Elk Parturition Habitat in Idaho

Report compiled by

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Introduction

The goal of this report is to describe a completed research project for predicting parturition habitat of elk in Idaho; and to provide managers with the results (GIS layers) from this analysis. In synopsis, we developed a model to predict the relative probability that an area on the landscape would be selected as a parturition site based on the following: (1) we used GPS location data from 2007-2020 and associated movement patterns of adult female elk to identify putative parturition locations; (2) we estimated the parameters of resource selection functions by comparing the habitat characteristics of parturition locations to what was considered available on the landscape. (3) we used the estimated resource selection functions to predict the relative probability that an area would be chosen as a parturition site. Because habitat characteristics vary substantially in Idaho and elk in different parts of the state may behave differently, we developed a separate model for 6 populations. For each population, we describe the results of the analyses and have provided GIS raster layers (K:/Wildlife/Wildlife Research/ElkCalvingHabitat) of predicted calving habitat at two extents. The first extent is the population boundary (see Figure 1) that we used to define broad-scale availability for the resource selection analysis. Because this is the extent we used to estimate model parameters, predictions will be most reliable within this boundary. If managers want to evaluate, and potentially use, predictions outside of the population boundaries, we also provided a more extensive prediction extent for each population. However, managers should exercise caution when using this larger extent as predictions may be unreliable outside of the population boundaries.

Methods

<u>Data compilation</u>

We used GPS locations collected from 1,091 adult (> 2 years old during previous breeding season) cow elk during 1 May to 31 July from 2007 to 2020. Multiple individuals were monitored for >1 year and so the number of ID by year individuals (ID-year) was 2,270. Most GPS collars were programmed to collect one location every 12 hrs. Those that collected locations more frequently were subset to a 12-hr interval. For each ID-year, we calculated movement metrics to identify periods of reduced moment and restricted area of use. Movement metrics included mean distance between successive locations over a 72-hr period and the maximum distance from the mean location during the 72-hr period. Of the 2,270 possible ID-year individuals, 1,105 had a sufficient number of locations (≥ 50 locations with associated movement metrics) to potentially identify parturition. For modelling calving habitat, it was preferable to error on the side of excluding individuals that potentially had a calf versus including individuals that did not. Thus, we developed a Shiny App that enabled me to graphically display locations and movement metrics to ensure movements were localized. We retained individuals where the parturition event was obvious as indicated by a substantial decline in the movement metrics and localized space use (Figure 2). To delineate the putative parturition location for subsequent analysis, we identified locations where the cow localized movements (“localized locations”; red dots in Figure 2). If there were >4 localized locations, the putative parturition site was determined by fitting a kernel density and taking the location of the maximum density. If there were ≤ 4 locations, we took the mean of the localized locations as the putative parturition site. Birth date was presumed to be the first day when movements became localized.

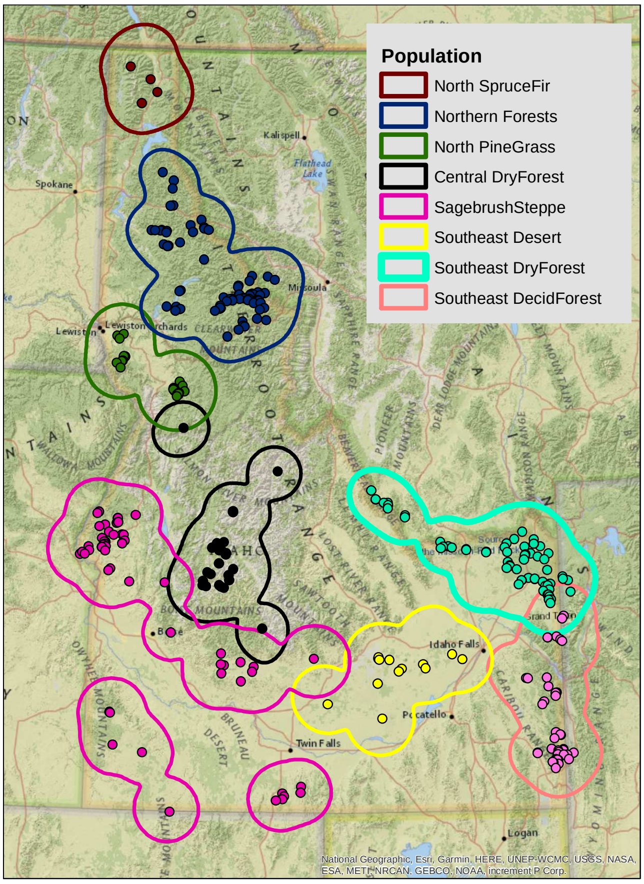


Figure 1. Parturition locations (dots) and boundaries of 8 populations used to model elk calving habitat in Idaho. Each population was modelled separately, excluding the North SpruceFir and Southeast Desert populations due to an insufficient number of parturition locations.

Statewide, there were 314 ID-years (241 individuals) where a parturition event was identified. Based on ecoregion characteristics we assigned each parturition location to one of 8 populations. Population boundaries were determined by fitting a kernel density estimate (smoothing parameter equaled 10km) to the combined GPS locations (excluding localized locations) of the individuals within each population. We analyzed calving habitat selection for each population separately excluding the North SpruceFir and Southeast Desert populations due to insufficient number of parturition locations to adequately fit a resource selection model (Table 1).

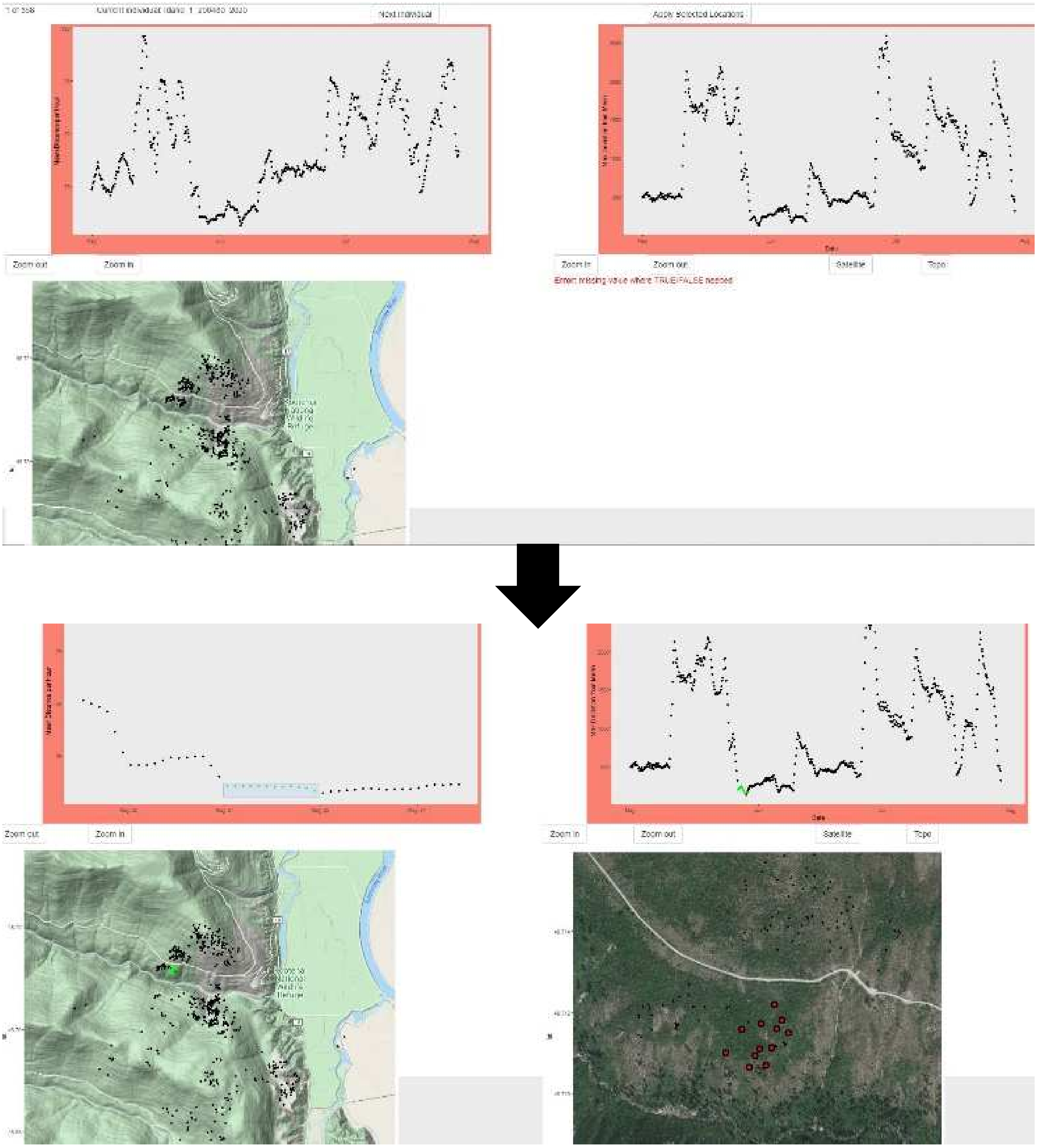


Figure 2. Interface of Shiny App used to identify localized parturition locations of elk in Idaho, 2007-2020. Top panel (above the arrow) shows GPS locations and plots of two movement metrics for an individual from 1 May to 31 July. Locations can be selected from the movement metric plots (bottom panel below the arrow) and the user can then see these selected locations on the landscape (bottom right panel). Once a set of locations are selected (green and red dots), these locations are then identified as “localized” for subsequent identification of the calving site.

Table 1. Summary of parturition data analyzed to model calving habitat in Idaho, 2007-2020.

Population	# Parturition locations	Range of years analyzed	Parturition date		
			Minimum	Maximum	Average
North SpruceFir	4	NA	5/24	6/27	6/3
Northern Forests	78	2009-2020	5/16	7/18	6/1
North PineGrass	29	2015-2018	5/13	7/2	5/31
Central DryForest	26	2008-2018	5/21	6/24	6/4
SagebrushSteppe	57	2016-2020	5/16	6/19	5/31
Southeast Desert	13	NA	5/27	7/3	6/10
Southeast DryForest	65	2011-2020	5/14	7/12	6/1
Southeast DecidForest	42	2007-2020	5/17	7/1	6/3
Total	**314**	**2007-2020**	**5/13**	**7/18**	**6/2**

Characterizing calving habitat

We considered 14 spatio-temporal covariates as potentially influencing selection of parturition sites (Table 2). We derived 5 (slope, sine of aspect, cosine of aspect, topographic position, and elevation) from a digital elevation model in which the temporal resolution was fixed (i.e., one layer for the analysis) and the spatial resolution was 186 m. We derived 7 categorical land-cover types (herbaceous, shrub, evergreen forest, deciduous forest, mixed forest, woody wetland, and crop) from the National Land Cover Database (NLCD) and one additional covariate that measured the distance to developed areas. The temporal resolution of covariates derived from NLCD was ~3-year intervals (2008, 2011, 2013, 2016, 2019) and the spatial resolution was 30m. Lastly, we calculated the distance to the edge of snow using data derived from SNODAS with a daily temporal resolution and spatial resolution equal to 800 m.

Analysis

We evaluated calving habitat selection by comparing use versus availability at 2 scales. We used a broad-scale analysis to determine the characteristics within the general area that elk chose as a parturition site. We measured use as the mean of each covariate (translates to a proportion for categorical covariates) within a 2.6-km radius circle centered on the putative calving location. We chose the 2.6-km radius to describe the "general area" based on the median distance (across all ID-years) from first location when movements became localized to the location one week prior. We measured availability by taking the mean of each covariate within a 2.6-km radius circle centered at ~300 points spaced evenly within the population boundary. For the local-scale analysis, we refined the broad-scale analysis by taking into account local characteristics that determined the actual parturition site once a general area was chosen (i.e., broad-scale selection). For the local-scale model, we measured use by taking the value of each covariate at the parturition location and compared this to the value of each covariate at 296 points spaced evenly within a 2.6-km circle centered on the parturition location.

Because the data spanned from 2007 to 2020, some of the covariates had substantial temporal variation (e.g., those derived from land cover and snow). Thus, we associated both used and available locations with the temporal layer that was closest in time to the date of the parturition location.

We modeled the probability that position *s* at time *t* would be selected as a parturition location using

$$u_{s,t} = \frac{w(X_{s,t},\beta)a_s}{\int_{g\in G} w(X_t,\beta)\mathrm{a}_g \mathrm{d}g}, \qquad \text{eqn 1}$$

where the denominator ensures that $u_{s,t}$ integrates to 1, and thus is a proper probability distribution. The habitat selection function is defined by $w(X_{s,t},\beta)$, where *X* is a vector of covariate values at position *s* at time *t* and β is a vector of selection coefficients. The availability distribution, *a* (i.e., the expected distribution of parturition sites in the absence of habitat selection), was a uniform distribution within the area (*G*) considered available for subsequent selection. Thus, *G* was the population boundary for the broad-scale analysis and the 2.6-km circle around the parturition site for the local-scale analysis. We estimated selection coefficients (βs) using conditional logistic regression, with strata defined by each ID-Year.

Table 2. Habitat covariates used to model parturition locations of elk in Idaho, 2007-2020.

Source	Covariate name	Description
Digital Elevation Model		
	Slope	Percent slope of topography
	Aspect cosine	Cosine of aspect
	Aspect sine	Sine of aspect
	Topographic position	Topographic position values range from negative (valleys) to 0 (side slope) to positive (ridgelines). It was calculated as the difference between the elevation at position *s* and the mean elevation within a 2.6km circle. The more negative the value, the steeper the valley (e.g., canyon), and the more positive the value, the sharper the ridgeline.
	Elevation	Elevation above sea level
NLCD		
	Herbaceous	Dominated by gramanoid or herbaceous vegetation, generally greater than 80% of total vegetation.
	Shrub	Dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.
	Evergreen forest	Dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.
	Deciduous forest	Dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.
	Mixed forest	Dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.
	Woody wetland	Forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
	Crop	Used for the production of annual crops and perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.
	Distance to developed	Distance to nearest cell categorized as developed
SNODAS		
	Distance to snow edge	If the location was in a cell categorized as not having snow cover on that day, the value was the distance to nearest cell categorized as having snow. If the location was in a cell categorized as having snow cover on that day, the value was the distance to nearest cell without snow times -1.

Candidate Models

To find the best model for predicting calving habitat, we fit multiple models with various combinations of covariates and used Akaike Information Criteria (AIC) for model selection. To reduce the number of potential covariates, we first eliminated from consideration cover types with no parturition locations for a particular population (Table 3). The proportion of Evergreen forest (population-scale covariate) was correlated with proportion of Shrub (-0.59), Slope (0.53), proportion of Herbaceous (-0.43), and slope (0.41). To avoid problems with collinearity, we removed proportion of Evergreen forest from the list of potential covariates for the broad-scale analysis. We did not include distance to snow edge as a covariate for the local-scale analysis because the spatial resolution of the SNODAS layer was too coarse. Lastly, we did not include Distance to developed as a covariate for the broad-scale analysis because of potentially confounding effects of capture location and because this covariate was correlated with slope (0.41). With the remaining covariates, we created a candidate set of models for each scale and population. For the broad-scale analysis, we began the candidate set with a model that only included cover types. For the fine-scale analysis we began with 2 simple models, one that included cover type and the other that included Distance to developed. We used these as the base models because cover type and developed areas have the potential to be influenced by management. For the additional covariates, we used an all subsets approach where each covariate was added to base model and then all possible combinations as well. To allow for non-linear relationships, we included a squared term for all continuous covariates. See Appendix for lists of competing models for each population and scale.

Table 3. Proportion of elk parturition sites located in each cover type in Idaho, 2007-2020. If there were no locations in a cover type, that cover type was not included in the candidate models for that particular population.

