2017

Effects of Roads on Black Bear Distribution in Southern Vermont

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An Honors College Thesis

by

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1 May 2017
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RH: Drasher • Bear Distribution and Roads

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Note on data: *This report is based on an analysis of a dataset that is part of a larger study by the Vermont Fish and Wildlife Department that has not yet been completed. The results may not reflect the final conclusions of the Deerfield Wind Black Bear Study. Please do not reproduce or publish any part of this report before first gaining permission from the author.*

Note on tense: *In this paper, I use 'we' when discussing the hypotheses formed and the analyses carried out for this research. This is in reference to the collaborative effort between the partners in this project: the Vermont Fish and Wildlife Department and University of Vermont Rubenstein School Wildlife & Fisheries Biology Program. I carried out all analyses independently for my thesis research, but feel that the partners should be recognized as an integral part of how this research came about.*

ABSTRACT

The American black bear (*Ursus americanus*) is a wide-ranging, large carnivore species that makes use of multiple habitat types throughout the year. In the northeastern US, black bears require large areas of relatively undisturbed forest and avoid development, such as urban and suburban areas. Roads represent another form of development that may affect the distribution of bears. However, the effects of roads remain largely unknown and represent a potential conservation concern. We sought to determine the relationship between roads and distribution of black bears in a forested region of southern Vermont. We examined the probability of occurrence of black bears using GPS-collar data (n = 30,179 locations) collected from a marked population of bears (n = 8 females, 15 males) from 2011 to 2014. We then constructed a set of 7 candidate models to explain occupancy that included combinations of three road types: secondary, vehicular, and local. Model selection techniques were used to determine the best model in the set. Models were performed separately for male and female bears, which have been shown to exhibit different distribution patterns elsewhere. The top model for each sex was the most complex in the set, and included the additive combination of all three road types. For males, vehicular and local roads positively affected occupancy, whereas secondary roads had a negative influence on occupancy. For females, vehicular and secondary roads positively affected occupancy, whereas local roads negatively affected occupancy. Our results indicate that small, low traffic, residential and ATV roads influence bear distribution; most likely by providing easy pathways to travel through the forested landscape and food resources not found elsewhere. Secondary and local roads also affect sexes differently, which could result in demographic and genetic consequences. Models provide a measure of the effect of different roads on bear distribution that can help inform decision-making about development in the forested landscapes of Vermont.

KEY WORDS: black bear, distribution, occupancy modeling, road effect, *Ursus*, Vermont

INTRODUCTION

Landscape connectivity is important for the success of many species, especially large carnivores that require expansive tracts of land for their home ranges (Noss et al. 1996). As development progresses and landscapes become increasingly fragmented by roads, large carnivore species are often negatively impacted (Fahrig and Rytwinski 2009, Long et al. 2011). Crossing roads becomes a necessity for large carnivores in a human-dominated landscape because of their large ranging requirements, making them more vulnerable to vehicle collisions, encounters with poachers due to increased road access, and other barrier effects that come with the presence of roads (Noss et al., 1996). These larger species usually reproduce infrequently and have fewer young, meaning that the lethal impacts of fragmentation can be more pronounced (Fahrig and Rytwinski 2009). Alternatively, roads may have positive effects for some species, by providing pathways of movement through complex landscapes, food resources, and refuges from predation (Berger 2007).

The American black bear (*Ursus americanus*) is a wide-ranging, large mammal species, and for this reason it is important to understand how roads and other forms of development affect their distribution across a landscape (Long et al. 2011). Black bears require a variety of habitat types throughout the year, due to their seasonal food requirements. Black bears feed in wetlands during the spring, consume berries in open areas during the summer and hard mast such as beechnuts (*Fagus grandifolia*) in the fall, and these food resources are found in different areas of the landscape (Hamelin 2011, Noyce and Garshelis 2011). In a fragmented landscape, bears may encounter various types of roadways when trying to access these diverse food sources (Lewis et al. 2011). Bears will also commonly travel outside of their home ranges in search of food in years when local food availability is low (Noyce and Garshelis 2011). When road-crossings do occur, there can be risk to both bears and motorists, and this issue is of concern to wildlife managers and transportation agencies (Girvetz et al. 2008). Additionally, roads can act as effective barriers to movement, and can result in demographic and genetic consequences (Trombulak and Frissell 2000).

Black bear occupancy has been analyzed at multiple spatial scales (Bettigole et al. 2014, Long et al. 2011). In Vermont, human development has been shown to be a negative predictor of black bear occupancy at a 5 km scale, while percentage of forested land was a positive predictor at a 5 km scale (Long et al. 2011). Research has been conducted on the movements and distribution of black bears across the United States (Costello et al. 2013, Cushman et al. 2006, Lewis et al. 2011, Noyce and Garshelis 2011, 2014), though research evaluating the impacts of different road classes on black bears is lacking. The impact of different road classes on black bear occupancy has not yet been assessed, but represents a concern especially in Vermont as nearly 90% of towns in the state are willing to increase development (Bettigole et al. 2014). Furthermore, sex differences with relation to occupancy and roads have yet to be explored.

We examined the influence of different road types on the distribution of black bears in southern Vermont. The study relied on data collected from GPS-collared bears as part of a broader project on black bear movements relative to wind development managed by the Vermont Fish and Wildlife Department (VFWD) in southern Vermont (Comeau and Hammond 2015). Our objective was to evaluate the effects of three road types on black bear occupancy, including secondary roads, vehicular roads, and local/residential roads (U.S. Census Bureau 2016). Based on observations during the study and the potential road impacts seen elsewhere (including with studies done on the impacts of different road classes on other species; Montgomery et al. 2013), we expected black bear occupancy to be negatively associated with secondary and local roads, which experience more traffic, and positively associated with vehicular roads, which may serve as movement corridors in more rural areas (U.S. Census Bureau 2016).

METHODS

Study Area

The complete study extent encompassed the Vermont counties of Bennington, Windham, and Windsor, the New York counties of Albany, Columbia, Rensselaer, Saratoga, Sullivan, and Warren, the Massachusetts counties of Berkshire, Franklin, Hampden, Hampshire, and Worcester, and Cheshire County in New Hampshire. It included the major state roadways of VT Routes 8, 9, and 100, MA Route 2, Interstates 91 and 90, and many local, service, and vehicular roads (Appendix I and II). Home ranges of the collared bears were found in the main study area located in southern Vermont, which is a part of the Manchester District of the Green Mountain National Forest managed by the US Forest Service. This Vermont portion of the study area is primarily forested, with little development aside from scattered homes, hunting camps, and small town centers. Populations of Searsburg and Readsboro (the two main towns in the study area) are 96 and 809, respectively (VT Census data, State of Vermont). Population density in Searsburg is 4.5 people per square mile, while population density in Readsboro is 22.2 people per square mile.

The forest in the Vermont study area is a mix of hardwoods and softwoods, including American beech (*Fagus grandifolia*), maple (*Acer spp.*), red oak (*Quercus rubra*), spruce (*Picea spp.*), and fir (*Abies spp.*). Some natural community types that occur in this area include lowland and montane spruce-fir forest, and red spruce-northern hardwood forest (Thompson and Sorenson 2005). The most critical food sources for bears in the study area are the extensive beech stands on the ridgelines on either side of VT Route 8. The bear-scarred beech trees on these ridgelines have been mapped by VFWD, with over 1,300 bear-scarred beech trees identified in one 300-foot (91.44 m) strip (Hammond & Austin, 2011). In the broader study extent, the prominent habitat type is Laurentian-Acadian Northern Hardwood Forest (description in Table 1, map in Appendix I; LANDFIRE 2017).

Data Collection

We collected locations on individual bears using GPS-radio collars and used them to build occupancy models. The Vermont Fish and Wildlife Department captured and collared bears beginning in 2011. Bears were captured during the months of May and June using culvert traps, Aldrich foothold traps, and trained bear hounds (Comeau and Hammond 2015). We used data from 23 individuals monitored from 2011 to 2014 (Table 2). GPS collars (Iridium TrackM, Lotek, Newmarket, Ontario, Canada) collected locations from bears every three hours from 15 March to 15 December, and every 35 hours during the winter months from 16 December to 14 March (Appendix III; Comeau and Hammond 2015).

Camera traps (PC900 Hyperfire Professional Covert IR, Reconyx, Holmen, Wisconsin, USA) were used to collect supplementary data on bear presence/absence near Route 9 in Searsburg, VT. Nineteen owned by VFWD and Vermont Agency of Transportation (VTrans) were placed underneath bridges of Route 9 in April 2016 to comply with the requirements of a separate wildlife connectivity study under the Staying Connected Initiative (Appendix IX; Marangelo 2017).

An additional ten cameras (Advantage Cam 8MP, Bushnell, Overland Park, Missouri, USA; purchased with a grant from the University of Vermont Office of Undergraduate Research) were also used for supplementary data. Cameras were set-up on 02 July 2016 and moved to new locations along Route 9 every two-three weeks through 23 October 2016. Four sections of road were sampled along Route 9, averaging roughly 100 m in length each (Appendix X). Locations were selected based on expert opinion of VFWD biologists to maximize detection.

