀ + NDVI ₂₇₀ ²	-111.59	4	231.39	0.05	0.04
3	ABIGSAGE ₂₇₀ + NDVI ₅₄₀ + NDVI ₅₄₀ ²	-111.62	4	231.46	0.11	0.04
4	ALLSAGE ₂₇₀ + NDVI ₅₄₀ + NDVI ₅₄₀ ²	-111.62	4	231.47	0.13	0.04
5	ABIGSAGE ₂₇₀ + NDVI + NDVI ²	-111.86	4	231.94	0.60	0.03
6	ALLSAGE ₂₇₀ + NDVI + NDVI ²	-111.91	4	232.03	0.69	0.03
7	BIGSAGE ₂₇₀ + NDVI ₂₇₀ + BIGSAGE ₂₇₀ _NDVI ₂₇₀	-112.16	4	232.54	1.19	0.02
8	ALLSAGE ₅₄₀ + NDVI ₂₇₀ + NDVI ₂₇₀ ²	-112.19	4	232.60	1.25	0.02
9	ASAGE ₅₄₀ + NDVI ₅₄₀ + NDVI ₅₄₀ ²	-112.20	4	232.63	1.29	0.02
10	ABIGSAGE ₅₄₀ + NDVI ₂₇₀ + NDVI ₂₇₀ ²	-112.24	4	232.69	1.35	0.02
11	ALLSAGE ₂₇₀ + NDVI _{1km} + NDVI _{1km} ²	-112.24	4	232.71	1.37	0.02
12	ABIGSAGE ₂₇₀ + NDVI _{1km} + NDVI _{1km} ²	-112.26	4	232.73	1.39	0.02
13	ABIGSAGE ₅₄₀ + NDVI ₅₄₀ + NDVI ₅₄₀ ²	-112.26	4	232.74	1.40	0.02
14	BIGSAGE ₂₇₀ + NDVI + BIGSAGE ₂₇₀ _NDVI	-112.31	4	232.84	1.50	0.02
15	BIGSAGE ₂₇₀ + NDVI ₅₄₀ + BIGSAGE ₂₇₀ _NDVI ₅₄₀	-112.32	4	232.87	1.52	0.02
16	BIGSAGE ₂₇₀ + NDVI ₂₇₀ + NDVI ₂₇₀ ²	-112.37	4	232.95	1.61	0.02
17	ALLSAGE ₅₄₀ + NDVI + NDVI ²	-112.47	4	233.16	1.81	0.02
18	BIGSAGE ₂₇₀ + NDVI + NDVI ²	-112.47	4	233.16	1.82	0.02
19	ABIGSAGE ₅₄₀ + NDVI + NDVI ²	-112.50	4	233.23	1.88	0.02

^a Variable definitions provided in Table 4.2

(PIPE_{1km}), was included in the AIC_c-selected disturbance submodel (Table 9.4).

The AIC_c-selected top deer mouse model was a combination of vegetation, abiotic, and disturbance factors. Deer mice were positively associated with moderate vegetation productivity, increased proportion of grassland land cover, and increased contagion of all sagebrush, but negatively associated with small-spatial extent of all big sagebrush and proximity to pipelines (Table 9.5). However, weight of evidence for the top model was low ($w_i = 0.14$), indicating there were other suitable candidate models. Variables in the other 15 candidate models with a cumulative Akaike weight of just ≥ 0.9 showed that, in addition to factors in the top model, deer mouse occur-

rence was positively associated with proximity to intermittent water but negatively associated with mixed shrubland and increased soil clay content (Table 9.5). The final composite probability of occurrence model is below.

(9.1)

$$\text{Prob} = 1 / (1 + (\exp(-(-3.96 - 2.20 * \text{ABIGSAGE}_{270} + 32.75 * \text{NDVI}_{270} - 41.77 * \text{NDVI}_{270}^2 + 5.87 * \text{GRASS}_{18\text{km}} + 0.02 * \text{CONTAG}_{3\text{km}} - 0.60 * \text{PIPE}_{1\text{km}} - 17.48 * \text{MIX}_{5\text{km}} + 0.87 * \text{iH2O}_{1\text{km}} - 0.06 * \text{CLAY} + 0.0026 * \text{CLAY}^2))))))$$

The composite model of deer mouse occurrence had good accuracy (ROC AUC = 0.79) when predicting deer mouse presence.

TABLE 9.3. Evaluation statistics from AIC_c -based univariate model selection for deer mouse occurrence 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]). All logistic regression models included all big sagebrush (0.27-km radius) and the quadratic form of NDVI (0.27-km radius) as the base model for all variables tested. We used AIC_c to identify the scale at which deer mice respond to individual variables.