Population	Herbaceous	Shrub	Evergreen forest	Deciduous forest	Woody wetland	Crop
NorthernForests	0.12	0.39	0.49	0	0	0
North_PondPineGrass	0.18	0.14	0.68	0	0	0
DryForest_Central	0.23	0.58	0.19	0	0	0
SagebrushSteppe	0.29	0.60	0.07	0	0	0.04
DryForest_Southeast	0.02	0.46	0.35	0.03	0.14	0
DecidForest_South	0.05	0.48	0.40	0.07	0	0

Predictions

We used the candidate model with the lowest AIC score for each population and scale to predict calving habitat across the landscape. We created a broad-scale prediction (i.e., the relative probability of an elk selecting to have a calf within the general area *A* described by the 2.6-km circle centered at position *s*) using the selection function in equation 1

$$\text{Pred\_Broad}(A_s) = \frac{w(X(A_s), \beta)}{\max\left[w(X(A_s), \beta)\right]} \qquad \text{eqn 2}$$

where the selection coefficients (βs) were the estimated parameters from the broad-scale best-model, $X(A_s)$ is the mean values of the covariates within the circle, and the denominator standardizes the relative probability of the resource selection function to range between 0 and 1 (Figure 3a). For temporal covariates (i.e., those derived from cover type and snow), we used the 2019 cover type layer and the average distance to snow edge on 1 June across all years analyzed. We then calculated a prediction for the best local-scale model,

$$\text{Pred\_Local}(s) = \frac{w(X_s, \beta)}{\max\left[w(X_s, \beta)\right]} \qquad \text{eqn 3}$$

where the selection coefficients (βs) were the estimated parameters from the local-scale best model and X_s were the values of the covariates at position *s* (Figure 3b).

To combine the two scales into a prediction that takes into account population and local scale selection, we first calculated the relative probability of selecting a location for a parturition site *conditional* on the elk having selected the general area (i.e., 2.6-km circle from broad-scale) using

$$\text{Rel\_Local}(s) = \frac{\text{Pred\_Local}(s)}{mean\left[\text{Pred\_Local}(A_s)\right]} \qquad \text{eqn 4}$$

where $mean\left[\text{Pred\_Local}(A_s)\right]$ was the mean of $\text{Pred\_Local}(s)$ within the 2.6-km circle centered on position *s*. By dividing the value of $\text{Pred\_Local}(s)$ by this expected value, $\text{Rel\_Local}(s)$ provides a measure of the relative increase, or decrease, in the probability that position *s* would be selected, given that an elk chose to have a calf in A_s (Figure 3c). We obtained the final prediction, taking into account population and local scale selection, by combining eqn 2 and 4 (Figure 3d),

$$\text{Pred}(s) = \frac{\text{Pred\_Pop}(A_s) \times \text{Rel\_Local}(s)}{\max\left(\text{Pred\_Pop}(A_s) \times \text{Rel\_Local}(s)\right)} \qquad \text{eqn 5}$$

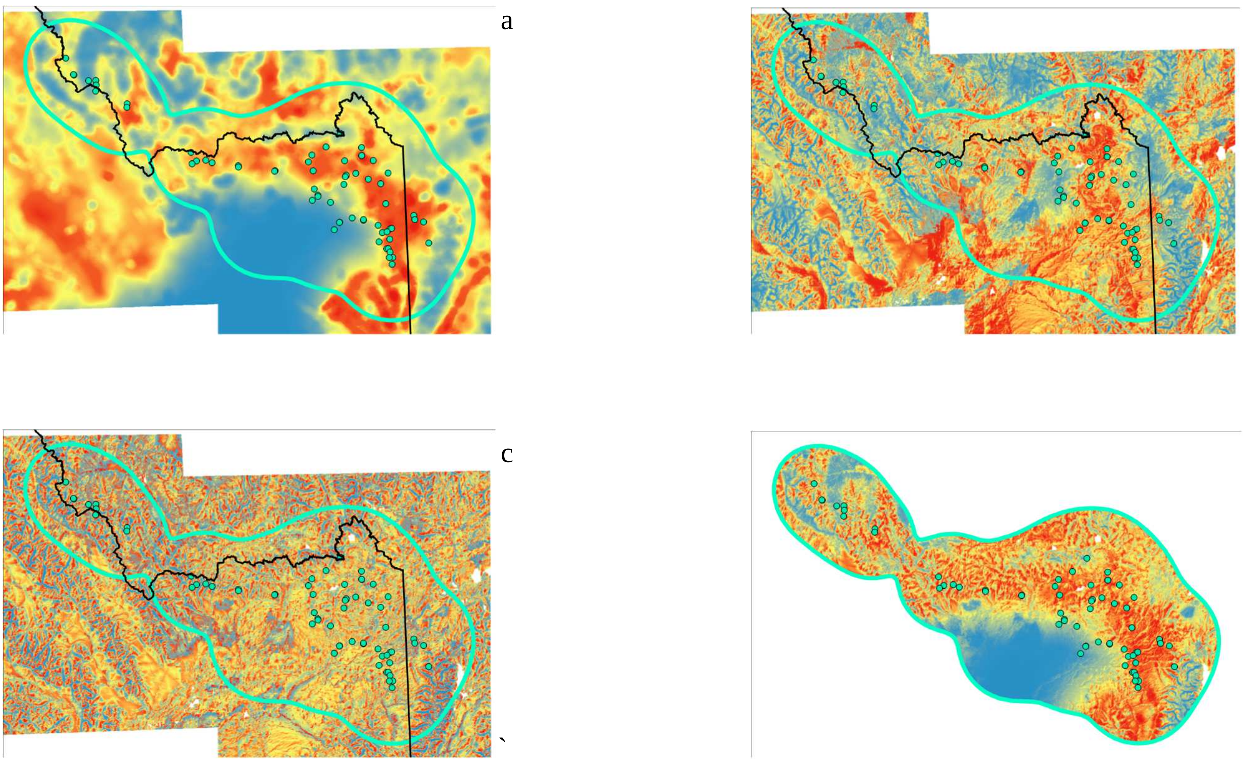


Figure 3. Predicted calving habitat for elk in the Southeast DryForest population in Idaho. For all panels, the relative probability ranges from 0 (blue) to 1 (red), blue outline is the population boundary and blue circles are the parturition locations. Panel (a) depicts population-scale selection (eqn 2 in Predictions section), panel (b) local-scale selection (eqn 3 in Predictions section), panel (c) relative local-scale selection conditional on having selected the general area at the population-scale (eqn 4 in Predictions section), and panel (d) relative probability of selection taking into account both population and local scale selection (eqn 5 in Predictions section).

Results

Of 314 partition events, most (64%) birth dates occurred during the last week of May through the first week of June (Table 1; Figure 4). Statewide, mean parturition date was 2 June with no substantial differences among most populations. The Southeast Desert population was approximately 1 week later than the other populations however, this could be due to a small sample size.

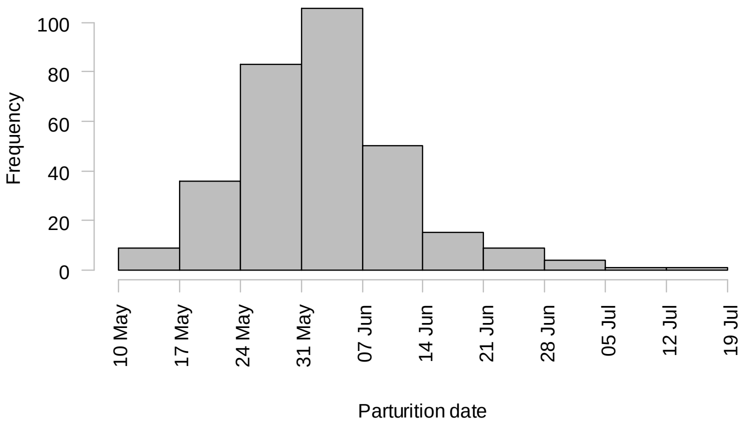


Figure 4. Histogram of parturition dates from 314 elk in Idaho, 2007-2020.

Beyond cover type, most of the best models for predicting calving habitat at the broad scale contained Elevation, Distance to snow covariates, and slope covariates (Table 4). At the local scale, there were few covariates that were consistently in the top model beyond the cover type and Distance to developed (Table 4). Most populations showed a strong preference for the Shrub covertype at both the broad and fine-scale (see subsections describing results for each population individual below).

Table 4. Relationship[1] between covariate values[2] and probability that a site will be selected for parturition based on the best predictive model for each population.

Population	Scale	Shrub	Herbaceous	Distance to developed[3]	Distance to snow[3]	Aspect	Elevation	Slope	TPI
Northern Forests	Broad	+	+	NA	-	W	600m	30	
North PineGrass	Broad	+	-	NA			1000m	40	
Central DryForest	Broad	+	+	NA	-				
SagebrushSteppe	Broad	+	+	NA	-	N	800m	10	
Southeast DryForest	Broad	+	-	NA	-				
Southeast DecidForest	Broad	+	-	NA			2200m	15	
Northern Forests	Local	+	+		NA				
North PineGrass	Local	+	+	+	NA				valley
Central DryForest	Local	+	+	+	NA				valley
SagebrushSteppe	Local	-	-	+	NA			20	
Southeast DryForest	Local	-	-	-	NA	N			ridge
Southeast DecidForest	Local	-	+	+	NA	S			

[1] Values in table indicate an increasing (+) or decreasing (-) change in the probability as the value of the covariate increases or the value most preferred for non-linear relationships.

[2] Shrub and herbaceous are the only cover types included in the table as they were included in candidate models for all populations.

[3] Distance to developed was not included as a potential covariate in the broad scale models because of potential confounding effects of capture location and a relatively high correlation (0.41) with slope. Distance to snow was not included in the local scale models because the spatial resolution was too coarse.

Results: Northern Forests

Of the 78 calving locations used for modeling the Northern Forests population, 42 were in the North Fork Clearwater, 17 in the St. Joe, 7 in Dworshak, 7 in the Lochsa, and 5 in the Coeur d'Alene drainages (Figure 5). At the broad scale, the probability that an area would be selected for halving a calf increased with increasing amounts of shrub and herbaceous cover, as slope approached ~30%, and western aspects; while the probability decreased with increasing elevation and distance to snow (Figure 6). At the fine scale, cover type were the only covariates retained in the best predictive model; the probability that an site would be selected increases by 3.1 times if it is in the Shrub cover type and by 3.6 times if it is in Herbaceous cover type.

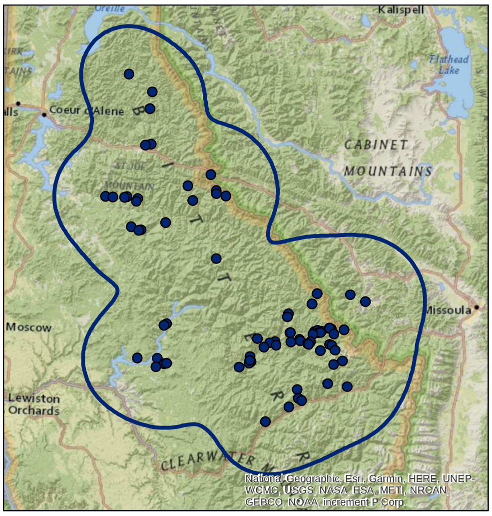


Figure 5. Parturition locations used to model calving habitat for the Northern Forests elk population.

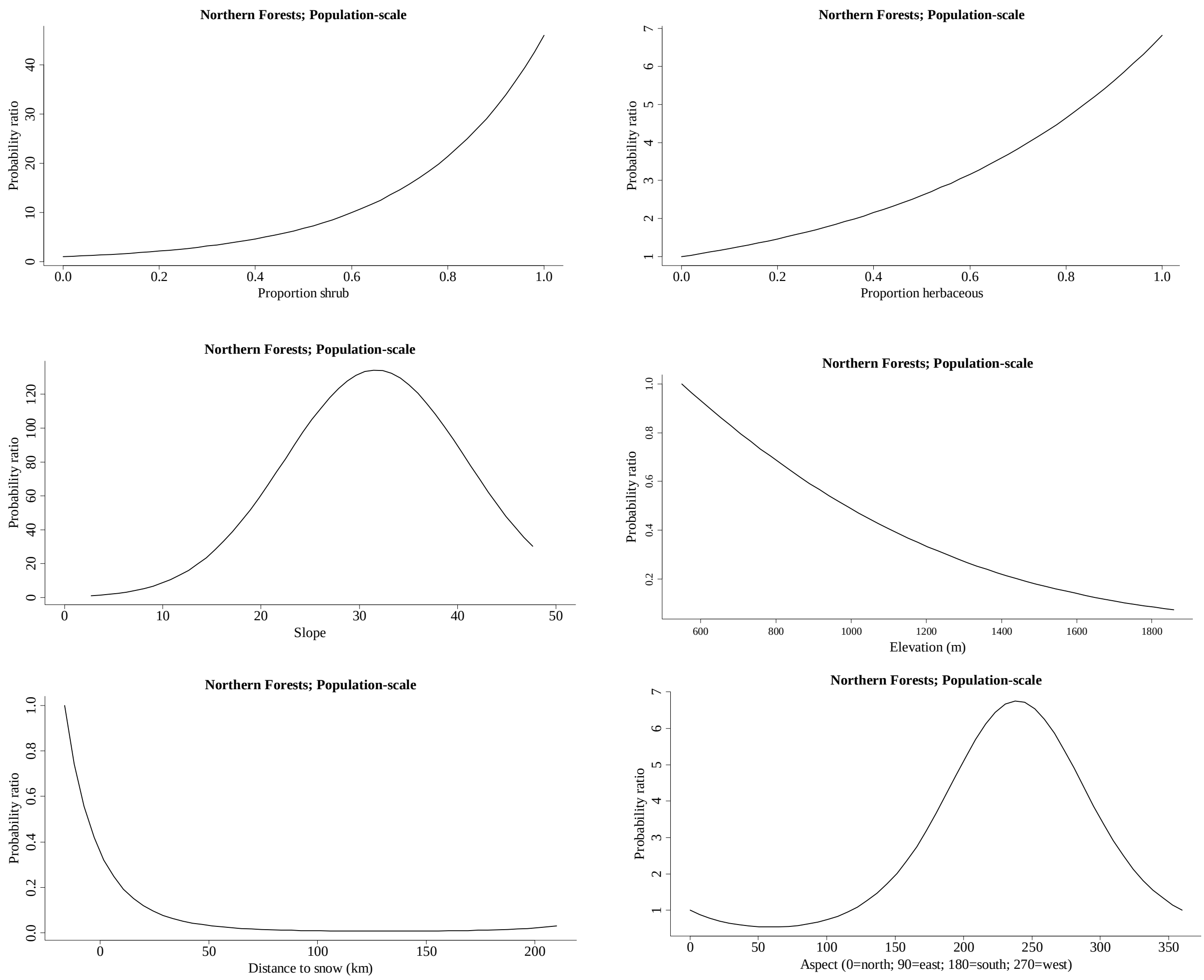
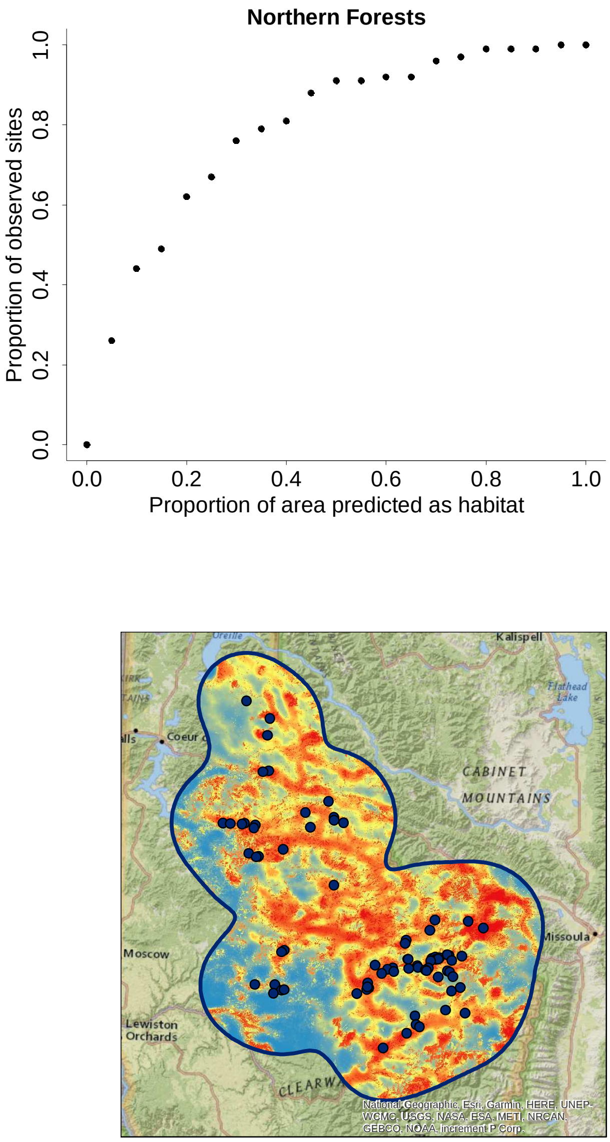


Figure 6. Relative change in the probability that an area will be selected as a parturition site at the broad-scale for covariates in the best predictive model.

