2016

Master's Project - Wildlife Habitat Linkages Surrounding the Lake George and Southern Lake Champlain Region

Sam E. Talbot
University of Vermont

Wildlife Habitat Linkages Surrounding Lake George and Southern Lake Champlain

Sam Talbot
M.S. Candidate in Natural Resources
Ecological Planning Program
Rubenstein School
University of Vermont

In partnership with:

Lake Champlain Land Trust

Lake George Land Conservancy

Table of Contents

Executive Summary 3

Introduction 5

Analysis Area and Focus Area 6

Wildland Blocks 6

Methods 8-12

- Habitat Suitability Modeling 8
- Corridor Modeling 9
- Corridor location 10

Results 11-21

- Final Corridors Map 11
- Corridor Width 12-13
- Corridor Evaluation 14-21
  - Conserved Land 14
  - Habitat Suitability 15
  - Land Classification 16-17
  - Streams 18
  - Roads 19
  - Corridor Attributes Summary Table 20
  - Corridor Evaluation Scores 21

Conclusion 22-23

References 24-25

Appendix 26-41

- Habitat Suitability Models and Corridor Slices 26-31
- Corridors Compared to Other Regional Modeling Data 32-37
- Residential Building Density 38
- Comparison of Geometric to Arithmetic Mean in HSM Outputs 39
- Land Classification by County 40-41
- Land Classification by County 42-44

Acknowledgements

Project Sponsors: Lake Champlain Land Trust and Lake George Land Conservancy

Graduate Committee: Matt Kolan, Jen Pontius, and Scott Merrill

Ecological Planning Program Advisors: Deane Wang and Jeff Hughes

Executive Summary

Connected landscapes are recognized as imperative for the livelihood of local biota who flourish in habitat threatened by fragmentation. In particular, heterogeneous landscapes (i.e. diverse patches ranging from native flora and fauna to human-dominated land use) that are susceptible to parcelization and development, pose a heightened urgency for conservation intervention, such as land protection, restoration, and management. The region surrounding Lake George and southern Lake Champlain exemplifies these characteristics. To the east lies the Green Mountains, with the Adirondack Mountains roughly 40 kilometers (25 miles) to the west. The landscape between the two lakes, referred to as the *focus area*, encompasses about 250 km^2 (97 mi^2) of predominantly forested landscape, rich in riparian, upland, and lacustrine habitat.

The purpose of this study was to distinguish large wildland blocks of suitable habitat within the 5,000 km^2 (1,930 mi^2) region of Lake George and southern Lake Champlain, and determine potential wildlife corridors between these blocks. Wildlife corridors facilitate movement across the landscape, ultimately promoting dispersal, migration, and genetic diversity of species. Three focal species—black bear (*Ursus americanus*), bobcat (*Lynx rufus*), and fisher (*Martes pennant*) were used as surrogates representing wide-ranging species that exist at low densities and are especially susceptible to human-induced habitat fragmentation. Given the spatial scale of the region, roughly the size of Delaware, the study utilized a Geographic Information Systems (GIS) approach to translate structural components of the matrix into functional connectivity.

Recent advances in geospatial technology allow for more efficient investigations across large and diverse landscapes. Although an increasing number of techniques and methodologies exist, this study utilizes one particular program, Corridor Designer, to conduct a least-cost corridor model of the region. This model was parameterized based on expert opinion from a recently published least-cost corridor study within a similar eco-region. The analysis identified three discrete latitudinal corridors. One corridor connects two conservation blocks, Bomoseen State Park and Pharaoh Lake Wilderness Area, while two corridors provide a northern and southern route between a pair of large unfragmented habitat blocks.

This study identified 23 criteria to evaluate each of the three corridors and examine the broader context within the region (Table 2 and Table 3). These criteria represent landscape features that affect (either positively or negatively) wildlife movement and conservation value, or describe corridor traits, such as overall length. Nine of the criteria reflect similar studies preformed in this region by various state and non-profit conservation organizations. Based on the outcome of corridor evaluation and overlap with auxiliary models, I recommend that conservation planning and action be prioritized in the Habitat Block Corridor—North (shown in green on Figure 6).

At this scale, these corridors are designed to promote demographic rescue of populations, enhance recolonization after local extirpation, and maintain or restore gene flow between patches. Corridors have the potential to also promote regular home range movement, including access to multiple patches, and increase the possibility for range expansion under climate change regimes. To prioritize these additional goals, further research is needed. Namely, corridor studies using movement data at a home range scale would provide empirical evidence of individual movement at finer resolution. This is most significant directly adjacent to and across Lake George and southern Lake Champlain, where there is a higher uncertainty of potential movement due to these large bodies of water.

Introduction

The Lake Champlain Land Trust (LCLT) and the Lake George Land Conservancy (LGLC) are currently undertaking a multi-year project to study the region between Lake George and southern Lake Champlain, with the subsequent goal of conserving farms, forest, and other natural areas. A multitude of landscape functions can motivate land conservation. One particular function, habitat connectivity, describes how easily species can move from one suitable habitat patch to another. In reviews of 110 total studies involving corridor effectiveness, Beier and Noss (1998) and Gilbert-Norton et al. (2010) show that corridors promote inter-patch movement of wildlife, based on animal presence in or movement through the corridor.

The goal of this study is to model potential wildlife corridors across the Lake George and southern Lake Champlain region, which will inform landscape scale conservation decisions. Although the area has seen limited increase in development over the past decade, it remains vulnerable to fragmentation due to inherent scenic and recreational value (see Figure 1 for examples of fragmented landscapes within the study region). Additionally, about 80% of Vermont's forests are privately owned by an aging demographic, which increases the potential for parcelization, a precursor to habitat fragmentation (VT DFPR and VT ANR 2015). Conserving land within these wildlife corridors reduces the risk of fragmentation and ensures they function to support species movement.

There are many approaches to modeling wildlife corridors and determining corridor quality. Some examine the structure of the landscape and highlight swaths of natural area within a patchwork of residential and commercial development. Other approaches analyze the degree to which the landscape promotes movement for individual or multiple species (Ament et al. 2014). For this study, I utilized the second approach, measuring the degree of connectivity as the lowest cost for wildlife to move from one large habitat patch to another. Notably, "cost" is paid in high mortality or increased energy expenditure. The technical term coined for an approach of this type is *least-cost path*.

