

Predictive Map of Canada Lynx Habitat Use in Colorado

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INTRODUCTION

In an effort to restore a viable population of federally threatened Canada lynx (*Lynx canadensis*) to the southern portion of their former range, 218 individuals were reintroduced into Colorado from 1999–2006 by the Colorado Division of Wildlife (CDOW, Devineau et al. 2010). In 2010, CDOW determined that the reintroduction effort met all benchmarks of success, and that a viable, self-sustaining population of Canada lynx had been established (Shenk and Kahn 2010). Attainment of this goal is a conservation success, but it has also created a series of issues for land management agencies to consider as they plan changes to the landscape. These issues require knowledge of the types of landscapes and forest stands important for reproduction, movement, dispersal, and general home range use by lynx.

As a first step toward providing this information, Theobald and Shenk (2011) conducted an analysis to describe the types of areas that were known to be used by re-introduced lynx. Specifically, they used LoCoH (Getz and Wilmsers 2004, Getz et al. 2007) methods to create a population-level utilization distribution (UD, a probability surface of lynx occurrence) for lynx in Colorado. They then summarized landscape attributes within the 90% isopleth (i.e., polygon(s) containing 90% of the probability surface) of this UD. This work provides valuable information regarding the types of areas that were *known* to be used by lynx from 1999 to 2010. By nature of the data collection and research focus, most of this “use” information was derived from core areas in the San Juan Mountains of southwest Colorado and Sawatch Range in the central part of the state.

The purpose of the current project is to extend the work of Theobald and Shenk (2011) by producing a map of *predicted* lynx use on a *statewide* scale. Such an exercise will identify areas within Colorado that should contain high quality lynx habitat, regardless of whether or not it was used by the sample of radio-telemetered individuals tracked during reintroduction research. Both works have strengths and weaknesses, but together they provide tools for prioritizing areas for conservation, development, and resource extraction with respect to potential impacts to lynx.

METHODS

Location Data

Location data were collected from reintroduced lynx using 2 types of telemetry devices. All lynx released into Colorado, and those subsequently captured or re-captured, were fitted with a traditional VHF transmitter. VHF data were collected via telemetry from fixed-wing aircraft at approximately weekly intervals when research was ongoing during winter (approximately December – March) and reproductive seasons (May – June), but less often otherwise. Beginning in April 2000, released and captured lynx were outfitted with dual VHF-Argos satellite collars. In addition to sampling via fixed-wing aircraft, the satellite portion of these collars transmitted repeatedly for 12 hours, 1 day per week, year-round. Nearly 40,000 combined locations were collected between VHF and satellite sampling. These data were originally intended for assessing the success of the reintroduction and served CDOW well in estimating survival, productivity, and dispersal. They were not intended for use in constructing a predictive map of habitat use. We used only the best subset of these data following the filters applied by Theobald and Shenk (2011). Specifically, locations obtained during the first 6 months post-release were removed in order to exclude atypical movements made by animals that had not yet settled into home ranges. Next, poor precision satellite data (e.g., Argos location codes A, B, Z, 0 which do not have associated error estimates) were filtered out because they were too unreliable to be informative of lynx habitat use. We minimized dependence among locations (satellite collars transmitted several times per day, and a VHF location could have been obtained during the same day as well) by retaining only the most precise location for each lynx on a given day. When ties occurred, a single location was randomly selected from among the most precise locations. Finally, we discarded all data from lynx that were located fewer than 30 times over the course of the study.

Predictor variables

After filtering the location data, we assembled raw covariate data. We obtained housing density (HDENS, units per 1000 ha), road density (RDENS, km/km² – all roads), slope (SLOPE), elevation (ELEV), topographic wetness (TW), distance to high-volume road segments (D10K, annual average daily traffic volume > 10,000 vehicles), and distance to mesic forest patches >50 ha (D50HA) from Theobald and Shenk (2011). We also downloaded vegetation data from the Colorado Vegetation Classification Project (CVCP, Colorado Division of Wildlife, U.S. Department of Interior Bureau of Land Management, U.S. Forest Service. <http://ndis.nrel.colostate.edu/coveg/>). CVCP is geographically limited to Colorado, but it accurately depicts many vegetation types that may be important to lynx including riparian zones and willow. Other vegetation data sources (i.e., LANDFIRE) have the advantage of a larger spatial extent, but classification of these non-forest vegetation types is not as detailed. We reclassified the 114 vegetation types in CVCP into 17 classes to simplify the number of covariates available for analysis (Appendix 1). Next, we divided the western portion of Colorado into 1.5 km × 1.5 km cells, which corresponds to 1 SD of the error distribution for the most imprecise

(satellite) locations retained for analysis, as well as the smallest 90% UD observed for an individual lynx (Theobald and Shenk 2011). We computed the proportion of different vegetation types in each cell as well as mean SLOPE, ELEV, TW, HDENS, RDENS, D10K, and D50HA. We excluded cells with mean elevations <2,438m (8000 ft), assuming such cells do not provide habitat for lynx. This cutoff is consistent with previous literature (McKelvey et al. 2000, Ruediger et al. 2000), and over 99% of locations from our dataset were above 2,438m. We then standardized each covariate using all cells we intended to make predictions for. To maximize precision of parameter estimates and guard against erroneous predictions later on, we computed a correlation matrix between the potential explanatory variables but none were highly correlated (correlation coefficients were all <0.52 for covariates listed here).