The final model for predicting calving habitat, taking into account both broad and local-scale selection, performed well in terms of sensitivity (i.e., model predicts habitat where parturition sites occur) and specificity (i.e., model predicts non-habitat where parturition sites do not occur; Figure 7). A good model will have low values of the proportion of area predicted as habitat and high values of the proportion of observed parturition sites within the habitat, for a given RSF cutoff. For example, if an resource selection function (RSF) value of 0.0276 from eqn 5 is taken as a cutoff for defining calving habitat for Northern Forests (i.e., values greater than this threshold are defined as habitat), then 79% of the observed parturition sites occurred within the area defined as calving habitat which constitutes ~35% of the area within the population boundary (Figure 7).



RSF value	Proportion of area predicted as habitat	Proportion of observed parturition sites
1.0000	0	0
0.1020	0.05	0.26
0.0665	0.1	0.44
0.0491	0.15	0.49
0.0403	0.2	0.62
0.0348	0.25	0.67
0.0308	0.3	0.76
0.0276	0.35	0.79
0.0249	0.4	0.81
0.0225	0.45	0.88
0.0204	0.5	0.91
0.0185	0.55	0.91
0.0167	0.6	0.92
0.0151	0.65	0.92
0.0134	0.7	0.96
0.0116	0.75	0.97
0.0097	0.8	0.99
0.0076	0.85	0.99
0.0050	0.9	0.99
0.0024	0.95	1
0.0000	1	1

Figure 7. Performance of the best model for predicting calving habitat of elk from the Northern Forests population in Idaho. Plot (top left) shows the sensitivity on the y-axis (model predicts habitat where parturition sites occur) versus the specificity on the x-axis (model predicts non-habitat where parturition sites do not occur) for particular values of the RSF used as a cutoff for defining habitat. As there is a tradeoff between sensitivity and specificity that is dependent on objectives, the table (top right) provides values of the RSF that can be used as a cutoff to provide the desired level of sensitivity versus specificity.

Results: North PineGrass

Of the 29 calving locations used for modeling the North PineGrass population, 20 were in the South Fork Clearwater drainage and 9 were from Craig Mounatin (Figure 8). At the broad scale, the probability that an area would be selected for halving a calf increased with increasing amounts of shrub cover and decreased with increasing amounts of herbaceous cover; increased with increasing slope; and increased as elevation approached ~1000m (Figure 9).

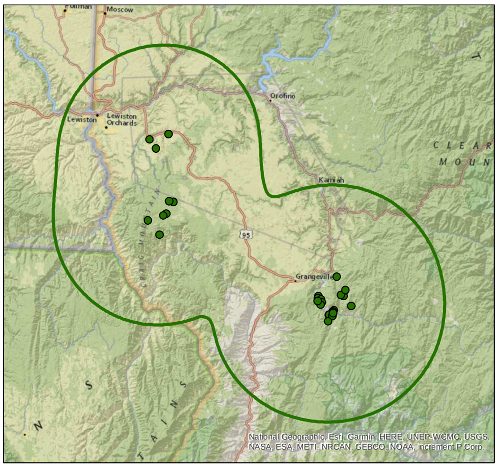


Figure 8. Parturition locations used to model calving habitat for the North PineGrass elk population.

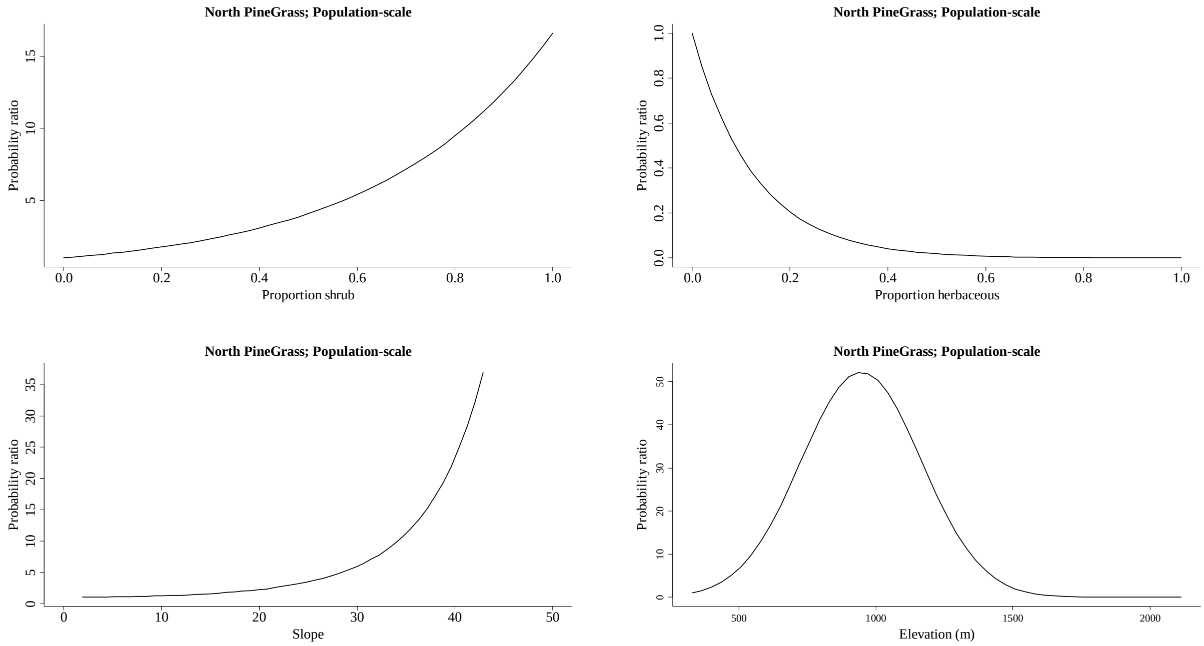
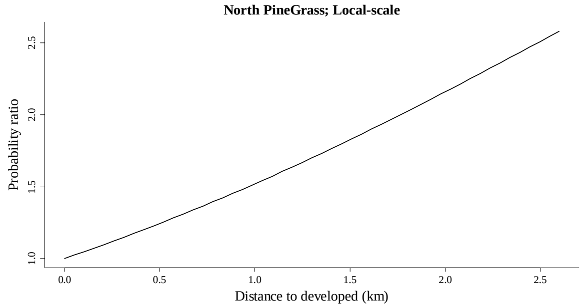


Figure 9. Relative change in the probability that an area will be selected as a parturition site at the broad-scale for covariates in the best predictive model.

At the fine scale, the probability that an site would be selected decreased by 0.67 if it is in the Shrub cover type; increased by 1.46 times if it is in Herbaceous cover type; increased with increasing distance to developed; and increased as topographic position index approached ~-150 indicating preference for valleys (Figure 10).



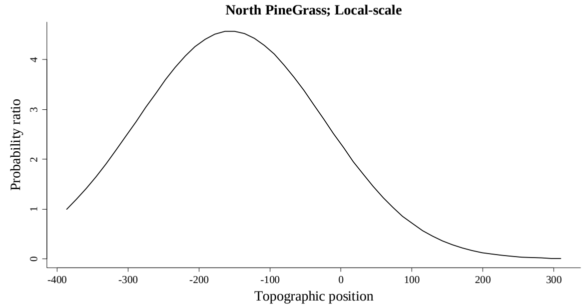
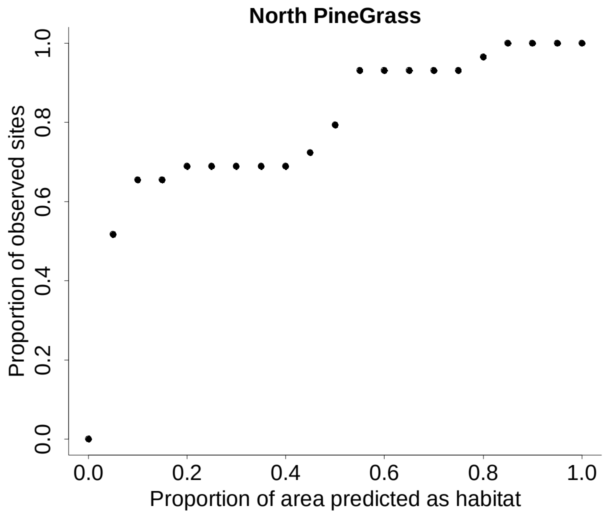


Figure 10. Relative change in the probability that site will be selected for parturition at the local scale for covariates in the best predictive model. Topographic position values range from negative (valleys) to 0 (side slope) to positive (ridgelines). The more negative the value, the steeper the valley (e.g., canyon), and the more positive the value, the sharper the ridgeline.

The final model for predicting calving habitat, taking into account both broad and local-scale selection, performed moderately in terms of sensitivity (i.e., model predicts habitat where parturition sites occur) and specificity (i.e., model predicts non-habitat where parturition sites do not occur; Figure 11). A good model will have low values of the proportion of area predicted as habitat and high values of the proportion of observed parturition sites within the habitat, for a given RSF cutoff. For example, if an resource selection function (RSF) value of 0.00122 from eqn 5 is taken as a cutoff for defining calving habitat for the North PineGrass population (i.e., values greater than this threshold are defined as habitat), then 93% of the observed parturition sites occurred within the area defined as calving habitat which constitutes ~55% of the area within the population boundary (Figure 11). Performance would likely increase with larger sample sizes (greater number of observed parturition sites). Additionally, the model appeared to perform better for elk in the South Fork Clearwater drainage than those on Craig Mountain (see Figure 11) suggesting that separate models might be needed in the future as sample sizes for each group increase sufficiently.



RSF value	Proportion of area predicted as habitat	Proportion of observed parturition sites
1.00000	0	0
0.02283	0.05	0.52
0.01111	0.1	0.66
0.00874	0.15	0.66
0.00685	0.2	0.69
0.00534	0.25	0.69
0.00422	0.3	0.69
0.00330	0.35	0.69
0.00255	0.4	0.69
0.00199	0.45	0.72
0.00157	0.5	0.79
0.00122	0.55	0.93
0.00093	0.6	0.93
0.00069	0.65	0.93
0.00048	0.7	0.93
0.00032	0.75	0.93
0.00019	0.8	0.97
0.00010	0.85	1
0.00004	0.9	1
0.00001	0.95	1
0.00000	1	1

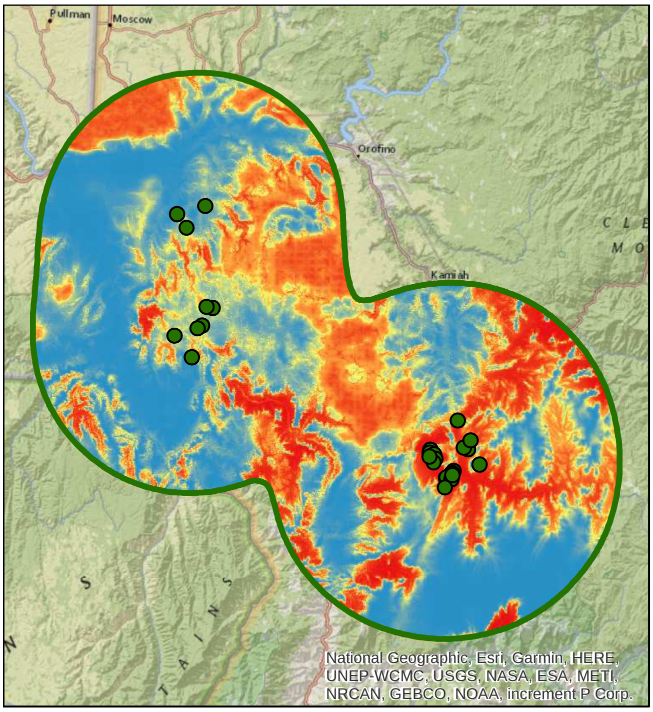
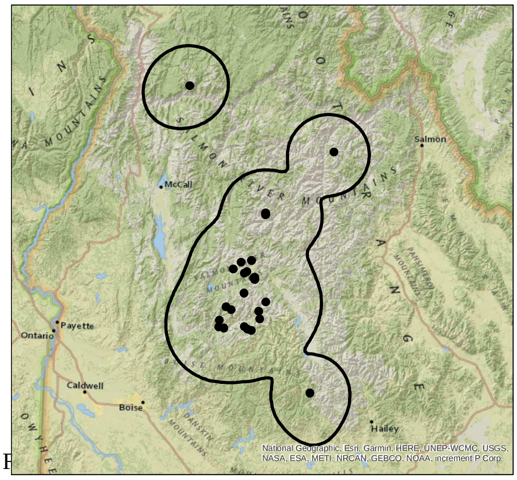


Figure 11. Performance of the best model for predicting calving habitat of elk from the Northern Forests population in Idaho. Plot (top left) shows the sensitivity on the y-axis (model predicts habitat where parturition sites occur) versus the specificity on the x-axis (model predicts non-habitat where parturition sites do not occur) for particular values of the RSF used as a cutoff for defining habitat. As there is a tradeoff between sensitivity and specificity that is dependent on objectives, the table (top right) provides values of the RSF that can be used as a cutoff to provide the desired level of sensitivity versus specificity.

Results: Central DryForest

Of the 26 calving locations used for modeling the Central DryForest population, most (21) were near the South Fork Payette river (Figure 12). At the broad scale, the probability that an area would be selected for halving a calf increased with increasing amounts of shrub cover and herbaceous cover; and increased near the snow edge (Figure 13).



F
habitat for the Central DryForest elk population.

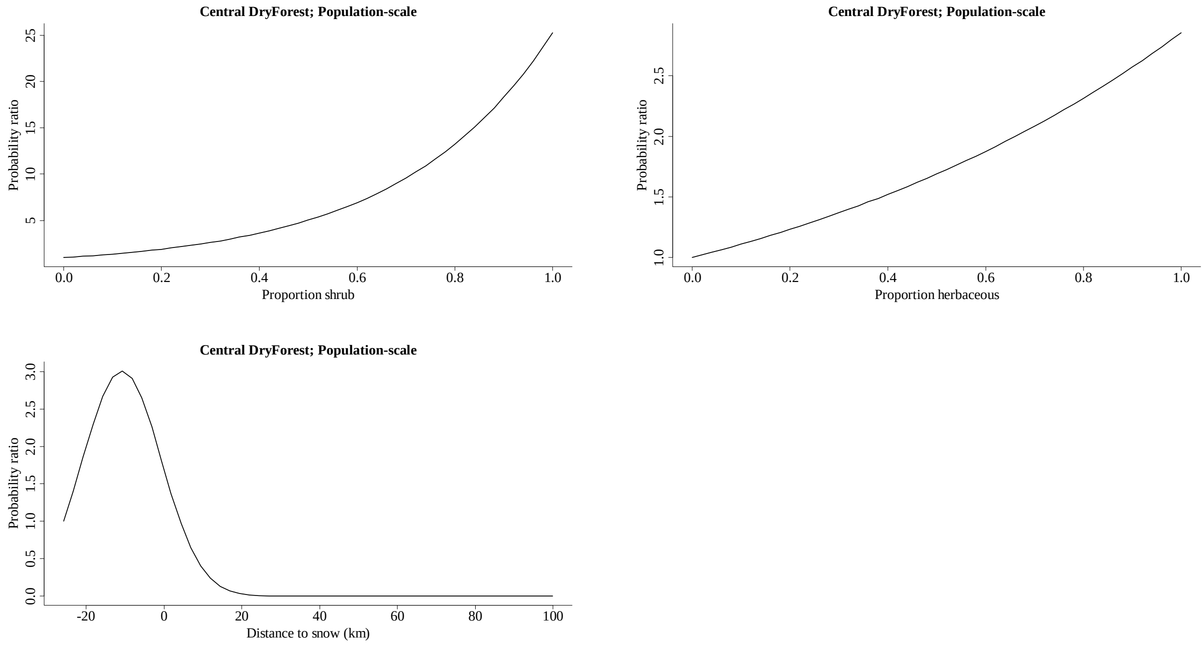


Figure 13. Relative change in the probability that an area will be selected as a parturition site at the broad-scale for covariates in the best predictive model.

