HABITAT RELATIONSHIPS OF CANADA LYNX IN SPRUCE BARK BEETLE-IMPACTED FORESTS

Analysis Summary – 19 March 2018

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Note: The information provided in this analysis is intended to inform forest planning on the Rio Grande National Forest. Given that our study has not yet been peer-reviewed, the information included in this document may change or may be amended to as we prepare our research results for publication. Therefore, no information in this document should be published without our explicit permission. Thank you.

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Management Issue

The Rio Grande National Forest (RGNF) includes some of the most important lynx habitat in Colorado. Approximately 85% of the 218 lynx reintroduced to Colorado from 1999-2007 were released on the RGNF. Although lynx have established home ranges in other parts of the state, most remain and reproduce in the high-elevation spruce-fir zone of southwestern Colorado, including the RGNF. Lynx depend on spruce-fir forests with dense understories across their distribution. However, by 2013, a spruce beetle outbreak killed approximately 85% of mature spruce in the subalpine cover types on the RGNF. There is a strong desire by the US Forest Service and industry to salvage beetle-killed trees across broad landscapes in southern Colorado. However, the consequence of timber salvage to lynx or even what constitutes suitable lynx habitat in beetle-impacted forests is entirely unknown. Biologists are therefore in the untenable position of being required to evaluate the impact of timber salvage to lynx without a scientific basis to support their decisions. ESA requires that agencies consider the impact of timber salvage to lynx as federally listed species.

The key questions that challenge lynx management in spruce-beetle impacted forest include:

1. How do spruce-beetle outbreaks affect the suitability of lynx habitat within the core use area of southern Colorado?
2. What forest structures and compositions are used by lynx in landscapes heavily influenced by spruce-beetle outbreaks?
3. How does structure and composition of insect impacted forests affect the relative density of snowshoe hares?
4. What areas and types of forest structure in the post-beetle landscape on the Rio Grande National Forest are most conducive to landscape restoration activities, including timber salvage, while minimizing potential impacts to lynx and snowshoe hare populations?

Our overarching research goal is to both advance our ecological understandings of how Canada lynx respond to insect-related disturbance as well as provide land managers the necessary information to develop on-the-ground silviculture/forest management that addresses timber salvage and lynx conservation at multiple spatial scales (landscape- and stand-level). Specific research objectives for our work are four-fold:

1) Determine seasonal changes in *landscape-level* patterns of resource selection for Canada lynx in spruce-beetle impacted forests;
2) Provide spatial maps that seasonally predict and delineate lynx habitat at a *landscape scale* relative to proposed timber salvage;
3) Evaluate seasonal changes in the composition and structural attributes of spruce-beetle impacted forests selected by Canada lynx *within home ranges at a fine-scale* (this informs silviculture prescriptions within forest stands);

4) Assess movement behavior of Canada lynx within spruce-beetle impacted landscapes (this will be a separate paper with a unique set of analyses that we will address in a separate research outline).

   a. First, we will evaluate how lynx move (e.g., speed of movement and direction of movement) through beetle-impacted forests using movement models (e.g., movement velocity, tortuosity).
   b. Second, we will evaluate how lynx movement is related to environmental factors using a step-selection function.
      i. The concept of functional responses may be relevant to this analysis.
   c. We will evaluate how lynx movement is different in forests impacted by spruce-beetles versus areas that were not impacted (using movement data previously collected in the San Juan Mountains (our earlier recreation study), west of the RGNF study area).

For all sections listed below, we will define winter and summer as the following: winter = Jan-April, summer = May-August.

Objective 1 and 2 – Landscape-level analyses

Methods

We collected GPS data (total fix rate = 88%) from 10 lynx (6 males and 4 females; 802-1715 locations per individual) during winter and 7 lynx (3 males and 4 females; 895-1272 locations per individual) during the summer of 2015-2017. This resulted in 11,628 locations for the winter and 7,721 during summer, which was our sample of lynx resource use. To characterize availability we randomly sampled our study area at a density of 1 location/500 m^2 for each lynx, which resulted in approximately 7,000 available locations per individual (i.e., use:availability ratio $\geq$ 1:4). Each location within the available sample was $\geq$100 m apart.

With our sample of use and availability, we then built resource selection functions (RSF) to examine selection behavior of lynx. We calculated landscape variables (Table 1) at multiple scales (100, 250, and 500 m^2) and evaluated which scale and function (i.e., linear or quadratic) was the most supported (based on AICc). We then evaluated correlations among all variables and prevented those that were >0.60 from entering the same model. Because we were interested in both prediction and understanding, we elected to search for the best abiotic model (i.e., precipitation, topographic, and anthropogenic variables in Table 1) using an all-subsets approach. With the best abiotic model identified, we then developed hypotheses concerning how lynx respond to forest canopy cover and sub-canopy tree densities (see Table 2 and 4). We used generalized linear mixed-model (i.e., random intercept for lynx) for our analyses and evaluate support for our hypotheses using AICc. We estimated standardized regression coefficients.

To validate predictions from our top models, we performed two assessments. First, we implemented a leave-one-out cross-validation, which is a technique to determine the robustness of a model's predictions. We sequentially withheld each lynx, re-ran the top model on the remaining lynx, and used the withheld lynx to test the model's predictions. Second, prior to all analyses, we withheld 10% of the GPS locations for each lynx to use as testing data. We overlaid our testing data (winter n = 1109 locations, summer n = 780 locations) on our predicted habitat maps derived from our top models, which allowed use to evaluate if areas of high predicted use were in fact used frequently by lynx. This second approach also allowed us to determine a threshold of habitat versus non-habitat based on these withheld data, which is often a central issue in forest planning.

Results

Below are a series of tables and figures that capture the results of the landscape-level analyses.

Table 1. List of landscape variables included in the modeling.

Theme	Variable	Units	Base Resolution	Reference
Canopy	Total % mortality	%	30 m^2	Savage et al. 2017
	POTR canopy cover	%	30 m^2	Savage et al. 2017
	PIEN canopy cover	%	30 m^2	Savage et al. 2017
	ABLA canopy cover	%	30 m^2	Savage et al. 2017
	PIEN-ABLA canopy cover	%	30 m^2	Savage et al. 2017
Live sub-canopy	PSME tree count	Count	30 m^2	Savage et al. 2017
	POTR tree count	Count	30 m^2	Savage et al. 2017
	PIEN tree count	Count	30 m^2	Savage et al. 2017
	ABLA tree count	Count	30 m^2	Savage et al. 2017
	PIEN-ABLA tree count	Count	30 m^2	Savage et al. 2017
Precipitation				
	Mean annual precipitation over 1981-2010	mm	800 m^2	PRISM
Topographic	Roughness	Index	30 m^2	Jenness 2004
	Heat load index	Index	30 m^2	McCune and Keon 2002, Theobald et al. 2015
	Topographic position index	Index	30 m^2	Guisan et al. 1999
Anthropogenic	Density of major roads and highways	m/ha	1,000 m^2	ColoradoView
	Density of USFS roads	m/ha	1,000 m^2	RGNF

Source for density of major rds and highways **–** http://ibis-live1.nrel.colostate.edu/cwis438/websites/ColoradoView/Data.php?WebSiteID=15

Source for density of USFS rds - Cheryl O'Brien

GIS Coordinator

USFS Rio Grande National Forest

Monte Vista, CO 81144

Figure 1. General summary of the lynx use and availability for forest canopy and subcanopy during **WINTER**.

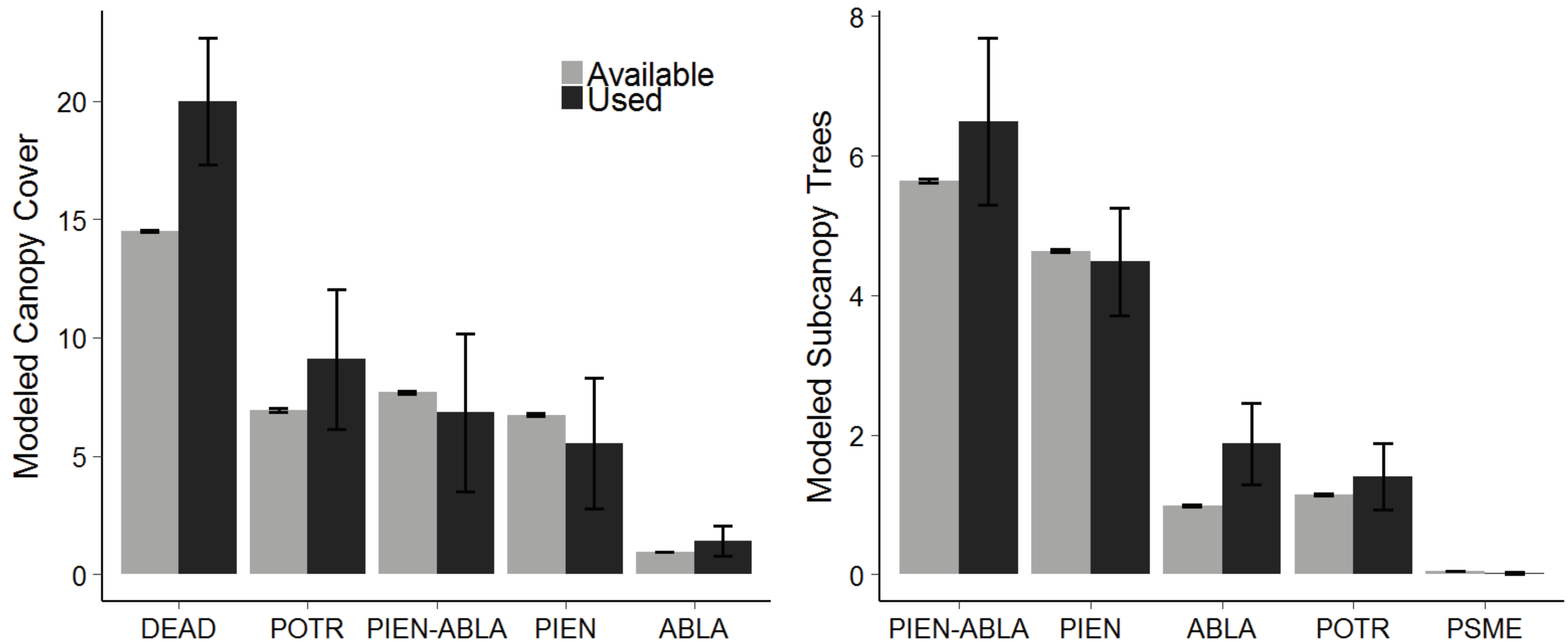


Table 2. Model selection table characterizing lynx resource selection during **WINTER**. The bolded model indicates the top performing model, which we used to generate lynx habitat maps.