I focused on the potential movement of three species: black bear (*Ursus americanus*), bobcat (*Lynx rufus*), and fisher (*Martes pennanti*). These three species play the role of *focal* or *surrogate* species, which are "species used to represent other species or aspects of the environment to attain a conservation objective" (Caro 2010). Black bear, bobcat, and fisher typify wide-ranging vertebrates that require sizeable areas of suitable habitat to thrive (Graves and Wang 2012). Additional benefits of contiguous habitat include enhanced biodiversity, improved environmental quality, recreational opportunities, and provision of ecosystem services (Ament et al. 2014; Crooks and Sanjayan 2006).

In order to develop this multispecies least-cost path model across a large landscape, I utilized an ArcGIS program designed specifically for this task. The program, Corridor Designer, provides a scientific approach to habitat linkage design (Jenness, Majka, and Beier 2014). The methodology behind Corridor Designer employs expert opinion and literature review to parameterize the model, assigning values to landscape characteristics associated with habitat suitability. These parameters were previously established by Graves and Wang (2012) to complete a wildlife corridor study north of my analysis area in the Split Rock Wildway of New York State. My study utilizes the Grave and Wang (2012) parameters because they were derived for the same set of focal species in a similar eco-region.

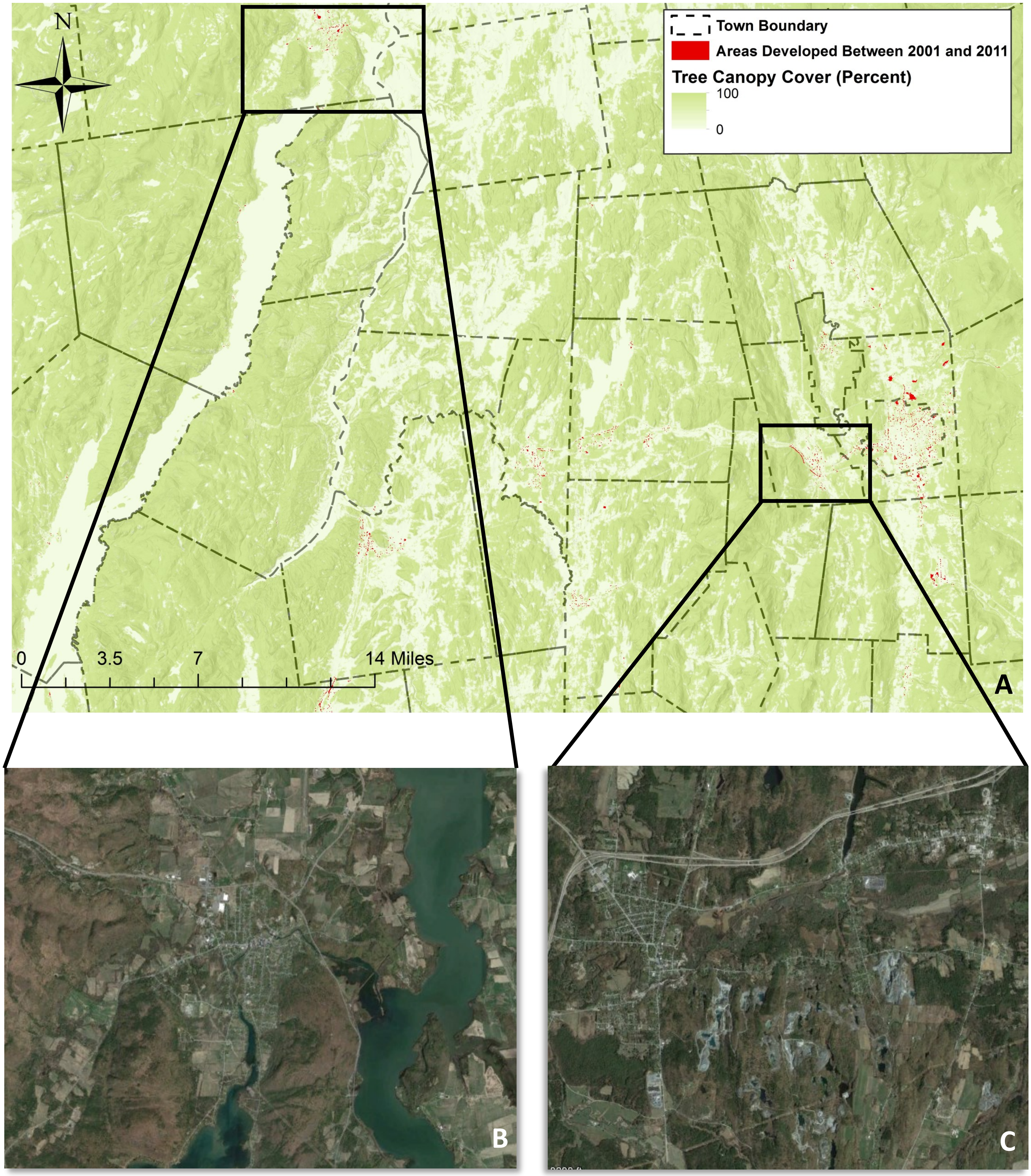


Figure 1: (A) Percent tree canopy cover in the Lake George and southern Lake Champlain region. Red areas depict land use change from *non-developed* to *developed* between the years of 2001-2011. (B) Landscape matrix within Ticonderoga, NY (2015) (2015) (C) Landscape matrix within West Rutland, VT—note quarrying activity

(Source: Vermont Center for Geographic Information, U.S. Geologic Survey, Google Earth)

Analysis Area and Focus Area

The analysis area defines the extent of each landscape layer included in the study, while the focus area reflects a particular interest of LCLT and LGLC. The former encompasses just under 5,000km^2 (1,930 mi^2) and stretches from the western edge of the Green Mountains to the eastern edge of the Adirondack Park. The analysis area extent reduces processing time of large spatial datasets, but still encompasses enough of the region to permit multiple choices for wildland blocks. The focus area highlights 250km^2 (97 mi^2) between Lake George and southern Lake Champlain threatened by fragmentation.