Category	Variable ^a	LL	K	AIC_c	ΔAIC_c	w_i
Vegetation	CFRST _{5km}	-110.83	5	232.00	0.00	0.33
	CFRST _{18km}	-110.99	5	232.31	0.32	0.28
	CFRST _{1km}	-111.16	5	232.66	0.67	0.23
	CFRST _{3km}	-111.55	5	233.43	1.44	0.16
	GRASS _{18km}	-109.85	5	230.02	0.00	0.52
	GRASS _{3km}	-111.48	5	233.29	3.26	0.10
	GRASS _{5km}	-111.52	5	233.37	3.35	0.10
	GRASS _{1km}	-111.54	5	233.40	3.38	0.10
	GRASS ₂₇₀	-111.55	5	233.44	3.41	0.09
	GRASS ₅₄₀	-111.56	5	233.45	3.43	0.09
	MIX _{5km}	-108.24	5	226.81	0.00	0.63
	MIX _{3km}	-109.71	5	229.74	2.93	0.14
	MIX _{1km}	-110.13	5	230.60	3.79	0.09
	MIX _{18km}	-110.25	5	230.83	4.02	0.08
	MIX ₅₄₀	-110.78	5	231.90	5.09	0.05
	RIP _{3km}	-109.97	5	230.27	0.00	0.36
	RIP _{1km}	-110.32	5	230.97	0.70	0.25
	RIP _{5km}	-110.44	5	231.21	0.94	0.22
	RIP _{18km}	-111.44	5	233.21	2.94	0.08
	RIP ₅₄₀	-111.47	5	233.27	3.00	0.08
	CONTAG _{3km}	-108.85	5	228.04	0.00	0.42
	EDGE _{3km}	-109.63	5	229.59	1.56	0.19
	CONTAG _{5km}	-109.90	5	230.13	2.10	0.15
	PATCH _{5km}	-109.97	5	230.27	2.24	0.14
	EDGE _{5km}	-111.32	5	232.97	4.93	0.04
	EDGE _{1km}	-111.53	5	233.39	5.35	0.03
	PATCH _{3km}	-111.53	5	233.40	5.36	0.03
	SALT _{18km}	-110.40	5	231.14	0.00	0.29
	SALT _{5km}	-110.68	5	231.41	0.27	0.25
	SALT _{3km}	-110.91	5	232.16	1.02	0.17
	SALT ₂₇₀	-111.37	5	233.07	1.93	0.11
	SALT ₅₄₀	-111.50	5	233.34	2.20	0.09
SALT _{1km}	-111.55	5	233.43	2.29	0.09	

TABLE 9.3. Continued

Category	Variable ^a	LL	K	AIC _c	ΔAIC _c	w _i
Abiotic	CLAY ^b	-105.92	6	224.23	0.00	0.79
	CLAY	-108.25	5	226.89	2.66	0.21
	CTI ^b	-109.44	6	231.29	0.00	0.72
	CTI	-111.38	5	233.16	1.87	0.28
	ELEV ^b	-109.20	6	230.81	0.00	0.63
	ELEV	-110.75	5	231.90	1.09	0.37
	iH2Od _{1km} ^c	-108.14	5	226.60	0.00	0.84
	iH2Od ₅₀₀ ^c	-110.05	5	230.43	3.83	0.12
	iH2Od ₂₅₀ ^c	-111.24	5	232.82	6.21	0.04
	pH2Od _{1km} ^c	-111.39	5	233.12	0.00	0.36
	pH2Od ₅₀₀ ^c	-111.50	5	233.33	0.21	0.32
	pH2Od ₂₅₀ ^c	-111.51	5	233.36	0.24	0.32
	SOIL _{cm}	-110.99	5	232.38	0.00	1.00
	SAND	-111.40	5	233.19	0.00	0.70
	SAND ^b	-111.23	6	234.86	1.67	0.30
	SOLAR	-111.51	5	233.42	0.00	0.52
	SOLAR ^b	-110.57	6	233.54	0.12	0.48
	Tmin	-109.97	5	230.34	0.00	0.73
	Tmin ^b	-109.95	6	232.30	1.96	0.27
	TRI _{3km}	-111.31	5	233.00	0.00	0.17
	TRI ₂₇₀	-111.46	5	233.31	0.31	0.15
	TRI	-111.47	5	233.32	0.32	0.15
	TRI _{1km}	-111.51	5	233.41	0.41	0.14
TRI _{18km}	-111.55	5	233.48	0.48	0.13	
TRI ₃₄₀	-111.56	5	233.51	0.51	0.13	
TRI _{5km}	-111.56	5	233.51	0.51	0.13	
Disturbance	AG _{1km} ^c	-111.91	5	234.16	0.00	0.38
	AG ₂₅₀ ^c	-112.11	5	234.55	0.40	0.31
	AG ₅₀₀ ^c	-112.14	5	234.62	0.47	0.30
	MjRD _{1km} ^c	-110.85	5	232.04	0.00	0.53
	MjRD ₅₀₀ ^c	-111.48	5	233.29	1.25	0.28
	MjRD ₂₅₀ ^c	-111.86	5	234.05	2.01	0.19
	PIPE _{1km} ^c	-109.65	5	229.63	0.00	0.41
	PIPE ₅₀₀ ^c	-109.76	5	229.84	0.21	0.37
	PIPE ₂₅₀ ^c	-110.31	5	230.96	1.33	0.21
	POWER ₂₅₀ ^c	-110.75	5	231.84	0.00	0.45

