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Correlates of Canada Lynx Reproductive Success in Northwestern Montana

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CORRELATES OF CANADA LYNX REPRODUCTIVE SUCCESS IN NORTHWESTERN MONTANA

By

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ABSTRACT

Habitat loss and fragmentation continue to threaten the persistence of forest carnivores in the contiguous US. The recovery of federally threatened species, such as the Canada lynx (*Lynx canadensis*), will be greatly enhanced by identifying a demographic-based definition of lynx habitat based on habitat analyses of animals with differential reproductive success. We collected field data on denning and offspring survival in northwestern Montana from 1998–2012. We used these data to define four response variables as measures of female Canada lynx reproductive success: (1) potential reproductive events, (2) initial litter size, (3) litter success (≥1 survivor), and (4) surviving litter size. We used mixed models to evaluate the effects of habitat and maternal condition on these response variables. Specifically, we tested *a-priori* hypotheses of relationships between reproductive success parameters and various habitat covariates representing the abundance and spatial configuration of five simplified forest structure types within occupied female lynx home ranges. Additional *a-priori* hypotheses were tested on the relationships between reproductive success parameters and maternal covariates, including female body condition, age, and previous reproductive performance. The most important predictors for overall lynx reproductive success within occupied female home ranges were the connectivity of mature forest, intermediate (10–15%) amounts of young regenerating forest, young regenerating forest patches with low perimeter-area ratios, and the adjacency of mature forest to young regenerating forest types. Female lynx home ranges that contain greater than 50% mature forest and approximately 10–15% young regenerating forest appear to be the optimal composition of forest structure types. Additionally, greater connectivity of mature forest, when combined with young regenerating forest patches with low perimeter-area ratios, appears to be the optimal configuration of forest structure types. Incorporating these results into current and long-term land management plans will provide a valuable conservation tool to ensure the persistence of threatened Canada lynx populations in the western US.

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INTRODUCTION

Habitat loss and fragmentation threaten the persistence of wildlife (Wilcove et al. 1998, Fahrig 2003, Yiming and Wilcove 2005, Hanski 2011) by negatively affecting species' abundance and distribution (Gehring and Swihart 2002, Crooks and Sanjayan 2006). Species with naturally low population densities and fecundity, and large individual and population-level ranges, such as forest carnivores, are especially sensitive to habitat loss and fragmentation (Andrén 1994, Noss et al. 1996, Weaver et al. 1996, Crooks 2002). In the northern US Rocky Mountains, anthropogenic habitat fragmentation has altered the spatial configuration of historical habitats, resulting in a mosaic of remnant forest patches interspersed with altered patches of various forest successional stages (USFWS 2000). Forest mosaics can impact the biotic and abiotic characteristics of remnant forest patches (Saunders et al. 1991) by increasing edge-to-area ratios of forested patches and decreasing connectivity and proximity between remnant patches (Saunders et al. 1991, Prugh et al. 2008). Changes to forest connectivity can directly impact the ability of wildlife to move within and across the landscape to access resources necessary for survival and reproduction (Taylor et al. 1993).

Wildlife habitat quality has primarily been evaluated using estimates of species occurrence, abundance, or habitat selection (VanHorne 1983, Garshelis 2000, Bock and Jones 2004, Prugh et al. 2008). However, these metrics can sometimes be misleading measures of population performance, especially in systems with strong source-sink dynamics (Murphy 2001, Kreuzer and Huntley 2003, Mosser et al. 2009). Instead, measures of reproductive success (i.e. probability of reproducing, number of offspring, offspring survival) are considered better indicators of source-sink dynamics and overall habitat quality (Beckmann and Berger 2003a, 2003b), based on the assumption that an individual's reproductive success will be higher in better quality habitats. For example, for lions (*Panthera leo*) in Serengeti National Park, reproductive success (yearling cubs per female) proved a more sensitive and accurate measure of "source" habitats than measures of density, which included "sink" habitats occupied by non-reproductive females (Mosser et al. 2009).

Reproductive success is often easier to measure for smaller organisms (i.e. birds); assessing reproductive success for mammalian carnivores poses a significant challenge because long-term data collection is expensive, time intensive, and often yields small sample sizes. As a result, few long-term datasets containing multiple reproductive success parameters have been incorporated into habitat evaluations for most species of mammalian carnivores. While reproductive success of mammalian carnivores can be difficult to measure, it is essential for highly effective management to relate reproductive success to habitat quality, especially in the recovery of threatened and endangered species.

In the contiguous US, the Canada lynx (*Lynx canadensis*) is a federally threatened, rare forest carnivore. Canada lynx, as well as their primary prey species, the snowshoe hare (*Lepus americanus*), are predominantly associated with dense mature subalpine coniferous forest types in the western US (Koehler et al. 2008, Squires et al. 2010, Ivan et al. 2014) and dense young mixed conifer/deciduous forest types in the eastern US (Burdett 2008, Vashon et al. 2008, McCann and Moen 2011). At the southern extent of their range, Canada lynx habitat is historically patchy and is subject to loss and fragmentation by some forest management practices (i.e. regeneration harvests, pre-commercial and commercial thins, prescribed burns), wildfires and insect infestations, and climate change (Aubrey et al. 2000, Hornseth et al. 2014, Koen et al. 2014). Research on Canada lynx (hereafter lynx) habitat has considered abundance, occurrence, habitat selection, and movement, but has yet to connect habitat with reproductive success. There is a pressing management need to understand this connection and gain further insight into the particular habitat resources and spatial configurations that support and enhance lynx populations.

Occupied lynx habitat in the western US occurs primarily on National Forest System (NFS) lands managed by the United States Forest Service (USFS). Within NFS lands, current conservation measures for managing lynx habitat limit the amount of combined human and natural disturbance within areas that represent approximate female lynx home ranges (USFS 2007). However, data gaps remain regarding the abundance and spatial arrangement of lynx habitat and how these habitats contribute to reproductive success and population persistence. The recovery of imperiled species, such as the lynx, will be greatly enhanced by land management practices supported by demographic-based definitions of habitat.

Our objective was to evaluate the effects of habitat and maternal covariates on reproductive success of female lynx within a portion of the species' southern range in northwestern Montana. Specifically, we (1) tested *a-priori* hypotheses (Table 1) of relationships between reproductive success parameters and habitat covariates representing the abundance and configuration of forest structure types and vegetation density within occupied female lynx home ranges. In addition to habitat, we (2) tested *a-priori* hypotheses (Table 1) of relationships between reproductive success parameters and maternal covariates representing female body condition, age category, and previous reproductive performance.

STUDY AREA

Our research focused on two primary study areas in northwestern Montana located in the Swan and Mission Mountains near Seeley Lake, MT and in the Purcell Mountains near Libby, MT (Figure 1). Elevations ranged from 1200 to 2400 m in the Seeley Lake study area (hereafter Seeley) and 800 to 2300 m in the Purcell Mountain study area (hereafter Purcells). Both study areas featured a diversity of montane habitats ranging from low to mid-elevation ponderosa pine (*Pinus ponderosa*) and dry Douglas-fir (*Pseudotsuga menziesii*) forests to high-elevation forests dominated by subalpine fir (*Abies lasiocarpa*), Engelmann spruce (*Picea engelmanii*), and lodgepole pine (*Pinus contorta*). The Purcells consisted almost entirely (>95%) of NFS lands, whereas Seeley contained approximately 48% NFS lands, 37% Plum Creek Timber Company lands [ownership of most Plum Creek Timber Company lands was transferred to state and federal agencies during the study in 2009–2010 (www.themontanalegacyproject.org, accessed 06/05/2014)], and lesser amounts of state, tribal, Bureau of Land Management, and private land (Squires et al. 2010).

METHODS

Field Data Collection and Response Variables

We trapped and collared female lynx in Seeley from 1998–2012, and in the Purcells from 2003–2012. We captured, handled, and collected morphological data, including body mass, from female lynx according to Squires et al. (2008), using methods approved by the Institutional Animal Care and Use Committee (IACUC permits 4–2008 and TE053737–1). We collared females with Very High Frequency (VHF) radio collars (Advanced Telemetry Solutions, Isanti, MN) from 1998–2004, and with store-on-board GPS collars (Lotek Wireless, Newmarket, Ontario, Canada and Sirtrack Ltd., Havelock North, New Zealand) from 2005–2012. We located females with VHF collars every 1–2 weeks using aerial telemetry, and GPS collars collected a location every 30 minutes for 24 hours, every other day for 6–8 months. We monitored females until they died, disappeared from the study area, radio collars failed, or until the end of the study period. We used telemetry to locate natal dens of females within 1–2 weeks of parturition and recorded the number of kittens per litter. Females exhibit central place foraging behavior from natal (parturition) and maternal (rearing) dens during the first 6–8 weeks of kittens' lives (Olson et al. 2011, Vashon et al. 2012); therefore, we likely detected all reproductive events of radio collared females where kittens survived the perinatal period. When possible, we backtracked females with known litters to determine survival of kittens to 8–10 months old (January/February).

We used denning and backtracking data to define four response variables as measures of reproductive success: (1) potential reproductive events, (2) initial litter size, (3) litter success, and (4) surviving litter size. We defined potential reproductive events as a binary variable where a female either produced a litter or did not produce a litter that year. We then removed all observations in which a female did not produce a litter and subsequently defined initial litter size as the number of offspring in natal dens. We defined litter success as a binary variable where at least one offspring survived until 8–10 months old (January or February), or where none of the offspring survived to this age. We then removed all observations in which none of the offspring survived until 8–10 months old to define surviving litter size, which is the number of offspring that survived to 8–10 months old.

Covariate Data Collection and Predictions

We created female home ranges using location data to analyze habitat composition and spatial configuration within female home ranges. Because core areas represent the most intensively used portions of a home range (Bingham and Noon 1997, Seaman et al. 1999), we estimated home ranges at two spatial extents to determine whether 50% annual core areas (hereafter core areas) were potentially more predictive of lynx reproductive success than 90% annual home ranges (hereafter home ranges). We used ArcGIS® 9.3.1 [Environmental Systems Research Institute

(ESRI), Inc., Redlands, CA, USA] and the Home Range Tools Extension (HRT; Rodgers et al. 2007) to estimate core areas and home ranges using the fixed-kernel density method (Worton 1989) and a reference smoothing factor (href, Worton 1995) of 1.0. We considered females with sufficient location data (≥30 locations, Seaman et al. 1999) and whose home ranges were covered by our vegetation data layer. Detailed methods for core area and home range estimation are included in Appendix A.

We used the US Forest Service's Vegetation Mapping Program (VMap) layer (Brewer et al. 2004) as a repeatable method to delineate forest patches within female home ranges based on their spectral signature and we visually assigned 5 forest structural types to these patches: 1) open—trees not present; 2) thin forest—naturally sparsely stocked or mechanically thinned stands with a discontinuous canopy and a visible forest floor; 3) young regenerating forest—trees generally <10 cm diameter at breast height (DBH), with continuous canopy or dense deciduous shrub understory; 4) old regenerating forest—previously harvested or thinned with trees generally >10 cm DBH, continuous canopy or dense deciduous shrub understory; and 5) mature forest—large trees, continuous canopy, and no evidence of recent disturbance. We tested the accuracy of the layer by ground-truthing 187 random test locations stratified by study area and forest structure type. Overall accuracy was 93% with 87 of 93 locations classified correctly in Seeley and 87 of 94 locations classified correctly in the Purcells. We used the raster version of Fragstats software (v.4.2; McGarigal et al. 2012) to quantify all habitat covariates that described forest structure type composition and spatial configuration within female home ranges.

Home range composition describes the variety and abundance of forest structure types, whereas home range configuration describes the spatial character and arrangement of forest structure types within a home range (McGarigal and Marks 1994). We estimated two covariates representing home range composition (Table 2): percent composition, and area-weighted mean patch size; and five covariates representing home range configuration (Table 2): patch density, edge-contrast, contagion (fragmentation), correlation length (connectivity), and area-weighted mean perimeter-area ratio (patch area and shape).

Because we did not assess snowshoe hare abundances or densities within female home ranges, we assumed snowshoe hare densities varied by forest structure type. Dense mature forest and dense young forest types in the western US have been consistently identified as capable of supporting the highest snowshoe hare densities relative to other forest types across multiple regions and seasons (Griffin 2004, Griffin and Mills 2009, Berg et al. 2012, Ivan et al. 2014). Therefore, based on existing knowledge of important forest types for lynx and snowshoe hares, we predicted (Table 1) reproductive success would be positively related to mature forest (Koehler et al. 2008, Squires et al. 2008, 2010), old regenerating forest (Squires et al. 2008, 2010) and young regenerating forest (Burdett 2008, Griffin and Mills 2009, McCann and Moen 2011); and negatively related to thin forest and open areas (Squires et al. 2010).