Wildland Blocks

The least-cost path analysis approach of corridor modeling examines movement between two specific areas of the landscape able to support wildlife populations (referred to as "wildland blocks"). This study establishes two pairs of wildland blocks: referred to as "conserved blocks" (depicted in orange in Figure 2) and "habitat blocks" (depicted as green in Figure 2) respectively. Conservation status, degree of fragmentation, and habitat quality were taken into account when defining the two pairs of wildland blocks. These qualities ensure the corridor connects areas that can foster wildlife populations now and into the future. Within each wildland block, endpoints are located based on parameters set by Graves and Wang (2012). These endpoints act as the starting positions for the analysis and contain unfragmented high-quality habitat.

Conserved Blocks

The conserved blocks consists of two conserved areas on either side of Lake George and southern Lake Champlain. One of these is Bomoseen State Park—owned and managed by the Agency of Natural Resources. About 3,576 acres is publically accessible and contains a mixture of forested uplands and wetlands. The most notable water feature of Bomoseen State Park is Lake Bomoseen—the largest lake found completely within Vermont. The second conserved block, Pharaoh Lake Wilderness Area, lies to the western side of Lake George. This state-owned land constitutes a much larger area: 46,283 acres. Similar to Bomoseen State Park, Pharaoh Lake Wilderness Area derives its name from the impressive water feature contained within its bounds. In total 39 bodies of water add to the wildlife value of this large protected area.

Habitat Blocks

The habitat blocks are extracted from habitat modeling efforts of Vermont and New York state agencies. The first encompasses 23,611 acres which have been designated by Vermont Fish and Wildlife as an "area of contiguous forest and other natural habitat that is unfragmented by roads, development, or agriculture". The VT Fish & Wildlife 2006 landscape analysis identified habitat blocks across the state, and ranked these areas based on conservation value and potential threat to fragmentation. This particular habitat block is one of two over 23,000 acres west of the Green Mountain Range within the state. One of the conservation values evaluated in the Fish and Wildlife study is the "habitat block's contribution to connectivity at a landscape level" (Sorenson and Osborne 2014). This Vermont habitat block falls within the highest ranking for that particular category.

The other habitat block was determined using a dataset produced by The New York Department of Environmental Conservation for their 2011 strategic plan for state forest management. Unlike the Vermont habitat analysis, this study designates "forest matrix blocks" by accounting for landscape structure as well as function. Their study utilizes two key factors: "the home range of wide-ranging animal species and historical patch sizes that result from natural disturbance events within the landscape" (NYDEC 2011). The New York forest matrix block utilized in my study consists of 33,160 acres within the St. Lawrence/Champlain Valley eco-region on the west side of Lake George. Roughly 78% of this acreage is conserved under a combination of state ownership in fee and privately owned easement.

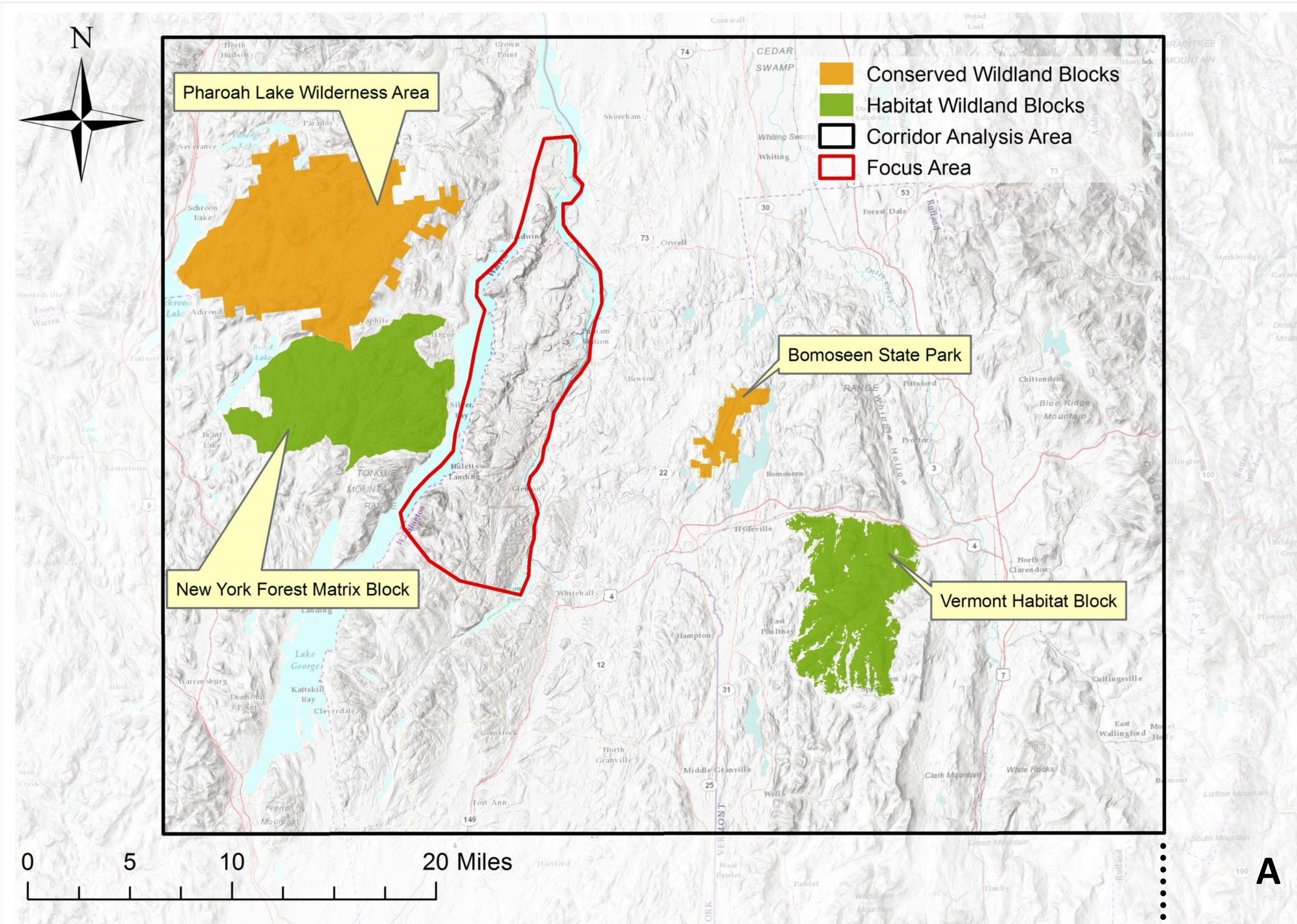


Figure 2: (A) Map depicting the overall analysis area (black outline), study focus area (red outline), and the two pairs of wildland blocks.