Modeling Approach

We modeled distribution and the effects of roads using an occupancy modeling approach. An occupancy model predicts the probability of occurrence at any given site in the landscape as a function of covariates, such as amounts of different habitat, and is commonly used to map the distribution of a species (Mackenzie et al. 2006). Occupancy modeling uses the multinomial maximum likelihood function to estimate parameters. We used location data to build models, which represent presence-only locations. These models are limited in that they do not account for detection probability, but given the number of animals and locations in the study, we believe any biases related to detection were minimal (Royle et al. 2012).

Our modeling approach involved building a set of candidate models, then confronting each model with the data and ranking the results using model selection techniques (Burnham and Anderson 2002). We used Akaike's Information Criterion to rank models, and considered models with a ΔAIC < 2 to have strong empirical support (Burnham and Anderson 2002). Models were built using the MaxLike package for R (Royle et al. 2012, R Core Team 2015).

Black bear occupancy in Vermont is a function of forest cover (of any type) and amount of development within 5km of a given site based on a statewide study of occupancy by Long et al. 2011. This study included the effects of larger roads in their analysis, and a model averaged parameter estimate for roads indicated a small positive effect on occupancy; however, confidence intervals around this estimate overlapped zero indicating that the true effect could in fact be zero (or no effect.) Observations in our study area suggested that roads may be influencing movement, and thus probably distribution, so we constructed models to more closely examine how different roads types, not just large roads, influence occupancy.

Our model set included all additive combinations of three road types (7 total models): secondary, vehicular, and local. Road covariates follow the TIGER road classification (U.S. Census Bureau 2016). Secondary roads are considered to be under the U.S., state, or county highway systems. These roads have one or more lanes of traffic in either direction, and may or may not be divided. In Vermont, secondary roads are considered to be Class 1 or 2 roads

(Vermont Land Use Education and Training Collaborative). Local roads include any residential roads, rural roads, and city streets that are primarily paved but may also be dirt. In Vermont, these local roads fall under the Class 3 and 4 road designations (Vermont Land Use Education and Training Collaborative). Vehicular roads are any unpaved trails that require four-wheel-drive vehicles for access; these are considered to be "legal trails" in Vermont (Vermont Land Use Education and Training Collaborative). We did not include primary roads (high traffic, high speed limit highways) as a covariate in our models because no primary roads passed directly through the study area. Service roads, or those that provide service access to highways or other major roads, were also excluded because they are closely associated with secondary roads (usually short in length and immediately parallel to secondary roads.) We also did not control for the effects of forest and development (the main covariates in Long et al. 2011) because the landscape was dominated by forest cover (>90%) and very little development occurred in the region (see Appendix I). We estimated a top ranking model for each sex.

We obtained maps of each road type from the U.S. Census Bureau TIGER road database. For each road type, we created a new raster map (30 x 30 m pixel) in which each pixel represented distance to nearest road (Appendices IV-VIII). We calculated distance measures using geographic information systems software (ArcGIS 10, ESRI, Redlands, California, USA). Raster values were then converted to z-scores for modeling (Royle et al. 2012). The z-score maps represented our covariates.

Model Performance

Model performance was evaluated using Receiver–Operating-Characteristic (ROC) curves (Fielding and Bell 1997). An ROC curve in the context of this study provides a measure of how well a model correctly predicted occupancy than falsely predicted it. To develop an ROC curve, we used a set of 'present' locations (truly occupied sites), which included a set of reserved telemetry data (250 locations for each sex) and a set of 'absence' data, which include an equal number of random locations in the landscape, where we assumed bears were absent. For each sex, we applied the top ranking model to the present and absent locations, then plotted the rate of true positive and false positive predictions across a range of thresholds to create the ROC curve. The area under the curve (AUC) provides a measure of model performance. We considered a model with an AUC >0.70 to have good predictive ability.

RESULTS

We collected 30,179 bear locations, including 9,713 female locations and 20,466 male locations from 2011 to 2014 (Table 2, Appendix III). The mean ± SD distances (m) of female bear points to the nearest roads were 1541.13 ± 1161.99 for secondary roads, 894.88 ± 641.90 for local roads, and 2958.49 ± 1616.86 for vehicular roads. The mean ± SD distances (m) of male bear points to the nearest roads were 2304.43 ± 1602.61 for secondary roads, 1018.19 ± 880.04 for local roads, and 2910.83 ± 1553.93 for vehicular roads. The distances to nearest road among all pixels in the study area were used to calculate z-scores. These mean ± SD distances (m) were 4399.94 ± 5337.81 for secondary roads, 3090.40 ± 5576.49 for local roads, and 5984.25 ± 5854.38 for vehicular roads (Appendices IV-VIII).

For both male and female black bears, the top-ranking model was the most complex in the set and included all three road covariates (Table 3). Simpler models with one or two covariates did not have empirical support for either sex (Table 3). For male bears, occupancy increased as distance to secondary roads increased, and occupancy decreased as distance to local and vehicular roads increased (Fig. 1). For female bears, occupancy increased as distance to local roads increased, and occupancy decreased as distance to local and vehicular roads increased (Fig. 2). Confidence intervals (95%) around covariates did not overlap zero for any covariates suggesting that effects were meaningful (Table 4). ROC curves indicated that both male and female top models had good predictive ability (Fig. 3). The AUC values for the male and female top models were 0.68 and 0.74, respectively.

The Reconyx PC900 Hyperfire Professional Covert IR cameras were set for a total of 365 days in stationary locations (April 6, 2016 – April 6, 2017), and the Bushnell Advantage Cam 8MP cameras were set for a total of 104 days in rotating locations. During this time there were four individual detections of black bears on three cameras underneath bridges of VT Route 9 in Searsburg, VT. Detections occurred in July, August and October.

DISCUSSION

The American black bear is a large carnivore species that has ecological, cultural, and economic importance in the Vermont landscape (Vermont Fish and Wildlife Department 2009). Black bears are harvested and managed as a game species throughout the state and region (Vermont Fish and Wildlife Department 2009). Previous studies indicated that black bears are sensitive to anthropomorphic changes in the landscape and often avoid developed areas (Long et al. 2011). Roads represent an important feature of the Vermont landscape that may act as a barrier and challenge to managing the statewide population. We examined the effect of roads on the distribution of black bears, and specifically how different classes of road (secondary, local, vehicular) affect the probability of a black bear occurring at any given site in the landscape by modeling GPS collar locations. The top models for male and female bears suggest that the additive combination of secondary, local, and vehicular roads were most influential in shaping occupancy and distribution. Road types had different effects on male and female black bear occupancy: secondary roads were positively associated with female bear occupancy and negatively associated with male bear occupancy, and local roads were positively associated with male bear occupancy and negatively associated with female bear occupancy. Vehicular roads were positively associated with occupancy of both male and female bears.

Local roads had different effects on male and female bears. Local roads included all residential and city roads, and may be found in areas of high, medium, or low human development. The differences in effects on male and female bears may be explained by the ideal-despotic distribution model (Beckmann and Berger 2003), which predicts that less-dominant individuals (in this case, female bears) have less choice of ideal habitat than more-dominant individuals (male bears.) If male bears are associating with local roads because of the opportunities to access anthropogenic food resources of high caloric value (e.g. birdseed, trash, compost), they may be limiting access of these resources to less-dominant females. Another explanation for the negative association of females with local roads might be differences in behavior, such as what might be seen in females traveling with young cubs (Beckmann and Berger 2003).

The negative association of male bears and secondary roads is supported by the camera trap data, where bears were only detected traveling near secondary road VT Route 9 in three instances during a year of monitoring. However, secondary roads were positively associated with female bear occupancy. This trend may also be explained by the ideal-despotic distribution model, in that female bears may be occupying areas of low male bear density (Beckmann and Berger 2003). One of the female bears in this study (Bear 5; Table 2) has been known to cross secondary road VT Route 9 to access anthropogenic food resources provided by an individual living in Wilmington, VT, and has also been detected by one of the cameras placed underneath VT Route 9. This may also have impacted the results among the relatively few female bear points included in the analysis. Bear 5 was kept in the analysis so as not to decrease the number of female bear points, as there were fewer female bear points available than male bear points.

Vehicular roads may serve as travel corridors for individuals in this region. During the trapping periods in this study, black bear tracks were observed on stretches of rural, unpaved vehicular roads, suggesting that bears use these more secluded roads for easy unobstructed movement. Both male and female bear top models suggested that occupancy is positively associated with vehicular roads, and these roads located within this generally unpopulated region may serve as travel corridors. Vehicular roads may have population-level impacts: these corridors could facilitate the movement of genetic material between subpopulations of bears. Impacts on genetic diversity are especially prominent in large carnivore species with low reproductive rates, and the establishment of vehicular roads in rural areas may be used to facilitate movement between fragmented bear populations (Fahrig and Rytwinski 2009).