We considered percent composition for all five forest structure types and also considered collapsed categories [i.e. forest (mature + old regenerating), open/sparse (open + thin)], because percent composition is often the most useful information that can be derived for fragmentation analyses (McGarigal and Marks 1994). For all other habitat covariates, unless otherwise specified, we only included mature forest and young regenerating forest structure types because of their known importance to lynx and snowshoe hares in the contiguous US (Ruggiero et al. 2000, Burdett 2008, Koehler et al. 2008, Squires et al. 2010, McCann and Moen 2011). We selected area-normalized metrics or area-normalized the data before analysis because occupied core areas and home ranges varied in total area.

We considered connectivity of mature forest patches within each female home range using “correlation length”, a landscape metric based on the average extensiveness of connected patches of a focal habitat type within a given landscape (Fragstats; McGarigal and Marks 1994). This can be interpreted as the average distance a female lynx can traverse her home range without exiting mature forest, starting from a random point and moving in a random direction (Keitt et al. 1997). Because this metric is sensitive to area, we area-normalized correlation length (Kevin McGarigal, University of Minnesota, personal communication) by (1) quantifying the “potential” correlation length for each home range if the entire home range was one contiguous patch of mature forest; (2) quantifying “realized” correlation length for each home range, or the ability for the female to traverse her home range without exiting mature forest given the existing forest mosaic within the home range; (3) dividing the “realized” correlation length by the “potential” correlation length for each home range, resulting in a traversability index scaled 0–1, with values closer to 0 representing low traversability of home ranges and values closer to 1 representing high traversability. We predicted reproductive success would be positively related to home ranges with high traversability (hereafter connectivity) of mature forest. We also evaluated connectivity of mature and old regenerating forest patches combined to test the importance of overall forest connectivity within female home ranges.

We considered perimeter-area ratio for mature forest and young regenerating forest types because patches of equal area may vary significantly in the amount of their area exposed to edge. Patches with elongated or irregular shapes have higher perimeter-area ratios than patches of the same area with simple compact shapes (i.e. circle or square). Additionally, small patches generally have higher perimeter-area ratios than larger patches (Helzer and Jelinski 1999). We predicted reproductive success would be negatively correlated to perimeter-area ratio, a strong correlate of fragmentation (McGarigal and Marks 1994). Additionally, we considered edge-contrast density for forest (mature and old regenerating forest combined) and non-forest (open and thin forest combined). We predicted reproductive success would be negatively related to forest and non-forest edge density. We considered the potential importance of edge density between mature forest and young regenerating forest (Griffin and Mills 2009, Lewis et al. 2011). We predicted reproductive success would be positively related to mature forest and young regenerating forest edge density because these forest structure types are considered "source" populations for snowshoe hares (Griffin and Mills 2009). Additionally, the adjacency of these forest structure types could enhance snowshoe hare population growth (Griffin and Mills 2009, Lewis et al. 2011).

Dense vegetation is an important habitat component for both lynx (Murray 2003, Moen et al. 2008, Fuller and Harrison 2010, Squires et al. 2010) and snowshoe hares (Griffin 2004, Fuller and Harrison 2005, Griffin and Mills 2009, Scott 2009). Therefore, we predicted reproductive success would be positively related to vegetation density in female home ranges. To assess vegetation density, we used the normalized difference vegetation index (NDVI) using ArcGIS® 9.3.1 [Environmental Systems Research Institute (ESRI), Inc., Redlands, CA, USA]. This index is constructed from remotely sensed data that measures reflected light from the earth's surface, and provides an assessment of the relative density and condition of vegetation. As such, Squires et al. (2013) suggested NDVI is a potential surrogate for horizontal cover. The advantage to using NDVI is that the entirety of each home range's vegetative cover could be assessed without the extensive cost and effort of performing surveys on the ground. Low values of NDVI correlate with open, non-vegetated or low-productivity areas, whereas high values of NDVI correlate with densely vegetated areas, such as thick shrubs and intact forests (Gamon et al. 1995). We estimated mean NDVI values for each female home range using composites derived from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) during the peak-growing season (July 9–July 30, 2007).

Additionally, another habitat covariate we utilized to assess vegetation density was the Compound Topographic Index (CTI), a steady state wetness index that is strongly correlated with soil moisture (Moore et al. 1991). We assumed vegetation in more moist areas would regenerate and produce more biomass (i.e. potential horizontal cover) than drier areas following disturbances. Therefore, we predicted reproductive success would be positively related to mean soil moisture. We estimated the mean and range of CTI values for each home range using the Geomorphometry and Gradient Metrics extension (version1.01; Evans and Oakleaf accessed 02/20/2013) for ArcGIS® 9.3.1.

We analyzed variation in lynx reproductive success parameters relative to three measures of maternal condition: body mass, maternal age category, and an individual's reproductive performance the previous year (reproductive event, initial litter size, litter success, and surviving litter size).

We chose body mass as a surrogate for maternal fitness because starvation is a leading cause of mortality for lynx in both northern (Poole et al. 1996, Slough and Mowat 1996) and southern populations (Devineau et al. 2010, John Squires personal communication, Vashon et al. 2012) and generally occurs during the winter in our study areas (John Squires, USFS-Rocky Mountain Research Station, personal communication). We only considered body mass measurements that were collected during the winter prior to each reproductive event, when the potential effect of diminished body condition on the reproductive capacity of an individual would be most pronounced. Body mass has been positively correlated with various reproductive success parameters in other mammals (Stearns 1992); therefore, we predicted lynx reproductive success would be positively related to body mass. We also considered a standardized measure of body mass by dividing body mass by body length (tip of the nose to tip of the tail) to account for potential physiological differences between female lynx.

We assigned females to three age categories (2, 3, and >3 years old) based on known age for females first observed as kittens and/or an analysis of tooth annuli collected from mortalities, and assigned unknown aged females to the >3 years old age category after we had monitored a female >3 years. We selected these age categories based on our ability to distinguish age in the field and for comparison with other studies (Mowat et al. 1996, Palomares et al. 2005, Nilsen et al. 2012, Gaillard et al. 2014). We predicted reproductive success would be positively related to female age categories and reproductive performance the previous year, a common relationship in mammals (Fisher 1930, Pianka and Parker 1975, Clutton-Brock 1984, Sydeman et al. 1991, Hadley et al. 2007).

Statistical Analysis

We used generalized linear mixed models (GLMM; Bolker et al. 2009) with a binomial distribution and a logit link function to test the effects of all covariates on 1) potential reproductive events and 2) litter success. We used linear mixed models with a normal Gaussian distribution to test the effects of all covariates on 3) initial litter size and 4) surviving litter size. All statistical analyses were performed in R version 2.15.2 (R Core Team 2013) using the lme4 package (Bates et al. 2014). We included the identity of individual females as a random effect to control for repeated measures of the same individuals over time. We constructed candidate models from important (*P* <0.25) habitat covariates (Appendix B) that we identified using univariate linear regression (following Hosmer and Lemeshow 2000). For comparison and consistency, we used the same set of candidate models for all four reproductive success analyses. For maternal covariate analysis, we used univariate models only due to high variation in sample sizes (Table 3). We evaluated covariates for normality and tested covariates for collinearity, retaining the covariate with greater univariate significance when variables were correlated ($| r | > 0.7$; Menard 1995). For example, connectivity of mature forest was correlated with connectivity of all forest (mature and old regenerating forest combined, $r = 0.76$) and percent composition of mature forest ($r = 0.92$). We retained connectivity of mature forest in our models because it was more significant in all analyses. Perimeter-area ratio of young regenerating forest patches was inversely correlated with mean area of young regenerating forest patches ($r = –0.71$). We retained perimeter-area ratio because it reflects both area and shape of patches and it was more significant in all analyses.

We used the Akaike Information Criterion corrected for small sample sizes (AIC_c: Burnham and Anderson 2002) to rank models. We interpreted models with 2 AIC_c of the top model to have similar support, and evaluated Akaike weights (w_i) as evidence of the relative likelihood of the model given the set of candidate models (Burnham and Anderson 2002). We provide coefficient estimates (β), standard errors (SE), and 95% confidence intervals (CI) as indicators of direction and strength of covariate relationships.

RESULTS

We monitored 36 females (Purcells = 17, Seeley = 19) of reproductive age (≥2 years old) for an average of 2.7 ± 1.9 years (mean ± SD, range = 1–7) from 1998–2012. These females produced 61 litters (150 kittens) out of 97 potential reproductive events, a proportion of 0.63. Older females (>3 years) were more likely to produce a litter than 2 year olds ($\beta = 1.482$, SE = 0.723, $P = 0.055$) with a proportion of 0.71 ($n = 61$) of older females producing a litter, but were only marginally more likely to produce a litter than 3 year olds (β = 1.148, SE = 0.855, *P* = 0.161). The proportion of 3 year olds producing a litter was 0.5 (*n* = 12), and 2 year olds was 0.42 (*n* = 12), which was not statistically different (β = 0.338, SE = 0.908, *P* = 0.709).

Average litter size was 2.46 ± 0.8 kittens (mean ± SD, *n* = 61 litters). Litter sizes varied from 1 to 5 kittens per litter with 2 or 3 kittens being the most frequently observed in both study areas (Table 4). Average female body mass was 9.04 ± 0.8 kg (mean ± SE, *n* = 65, range = 7.25–11). Body mass, and body mass divided by body length, were not strong correlates of reproductive success in any analyses (Tables 5–8).

Our analysis of litter success consisted of 16 females that produced 40 litters (98 kittens) with known survival data. Thirty-two litters had ≥1 kitten survive to 8–10 months old resulting in an overall litter success rate of 80%. Fifty-seven of the 98 kittens survived to 8–10 months old, resulting in an individual survival rate of 58.2%. Females that produced a litter the previous year were marginally more likely to have ≥1 kitten survive to 8–10 months old the present year (β = 0.703, SE = 0.385, *P* = 0.077).

Mature forest was the dominant forest structure type in both annual core areas and annual home ranges. Mature forest comprised an average 49 ± 13% (mean ± SD, range = 7–79, *n* = 23) of core areas and an average 50 ± 15% (range = 18–69) of home ranges. Young regenerating forests comprised an average 13 ± 6% (range = 1–26) of core areas and an average 11 ± 4% (range = 4–24) of home ranges. Old regenerating, naturally or mechanically thinned, and open forest structure types comprised the remaining area. Average percent compositions of the different forest structure types did not vary substantially by study area or spatial extent (Appendix C).

Females that produced litters had core areas with intermediate amounts of young regenerating forest (10–15%, Figure 3), greater connectivity of mature forest (Figure 2), and greater edge density between mature and young regenerating forest (Figure 2) than core areas of females that did not produce litters (Tables 9–10). Specifically, the percentage of young regenerating forest had a strong positive linear appearance until the composition reached approximately 10–15% of the core area. Above this level of composition, the probability of producing a litter declined (Figure 3). Hereafter, we refer to this relationship as "intermediate amounts of young regenerating forest". Similar to our core area results, females that produced litters had home ranges with intermediate amounts of young regenerating forest, greater connectivity of mature forest, and greater edge density between mature and young regenerating forest than home ranges of females that did not produce litters (Tables 11–12).

Females with larger initial litter sizes had core areas with greater connectivity of mature forest, and young regenerating forest patches with low perimeter-area ratio as compared to core areas of females with smaller initial litter sizes (Figure 4, Tables 13–14). At the home range extent, females with larger initial litter sizes had home ranges with higher densities of young regenerating forest patches, higher percent composition of mature forest, lower percent composition of old regenerating forest, young regenerating forest patches with low perimeter-area ratios, lower moisture variance and were less fragmented than home ranges of females with smaller initial litter sizes (Tables 15–16).

For litter success, at both spatial extents, all 95% confidence intervals for model covariates overlapped zero, indicating that no habitat covariates were strongly significant at the given confidence level (Table 18; Table 20). This suggests either high model selection uncertainty, none of the covariates were important predictors for litter success, or our limited sample size ($n = 38$) constrained opportunities to evaluate the robustness of factors that affected litter success (Tables 17–20).

Females with larger surviving litter sizes had core areas with higher mean vegetation density (NDVI), young regenerating forest patches with low perimeter-area ratio, and lower moisture variance than core areas of females with smaller surviving litter sizes (Figure 5, Tables 21–22). At the home range extent, females with larger surviving litter sizes had less fragmented home ranges, lower moisture variance, young regenerating forest patches with low perimeter-area ratio, and lower percent composition of old regenerating forest than home ranges of females with smaller surviving litter sizes (Tables 23–24*)*.

Habitat covariates were better predictors of reproductive events at the core area (AIC_c = 74.53, Table 9) than at the home range (AIC_c = 83.18, Table 11) extent. To a lesser degree, habitat covariates were better predictors of initial litter sizes at the core area (AIC_c = 124.44, Table 13) than at the home range (AIC_c = 126.62, Table 15) extent. Habitat covariates were similarly predictive of litter success at the core area (AIC_c = 39.21, Table 17) and the home range (AIC_c = 38.32, Table 19) extent, and also similarly predictive of surviving litter sizes at the core area (AIC_c = 75.59, Table 21) and the home range (AIC_c = 75.07, Table 23) extent.