(B) Locus Map

(Basemap Sources: Vermont Center for Geographic Information, U.S. Geologic Survey, ESRI)

	Wildland Blocks	Total Area (acres)	Percent Conserved	Euclidean Distance (center to center)
Conserved Blocks	Bomoseen State Park	3,721	100	40 km (25 m)
	Pharaoh Lake Wilderness Area	47,394	100	
Habitat Blocks	Vermont Habitat Block	23,611	4	36 km (22 m)
	New York Forest Matrix Block	33,120	78	

Table 1: Comparison of wildland block characteristics.

Methods

The methods used in this study are depicted on pages 8-10. This methodology reflects Majka et al.(2007), while parameters were derived from Graves and Wang (2012). The methods are separated into three successive phases: (1) habitat suitability modeling, (2) corridor modeling, and (3) corridor location. This process resulted in three distinct corridors across the analysis area (see Results: pages 11-21)

Habitat Suitability Modeling

Phase 1 The first step in Corridor Designer's modeling process creates an estimate of habitat suitability. A score was assigned to each *classification* within a *landscape factor* (see table headings below for clarification). For example: a score of 50 (out of 100) was assigned to valley bottom (*a classification*) within topographic position (*a landscape factor*). Each landscape factor was then weighted to reflect its perceived importance to the individual species.

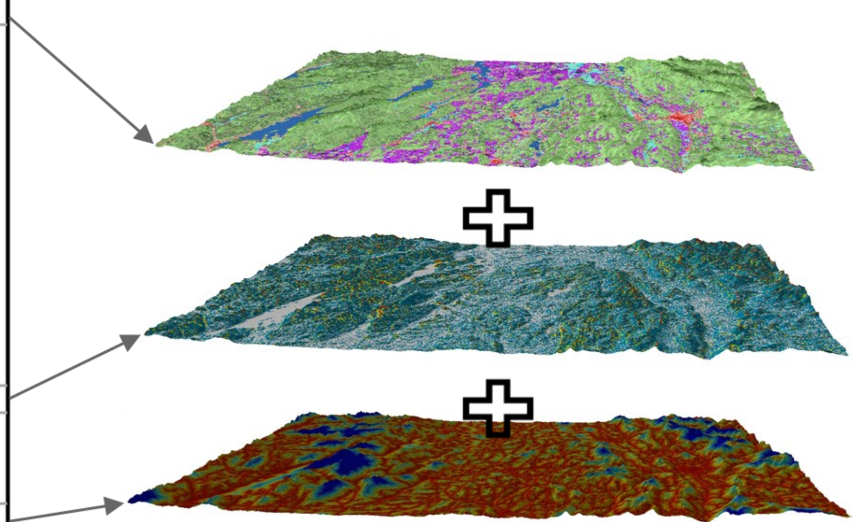
Beier et al. (2007) highlight the fact that determining habitat suitability scores requires a considerable amount of time and resources. To address this issue, but still utilize credible model inputs, I employed a set of scores derived by Graves and Wang (2012) based on literature review and expert opinion. Their study was conducted using the same focal species in a similar ecoregion to that of the Lake George region (scores related to all three focal species are available in the appendix pages 42-44).

Pixel by pixel (30 m x 30 m), each of the landscape factors were reclassified, weighted, and summed using the arithmetic mean.

Then, the habitat suitability model was converted into a layer representing resistance to wildlife movement. To arrive at this layer, the corridor designer approach employs an assumption that habitat suitability equals habitat permeability. The model also relies on the statement that wildlife resistance is the inverse of habitat permeability. Therefore, resistance is the inverse of habitat suitability.

Landscape Factor and Class	Habitat Suitability Score	Landscape Factor Weight
Black Bear: Land Cover Classification		
Developed, High Intensity	10	75
Developed, Medium Intensity	30	
Developed, Low Intensity	30	
Developed, Open Space	30	
Cultivated Crops	40	
Pasture/Hay	10	
Grassland/Herbaceous	40	
Deciduous Forest	100	
Evergreen Forest	80	
Mixed Forest	90	
Scrub/Shrub	90	
Palustrine Forested Wetland	60	
Palustrine Scrub/Shrub Wetland	60	
Palustrine Emergent Wetland	60	
Bare Land	0	
Open Water	30	
Black Bear: Topographic Position		
Valley Bottom	50	20
Flat-gentle Slope	50	
Steep Slope	50	
Ridgetop	80	
Black Bear: Distance to Roads		
0-50 m	10	5
50-200 m	20	
> 200 m	100	

Adapted from Graves & Wang (2012)



$$\frac{\text{Weighted sum for each pixel}}{\text{Number of landscape factors}}$$

Figure 3: Diagram illustrating Phase 1 of the methods. Habitat suitability scores are weighted and applied to each landscape factor's corresponding raster. The rasters are then combined using an arithmetic mean.

Corridor Modeling

Phase 2 Next, the resistance layer (depicted as the black and white layer below) was converted to cost-weighted distance. This new layer places each pixel in context with the surrounding landscape. More specifically, each pixel is scored based on the lowest cumulative cost to reach a particular habitat block. Cost-weighted distance is calculated twice for each pixel—once for each habitat block. In the simplified example grid in Figure 4, the cost-distance to go from the circled pixel to Endpoint 1 would be 158. This number is relative to the all the other pixels in the analysis area. It is also important to note that cost is "paid" by organisms in mortality and energy expenditure and may not necessarily correlate to the amount of time required to move through a landscape.

Once the cost layer was created for each focal species, least-cost path was calculated for both sets of wildland blocks. The subsequent map layer depicted a single-pixel wide path. Beier et al. (2007) emphasize the fact that pixel wide corridors are not nearly enough space to be biologically relevant or worthy of conservation. Therefore, corridor slices were created, which increase incrementally in width and decrease in permeability.