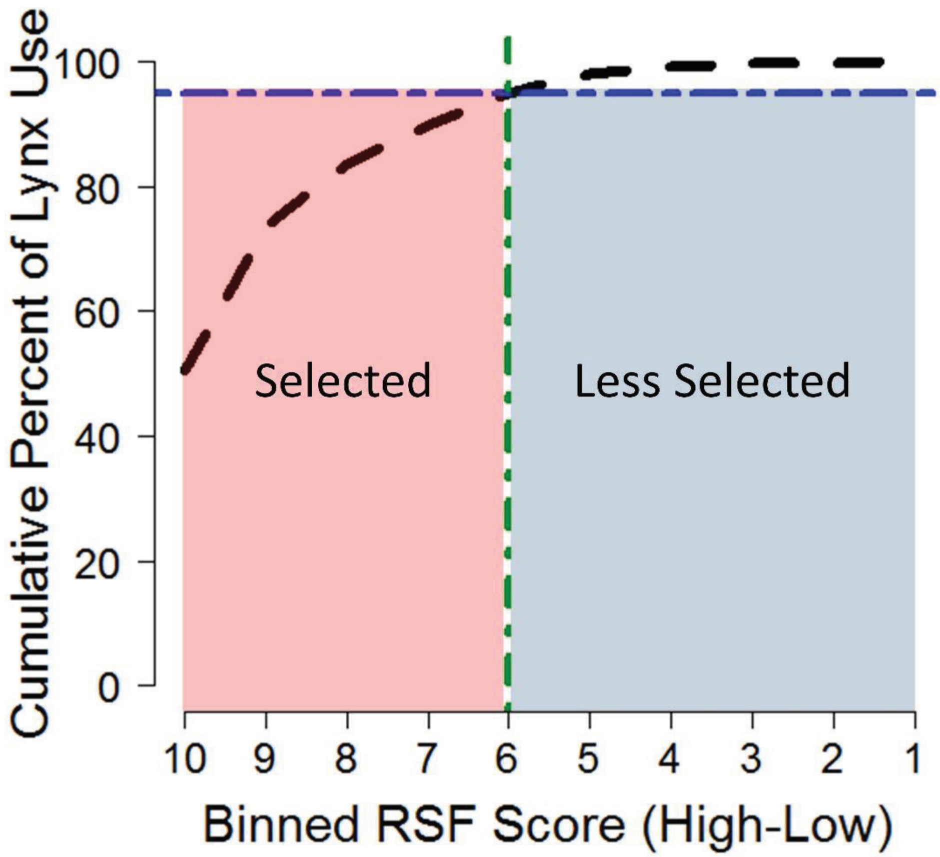
Thematic assessment	Model description	LL	ΔAIC_c	*w*	Rank
Canopy cover	Abiotic + ABLA	-25400.87	2767.94	0	2
	Abiotic + PIEN	-25519.16	3004.54	0	4
	Abiotic + PIEN-ABLA	-25534.85	3035.92	0	5
	Abiotic + POTR	-25443.78	2853.77	0	3
	Abiotic + Dead canopy	-24016.89	0.00	1	1
Sub-canopy tree count	Abiotic + ABLA	-25144.49	485.80	0	3
	Abiotic + PIEN	-25161.53	519.88	0	4
	Abiotic + PIEN-ABLA	-24901.59	0.00	1	1
	Abiotic + POTR	-25431.92	1060.66	0	5
	Abiotic + PSME	-25068.59	334.00	0	2
Canopy and sub-canopy	Abiotic + Dead canopy + PIEN-ABLA subcanopy	-23816.91	587.31	0	3
	Abiotic + Dead canopy + PIEN-ABLA subcanopy + PSME subcanopy	-23567.53	90.57	0	2
	Abiotic + Dead canopy + POTR canopy + PIEN-ABLA subcanopy + PSME subcanopy	**-23521.25**	**0.00**	**1**	**1**
	Abiotic only	-25536.73	4022.97	0	4
	Null	-30927.39	14790.28	0	5

Note – variables had to be uncorrelated ($r < 0.60$). ABLA canopy was correlated with PIEN-ABLA subcanopy AND ABLA subcanopy was correlated with PIEN-ABLA subcanopy.

Table 3. Standardized parameter estimates from the top **WINTER** model listed in Table 2 above. Of the forest layers, Canada lynx exhibited the strongest selection of dead canopy followed by PIEN-ABLA subcanopy.

Theme	Covariate	β	SE	*p*
Abiotic	Roughness	-0.183	0.012	<0.001
	Heat load index	0.195	0.013	<0.001
	Topographic position index	-0.078	0.012	<0.001
	Mean annual precipitation over 1981-2010	-1.682	0.031	<0.001
	Mean annual precipitation over 1981-2010 ^{2}	-0.499	0.020	<0.001
	Density of major roads and highways	-0.449	0.022	<0.001
	Density of USFS roads	0.457	0.012	<0.001
Forest	Dead canopy	0.672	0.015	<0.001
	POTR canopy	0.129	0.013	<0.001
	PIEN-ABLA subcanopy	0.247	0.014	<0.001
	PSME subcanopy	-0.391	0.022	<0.001

Figure 2. Cumulative percent of lynx use from the withheld data (i.e., 10% for each lynx) as a function of the predicted resource selection (RSF) score (high-low) for **WINTER**. This figure demonstrates that a RSF score of 6-10 captures 95% of the withheld lynx use. In other words a RSF score of 6-10 indicates the majority of lynx habitat (based on a 95% cutpoint), where RSF scores 1-5 indicates areas generally avoided. This concept was used to make the binary habitat map in Figure 4 below.



Additional details on validation:

1) Leave a lynx out validation (10 lynx): mean $r_s = 0.90$ (sd = 0.23)
2) Withheld data: $r_s = 0.99$, $p < 0.001$

Figure 3. Relative probability of lynx use from our top resource selection function during **WINTER.** Values of 1 indicate low probability of use and values of 10 indicate high probability of use.

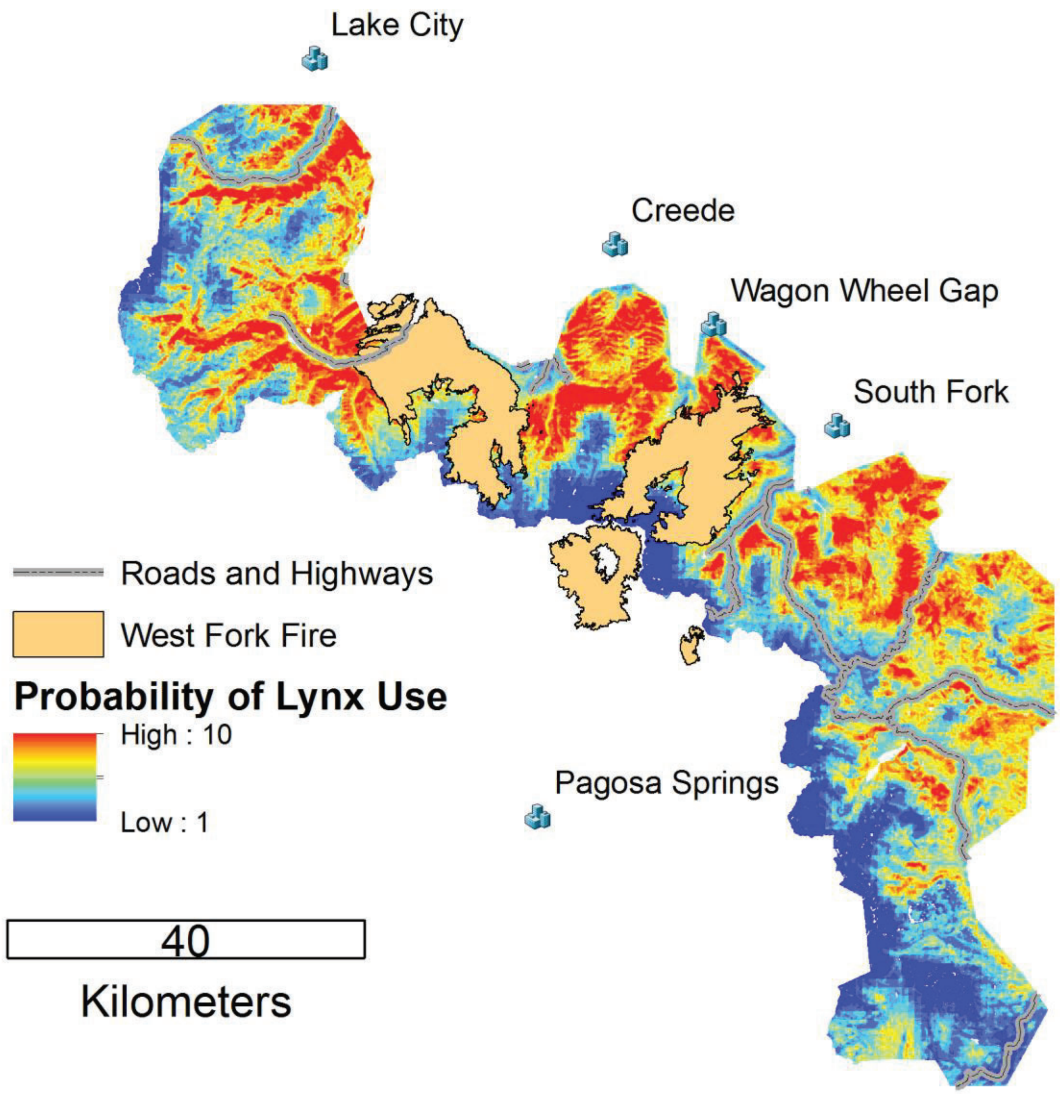


Figure 4. Binary depiction of the probability of lynx use from our top resource selection function during **WINTER.** "Selected" indicates the RSF scores (i.e., 6-10) that captured 95% of the withheld lynx use (see Figure 2 above). "Selected" = 378,877 acres (1,533 km^2) and "Less Selected" = 377,513 acres (1,528 km^2).