The differences seen in occupancy between male and female bears may be explained by the life history of the species. Males and females have different home range sizes, with those of males encompassing much broader areas than those of females. On average, home range sizes for males and females average 42 km^2 and 15 km^2, respectively (Larivière 2001). Because of the differences in home range size, male and female bears may encounter roads at different rates, and the variation in road encounter rates between the sexes may have an impact on occupancy. Local roads are prominent throughout the study area, and males may encounter these roads more often simply because they are traveling greater distances to seek out mates, access diverse food resources, or to establish a home range during their juvenile years (Larivière, 2001). Sex differences were observed in the effects of the covariates, with secondary roads having a positive association with female occupancy and a negative association with male occupancy. Additionally, local roads were positively associated with male occupancy and negatively associated with female occupancy. If models were performed that combined both male and female bear data, the differences in effects may be concealed.

The top models generally had good predictive ability based on receiver-operating-characteristic curves, although the male model was slightly lower than our 0.70 threshold. Model performance could be improved by incorporating other variables into models that may be influencing occupancy. Variables could include amounts of specific forest cover types (e.g., beech, maple, hemlock), topography, climate factors, and sources of anthropogenic food. Further examining occupancy by season may also improve models of bear occupancy. Black bears use different habitat types in different seasons, and travel rates may vary across seasons depending on the proximity of their food resources to core home ranges (Noyce and Garshelis 2011). During times of food shortages (e.g., spring, after den emergence) a positive association with local roads might emerge, as access to anthropogenic food sources of high caloric value (e.g. birdseed) is readily available. During the fall when bear hunting seasons take place, occupancy may be negatively associated with the presence of vehicular roads, as these roads provide increased access to hunters. Another approach that could be taken is to analyze the impacts of roads on occupancy of bears in different age classes and across sexes. Young males and females travel greater distances to establish their own home ranges, yet females will typically establish a home range that is adjacent to that of their mothers, while males will continue to travel into areas with less competition from other bears (Larivière, 2001). Finally, comparing the impact of roads on occupancy in years of varying food availability could shed light on whether bears are able to travel through areas fragmented by different classes of roads to access food resources. In this study, the amount of GPS point per individual bear varied greatly, ranging from 78 to 2,830 points for female bears and 103 to 3,217 points for male bears. This may have served as a source of bias, although we believe the impact is minimal due to the large quantity of points used in the analysis.

An understanding of how road classes impact black bear occupancy can have management and development implications. Road classes that have negative impacts on occupancy may be targeted for mitigation strategies. The effects of fragmentation can be mitigated through different road management techniques, such as the use of overpasses, underpasses, and culverts as road-crossing structures (Glista et al. 2009, Sawaya et al. 2013). Roadside fencing can also be used to reduce the probability of collisions, or guide wildlife to a safe crossing structure (Loraamm and Downs 2016). To be effective, these structures should be planned in areas where wildlife crossings are occurring regularly, and should be planned in conjunction with transportation agencies and wildlife biologists (Glista et al. 2009).

If male bears are associating with local roads due to the availability of anthropogenic food resources, mitigation practices might also be necessary in residential areas. Habituation of black bears to residential areas can have consequences for both bears and humans. Bears that seek out food resources in residential areas have a higher mortality risk, not only from collisions with vehicles but also from lethal human-bear conflict management strategies (Merkle et al. 2013). While some bears may avoid entering residential areas due to these risks (our analysis suggests that female bears may be avoiding these areas), other bears may choose to enter residential areas to access readily available anthropogenic food sources because of their high-caloric value (Merkle et al. 2013). To mitigate this association with local roads and residential areas, the public should be educated on the risks of attracting bears to residential areas and advised to remove bird feeders during the active season of black bears (the Vermont Fish and Wildlife Department recommends that residents remove birdfeeders from April 1-December 1.) Additionally, fruit trees have been known to attract bears to residential areas (Merkle et al. 2013). If bears are known to feed on fruit trees in residential areas, electric fencing may be used as a deterrent (this may also be used to secure compost piles and beehives.) The use of adverse conditioning (rubber slugs, pepper spray, chasing) on bears coming into residential areas can be effective in altering behavior if done early and consistently (Mazur 2010).

Road classes that promote occupancy (such as vehicular roads, as our analysis suggests) may be used as tools to facilitate movement between fragmented populations. The Florida black bear (*Ursus americanus floridanus*) population represents a group of bears severely impacted by fragmentation and human development. The home ranges of Florida black bears are constrained to a relatively small area by major roads (Maehr et al. 2003). Vehicular roads and trails may be utilized in the landscape as corridors in order to facilitate movement of fragmented bear populations, like the Florida black bear populations, to other areas. Additional research should be done to determine how other classes of roads affect black bear occupancy, and how these road classes may interact with other variables on the landscape.

ACKNOWLEDGMENTS

I would like to thank my advisor Jed Murdoch for all of the guidance and support with every aspect of this thesis. I would also like to thank my Committee Member Kimberly Wallin, as well as my Research Methods professor Brendan Fisher for guiding me through the process of grant writing and proposal writing. Thank you to David Gudex-Cross, for providing me with invaluable assistance on the GIS portion of this project. The summer research for this project would not have been possible without the SURF grant funding provided by the UVM Office of Undergraduate Research. Thank you to the Rubenstein School and UVM Honors College for the opportunity to pursue this research and the continued support throughout my undergraduate career.

I would also like to thank my Vermont Fish and Wildlife partners, Forrest Hammond and Jaclyn Comeau, for providing this research opportunity and allowing me to work with their data. Finally, I would like to thank Tom Rogers of Vermont Fish and Wildlife for being a mentor throughout this process.

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FIGURE LEGENDS

Figure 1. Occupancy probability of male bears in relation to each road covariate in a top ranking model of GPS-telemetry location data collected from 2011 to 2014 in southern Vermont.

Figure 2. Occupancy probability of female bears in relation to each road covariate in a top ranking model of GPS-telemetry location data collected from 2011 to 2014 in southern Vermont.

Figure 3. Receiver-Operating-Characteristic (ROC) curves showing the performance of top models at predicting occupancy of male and female black bears in the study area.

TABLES

Table 1. Descriptions of LANDFIRE Existing Vegetation Type land cover raster and TIGER road data, and predicted effect on black bear occupancy.

Variable	Code	Description	Measure	Predicted effect on Ψ	Source
Laurentian-Acadian Northern Hardwoods	LANH	Dry-mesic to wet-mesic at low-high elevation; *A. saccharum*, *B. alleghaniensis*, and *F. grandifolia* dominant	Not included in models	Positive	LANDFIRE 2017
Secondary Roads	roadsc	All secondary roads (state highways)	Distance to (z-score)	Negative	U.S. Census Bureau 2016
Local Roads	roadl	All local neighborhood roads	Distance to (z-score)	Negative	U.S. Census Bureau 2016
Vehicular Roads	roadv	All vehicular roads (logging, 4WD trails)	Distance to (z-score)	Positive	U.S. Census Bureau 2016

Table 2. Bear data, including sex, number of locations, and dates that each bear was collared by the Vermont Fish and Wildlife Department from 2011 to 2014.

Bear	Sex	# of locations	Dates collared
1	F	1,015	Jul 23, 2014 – Nov. 30, 2014
2	F	860	Jun 25, 2012 – Oct. 13, 2012
3	F	2,830	Jun 12, 2013 – Oct. 30, 2014
4	F	78	Jun 22, 2012 – Jul. 2, 2012
5	F	1,081	Jun 27, 2014 – Nov. 26, 2014
6	F	1,315	Jun 27, 2014 – Dec. 14, 2014
7	F	2,431	May 7, 2012 – Aug. 17, 2012, Jun 17, 2013 – Mar. 16, 2014
8	F	103	Aug 7, 2014 – Aug. 18, 2014
9	M	643	Jun 13, 2013 - Sep. 9, 2013
10	M	924	Jun 4, 2014 – Oct. 2, 2014
11	M	734	May 21, 2013 – Sep. 9, 2013
12	M	544	May 7, 2012 – July 1, 2012
13	M	1,562	Jun 14, 2013 – Mar. 7, 2014
14	M	2,088	Jun 14, 2013 – Jun. 14, 2014
15	M	1,416	Jun 13, 2013 – Mar. 27, 2014
16	M	1,124	Oct 12, 2011 – May 26, 2012
17	M	545	May 8, 2012 – Jul. 14, 2012
18	M	3,217	Jun 16, 2013 – Nov. 24, 2014
19	M	499	Jun 11, 2012 – Aug. 24, 2012
20	M	2,338	Jun 26, 2012 – Jun. 27, 2012, Jun 12, 2013 – Jul. 26, 2014
21	M	3,109	Jun 21, 2013 – Nov. 25, 2014
22	M	1,086	May 21, 2013 – Sep. 29, 2013, Jun 27, 2014 – Jul. 8, 2014
23	M	637	Jun 5, 2014 – Sep. 3, 2014

Table 3. Ranking of models of bear occupancy probability for male and female bear data. Models ranked using Akaike's Information Criterion, and those with a ΔAIC <2 were considered to have strong empirical support.