TABLE 9.3. Continued

Category	Variable ^a	LL	K	AIC _c	ΔAIC _c	w _i
	POWER ₅₀₀ ^c	-111.20	5	232.74	0.90	0.29
	POWER _{1km} ^c	-111.29	5	232.91	1.07	0.26
	RDdens _{18km}	-111.53	5	233.38	0.00	0.17
	RDdens ₅₄₀	-111.78	5	233.89	0.51	0.13
	RDdens _{5km}	-111.94	5	234.22	0.84	0.11
	2RD ₅₀₀ ^c	-111.95	5	234.23	0.85	0.11
	2RD _{1km} ^c	-111.97	5	234.27	0.88	0.11
	2RD ₂₅₀ ^c	-111.98	5	234.30	0.92	0.11
	RDdens _{3km}	-112.08	5	234.50	1.12	0.10
	RDdens _{1km}	-112.15	5	234.64	1.26	0.09
	RDdens ₂₇₀	-112.15	5	234.64	1.26	0.09
	WELL ₅₀₀ ^c	-112.15	5	234.35	0.00	0.37
	WELL ₂₅₀ ^c	-112.15	5	234.64	0.29	0.32
	WELL _{1km} ^c	-112.15	5	234.64	0.30	0.32

^a Variable definitions provided in Table 4.2

^b Quadratic function (variable + variable²)

^c Distance decay function ($e^{(\text{Euclidean distance from feature}/\text{distance parameter})}$)

Accuracy of the model-averaged predictor was an improvement over the AIC_c-selected top model (ROC AUC = 0.74). Our model of deer mouse occurrence had an optimal sensitivity-specificity equality threshold of 0.68 when determining presence/absence that resulted in 71.0% of survey block locations being correctly classified.

Spatial Application, Dose Response, and Model Evaluation

Deer mouse occurrence was predicted throughout the WBEA area (Fig. 9.3). Based on our optimal cutoff point and a binary presence/absence classification, 180,321 km² (52.5%) of suitable deer mouse habitat was predicted within the Wyoming Basins (Fig. 9.4). Deer mice were more likely to occur in areas with >41% (entire range at +1 SD) all big sagebrush habitat within a 0.27 km (Fig. 9.5). Independent data were not available for evaluating the output of this model.

DISCUSSION

The small mammal community in the WBEA area was dominated by deer mice with predicted suitable habitat occurring throughout the region. Deer mice are habitat generalists and commonly are the most abundant small mammal species (Reynolds 1980, Morris 1992, Hanser and Huntly 2006, Borchgrevink et al. 2010). Despite this generalist nature, our model identifies several habitat, abiotic, and anthropogenic disturbance characteristics that influence the distribution of deer mice.

Importance of the quantity of sagebrush habitat to distribution of deer mice in the region was unclear. Although the regression coefficient was negative, our dose response analysis indicated that deer mice were more likely to occur in habitats with more than 41% all big sagebrush within 0.27 km, once all other factors were considered. Previous research has found both indifference and attraction to shrublands;

deer mouse abundance did not change in response to sagebrush removal (Parmenter and MacMahon 1983), but deer mice have an affinity for shrubland habitat showing increased abundance in sagebrush and other shrubland types (Feldhamer 1979, Reynolds 1980), preferentially foraging under shrubs (Kotler 1984).