DISCUSSION

Our results supported our hypotheses about the effects of maternal age category on lynx reproductive success (Table 1) in that older females (>3 years) had a higher probability of producing a litter than 2 year old females. This suggests that female lynx in our study areas may delay reproduction similar to northern lynx populations when snowshoe hare abundances are low (Brand and Keith 1979, Poole 1994, Slough and Mowat 1996). The average litter size in our study (2.46 kittens; Squires in prep) was similar to average litter sizes for lynx in other areas of the contiguous US (Vashon et al. 2005, Moen et al. 2008, Shenk 2008, Vashon et al. 2012).

Contrary to our predictions, maternal body mass was not a good predictor for reproductive success possibly because body mass measurements were recorded whenever females were captured in the winter, when lynx are potentially more resource-limited and female body mass may vary naturally (i.e. higher body mass in early winter, lower body mass in late winter). Similarly, maternal body mass was not predictive of litter size in Eurasian lynx (*Lynx lynx*) (Gaillard et al. 2014).

Many of our hypotheses about the effects of forest structure type composition and configuration on female lynx reproductive success were supported (Table 1). We found that connectivity of mature forest, percent composition of young regenerating forest and young regenerating forest patches with low perimeter-area ratio, and adjacency of mature to young regenerating forest types were the most important predictors for overall lynx reproductive success in our study areas.

Landscapes containing a heterogeneous mix of forest structure types provide lynx foraging habitat throughout the year (Poole et al. 1996, McKelvey et al. 2000, Hoving et al. 2004, Squires et al. 2010). We found production of litters, larger initial litter sizes, and larger surviving litter sizes occurred where home ranges contained a relatively contiguous mature forest background with intermediate amounts (10–15%) of young forest patches with low perimeter-area ratio.

All female home ranges within our study areas were altered to a large degree by land management actions (i.e. regeneration harvests, pre-commercial and commercial thinning, prescribed burns, etc.). Female home ranges ranged from relatively contiguous mature forest background among a mixture of different forest structure types (Figure 2), to those with smaller and more isolated mature forest patches surrounded by different forest structure types. The contiguous mature forest component, which we have referred to as greater connectivity of mature forest within female home ranges, was the only home range configuration metric that was strongly related to both successful reproduction and larger initial litter sizes.

We suggest a threshold may exist for the positive effect of young regenerating forest, and that intermediate amounts (10–15%) are most conducive for lynx reproductive events (Figure 3). This positive relationship may be related to higher densities of snowshoe hares in young regenerating forest patches during summer (Griffin and Mills 2009). However, home ranges with greater proportions of young forest (i.e. >15%) may compromise foraging habitat for lynx in the winter. Mature forest is the most stable and consistent annual forest structure type for snowshoe hares and lynx in the western U.S. (Griffin 2004, Griffin and Mills 2009, Squires et al. 2010, Berg et al. 2012, Ivan et al. 2014).

Although mature forest is the most crucial and limiting forest structure type for lynx (due to its long regeneration time) and provides high-quality, year-round snowshoe hare habitat, our findings suggest young regenerating forest in conjunction with mature forest may further enhance the reproductive success of lynx. Mature forest with low tree limbs and a substantial understory can provide lynx foraging habitat for long periods of time (Murray et al. 1994, Koehler et al. 2008, Squires et al. 2010), whereas habitat for hares in young regenerating forest habitat is temporary; trees eventually grow taller and become inaccessible to snowshoe hares. When this happens, the trees shade out the understory, resulting in unsuitable habitat for an extended period of time before the stand develops mature forest charachteristics. The duration of time in suitable versus unsuitable habitat will vary, depending on the species composition of the regenerating stand and site characteristics.

We further suggest the potential benefit of the adjacency of “source” forest structure types (i.e. mature forest and young regenerating forest) for snowshoe hares and thus lynx foraging. Female home ranges with greater adjacency of mature and young regenerating forest types were positively associated with both probability of producing a litter and litter success. Overall population growth of snowshoe hares in Montana was higher in dense mature and dense young forest types and in open young and open mature forest types (Griffin and Mills 2009). They further proposed that dense mature forest adjacent to dense young forest would likely be more valuable than the adjacency of either forest structure type to an open or thin forest structure type. In Washington, landscapes with contiguous snowshoe hare habitat or those surrounded by a mosaic of similar habitat quality supported higher snowshoe hares abundances than more fragmented landscapes (Lewis et al. 2011). Potential explanations for the importance of the adjacency between mature forest and young regenerating forest could be related to snowshoe hare daily movements among forest structure types (Walker 2005, Griffin and Mills 2009), dispersal (Griffin and Mills 2009), or seasonal shifts of snowshoe hares between mature forests and adjacent young regenerating forests (Ivan et al. 2014). Ivan et al. (2014) evaluated intra- and inter-seasonal snowshoe hare movement patterns in Colorado for 3 forest types (young lodgepole, old lodgepole, and mature spruce-fir forest). They discovered that snowshoe hares shifted from young lodgepole forests into older adjacent forests during winter and reversed this movement in the summer. Similar to previous studies of snowshoe hare movement, the authors proposed this seasonal shift could be due to an interaction between snow depth and tree canopy, suggesting that snow could make younger forests less available or less secure for hares in the winter (Ivan et al. 2014).

We found that female lynx with home ranges containing 10–15% composition of young regenerating forest patches with low perimeter-area ratio had larger litter sizes. These patches of young regenerating forest may provide higher densities of prey for female lynx and kittens during the summer, especially when females are strongly associated with den sites and are restricted in foraging movements. For example, female lynx use natal (parturition) and multiple maternal den locations for rearing their offspring over a period of 6–8 weeks during early summer (mid-May–mid July) (Slough 1999, Moen et al. 2008, Olson et al. 2011) and exhibit a central place foraging behavior with movement restricted to a small foraging radius [2–3 km from den sites in Minnesota (Moen et al. 2008); 2.1 km in Montana (Olson et al. 2011)]. Lynx den most frequently in mature forest stands in the western US; for example, all lynx dens in Washington (*n* = 3) and 80% of lynx dens in Montana (*n* = 55) were located in mature forest stands (Koehler et al. 2008, Squires et al. 2008). We suggest female lynx may benefit from "source" patches of young regenerating forest adjacent to mature forest within their home ranges.

Existing literature regarding the importance of old regenerating forest to lynx is equivocal, suggesting old regenerating forest without a dense understory (i.e. during stem-exclusion period) will only become high quality lynx habitat once a dense understory develops (USFS 2007). We suggest that higher amounts of old regenerating forest with lesser amounts of mature forest may be negatively associated with lynx reproductive success. Females with home ranges containing higher amounts of old regenerating forest had smaller initial litter sizes than females with home ranges containing lesser amounts of old regenerating forest. However, we interpret these results with caution because our sample size was small and because once a dense understory has developed, older regenerating forests will transition into snowshoe hare and thus lynx foraging habitat once again (USFS 2007).

Future Research Recommendations

To improve and expand upon these findings, we recommend future studies consider tree species composition within female home ranges to refine our current understanding of lynx habitat. For example, within the mature forest component of a female's home range, the amount of spruce-fir forest is likely more important than other tree species compositions (Squires and Ruggiero 2007, Squires et al. 2008, 2010).

Furthermore, future investigations that incorporate a continuous landscape gradient framework (i.e. pixels) instead of the classic categorical patch-mosaic framework may provide additional insight into the realized niche (McGarigal et al. 2009, Cushman et al. 2010) of lynx in the contiguous U.S. For example, the frequency and distribution of dense pockets of high quality lynx habitat within forested stands could be an important consideration. Finally, developing models that project forest structure types through time may provide valuable guidance for current and future land management actions. This would ensure these actions are sensitive to lynx habitat needs, a critical step for recovery planning.

MANAGEMENT IMPLICATIONS

We suggest that lynx reproductive success is related to forest structure type abundance and spatial configuration within female home ranges. A habitat mosaic comprised of higher percentages and connectivity of mature forest interspersed with patches of young regenerating forest will likely support and enhance lynx reproductive success within our study areas. Female lynx home ranges consisting of >50% mature forest and approximately 10–15% young regenerating forest at both home range extents appears to be the optimal composition of forest structure types. Additionally, greater connectivity of mature forest combined with young regenerating forest patches with low perimeter-area ratios appears to be the optimal configuration of forest structure types.

Current management of US Forest Service lands that contain lynx habitat allows for no greater than 30% young forest within a predefined lynx analysis unit (Ruediger et al. 2000, USFS 2007). We suggest 10–15% composition of young regenerating forest may be more appropriate, and suggest that lesser amounts (<10%) and greater amounts (>15%) may negatively affect lynx reproductive output.

In the short term, timber harvest and natural disturbances can create high quality summer habitat for snowshoe hares. However, there is also a long period of time when these stands will no longer retain high quality snowshoe hare/lynx habitat characteristics, as they progress through seral stages from young regenerating to mature stands. Therefore, we suggest current forest management practices retain existing mature forest patches that provide year-round snowshoe hare habitat, and maintain connectivity of those patches within lynx habitat by avoiding further fragmentation. Land management practices should be carefully evaluated and planned at the home range level; long-term management plans should be developed that will favor maintaining and enhancing the connectivity and abundance of mature forest spatially and temporally within lynx habitat.

TABLES AND FIGURES

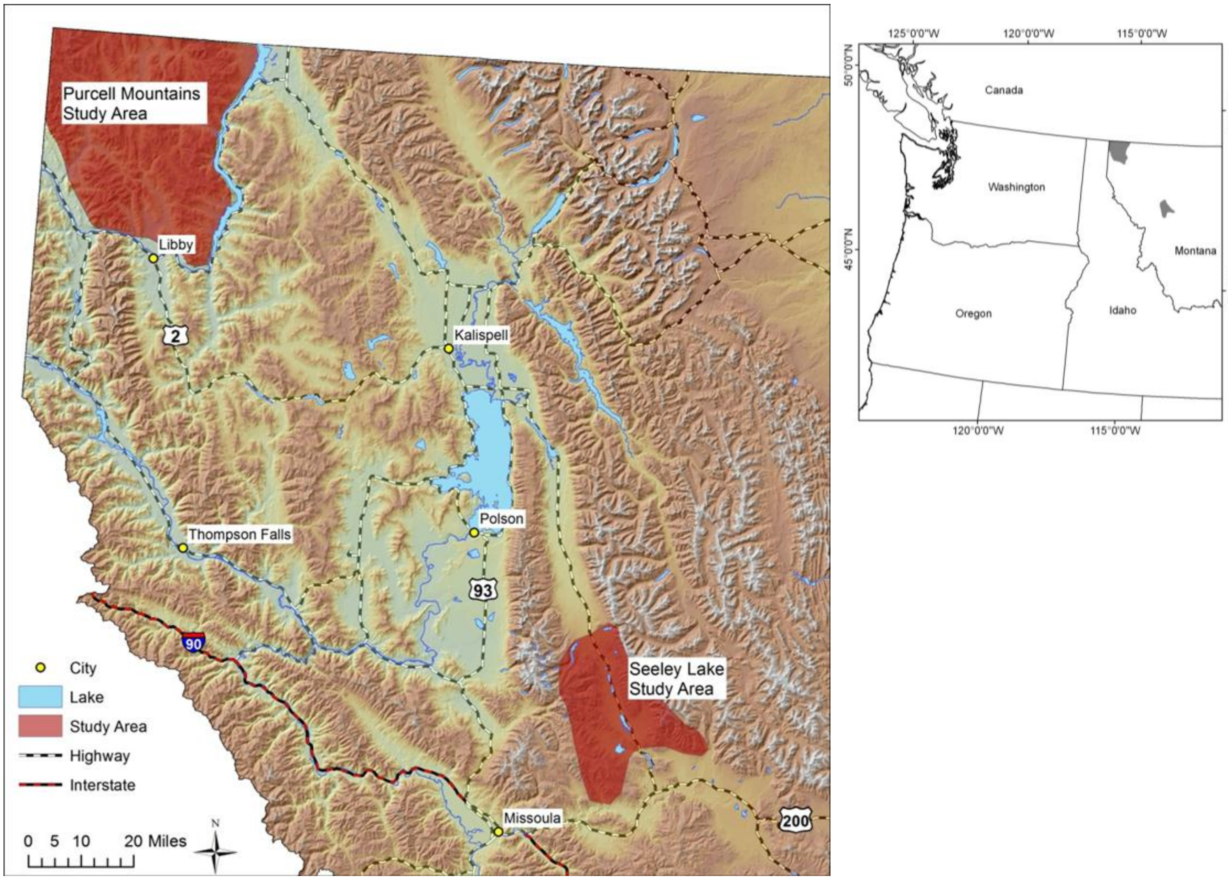

Figure 1. Purcell Mountains and Seeley Lake study areas in the range of Canada lynx (Lynx canadensis) in northwestern Montana, USA. Region is highlighted in grey in the inset map.