Analysis

The response variable of interest for our models was the number of locations per individual in each cell, which we sought to predict using landscape attributes of the cells. We only used cells with ≥ 1 location for the purpose of constructing models. Excluding cells with no locations (zero counts) results in models that reflect relative use by lynx rather than resource selection. Thus in the generation of the model, we avoided delineation of what was available and suitable to lynx but never used (i.e., we avoided decisions regarding how many zero-count cells to include in the dataset and where they should come from on the landscape), which is a criticism of resource selection approaches. Furthermore, given ~10 years of work including weekly locations on hundreds of animals, we argue that nearly all cells in the Core Study Area that were suitable and available included ≥ 1 lynx location. This approach does, however, warrant the use of zero-truncated probability models to avoid possibly introducing bias in parameter estimates (Zuur et al. 2009, p. 269). In addition, we expected the data to be over-dispersed (variance of the counts was expected to be larger than the mean), we knew the number of locations collected per animal varied considerably, and we anticipated spatial autocorrelation in the residuals. To evaluate these assertions and determine the best model structure for our data, we successively compared the fits of a basic Poisson generalized linear model (GLM), negative binomial GLM, zero-truncated negative binomial (ZTNB), and ZTNB with an offset (offset accounts for variation in number of locations per individual). We compared the fit of these alternate structures using Akaike's Information Criterion (AIC, Burnham and Anderson 2002) and found that fitting a basic negative binomial GLM was an improvement over a Poisson ($\Delta\text{AIC} = 700.4$), ZTNB was an improvement over the negative binomial ($\Delta\text{AIC} = 6463.0$), and ZTNB with an offset provided the best fit ($\Delta\text{AIC} = 53.7$). Thus, we used a ZTNB with an offset as the base model structure. We fit all models using the VGAM package (Yee 2010, 2011) in R (R Core Development Team 2011). To assess spatial autocorrelation we computed a variogram using the gstat package (Pebesma 2004) and standardized residuals from a highly parameterized model (including all covariates below; Figure 1). We found minimal autocorrelation, so we proceeded to build ZTNB models absent spatial structure in the error term. Within the general ZTNB model structure, we specified the candidate model set by including combinations of covariates for modeling the mean count for each cell as follows:

- 1) Lynx are associated with conifer forests and deep snow, and they rely heavily on snowshoe hares. In the Southern Rockies, lynx occur largely in conifer stands within the sub-alpine zone (Aubry et al. 2000). Therefore, we included proportion spruce/fir (SF, *Picea engelmannii/Abies lasiocarpa*), mixed spruce/fir (MIXSF, spruce/fir mixed with Douglas-fir [*Pseudotsuga menziesii*], aspen [*Populus tremuloides*], and/or lodgepole pine [*Pinus contorta*]), distance to forest patch >50ha (D50HA), ELEV, and SLOPE in every model. We expected positive associations with each of these covariates except D50HA, which we expected to be negative.
- 2) Research conducted during the reintroduction of lynx into Colorado focused primarily in the southern portion of the state. Lodgepole pine (LODGE) occurs only in the northern portion of the state, so we know relatively little regarding the importance of this vegetation type with respect to habitat use by lynx. Therefore, we included a LODGE effect in some models, but when LODGE entered as a covariate, we also included a LODGE × latitude (NORTH) interaction to attempt to account for the distribution of this forest type in Colorado. Thus, lodgepole pine was allowed to be an important predictor of lynx use (or not) depending on latitude.
- 3) Vegetation types other than spruce/fir occur in or adjacent to the subalpine zone. We know relatively little about how lynx use these types but they may be important intermittently and/or as travel corridors. Therefore, we also built models that included combinations of montane forest (MONFOR: Douglas-fir, Ponderosa pine [*Pinus ponderosa*], and mixed Doug-fir/ponderosa pine), aspen (ASPEN), willow (WILLOW), and montane shrub (MONSHB: Gambel oak [*Quercus gambelii*], serviceberry [*Amelanchier utahensis*], and snowberry [*Symphoricarpos* sp.]).
- 4) Though lynx are considered a high elevation species, we opted to exclude “alpine” in any model because lynx are forest-dwelling, and there are few opportunities to manage structure of alpine areas, which included both alpine tundra and rock/snow/ice.
- 5) Lynx are often considered reclusive. Thus, covariates representing human development might be important predictors of habitats used (or not used) by lynx, and we initially considered HDENS, RDENS, and D10K as potential covariates to include in the model set. However, initial model-fitting resulted in HDENS and RDENS having slightly positive effects on lynx locations (but confidence intervals on these slopes were largely centered on zero indicating the effect was negligible), which is probably an artifact of the trapping/collaring effort that often occurred near roads due to logistical considerations. Many cells outside of those used to construct the models had HDENS and RDENS scores that were orders of magnitude above those used to construct the models. Thus, when projected to the entire set of cells covering western Colorado, these models predicted the best lynx habitat in highly developed, urban areas with high road density. Given this implausible result, we excluded HDENS and RDENS from the analysis. We retained D10K because high volume road segments occurred throughout broad areas used

by lynx (nearly every state highway has high volume segments) and it did not result in completely implausible results. We expected counts of lynx locations to be positively associated with distance to high traffic volume road segments.