At the fine scale, the probability that an site would be selected increased by 3.1 times if it is in the Shrub cover type and by 2.9 times if it is in Herbaceous cover type; increased with increasing distance to developed; and increased as topographic position index approached ~-220 indicating preference for valleys (Figure 14).

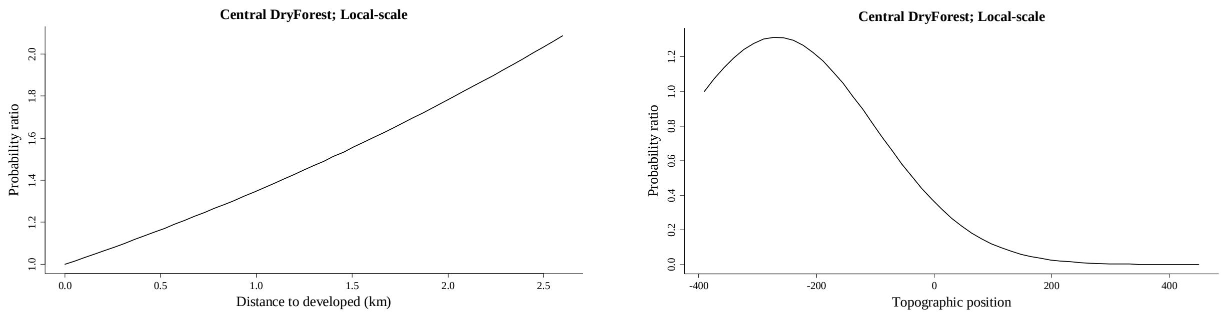
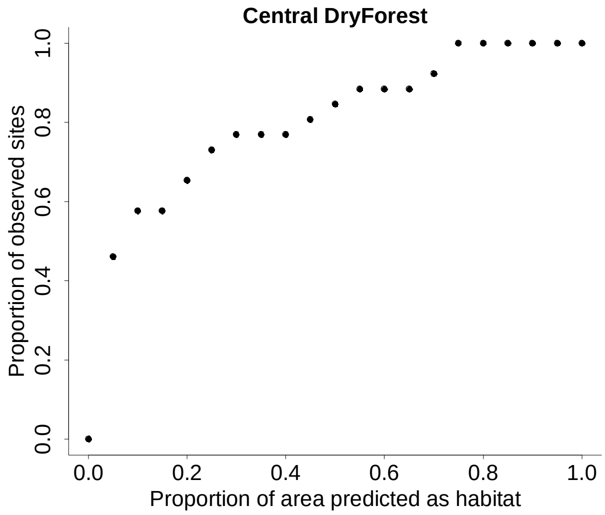


Figure 14. Relative change in the probability that site will be selected for parturition at the local scale for covariates in the best predictive model. Topographic position values range from negative (valleys) to 0 (side slope) to positive (ridgelines). The more negative the value, the steeper the valley (e.g., canyon), and the more positive the value, the sharper the ridgeline.

The final model for predicting calving habitat, taking into account both broad and local-scale selection, performed well in terms of sensitivity (i.e., model predicts habitat where parturition sites occur) and specificity (i.e., model predicts non-habitat where parturition sites do not occur; Figure 15). A good model will have low values of the proportion of area predicted as habitat and high values of the proportion of observed parturition sites within the habitat, for a given RSF cutoff. For example, if an resource selection function (RSF) value of 0.01953 from eqn 5 is taken as a cutoff for defining calving habitat for the Central DryForest population (i.e., values greater than this threshold are defined as habitat), then 77% of the observed parturition sites occurred within the area defined as calving habitat which constitutes ~30% of the area within the population boundary (Figure 15).



RSF value	Proportion of area predicted as habitat	Proportion of observed parturition sites
1.00000	0	0
0.10485	0.05	0.46
0.06379	0.1	0.58
0.04435	0.15	0.58
0.03262	0.2	0.65
0.02491	0.25	0.73
0.01953	0.3	0.77
0.01551	0.35	0.77
0.01234	0.4	0.77
0.00985	0.45	0.81
0.00787	0.5	0.85
0.00627	0.55	0.88
0.00493	0.6	0.88
0.00380	0.65	0.88
0.00282	0.7	0.92
0.00202	0.75	1
0.00138	0.8	1
0.00089	0.85	1
0.00049	0.9	1
0.00021	0.95	1
0.00000	1	1

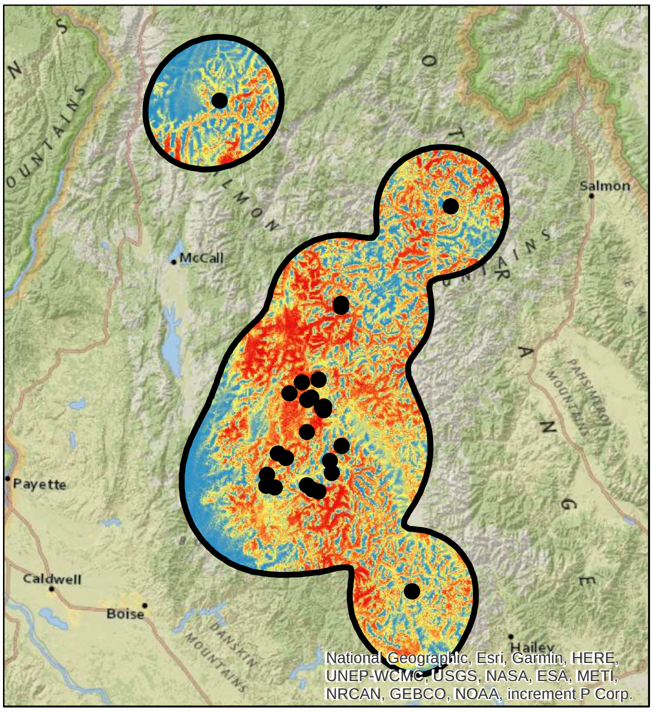
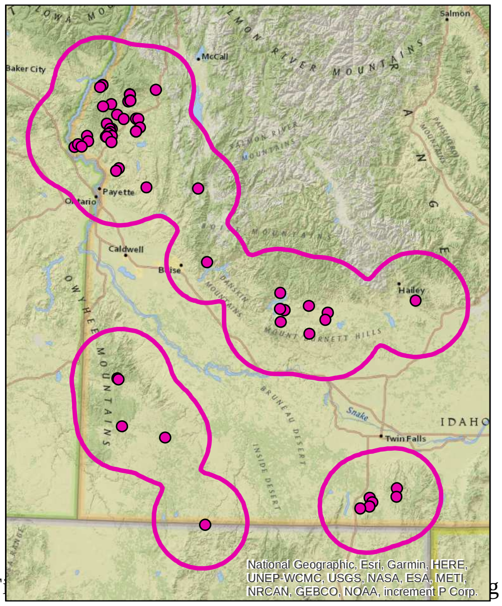


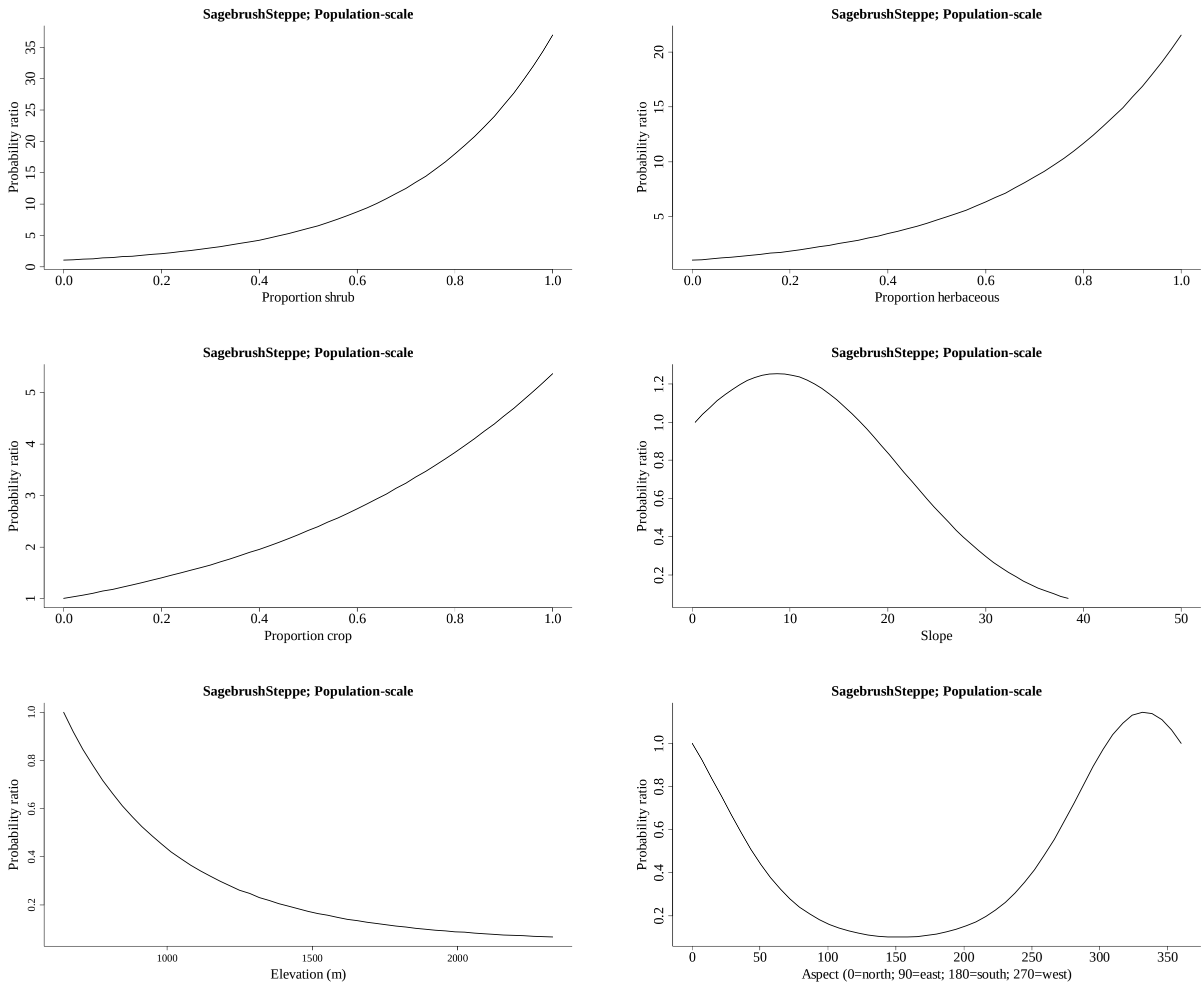
Figure 15. Performance of the best model for predicting calving habitat of elk from the Central DryForest population in Idaho. Plot (top left) shows the sensitivity on the y-axis (model predicts habitat where parturition sites occur) versus the specificity on the x-axis (model predicts non-habitat where parturition sites do not occur) for particular values of the RSF used as a cutoff for defining habitat. As there is a tradeoff between sensitivity and specificity that is dependent on objectives, the table (top right) provides users values of the RSF that can be used as a cutoff to provide the desired level of sensitivity versus specificity.

Results: SagebrushSteppe

Of the 57 calving locations used for modeling the SagebrushSteppe population, most (46) were along the northern edge of the Snake River plain (Figure 16). At the broad scale, the probability that an area would be selected for halving a calf increased with increasing amounts of shrub herbaceous, and crop cover; increased as slope approached ~10%; decreased with increasing elevation; increased on northerly aspects; increased near the snow edge; and generally decreased with increasing distance to the snow edge (Figure 17).



Fi g habitat for the SagebrushSteppe elk population.



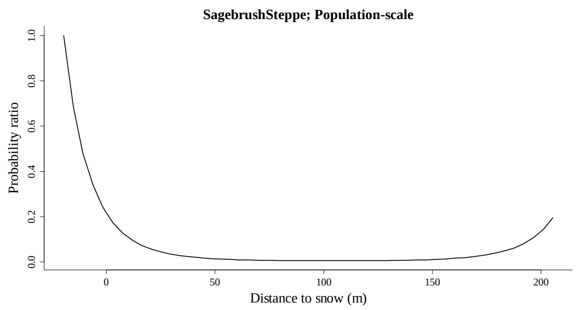
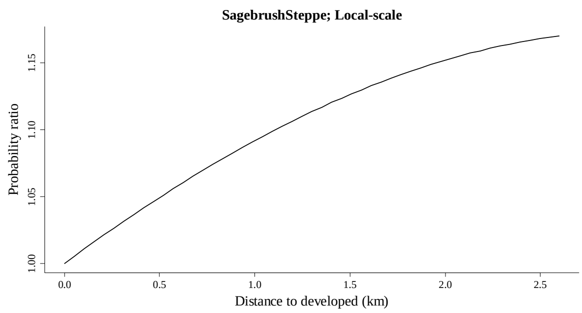


Figure 17. Relative change in the probability that an area will be selected as a parturition site at the broad-scale for covariates in the best predictive model.

At the fine scale, the probability that an site would be selected decreased by 0.82 times if it is in the Shrub cover type, by 0.57 times if it is in Herbaceous cover type, and increased by 1.95 times if in the Crop covertype; increased with increasing distance to developed; and increased as slope approached ~20% (Figure 18).



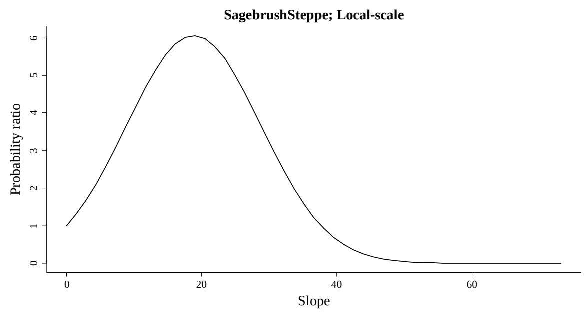
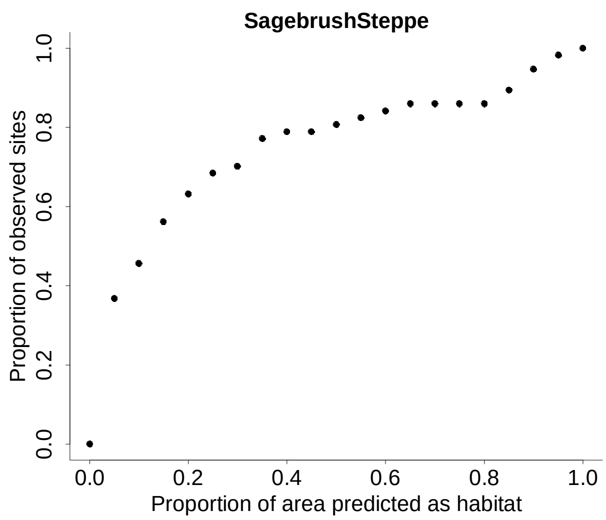


Figure 18. Relative change in the probability that site will be selected for parturition at the local scale for covariates in the best predictive model.