Deer mice were positively associated with grasslands and sagebrush contagion. Although these results seem contradictory, these patterns also can be complementary. As grassland land cover increases, the distribution of sagebrush/non-sagebrush land cover patches may have a more clumped distribution across the landscape. The patches of sagebrush may act as refugia during times of disturbance in the surrounding landscape (Hanser and Huntly 2006). Deer mice were also positively associated with moderate habitat productivity (NDVI) and intermittent water sources. In the Great Basin, deer mice are three times more abundant in lowland meadows than in drier, less productive upland habitats (McAdoo et al. 1986), and in New Mexico deer mice are more abundant in arroyos (Jorgensen et al. 1998). Lowland mixed shrubland habitats, dominated by rabbitbrush (*Chrysothamnus* spp.) and other mixed shrubs with low cover of forbs and grasses, are generally less productive sites and therefore, owing to reduced food resources, may not support high densities of deer mice. We found a negative, non-linear relationship between deer mouse occurrence and percent clay content in soils. Deer mice construct deep, long, and complex burrows in soils with increasing clay content (Laundré and Reynolds 1993). This increased effort for burrow construction may be a response to lack of sufficient above ground cover or other environmental characteristics.

The negative association of deer mice with proximity to pipelines may be due to the altered plant community along pipeline rights-of-way. Alterations can be quite substantial locally, given that pipe-

TABLE 9.4. Results of AIC_c-based submodel selection for deer mouse occurrence in the Wyoming Basins Ecoregional Assessment Area. 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) are shown for each model with ΔAIC_c ≤ 2.

Category	Number	Model ^a	LL	K	AIC _c	ΔAIC _c	w _i
Vegetation	1	ABIGSAGE ₂₇₀ + NDVI ₁₂₇₀ + NDVI ₁₂₇₀ ² + GRASS _{18km} + MIX _{3km} + CONTAG _{3km}	-102.09	7	218.81	0.00	0.35
	2	ABIGSAGE ₂₇₀ + NDVI ₁₂₇₀ + NDVI ₁₂₇₀ ² + GRASS _{18km} + RIP _{3km} + CONTAG _{3km}	-102.31	7	219.24	0.43	0.28
Abiotic	1	ABIGSAGE ₂₇₀ + NDVI ₁₂₇₀ + NDVI ₁₂₇₀ ² + CLAY + CLAY ² + iHZOd _{1km}	-102.54	7	219.72	0.00	0.47
Disturbance	1	ABIGSAGE ₂₇₀ + NDVI ₁₂₇₀ + NDVI ₁₂₇₀ ² + PIPE _{1km}	-108.71	5	227.75	0.00	0.12
	2	ABIGSAGE ₂₇₀ + NDVI ₁₂₇₀ + NDVI ₁₂₇₀ ² + PIPE _{1km} + RDdens _{18km}	-107.71	6	227.89	0.15	0.11
	3	ABIGSAGE ₂₇₀ + NDVI ₁₂₇₀ + NDVI ₁₂₇₀ ² + Mjrd _{1km} + PIPE _{1km} + RDdens _{18km}	-107.38	7	229.38	1.63	0.05
	4	ABIGSAGE ₂₇₀ + NDVI ₁₂₇₀ + NDVI ₁₂₇₀ ² + PIPE _{1km} + POWER ₂₅₀	-108.50	6	229.47	1.72	0.05
	5	ABIGSAGE ₂₇₀ + NDVI ₁₂₇₀ + NDVI ₁₂₇₀ ² + PIPE _{1km} + POWER ₂₅₀ + RDdens _{18km}	-107.43	7	229.50	1.75	0.05
	6	ABIGSAGE ₂₇₀ + NDVI ₁₂₇₀ + NDVI ₁₂₇₀ ² + Mjrd _{1km} + PIPE _{1km}	-108.55	6	229.58	1.83	0.05
	7	ABIGSAGE ₂₇₀ + NDVI ₁₂₇₀ + NDVI ₁₂₇₀ ² + PIPE _{1km} + RDdens _{18km} + WELL ₅₀₀	-107.53	7	229.69	1.94	0.04

^a Variable definitions provided in Table 4.2

TABLE 9.5. Results of AIC_c-based model selection for the combined deer mouse 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 [Δ AIC_c], and cumulative Akaike weight [$\sum w_i$]). Models shown with cumulative Akaike weight (w_i) of just ≥ 0.9 .