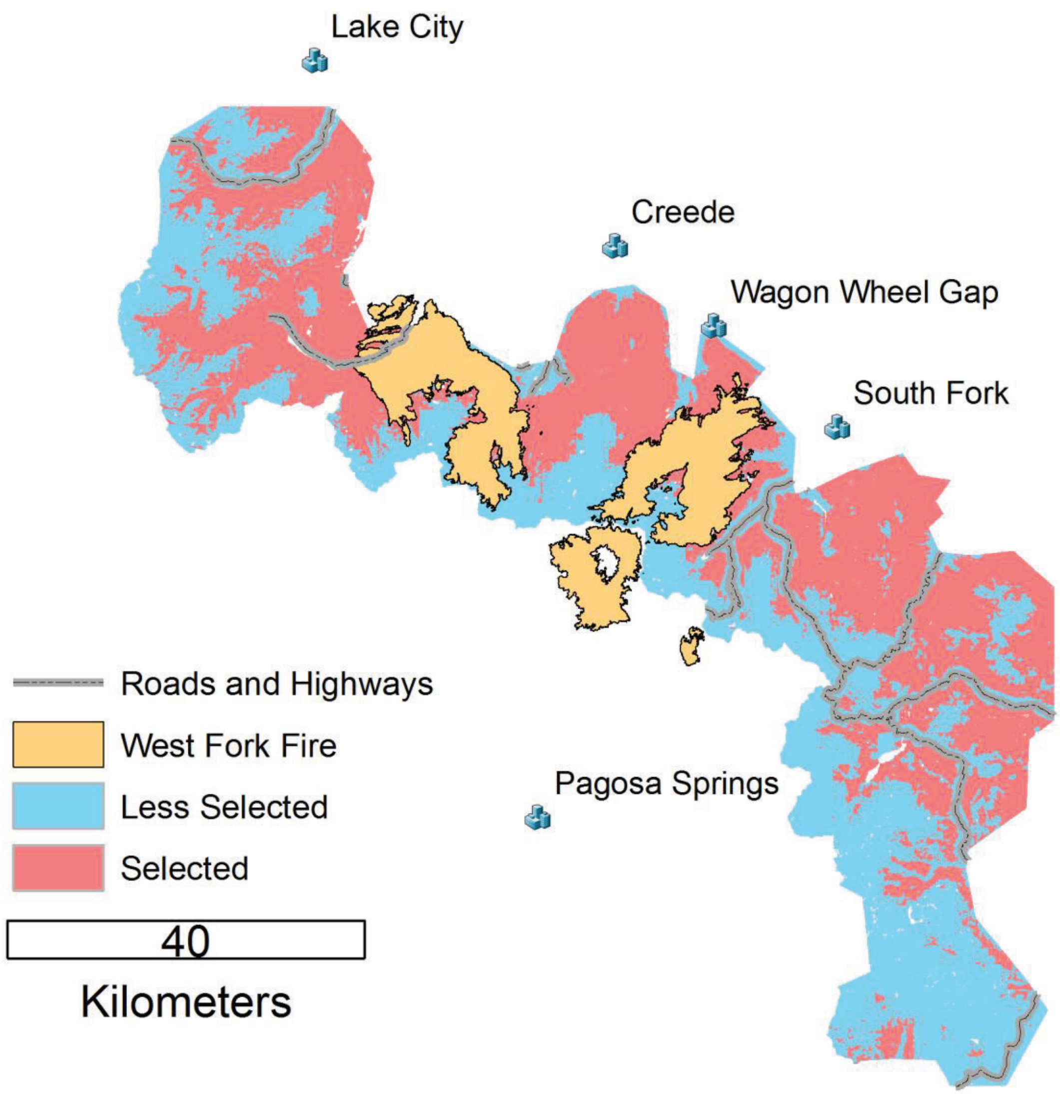


Figure 5. General summary of the lynx use and availability for forest canopy and subcanopy during **SUMMER**.

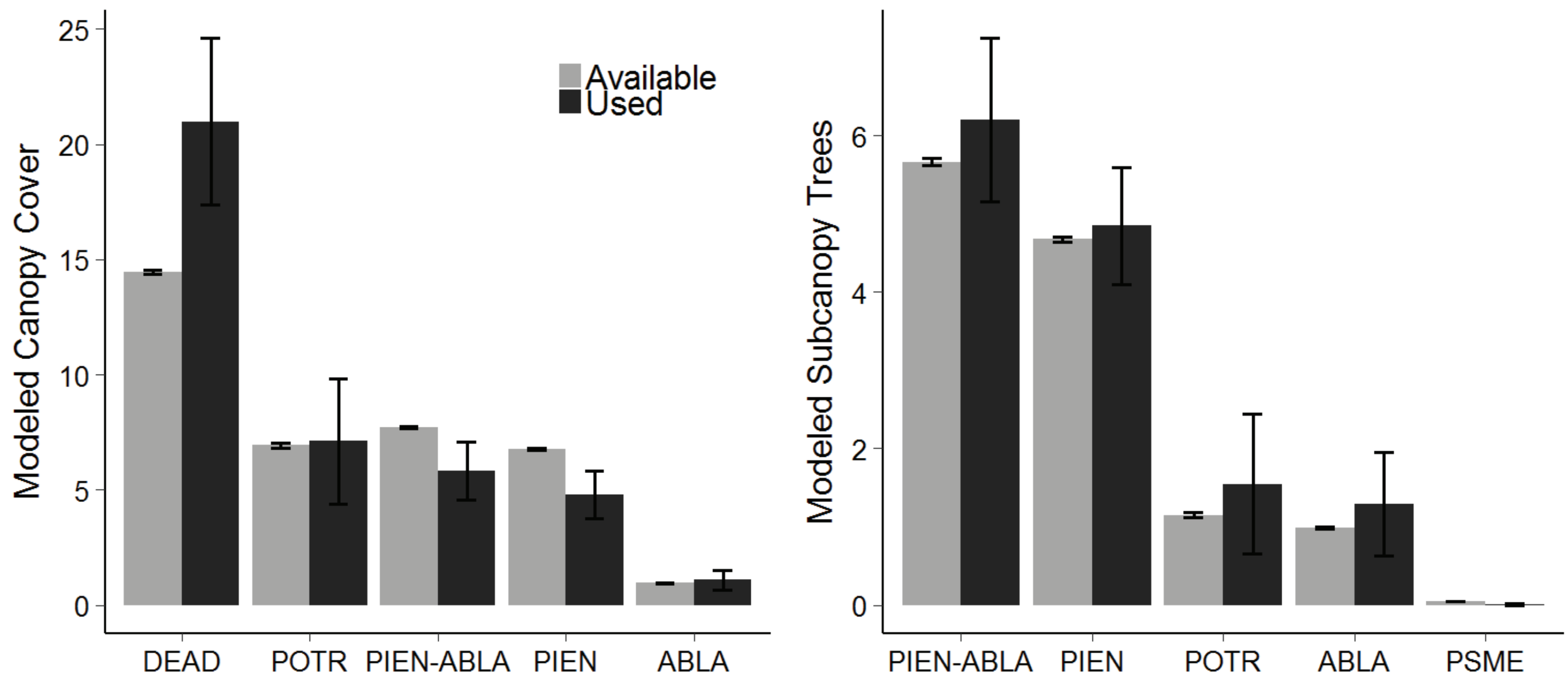


Table 4. Model selection table characterizing lynx resource selection during **SUMMER**. The bolded model indicates the top performing model, which we used to generate lynx habitat maps.

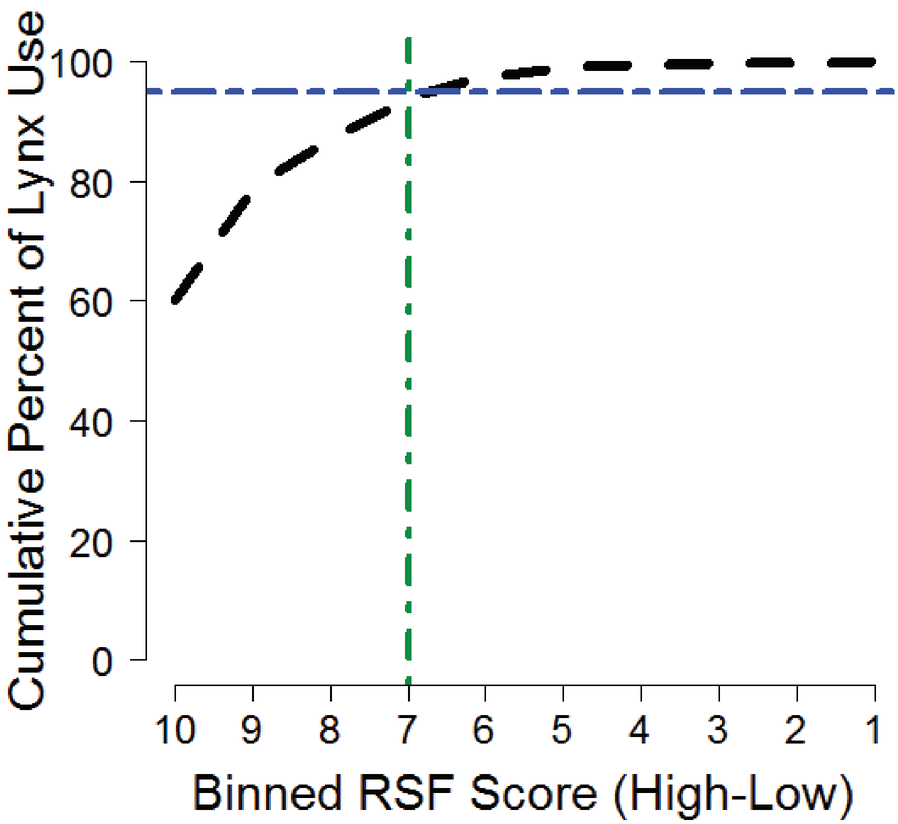
Thematic assessment	Model description	LL	ΔAIC_c	*w*	Rank
Canopy cover	Abiotic + ABLA	-17090.43	3027.25	0	5
	Abiotic + PIEN	-16950.72	2747.82	0	2
	Abiotic + PIEN-ABLA	-16982.84	2812.07	0	4
	Abiotic + POTR	-16981.31	2809.00	0	3
	Abiotic + Dead canopy	-15576.81	0.00	1	1
Sub-canopy tree count	Abiotic + ABLA	-17056.79	830.97	0	4
	Abiotic + PIEN	-16806.79	330.97	0	2
	Abiotic + PIEN-ABLA	-16878.48	474.35	0	3
	Abiotic + POTR	-17083.10	883.59	0	5
	Abiotic + PSME	-16641.30	0.00	1	1
Canopy and sub-canopy	Abiotic + Dead canopy + PSME subcanopy	-15228.09	558.83	0	3
	Abiotic + Dead canopy + PIEN canopy + PSME subcanopy + PIEN subcanopy	-14953.71	14.07	0	2
	Abiotic + Dead canopy + PIEN canopy + POTR canopy + PSME subcanopy + PIEN subcanopy	**-14945.67**	**0.00**	**1**	**1**
	Abiotic only	-17090.52	4279.70	0	4
	Null	-20934.42	11953.48	0	5

