PROGRESS REPORT
for
COOPERATIVE BOBCAT RESEARCH PROJECT

Period Covered:
1 January – 31 March 2013

Prepared by

John A. Litvaitis, Gregory Reed, Tyler Mahard, and Marian K. Litvaitis
Department of Natural Resources
University of New Hampshire
Durham, NH
20 May 2013
SUMMARY BY STUDY OBJECTIVES

OBJECTIVE I -- DEVELOP PROTOCOL TO ESTIMATE CURRENT ABUNDANCE OF BOBCATS AND TRACK POPULATIONS STATEWIDE.

Approach #1: Use of transmitter-equipped bobcats to model suitable habitats and generate density estimate based on area requirements.

We continue our efforts to refine a statewide map of bobcat habitat suitability. During this reporting period, modeling was done at two orders of selection (second and third order) using two approaches. Second-order selection is the positioning of individual home ranges within the geographic range of a species whereas third order is the selection of locations within a home range. Suitability models were developed using Resource Selection Probability Functions (RSPF) that measure an organism’s use of a particular habitat feature relative to its availability and result in a probability of selection from 0 to 1 (Manly et al. 2002). Subsequent analyses were then combined (multiplicably) to create one scale-dependent resource selection function (SRSF; Johnson et al. 2004, DeCesare et al. 2012). This analysis takes advantage of the hierarchical habitat selection observed in animals (Johnson 1980).

The main factors believed to effect bobcat home-range placement (2nd order section) are winter severity (McCord 1974, Fox 1990) and human development (Crooks 2002, Lovallo and Anderson 2002). We investigated home range selection using sightings solicited from the public from 2007-2013 (Broman et al. 2013). Bobcats were often observed in backyards or along roads; therefore, these data are biased towards areas of high human and road densities. Given that inherent bias in observations, we only analyzed climatic or topographic variables that could limit home range placement by bobcats in New Hampshire. We believe this is justified because the influences of roads and development are quantified in subsequent third-order analysis. To determine ‘used’ and ‘unused’ locations each sighting was buffered by the maximum home range size of the collared bobcats. Maximum home range size was used to insure that all possible home range areas were sampled. One thousand random points were then generated throughout the state. Points that fell within the buffered home range were considered ‘used’, and ones that were not within the range were considered ‘unused’.

Resource selection was investigated using an elevation layer derived from a digital elevation map (1 km resolution) and two snow depth layers developed in ArcGIS (Callahan 2013) from the Snow...
Data Assimilation System (SNODAS) Data Products at the National Snow and Ice Data Center (NSIDC). One snow layer was average monthly (November-March) maximum snow depth and the other was average monthly (November-March) mean snow depth. All variables were highly correlated (r>0.7), so only one was included in each model. Models with quadratic terms were included because we suspect that bobcats respond to snow/elevation in a nonlinear manner. The model with average monthly (November-March) mean snow depth was considered the best model as judged by AICc (Table 1). Probability of use by bobcats declined with increasing mean monthly snow depth (Fig. 1). Increasing snow depth likely results in bobcats have difficulty locating and capturing prey and they may be at a competitive disadvantage to lynx, resulting in avoidance of greater snow depths (McCord 1974).

Table 1. Models used to investigate second-order habitat selection (home range placement) by bobcats in New Hampshire. Model variables included average monthly (November-March) maximum snow depth (Snow_Max), average monthly (November-March) mean snow depth (Snow_Mean), and elevation (Elevation). Incidental observations reported by the public between 2007 and 2013 were used to model the relationship between probability of use and the habitat variables.

<table>
<thead>
<tr>
<th>Model</th>
<th>K</th>
<th>AICc</th>
<th>Delta_AICc</th>
<th>AICcWt</th>
<th>Cum.Wt</th>
<th>LL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snow_Mean</td>
<td>2</td>
<td>520.14</td>
<td>0.00</td>
<td>0.66</td>
<td>0.66</td>
<td>-258.07</td>
</tr>
<tr>
<td>Snow_Mean²</td>
<td>3</td>
<td>521.50</td>
<td>1.35</td>
<td>0.34</td>
<td>1</td>
<td>-257.74</td>
</tr>
<tr>
<td>Snow_Max²</td>
<td>3</td>
<td>541.47</td>
<td>21.33</td>
<td>0</td>
<td>1</td>
<td>-267.72</td>
</tr>
<tr>
<td>Snow_Max</td>
<td>2</td>
<td>542.31</td>
<td>22.17</td>
<td>0</td>
<td>1</td>
<td>-269.15</td>
</tr>
<tr>
<td>Elevation</td>
<td>2</td>
<td>618.66</td>
<td>98.52</td>
<td>0</td>
<td>1</td>
<td>-306.32</td>
</tr>
<tr>
<td>Elevation²</td>
<td>3</td>
<td>634.11</td>
<td>113.97</td>
<td>0</td>
<td>1</td>
<td>-315.05</td>
</tr>
</tbody>
</table>