- 6) Lynx often make long-distance movements outside of the winter season, and these movements may include use of many types of vegetation. Therefore, we fit the model set to summer locations (April through October) and then to winter locations (November through March). Seasonal definitions were based on mean daily movement patterns of telemetered lynx (Theobald and Shenk unpublished data). We expected that the association between lynx locations and vegetation types other than SF and MIXSF would vary with season, with more use of these perceived secondary types during summer.

In summary, our model set included all combinations of 5 vegetation types (LODGE, MONFOR, ASPEN, WILLOW, MONSHB) and D10K and TW. Each combination was always paired with the base covariates (SF, MIXSF, ELEV, SLOPE, D50HA) listed in 1) above. This resulted in $2^7 = 128$ models. We used Akaike's Information Criterion (AIC, Burnham and Anderson 2002) to determine which model structures best explained variation in lynx locations, to assess the importance of each covariate, and to model-average predictions of lynx use for each cell across all models. Predictions were defined as the probability of observing at least 10 locations in a cell over a hypothetical 10-year sampling period, which corresponds to an average of 1 location per year over the time frame of the actual data generating process. We color-coded predictions into 10 quantiles for display such that each color represents 10% of the total (i.e., the darkest red represents the predicted best 10% of cells, dark red plus deep orange represent the predicted best 20% of cells, etc.)

RESULTS

The final winter dataset consisted of 3,915 locations from 68 individuals (min = 30 locations/lynx, max = 113, mean = 57.6). Winter cell counts ranged from 1 to 29 (mean = 2.3). Summer data consisted of 5,464 locations from 74 individuals (min = 30, max = 178, mean = 73.8). Summer cell counts ranged from 1 to 36 total lynx locations (mean = 2.8).

Predicted Winter Use

As expected, relative predicted use by lynx during winter months was negatively associated with D50HA and positively associated with SF, MIXSF, ELEV, and SLOPE (Table 1). Of these associations, SF was strongest (largest magnitude and 95% confidence interval [$\pm 2 \times SE$] was well away from zero), followed by ELEV, SLOPE, and D50HA, and MIXSF, respectively. Of the covariates that were not included in every model, TW and ASPEN appeared in most of the top models (Table 3), were strongly, positively associated with use, and were the only effects in this group that were clearly different from zero. MONSHB was negatively associated with predicted lynx use, but evidence for this effect was weak. WILLOW, MONFOR, and D10K were somewhat

positively associated with lynx use, but evidence for these effects was relatively weak as well. LODGE and NORTH did not appear in any of the top models (Table 3).

The winter predictive map reflects the strong effect of SF. Arbitrarily defining the top 20% of predictions as high quality lynx habitat, there are 1,869,975 ha of such habitat in Colorado. Most of this is predicted to occur in the southern part of the state in the San Juan, Culebra, and Wet Mountain Ranges (Figure 2). In the central portion of the state, high predicted use is expected in the northern Sawatch and West Elk Ranges, along with Grand Mesa. The Park Range and Flat Tops comprise the best predicted winter lynx habitat farther north (Figure 2).

Predicted Summer Use

Associations between relative predicted summer use and SF, MIXSF, ELEV, SLOPE, and D50HA were similar to those observed during winter (Table 2). However, the associations with D50HA and SLOPE were stronger (larger effect and 95% CI indicated clear separation from zero) during summer. Of the covariates not included in every model, MONFOR and MONSHB were negatively associated with lynx locations; LODGE, LODGE \times NORTH, ASPEN, and D10K were positively associated. The effects of LODGE \times NORTH, MONFOR, ASPEN, and D10K were substantially different from zero based on 95% CIs. Effects of other covariates were not clearly different from zero.

The summer predictive map reflects more dispersed predicted use by lynx with the LODGE \times NORTH interaction playing a larger role (Figure 3). The central and southern Sawatch Range in central Colorado is predicted to have more use than during winter, whereas use on Grand Mesa is predicted to decline. In the northern part of the state, lynx use is predicted to shift more toward the Medicine Bow and Front Ranges. Using the same definition as before, we predict 1,791,675 ha of high quality summer habitat in Colorado. The overlap between high quality summer and winter cells (as arbitrarily defined above) is ~93%.

DISCUSSION

The data analyzed here were not collected for the purpose of constructing a predictive map and suffer from at least two shortcomings. First, the locations were not precise. We attempted to account for this imprecision by modeling at a 1.5 km scale, but matching covariates, response variables, and predictions at this scale reduces the clarity of relationships and weakens the modeling process. Second, the bulk of the reintroduction research effort, from which these data originated, was conducted in the southern and central portions of Colorado. Lodgepole pine only occurs in the northern 2/3 of the state, and is dominant there. Thus, predicting lynx habitat use in northern Colorado is difficult because the landscape is very different, yet we have little data available to help model lynx

response to that landscape. That is, we are extrapolating beyond the range of covariates used to fit the models, which is tenuous. Caution should be exercised in interpreting results north of I-70.