Note – variables had to be uncorrelated ($r < 0.60$). PIEN subcanopy was correlated with PIEN-ABLA subcanopy.

Table 5. Standardized parameter estimates from the top **SUMMER** model listed in Table 4 above. Of the forest layers, Canada lynx exhibited the strongest selection of dead canopy followed by PIEN subcanopy.

Theme	Covariate	β	SE	*p*
Abiotic	Roughness	0.735	0.016	<0.001
	Heat load index	-0.209	0.014	<0.001
	Topographic position index	-0.076	0.014	<0.001
	Mean annual precipitation over 1981-2010	-1.305	0.035	<0.001
	Mean annual precipitation over 1981-2010 ^{2}	-0.469	0.024	<0.001
	Density of major roads and highways	-0.413	0.032	<0.001
	Density of USFS roads	0.490	0.016	<0.001
Forest	Dead canopy	0.815	0.020	<0.001
	PIEN canopy	-0.613	0.030	<0.001
	POTR canopy	0.074	0.018	<0.001
	PIEN subcanopy	0.343	0.026	<0.001
	PSME subcanopy	-0.911	0.052	<0.001

Figure 6. Cumulative percent of lynx use from the withheld data (i.e., 10% for each lynx) as a function of the predicted resource selection (RSF) score (high-low) for **SUMMER**. This figure demonstrates that a RSF score of 7-10 captures 95% of the withheld lynx use. In other words a RSF score of 7-10 indicates lynx habitat (based on a 95% cutpoint), where RSF scores 1-5 indicate non-habitat.

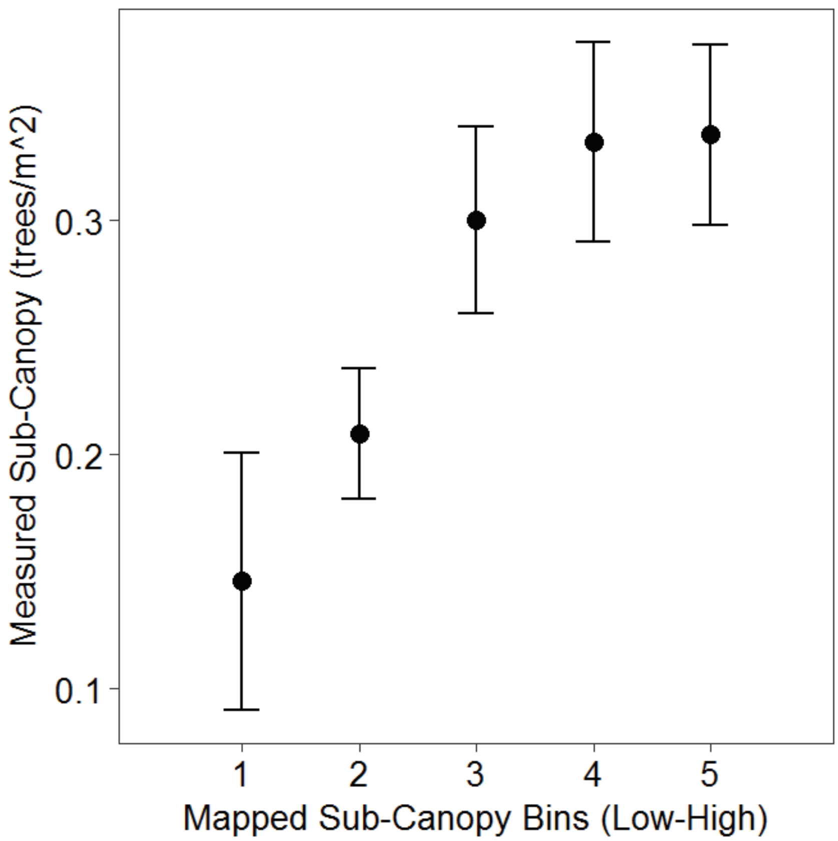


Additional details on validation:

1) Leave a lynx out validation (7 lynx): mean $r_s = 0.92$ (sd = 0.07)
2) Withheld data: $r_s = 0.99$, $p < 0.001$

*****NOTE - We have made the summer maps, but they are nearly identical to the winter maps. Thus, we did not show them for this summary.***

Assessed how our total sub-canopy density (i.e., collected in the field) was distributed across the map of total sub-canopy count (from Savage et al. 2017). We overlaid our field data (collected at lynx used and random points) on the map, binned up the map into a low to high gradient (5 bins with 146-148 field plots within each), and evaluated how the mean sub-canopy density (as measured in the field) changed across the mapped gradient. Below shows the result. This evaluation is even more impressive because we know lynx use areas of high sub-canopy density...so the evaluation is over a truncated gradient (on the high end), but still shows a positive relationship. Pretty amazing. Means ± 90% CIs.



Objective 3 – Stand-level analyses

Methods

We collected forest data at used (i.e., GPS) and available locations for Canada lynx at winter and summer locations during 2015-2017. To define and sample available locations for each lynx, we developed 95% fixed kernel home ranges for both winter and summer. We sampled used and available locations equally (i.e., approximately 1:1) for both winter and summer. We sampled 457 used and available plots during winter (41-52 plots per lynx) for 10 different lynx (4 females and 6 males). We samples 278 plots during summer (43-50 plots per lynx) for 6 lynx (4 females and 2 males).

At each plots we recorded many forest and stand-level attributes. This included (1) horizontal cover, (2) pellet density of snowshoe hares, (3) cover of grass, forbs, and shrubs, (4) downed woody debris, (5) stem density of understory (i.e., ≤19 ft tall) by species and overall, (6) canopy cover (by species and live and dead trees), and (7) tree density and size for larger-sized trees (i.e., ≥3 inches DBH, live by species and dead). Tree density (live, dead, and snags) and size was collected using a 1/10th acre plot, which allowed us to incorporate those data into the Forest Vegetation Simulator (FVS; variant CR and forest 213) to calculate many USFS corporate metrics for live trees by species as well as dead trees.

We used FVS to calculate a variety of forest metrics. For live trees (i.e., 53% of all trees), we calculated overall and species-specific trees per acre (TPA), quadratic mean diameter (QMD), basal area (BA), canopy cover, and stand density index (SDI). The species representing most (i.e., 98.5%) of the trees included: 35% subalpine fir (ABLA - *Abies lasiocarpa*), 24% Engelman's spruce (PIEN - *Picea engelmannii*), 5% blue spruce (PIPU - *Picea pungens*), and 34.5% quaking aspen (POTR - *Populus tremuloides*). In addition, we calculated the TPA for each species by four different size classes: 3-4.9 inches, 5-8.9 inches, 9-15.9 inches, and ≥16 inches. For dead trees (i.e., 35% of all trees), we calculated the same metrics, but did not include SDI. All species except blue spruce were included in the dead trees; ABLA (11.5%), PIEN (73.5%), and POTR (12%) accounted for 97% of the dead trees. Finally, for snags (i.e., 12% of all trees) we calculated overall TPA, QMD, and BA.

We implemented a multi-step process to reduce the number of potential variables and develop models that characterized resource use by Canada lynx. First, we developed a series of univariate models to identify the variables that were more supported (i.e., ≥2ΔAICc values) than a null (i.e., intercept-only) model. Second, we evaluated pairwise correlations among the remaining variables and excluded those that were contributing to correlations of $|r| > 0.60$; when two variables were correlated we selected the one with the lowest AICc value. Third, with our reduced set of variables we then used the least absolute shrinkage and operator (LASSO; Groll and Tutz 2014) to identify the most predictive of the potential variables (i.e., those that did not shrink to approximately 0). We assess lambda values (i.e., the log-likelihood penalty term) between 0-500 within the LASSO and selected the optimal lambda using AICc. Finally, we additionally searched all-subsets of models using the variables identified in the LASSO and selected the top model(s) using AICc. We used generalized linear mixed-model (i.e., random intercept for lynx) for all analyses and estimated standardized regression coefficients for our top models.

To complement our resource selection analyses, we evaluated functional responses in habitat use for variables that received the strongest selection or avoidance. For each variable we calculated the mean resource value at used and available locations. We then used a linear model to test for deviations in proportional habitat use (intercept = 0 and slope = 1), which would indicate a functional response. Functional responses in habitat use provided important insight concerning how Canada lynx altered their use of a forest resource as that resourced changed in availability.