Number	Intercept	ABIGSAGE ₂₇₀	NDVI ₂₇₀	NDVI ₂₇₀ ²	GRASS _{18km}	CONTAG _{3km}	PIPE _{1km}
1	-5.26 (2.00)	-2.50 (1.10)	38.75 (11.03)	-49.69 (13.92)	15.46 (5.65)	0.03 (0.01)	-1.43 (0.58)
2	-5.43 (2.05)	-2.55 (1.10)	39.99 (11.32)	-51.13 (14.29)	14.54 (5.70)	0.03 (0.01)	
3	-4.11 (1.86)	-1.75 (0.89)	33.51 (10.49)	-43.17 (13.36)			-1.21 (0.56)
4	-4.12 (1.85)	-2.49 (1.05)	32.14 (10.57)	-40.47 (13.47)		0.02 (0.01)	
5	0.05 (1.94)	-2.78 (1.06)	19.37 (10.99)	-25.21 (13.72)		0.02 (0.01)	
6	-2.40 (2.06)	-1.62 (0.84)	23.15 (10.89)	-29.07 (13.60)			
7	-4.01 (1.85)	-2.57 (1.02)	31.68 (10.40)	-39.81 (13.21)		0.02 (0.01)	-1.41 (0.56)
8	-6.68 (2.08)	-2.31 (1.06)	39.89 (11.17)	-49.06 (14.09)	13.27 (5.74)	0.03 (0.01)	
9	-0.43 (1.93)	-1.63 (0.89)	20.57 (10.92)	-28.09 (13.66)			
10	-5.88 (2.03)	-1.32 (0.89)	38.37 (10.84)	-48.66 (13.74)	9.42 (5.24)		-1.53 (0.56)
11	-0.19 (1.93)	-1.80 (0.88)	22.42 (10.89)	-30.07 (13.61)			-1.17 (0.54)
12	-5.93 (2.07)	-1.30 (0.90)	39.07 (11.20)	-49.33 (14.20)	7.63 (5.24)		
13	-4.56 (1.83)	-1.66 (0.88)	34.33 (10.51)	-43.38 (13.39)			
14	-2.21 (1.70)	-2.83 (1.09)	29.77 (10.34)	-39.48 (13.21)		0.02 (0.01)	-1.09 (0.56)
15	-4.35 (1.83)	-1.79 (0.87)	33.53 (10.32)	-42.39 (13.11)			-1.38 (0.54)
16	-5.87 (2.02)	-2.61 (1.08)	40.60 (11.19)	-50.89 (14.12)	14.99 (5.73)	0.03 (0.01)	

^a Variable definitions provided in Table 4.2

line construction activities result in ~25-m wide corridors with decreased shrub cover and increased grass cover that persists for years following construction (Booth and Cox 2009). Within the Wyoming Basins, the extensive distribution of pipelines (Knick et al. 2011) may have a broad negative influence on deer mice.

Deer mice serve many roles and are an important species shaping sagebrush ecosystem function (deGroot et al. 2002); understanding the factors influencing this species may increase our ability to manage conservation species of concern. Deer mice are frequent prey for reptilian predators such as gopher snakes (*Pituophis melanoleucus*) and western rattlesnakes (*Crotalus viridis*; Diller and Johnson 1988), avian predators such as burrowing owls (*Speotyto cunicularia*; Plumpton and Lutz 1993) and great horned owls (*Bubo virgin-*

ianus; Zimmerman et al. 1996), and mammalian predators, including coyotes (*Canis latrans*; Johnson and Hansen 1979). Deer mice predate avian nests in multiple ecosystems (Bayne and Hobson 1997, Rogers et al. 1997, Pietz and Granfors 2000). Deer mice consume large numbers of seeds (Everett et al. 1978, Kotler 1984), limit beetle abundance (Parmenter and MacMahon 1988) and may, in some cases, competitively exclude other small mammal species (Kotler 1984). Deer mice also serve as a reservoir for zoonotic diseases such as Hantavirus (Childs et al. 1994). Although we were unable to develop models of deer mouse abundance, our data suggest abundance varies widely across habitats. The large distribution and variable abundance of the species suggests that deer mice may play a significant role in overall ecosystem processes in the Wyoming Basins.