In addition to issues regarding the location data, we also lack important vegetation data that could be crucial in making accurate predictions. Snowshoe hares (*Lepus americanus*) are tied to forests with dense understory cover throughout their range (Hodges 2000a;b), including Colorado (Dolbeer and Clark 1975, Zahratka and Shenk 2008, Ivan 2011). Given the close tie between hares and lynx, habitat use of the latter should be strongly tied to understory cover as well. However, we have no covariate data for understory. Our models treat all spruce/fir, mixed spruce/fir, and lodgepole forests equally, but the quality of these forests likely varies considerably. The value of a cell could be modified by topographic wetness, however, and we hope that variable served as an adequate surrogate for understory cover. Additionally, pine beetle (*Dendroctonus ponderosae*) and spruce beetle (*Dendroctonus rufipennis*) epidemics throughout the state are drastically changing the structure and composition of current and future forests. Our predictions are based on forest composition prior to these outbreaks.

Despite these weaknesses, the predictive maps constructed here also have a distinct strength in that they were constructed objectively from rigorous mathematical models based on empirical data collected from wild lynx. They are the first such maps for Colorado. Results from this effort confirm relationships that were already known (e.g., lynx are strongly positively associated with high elevation, wet spruce/fir and mixed spruce/fir forests but avoid lower elevation, drier montane forests and montane shrublands), and highlight others that may be of interest. For instance, we found clear evidence that lynx use was positively associated with ASPEN during both summer and winter. It is unclear what the ecological relationship between the two might be and we have no causal evidence for ASPEN driving lynx use. However, this pattern is not a simple artifact of ASPEN occurring near SF or MIXSF – our preliminary vetting of potential covariates indicated that the correlation between ASPEN and SF or MIXSF was small and negative (-0.15 and -0.14, respectively). We also found evidence that lynx use of lodgepole forests may increase during summer, and that they tend to avoid areas near high traffic volume road segments, especially in summer.

The strengths of this analysis and resulting maps merit their inclusion as a tool for making land management decisions. However, inherent weaknesses of the data require the reader to exercise caution when interpreting results. These maps should be viewed as a compliment to expert opinion and existing maps produced by other means. When assessing habitat quality for lynx at a given project site, it is imperative that managers consider current stand characteristics (especially understory) in formulating land use plans or specific management recommendations relative to lynx.

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Table 1. Model selection results (top 10 of 128) and parameter estimates (SE) for zero-truncated negative binomial models fit to cell counts of Canada lynx locations collected during winter (November – March) 1999-2010, southwest and central Colorado, USA.

SF	MIXSF	D50HA	ELEV	SLOPE	TW	LODGE	NORTH	LODGE: NORTH	MONFOR	ASPEN	WILLOW	MONSHB	D10K	AIC	Δ AIC	AIC Wt.	<i>K</i>
0.44 (0.06)	0.11 (0.08)	-1.58 (0.86)	0.44 (0.11)	0.28 (0.07)	0.54 (0.1)					0.27 (0.08)				4646.4	0.00	0.13	9
0.48 (0.07)	0.13 (0.08)	-1.59 (0.85)	0.4 (0.12)	0.3 (0.07)	0.53 (0.1)					0.29 (0.08)	0.05 (0.04)			4646.8	0.40	0.11	10
0.44 (0.06)	0.13 (0.08)	-1.62 (0.86)	0.44 (0.11)	0.28 (0.07)	0.54 (0.1)					0.27 (0.08)			0.09 (0.09)	4647.3	0.87	0.09	10
0.43 (0.07)	0.1 (0.08)	-1.58 (0.85)	0.41 (0.12)	0.28 (0.07)	0.54 (0.1)					0.28 (0.08)		-0.31 (0.38)		4647.6	1.17	0.07	10
0.48 (0.07)	0.15 (0.08)	-1.62 (0.86)	0.41 (0.12)	0.3 (0.07)	0.53 (0.1)					0.28 (0.08)	0.05 (0.04)		0.09 (0.09)	4647.8	1.41	0.06	11
0.47 (0.07)	0.12 (0.08)	-1.58 (0.85)	0.37 (0.12)	0.29 (0.07)	0.53 (0.1)					0.29 (0.08)	0.05 (0.04)	-0.34 (0.39)		4647.9	1.45	0.06	11
0.46 (0.07)	0.12 (0.08)	-1.6 (0.86)	0.49 (0.14)	0.28 (0.07)	0.54 (0.1)				0.15 (0.22)	0.29 (0.08)				4648.0	1.55	0.06	10
0.5 (0.07)	0.14 (0.08)	-1.6 (0.85)	0.45 (0.14)	0.3 (0.07)	0.53 (0.1)				0.17 (0.22)	0.31 (0.09)	0.05 (0.04)			4648.3	1.83	0.05	11
0.43 (0.07)	0.12 (0.08)	-1.61 (0.86)	0.42 (0.12)	0.28 (0.07)	0.54 (0.1)					0.27 (0.08)		-0.3 (0.38)	0.09 (0.09)	4648.5	2.07	0.05	11
0.45 (0.07)	0.14 (0.08)	-1.64 (0.86)	0.49 (0.14)	0.28 (0.07)	0.54 (0.1)				0.15 (0.22)	0.29 (0.08)			0.1 (0.09)	4648.8	2.39	0.04	11

Table 2. Model selection results (top 10 of 128) and parameter estimates (SE) for zero-truncated negative binomial models fit to cell counts of Canada lynx locations collected during summer (April – October) 1999-2010, southwest and central Colorado, USA.