Model	AIC	ΔAIC	Weight	Parameters
Female				
roadsc+roadl+roadv	157120.8	0.0	1	4
roadsc+roadv	157290.0	169.2	0	3
roadl+roadv	157406.9	286.1	0	3
roadv	157559.8	439.0	0	2
roadsc+roadl	157942.9	822.1	0	3
roadsc	157946.1	825.3	0	2
roadl	158234.4	1113.6	0	2
Male				
roadsc+roadl+roadv	357881.4	0.0	1	4
roadl+roadv	358005.2	123.8	0	3
roadsc+roadv	358284.9	403.5	0	3
roadsc+roadl	360201.3	2319.9	0	3
roadl	360204.4	2323.0	0	2
roadv	360468.8	2587.4	0	2
roadsc	361363.3	3481.9	0	2

Table 3. Parameter estimates (betas) along with standard errors and 95% upper and lower confidence intervals for female and male bear models.

Parameter	Beta	SE	95% UCI	95% LCI
Female				
Intercept	-1.41	0.10	-1.214	-1.61
roadsc	-4.30	0.20	-3.904	-4.70
roadl	4.18	0.19	4.560	3.80
roadv	-2.31	0.16	-1.989	-2.63
Male				
Intercept	-0.95	0.26	-0.44	-1.47
roadsc	8.32	0.67	9.63	7.00
roadl	-14.33	0.97	-12.42	-16.23
roadv	-21.77	1.09	-19.64	-23.91

FIGURES

Figure 1.

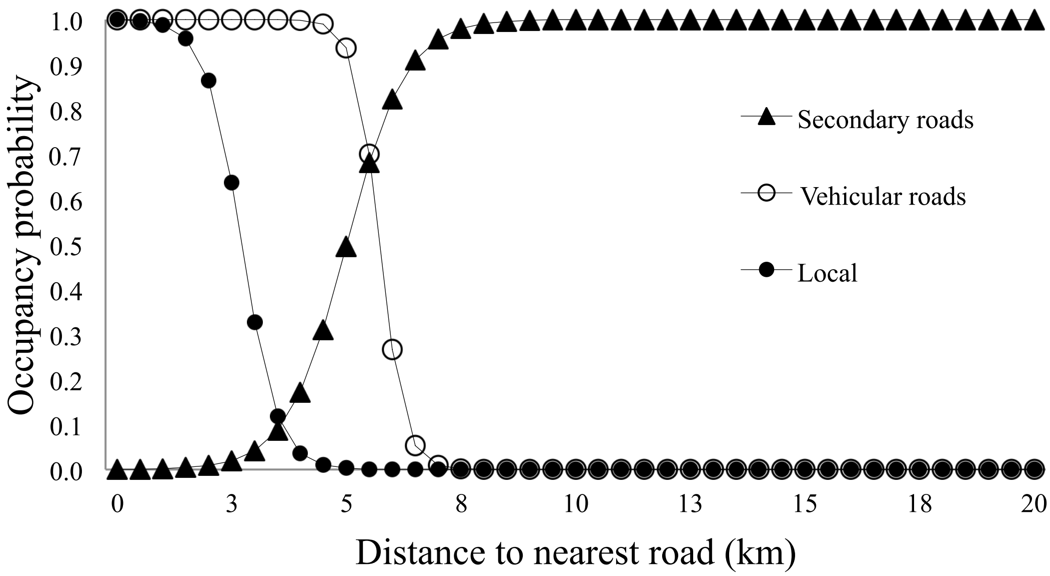
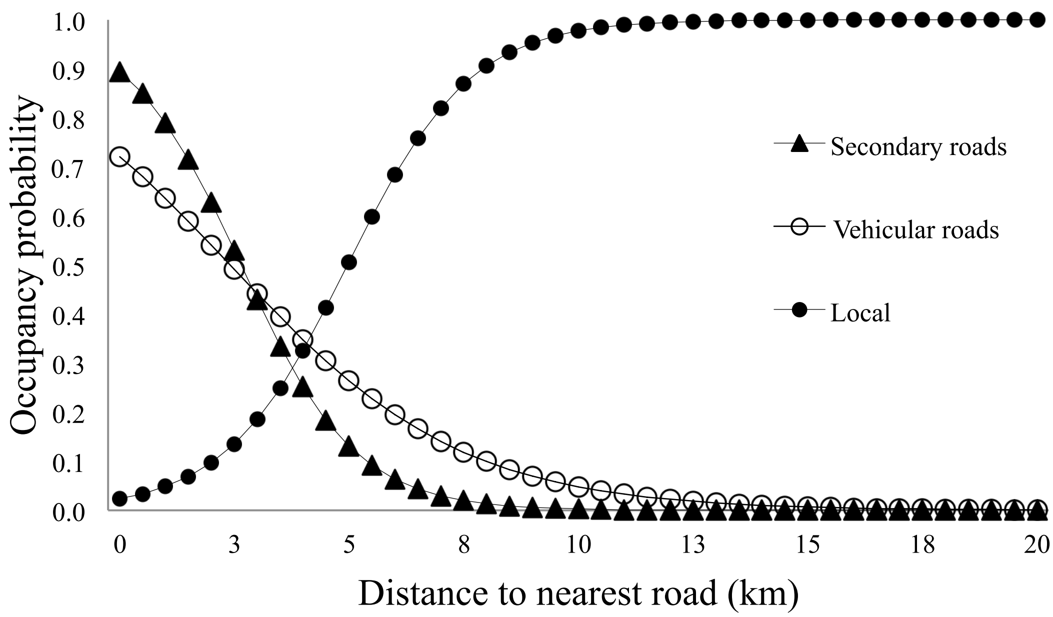
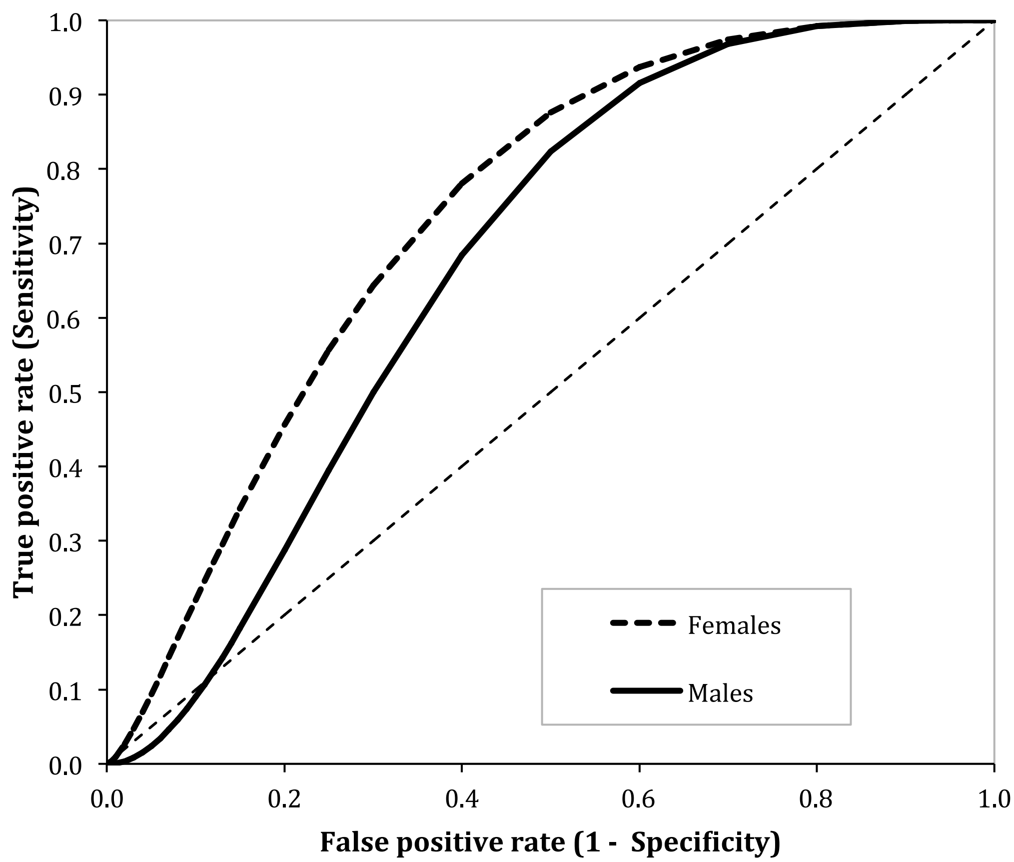


Figure 2.