The model used to investigate third-order selection (Fig. 2) was described in the previous progress report; however, this time it was re-fit using the Package ‘ResourceSelection’ in R (R Core Team 2012, Lele et al. 2013). This package fits a Resource Selection Probability Function (RSPF) and represents the true probability of selection. This differs from and improves upon a Resource Selection Function (RSF) in that an RSF is only proportional to the probably of selection (Lele and Keim 2006, Lele 2009). Variables used included NLCD 2006 (Fry et al. 2011; layers collapsed to open water, light development, heavy development, barren, evergreen forests, deciduous forests, mixed forests, shrub/scrub, agriculture, and wetlands), distance to forest edge (excluding open water/forest edge), elevation, slope, aspect, and a vector ruggedness measurement (VRM, Sappington et al. 2007). Bobcats selected for forests, shrub/scrub, and wetlands, and selected against
developed areas, agricultural areas, and open water. They preferred more rugged and steeper sloped areas, with southern facing slopes, and at lower elevations. Avoidance of high road density and selection for areas closer to forest edge were also important variables.

![Figure 1](image)

**Figure 1.** Bobcat relative probability of use based on average mean monthly snow depth between November-March 2007-2012.

The model used to investigate third-order selection (Fig. 2) was described in the previous progress report; however, this time it was re-fit using the Package ‘ResouceSelection’ in R (R Core Team 2012, Lele et al. 2013). This package fits a Resource Selection Probability Function (RSPF) and represents the true probability of selection. This differs from and improves upon a Resource Selection Function (RSF) in that an RSF is only proportional to the probably of selection (Lele and Keim 2006, Lele 2009). Variables used included NLCD 2006 (Fry et al. 2011; layers collapsed to open water, development, barren, evergreen forests, deciduous forests, mixed forests, shrub/scrub, agriculture, and wetlands), road density (km/km²), distance to forest edge (excluding open water/forest edge), elevation, slope, aspect, and a vector ruggedness measurement (VRM, Sappington et al. 2007). Bobcats selected for forests, shrub/scrub, and wetlands, and selected against developed areas, agricultural areas, and open water. They preferred more rugged and steeper sloped areas, with southern facing slopes, and at lower elevations. Avoidance of high road density and selection for areas closer to forest edge were also important variables.

The resulting models of second and third-order selection were combined by multiplying them together using Raster Calculator in ArcMap 10 (Fig. 3, Johnson et al. 2004). It can be seen that there
Figure 2. Bobcat habitat suitability modeled at two scales of selection. Second order: using sightings and snow depth (left). Third order: using GPS-telemetry locations and land cover, road density, slope, aspect, elevation, V/RM, and distance to forest edge.
Figure 3. Bobcat habitat suitability map for New Hampshire utilizing two spatial scales. Incidental observations were solicited from the public and used to model second-order selection. GPS-telemetry locations from 18 collared bobcats were used to model third-order habitat selection. Maps were then combined to generate a scale-integrated map of habitat selection.
is a strong selection for more southern portions of the state and for lower elevations, likely a consequence of deeper snow accumulation in the White Mountains and Coos County. Additionally, highly developed areas are avoided, especially along the I-93 corridor and throughout the Merrimack Valley. Outside of these areas, it seems that most of the state is moderate to good habitat.

While the models pass the quick visual test, more work needs to be done on validation. The third order selection model was tested with \( k \)-fold cross validation and proved to be of good predictive value. Similar measure must be done for both second order models, as well as the final model. Once a properly validated final model is completed, estimates of potential population will be made using home range sizes and collared bobcats suitability scores extracted from the models.

**Approach #2: Development of a method to monitor abundance of bobcat populations based on trail cameras and citizen scientist volunteers.**

*Determining an effective set of attractants –* A camera survey took place on a large property in Barrington to test the efficacy of electronic predator calling units (*FurFindR* brand by Wasatch Wildlife Products). Twenty detection stations were deployed along unpaved forested roads closed to public use. Stations were grouped into two transects of 10 cameras spaced 100 meters apart. All stations consisted of a trail camera (*Bushnell Trophy Cam*), coyote urine, catnip oil, and a CD. Alternate stations were also equipped with predator-calling units. In 200 successful trap nights, 30 detection events were documented (Fig. 4). Stations with scent and a CD produced more detection events, but medium-sized carnivores were only documented at stations equipped with predator calling units. Detected medium-sized carnivores included red foxes \( (n = 2) \), raccoon \( (n = 1) \), and fisher \( (n = 1) \). No bobcats were detected during this survey. However, bobcat tracks were found less than 1 km away from the nearest detection station at the conclusion of the survey.