Because one of our main objectives was to inform forest management, we developed a series of summaries that characterized forest metrics at used and available lynx locations during the winter and summer. These summaries provided essential information for forest managers to apply our results to on-the-ground efforts (see Tables 1-9).

Results

Below are a series of tables and figures that capture the results of the stand-level analyses.

Table 1. Mean (Range) of plot and forest metrics at used and available locations for Canada lynx during both **WINTER** and **SUMMER**. Units for each variable are as follows: horizontal cover (%), snowshoe hare pellets (mean pellets/1 m^2 subplot), grass cover (%), forb cover (%), shrub cover (%), sub-canopy density (trees/acre), downed woody debris volume (m^3), and downed woody debris count (count).

Season	Variable	Available	Used
Winter	Horizontal cover	40 (26-48)	53 (47-61)
	Snowshoe hare pellets	2.7 (1.2-5.7)	5.9 (3.2-12.2)
	Grass cover	18 (12-24)	8 (5-12)
	Forb cover	23 (18-35)	23 (18-30)
	Shrub cover	13 (10-19)	13 (8-19)
	ABLA Sub-canopy density	118 (16-437)	318 (53-523)
	PIEN Sub-canopy density	115 (9-232)	181 (115-301)
	PIPU Sub-canopy density	24 (0-77)	21 (0-60)
	POTR Sub-canopy density	365 (0-730)	458 (25-838)
	SALIX Sub-canopy density	91 (0-913)	1 (0-8)
	Total Sub-canopy density	912 (390-1496)	1174 (567-1577)
	Downed woody debris volume	0.174 (0.107-0.388)	0.208 (0.121-0.371)
	Downed woody debris count	4 (2-5)	5 (3-8)
Summer	Horizontal Cover	48 (40-57)	59 (54-64)
	Snowshoe hare pellets	5.2 (2.6-8.1)	7.5 (3.8-12.8)
	Grass cover	11 (4-18)	6 (3-11)
	Forb cover	24 (17-27)	22 (17-26)
	Shrub cover	15 (10-17)	18 (12-23)
	ABLA Sub-canopy density	195 (22-452)	352 (90-595)
	PIEN Sub-canopy density	147 (116-195)	199 (120-282)
	PIPU Sub-canopy density	26 (8-36)	38 (0-98)
	POTR Sub-canopy density	385 (141-613)	469 (340-882)
	SALIX Sub-canopy density	5 (0-31)	59 (0-353)
	Total Sub-canopy density	941 (613-1171)	1308 (1029-1474)
	Downed woody debris volume	0.176 (0.116-0.258)	0.218 (0.155-0.264)
	Downed woody debris count	5 (3-6)	6 (4-8)

Table 2. Mean (Range) tree metrics (tree is ≥3" DBH) at used and available locations for Canada lynx during both **WINTER** and **SUMMER**. Units for each variable are as follows: TPA (trees per acre), BA (ft^2/acre), SDI (index), and QMD (inches).

Season	Form	Variable	Available	Used
Winter	Live	TPA	170 (99-251)	232 (155-300)
	Live	BA	40 (30-54)	51 (28-75)
	Live	SDI	84 (65-119)	111 (63-153)
	Live	QMD	5 (4-7)	6 (5-8)
	Dead	TPA	109 (61-171)	147 (93-193)
	Dead	BA	45 (21-86)	58 (37-79)
	Dead	QMD	6 (4-10)	8 (7-9)
	Snags	TPA	51 (7-106)	41 (11-69)
	Snags	BA	13 (4-28)	10 (6-14)
	Snags	QMD	4 (3-6)	5 (4-7)
Summer	Live	TPA	212 (149-304)	225 (153-310)
	Live	BA	46 (27-65)	50 (24-68)
	Live	SDI	100 (60-142)	108 (55-134)
	Live	QMD	5 (5-6)	6 (5-7)
	Dead	TPA	151 (100-217)	157 (130-205)
	Dead	BA	63 (37-95)	72 (50-108)
	Dead	QMD	7 (6-9)	10 (8-10)
	Snags	TPA	45 (21-60)	36 (21-53)
	Snags	BA	11 (6-16)	10 (4-16)
	Snags	QMD	4 (3-6)	6 (3-8)

Table 3. Mean (Range) tree sizes (tree is ≥3" DBH) by species at used and available locations for Canada lynx during both **WINTER** and **SUMMER**. QMD units are inches.

Season	Form	Variable	Available	Used
Winter	Live	ABLA QMD	3 (1-7)	4 (2-7)
	Live	PIEN QMD	3 (2-6)	4 (3-5)
	Live	PIPU QMD	1 (0-3)	2 (0-5)
	Live	POTR QMD	2 (0-4)	4 (1-5)
	Dead	ABLA QMD	2 (0-6)	3 (1-5)
	Dead	PIEN QMD	6 (3-11)	8 (6-9)
	Dead	POTR QMD	2 (0-3)	2 (0-3)
Summer	Live	ABLA QMD	3 (1-5)	5 (2-7)
	Live	PIEN QMD	3 (3-4)	4 (4-5)
	Live	PIPU QMD	2 (1-3)	2 (0-2)
	Live	POTR QMD	4 (3-5)	3 (2-4)
	Dead	ABLA QMD	1 (0-3)	3 (1-5)
	Dead	PIEN QMD	7 (6-9)	10 (8-11)
	Dead	POTR QMD	2 (1-2)	1 (1-3)

Table 4. Mean (Range) canopy cover (%) for trees (tree is ≥3" DBH) at used and available locations for Canada lynx during both **WINTER** and **SUMMER**.

Season	Variable	Available	Used
Winter	Live ABLA canopy cover	6 (2-15)	12 (3-19)
	Dead ABLA canopy cover	1 (0-3)	2 (0-3)
	Live PIEN canopy cover	3 (1-7)	6 (4-8)
	Dead PIEN canopy cover	10 (3-18)	13 (6-21)
	Live PIPU canopy cover	2 (0-5)	2 (0-10)
	Live POTR canopy cover	14 (1-26)	14 (4-22)
	Total (live and dead) canopy cover	38 (25-46)	50 (43-62)
	Percent of plots in an Open stage (0-10% canopy cover)	22 (4-38)	1 (0-4)
	Percent of plots in a Low stage (11-40% canopy cover)	30 (13-57)	32 (16-55)
	Percent of plots in Medium stage (41-70% canopy cover)	33 (23-67)	47 (32-67)
	Percent of plots in a Closed stage (>70% canopy cover)	15 (5-26)	19 (4-44)
Summer	Live ABLA canopy cover	7 (1-12)	11 (4-19)
	Dead ABLA canopy cover	1 (0-1)	2 (1-4)
	Live PIEN canopy cover	5 (4-7)	6 (4-9)
	Dead PIEN canopy cover	12 (8-15)	13 (10-19)
	Live PIPU canopy cover	2 (1-3)	1 (0-2)
	Live POTR canopy cover	12 (10-16)	11 (6-17)
	Total (live and dead) canopy cover	40 (32-47)	45 (42-50)
	Percent of plots in an Open stage (0-10% canopy cover)	14 (0-22)	2 (0-5)
	Percent of plots in a Low stage (11-40% canopy cover)	34 (23-56)	41 (24-50)
	Percent of plots in Medium stage (41-70% canopy cover)	41 (35-50)	49 (36-57)
	Percent of plots in a Closed stage (>70% canopy cover)	11 (4-22)	8 (0-19)

Table 5. Mean (Range) trees per acre (TPA) for **LIVE** trees (tree is ≥3" DBH) across species (ABLA, PIEN, PIPU, POTR) at used and available locations for Canada lynx during both **WINTER** and **SUMMER**.

Season	Species	Variable	Available	Used
Winter	ABLA	TPA within 3-4.9"	17 (4-39)	43 (12-93)
	ABLA	TPA within 5-8.9"	14 (3-34)	33 (8-52)
	ABLA	TPA within 9-15.9"	6 (0-20)	11 (3-25)
	ABLA	TPA within ≥16"	0 (0-5)	1 (0-5)
Summer	ABLA	TPA within 3-4.9"	29 (4-74)	52 (10-115)
	ABLA	TPA within 5-8.9"	25 (0-66)	36 (13-76)
	ABLA	TPA within 9-15.9"	9 (0-19)	13 (2-23)
	ABLA	TPA within ≥16"	1 (0-1)	2 (0-4)
Winter	PIEN	TPA within 3-4.9"	20 (5-35)	32 (16-42)
	PIEN	TPA within 5-8.9"	13 (4-26)	22 (11-40)
	PIEN	TPA within 9-15.9"	1 (0-4)	3 (0-11)
	PIEN	TPA within ≥16"	0 (0-1)	0 (0-1)
Summer	PIEN	TPA within 3-4.9"	35 (25-48)	31 (21-44)
	PIEN	TPA within 5-8.9"	17 (8-30)	22 (10-29)
	PIEN	TPA within 9-15.9"	2 (0-7)	2 (0-4)
	PIEN	TPA within ≥16"	0 (0-0)	1 (0-2)
Winter	PIPU	TPA within 3-4.9"	5 (2-12)	5 (0-11)
	PIPU	TPA within 5-8.9"	6 (1-18)	4 (0-10)
	PIPU	TPA within 9-15.9"	2 (0-5)	2 (0-12)
	PIPU	TPA within ≥16"	0 (0-0)	0 (0-1)
Summer	PIPU	TPA within 3-4.9"	5 (2-7)	3 (0-10)
	PIPU	TPA within 5-8.9"	5 (3-11)	4 (1-6)
	PIPU	TPA within 9-15.9"	1 (1-2)	1 (0-3)
	PIPU	TPA within ≥16"	0 (0-1)	0 (0-1)
Winter	POTR	TPA within 3-4.9"	30 (0-102)	22 (4-60)
	POTR	TPA within 5-8.9"	40 (1-82)	37 (12-73)
	POTR	TPA within 9-15.9"	10 (1-16)	11 (4-21)
	POTR	TPA within ≥16"	0 (0-3)	0 (0-0)
Summer	POTR	TPA within 3-4.9"	23 (7-43)	21 (6-34)
	POTR	TPA within 5-8.9"	44 (25-59)	28 (11-47)
	POTR	TPA within 9-15.9"	16 (7-26)	7 (3-17)
	POTR	TPA within ≥16"	0 (0-1)	0 (0-1)

Table 6. Mean (Range) trees per acre (TPA) for **DEAD** trees (tree is ≥3” DBH) across species (ABLA, PIEN, POTR) at used and available locations for Canada lynx during both **WINTER** and **SUMMER**.