SF	MIXSF	D50HA	ELEV	SLOPE	TW	LODGE	NORTH	LODGE: NORTH	MONFOR	ASPEN	WILLOW	MONSHB	D10K	AIC	ΔAIC	AIC Wt.	K
0.4 (0.07)	0.15 (0.07)	-3.56 (0.87)	0.49 (0.13)	0.45 (0.06)	0.46 (0.09)	0.09 (0.11)	-0.01 (0.1)	0.34 (0.12)	-1.53 (0.4)	0.22 (0.08)		-0.87 (0.52)	0.19 (0.08)	6658.1	0.00	0.29	15
0.42 (0.07)	0.16 (0.07)	-3.54 (0.87)	0.54 (0.13)	0.46 (0.06)	0.45 (0.09)	0.12 (0.11)	0.00 (0.1)	0.35 (0.12)	-1.53 (0.39)	0.22 (0.08)			0.19 (0.08)	6659.2	1.06	0.17	14
0.39 (0.07)	0.14 (0.07)	-3.57 (0.87)	0.5 (0.13)	0.45 (0.06)	0.47 (0.09)	0.09 (0.11)	0.00 (0.1)	0.34 (0.12)	-1.53 (0.4)	0.22 (0.08)	-0.01 (0.04)	-0.86 (0.52)	0.19 (0.08)	6660.0	1.88	0.11	16
0.41 (0.07)	0.15 (0.07)	-3.55 (0.87)	0.55 (0.13)	0.45 (0.06)	0.46 (0.09)	0.11 (0.11)	0.01 (0.1)	0.35 (0.12)	-1.53 (0.39)	0.21 (0.08)	-0.02 (0.04)		0.19 (0.08)	6661.0	2.88	0.07	15
0.4 (0.07)	0.12 (0.07)	-3.56 (0.87)	0.49 (0.13)	0.46 (0.06)	0.47 (0.09)	0.13 (0.11)	-0.08 (0.1)	0.24 (0.12)	-1.53 (0.4)	0.23 (0.08)		-0.87 (0.52)		6661.1	3.01	0.06	14
0.42 (0.07)	0.13 (0.07)	-3.55 (0.87)	0.54 (0.13)	0.46 (0.06)	0.46 (0.09)	0.15 (0.11)	-0.08 (0.1)	0.25 (0.12)	-1.53 (0.4)	0.22 (0.08)				6662.2	4.09	0.04	13
0.37 (0.06)	0.11 (0.06)	-3.28 (0.81)	0.29 (0.12)	0.41 (0.06)	0.41 (0.08)				-1.7 (0.39)	0.16 (0.08)		-1.08 (0.52)	0.15 (0.07)	6662.2	4.13	0.04	12
0.39 (0.07)	0.11 (0.07)	-3.57 (0.87)	0.5 (0.13)	0.46 (0.06)	0.47 (0.09)	0.12 (0.11)	-0.08 (0.1)	0.23 (0.12)	-1.53 (0.4)	0.22 (0.08)	-0.01 (0.04)	-0.87 (0.52)		6663.1	4.97	0.02	15
0.34 (0.06)	0.1 (0.06)	-3.34 (0.82)	0.33 (0.12)	0.4 (0.06)	0.43 (0.08)				-1.69 (0.39)	0.15 (0.08)	-0.04 (0.04)	-1.03 (0.52)	0.15 (0.07)	6663.3	5.14	0.02	13
0.3 (0.06)	0.1 (0.06)	-3.98 (0.88)	0.3 (0.11)	0.45 (0.06)	0.45 (0.09)	0.02 (0.11)	-0.04 (0.1)	0.3 (0.12)	-1.64 (0.39)			-0.8 (0.51)	0.19 (0.08)	6663.4	5.26	0.02	14

Table 3. Cumulative AIC weights for variables included in all combinations (n = 128 total models) to model relative habitat use by Canada lynx in Colorado, USA, 1999-2010. Variables with higher weights tend to be included in models that fit the data best.

Winter		Summer	
TW	1.00	TW	1.00
ASPEN	0.96	MONFOR	1.00
WILLOW	0.43	ASPEN	0.90
D10K	0.37	LODGE	0.85
MONSHB	0.35	NORTH	0.85
MONFOR	0.31	D10K	0.80
LODGE	0.06	MONSHB	0.65
NORTH	0.06	WILLOW	0.30