The final model for predicting calving habitat, taking into account both broad and local-scale selection, performed moderately in terms of sensitivity (i.e., model predicts habitat where parturition sites occur) and specificity (i.e., model predicts non-habitat where parturition sites do not occur; Figure 19). A good model will have low values of the proportion of area predicted as habitat and high values of the proportion of observed parturition sites within the habitat, for a given RSF cutoff. For example, if an resource selection function (RSF) value of 0.02141 from eqn 5 is taken as a cutoff for defining calving habitat for the SagebrushSteppe population (i.e., values greater than this threshold are defined as habitat), then 79% of the observed parturition sites occurred within the area defined as calving habitat which constitutes ~40% of the area within the population boundary (Figure 19). The model performed better for elk north of the Snake River plain (where most of the parturition sites occurred) than those to the south (see Figure 19) suggesting that separate models might be needed in the future as sample sizes for each group increase sufficiently.



RSF value	Proportion of area predicted as habitat	Proportion of observed parturition sites
1.00000	0	0
0.09093	0.05	0.37
0.06148	0.1	0.46
0.04834	0.15	0.56
0.03997	0.2	0.63
0.03378	0.25	0.68
0.02884	0.3	0.7
0.02483	0.35	0.77
0.02141	0.4	0.79
0.01844	0.45	0.79
0.01580	0.5	0.81
0.01348	0.55	0.82
0.01143	0.6	0.84
0.00966	0.65	0.86
0.00815	0.7	0.86
0.00678	0.75	0.86
0.00551	0.8	0.86
0.00433	0.85	0.89
0.00310	0.9	0.95
0.00159	0.95	0.98
0.00000	1	1

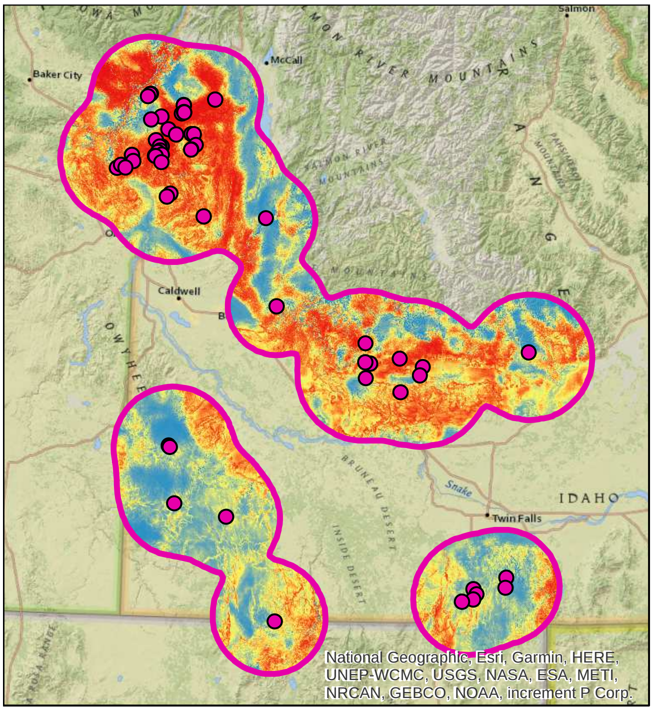
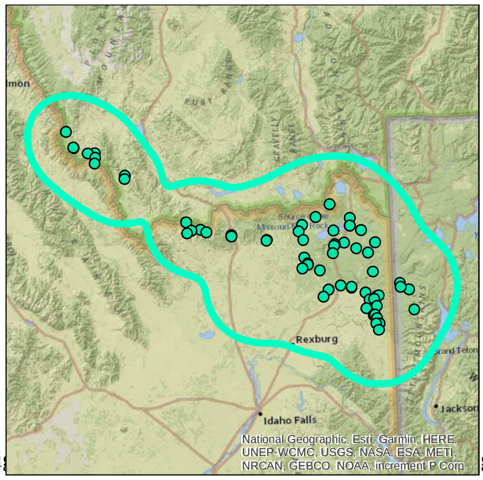


Figure 19. Performance of the best model for predicting calving habitat of elk from the SagebrushSteppe population in Idaho. Plot (top left) shows the sensitivity on the y-axis (model predicts habitat where parturition sites occur) versus the specificity on the x-axis (model predicts non-habitat where parturition sites do not occur) for particular values of the RSF used as a cutoff for defining habitat. As there is a tradeoff between sensitivity and specificity that is dependent on objectives, the table (top right) provides values of the RSF that can be used as a cutoff to provide the desired level of sensitivity versus specificity.

Results: Southeast DryForest

Of the 65 calving locations used for modeling the Southeast DryForest population, most (45) were in the Island Park Zone (Figure 20). At the broad scale, the probability that an area would be selected for halving a calf increased with increasing amounts of shrub, deciduous forest, and woody wetland cover and decreased with the amount of herbaceous cover; increased as distance to snow edge approached ~10km (Figure 21).



Fi g
habitat for the Southeast DryForest elk population.

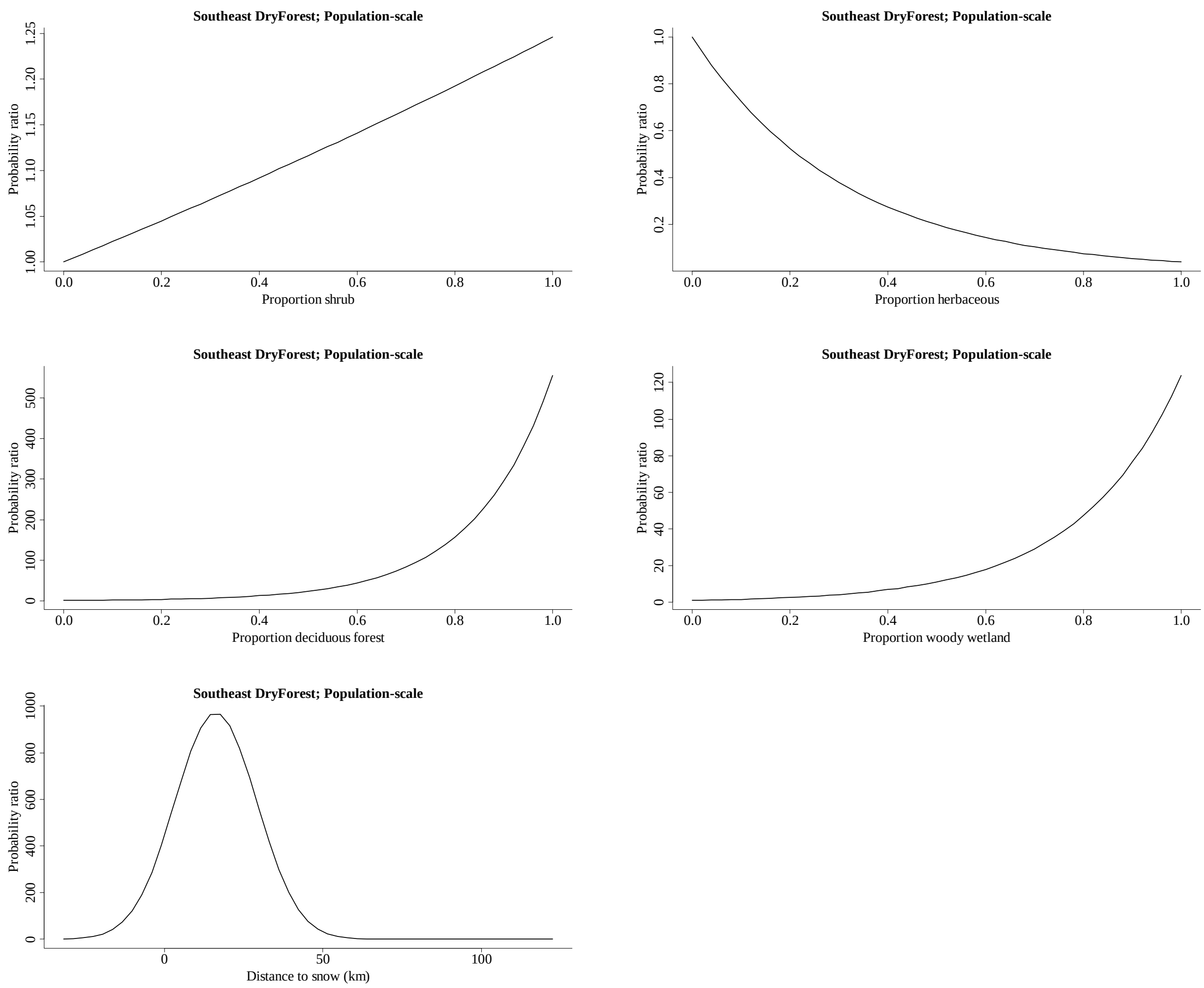


Figure 21. Relative change in the probability that an area will be selected as a parturition site at the broad-scale for covariates in the best predictive model.

At the fine scale, the probability that an site would be selected decreased by 0.62 times if it is in the Shrub cover type, by 0.13 times if it is in Herbaceous cover type, and increased by 1.4 times if in the Deciduous forest covertype and 4.6 times if in the Woody wetland cover type; increased for northerly aspects; decreased with increasing distance to developed; and increased as as topographic position approached 100, indicating a preference for ridgelines (Figure 22).

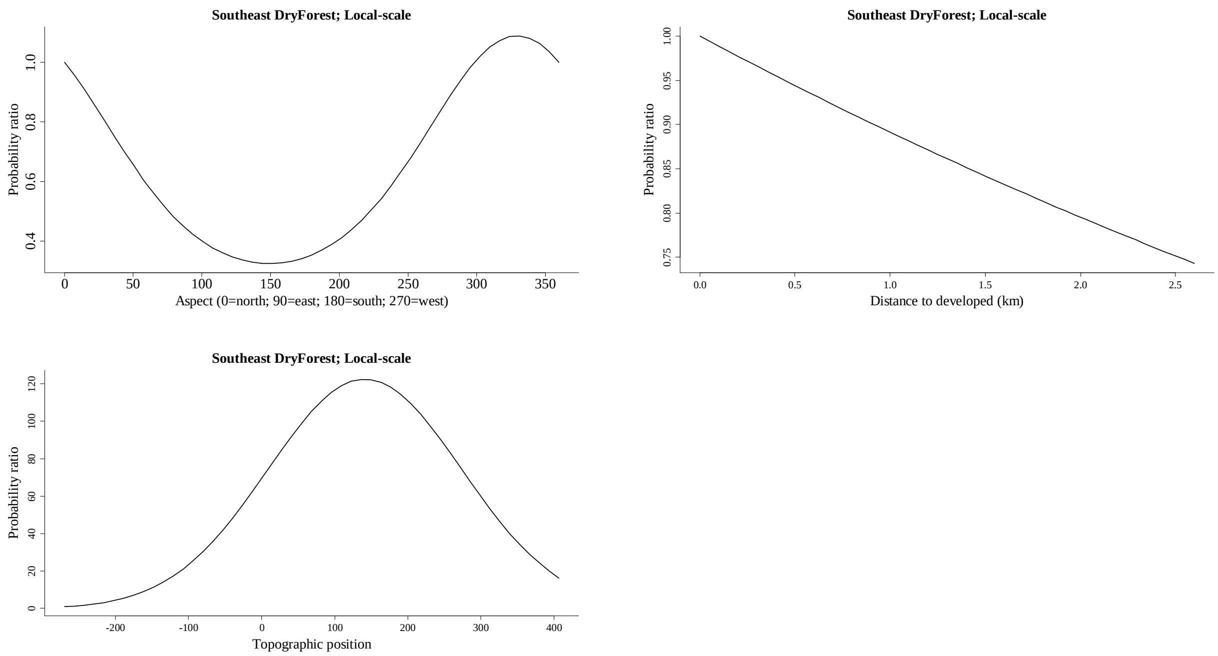
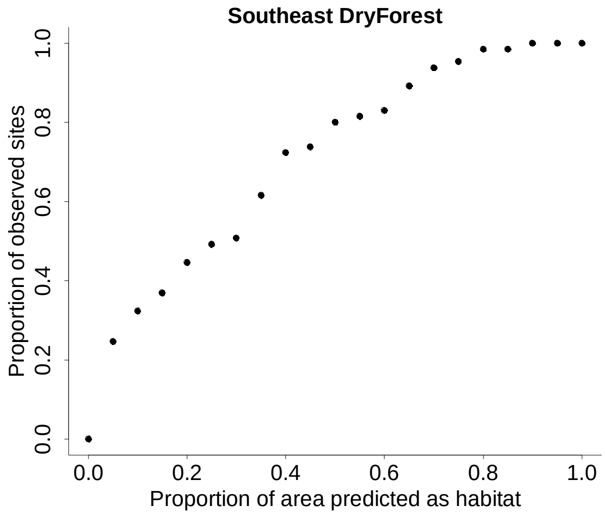


Figure 22. Relative change in the probability that site will be selected for parturition at the local scale for covariates in the best predictive model. Topographic position values range from negative (valleys) to 0 (side slope) to positive (ridgelines). The more negative the value, the steeper the valley (e.g., canyon), and the more positive the value, the sharper the ridgeline.

The final model for predicting calving habitat, taking into account both broad and local-scale selection, performed moderately well in terms of sensitivity (i.e., model predicts habitat where parturition sites occur) and specificity (i.e., model predicts non-habitat where parturition sites do not occur; Figure 23). A good model will have low values of the proportion of area predicted as habitat and high values of the proportion of observed parturition sites within the habitat, for a given RSF cutoff. For example, if an resource selection function (RSF) value of 0.01806 from eqn 5 is taken as a cutoff for defining calving habitat for the Southeast DryForest population (i.e., values greater than this threshold are defined as habitat), then 80% of the observed parturition sites occurred within the area defined as calving habitat which constitutes ~50% of the area within the population boundary (Figure 23).



RSF value	Proportion of area predicted as habitat	Proportion of observed parturition sites
1.00000	0	0
0.06486	0.05	0.25
0.05044	0.1	0.32
0.04265	0.15	0.37
0.03722	0.2	0.45
0.03301	0.25	0.49
0.02945	0.3	0.51
0.02630	0.35	0.62
0.02337	0.4	0.72
0.02068	0.45	0.74
0.01806	0.5	0.8
0.01547	0.55	0.82
0.01286	0.6	0.83
0.01026	0.65	0.89
0.00772	0.7	0.94
0.00532	0.75	0.95
0.00326	0.8	0.98
0.00184	0.85	0.98
0.00070	0.9	1
0.00009	0.95	1
0.00000	1	1

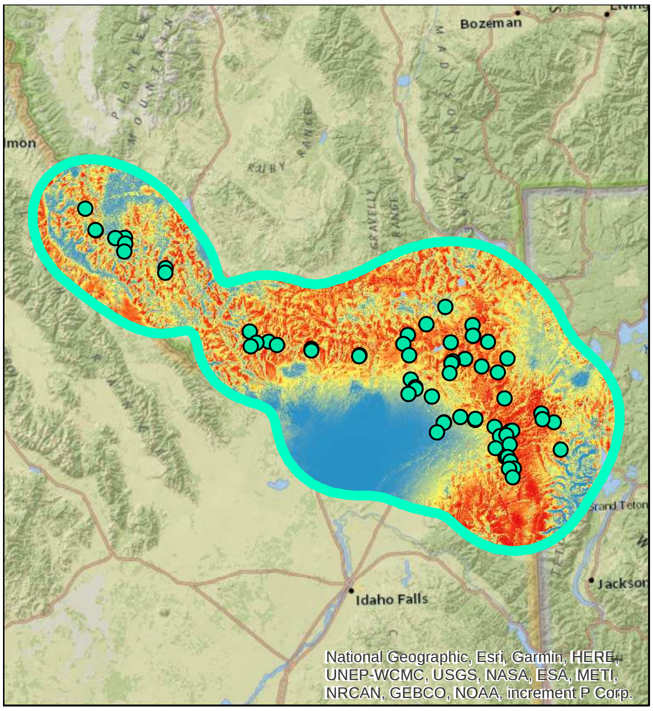
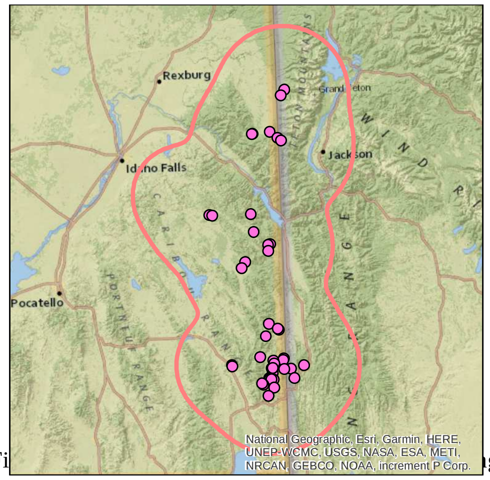


Figure 23. Performance of the best model for predicting calving habitat of elk from the Southeast DryForest population in Idaho. Plot (top left) shows the sensitivity on the y-axis (model predicts habitat where parturition sites occur) versus the specificity on the x-axis (model predicts non-habitat where parturition sites do not occur) for particular values of the RSF used as a cutoff for defining habitat. As there is a tradeoff between sensitivity and specificity that is dependent on objectives, the table (top right) provides users values of the RSF that can be used as a cutoff to provide the desired level of sensitivity versus specificity.