Season	Species	Variable	Available	Used
Winter	ABLA	TPA within 3-4.9”	5 (1-10)	5 (1-15)
	ABLA	TPA within 5-8.9”	7 (1-17)	8 (2-20)
	ABLA	TPA within 9-15.9”	3 (1-14)	3 (0-6)
	ABLA	TPA within ≥16”	0 (0-1)	0 (0-1)
Summer	ABLA	TPA within 3-4.9”	3 (0-5)	7 (2-20)
	ABLA	TPA within 5-8.9”	5 (0-8)	12 (8-24)
	ABLA	TPA within 9-15.9”	2 (0-5)	5 (2-9)
	ABLA	TPA within ≥16”	0 (0-0)	0 (0-1)
Winter	PIEN	TPA within 3-4.9”	13 (3-33)	20 (4-32)
	PIEN	TPA within 5-8.9”	31 (16-60)	54 (23-78)
	PIEN	TPA within 9-15.9”	23 (11-40)	30 (16-55)
	PIEN	TPA within ≥16”	5 (1-15)	6 (2-9)
Summer	PIEN	TPA within 3-4.9”	23 (9-36)	21 (10-33)
	PIEN	TPA within 5-8.9”	52 (30-87)	47 (23-70)
	PIEN	TPA within 9-15.9”	34 (16-53)	38 (25-56)
	PIEN	TPA within ≥16”	7 (4-11)	9 (5-16)
Winter	POTR	TPA within 3-4.9”	9 (0-23)	8 (0-15)
	POTR	TPA within 5-8.9”	8 (0-23)	8 (1-16)
	POTR	TPA within 9-15.9”	1 (0-2)	2 (0-5)
	POTR	TPA within ≥16”	0 (0-1)	0 (0-0)
Summer	POTR	TPA within 3-4.9”	6 (2-15)	7 (1-18)
	POTR	TPA within 5-8.9”	11 (5-19)	7 (1-13)
	POTR	TPA within 9-15.9”	2 (1-4)	1 (0-3)
	POTR	TPA within ≥16”	0 (0-2)	0 (0-0)

Table 7. Mean (Range) basal area (BA – ft^2/acre) for **LIVE** trees (tree is ≥3" DBH) across species (ABLA, PIEN, PIPU, POTR) at used and available locations for Canada lynx during both **WINTER** and **SUMMER**.

Season	Species	Variable	Available	Used
Winter	ABLA	BA within 3-4.9"	1 (0-3)	3 (1-6)
	ABLA	BA within 5-8.9"	3 (1-8)	7 (2-11)
	ABLA	BA within 9-15.9"	4 (0-14)	8 (1-18)
	ABLA	BA within ≥16"	1 (0-11)	2 (0-9)
Summer	ABLA	BA within 3-4.9"	2 (0-5)	3 (1-7)
	ABLA	BA within 5-8.9"	5 (0-13)	9 (1-17)
	ABLA	BA within 9-15.9"	1 (0-2)	4 (0-10)
	ABLA	BA within ≥16"	2 (2 -3)	2 (1-3)
Winter	PIEN	BA within 3-4.9"	1 (0-2)	2 (1-3)
	PIEN	BA within 5-8.9"	3 (0-5)	4 (2-8)
	PIEN	BA within 9-15.9"	1 (0-3)	2 (0-8)
	PIEN	BA within ≥16"	1 (0-3)	0 (0-1)
Summer	PIEN	BA within 3-4.9"	2 (2-3)	2 (1-3)
	PIEN	BA within 5-8.9"	3 (2-6)	4 (2-6)
	PIEN	BA within 9-15.9"	1 (0-3)	1 (0-2)
	PIEN	BA within ≥16"	0 (0-0)	3 (0-12)
Winter	PIPU	BA within 3-4.9"	0 (0-1)	0 (0-1)
	PIPU	BA within 5-8.9"	1 (0-4)	1 (0-2)
	PIPU	BA within 9-15.9"	1 (0-4)	2 (0-9)
	PIPU	BA within ≥16"	0 (0-0)	0 (0-0)
Summer	PIPU	BA within 3-4.9"	0 (0-0)	0 (0-1)
	PIPU	BA within 5-8.9"	1 (1-2)	1 (0-1)
	PIPU	BA within 9-15.9"	1 (0-2)	1 (0-2)
	PIPU	BA within ≥16"	0 (0-0)	0 (0-0)
Winter	POTR	BA within 3-4.9"	2 (0-7)	2 (0-4)
	POTR	BA within 5-8.9"	8 (0-17)	8 (3-16)
	POTR	BA within 9-15.9"	6 (0-11)	7 (2-14)
	POTR	BA within ≥16"	1 (0-5)	0 (0-1)
Summer	POTR	BA within 3-4.9"	2 (1-3)	1 (0-2)
	POTR	BA within 5-8.9"	10 (6-13)	6 (2-11)
	POTR	BA within 9-15.9"	10 (4-16)	5 (2-11)
	POTR	BA within ≥16"	1 (0-2)	1 (0-1)

Table 8. Mean (Range) basal area (BA – ft^2/acre) for **DEAD** trees (tree is ≥3" DBH) across species (ABLA, PIEN, POTR) at used and available locations for Canada lynx during both **WINTER** and **SUMMER**.

Season	Species	Variable	Available	Used
Winter	ABLA	BA within 3-4.9"	0 (0-1)	0 (0-1)
	ABLA	BA within 5-8.9"	2 (0-4)	2 (1-4)
	ABLA	BA within 9-15.9"	2 (0-10)	2 (0-4)
	ABLA	BA within ≥16"	0 (0-1)	1 (0-2)
Summer	ABLA	BA within 3-4.9"	0 (0-0)	1 (0-1)
	ABLA	BA within 5-8.9"	1 (0-2)	3 (2-5)
	ABLA	BA within 9-15.9"	2 (0-4)	4 (2-5)
	ABLA	BA within ≥16"	0 (0-0)	1 (0-2)
Winter	PIEN	BA within 3-4.9"	1 (0-2)	1 (0-2)
	PIEN	BA within 5-8.9"	7 (4-14)	12 (5-18)
	PIEN	BA within 9-15.9"	17 (7-29)	22 (11-38)
	PIEN	BA within ≥16"	11 (2-33)	11 (3-17)
Summer	PIEN	BA within 3-4.9"	2 (1-3)	1 (1-2)
	PIEN	BA within 5-8.9"	12 (7-20)	11 (6-17)
	PIEN	BA within 9-15.9"	25 (12-38)	28 (19-44)
	PIEN	BA within ≥16"	15 (7-24)	21 (9-36)
Winter	POTR	BA within 3-4.9"	1 (0-2)	1 (0-1)
	POTR	BA within 5-8.9"	2 (0-5)	2 (0-4)
	POTR	BA within 9-15.9"	1 (0-2)	1 (0-4)
	POTR	BA within ≥16"	0 (0-1)	0 (0-1)
Summer	POTR	BA within 3-4.9"	1 (0-1)	1 (0-1)
	POTR	BA within 5-8.9"	2 (1-4)	1 (0-3)
	POTR	BA within 9-15.9"	1 (1-2)	0 (0-2)
	POTR	BA within ≥16"	0 (0-2)	0 (0-0)

Table 9. Mean (Range) stand density index (SDI) for all **LIVE** trees (tree is ≥3” DBH) across species (ABLA, PIEN, PIPU, POTR) at used and available locations for Canada lynx during both **WINTER** and **SUMMER**.

Season	Species	Variable	Available	Used
Winter	ABLA	SDI within 3-4.9”	3 (1-8)	9 (3-18)
	ABLA	SDI within 5-8.9”	7 (2-18)	16 (4-24)
	ABLA	SDI within 9-15.9”	8 (1-26)	15 (3-32)
	ABLA	SDI within ≥16”	2 (0-16)	4 (0-14)
Summer	ABLA	SDI within 3-4.9”	6 (1-15)	11 (4-23)
	ABLA	SDI within 5-8.9”	12 (0-29)	17 (6-34)
	ABLA	SDI within 9-15.9”	11 (1-24)	17 (3-31)
	ABLA	SDI within ≥16”	2 (0-3)	6 (0-17)
Winter	PIEN	SDI within 3-4.9”	4 (1-7)	7 (3-8)
	PIEN	SDI within 5-8.9”	6 (2-12)	9 (4-19)
	PIEN	SDI within 9-15.9”	2 (0-6)	4 (1-14)
	PIEN	SDI within ≥16”	1 (0-5)	0 (0-2)
Summer	PIEN	SDI within 3-4.9”	7 (5-10)	6 (5-8)
	PIEN	SDI within 5-8.9”	7 (4-13)	10 (4-14)
	PIEN	SDI within 9-15.9”	2 (1-7)	2 (0-4)
	PIEN	SDI within ≥16”	0 (0-0)	3 (0-15)
Winter	PIPU	SDI within 3-4.9”	1 (0-3)	1 (0-3)
	PIPU	SDI within 5-8.9”	3 (0-9)	2 (0-5)
	PIPU	SDI within 9-15.9”	2 (0-7)	3 (0-17)
	PIPU	SDI within ≥16”	1 (0-2)	1 (0-4)
Summer	PIPU	SDI within 3-4.9”	1 (1-1)	1 (0-2)
	PIPU	SDI within 5-8.9”	2 (1-5)	2 (0-3)
	PIPU	SDI within 9-15.9”	1 (0-3)	2 (0-4)
	PIPU	SDI within ≥16”	1 (0-3)	1 (0-3)
Winter	POTR	SDI within 3-4.9”	6 (0-20)	19 (1-38)
	POTR	SDI within 5-8.9”	19 (1-38)	18 (6-35)
	POTR	SDI within 9-15.9”	12 (1-20)	13 (4-26)
	POTR	SDI within ≥16”	1 (0-8)	0 (0-1)
Summer	POTR	SDI within 3-4.9”	5 (2-9)	4 (1-6)
	POTR	SDI within 5-8.9”	22 (13-29)	13 (5-23)
	POTR	SDI within 9-15.9”	19 (8-30)	9 (3-21)
	POTR	SDI within ≥16”	1 (0-3)	1 (0-2)

Table 10. List of uncorrelated covariates used in modeling resource selection of Canada lynx in **WINTER** and **SUMMER**. The ΔAICc indicates the improvement of the covariate relative the "null" model (i.e., intercept only).