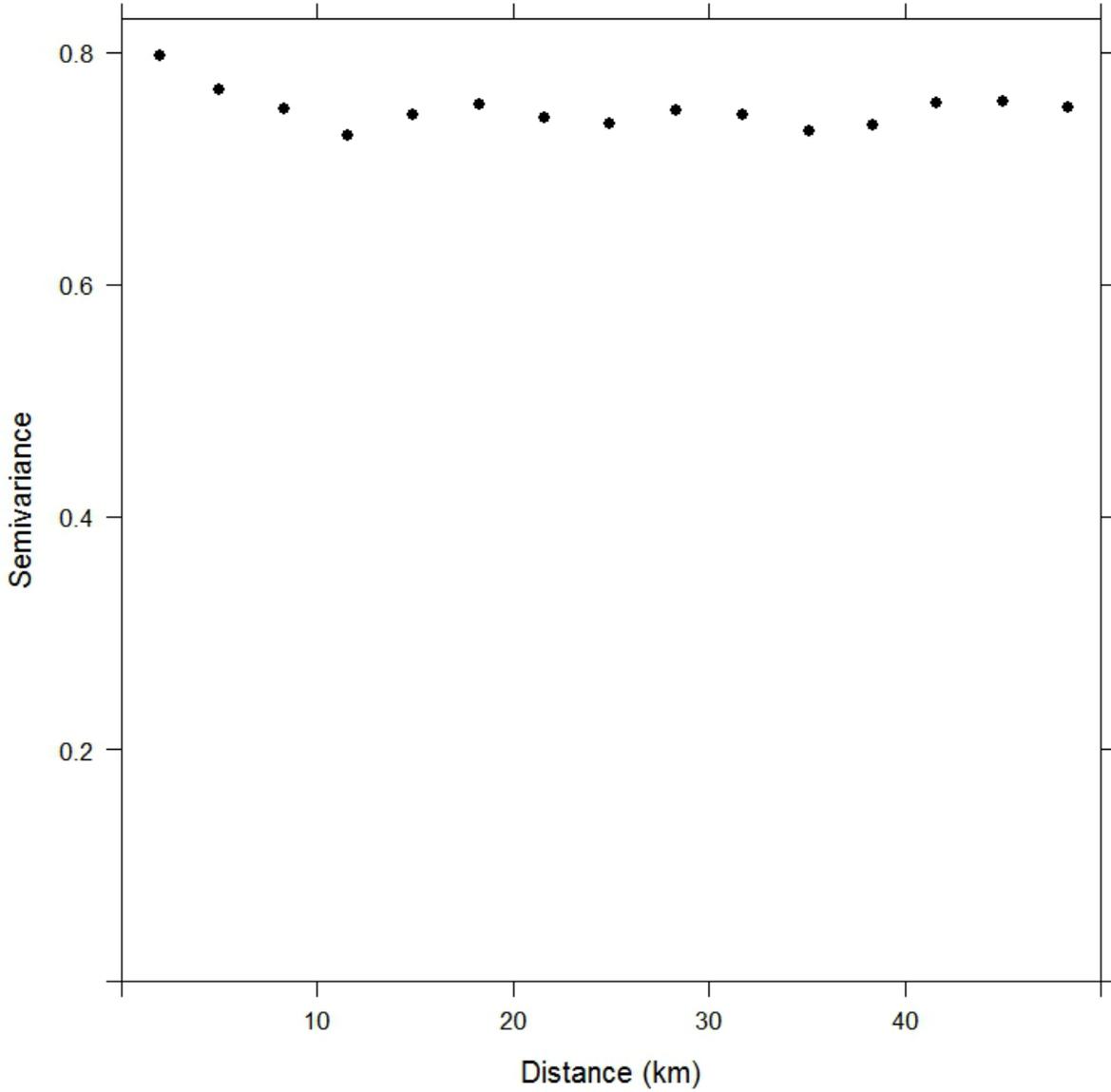


Figure 1. Variogram constructed using standardized residuals from a highly parameterized model fit to count data of lynx locations within $1.5\text{km} \times 1.5\text{km}$ cells, 1999-2011, southwestern and central Colorado. Variance among pairs of points is similar regardless of the distance separating them, indicative of a lack of residual spatial autocorrelation after fitting important covariate effects. Strong evidence of spatial autocorrelation in residuals would result in a graph with small variance between pairs of points that are near to each other, and larger variance at greater distances (i.e., a monotonically increasing pattern).