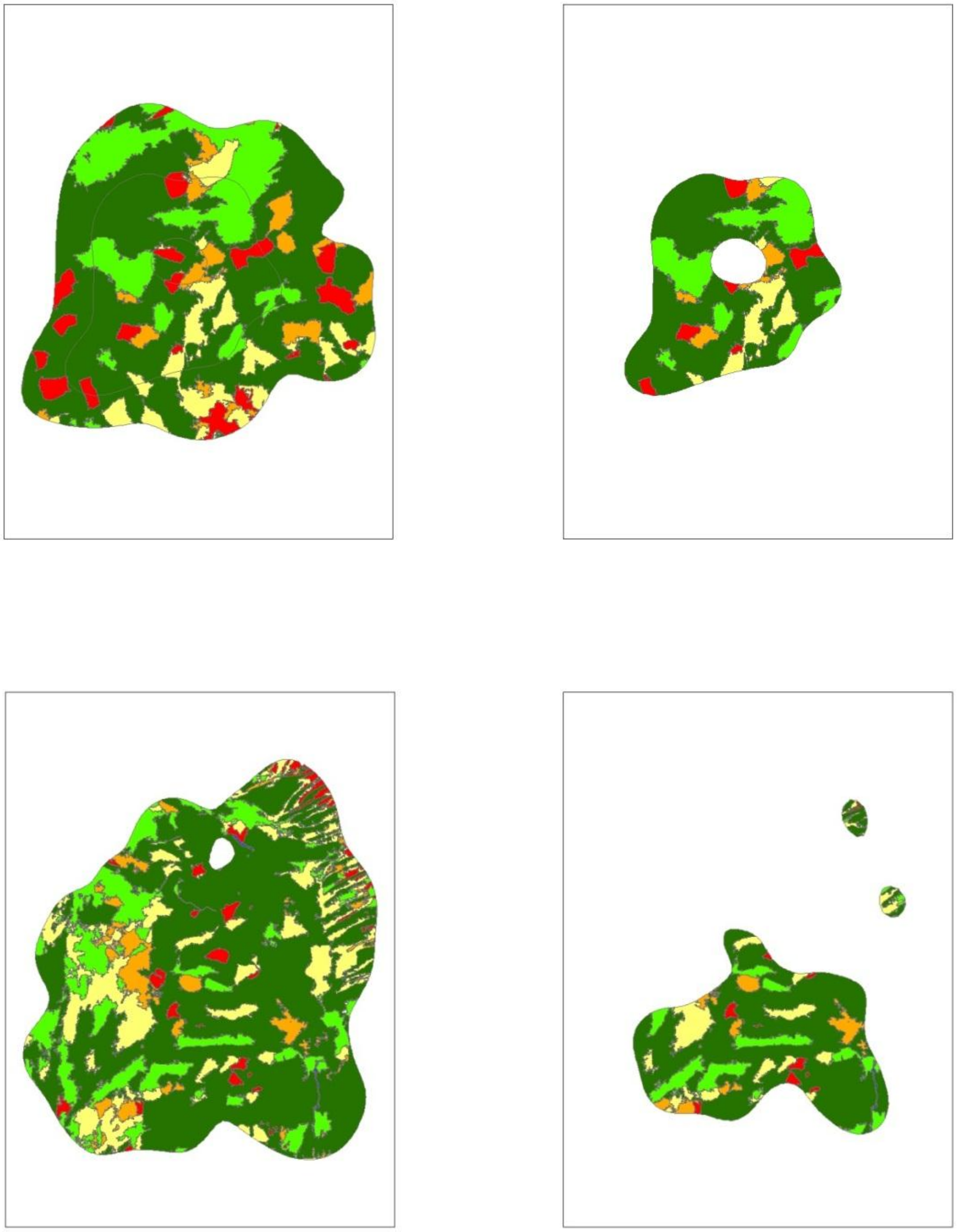

Figure 2. Two female Canada lynx (*Lynx canadensis*) home ranges (left) with associated core areas (right) in the Purcell Mountains and Seeley Lake study areas in northwestern Montana, USA which illustrate the importance of connectivity of mature forest (dark green) and the importance of young regenerating forest (yellow) adjacency to mature forest. Core areas of females that produced litters had higher connectivity of mature forest and higher adjacency between mature forest and young regenerating forest types. Forest structure categories include: mature forest (dark green), old regenerating forest (light green), young regenerating forest (yellow), thin (orange), and open areas (red).

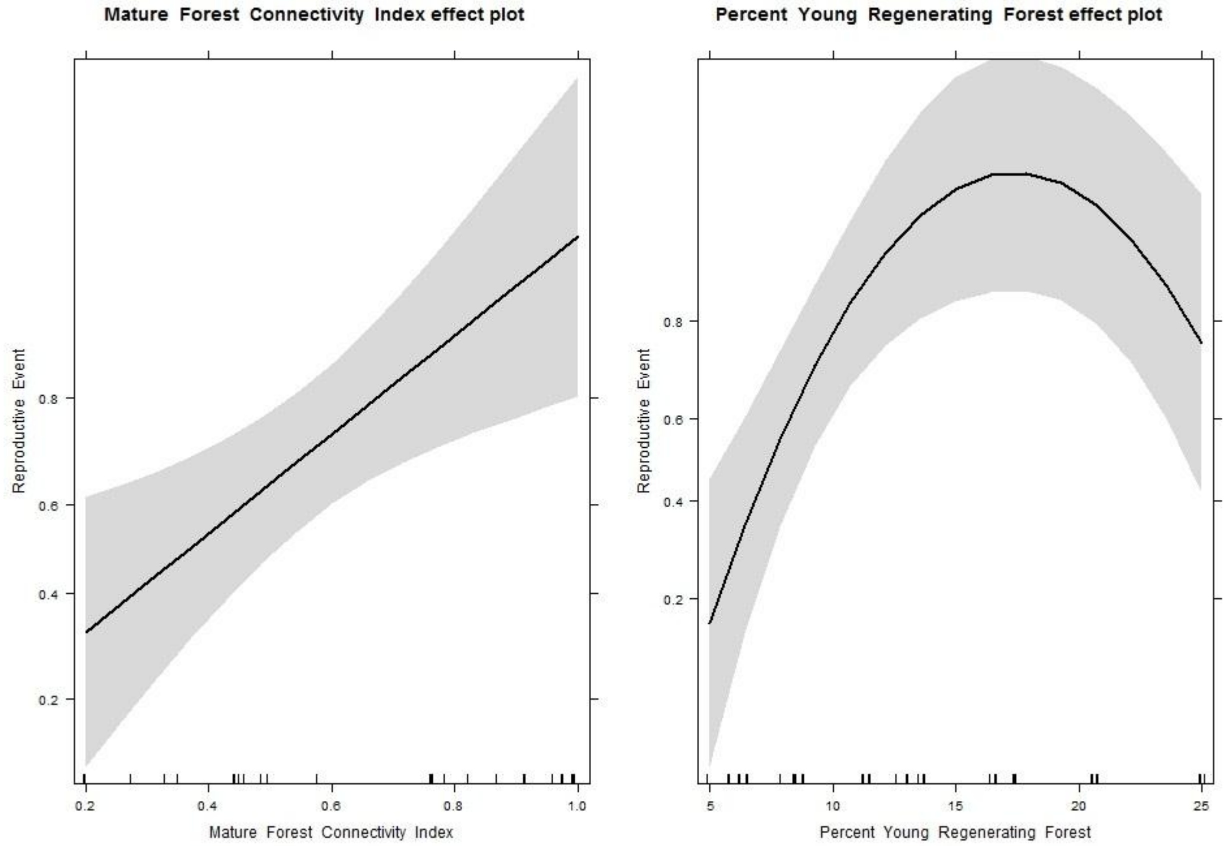

Figure 3. Predicted probability plots for potential reproductive events as functions of individual covariates from generalized linear mixed effects models of Canada lynx (*Lynx canadensis*) reproductive success in northwestern Montana, USA, 1998–2012. Plots depict relationships between individual covariates and parameters with other covariates fixed at mean values. Numerical covariate relationships are illustrated as functions (black lines) with 95% CIs (gray shading). Model selection results are presented in Tables 9–12. Covariates are defined in Table 2.

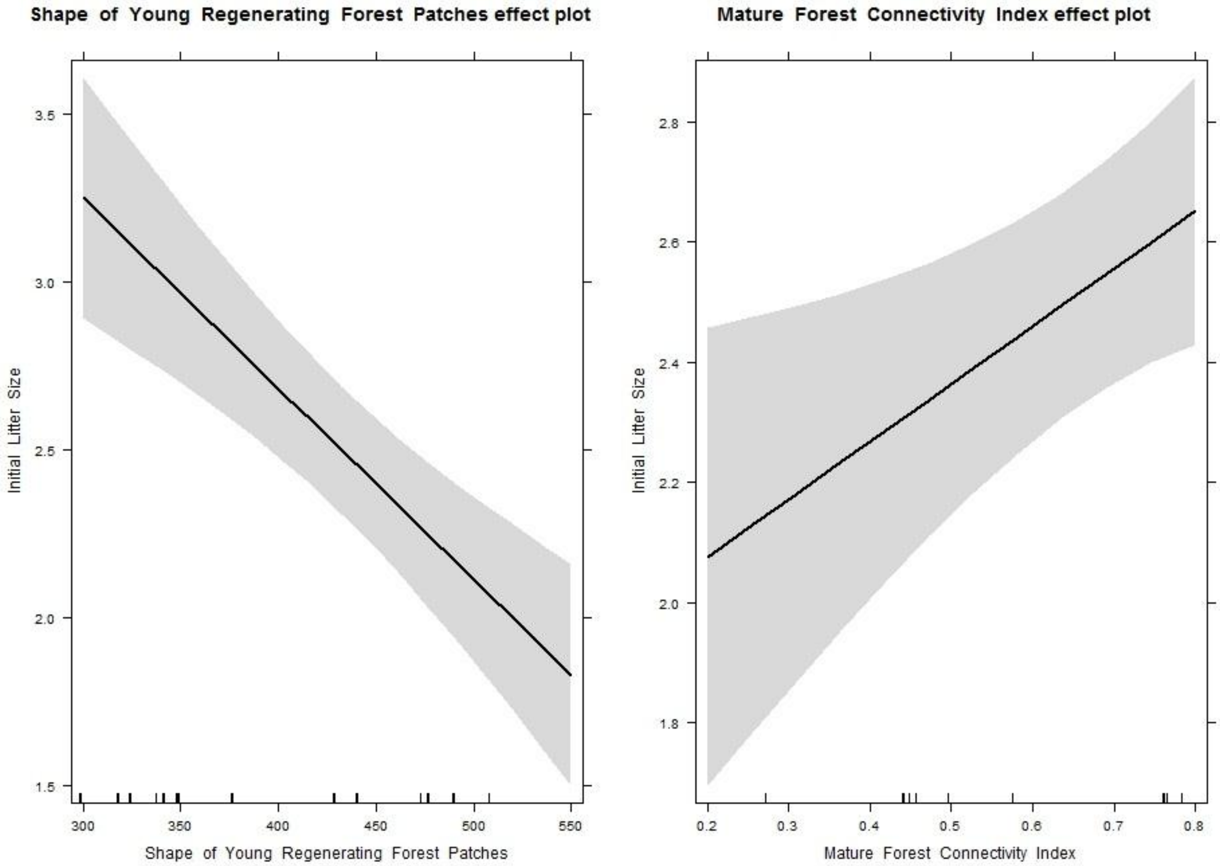

Figure 4. Predicted probability plots for initial litter size as functions of individual covariates from linear mixed effects models of Canada lynx (*Lynx canadensis*) reproductive success in northwestern Montana, USA, 1998–2012. Plots depict relationships between individual covariates and parameters with other covariates fixed at mean values. Numerical covariate relationships are illustrated as functions (black lines) with 95% CIs (gray shading). Model selection results are presented in Tables 13–16. Covariates are defined in Table 2.