Season	Covariate	ΔAICc from Null Model
Winter	Horizontal cover	-36
	Grass cover	-33
	Snowshoe hare pellets	-30
	Live ABLA TPA within 3-4.9"	-30
	Total canopy cover	-27
	Live ABLA QMD	-26
	ABLA Sub-canopy density	-23
	Live PIEN canopy cover	-23
	Live QMD	-22
	Dead QMD	-22
	Live PIEN QMD	-20
	Dead PIEN TPA within 5-8.9"	-16
	Live TPA	-14
	Downed woody debris count	-11
	Live POTR QMD	-11
	Live PIEN TPA within 5-8.9"	-11
	Live ABLA TPA within 9-15.9"	-10
	Live PIEN TPA within 3-4.9"	-8
	Dead BA	-5
	PIEN Sub-canopy density	-4
	Total Sub-canopy density	-3
	Snag QMD	-2
Summer	Dead PIEN QMD	-17
	Horizontal cover	-16
	Grass cover	-9
	Live ABLA QMD	-9
	Live ABLA TPA within 3-4.9"	-8
	ABLA Sub-canopy density	-6
	Total Sub-canopy density	-6
	Live QMD	-6
	Snowshoe hare pellets	-4
	Live PIEN QMD	-4
	Snag QMD	-4

Table 11. Standardized parameter estimates from the top and most parsimonious **WINTER** and **SUMMER** model.

Season	Covariate	β	SE	*p*
Winter	Horizontal cover	0.239	0.124	0.054
	Snowshoe hare pellets	0.245	0.132	0.063
	Canopy cover of live PIEN	0.353	0.118	0.003
	QMD of live ABLA	0.267	0.121	0.027
	QMD of live POTR	0.321	0.113	0.004
	QMD of dead trees	0.366	0.152	0.016
	TPA of live ABLA 3-4.9 inches in DBH	0.328	0.145	0.023
	TPA of dead PIEN 5-8.9 inches in DBH	0.328	0.143	0.022
	BA of dead trees	-0.319	0.161	0.047
Summer	Horizontal cover	0.427	0.139	0.002
	Snowshoe hare pellets	0.231	0.139	0.078
	QMD of dead PIEN	0.492	0.142	0.001
	QMD of dead ABLA	0.263	0.135	0.051

Figure 1. Predicted relationships (with 90% CIs) characterizing functional responses in habitat use by Canada lynx during the **WINTER**. The diagonal line indicates proportional habitat use. Each data point represents the mean value at used and available locations for each lynx (±1 SE).

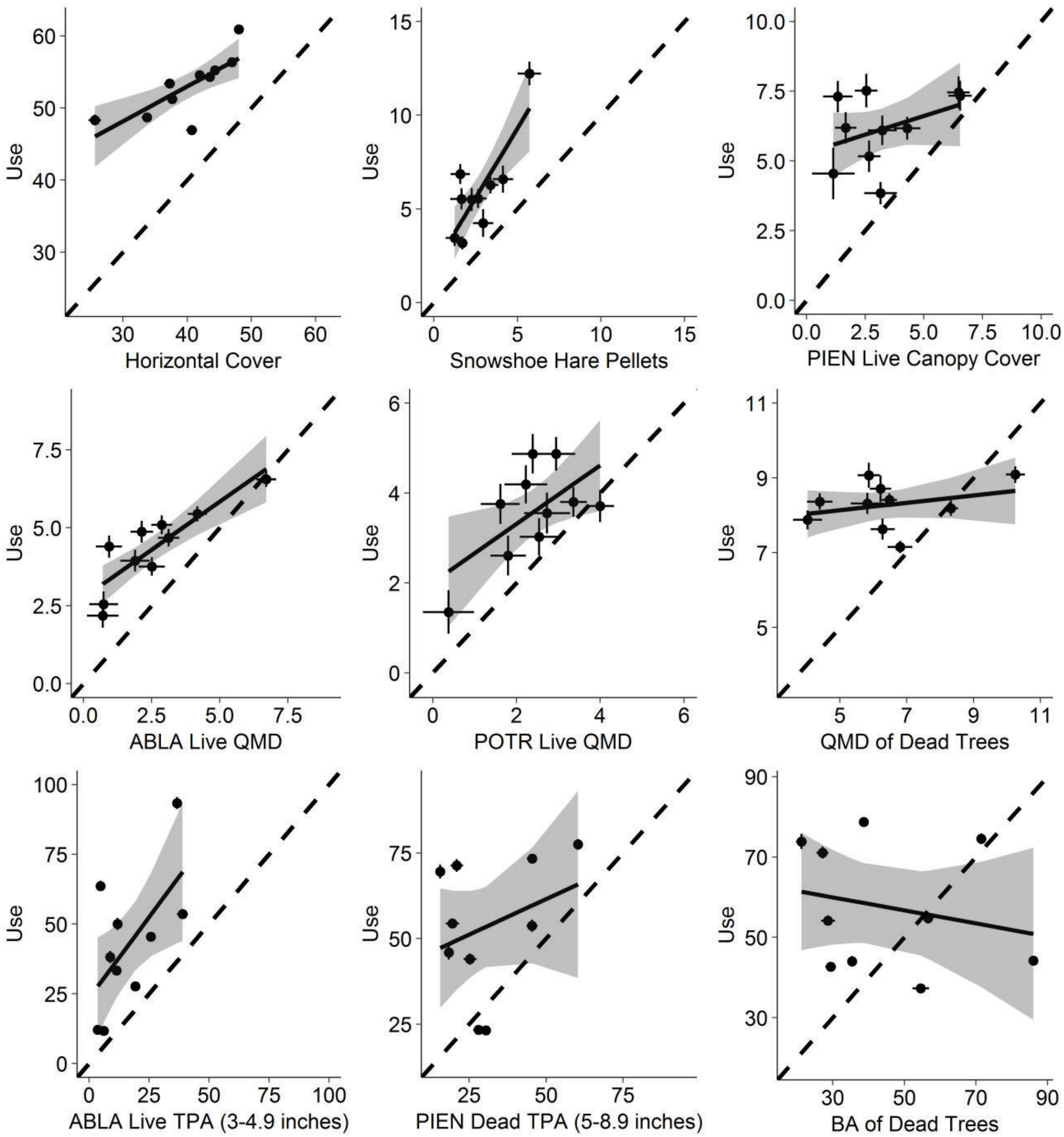
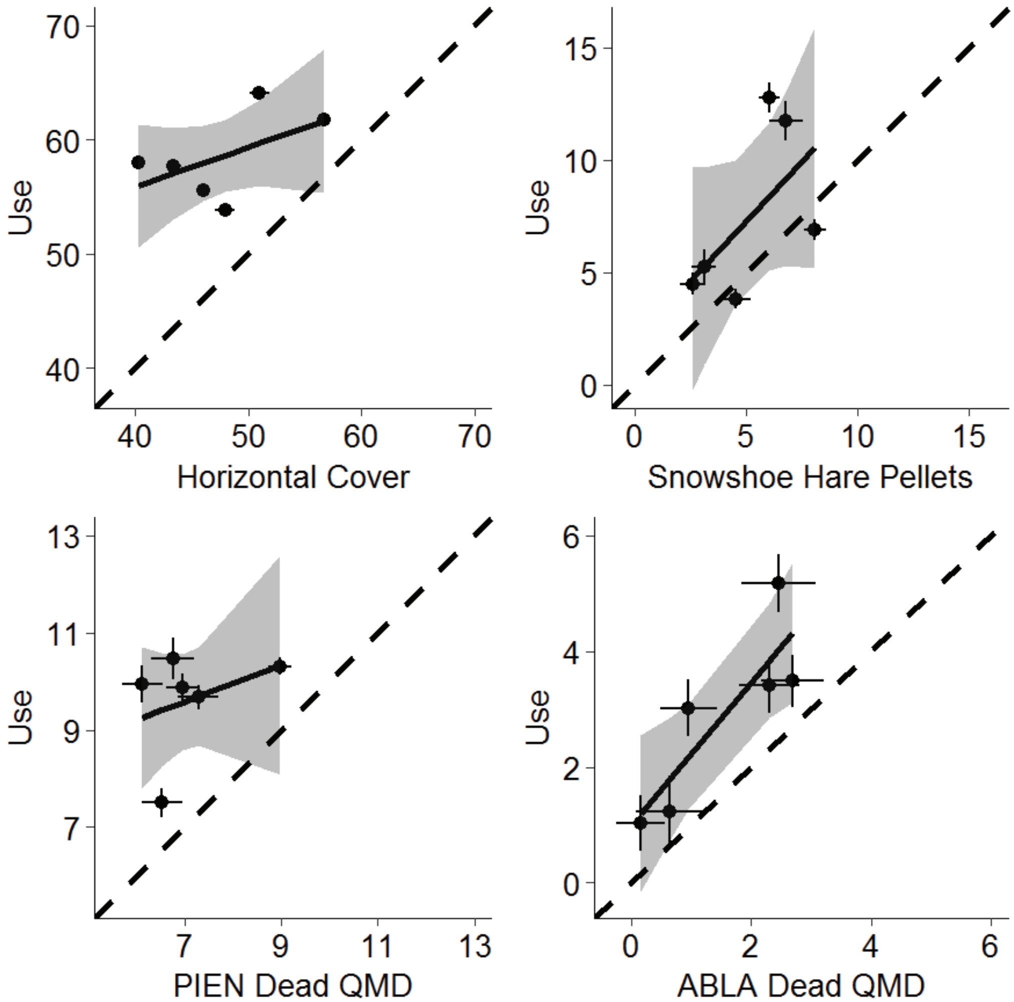
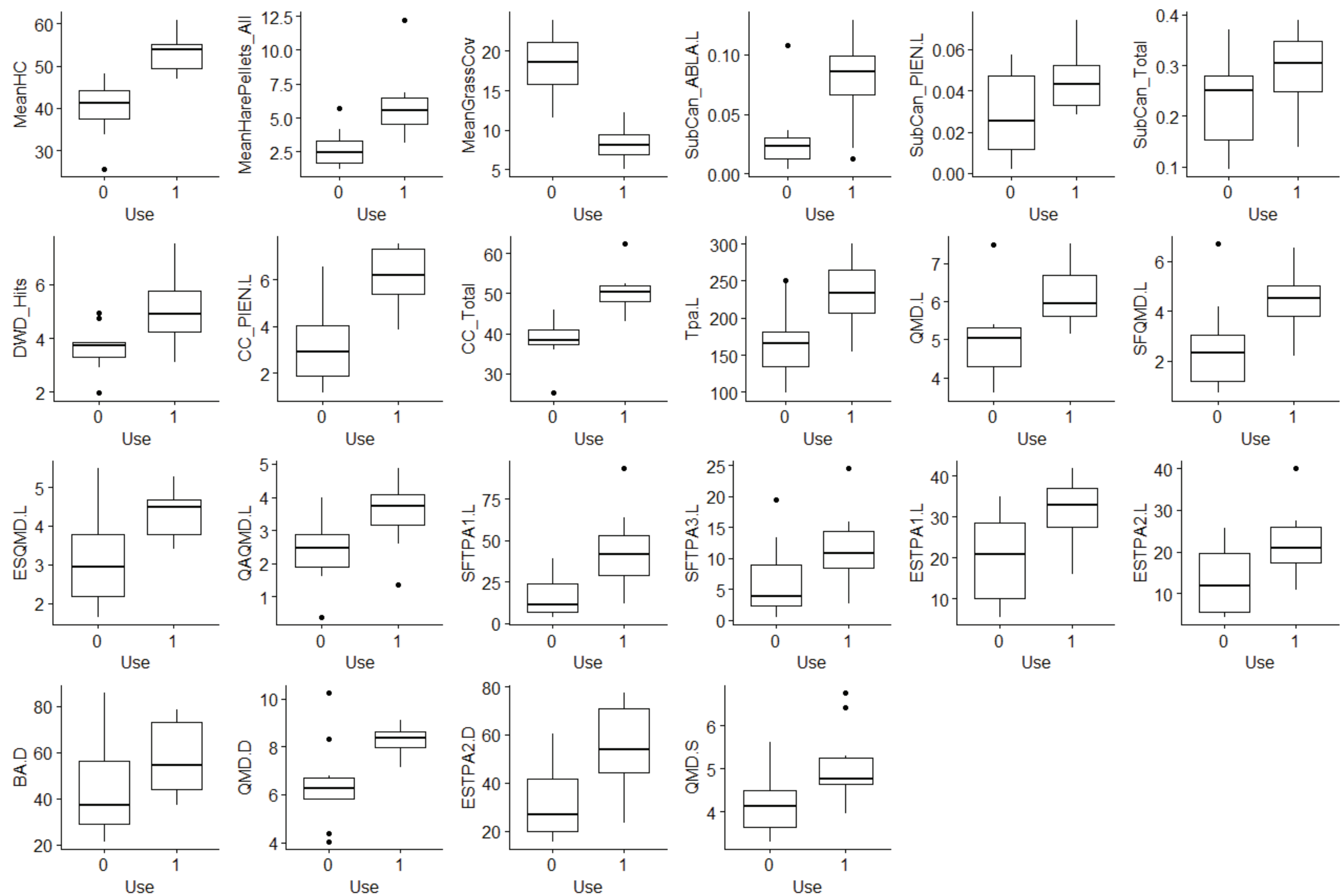