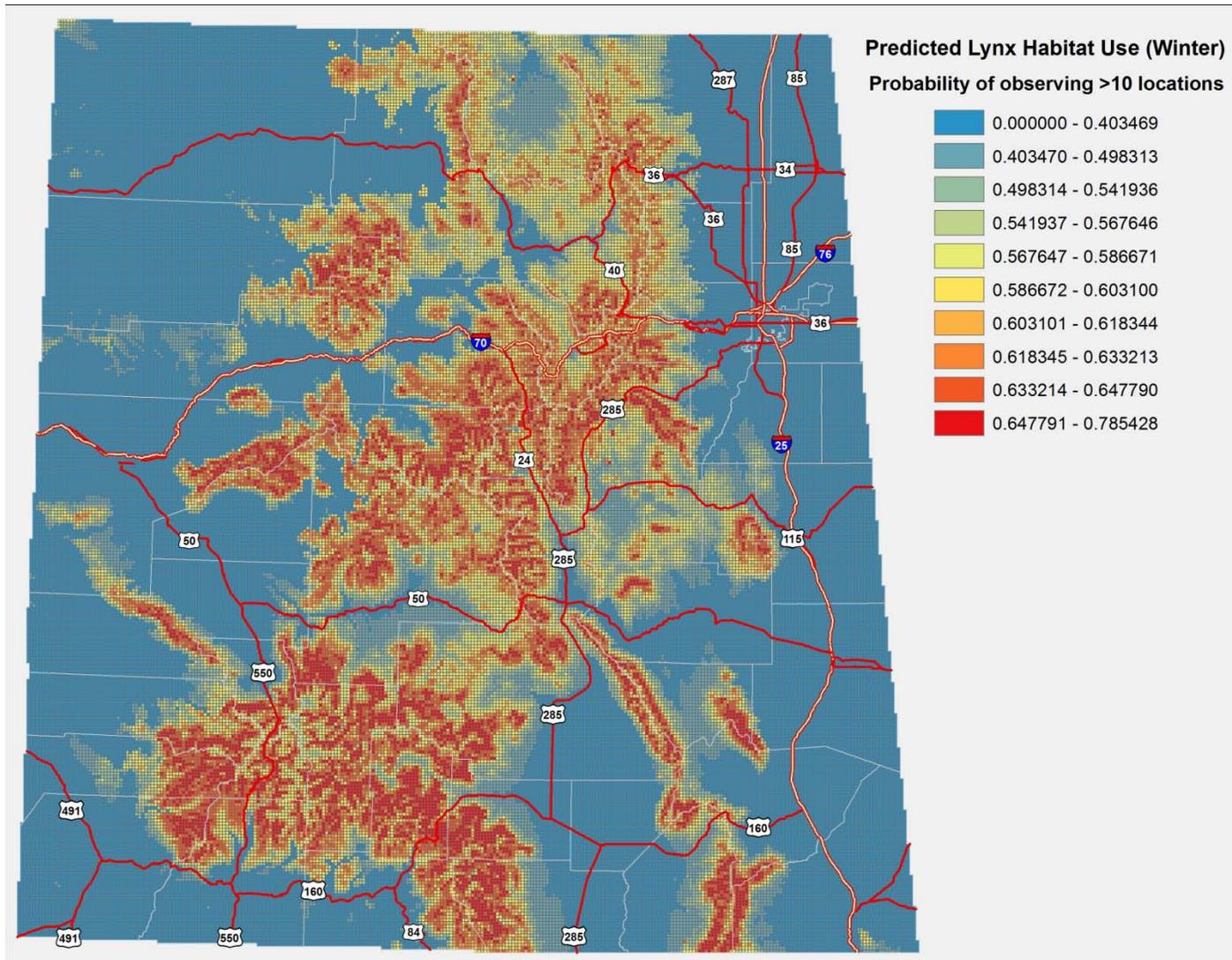


Figure 2. Predicted winter habitat use by Canada lynx in western Colorado. Predictions are probabilities of observing at least 10 locations within a 1.5×1.5 km cell over a hypothetical 10-year sampling period. Predictions were averaged across 128 models constructed using all combinations of covariates of interest.