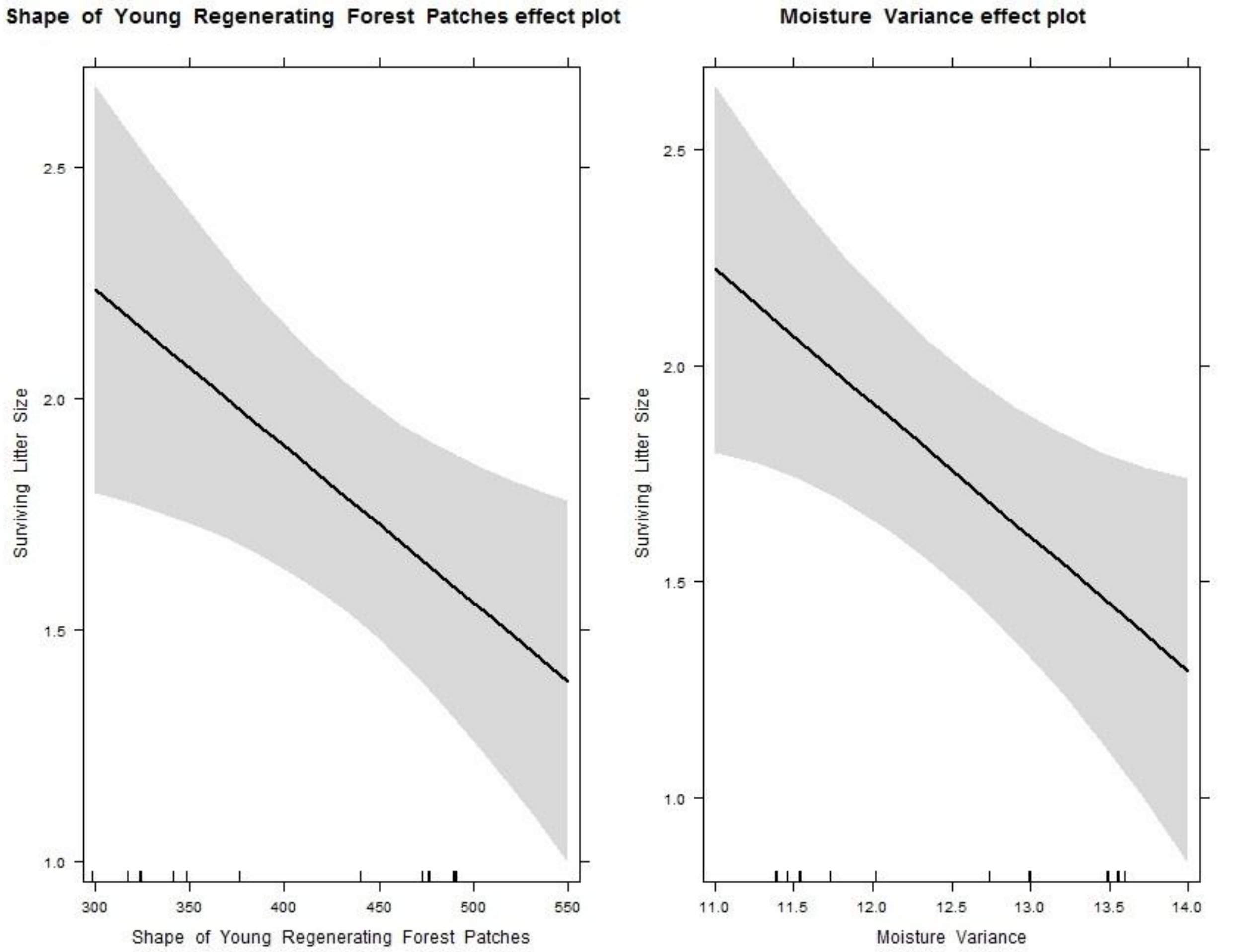

Figure 5. Predicted probability plots for surviving litter size as functions of individual covariates from linear mixed effects models of Canada lynx (*Lynx canadensis*) reproductive success in northwestern Montana, USA, 1998–2012. Plots depict relationships between individual covariates and parameters with other covariates fixed at mean values. Numerical covariate relationships are illustrated as functions (black lines) with 95% CIs (gray shading). Model selection results are presented in Tables 21–24. Covariates are defined in Table 2.

Table 1. Summary of hypotheses and predictions for all response variables representing measures of reproductive success: Covariates included in top models are identified in bold and covariates with confidence intervals that did not overlap zero are identified by an asterisk (*). Definitions of maternal covariates[a] are provided below and definitions of habitat covariates are provided in Table 2.

Covariates[a]	Predictions	Summary of major findings
Maternal		
body mass	$\beta > 0$	
mass_body length	$\beta > 0$	
age category	**$\beta > 0$**	**>3 years old compared to 2 year olds**
reproductive event previous year	**$\beta > 0$**	
litter size previous year	$\beta > 0$	
litter success previous year	$\beta > 0$	
survival size previous year	$\beta > 0$	
Forest structural types		
open	$\beta < 0$	
thin	$\beta < 0$	
young	**$\beta > 0$***	**%*, patch density*, patch shape***
old	**$\beta > 0$***	**%***
mature	**$\beta > 0$***	**%*, connectivity***
forest (mature +old)	$\beta > 0$	
sparse (thin +open)	$\beta < 0$	
young and mature	**$\beta > 0$***	**edge density***
all forest types combined	**$\beta < 0$***	**contagion* (fragmentation)**
Vegetation density		
mean NDVI	**$\beta > 0$***	**vegetation density***
mean CTI (soil moisture)	$\beta > 0$	
range CTI (soil moisture)	**$\beta < 0$***	**moisture variance***

[a] Maternal covariates are defined as follows: *body mass*, female weight in kilograms; *mass_body length,* body mass in kilograms divided by body length in centimeters; *age category*, categorical variable [2 year olds, 3 year olds or >3 year olds]; *reproductive event previous year,* reproductive event recorded the previous year (binary); *litter size previous year,* initial litter size recorded the previous year; *litter success previous year,* litter survival (≥1 survivor) recorded the previous year (binary); *survival size previous year*, the number of kittens that survived to 8–10 months old the previous year.

Table 2. Landscape metrics used to analyze home range composition and configuration by forest structure types within female Canada lynx (*Lynx canadensis*) home ranges in northwestern Montana, USA, from 1998−2012.

Covariates	Units	Description
percent composition	%	Percentage of the home range comprised of the corresponding habitat type
area-weighted mean patch	ha	Similar to mean patch area, however emphasis is placed on the mean patch area of larger patches
correlation length (connectivity)	0−1 index	A measure of patch extent, how far across the landscape a patch extends until it reaches a boundary with another patch type
patch density	# per 100 ha	Number of patches per hectare (class level)
patch shape	edge/ha	Shape complexity of patches, where shape is defined by perimeter-area relationships
edge contrast	m/ha	The total length of edge per hectare, weighted by the contrast between different habitat types
contagion	%	Measure of the aggregation of habitat types, approaches 100 when all patch types are equally adjacent to other patch types

*For complete descriptions and algorithms see McGarigal and Marks (1994).

Table 3. Number of observations and unique females included in statistical analyses for Canada lynx (*Lynx canadensis*) in northwestern Montana, USA, from 1998–2012. Definitions of maternal covariates[a] are provided below. Sample sizes (*n*) and number of females included in each analysis are identified.

Covariates[a]	Potential reproductive events		Initial litter size		Litter success		Surviving litter size	
	n	Females	*n*	Females	*n*	Females	*n*	Females
body mass	65	33	42	20	26	13	19	10
mass_body length	52	30	33	18	20	12	15	9
age category	85	34	54	21	36	16	28	14
litter size present year	61	22	61	22	40	16	32	14
litter previous year	61	23	45	18	29	13	23	12
litter size previous year	61	23	45	18	29	13	23	12
survival previous year	35	14	29	12	25	11	20	10
survival size previous year	29	13	24	11	21	10	17	9
all habitat covariates	78	23	54	17	38	15	32	13

[a] Maternal covariates are defined as follows: *body mass*, female weight in kilograms; *mass_body length,* body mass in kilograms divided by body length in centimeters; *age category*, categorical variable [2 year olds, 3 year olds or >3 year olds]; *reproductive event previous year,* reproductive event recorded the previous year (binary); *litter size previous year,* initial litter size recorded the previous year; *litter success previous year,* litter survival (≥1 survivor) recorded the previous year (binary); *survival size previous year,* the number of kittens that survived to 8−10 months old the previous year.

Table 4. Baseline information for initial litter sizes and initial litter sizes subset by litters with known survival data for female Canada lynx (*Lynx canadensis*) in northwestern Montana, USA, from 1998−2012.

Litter sizes			Litter sizes with known survival					
Litter size	*n*	Total kittens	Litter size	*n*	Total kittens	Total survivors	Probability of survival	Number of kittens that survive at each litter size
1	6	6	1	4	4	4	1.000	1.00
2	27	54	2	20	40	23	0.575	1.15
3	24	72	3	12	36	17	0.472	1.42
4	2	8	4	2	8	7	0.875	3.50
5	2	10	5	2	10	6	0.600	3.00
Total	61	150	Total	40	98	57	0.582	

Table 5. Univariate models tested to explain variation in *potential reproductive events (binary) for female Canada lynx (*Lynx canadensis)* in northwestern Montana, USA, from 1998−2012. Definitions of maternal covariates[a] are provided below. Beta coefficients (β), standard errors (SE), 95% confidence intervals (95% CI), p-values, sample size (*n*) and number of females are identified.

Covariates[a]		β	SE	95% CI	p-value	*n*	Females
body mass		0.184	0.4427	−0.838, 1.211	0.677	65	33
mass_body length		−18.227	16.379	−57.701, 16.539	0.266	52	30
age category	2 yr (dummy)	−0.619	0.6875	−2.333, 0.824	0.368	85	34
	3 yr: 2 yr	0.338	0.9083	−1.624, 2.364	0.709		
	>3 yr: 2yr	**1.482**	**0.7232**	**−0.125, 3.393**	**0.055**		
	3 yr: >3 yr	−1.148	0.8547	−2.94, 0.434	0.161		
reproductive event previous year		0.455	0.7172	−2.075, 2.076	0.526	61	23
litter size previous year		0.079	0.5239	−1.036, 1.265	0.881	44	17
litter success previous year		−0.142	1.3630	−4.459, 3.393	0.917	35	14
survival size previous year		−0.248	0.6407	−1.628 1.636	0.699	29	13

[a] Maternal covariates are defined as follows: *body mass*, female weight in kilograms; *mass_body length*, body mass in kilograms divided by body length in centimeters; *age category*, categorical variable [2 year olds, 3 year olds or >3 year olds]; *reproductive event previous year,* reproductive event recorded the previous year (binary); *litter size previous year,* initial litter size recorded the previous year; *litter success previous year,* litter survival (≥1 survivor) recorded the previous year (binary); *survival size previous year,* the number of kittens that survived to 8−10 months old the previous year.

Table 6. Univariate models tested to explain variation in *initial litter size for female Canada lynx (*Lynx canadensis*) in northwestern Montana, USA, from 1998−2012. Beta coefficients (β), standard errors (SE), 95% confidence intervals (95% CI), p-values, sample size (*n*), and number of females are identified. Definitions of maternal covariates[a] are provided below.

Covariates[a]		β	SE	95% CI	p-value	*n*	Females
body mass		−0.113	0.1657	−0.446, 0.275	0.500	42	20
mass_body length		−5.908	6.4390	−18.904, 7.086	0.362	33	18
age category	2 yr (dummy)	2.817	0.3556	2.107, 3.527	≤0.001	54	21
	3 yr: 2 yr	−0.463	0.4642	−1.395, 0.465	0.321		
	>3 yr: 2yr	−0.415	0.3742	−1.161, 0.333	0.271		
	3 yr: >3 yr	−0.048	0.3439	−0.739, 0.639	0.889		
reproductive event previous year		0.385	0.2599	−0.139, 0.906	0.143	45	18
litter size previous year		−0.038	0.1244	−0.364, 0.226	0.803	35	15
litter success previous year		0.542	0.3411	−0.157, 1.233	0.124	29	12
survival size previous year		−0.072	0.1659	−0.462, 0.267	0.665	24	11

[a] Maternal covariates are defined as follows: *body mass*, female weight in kilograms; *mass_body length*, body mass in kilograms divided by body length in centimeters; *age category*, categorical variable [2 year olds, 3 year olds or >3 year olds]; *reproductive event previous year,* reproductive event recorded the previous year (binary); *litter size previous year,* initial litter size recorded the previous year; *litter success previous year,* litter survival (≥1 survivor) recorded the previous year (binary); *survival size previous year,* the number of kittens that survived 8−10 months old the previous year.

Table 7. Univariate models tested to explain variation in the probability of *litter success for female Canada lynx (*Lynx canadensis*) in northwestern Montana (1998−2012). Beta coefficients (β), standard errors (SE), and 95% confidence intervals (95% CI), p-values, sample size (*n*), and number of females are identified. Definitions of maternal covariates[a] are provided below.