Results: Southeast DecidForest

Of the 42 calving locations used for modeling the Southeast DecidForest population, most (26) were in the Diamond Creek area (Figure 24). At the broad scale, the probability that an area would be selected for halving a calf increased with increasing amounts of shrub and deciduous forest cover, and decreased with the amount of herbaceous cover; increased as slope approached ~15%, increased elevation approached ~2100m (Figure 25).



Fi g
habitat for the Southeast DryForest elk population.

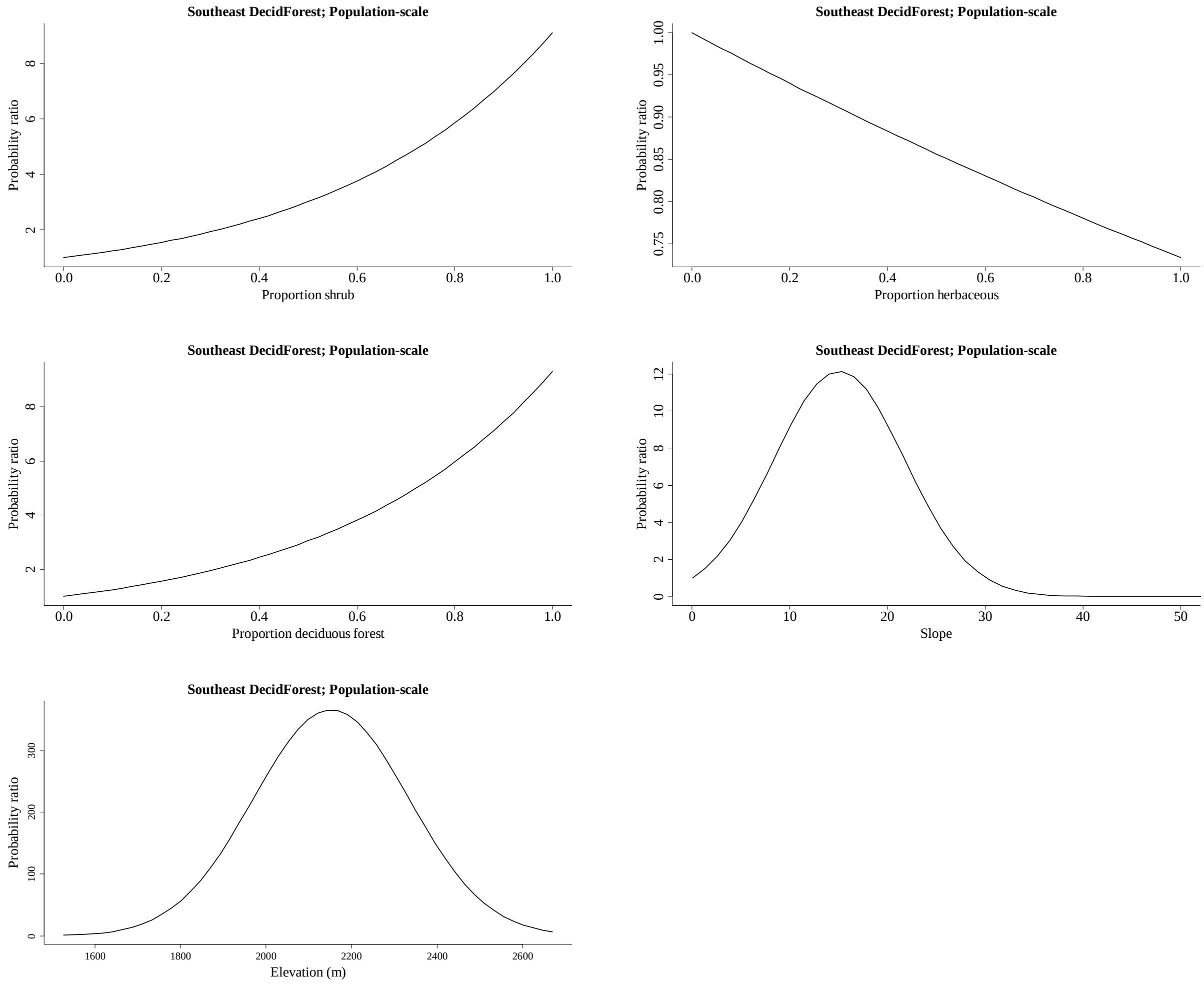


Figure 25. Relative change in the probability that an area will be selected as a parturition site at the broad-scale for covariates in the best predictive model.

At the fine scale, the probability that an site would be selected decreased by 0.74 times if it is in the Shrub cover type, increased by 4.13 times if it is in Herbaceous cover type, and increased by 1.4 times if in the Deciduous forest cover type; increased for southerly aspects; and increased with increasing distance to developed(Figure 26).

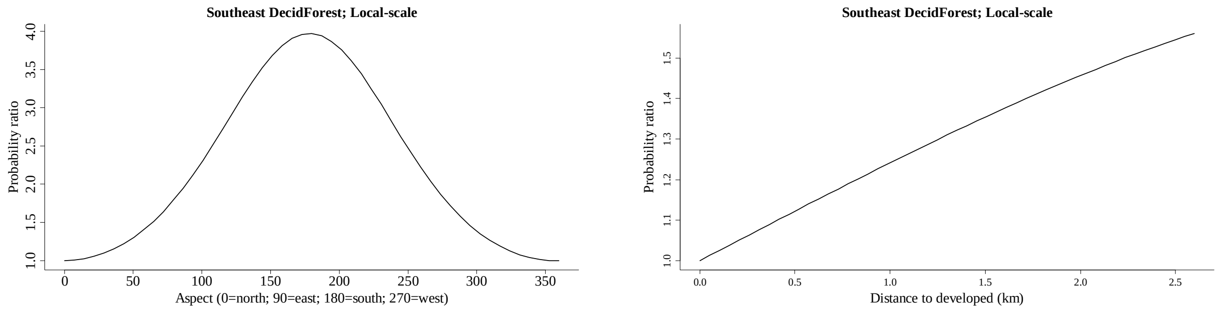
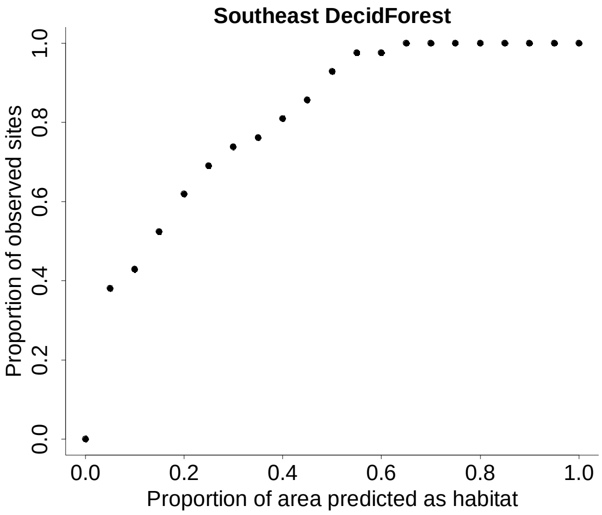


Figure 26. Relative change in the probability that site will be selected for parturition at the local scale for covariates in the best predictive model.

The final model for predicting calving habitat, taking into account both broad and local-scale selection, performed well in terms of sensitivity (i.e., model predicts habitat where parturition sites occur) and specificity (i.e., model predicts non-habitat where parturition sites do not occur; Figure 27). A good model will have low values of the proportion of area predicted as habitat and high values of the proportion of observed parturition sites within the habitat, for a given RSF cutoff. For example, if an resource selection function (RSF) value of 0.01079 from eqn 5 is taken as a cutoff for defining calving habitat for the Southeast DryForest population (i.e., values greater than this threshold are defined as habitat), then 81% of the observed parturition sites occurred within the area defined as calving habitat which constitutes ~40% of the area within the population boundary.



RSF value	Proportion of area predicted as habitat	Proportion of observed parturition sites
1.00000	0	0
0.06419	0.05	0.38
0.04324	0.1	0.43
0.03268	0.15	0.52
0.02574	0.2	0.62
0.02068	0.25	0.69
0.01669	0.3	0.74
0.01349	0.35	0.76
0.01079	0.4	0.81
0.00850	0.45	0.86
0.00650	0.5	0.93
0.00482	0.55	0.98
0.00343	0.6	0.98
0.00229	0.65	1
0.00145	0.7	1
0.00089	0.75	1
0.00052	0.8	1
0.00030	0.85	1
0.00016	0.9	1
0.00006	0.95	1
0.00000	1	1

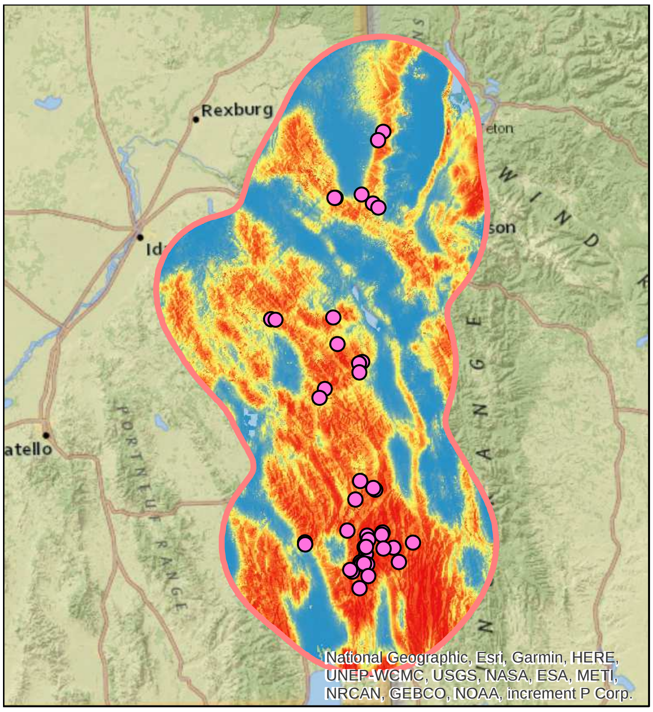


Figure 27. Performance of the best model for predicting calving habitat of elk from the Southeast DryForest population in Idaho. Plot (top left) shows the sensitivity on the y-axis (model predicts habitat where parturition sites occur) versus the specificity on the x-axis (model predicts non-habitat where parturition sites do not occur) for particular values of the RSF used as a cutoff for defining habitat. As there is a tradeoff between sensitivity and specificity that is dependent on objectives, the table (top right) provides users values of the RSF that can be used as a cutoff to provide the desired level of sensitivity versus specificity.

Discussion

The goal of this analysis was to provide managers with a quantitative prediction of elk calving habitat statewide. It is important to understand that this analysis was not the result of a designed research project, but an attempt to make use available data to provide information that several managers have sought for years. Because we did not collect data specifically for modeling calving habitat, this imposed some limitations on our results. For example, we were unable to evaluate the influence of Distance to developed areas at the broad scale due to capture locations; and some populations may have been limited by sample size. Despite these limitations, most models of predicted calving habitat performed moderately to well and should be useful for many applications.

In general, the effect of individual covariates on the probability that an area will be selected as a parturition site should be interpreted independently for each population. However, there were several consistent effects across populations. At the broad scale, most populations selected areas with higher amounts of shrub cover with moderate to steep slopes close to the snow line. Aspect was included in 2 of the top models at the broad scale with elk in Northern Forests selecting for south-westerly aspects while elk in the SagebrushSteppe selected for northerly aspects. We suspect the difference in preferred aspects is related to the lushness of the vegetation for these populations during late-May and early-June. While topographic position was not included in any of the top models at the broad scale, it was included for 3 of the 6 populations at the local scale, suggesting that the effect is likely more localized and might be related to localized vegetation characteristics.

As a final note on assessing the validity of model predictions for a particular population, we wanted to to convey the following ideas. We evaluated model performance using measures of sensitivity (i.e., model predicts habitat where parturition sites occur) versus specificity (i.e., model predicts non-habitat where parturition sites do not occur). Using this measure, a highly predictive model would have high success predicting actual parturition sites while simultaneously excluding large areas within the population boundary as calving habitat. It is important to realize that a model can be deemed to perform poorly if there are no strong habitat preferences within the population or if preferred habitat is ubiquitous on the landscape. This result does not necessarily suggest a failure in the data or modeling approach, it is simply a reflection of the fact that calving habitat may constitute a large proportion of the area considered available. Assuming that there are strong preferences and that preferred habitat constitutes a small proportion of the landscape, a model can perform poorly for a variety of reasons. Probably the most likely reasons specific for this project is either small sample sizes, a failure to include important covariates or model structures (e.g., covariate combinations), or misidentification of population membership (e.g., lumping elk into a single population that should be separated or not including elk in a particular population for which they are more similar than the population that they were assigned). Additionally, we simplified our predictions by using the most recent NLCD data (i.e., 2019) and the mean snow cover on June 1 (across all years). Thus, our predictions do not necessarily match the year and time when our observed parturition events occurred and our evaluation of model performance should be viewed as a minimum level of performance.

Moving forward, it is likely that IDFG will want to update or expand these analyses in the future. We hope that this report will provide managers with a foundation for developing ideas and approaches to communicate with research so that the next round will be an improvement not only in terms of increasing sample size.

Appendix

Best Models

Population	Scale	Model
NorthernForests	Population	case~prop_He+prop_Sh+DistToSnow+DistToSnow_2+Asp_Sine+Asp_Cos+Elevation+Elevation_2+Slope+Slope_2+strata(ID_Year)
North_PondPineGrass	Population	case~Dist_D+Dist_D_2+prop_He+prop_Sh+prop_DF+Elevation+Elevation_2+Slope+Slope_2+strata(ID_Year)
DryForest_Central	Population	case~Dist_D+Dist_D_2+prop_He+prop_Sh+DistToSnow+DistToSnow_2+Asp_Sine+Asp_Cos+strata(ID_Year)
SagebrushSteppe	Population	case~Dist_D+Dist_D_2+prop_He+prop_Sh+prop_Cr+DistToSnow+DistToSnow_2+Asp_Sine+Asp_Cos+Elevation+Elevation_2+Slope+Slope_2+strata(ID_Year)
DryForest_Southeast	Population	case~Dist_D+Dist_D_2+prop_He+prop_Sh+prop_DF+prop_WW+DistToSnow+DistToSnow_2+strata(ID_Year)
DecidForest_South	Population	case~Dist_D+Dist_D_2+prop_He+prop_Sh+prop_DF+Elevation+Elevation_2+Slope+Slope_2+strata(ID_Year)
NorthernForests	Local	case~NLCD_type+strata(ID_Year)
North_PondPineGrass	Local	case~Dist_D+Dist_D_2+NLCD_type+TPI+TPI_2+strata(ID_Year)
DryForest_Central	Local	case~Dist_D+Dist_D_2+NLCD_type+TPI+TPI_2+strata(ID_Year)
SagebrushSteppe	Local	case~Dist_D+Dist_D_2+NLCD_type+Slope+Slope_2+strata(ID_Year)
DryForest_Southeast	Local	case~Dist_D+Dist_D_2+NLCD_type+Asp_Sine+Asp_Cos+TPI+TPI_2+strata(ID_Year)
DecidForest_South	Local	case~Dist_D+Dist_D_2+NLCD_type+Asp_Sine+Asp_Cos+strata(ID_Year)

Results of population-scale model selection.