The allowable cost threshold (i.e. amount of poor habitat allowed in the corridor) was set to integer values from 1 to 10 percent of the maximum path cost. Ten nested corridors resulted from this method for each focal species and for both sets of wildland blocks (i.e. between Pharaoh Lake and Bomoseen, as well as between the Vermont Habitat Block and New York Forest Matrix Block). Single species corridors were combined (unioned) to create nested corridors for all three focal species. Corridors with an allowable cost threshold of 1, 3, 5, 7 and 9 percent of the maximum cost are presented in Figure 5.

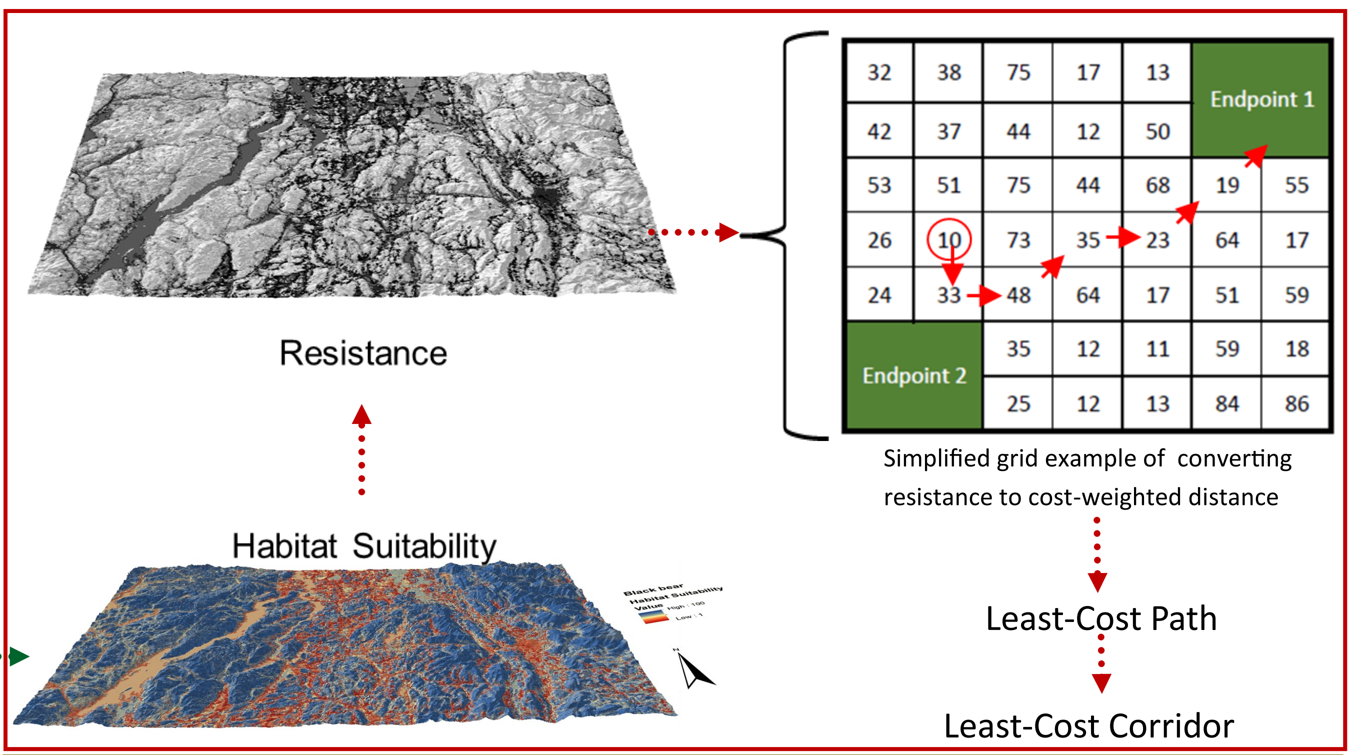


Figure 4: Diagram illustrating Phase 2 of the methods. Inverse values of the habitat suitability layer are used to produce a resistance layer. Cost-weighted distance is calculated using the values within the resistance layer.

Corridor Location

Phase 3 The main determinant of corridor location is the presence of the most permeable landscape. Additionally, corridor size is a direct result of established corridor width. There are several factors to consider when determining a reasonable corridor width. Based on Graves and Wang (2012), I set two bounds for corridor width: greater than 300 m wide and an average width no greater than 2 km. Although a wider corridor would be more suitable for wildlife movement, it is less feasible to conserve. On the other hand, if the corridor is too narrow, then it may not encompass enough permeable landscape. Based on model outputs I located three distinct corridors as depicted in Figure 5. To arrive at the final corridors (Figure 6), a systematic approach was taken, informed by Graves and Wang (2012) and Beier et al. (2007). I isolated the 1% corridor slices (Figure 5 (C)) in order to identify the best model outputs depicting continuous strands of low movement cost. Three of these had no restrictive bottlenecks, although there were still areas below the minimum 300 m wide threshold. I located these narrow regions and expanded the corridor into areas of marginally higher cost—i.e. the 2% corridor slices. Final corridors that contain a higher proportion of 1% corridor slices are more permeable than those with more 2% slices. This concept is depicted in Figure 7.