1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Occupancy probability
0
3
5
8
10
13
15
18
20
Distance to nearest road (km)
Secondary roads
Vehicular roads
Local

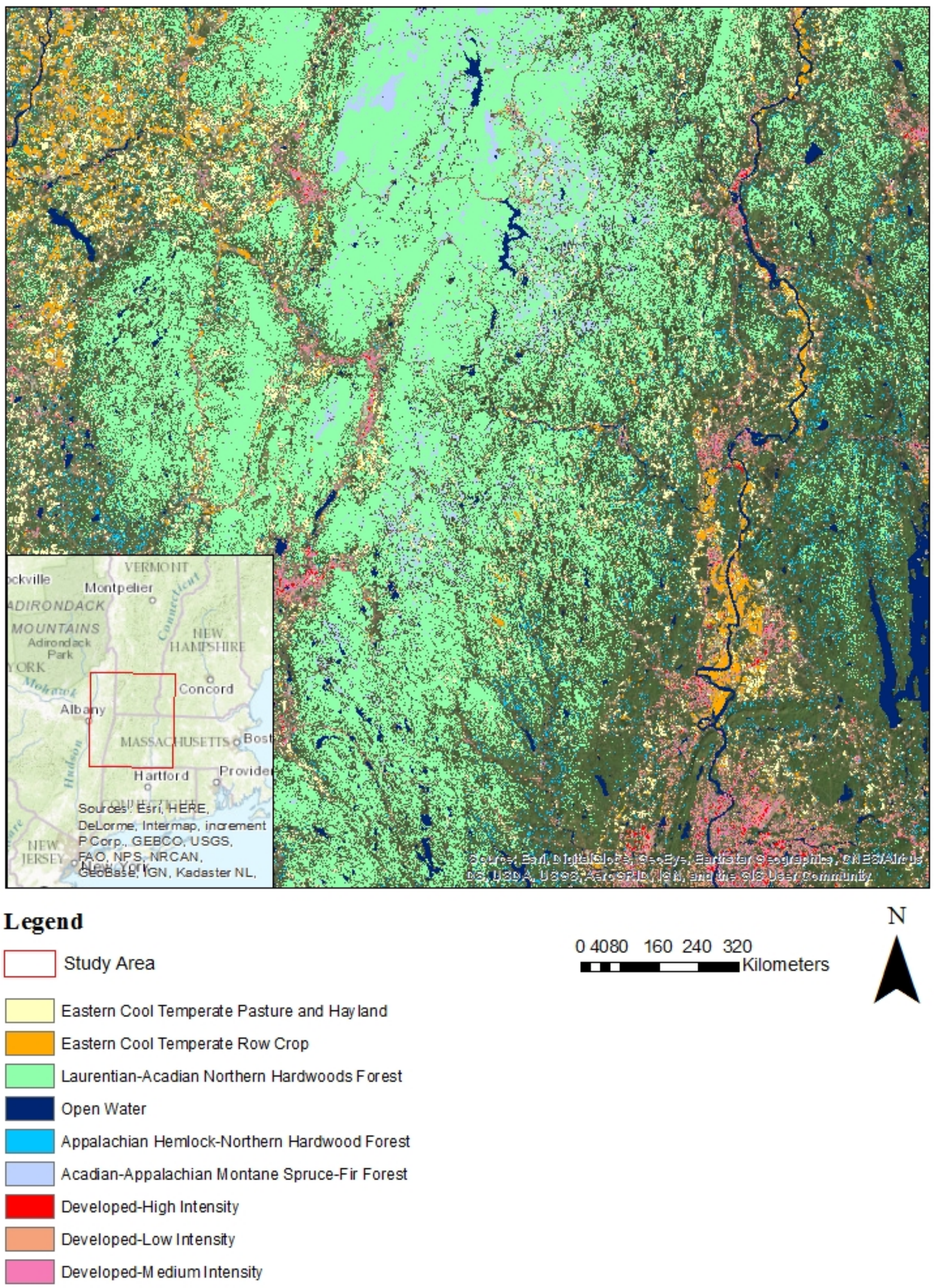
Figure 3.



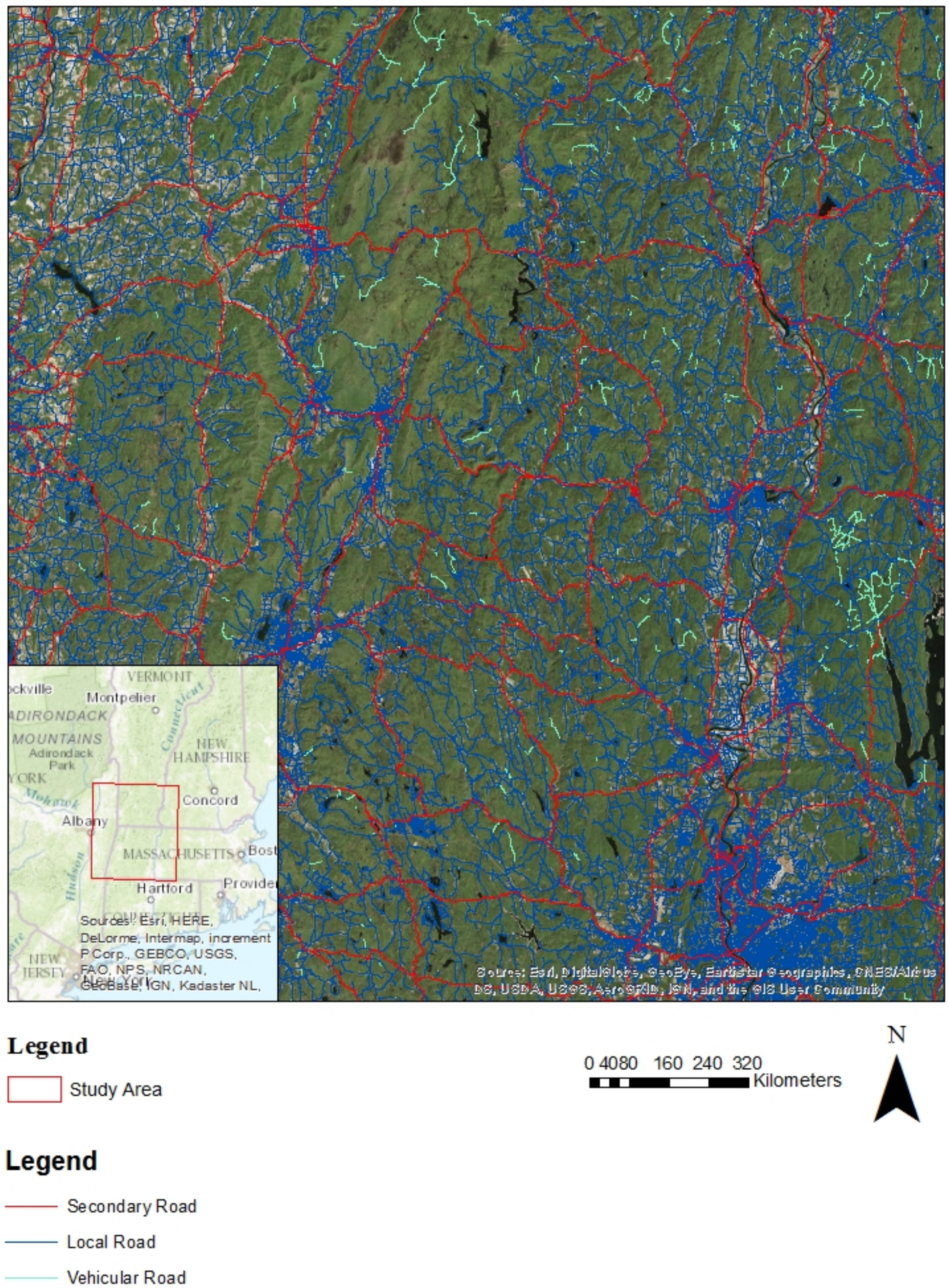
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
True positive rate (Sensitivity)
0.0
0.2
0.4
0.6
0.8
1.0
False positive rate (1 - Specificity)
Females
Males