Population	Scale	Model	n_event	LL	AIC	delt_AIC	Weight
NorthernForests	Population	case~prop_He+prop_Sh+DistToSnow+DistToSnow_2+Asp_Sine+Asp_Cos+Elevation+Elevation_2+Slope+Slope_2+strata(ID_Year)	78	-416.9	853.8	0.0	0.45
NorthernForests	Population	case~prop_He+prop_Sh+DistToSnow+DistToSnow_2+Elevation+Elevation_2+Slope+Slope_2+strata(ID_Year)	78	-419.1	854.1	0.3	0.38
NorthernForests	Population	case~prop_He+prop_Sh+Elevation+Elevation_2+Slope+Slope_2+strata(ID_Year)	78	-423.0	857.9	4.2	0.06
NorthernForests	Population	case~prop_He+prop_Sh+Asp_Sine+Asp_Cos+Slope+Slope_2+strata(ID_Year)	78	-423.1	858.2	4.4	0.05
NorthernForests	Population	case~prop_He+prop_Sh+Slope+Slope_2+strata(ID_Year)	78	-425.1	858.3	4.5	0.05
NorthernForests	Population	case~prop_He+prop_Sh+DistToSnow+DistToSnow_2+Asp_Sine+Asp_Cos+Slope+Slope_2+strata(ID_Year)	78	-422.5	861.0	7.3	0.01
NorthernForests	Population	case~prop_He+prop_Sh+DistToSnow+DistToSnow_2+Slope+Slope_2+strata(ID_Year)	78	-424.6	861.3	7.5	0.01
NorthernForests	Population	case~prop_He+prop_Sh+DistToSnow+DistToSnow_2+Asp_Sine+Asp_Cos+Elevation+Elevation_2+strata(ID_Year)	78	-426.9	869.9	16.1	0.00
NorthernForests	Population	case~prop_He+prop_Sh+DistToSnow+DistToSnow_2+Elevation+Elevation_2+strata(ID_Year)	78	-429.3	870.6	16.9	0.00
NorthernForests	Population	case~prop_He+prop_Sh+DistToSnow+DistToSnow_2+Asp_Sine+Asp_Cos+strata(ID_Year)	78	-431.4	874.7	20.9	0.00
NorthernForests	Population	case~prop_He+prop_Sh+DistToSnow+DistToSnow_2+strata(ID_Year)	78	-433.7	875.5	21.7	0.00
NorthernForests	Population	case~prop_He+prop_Sh+Asp_Sine+Asp_Cos+strata(ID_Year)	78	-435.9	879.9	26.1	0.00
NorthernForests	Population	case~prop_He+prop_Sh+strata(ID_Year)	78	-438.2	880.3	26.6	0.00
NorthernForests	Population	case~prop_He+prop_Sh+Elevation+Elevation_2+strata(ID_Year)	78	-436.6	881.1	27.3	0.00
NorthernForests	Population	case~prop_He+prop_Sh+Asp_Sine+Asp_Cos+Elevation+Elevation_2+strata(ID_Year)	78	-434.6	881.1	27.3	0.00
North_PondPineGrass	Population	case~prop_He+prop_Sh+prop_DF+Elevation+Elevation_2+Slope+Slope_2+strata(ID_Year)	29	-133.8	281.6	0.0	0.41
North_PondPineGrass	Population	case~prop_He+prop_Sh+prop_DF+DistToSnow+DistToSnow_2+Elevation+Elevation_2+Slope+Slope_2+strata(ID_Year)	29	-132.0	282.0	0.4	0.34
North_PondPineGrass	Population	case~prop_He+prop_Sh+prop_DF+DistToSnow+DistToSnow_2+Asp_Sine+Asp_Cos+Elevation+Elevation_2+Slope+Slope_2+strata(ID_Year)	29	-130.4	282.8	1.1	0.23
North_PondPineGrass	Population	case~prop_He+prop_Sh+prop_DF+DistToSnow+DistToSnow_2+Elevation+Elevation_2+strata(ID_Year)	29	-138.1	290.1	8.5	0.01
North_PondPineGrass	Population	case~prop_He+prop_Sh+prop_DF+DistToSnow+DistToSnow_2+Asp_Sine+Asp_Cos+Elevation+Elevation_2+strata(ID_Year)	29	-136.7	291.4	9.8	0.00
North_PondPineGrass	Population	case~prop_He+prop_Sh+prop_DF+Elevation+Elevation_2+strata(ID_Year)	29	-141.2	292.3	10.7	0.00
North_PondPineGrass	Population	case~prop_He+prop_Sh+prop_DF+Asp_Sine+Asp_Cos+Elevation+Elevation_2+strata(ID_Year)	29	-139.3	292.6	11.0	0.00
North_PondPineGrass	Population	case~prop_He+prop_Sh+prop_DF+DistToSnow+DistToSnow_2+Slope+Slope_2+strata(ID_Year)	29	-144.5	302.9	21.3	0.00
North_PondPineGrass	Population	case~prop_He+prop_Sh+prop_DF+DistToSnow+DistToSnow_2+Asp_Sine+Asp_Cos+Slope+Slope_2+strata(ID_Year)	29	-143.5	304.9	23.3	0.00
North_PondPineGrass	Population	case~prop_He+prop_Sh+prop_DF+Slope+Slope_2+strata(ID_Year)	29	-148.2	306.4	24.8	0.00
North_PondPineGrass	Population	case~prop_He+prop_Sh+prop_DF+strata(ID_Year)	29	-151.2	308.4	26.7	0.00
North_PondPineGrass	Population	case~prop_He+prop_Sh+prop_DF+strata(ID_Year)	29	-151.2	308.4	26.7	0.00
North_PondPineGrass	Population	case~prop_He+prop_Sh+prop_DF+Asp_Sine+Asp_Cos+Slope+Slope_2+strata(ID_Year)	29	-147.5	309.1	27.4	0.00
North_PondPineGrass	Population	case~prop_He+prop_Sh+prop_DF+Asp_Sine+Asp_Cos+strata(ID_Year)	29	-150.0	310.0	28.4	0.00
North_PondPineGrass	Population	case~prop_He+prop_Sh+prop_DF+DistToSnow+DistToSnow_2+strata(ID_Year)	29	-150.8	311.7	30.0	0.00
North_PondPineGrass	Population	case~prop_He+prop_Sh+prop_DF+DistToSnow+DistToSnow_2+Asp_Sine+Asp_Cos+strata(ID_Year)	29	-149.4	312.8	31.1	0.00
DryForest_Central	Population	case~prop_He+prop_Sh+DistToSnow+DistToSnow_2+strata(ID_Year)	26	-139.4	286.7	0.0	0.34
DryForest_Central	Population	case~prop_He+prop_Sh+DistToSnow+DistToSnow_2+Asp_Sine+Asp_Cos+strata(ID_Year)	26	-137.6	287.2	0.5	0.27
DryForest_Central	Population	case~prop_He+prop_Sh+DistToSnow+DistToSnow_2+Elevation+Elevation_2+strata(ID_Year)	26	-138.8	289.5	2.8	0.08
DryForest_Central	Population	case~prop_He+prop_Sh+DistToSnow+DistToSnow_2+Asp_Sine+Asp_Cos+Slope+Slope_2+strata(ID_Year)	26	-136.8	289.6	2.9	0.08
DryForest_Central	Population	case~prop_He+prop_Sh+DistToSnow+DistToSnow_2+Slope+Slope_2+strata(ID_Year)	26	-138.9	289.8	3.1	0.07
DryForest_Central	Population	case~prop_He+prop_Sh+DistToSnow+DistToSnow_2+Asp_Sine+Asp_Cos+Elevation+Elevation_2+strata(ID_Year)	26	-137.1	290.2	3.5	0.06
DryForest_Central	Population	case~prop_He+prop_Sh+DistToSnow+DistToSnow_2+Asp_Sine+Asp_Cos+Elevation+Elevation_2+Slope+Slope_2+strata(ID_Year)	26	-136.2	292.5	5.8	0.02
DryForest_Central	Population	case~prop_He+prop_Sh+DistToSnow+DistToSnow_2+Elevation+Elevation_2+Slope+Slope_2+strata(ID_Year)	26	-138.3	292.6	5.9	0.02
DryForest_Central	Population	case~prop_He+prop_Sh+Asp_Sine+Asp_Cos+strata(ID_Year)	26	-142.3	292.6	5.9	0.02
DryForest_Central	Population	case~prop_He+prop_Sh+Asp_Sine+Asp_Cos+Slope+Slope_2+strata(ID_Year)	26	-140.5	293.0	6.3	0.01
DryForest_Central	Population	case~prop_He+prop_Sh+strata(ID_Year)	26	-144.8	293.6	6.9	0.01
DryForest_Central	Population	case~prop_He+prop_Sh+strata(ID_Year)	26	-144.8	293.6	6.9	0.01
DryForest_Central	Population	case~prop_He+prop_Sh+Asp_Sine+Asp_Cos+Elevation+Elevation_2+strata(ID_Year)	26	-141.6	295.2	8.5	0.00
DryForest_Central	Population	case~prop_He+prop_Sh+Slope+Slope_2+strata(ID_Year)	26	-143.7	295.3	8.6	0.00
DryForest_Central	Population	case~prop_He+prop_Sh+Elevation+Elevation_2+strata(ID_Year)	26	-143.9	295.8	9.1	0.00
DryForest_Central	Population	case~prop_He+prop_Sh+Elevation+Elevation_2+Slope+Slope_2+strata(ID_Year)	26	-143.1	298.3	11.5	0.00
SagebrushSteppe	Population	case~prop_He+prop_Sh+prop_Cr+DistToSnow+DistToSnow_2+Asp_Sine+Asp_Cos+Elevation+Elevation_2+Slope+Slope_2+strata(ID_Year)	57	-292.4	606.9	0.0	0.53
SagebrushSteppe	Population	case~prop_He+prop_Sh+prop_Cr+DistToSnow+DistToSnow_2+Asp_Sine+Asp_Cos+Elevation+Elevation_2+strata(ID_Year)	57	-295.3	608.5	1.6	0.23
SagebrushSteppe	Population	case~prop_He+prop_Sh+prop_Cr+DistToSnow+DistToSnow_2+Elevation+Elevation_2+Slope+Slope_2+strata(ID_Year)	57	-295.5	608.9	2.0	0.19
SagebrushSteppe	Population	case~prop_He+prop_Sh+prop_Cr+DistToSnow+DistToSnow_2+Elevation+Elevation_2+strata(ID_Year)	57	-299.0	612.1	5.2	0.04
SagebrushSteppe	Population	case~prop_He+prop_Sh+prop_Cr+DistToSnow+DistToSnow_2+Asp_Sine+Asp_Cos+Slope+Slope_2+strata(ID_Year)	57	-301.4	620.7	13.9	0.00
SagebrushSteppe	Population	case~prop_He+prop_Sh+prop_Cr+DistToSnow+DistToSnow_2+Slope+Slope_2+strata(ID_Year)	57	-304.5	622.9	16.1	0.00
SagebrushSteppe	Population	case~prop_He+prop_Sh+prop_Cr+DistToSnow+DistToSnow_2+Asp_Sine+Asp_Cos+strata(ID_Year)	57	-305.9	625.8	19.0	0.00
SagebrushSteppe	Population	case~prop_He+prop_Sh+prop_Cr+DistToSnow+DistToSnow_2+strata(ID_Year)	57	-309.3	628.7	21.8	0.00
SagebrushSteppe	Population	case~prop_He+prop_Sh+prop_Cr+Asp_Sine+Asp_Cos+Elevation+Elevation_2+strata(ID_Year)	57	-309.2	632.4	25.6	0.00
SagebrushSteppe	Population	case~prop_He+prop_Sh+prop_Cr+Elevation+Elevation_2+Slope+Slope_2+strata(ID_Year)	57	-311.1	636.2	29.3	0.00
SagebrushSteppe	Population	case~prop_He+prop_Sh+prop_Cr+Elevation+Elevation_2+strata(ID_Year)	57	-314.1	638.1	31.3	0.00
SagebrushSteppe	Population	case~prop_He+prop_Sh+prop_Cr+Asp_Sine+Asp_Cos+Slope+Slope_2+strata(ID_Year)	57	-313.9	641.9	35.0	0.00
SagebrushSteppe	Population	case~prop_He+prop_Sh+prop_Cr+Asp_Sine+Asp_Cos+strata(ID_Year)	57	-316.1	642.2	35.3	0.00
SagebrushSteppe	Population	case~prop_He+prop_Sh+prop_Cr+Slope+Slope_2+strata(ID_Year)	57	-317.5	645.1	38.2	0.00
SagebrushSteppe	Population	case~prop_He+prop_Sh+prop_Cr+strata(ID_Year)	57	-320.5	646.9	40.1	0.00
SagebrushSteppe	Population	case~prop_He+prop_Sh+prop_Cr+strata(ID_Year)	57	-320.5	646.9	40.1	0.00