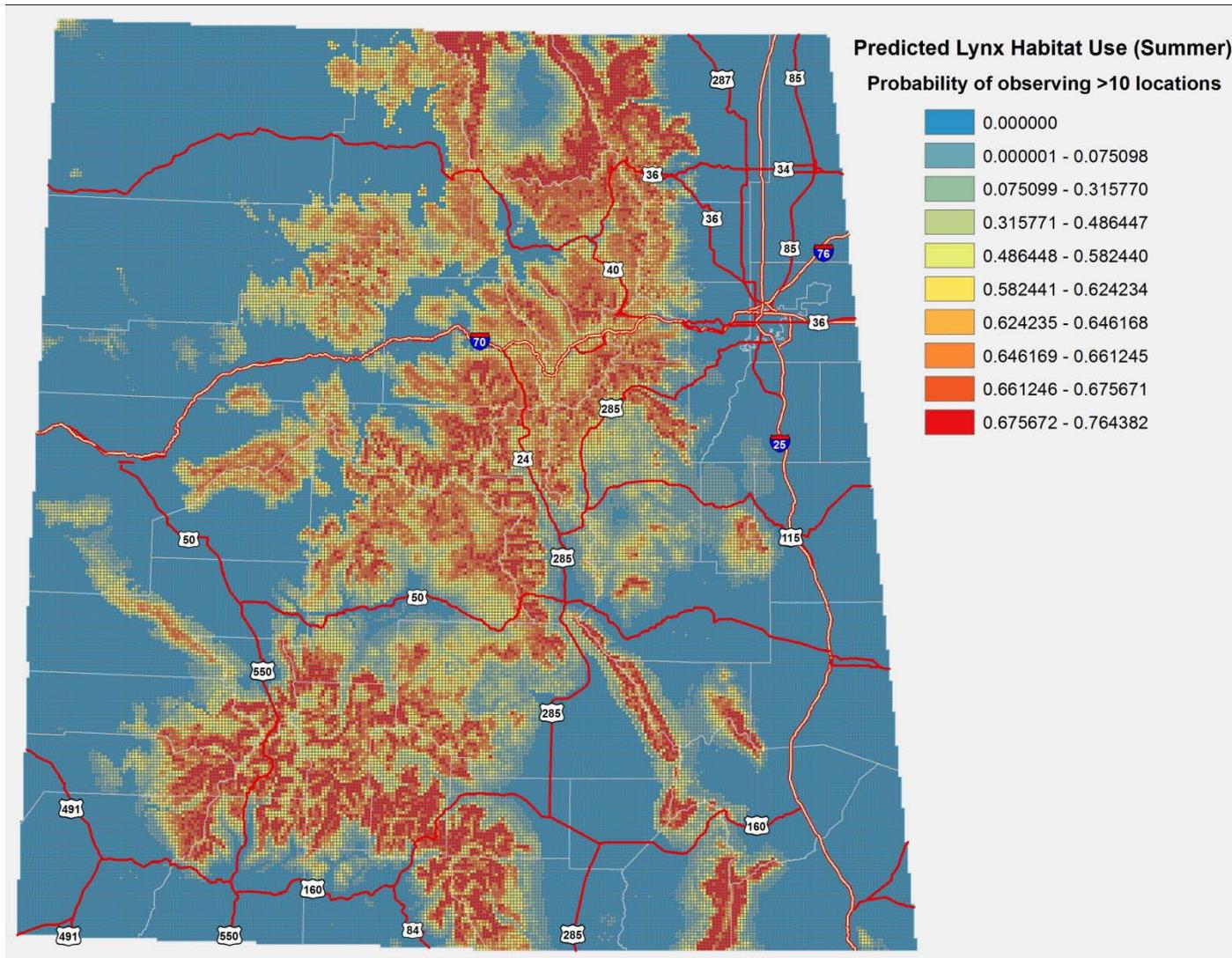


Figure 3. Predicted summer habitat use by Canada lynx in western Colorado. Predictions are probabilities of observing at least 10 locations within a 1.5×1.5 km cell over a hypothetical 10-year sampling period. Predictions were averaged across 128 models constructed using all combinations of covariates of interest.

Appendix 1. Raster reclassification of CVCP dataset for use in lynx predictive map analysis.

Lynx Reclass	CVCP Value	Description
Null	0	Unclassified
2	1	Urban/Built Up
2	2	Residential
2	3	Commercial
1	4	Agriculture Land
1	5	Dryland Ag
1	6	Irrigated Ag
1	7	Orchard
4	8	Rangeland
4	9	Grass/Forb Rangeland
8.2	10	Snakeweed/Shrub Mix
4	11	Grass Dominated
4	12	Forb Dominated
4	13	Grass/Forb Mix
4	15	Mid-grass Prairie
4	16	Short-grass Prairie
14	17	Sand Dune Complex
4	18	Foothill and Mountain Grasses
4	19	Disturbed Rangeland
4	20	Sparse Grass (Blowouts)
8.2	21	Shrub/Brush Rangeland
8.2	22	Sagebrush Community
8.2	23	Saltbush Community
8.2	24	Greasewood
8.2	25	Sagebrush/Gambel Oak Mix
8.2	26	Snakeweed
8.1	27	Snowberry
8.1	28	Snowberry/Shrub Mix
8.2	29	Bitterbrush Community
8.2	30	Salt Desert Shrub Community
8.2	31	Sagebrush/Greasewood
8.2	32	Shrub/Grass/Forb Mix
8.2	33	Sagebrush/Grass Mix
4	34	Rabbitbrush/Grass Mix
8.2	35	Sagebrush/Mesic Mtn Shrub Mix
4	36	Grass/Misc. Cactus Mix
4	37	Winterfat/Grass Mix
4	38	Bitterbrush/Grass Mix
4	39	Grass/Yucca Mix
8.2	40	Sagebrush/Rabbitbrush Mix
10	43	Pinon-Juniper
10	44	Juniper
8.1	46	Gambel Oak
8.2	47	Xeric Mountain Shrub Mix
8.1	48	Mesic Mountain Shrub Mix
8.1	49	Serviceberry/Shrub Mix
3.1	50	Upland Willow/Shrub Mix
8.2	51	Manzanita
10	53	PJ-Oak Mix
10	54	PJ-Sagebrush Mix
10	55	PJ-Mtn Shrub Mix
10	56	Sparse PJ/Shrub/Rock Mix
10	57	Sparse Juniper/Shrub/Rock Mix
10	58	Juniper/Sagebrush Mix
10	59	Juniper/Mtn Shrub Mix
11	62	Aspen
8.1	63	Aspen/Mesic Mountain Shrub Mix
13	65	Ponderosa Pine
9.1	66	Englemann Spruce/Fir Mix
13	67	Douglas Fir
12	68	Lodgepole Pine
9.1	69	Sub-Alpine Fir
9.1	70	Spruce/Fir Regeneration
9.2	71	Spruce/Lodgepole Pine Mix
13	72	Bristlecone Pine

13	73	Ponderosa Pine/Douglas Fir Mix
13	75	Limber Pine
9.2	77	Lodgepole/Spruce/Fir Mix
9.2	78	Fir/Lodgepole Pine Mix
9.2	79	Douglas Fir/Englemann Spruce Mix
13	80	Mixed Forest Land
9.1	81	Spruce/Fir/Aspen Mix
13	82	P. Pine/Gambel Oak Mix
13	83	Ponderosa Pine/Aspen Mix
13	84	Douglas Fir/Aspen Mix
13	85	P. Pine/Aspen/Gamble Oak Mix
12	86	Lodgepole Pine/Aspen Mix
9.2	87	Spruce/Fir/Lodgepole/Aspen Mix
13	88	Ponderosa Pine/Mesic Mtn. Shrub
13	89	Ponderosa Pine/Aspen/Mesic Mtn.
14	90	Barren Land
6	91	Rock
6	92	Talus Slopes & Rock Outcrops
1	93	Soil
2	94	Disturbed Soil
7	96	Alpine Meadow
7	97	Alpine Forb Dominated
7	98	Alpine Grass Dominated
7	99	Alpine Grass/Forb Mix
7	100	SubAlpine Shrub Community
6	101	Snow
7	102	Subalpine Meadow
7	103	Subalpine Grass/Forb Mix
3.2	104	Riparian
3.2	105	Forested Riparian
3.2	106	Cottonwood
3.1	108	Conifer Riparian
3.2	109	Shrub Riparian
3.1	110	Willow
3.2	111	Exotic Riparian Shrubs
3.2	112	Herbaceous Riparian
3.2	113	Sedge
5	114	Water