APPENDICES

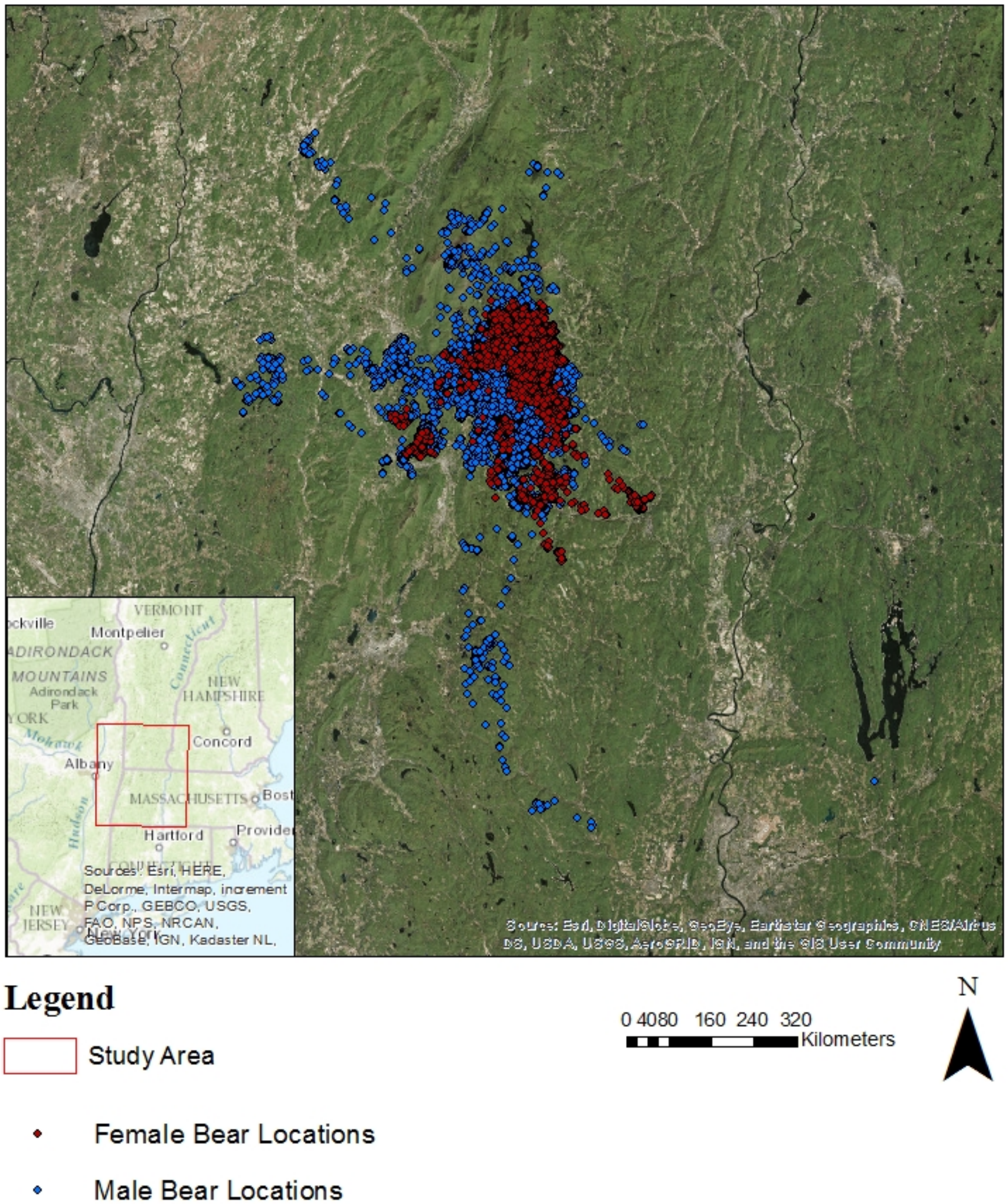
Appendix I. Land cover types in the study area (LANDFIRE 2017).



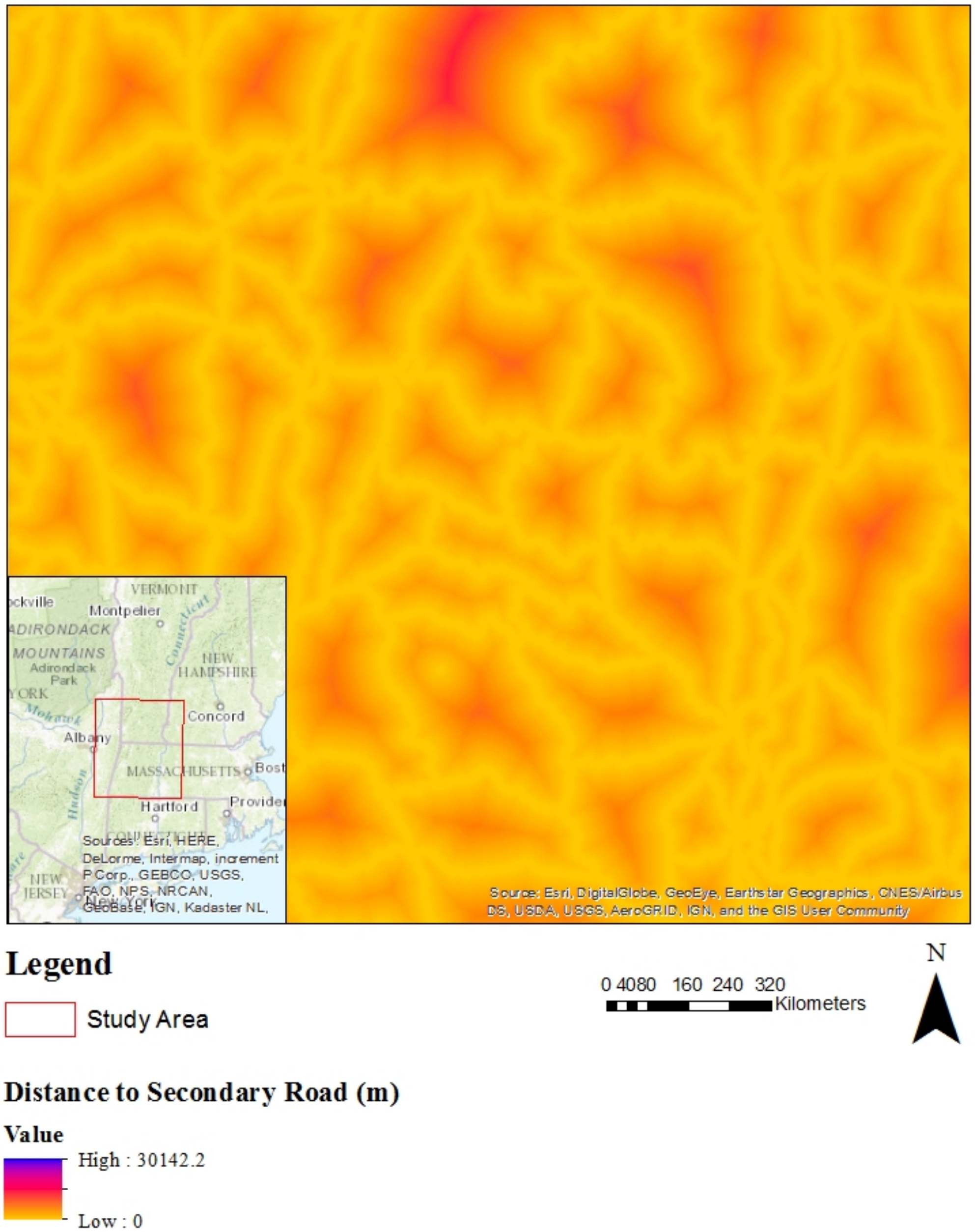
Appendix II. Secondary, local, vehicular, and service roads in the study area (U.S. Census Bureau 2016).



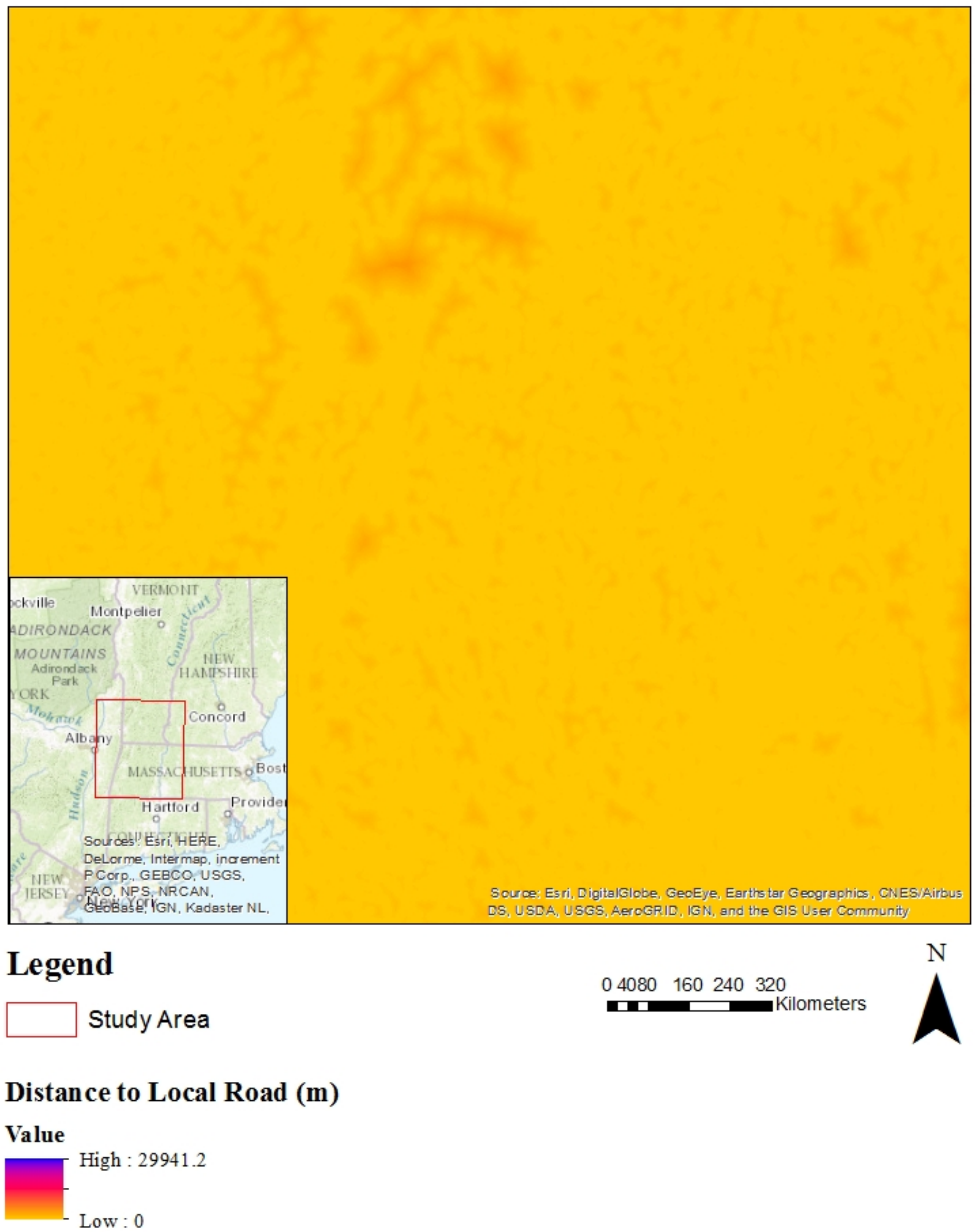
Appendix III. Male and female GPS collar locations, collected between 2011 and 2014 by the Vermont Fish and Wildlife Department.