TABLE 9.5. Extended

MIX _{5km}	iH2Od _{1km}	CLAY	CLAY ²	LL	K	AIC _c	ΔAIC _c	Σw _i
				-101.90	7	218.43	0.00	0.14
-40.14 (17.65)				-102.09	7	218.81	0.38	0.25
-38.76 (18.40)	1.79 (0.66)			-102.35	7	219.32	0.89	0.34
-41.39 (16.84)	1.64 (0.66)			-102.48	7	219.58	1.15	0.42
		-0.28 (0.17)	0.01 (0.01)	-102.51	7	219.66	1.22	0.49
	1.67 (0.66)	-0.19 (0.16)	0.01 (0.01)	-102.54	7	219.72	1.28	0.56
	1.72 (0.66)			-102.56	7	219.74	1.31	0.63
	1.37 (0.66)			-102.81	7	220.26	1.82	0.69
-40.94 (18.48)		-0.21 (0.16)	0.01 (0.01)	-103.04	7	220.72	2.28	0.73
	1.67 (0.65)			-103.15	7	220.92	2.49	0.77
		-0.27 (0.17)	0.01 (0.01)	-103.54	7	221.70	3.27	0.80
-43.16 (18.04)	1.57 (0.65)			-103.58	7	221.79	3.35	0.83
-43.08 (17.42)	1.69 (0.65)			-104.70	6	221.86	3.43	0.85
-36.04 (17.73)				-103.77	7	222.17	3.74	0.87
	1.75 (0.65)			-104.87	6	222.21	3.78	0.89
				-105.03	6	222.54	4.10	0.91

These numerous characteristics of deer mice highlight the interconnectedness of species in the sagebrush ecosystem and underscore the importance of increasing our understanding of factors influencing distribution and abundance of common species within the sagebrush ecosystem in addition to those species currently of conservation concern.

CONCLUSIONS

Our study is an illustration of the challenge that must be confronted when trying to develop models of small mammal occurrence across large spatial extents based on live-trapping. Prior to sampling, we estimated that using 350 traps we could sample up to 112 survey blocks (14 survey blocks per 10-day sample bout with four bouts per year for two years) using a one

pre-bait and three trapping night protocol, 168 survey blocks (21 per sample bout) using two trapping nights, and 256 survey blocks (32 per sample bout) using one trapping night. If we were able to sample all potential survey blocks without logistical constraints using a three trapping night protocol, we would have needed to trap a species on >44% of survey blocks (>30% with two trapping nights and >20% with one trapping night) to obtain enough occurrence locations to model a given species. However, in order to build robust models, it was necessary to maximize the total number of survey block samples because of the high potential for species to be absent when sampling across habitat and anthropogenic disturbance gradients.

Our sampling strategy, although optimized to obtain enough samples to construct species models, constrained our

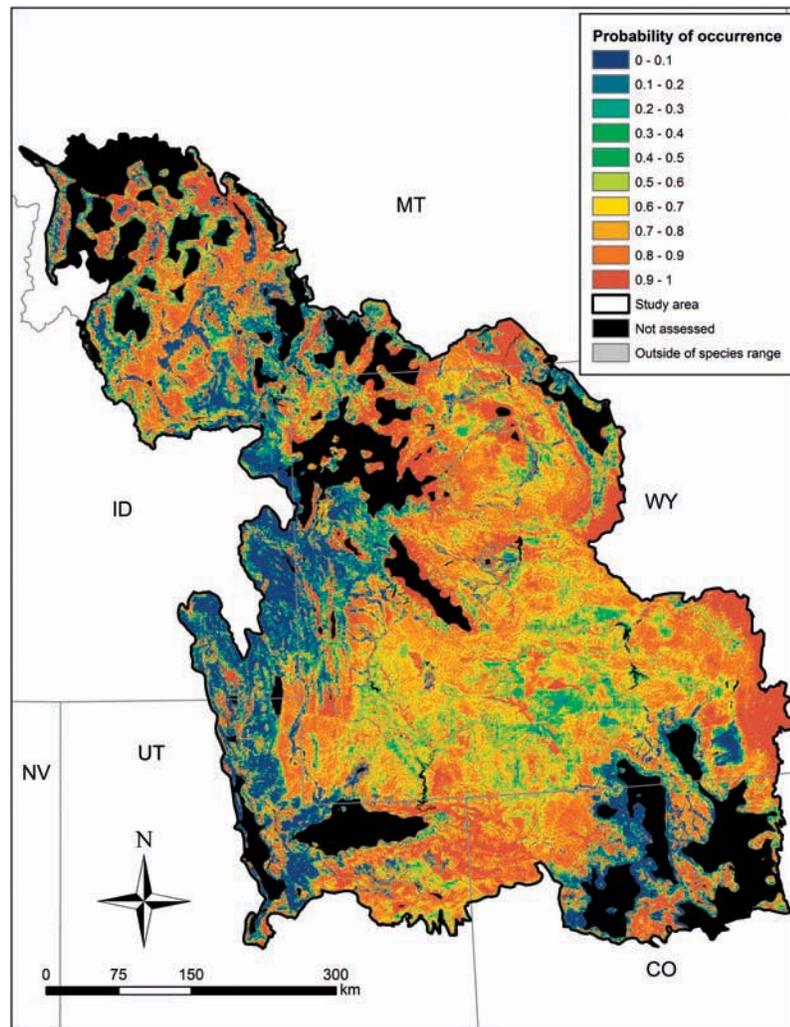


FIG. 9.3. Deer mouse probability of occurrence in the Wyoming Basins Ecoregional Assessment area. Black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water). Deer mice are likely to occur in areas with >0.68 probability.