Covariates[a]		β	SE	95% CI	p-value	*n*	Females
body mass		−0.187	0.5590	−1.720, 1.197	0.738	26	13
mass_body length		−2.986	19.502	−83.152, 101.46	0.878	20	12
age category	2 yr (dummy)	1.119	1.1682	−1.014, −4.765	0.338	36	16
	3 yr: 2 yr	−1.156	1.5349	−6.566, 1.813	0.451		
	>3 yr: 2yr	0.428	1.2718	−2.758, 3.217	0.737		
	3 yr: >3 yr	−1.584	1.3825	−6.836, 0.766	0.252		
reproductive event previous year		0.288	1.2583	−2.829, 2.589	0.819	29	13
litter size previous year		−0.229	0.4699	−1.246, 0.781	0.626	25	11
litter success previous year		0.348	1.2815	−2.808, 2.739	0.786	25	11
survival size previous year		0.091	0.6268	−1.086, 1.607	0.884	21	10

[a] Maternal covariates are defined as follows: *body mass*, female weight in kilograms; *mass_body length*, body mass in kilograms divided by body length in centimeters; *age category*, categorical variable [2 year olds, 3 year olds or >3 year olds]; *reproductive event previous year,* reproductive event recorded the previous year (binary); *litter size previous year,* initial litter size recorded the previous year; *litter success previous year,* litter survival (≥1 survivor) recorded the previous year (binary); *survival size previous year,* the number of kittens that survived to 8−10 months old the previous year.

Table 8. Univariate models tested to explain variation in *surviving litter size per litter for female Canada lynx (*Lynx canadensis*) in northwestern Montana, USA, from 1998−2012. Beta coefficients (β), standard errors (SE), and 95% confidence intervals (95% CI), p-values, sample size (*n*), and number of females are identified. Definitions of maternal covariates[a] are provided below.

Covariate[a]	β	SE	95% CI	p-value	*n*	Females
body mass	0.054	0.2545	−0.571, 0.589	0.845	19	10
mass_body length	−4.584	9.229	−23.957, 14.727	0.621	15	9
age category 2 yr (dummy)	2.044	0.3920	1.249, 2.839	≤0.001	28	14
3 yr: 2 yr	−0.363	0.5404	−1.528, 0.734	0.505		
>3 yr: 2yr	−0.364	0.4088	−1.197, 0.464	0.376		
3 yr: >3 yr	0.002	0.4537	−0.967, 0.922	0.997		
reproductive event previous year	**0.703**	**0.3845**	**−0.083, 1.490**	**0.077**	**23**	**12**
litter size previous year	−0.081	0.1415	−0.376, 0.294	0.613	20	10
litter success previous year	0.536	0.4410	−0.391, 1.469	0.244	20	10
survival size previous year	−0.144	0.1825	−0.556, 0.339	0.507	17	9

[a] Maternal covariates are defined as follows: *body mass*, female weight in kilograms; *mass_body length*, body mass in kilograms divided by body length in centimeters; *age category*, categorical variable [2 year olds, 3 year olds or >3 year olds]; *reproductive event previous year,* reproductive event recorded the previous year (binary); *litter size previous year,* initial litter size recorded the previous year; *litter success previous year,* litter survival (≥1 survivor) recorded the previous year (binary); *survival size previous year,* the number of kittens that survived to 8−10 months old the previous year.

Table 9. Model selection results for predicting potential reproductive events (binary) for female Canada lynx (*Lynx canadensis*) at the 50% core area extent in northwestern Montana, 1998−2012. Provided are number of parameters (*K*), Akaike Information Criterion corrected for small sample sizes (AIC_c), ΔAIC_c, Akaike weights (w_i), and log-likelihood (LL) for all models within 10 AIC_c of the top model. Covariates are described in Table 2. Analysis included 78 total observations from 23 female lynx.

Model	*K*	AIC_c	ΔAIC_c	w_i	LL
connectivity of mature forest + percent young forest^2	5	74.53	0.00	0.72	−31.85
edge density mature to young + percent young forest^2	5	76.46	1.93	0.27	−32.81
percent young forest^2	5	83.70	9.18	0.01	−37.58

Table 10. Top model parameter estimates for predicting potential reproductive events (binary) of female Canada lynx (*Lynx canadensis*) at the 50% core area extent in northwestern Montana, 1998−2012. Provided are coefficients (β), standard errors (SE), 95% confidence intervals (95% CI), and p-values for all models within 2 AIC_c of the top model. Covariates are described in Table 2. Analysis included 78 observations from 23 female lynx.

Top models	β	SE	95% CI	p-value
connectivity of mature forest + percent young forest^2				
connectivity of mature forest	4.560	1.5345	1.552, 7.568	0.003
percent young forest	1.019	0.2614	0.507, 1.532	≤0.001
percent young forest^2	–0.029	0.0081	−0.045, −0.014	≤0.001
edge density mature to young + percent young forest^2				
edge density mature to young	0.093	0.0322	0.030, 0.156	0.004
percent young forest	0.875	0.2359	0.412, 1.337	≤0.001
percent young forest^2	–0.030	0.0082	−0.046, −0.014	≤0.001

Table 11. Model selection results for predicting potential reproductive events (binary) for female Canada lynx (*Lynx canadensis*) at the 90% home range extent in northwestern Montana, 1998−2012. Provided are number of parameters (K), Akaike Information Criterion corrected for small sample sizes (AIC_c), $\Delta\mathrm{AIC}_c$, Akaike weights (w_i), and log-likelihood (LL) for all models within 10 AIC_c of the top model. Covariates are described in Table 2. Analysis included 78 observations from 23 female lynx.

Models	K	AIC_c	$\Delta\mathrm{AIC}_c$	w_i	LL
connectivity of mature forest + percent young forest^2	5	83.18	0.00	0.38	−36.17
edge density mature to young + percent young forest^2	5	84.51	1.34	0.19	−36.84
percent young forest^2	4	84.60	1.42	0.19	−38.02
contagion + percent young forest^2	5	86.67	3.49	0.07	−37.92
edge density mature to young + shape of mature forest patches	4	89.60	6.42	0.01	−40.52
patch density young forest + shape of young forest patches	4	89.97	6.79	0.01	−40.71
patch density young forest	5	90.22	7.04	0.03	−41.95
edge density mature to young	3	90.64	7.47	0.03	−42.16
mean moisture	3	90.74	7.56	0.03	−42.21
mean moisture + moisture variance	3	90.77	7.72	0.03	−42.22
intercept only	2	92.29	9.11	0.00	−44.06

Table 12. Top model parameter estimates for predicting potential reproductive events (binary) of female Canada lynx (*Lynx canadensis*) at the 90% home range extent in northwestern Montana, 1998−2012. Provided are coefficients (β), standard errors (SE), 95% confidence intervals (95% CI), and p-values for all models within 2 AIC_c of the top model. Covariates are described in Table 2. Analysis included 78 observations from 23 female lynx.

Top models	β	SE	95% CI	p-value
connectivity of mature forest + percent young forest^2				
connectivity of mature forest	3.038	1.6227	−0.143, 6.218	0.061
percent young forest	1.336	0.3759	0.599, 2.073	≤0.001
percent young forest^2	−0.047	0.0136	−0.073, −0.019	≤0.001
edge density mature and young + percent young forest^2				
edge density mature to young	0.066	0.0434	−0.019, 0.151	0.129
percent young forest	0.969	0.3011	0.379, 1.559	0.001
percent young forest^2	−0.038	0.0116	−0.061, −0.015	0.001
percent young forest^2				
percent young forest	1.121	0.3203	0.493, 1.748	≤0.001
percent young forest^2	−0.039	0.0119	−0.076, −0.016	0.001

Table 13. Model selection results for predicting initial litter size (range = 1−5 kittens) for female Canada lynx (*Lynx canadensis*) at the 50% core area extent in northwestern Montana, 1998−2012. Provided are number of parameters (*K*), Akaike Information Criterion corrected for small sample sizes (AIC_c), ΔAIC_c, Akaike weights (w_i), and log-likelihood (LL) for all models within 10 AIC_c of the top model. Covariates are described in Table 2. Analysis included 54 observations from 23 female lynx.

Models	*K*	AIC_c	ΔAIC_c	w_i	LL
connectivity of mature forest + shape of young forest patches	5	124.44	0.00	0.67	−56.60
shape of young forest patches	4	128.22	3.78	0.10	−59.70
percent old regenerating forest + shape of young forest patches	5	128.55	4.11	0.09	−58.65
vegetation productivity (NDVI) + shape of young forest patches	5	129.03	4.58	0.07	−58.89
edge density mature to young + shape of young forest patches	5	129.57	5.13	0.05	−59.16
vegetation productivity (NDVI)	4	133.19	8.74	0.01	−62.18

Table 14. Top model parameter estimates for predicting initial litter size (range = 1−5 kittens) for female Canada lynx (*Lynx canadensis*) at the 50% core area extent in northwestern Montana, 1998−2012. Provided are coefficients (β), standard errors (SE), 95% confidence intervals (95% CI), and p-values for all models within 2 AIC_c of the top model. Covariates are described in Table 2. Analysis included 54 observations from 23 female lynx.

Top models	β	SE	95% CI	p-value
connectivity of mature forest + shape of young forest patches				
connectivity of mature forest	0.959	0.3739	0.214, 1.705	0.013
shape of young forest patches	−0.006	0.0011	−0.008, −0.003	≤0.001

Table 15. Model selection results for predicting initial litter size (range = 1−5 kittens) for female Canada lynx (*Lynx canadensis*) at the 90% home range extent in northwestern Montana, 1998−2012. Provided are number of parameters (K), Akaike Information Criterion corrected for small sample sizes (AIC_c), ΔAIC_c, Akaike weights (w_i), and log-likelihood (LL) for all models within 10 AIC_c of the top model. Covariates are described in Table 2. Analysis included 54 total observations from 23 female lynx.

Models	K	AIC_c	ΔAIC_c	w_i	LL
contagion + percent mature forest	5	126.62	0.00	0.18	−57.68
shape of young forest patches + moisture variance	5	126.67	0.05	0.18	−57.71
shape of young forest patches + patch density young forest	5	127.10	0.48	0.14	−57.93
contagion + percent old regenerating forest	5	127.18	0.56	0.14	−57.96
shape of young forest patches	4	128.99	2.38	0.06	−60.09
contagion	4	133.09	5.98	0.01	−62.13
percent mature forest + percent open areas	5	133.30	6.20	0.01	−61.03
vegetation productivity (NDVI)	4	134.21	7.11	0.01	−62.70

Table 16. Top model parameter estimates for predicting initial litter size (range = 1−5 kittens) for female Canada lynx (*Lynx canadensis*) at the 90% home range extent in northwestern Montana, 1998−2012. Provided are coefficients (β), standard errors (SE), 95% confidence intervals (95% CI), and p-values for all models within 2 AIC_c of the top model. Covariates are described in Table 2. Analysis included 54 observations from 23 female lynx.

Top models	β	SE	95% CI	p-value
contagion + percent mature forest				
contagion	−0.078	0.0167	−0.111, −0.044	≤0.001
percent mature forest	0.026	0.0084	0.009, 0.043	0.003
shape of young forest patches + moisture variance				
shape of young forest patches	−0.004	0.0011	−0.007, −0.002	≤0.001
moisture variance	−0.149	0.0671	−0.284, −0.016	0.029
shape and density of young forest patches				
patch density young forest	0.463	0.2184	0.028, 0.910	0.038
shape of young forest patches	−0.006	0.0012	−0.008, −0.003	≤0.001
contagion + percent old regenerating forest				
contagion	−0.053	0.0129	−0.079, −0.027	≤0.001
percent old regenerating forest	−0.033	0.0109	−0.055, −0.011	0.004

Table 17. Model selection results for predicting litter success (binary) for female Canada lynx (*Lynx canadensis*) at the 50% core area extent in northwestern Montana, 1998−2012. Provided are number of parameters (K), Akaike Information Criterion corrected for small sample sizes (AIC_c), $\Delta\mathrm{AIC}_c$, Akaike weights (w_i), and log-likelihood (LL) for all models within 10 AIC_c of the top model. Covariates are described in Table 2. Analysis included 38 total observations from 15 female lynx.

Models	K	AIC_c	$\Delta\mathrm{AIC}_c$	w_i	LL
edge density mature to young + shape of mature forest patches	4	39.21	0.00	0.11	−15.00
edge density mature to young + connectivity of mature forest	4	39.88	0.67	0.08	−15.33
percent young forest	3	40.52	1.31	0.06	−16.91
intercept only	2	40.65	1.44	0.05	−18.15
edge density mature to young	3	40.86	1.65	0.04	−17.07
shape of mature forest patches	3	41.23	2.02	0.04	−17.26

Table 18. Top model parameter estimates for predicting litter success (binary) of female Canada lynx (*Lynx canadensis*) at the 50% core area extent in northwestern Montana, 1998−2012. Provided are coefficients (β), standard errors (SE), 95% confidence intervals (95% CI), and p-values for all models within 2 AIC_c of the top model. Covariates are described in Table 2. Analysis included 38 total observations from 15 female lynx.