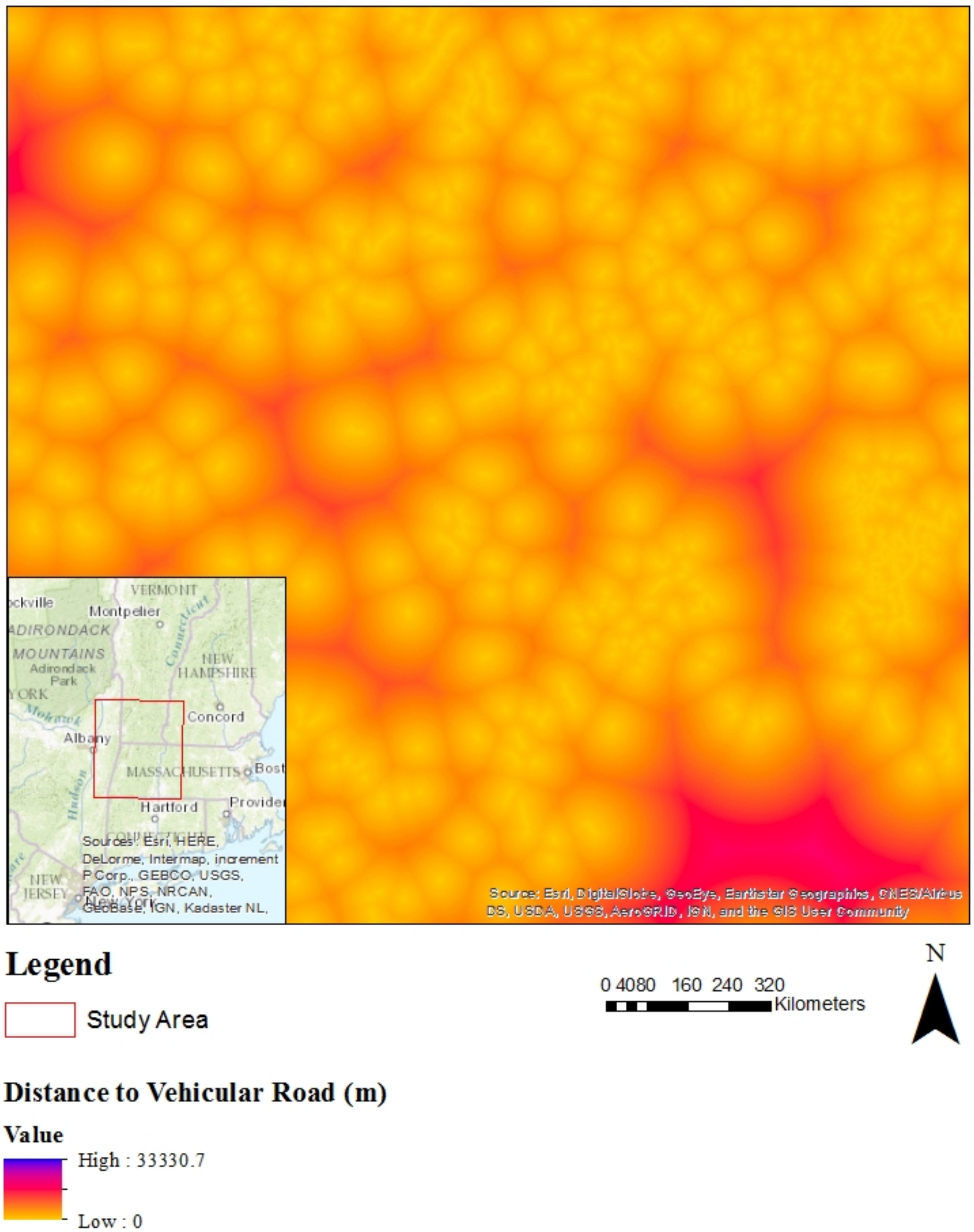
Appendix IV. Map showing the distance (m) of each pixel to the nearest secondary road (U.S. Census Bureau 2016).



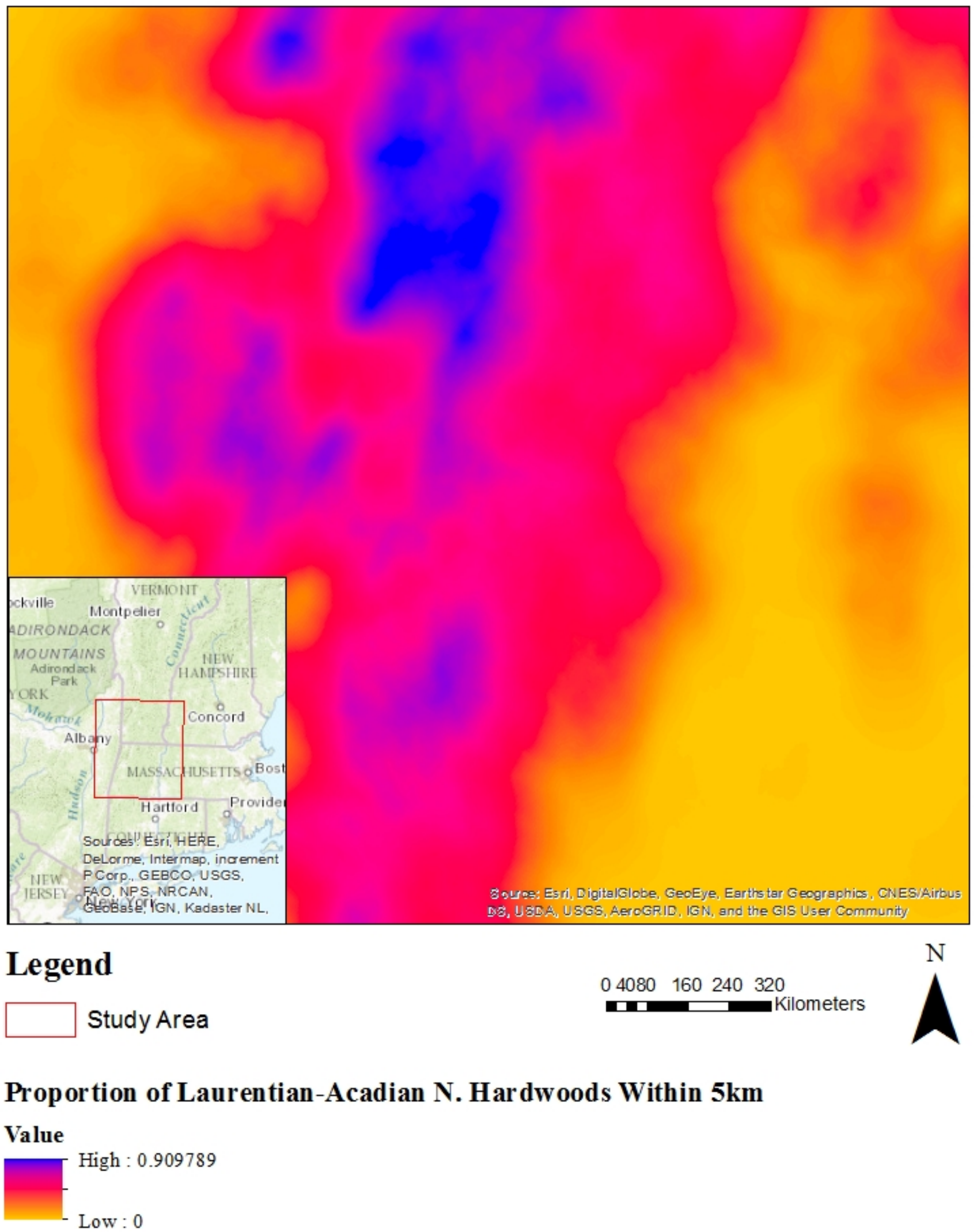
Appendix V. Map showing the distance (m) of each pixel to the nearest local road (U.S. Census Bureau 2016).