ability to develop species-specific density or capture probability estimates. The inability to apply formal statistical analysis techniques forced us to compare our raw capture rates with studies in similar habitat types to assess whether we were achieving comparable capture rates to other studies. Our sampling technique was successful at achieving a higher deer mouse capture rate (13.69 individuals per 100 trap nights) than previous studies in Wyoming where

the deer mouse capture rate in sagebrush was 0.55-1.73 individuals per 100 trap nights (Paramenter and MacMahon 1983); in Idaho capture rates range from 3.71 individuals per 100 trap nights on ungrazed sagebrush (Reynolds 1980) to 9.39 on isolated patches of sagebrush in agricultural fields (Hanser and Huntly 2006). Our capture rates for other species, such as least chipmunk (0.93 individuals per 100 trap nights), were similar to previous research

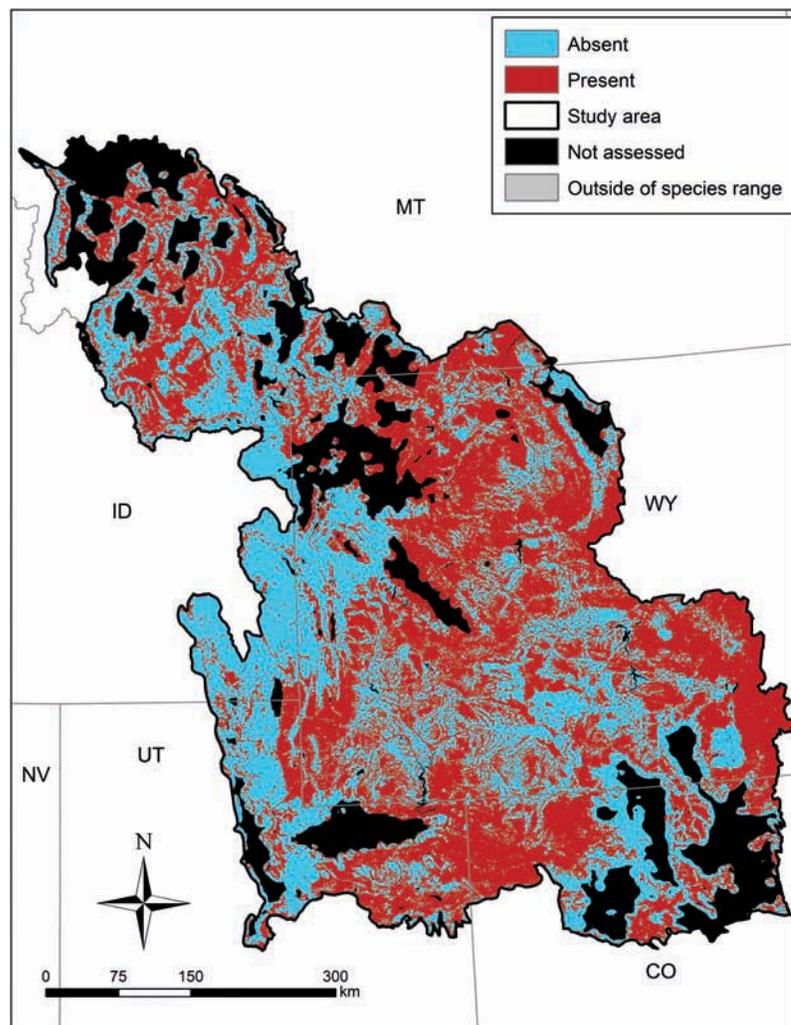


FIG 9.4. Distribution of deer mice in the Wyoming Basins Ecoregional Assessment area based on optimum probability cutoff threshold of 0.68. Black areas are outside the inference of our models (<3% sagebrush within 5 km or within a body of water).

in Wyoming (0.67 individuals per 100 trap nights; Paramenter and MacMahon 1983). Although these comparisons indicate we were successful in trapping a species where it occurred, these comparisons are not a substitute for a formal analysis of detection probability, which would provide a measure of the potential for species to occur on plots where we did not detect it.