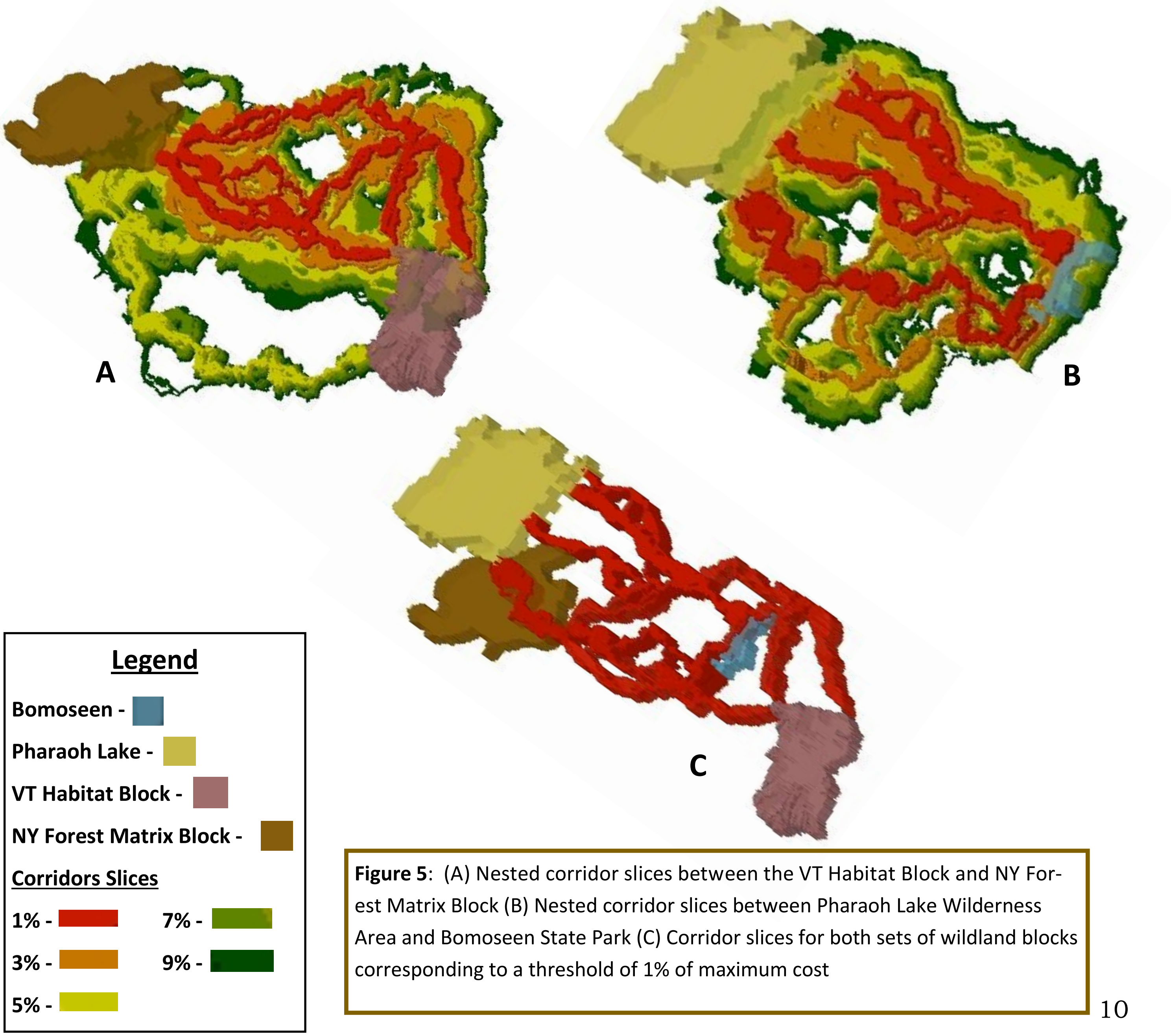


Figure 5: (A) Nested corridor slices between the VT Habitat Block and NY Forest Matrix Block (B) Nested corridor slices between Pharaoh Lake Wilderness Area and Bomoseen State Park (C) Corridor slices for both sets of wildland blocks corresponding to a threshold of 1% of maximum cost

Results

Study results are presented on pages 11-21. To better understand each corridor in the context of the landscape, many landscape characteristics are depicted here and summarized in Table 2. The three alternate corridors resulting from this study (Figure 6 below) are compared using 23 positive and negative effects on wildlife movement and conservational value, or corridor traits, such as overall length. Nine of the criteria reflect similar studies preformed in this region by various state and non-profit conservation organizations. These additional studies are depicted in the Appendix on pages 32-39.

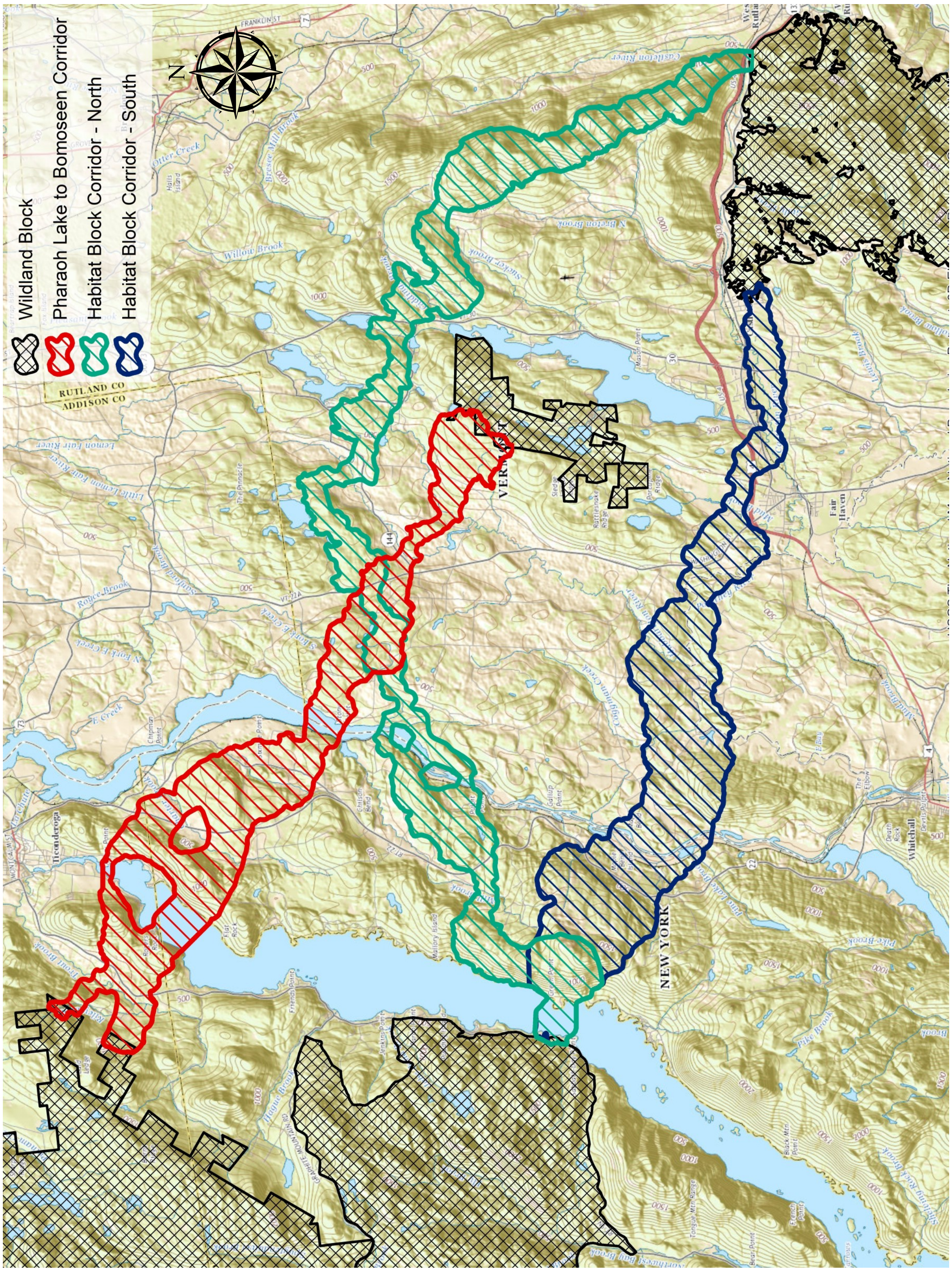
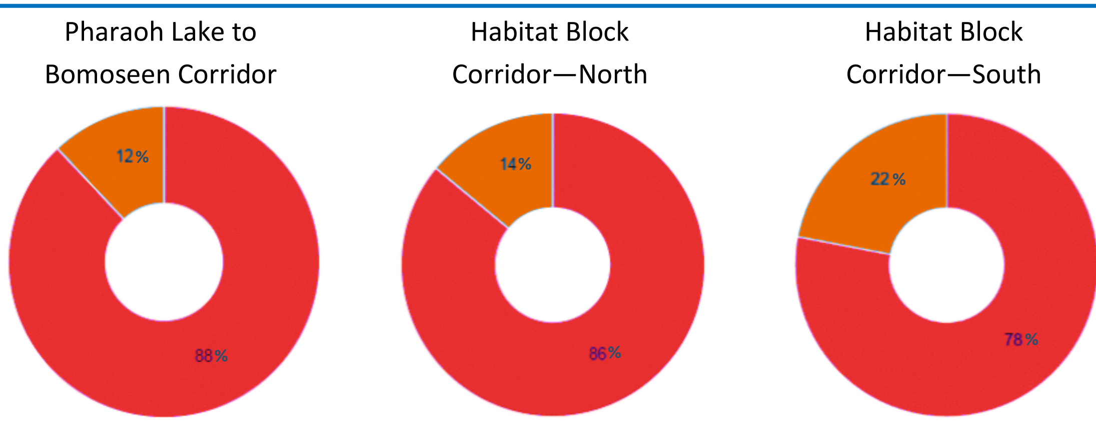