Top models	β	SE	95% CI	p-value
edge density mature to young + shape of mature forest patches				
edge density mature to young	0.123	0.0686	−0.011, 0.258	0.072
shape of mature forest patches	0.012	0.0087	−0.005, 0.029	0.168
edge density mature to young + connectivity of mature forest				
edge density mature to young	0.118	0.0634	−0.006, 0.242	0.062
connectivity of mature forest	−3.541	2.0852	−7.628, 0.546	0.089
percent young forest	0.149	0.1062	−0.032, 0.462	0.160
intercept only	1.488	0.4185	0.727, 2.393	≤0.001
edge density mature to young	0.061	0.0434	−0.021, 0.164	0.157
shape of mature forest patches	0.009	0.0084	−0.003, 0.035	0.305

Table 19. Model selection results for predicting litter success (binary) for female Canada lynx (*Lynx canadensis*) at the 90% home range extent in northwestern Montana, 1998−2012. Provided are number of parameters (K), Akaike Information Criterion corrected for small sample sizes (AIC_c), ΔAIC_c, Akaike weights (w_i), and log-likelihood (LL) for all models within 10 AIC_c of the top model. Covariates are described in Table 2. Analysis included 38 total observations from 15 female lynx.

Models	K	AIC_c	ΔAIC_c	w_i	LL
connectivity of mature forest	3	38.32	0.00	0.11	−15.81
edge density mature to young + connectivity of mature forest	4	38.70	0.37	0.08	−14.74
edge density mature to young + shape of mature forest patches	4	39.21	0.88	0.07	−15.00
connectivity of mature forest + percent young forest	4	39.53	1.20	0.06	−15.16
percent young forest	3	40.27	1.94	0.04	−16.78

Table 20. Top model parameter estimates for predicting litter success (binary) of female Canada lynx (*Lynx canadensis*) at the 90% home range extent in northwestern Montana, 1998−2012. Provided are coefficients (β), standard errors (SE), 95% confidence intervals (95% CI), and p-values for all models within 2 AIC_c of the top model. Covariates are described in Table 2. Analysis included 38 total observations from 15 female lynx.

Top models	β	SE	95% CI	p-value
connectivity of mature forest	−7.365	4.801	−19.894, −0.494	0.125
edge density mature to young + connectivity of mature forest				
edge density mature to young	0.059	0.046	−0.029, 0.149	0.191
connectivity of mature forest	−8.075	5.259	−18.385, 2.234	0.125
edge density mature to young + shape of mature forest patches				
edge density mature to young	0.064	0.0476	−0.029, 0.157	0.177
shape of mature forest patches	0.012	0.0128	−0.007, 0.044	0.148
connectivity of mature forest + percent young forest				
connectivity of mature forest	−7.159	5.355	−17.655, 3.337	0.181
percent young forest	0.148	0.134	−0.115, 0.412	0.269
percent young forest	0.211	0.133	−0.049, 0.472	0.112

Table 21. Model selection results for predicting surviving litter size (range = 1−4 kittens) for female Canada lynx (*Lynx canadensis*) at the 50% core area extent in northwestern Montana, 1998−2012. Provided are number of parameters (*K*), Akaike Information Criterion corrected for small sample sizes (AIC_c), ΔAIC_c, Akaike weights (w_i), and log-likelihood (LL) for all models within 10 AIC_c of the top model. Covariates are described in Table 2. Analysis included 31 total observations from 13 female lynx.

Models	*K*	AIC_c	ΔAIC_c	w_i	LL
shape of young forest patches + moisture variance	5	75.59	0.00	0.31	−31.60
vegetation productivity (NDVI) + moisture variance	5	77.59	2.00	0.12	−32.60
contagion+ moisture variance	5	78.61	3.02	0.08	−33.11
moisture variance	4	78.86	3.27	0.06	−34.66
shape of young forest patches	4	79.09	3.50	0.05	−34.78
intercept only	3	82.68	7.09	0.01	−37.90

Table 22. Top model parameter estimates for predicting surviving litter size (range = 1−4 kittens) for female Canada lynx (*Lynx canadensis*) at the 50% core area extent in northwestern Montana, 1998−2012. Provided are coefficients (β), standard errors (SE), 95% confidence intervals (95% CI), and p-values for all models within 2 AIC_c of the top model. Covariates are described in Table 2. Analysis included 31 total observations from 13 female lynx.

Top models	β	SE	95% CI	p-value
shape of young forest patches + moisture variance				
shape of young forest patches	−0.003	0.0013	−0.006, −0.0008	0.013
moisture variance	−0.309	0.1166	−0.546, −0.074	0.012
vegetation productivity + moisture variance				
vegetation productivity (NDVI)	7.827	3.7248	0.296, 15.359	0.042
moisture variance	−0.286	0.1240	−0.537, −0.035	0.027

Table 23. Model selection results for predicting surviving litter size (range = 1−4 kittens) for female Canada lynx (*Lynx canadensis*) at the 90% home range extent in northwestern Montana, 1998−2012. Provided are number of parameters (K), Akaike Information Criterion corrected for small sample sizes (AIC_c), ΔAIC_c, Akaike weights (w_i), and log-likelihood (LL) for all models within 10 AIC_c of the top model. Covariates are described in Table 2. Analysis included 31 total observations from 13 female lynx.

Models	K	AIC_c	ΔAIC_c	w_i	LL
contagion + moisture variance	5	75.07	0.00	0.33	−31.33
shape of young forest patches + moisture variance	5	76.77	1.70	0.14	−32.19
contagion	4	77.42	2.35	0.10	−33.94
moisture variance	4	78.20	3.13	0.07	−34.33

Table 24. Top model parameter estimates for predicting surviving litter size (range = 1−4 kittens) for female Canada lynx (*Lynx canadensis*) at the 90% home range extent in northwestern Montana, 1998−2012. Provided are coefficients (β), standard errors (SE), 95% confidence intervals (95% CI), and p-values for all models within 2 AIC$_c$ of the top model. Covariates are described in Table 2. Analysis included 31 total observations from 13 female lynx.

Top models	β	SE	95% CI	p-value
contagion + moisture variance				
contagion	−0.043	0.0166	−0.076, −0.009	0.014
moisture variance	−0.225	0.0945	−0.416, −0.033	0.022
shape of young forest patches + moisture variance				
shape of young forest patches	−0.003	0.0014	−0.006, −0.0001	0.008
moisture variance	−0.262	0.0943	−0.454, −0.071	0.038

APPENDICES

APPENDIX A

Home Range Estimation

We used ArcGIS® 9.3.1 (Environmental Systems Research Institute (ESRI), Inc., Redlands, CA, USA) and the Home Range Tools Extension (HRT; Rodgers et al. 2007) to estimate annual home ranges using the fixed-kernel density method (Worton 1989). We used a grid cell size of 100 m and an href smoothing parameter (Worton 1995) of 1.0. We estimated multi-annual home ranges for 23 female lynx using GPS and VHF telemetry data. We used 43,539 GPS locations and 1,057 VHF locations to estimate 90% and 50% kernel multi-annual home ranges for 23 female lynx. We used 50% kernel home ranges to evaluate the importance of core use areas. We used the kernel method to minimize inclusion of unused areas in the analysis (Girard et al. 2002) and to minimize home range overestimation concerns (Seaman et al. 1999). When available, multi-annual home ranges were constructed combining GPS and VHF telemetry data for each female over multiple years. Only females whose home range size had become asymptotic given their number of locations were included in the analysis. The average number of locations per female was 1,893 (range = 36−3,416). Telemetry locations that were recorded during the process of initializing GPS collars, and locations after the collar dropped were removed. Additionally, locations that were considered outside of the animals normal movements such as exploratory movements were removed. To validate the use of annual home ranges as representative for each female lynx, we subset winter and summer home range and annual home ranges by year for females with multiple years of telemetry data. Consistent with existing literature (Ruediger et al. 2000), these home ranges did not vary substantially by year. Two young females utilized a larger than average geographical area until their first reproductive event in which the home range area became much smaller and stabilized. We checked all females' telemetry data for this type of behavior and removed locations that were collected prior to first reproductive events.

APPENDIX B

Home Range Composition by Forest Structure Type

Table B.1. Mean composition (%) by forest structure type in home ranges and core areas for female Canada lynx (*Lynx canadensis*) in northwestern Montana, 1998−2012. Presented are mean percent values for Purcell Mountains and Seeley Lake study areas combined, and for each study area individually by forest structure type. Median percent composition is presented in parentheses and standard deviation (SD) is provided.

Forest structure type	% Composition (50% core area)	SD	% Composition (90% home range)	SD
Forest (mature forest + old regenerating forest)	73	13	73	10
Seeley	76	14	74	12
Purcells	69	12	72	9
Mature forest	49	18	50	15
Seeley	50	22	52	15
Purcells	48	14	48	16
Old regenerating forest	24	13	23	10
Seeley	26	10	22	4
Purcells	22	15	24	14
Sparse (Young forest + Thin + Open)	27	13	27	10
Seeley	24	13	26	12
Purcells	31	12	28	9
Young forest	13	6	11	4
Seeley	11	4	9	4
Purcells	15	7	12	5
Thin	10	7	11	5
Seeley	10	7	12	6
Purcells	10	7	9	4
Open	4	4	6	4
Seeley	3	4	5	5
Purcells	5	4	7	3

APPENDIX C

Complete Univariate Analysis for Reproductive Success Models

Table C.1. Parameter estimates for univariate models from a mixed effects logistic regression analysis of the effects of habitat composition and configuration on potential reproductive events for female Canada lynx (*Lynx canadensis*) in northwestern Montana from 1998−2012. Beta coefficients (β), standard errors (SE), and 95% confidence intervals (95% CI) are identified. Parameters include a variety of landscape metrics at the core area extent (50% KDE). Covariates are described in Table 2. Confidence intervals that do not overlap zero are identified in bold. Analysis included 78 total observations from 23 female lynx.

50% core areas	β	SE	p-value	95% CI
percent mature forest	0.024	0.0258	0.360	−0.032, 0.096
percent old regenerating forest	−0.076	0.0354	0.031	−0.179, −0.007
percent young + percent young forest^2				
percent young	0.832	0.2224	0.0002	0.412, 1.337
percent young forest^2	−0.026	0.0073	0.0004	−0.049, −0.012
percent thin	−0.004	0.0766	0.959	−0.198, 0.173
percent open	0.054	0.1248	0.667	−0.252, 0.344
percent forest (mature forest + old regenerating forest)	−0.029	0.0345	0.394	−0.111, 0.053
percent thin/open	0.008	0.0540	0.885	−0.128, 0.133
percent thin/open/young	0.029	0.0345	0.393	−0.053, 0.112
edge density mature to young	0.093	0.0345	0.007	0.026, 0.195
edge density forest to non-forest	0.002	0.0167	0.907	−0.041, 0.039
patch density young forest	1.684	0.7069	0.017	0.525, 3.721
patch density mature forest	−0.156	0.3664	0.671	−0.998, 0.748
mean moisture	3.529	1.655	0.033	0.214, 8.307
moisture variance	−0.676	0.3732	0.070	−1.776, 0.066
vegetation productivity (NDVI)	6.950	13.561	0.608	−23.208, 41.351
connectivity of mature forest	2.628	1.602	0.101	−0.659, 7.452
shape of young forest patches	−0.008	0.0047	0.105	−0.020, 0.002
contagion	−0.045	0.0433	0.301	−0.149, 0.057

Table C.2. Parameter estimates for univariate models from a mixed effects logistic regression analysis of the effects of habitat composition and configuration on potential reproductive events for female Canada lynx (*Lynx canadensis*) in northwestern Montana from 1998−2012. Beta coefficients (β), standard errors (SE), and 95% confidence intervals (95% CI) are identified. Parameters include a variety of landscape metrics at the home range (90% KDE) extent. Covariates are described in Table 2. Confidence intervals that do not overlap or barely overlap zero are identified in bold. Analysis included 78 total observations from 23 female lynx.