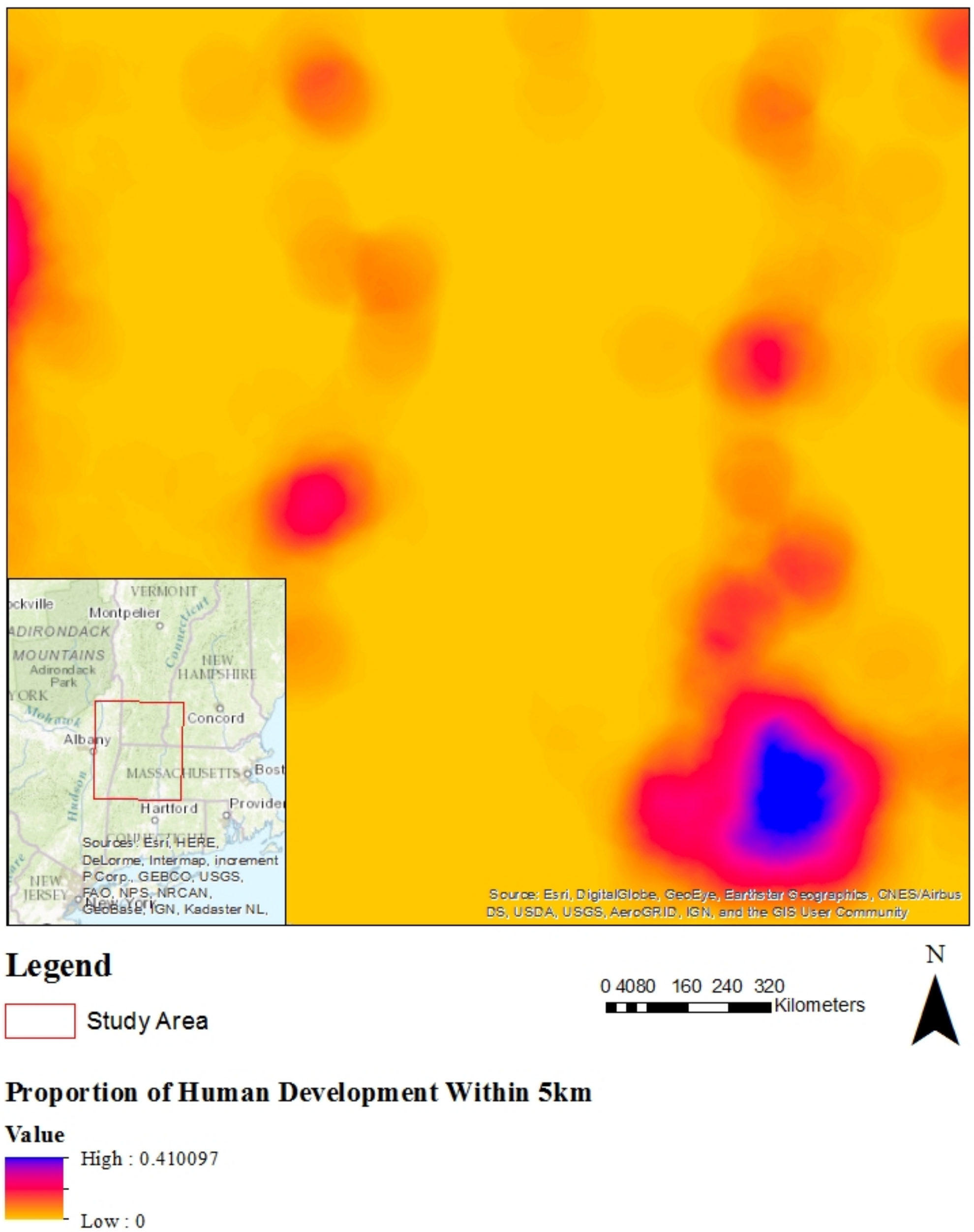
Appendix VI. Map showing the distance (m) of each pixel to the nearest vehicular road (U.S. Census Bureau 2016).



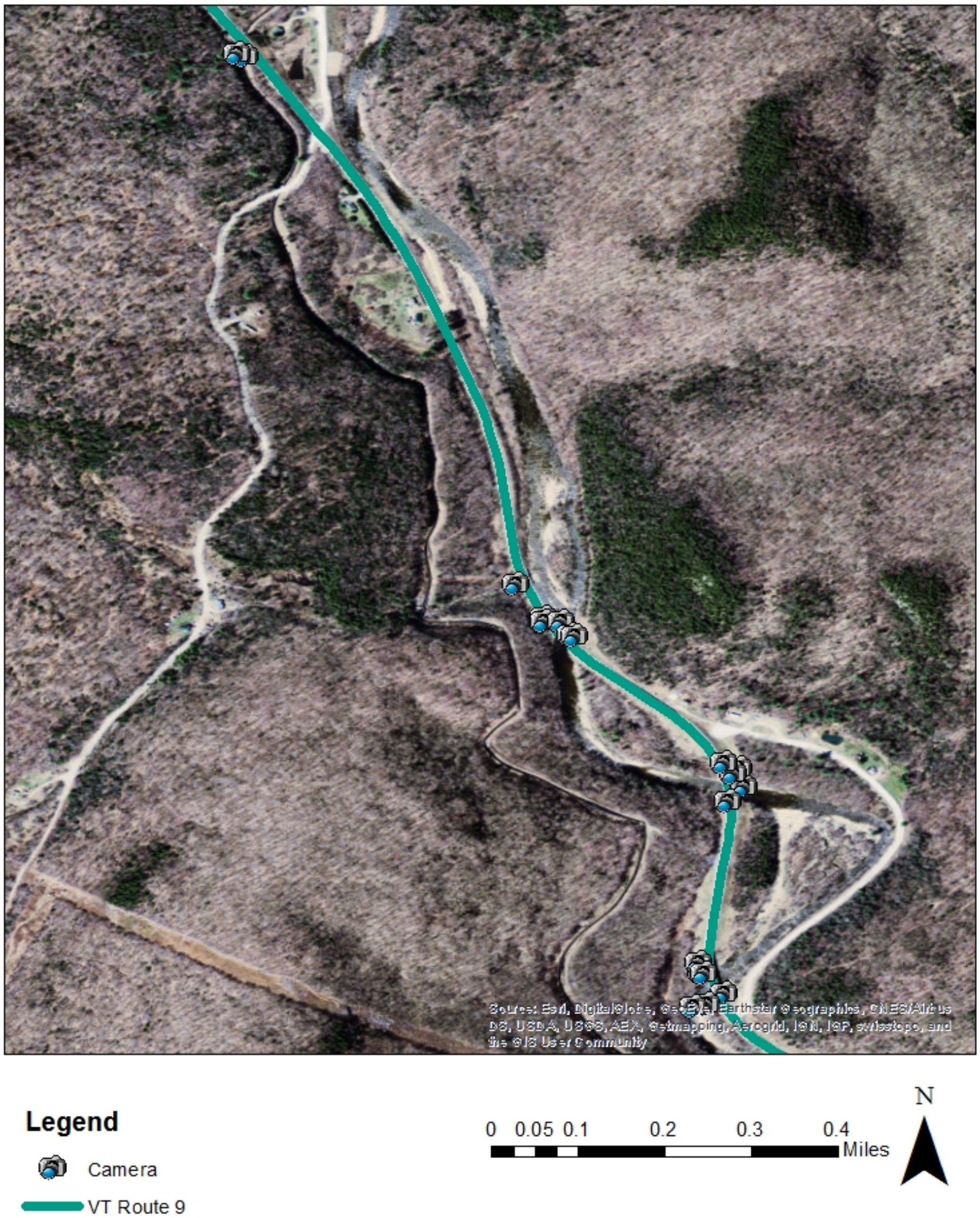
Appendix VII. Proportion of the dominant forest cover type, Laurentian-Acadian Northern Hardwoods forest (5 km scale), in the study area (see Table 2. for description; LANDFIRE 2017).



Appendix VIII. Proportion of human development areas (5 km scale) in the study area (see Table 2. for description; LANDFIRE 2017).



Appendix IX. Map of camera locations along VT Rt. 9 for the 19 VFWD/VTrans Reconyx PC900 Hyperfire Professional Covert IR cameras, placed in Searsburg, Vermont in April 2016 with data collected through April 2017.



Appendix X. Map of locations along VT Rt. 9 for the ten Bushnell Advantage Cam 8MP cameras, which were placed on June 29, 2016 and moved to new locations every two-three weeks through October 23, 2016 (four sampling stretches shown.)

Appendix XI. Individuals, organizations, and partners that assisted with this research.

Data
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Field Work
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The Staying Connected Initiative

Funding
University of Vermont Office of Undergraduate Research