Population	Scale	Model	n_event	LL	AIC	delt_AIC	Weight
DryForest_Southeast	Population	case~prop_He+prop_Sh+prop_DF+prop_WW+DistToSnow+DistToSnow_2+strata(ID_Year)	65	-352.3	716.5	0.0	0.46
DryForest_Southeast	Population	case~prop_He+prop_Sh+prop_DF+prop_WW+DistToSnow+DistToSnow_2+Asp_Sine+Asp_Cos+strata(ID_Year)	65	-350.9	717.7	1.2	0.25
DryForest_Southeast	Population	case~prop_He+prop_Sh+prop_DF+prop_WW+DistToSnow+DistToSnow_2+Elevation+Elevation_2+strata(ID_Year)	65	-351.8	719.5	3.0	0.10
DryForest_Southeast	Population	case~prop_He+prop_Sh+prop_DF+prop_WW+DistToSnow+DistToSnow_2+Slope+Slope_2+strata(ID_Year)	65	-352.2	720.4	3.8	0.07
DryForest_Southeast	Population	case~prop_He+prop_Sh+prop_DF+prop_WW+DistToSnow+DistToSnow_2+Asp_Sine+Asp_Cos+Elevation+Elevation_2+strata(ID_Year)	65	-350.4	720.7	4.2	0.06
DryForest_Southeast	Population	case~prop_He+prop_Sh+prop_DF+prop_WW+DistToSnow+DistToSnow_2+Asp_Sine+Asp_Cos+Slope+Slope_2+strata(ID_Year)	65	-350.8	721.6	5.1	0.04
DryForest_Southeast	Population	case~prop_He+prop_Sh+prop_DF+prop_WW+DistToSnow+DistToSnow_2+Elevation+Elevation_2+Slope+Slope_2+strata(ID_Year)	65	-351.7	723.4	6.9	0.01
DryForest_Southeast	Population	case~prop_He+prop_Sh+prop_DF+prop_WW+DistToSnow+DistToSnow_2+Asp_Sine+Asp_Cos+Elevation+Elevation_2+Slope+Slope_2+strata(ID_Year)	65	-350.3	724.6	8.0	0.01
DryForest_Southeast	Population	case~prop_He+prop_Sh+prop_DF+prop_WW+Elevation+Elevation_2+strata(ID_Year)	65	-358.6	729.3	12.7	0.00
DryForest_Southeast	Population	case~prop_He+prop_Sh+prop_DF+prop_WW+Asp_Sine+Asp_Cos+Elevation+Elevation_2+strata(ID_Year)	65	-357.6	731.2	14.7	0.00
DryForest_Southeast	Population	case~prop_He+prop_Sh+prop_DF+prop_WW+Elevation+Elevation_2+Slope+Slope_2+strata(ID_Year)	65	-358.4	732.8	16.3	0.00
DryForest_Southeast	Population	case~prop_He+prop_Sh+prop_DF+prop_WW+strata(ID_Year)	65	-362.5	733.1	16.6	0.00
DryForest_Southeast	Population	case~prop_He+prop_Sh+prop_DF+prop_WW+strata(ID_Year)	65	-362.5	733.1	16.6	0.00
DryForest_Southeast	Population	case~prop_He+prop_Sh+prop_DF+prop_WW+Asp_Sine+Asp_Cos+strata(ID_Year)	65	-361.7	735.4	18.8	0.00
DryForest_Southeast	Population	case~prop_He+prop_Sh+prop_DF+prop_WW+Slope+Slope_2+strata(ID_Year)	65	-362.0	736.0	19.5	0.00
DryForest_Southeast	Population	case~prop_He+prop_Sh+prop_DF+prop_WW+Asp_Sine+Asp_Cos+Slope+Slope_2+strata(ID_Year)	65	-361.2	738.4	21.9	0.00
DecidForest_South	Population	case~prop_He+prop_Sh+prop_DF+Elevation+Elevation_2+Slope+Slope_2+strata(ID_Year)	42	-209.6	433.2	0.0	0.71
DecidForest_South	Population	case~prop_He+prop_Sh+prop_DF+DistToSnow+DistToSnow_2+Elevation+Elevation_2+Slope+Slope_2+strata(ID_Year)	42	-209.0	435.9	2.8	0.18
DecidForest_South	Population	case~prop_He+prop_Sh+prop_DF+DistToSnow+DistToSnow_2+Asp_Sine+Asp_Cos+Elevation+Elevation_2+Slope+Slope_2+strata(ID_Year)	42	-207.7	437.3	4.2	0.09
DecidForest_South	Population	case~prop_He+prop_Sh+prop_DF+Elevation+Elevation_2+strata(ID_Year)	42	-215.7	441.4	8.2	0.01
DecidForest_South	Population	case~prop_He+prop_Sh+prop_DF+Asp_Sine+Asp_Cos+Elevation+Elevation_2+strata(ID_Year)	42	-214.9	443.8	10.7	0.00
DecidForest_South	Population	case~prop_He+prop_Sh+prop_DF+DistToSnow+DistToSnow_2+Elevation+Elevation_2+strata(ID_Year)	42	-215.2	444.4	11.3	0.00
DecidForest_South	Population	case~prop_He+prop_Sh+prop_DF+DistToSnow+DistToSnow_2+Slope+Slope_2+strata(ID_Year)	42	-216.4	446.8	13.6	0.00
DecidForest_South	Population	case~prop_He+prop_Sh+prop_DF+DistToSnow+DistToSnow_2+Asp_Sine+Asp_Cos+Elevation+Elevation_2+strata(ID_Year)	42	-214.4	446.8	13.6	0.00
DecidForest_South	Population	case~prop_He+prop_Sh+prop_DF+Slope+Slope_2+strata(ID_Year)	42	-218.5	446.9	13.8	0.00
DecidForest_South	Population	case~prop_He+prop_Sh+prop_DF+DistToSnow+DistToSnow_2+Asp_Sine+Asp_Cos+Slope+Slope_2+strata(ID_Year)	42	-214.7	447.4	14.2	0.00
DecidForest_South	Population	case~prop_He+prop_Sh+prop_DF+Asp_Sine+Asp_Cos+Slope+Slope_2+strata(ID_Year)	42	-216.8	447.6	14.5	0.00
DecidForest_South	Population	case~prop_He+prop_Sh+prop_DF+DistToSnow+DistToSnow_2+strata(ID_Year)	42	-228.2	466.5	33.3	0.00
DecidForest_South	Population	case~prop_He+prop_Sh+prop_DF+DistToSnow+DistToSnow_2+Asp_Sine+Asp_Cos+strata(ID_Year)	42	-226.7	467.4	34.2	0.00
DecidForest_South	Population	case~prop_He+prop_Sh+prop_DF+strata(ID_Year)	42	-231.2	468.4	35.3	0.00
DecidForest_South	Population	case~prop_He+prop_Sh+prop_DF+strata(ID_Year)	42	-231.2	468.4	35.3	0.00
DecidForest_South	Population	case~prop_He+prop_Sh+prop_DF+Asp_Sine+Asp_Cos+strata(ID_Year)	42	-229.5	468.9	35.7	0.00

Results of local-scale model selection.

Population	Scale	Model	n_event	LL	AIC	delt_AIC	Weight
NorthernForests	Local	case~NLCD_type+strata(ID_Year)	76	-419.9	843.8	0.0	0.80
NorthernForests	Local	case~Dist_D+Dist_D_2+NLCD_type+strata(ID_Year)	76	-419.8	847.5	3.7	0.12
NorthernForests	Local	case~Dist_D+Dist_D_2+NLCD_type+Slope+Slope_2+strata(ID_Year)	76	-419.4	850.8	7.0	0.02
NorthernForests	Local	case~Dist_D+Dist_D_2+NLCD_type+TPI+TPI_2+strata(ID_Year)	76	-419.5	851.0	7.3	0.02
NorthernForests	Local	case~Dist_D+Dist_D_2+NLCD_type+Asp_Sine+Asp_Cos+strata(ID_Year)	76	-419.7	851.5	7.7	0.02
NorthernForests	Local	case~Dist_D+Dist_D_2+NLCD_type+TPI+TPI_2+Slope+Slope_2+strata(ID_Year)	76	-419.2	854.3	10.5	0.00
NorthernForests	Local	case~Dist_D+Dist_D_2+NLCD_type+Asp_Sine+Asp_Cos+Slope+Slope_2+strata(ID_Year)	76	-419.4	854.7	11.0	0.00
NorthernForests	Local	case~Dist_D+Dist_D_2+NLCD_type+Asp_Sine+Asp_Cos+TPI+TPI_2+strata(ID_Year)	76	-419.5	855.0	11.2	0.00
NorthernForests	Local	case~Dist_D+Dist_D_2+NLCD_type+Asp_Sine+Asp_Cos+TPI+TPI_2+Slope+Slope_2+strata(ID_Year)	76	-419.1	858.3	14.5	0.00
NorthernForests	Local	case~Dist_D+Dist_D_2	76	-505.3	1014.5	170.7	0.00
North_PondPineGrass	Local	case~Dist_D+Dist_D_2+NLCD_type+TPI+TPI_2+strata(ID_Year)	28	-151.84	315.68	0	0.38
North_PondPineGrass	Local	case~Dist_D+Dist_D_2+NLCD_type+TPI+TPI_2+Slope+Slope_2+strata(ID_Year)	28	-150.32	316.63	0.95	0.24
North_PondPineGrass	Local	case~NLCD_type+strata(ID_Year)	28	-156.62	317.23	1.55	0.18
North_PondPineGrass	Local	case~Dist_D+Dist_D_2+NLCD_type+Slope+Slope_2+strata(ID_Year)	28	-153.59	319.19	3.51	0.07
North_PondPineGrass	Local	case~Dist_D+Dist_D_2+NLCD_type+Asp_Sine+Asp_Cos+TPI+TPI_2+strata(ID_Year)	28	-151.78	319.56	3.88	0.05
North_PondPineGrass	Local	case~Dist_D+Dist_D_2+NLCD_type+Asp_Sine+Asp_Cos+TPI+TPI_2+Slope+Slope_2+strata(ID_Year)	28	-150.18	320.37	4.69	0.04
North_PondPineGrass	Local	case~Dist_D+Dist_D_2+NLCD_type+strata(ID_Year)	28	-156.3	320.61	4.93	0.03
North_PondPineGrass	Local	case~Dist_D+Dist_D_2+NLCD_type+Asp_Sine+Asp_Cos+Slope+Slope_2+strata(ID_Year)	28	-153.46	322.93	7.25	0.01
North_PondPineGrass	Local	case~Dist_D+Dist_D_2+NLCD_type+Asp_Sine+Asp_Cos+strata(ID_Year)	28	-156.27	324.53	8.85	0.00
North_PondPineGrass	Local	case~Dist_D+Dist_D_2	28	-183.56	371.13	55.45	0.00
DryForest_Central	Local	case~Dist_D+Dist_D_2+NLCD_type+TPI+TPI_2+strata(ID_Year)	26	-136.34	284.68	0	0.42
DryForest_Central	Local	case~Dist_D+Dist_D_2+NLCD_type+Asp_Sine+Asp_Cos+TPI+TPI_2+strata(ID_Year)	26	-134.66	285.32	0.64	0.31
DryForest_Central	Local	case~Dist_D+Dist_D_2+NLCD_type+TPI+TPI_2+Slope+Slope_2+strata(ID_Year)	26	-135.3	286.61	1.93	0.16
DryForest_Central	Local	case~Dist_D+Dist_D_2+NLCD_type+Asp_Sine+Asp_Cos+TPI+TPI_2+Slope+Slope_2+strata(ID_Year)	26	-133.76	287.51	2.83	0.10
DryForest_Central	Local	case~NLCD_type+strata(ID_Year)	26	-144.55	293.1	8.42	0.01
DryForest_Central	Local	case~Dist_D+Dist_D_2+NLCD_type+strata(ID_Year)	26	-144.42	296.84	12.16	0.00
DryForest_Central	Local	case~Dist_D+Dist_D_2+NLCD_type+Asp_Sine+Asp_Cos+strata(ID_Year)	26	-143	298	13.32	0.00
DryForest_Central	Local	case~Dist_D+Dist_D_2+NLCD_type+Slope+Slope_2+strata(ID_Year)	26	-143.35	298.69	14.01	0.00
DryForest_Central	Local	case~Dist_D+Dist_D_2+NLCD_type+Asp_Sine+Asp_Cos+Slope+Slope_2+strata(ID_Year)	26	-142.09	300.17	15.49	0.00
DryForest_Central	Local	case~Dist_D+Dist_D_2	26	-170.85	345.69	61.01	0.00
SagebrushSteppe	Local	case~Dist_D+Dist_D_2+NLCD_type+Slope+Slope_2+strata(ID_Year)	55	-305.45	624.89	0	0.43
SagebrushSteppe	Local	case~Dist_D+Dist_D_2+NLCD_type+TPI+TPI_2+Slope+Slope_2+strata(ID_Year)	55	-304.14	626.28	1.39	0.22
SagebrushSteppe	Local	case~Dist_D+Dist_D_2+NLCD_type+Asp_Sine+Asp_Cos+Slope+Slope_2+strata(ID_Year)	55	-304.63	627.25	2.36	0.13
SagebrushSteppe	Local	case~NLCD_type+strata(ID_Year)	55	-310.95	627.9	3.01	0.10
SagebrushSteppe	Local	case~Dist_D+Dist_D_2+NLCD_type+Asp_Sine+Asp_Cos+TPI+TPI_2+Slope+Slope_2+strata(ID_Year)	55	-303.3	628.59	3.7	0.07
SagebrushSteppe	Local	case~Dist_D+Dist_D_2+NLCD_type+strata(ID_Year)	55	-310.47	630.94	6.05	0.02
SagebrushSteppe	Local	case~Dist_D+Dist_D_2+NLCD_type+TPI+TPI_2+strata(ID_Year)	55	-308.7	631.4	6.51	0.02
SagebrushSteppe	Local	case~Dist_D+Dist_D_2+NLCD_type+Asp_Sine+Asp_Cos+strata(ID_Year)	55	-309.63	633.26	8.37	0.01
SagebrushSteppe	Local	case~Dist_D+Dist_D_2+NLCD_type+Asp_Sine+Asp_Cos+TPI+TPI_2+strata(ID_Year)	55	-307.85	633.7	8.81	0.01
SagebrushSteppe	Local	case~Dist_D+Dist_D_2	55	-365.24	734.48	109.59	0.00

Population	Scale	Model	n_event	LL	AIC	delt_AIC	Weight
DryForest_Southeast	Local	case~Dist_D+Dist_D_2+NLCD_type+Asp_Sine+Asp_Cos+TPI+TPI_2+strata(ID_Year)	65	-338.76	697.53	0	0.57
DryForest_Southeast	Local	case~Dist_D+Dist_D_2+NLCD_type+Asp_Sine+Asp_Cos+strata(ID_Year)	65	-342.03	700.06	2.53	0.16
DryForest_Southeast	Local	case~Dist_D+Dist_D_2+NLCD_type+Asp_Sine+Asp_Cos+TPI+TPI_2+Slope+Slope_2+strata(ID_Year)	65	-338.43	700.87	3.34	0.11
DryForest_Southeast	Local	case~NLCD_type+strata(ID_Year)	65	-346.84	701.69	4.16	0.07
DryForest_Southeast	Local	case~Dist_D+Dist_D_2+NLCD_type+TPI+TPI_2+strata(ID_Year)	65	-343.3	702.6	5.07	0.04
DryForest_Southeast	Local	case~Dist_D+Dist_D_2+NLCD_type+Asp_Sine+Asp_Cos+Slope+Slope_2+strata(ID_Year)	65	-341.74	703.47	5.94	0.03
DryForest_Southeast	Local	case~Dist_D+Dist_D_2+NLCD_type+strata(ID_Year)	65	-346.59	705.18	7.65	0.01
DryForest_Southeast	Local	case~Dist_D+Dist_D_2+NLCD_type+TPI+TPI_2+Slope+Slope_2+strata(ID_Year)	65	-342.87	705.75	8.22	0.01
DryForest_Southeast	Local	case~Dist_D+Dist_D_2+NLCD_type+Slope+Slope_2+strata(ID_Year)	65	-346.2	708.41	10.88	0.00
DryForest_Southeast	Local	case~Dist_D+Dist_D_2	65	-419.76	843.52	145.99	0.00
DecidForest_South	Local	case~Dist_D+Dist_D_2+NLCD_type+Asp_Sine+Asp_Cos+strata(ID_Year)	42	-230.42	474.84	0	0.35
DecidForest_South	Local	case~Dist_D+Dist_D_2+NLCD_type+Asp_Sine+Asp_Cos+TPI+TPI_2+strata(ID_Year)	42	-228.43	474.86	0.02	0.35
DecidForest_South	Local	case~NLCD_type+strata(ID_Year)	42	-235.45	476.91	2.07	0.13
DecidForest_South	Local	case~Dist_D+Dist_D_2+NLCD_type+Asp_Sine+Asp_Cos+TPI+TPI_2+Slope+Slope_2+strata(ID_Year)	42	-228.35	478.7	3.86	0.05
DecidForest_South	Local	case~Dist_D+Dist_D_2+NLCD_type+Asp_Sine+Asp_Cos+Slope+Slope_2+strata(ID_Year)	42	-230.4	478.81	3.97	0.05
DecidForest_South	Local	case~Dist_D+Dist_D_2+NLCD_type+TPI+TPI_2+strata(ID_Year)	42	-232.71	479.41	4.57	0.04
DecidForest_South	Local	case~Dist_D+Dist_D_2+NLCD_type+strata(ID_Year)	42	-235.01	480.02	5.18	0.03
DecidForest_South	Local	case~Dist_D+Dist_D_2+NLCD_type+TPI+TPI_2+Slope+Slope_2+strata(ID_Year)	42	-232.65	483.3	8.46	0.01
DecidForest_South	Local	case~Dist_D+Dist_D_2+NLCD_type+Slope+Slope_2+strata(ID_Year)	42	-235	484	9.16	0.00
DecidForest_South	Local	case~Dist_D+Dist_D_2	42	-276.11	556.22	81.38	0.00