Factors that may have influenced our ability to detect individual small mammal

species included trap shyness, density and distribution, and population cycling. Trap shyness is a situation in which certain species or individuals are prone to avoid traps, and avoidance may lead to false negative results from trapping surveys (Otis *et al.* 1978). One way to overcome this constraint would be to provide individuals enough time to become comfortable with the traps and begin to use the provided food resource; this could be achieved

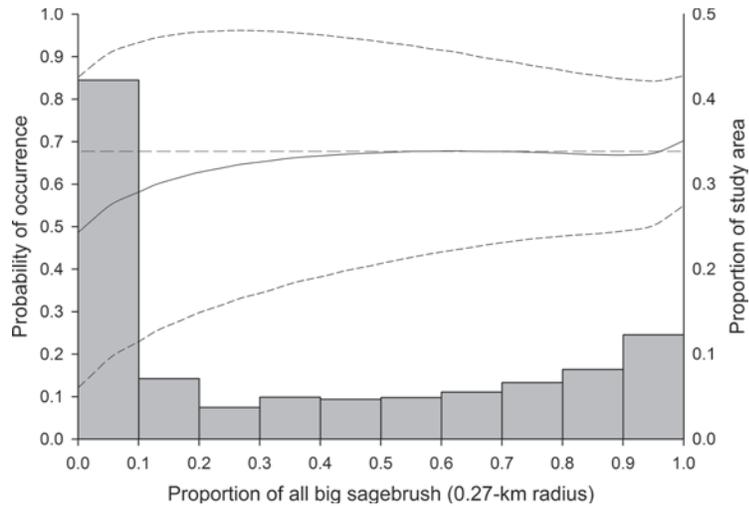


FIG. 9.5. The distribution of deer mouse probability of occurrence within the Wyoming Basins Ecoregional Assessment area in relation to proportion of all big sagebrush (*Artemisia tridentata*) within a 0.27-km radius. Mean probability of occurrence (black line, ± 1 SD [dashed lines]) values were calculated in each one percent increment of all big sagebrush within a 0.27-km radius moving window. Range of predictions relate to the observed range of sagebrush at study site locations. The dashed horizontal line represents the optimal cutoff threshold (0.68), above which occurrence is predicted. Histogram values represent the proportion of the total study area in each 10% segment of all big sagebrush within 0.27 km.

by increasing the length of time a site is trapped. Additional trapping techniques, such as pitfall or snap traps (Gitzen et al. 2001), which have a different mechanism for capture, may increase the likelihood of capture for species shy of Sherman or other live traps. In our case, we made the tradeoff to trap more locations rather than stay at a site, and we were limited to the use of Sherman live traps.

Low population density and clumped distributions influence species detectability. For instance, sagebrush voles have low population densities/capture rates, as well as clumped distributions. Capture rates are usually quite low throughout the range of the sagebrush vole (0.01-5.0 per 100 trap nights); the majority of sagebrush vole studies have capture rates on the low end this range (Dobkin and Sauder 2004). Low capture rates may require a more intense trapping (traps per survey block) to achieve detections of rare or low abundance species. Studies conducted in optimal habitats detected higher sagebrush

vole capture rates (Millican and Keller 1986, O'Farrell 1975, Oldemeyer and Allen-Johnson 1988). Therefore, the habitat tolerance range for sagebrush voles may limit the ability for it and other species with similar characteristics to be sampled using random site selection and low intensity trapping.

Population cycling can also influence detectability and is a well-known characteristic of many mammal populations (Korpimäki et al. 2004), with causes ranging from increased food availability to favorable weather conditions. During low abundance periods of these cycles, species may be more difficult to detect. Also, seasonal activity patterns may lead to annual cycles of detectability for certain species. The timing of our trapping (July-September) coincided with the decreasing seasonal phase of activity for many small mammal species in the sagebrush system (O'Farrell 1974) and therefore may have limited our ability to detect some species.

We have demonstrated the challenge of designing and collecting the empirical data necessary to construct spatially explicit statistical models of small mammal distribution and abundance across large spatial extents. Even with a study design optimized for reducing logistical costs associated with sampling large spatial extents (Ch. 4), we were able to only obtain enough samples to model the most common species (but see Ch. 7 for the least chipmunk). Timing of surveys and number of nights available for trapping are important factors in planning field operations if conducting a large multitaxa effort similar to the WBEA. To adequately sample small mammals at large spatial extents the necessary resources include (1) time to visit a large number of sample locations with multiple nights at each location and (2) a large enough quantity of traps necessary to run multiple crews/survey blocks simultaneously. Future landscape-scale research on small mammal distributions would benefit from additional resources devoted specifically to small mammal sampling.

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APPENDIX 9.1.

Descriptive statistics for explanatory variables used to model deer mouse occurrence. 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>.