Figure 6: Map showing three discrete corridors across the landscape based on least-cost path analysis. One corridor resulted between the conserved blocks ("Pharaoh Lake to Bomoseen Corridor") and two corridors between the habitat blocks ("Habitat Block Corridor—North" and "Habitat Block Corridor—South").

Corridor Width

Corridors should be wide enough to allow for safe passage of focal species, but not so wide as to hinder conservation efforts. In narrow regions, known as bottlenecks, higher peripheral travel cost can reduce species ability to disperse and may lead to edge effects associated with poorer habitat. Higher cost can result from more impermeable barriers, such as roads and permanent development. To better understand the causes behind bottlenecks, higher resolution data such as aerial maps, road structures, or empirical data showing wildlife movement can be investigated at particularly narrow region of the corridors. Corridor width, including potential bottlenecks, for each corridor is presented in Figure 8.



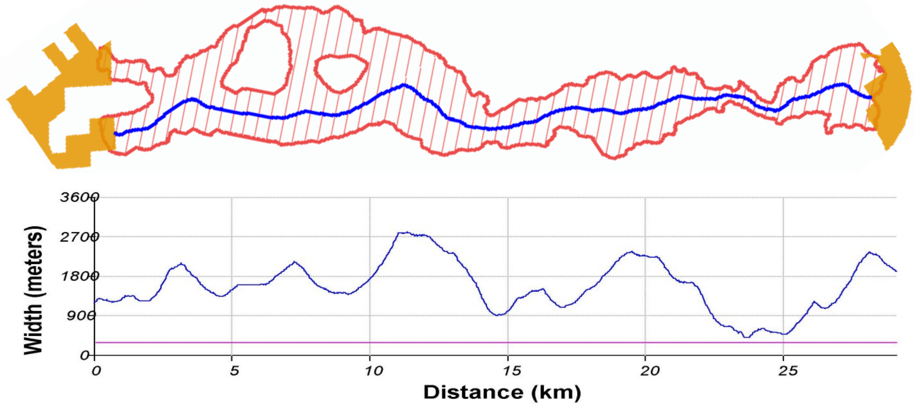
Top 1 % of lowest travel cost (i.e. best habitat and lowest resistance)

Top 2 % of lowest travel cost (i.e. second best habitat and second lowest resistance)

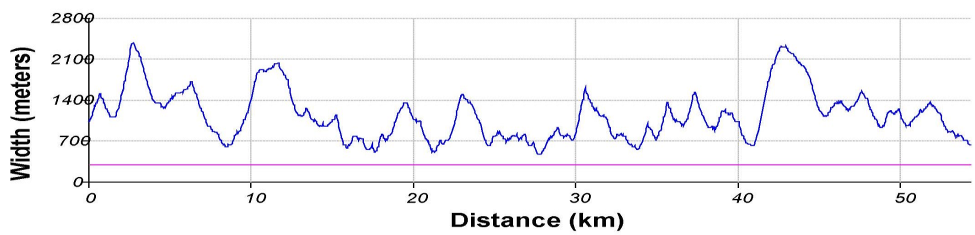
Figure 7: Proportion of 1% cost threshold and 2% cost threshold for each corridor. This is depicted visually below. Final corridors that contain a higher proportion of 1% corridor slices are more permeable than those with more 2% slices.