Further camera spacing and the use of a commercial gland-based lure may have increased the success of this survey in detecting bobcats. Further camera spacing would have made for a larger study area, and increased the number of potential bobcats within the study area. A commercial gland-based lure may provide a scent that is more enticing to bobcats and may draw in bobcats from a farther distance than coyote urine, catnip oil, or predator calling units.
Figure 4. Detection events for medium-sized carnivores, non-medium-sized carnivores, and all wildlife species. Detection events are one or more photos of a species separated by at least 0.5 hours.

Gaging survey effort -- Studies that used detection stations to survey bobcat or lynx were analyzed to provide a sense of the possible range of detection rates (number of bobcat detection events per camera per 24-hour period) (Table 2). This allows for estimation of the survey effort necessary to detect the desired number of bobcats. Detection rates were successfully obtained or calculated from 10 of these published studies. The remaining studies (Gabor et al. 1994, Sargeant et al. 1998, Howard et al. 2002, Burdett et al. 2006, George and Crooks 2006, Larrucea et al. 2007) did not provide methods or results that allowed us to confidently calculate detection rates.

Based on these results, we expect detection rates between 0.01 and 0.04 to be typical for camera surveys in New Hampshire. Diefenbach et al. (1994) and Heilbrun et al. (2006) report detection rates >0.04. However, Diefenbach et al. (1994) conducted their surveys on an island on which the bobcat population was artificially increased to an estimated density of 0.48 bobcats/km². Heilbrun et al. (2006) attributed their high detection rate to the dense chaparral vegetation of their study area, which they suggest encouraged bobcat use of paths along which cameras were placed. They also estimated bobcat density in their study area to be 0.48 bobcats/km². Whether or not detection rates greater than 0.04 are attainable in New Hampshire is unknown.
Table 2. Studies that used detection stations to survey bobcats or lynx* and number of bobcat detection events per camera per 24-hour period.

<table>
<thead>
<tr>
<th>Reference</th>
<th>State</th>
<th>Detection Station</th>
<th>Stations</th>
<th>Trap Nights</th>
<th>Captures</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adams 2009</td>
<td>WI</td>
<td>Hair</td>
<td>480</td>
<td>13440</td>
<td>2</td>
<td>0.0001</td>
</tr>
<tr>
<td>Comer et al. 2011</td>
<td>TX</td>
<td>Camera</td>
<td>20</td>
<td>1680</td>
<td>15</td>
<td>0.0089</td>
</tr>
<tr>
<td>Conner et al. 1983</td>
<td>FL</td>
<td>Track</td>
<td>30</td>
<td>720</td>
<td>-</td>
<td>0.0100</td>
</tr>
<tr>
<td>Kelly &amp; Holub 2008</td>
<td>VA</td>
<td>Camera (passive)</td>
<td>15</td>
<td>891</td>
<td>13</td>
<td>0.0146</td>
</tr>
<tr>
<td>Nielson &amp; McCollough 2009*</td>
<td>ME</td>
<td>Camera</td>
<td>36</td>
<td>2512</td>
<td>-</td>
<td>0.0179</td>
</tr>
<tr>
<td>Litvaitis et al. 2012</td>
<td>NH</td>
<td>Camera</td>
<td>24</td>
<td>474</td>
<td>10</td>
<td>0.0211</td>
</tr>
<tr>
<td>Harrison 2006</td>
<td>NM</td>
<td>Camera</td>
<td>-</td>
<td>140</td>
<td>5</td>
<td>0.0357</td>
</tr>
<tr>
<td>Chamberlain et al. 1999</td>
<td>MS</td>
<td>Track</td>
<td>47</td>
<td>550</td>
<td>20</td>
<td>0.0364</td>
</tr>
<tr>
<td>Heilbrun et al. 2006</td>
<td>TX</td>
<td>Camera (passive)</td>
<td>10</td>
<td>948</td>
<td>49</td>
<td>0.0517</td>
</tr>
<tr>
<td>Diefenbach et al. 1994</td>
<td>GA</td>
<td>Track</td>
<td>190</td>
<td>-</td>
<td>-</td>
<td>0.0530</td>
</tr>
</tbody>
</table>

Models were produced based on a liberal range of documented capture rates (0.01 to 0.06) to provide a sense of the data collection power required from citizen scientists to detect a given number of bobcats (Fig. 5). These models will also be useful for designing camera surveys.