90% home range	β	SE	p-value	95% CI
percent mature forest	0.006	0.0313	0.851	−0.066, 0.083
percent old regenerating forest	−0.041	0.0419	0.330	−0.149, 0.053
percent young forest + percent young forest^2				
percent young forest	1.121	0.3203	0.0005	
percent young forest^2	−0.039	0.0119	0.001	−0.076, −0.016
percent thin	−0.049	0.0951	0.602	−0.293, 0.164
percent open	0.113	0.1070	0.289	−0.121, 0.382
percent forest (mature forest + old regenerating forest)	−0.032	0.0438	0.463	−0.138, 0.069
percent thin/open	0.013	0.0571	0.820	−0.122, 0.149
percent thin/open/young	0.034	0.0438	0.438	−0.068, 0.140
edge density mature to young	0.074	0.0375	0.049	−0.0004, 0.175
edge density forest to non-forest	0.012	0.0232	0.590	−0.041, 0.071
patch density young forest	2.192	1.0930	0.045	0.114, 5.000
patch density mature forest	−0.289	1.0515	0.783	−2.957, 2.094
mean moisture	3.562	1.7960	0.047	−0.68, 8.868
moisture variance	−0.392	0.3294	0.234	−1.325, 0.298
vegetation productivity (NDVI)	11.249	14.907	0.450	−21.313, 50.847
connectivity of mature forest	1.028	1.9739	0.602	−3.396, 6.140
shape of young forest patches	−0.006	0.0054	0.267	−0.019, 0.006
contagion	−0.075	0.0532	0.158	−0.209, 0.041

Table C.3. Parameter estimates for univariate models from a mixed effects linear regression analysis for the effects of habitat composition and configuration on litter size for female Canada lynx (*Lynx canadensis*) in northwestern Montana from 1998−2012. Beta coefficients (β), standard errors (SE), and 95% confidence intervals (95% CI) are identified. Parameters include a variety of landscape metrics at the core area extent (50% KDE). Covariates are described in Table 2. Confidence intervals that do not overlap zero are identified in bold. Analysis included 54 total observations from 23 female lynx.

50% core areas	β	SE	p-value	95% CI
percent mature forest	0.003	0.0078	0.738	−0.015, 0.019
percent old regenerating forest	−0.022	0.0108	0.052	−0.047, 0.0002
percent young forest	0.039	0.0221	0.082	−0.005, 0.088
percent thin	0.006	0.0207	0.770	−0.038, 0.053
percent open	0.030	0.0378	0.427	−0.046, 0.118
percent forest (mature forest + old regenerating forest)	−0.013	0.0111	0.252	−0.039, 0.009
percent thin/open	0.008	0.0146	0.607	−0.023, 0.042
percent thin/open/young	0.015	0.0111	0.191	−0.008, 0.041
edge density mature to young	0.015	0.0123	0.238	−0.012, 0.042
edge density forest to non-forest	−0.007	0.0050	0.162	−0.018, 0.003
patch density young forest	0.279	0.2034	0.181	−0.151, 0.739
patch density mature forest	−0.039	0.1155	0.738	−0.295, 0.194
mean moisture	0.783	0.5113	0.138	−0.287, 1.941
moisture variance	−0.192	0.0933	0.063	−0.400, 0.012
vegetation productivity (NDVI)	10.121	3.1990	0.004	3.742, 16.907
connectivity of mature forest	0.172	0.4941	0.729	−0.907, 1.232
shape young forest patches	−0.004	0.0011	0.0002	−0.007, −0.002
contagion	−0.031	0.0138	0.028	−0.064, −0.004

Table C.4. Parameter estimates for univariate models from a mixed effects linear regression analysis for the effects of habitat composition and configuration on litter size for female Canada lynx (*Lynx canadensis*) in northwestern Montana from 1998−2012. Beta coefficients (β), standard errors (SE), and 95% confidence intervals (95% CI) are identified. Parameters include a variety of landscape metrics at the home range extent (90% KDE). Covariates are described in Table 2. Confidence intervals that do not overlap zero are identified in bold. Analysis included 54 total observations from 23 female lynx.

90% home range	β	SE	p-value	95% CI
percent mature forest	−0.0003	0.0090	0.970	−0.021, 0.019
percent old regenerating forest	−0.023	0.0134	0.099	−0.052, 0.005
percent young forest	0.073	0.0315	0.028	0.009, 0.142
percent thin	−0.005	0.0258	0.855	−0.059, 0.053
percent open	0.065	0.0297	0.033	0.006, 0.134
percent forest (mature forest + old regenerating forest)	−0.022	0.0135	0.114	−0.053, 0.005
percent thin/open	0.015	0.0159	0.355	−0.017, 0.052
percent thin/open/young	0.022	0.0135	0.103	−0.005, 0.054
edge density mature to young	0.012	0.0113	0.316	−0.013, 0.037
edge density forest to non-forest	−0.007	0.0069	0.341	−0.022, 0.009
patch density young forest	0.079	0.3032	0.795	−0.588, 0.750
patch density mature forest	−0.110	0.3202	0.732	−0.832, 0.549
mean moisture	0.478	0.6038	0.434	−0.813, 1.790
moisture variance	−0.187	0.0742	0.022	−0.356, −0.033
vegetation productivity (NDVI)	10.345	3.4850	0.006	3.381, 18.595
connectivity of mature forest	0.097	0.5509	0.860	−1.100, 1.305
shape of young forest patches	−0.005	0.0012	0.0004	−0.007, −0.002
contagion	−0.044	0.0142	0.003	−0.078, −0.016

Table C.5. Parameter estimates for univariate models from a mixed effects logistic regression analysis of the effects of habitat composition and configuration on litter success (binary) for female Canada lynx (*Lynx canadensis*) in northwestern Montana from 1998−2012. Beta coefficients (β), standard errors (SE), and 95% confidence intervals (95% CI) are identified. Parameters include a variety of landscape metrics at the core area extent (50% KDE). Covariates are described in Table 2. Confidence intervals that do not overlap zero are identified in bold. Analysis included 38 total observations from 15 female lynx.

50% core areas	β	SE	p-value	95% CI
percent mature forest	−0.015	0.0269	0.566	−0.110, 0.035
percent old regenerating forest	−0.009	0.0399	0.817	−0.092, 0.092
percent young forest	0.149	0.1062	0.160	−0.032, 0.462
percent thin	0.022	0.0742	0.764	−0.124, 0.249
percent open	0.094	0.1422	0.508	−0.157, 0.505
percent forest (mature forest + old regenerating forest)	−0.052	0.0499	0.295	−0.215, 0.031
percent thin/open	0.026	0.0548	0.638	−0.075, 0.200
percent thin/open/young	0.053	0.0494	0.286	−0.030, 0.219
edge density mature to young	0.061	0.0434	0.157	−0.021, 0.164
edge density forest to non-forest	0.025	0.0232	0.285	−0.017, 0.105
patch density young forest	0.465	0.6985	0.506	−1.076, 2.051
patch density mature forest	0.283	0.3970	0.477	−0.446, 1.233
mean moisture	−0.155	1.7841	0.931	−4.258, 3.822
moisture variance	−0.126	0.3804	0.741	−1.019, 0.633
vegetation productivity (NDVI)	2.300	12.7549	0.857	−26.811, 31.427
connectivity of mature	−2.046	1.8470	0.268	−9.437, 1.382
shape of young forest patches	−0.003	0.0044	0.557	−0.013, 0.006
shape of mature forest patches	0.009	0.0085	0.305	−0.003, 0.035
contagion	−0.036	0.0516	0.482	−0.186, 0.064

Table C.6. Parameter estimates for univariate models from a mixed effects logistic regression analysis of the effects of habitat composition and configuration on litter success (binary) for female Canada lynx (*Lynx canadensis*) in northwestern Montana from 1998−2012. Beta coefficients (β), standard errors (SE), and 95% confidence intervals (95% CI) are identified. Parameters include a variety of landscape metrics at the home range extent (90% KDE). Covariates are described in Table 2. Confidence intervals that do not overlap zero are identified in bold. Analysis included 38 total observations from 15 female lynx.

90% home range	β	SE	p-value	95% CI
percent mature forest	−0.054	0.0458	0.240	−0.219, 0.019
percent old regenerating forest	0.055	0.0647	0.396	−0.052, 0.287
percent young forest	0.211	0.1330	0.112	−0.038, 0.508
percent thin	0.021	0.0916	0.818	−0.149, 0.347
percent open	0.083	0.1133	0.465	−0.121, 0.397
percent forest (mature forest + old regenerating forest)	−0.067	0.0629	0.285	−0.236, 0.038
percent thin/open	0.030	0.0581	0.604	−0.073, 0.229
percent thin/open/young	0.068	0.0629	0.281	−0.038, 0.235
edge density mature to young	0.040	0.0401	0.320	−0.041, 0.131
edge density forest to non-forest	0.033	0.0334	0.318	−0.027, 0.125
patch density young forest	0.751	0.9688	0.438	−1.359, 3.111
patch density mature forest	1.663	1.1820	0.159	−0.503, 4.327
mean moisture	−0.444	1.9828	0.823	−5.336, 3.820
moisture variance	0.010	0.3272	0.975	−0.674, 0.783
vegetation productivity (NDVI)	8.259	14.6430	0.573	−22.880, 41.869
connectivity of mature forest	−7.365	4.8010	0.125	−19.894, −0.494
shape of young forest patches	−0.0003	0.0049	0.951	−0.012, 0.010
shape of mature forest patches	0.015	0.0123	0.220	−0.004, 0.048
contagion	−0.065	0.0612	0.284	−0.229, 0.048

Table C.7. Parameter estimates for univariate models from a mixed effects linear regression analysis of the effects of habitat composition and configuration on surviving litter size (range=1−4 kittens) for female Canada lynx (*Lynx canadensis*) in northwestern Montana from 1998−2012. Beta coefficients (β), standard errors (SE), and 95% confidence intervals (95% CI) are identified. Parameters include a variety of landscape metrics at the core area extent (50% KDE). Covariates are described in Table 2. Confidence intervals that do not overlap zero are identified in bold. Analysis included 31 total observations from 13 female lynx.

50% core area	β	SE	p-value	95% CI
percent mature forest	−0.0002	0.0095	0.984	−0.020, 0.021
percent old regenerating forest	−0.016	0.0158	0.331	−0.051, 0.017
percent young forest	0.058	0.0248	0.038	0.004, 0.108
percent thin	−0.004	0.0253	0.873	−0.058, 0.050
percent open	0.028	0.0449	0.531	−0.065, 0.126
percent forest (mature forest + old regenerating forest)	−0.013	0.0135	0.367	−0.041, 0.017
percent thin/open	0.002	0.0178	0.895	−0.035, 0.041
percent thin/open/young	0.016	0.0134	0.239	−0.012, 0.046
edge density mature to young	0.022	0.0149	0.153	−0.009, 0.054
edge density forest to non-forest	−0.007	0.0079	0.404	−0.024, 0.009
patch density young forest	0.240	0.2641	0.367	−0.306, 0.825
patch density mature forest	0.193	0.1121	0.146	−0.097, 0.420
mean moisture	1.239	0.6472	0.098	−0.300, 2.761
moisture variance	−0.361	0.1269	0.011	−0.621, −0.098
vegetation productivity (NDVI)	10.305	3.8600	0.017	2.284, 18.112
connectivity of mature forest	−0.092	0.6052	0.883	−1.329, 1.296
shape of young forest patches	−0.004	0.0014	0.012	−0.007, −0.001
shape of mature forest patches	−0.0002	0.0014	0.879	−0.003, 0.003
contagion	−0.027	0.0165	0.118	−0.063, 0.008

Table C.8. Parameter estimates for univariate models from a mixed effects linear regression analysis of the effects of habitat composition and configuration on surviving litter size (range=1−4 kittens) for female Canada lynx (*Lynx canadensis*) in northwestern Montana from 1998−2012. Beta coefficients (β), standard errors (SE), and 95% confidence intervals (95% CI) are identified. Parameters include a variety of landscape metrics at the home range extent (90% KDE). Covariates are described in Table 2. Confidence intervals that do not overlap zero are identified in bold. Analysis included 31 total observations from 13 female lynx.

90% home range	β	SE	p-value	95% CI
percent mature forest	−0.008	0.0112	0.511	−0.031, 0.017
percent old regenerating forest	−0.008	0.0187	0.675	−0.048. 0.031
percent young forest	0.085	0.0488	0.092	−0.015, 0.194
percent thin	0.0002	0.0336	0.995	−0.072, 0.071
percent open	0.074	0.0312	0.036	0.006, 0.138
percent forest (mature forest + old regenerating forest)	−0.026	0.0162	0.137	−0.059, 0.009
percent thin/open	0.019	0.0189	0.317	−0.021, 0.059
percent thin/open/young	0.027	0.0162	0.125	−0.009, 0.060
edge density mature to young	0.009	0.0149	0.553	−0.022, 0.044
edge density forest to non-forest	−0.007	0.0114	0.572	−0.030, 0.018
patch density young forest	0.155	0.3556	0.668	−0.587, 1.009
patch density mature forest	0.220	0.3971	0.588	−0.666, 1.045
mean moisture	0.642	0.7847	0.430	−1.091, 2.294
moisture variance	−0.299	0.1030	0.008	−0.516, −0.089
vegetation productivity (NDVI)	10.944	4.4250	0.027	1.500, 19.912
connectivity of mature forest	−0.445	0.7176	0.550	−1.925, 1.159
shape of young forest patches	−0.004	0.0016	0.034	−0.007, −0.0004
shape of mature forest patches	0.0007	0.0027	0.809	−0.005, 0.006
contagion	−0.055	0.0173	0.005	−0.089, −0.019

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