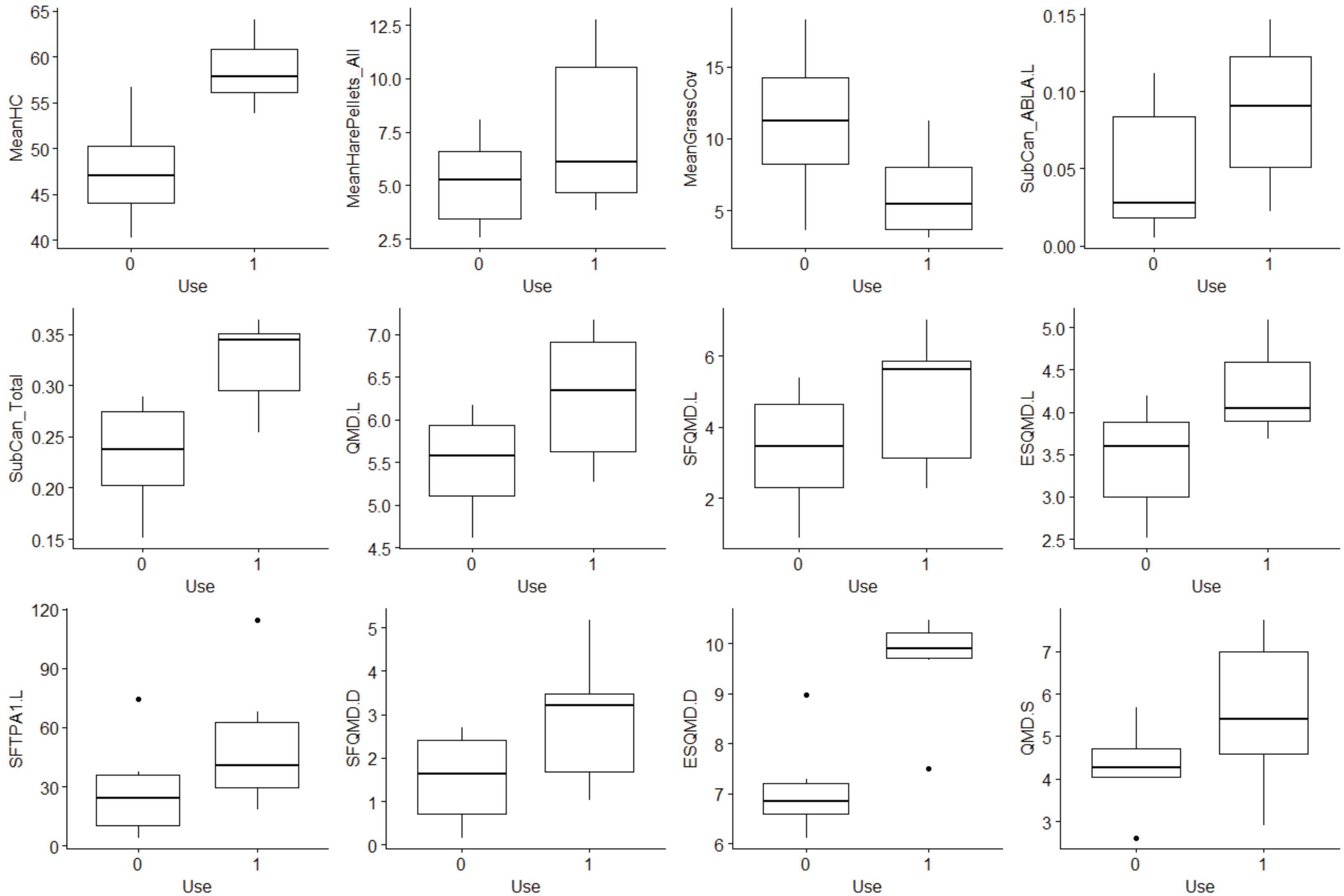
Figure 2. Predicted relationships (with 90% CIs) characterizing functional responses in habitat use by Canada lynx during the **SUMMER**. The diagonal line indicates proportional habitat use. Each data point represents the mean value at used and available locations for each lynx (±1 SE).



Supplemental Figure 1. Boxplots of the suite of uncorrelated covariates considered for modeling Canada lynx resource use in the **WINTER**.



Supplemental Figure 2. Boxplots of the suite of uncorrelated covariates considered for modeling Canada lynx resource use in the **SUMMER**.



Horizontal Cover Analyses

Table 1. Standardized parameter estimates from our linear models evaluating the effect of trees/acre on horizontal cover at lynx used and available locations during the winter and summer. ****Note – ABLA subcanopy alone exhibits a R^2 of 0.15…explains half of the total variation explained by our winter model.***

	Winter			Summer		
Covariate	β	SE	*p*	β	SE	*p*
Intercept	46.743	0.886	<0.001	53.111	1.036	<0.001
ABLA sub-canopy TPA	7.303	1.064	<0.001	7.889	1.274	<0.001
PIEN sub-canopy TPA	3.985	1.027	<0.001	2.848	1.145	0.013
PIPU sub-canopy TPA	1.218	0.899	0.176	3.779	1.046	<0.001
POTR sub-canopy TPA	3.818	0.937	<0.001	7.565	1.161	<0.001
SALIX sub-canopy TPA	2.124	0.889	0.001	3.429	1.051	0.001
Live TPA	3.499	1.094	0.001	1.819	1.454	0.212
Live ABLA TPA	1.021	1.173	0.385	2.392	1.529	0.119
Live PIEN TPA	1.868	1.112	0.094	4.760	1.321	<0.001
Dead PIEN TPA	2.650	0.972	0.007	2.135	1.158	0.066
Model R^2	*0.30*			*0.40*		