Figure 5. Survey effort required to detect 10, 25, 50, and 100 bobcats at detection rates of 0.01 and 0.06 bobcats/trap-night. Detection rate (R) and number of bobcat detection events (N) are constant along curves as the ratio of number of cameras to nights (number of 24-hour periods during which all camera must be active) varies.
**Approach #3:** Evaluate the application of population genetics using tissue from road-killed bobcats.

Work continues on this and will be updated in subsequent reports.

**OBJECTIVE II -- COMPARE ABUNDANCE OF BOBCATS IN NEW HAMPSHIRE TO POPULATIONS IN ADJACENT STATES.**

Additional activity on this objective will occur after a more comprehensive evaluation of the second-generation habitat suitability map has been completed and additional tissue samples are collected from road-killed bobcats.

**OBJECTIVE III -- IDENTIFY POTENTIAL WILDLIFE CORRIDORS.**

Identification of wildlife corridors is being refined using the third-order RSF map and the expert opinion map generated by NHFG and NH Audubon. Our first step was to validate and compare both maps at the bobcat home range scale before extrapolating them out to the rest of the state. Previous efforts (detailed in Progress Report VII; Appendix 1) only considered the third order RSF map and not the expert opinion layer. The previous analysis connected all locations to generate a movement path, meaning missed GPS fixes were not taken into account. Likely this is the explanation for poor results seen during the first phase of analysis. The current effort removed all segments that were not the result of two subsequent GPS fixes.

Results were more explanatory with the improved methods and addition of the expert opinion resistance layer. Visually, the two resistance layers are relatively similar with roads and developed areas being the major barriers present in each resistant map. The RSF map had greater fine scale detail, which was expected given the empirical methods used and the additional habitat layers included. It also had 16 out of 18 actual paths score higher than random paths \((p<0.05; \text{Fig. 6})\), most likely a result of this added detail. The expert opinion model had a majority of the bobcats’ actual paths score higher than random paths \((12 \text{ of } 18, p<0.05\)) , although less than the RSF model. Most likely this a product of the fine scale validation of potential movements at the home range level, and may not necessarily explain movement and gene flow at landscape scales.
Figure 6. Differences between the ‘actual’ path (set to 0) and mean ‘random’ path scores. Scores below zero show bobcats selected a better path through their individual home range, as predicted by the connectivity models. Scores are bounded by 1 SE.

Given that models performed relatively well at the home range level for collared bobcats they were extrapolated to a larger portion of the state, along Highway 101 (Fig. 7). They were then tested in the field using camera traps to determine the applicability of using bobcats as a surrogate species for connectivity conservation planning. From January-April 2013 29 sites were sampled 1-5 times for approximately 10 days. Sites were baited with coyote urine and catnip oil and CD was hung nearby to act as a visual attractant. All animals that triggered the camera were noted, but data analysis will focus on carnivores. Additionally, habitat measurements both in the field and using GIS were taken for each site. Preliminary analysis has begun to assess whether species richness and/or the presence of certain species increases in areas with higher connectivity scores for bobcats. Habitat measurements will be used to test whether these scores are the product of site specific habitat characteristics or a function of the larger landscape. Future work will include modeling connectivity at region and statewide scales.
Figure 7. Extrapolated connectivity models centered on Highway 101 in southeastern New Hampshire. Cameras were placed approximately every 1km along the road to test the applicability of using connectivity models derived for bobcats for other forest carnivores.
Literature Cited

Adams, L.M. 2009. Use of non-invasive surveys to validate predicted bobcat (*Lynx rufus*) habitat distribution in Wisconsin from landscape-scale GIS information. M.S. Thesis, University of Wisconsin, Stevens Point


Callahan, C. 2013. [SNODAS season snow depth files]. Unpublished data.


Appendix I

Figure 8. Modeling scheme to test connectivity predictions for bobcats. RSF generated using all location except from Bobcat #26, with his locations overlaid. This served as the ‘conductivity’ layer (top left). Sampling protocol adopted from Anderson et al. (2012) to map connectivity in bobcat home range with minimal source/ground bias (top right). Output from circuit theory using top as source/ bottom as ground, bottom as source/ top as ground, left as source/ right as ground, and right as source/ left as ground (middle panels – L to R). Cumulative circuit theory map with Bobcat #26’s ‘actual’ path (bottom left). ‘Actual’ path overlaid with 100 ‘random’ paths, rotated and shifted (bottom right).