Figure 8: Corridor width depicted spatially and graphically for each of the three corridors. Blue lines represent corridor centerline. Make note of narrower widths, which suggest the presence of bottlenecks within the landscape. (A) Pharaoh Lake to Bomoseen Corridor; B) Habitat Block Corridor—North; (C) Habitat Block Corridor—South

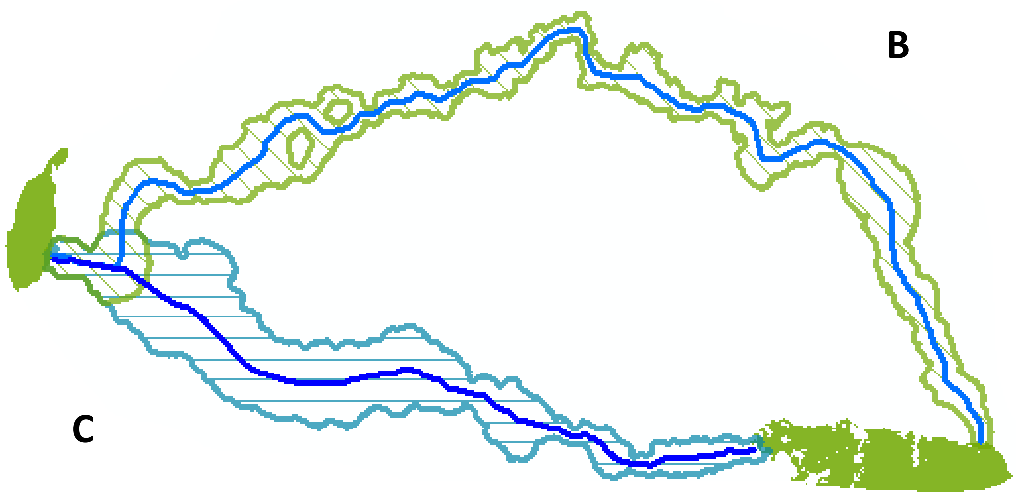
Corridor Width



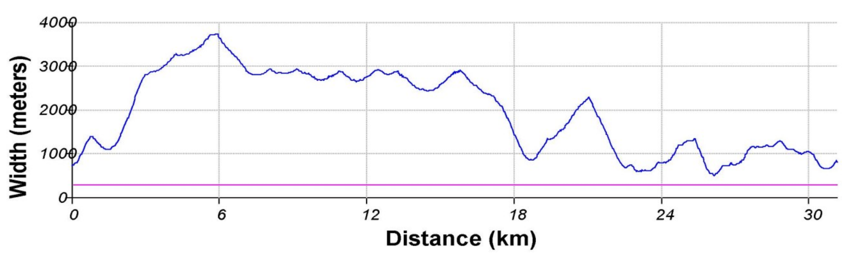
A



B



C

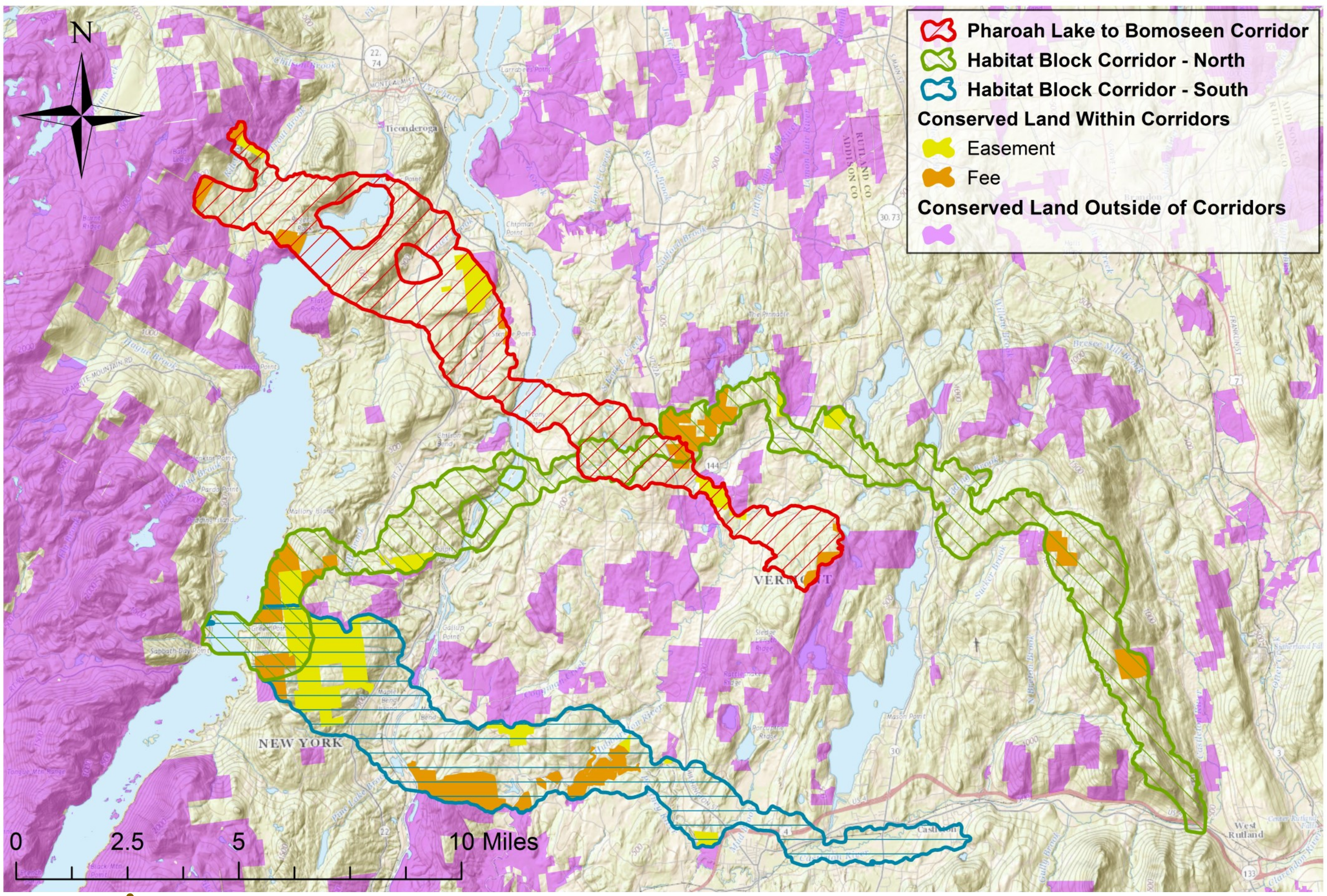


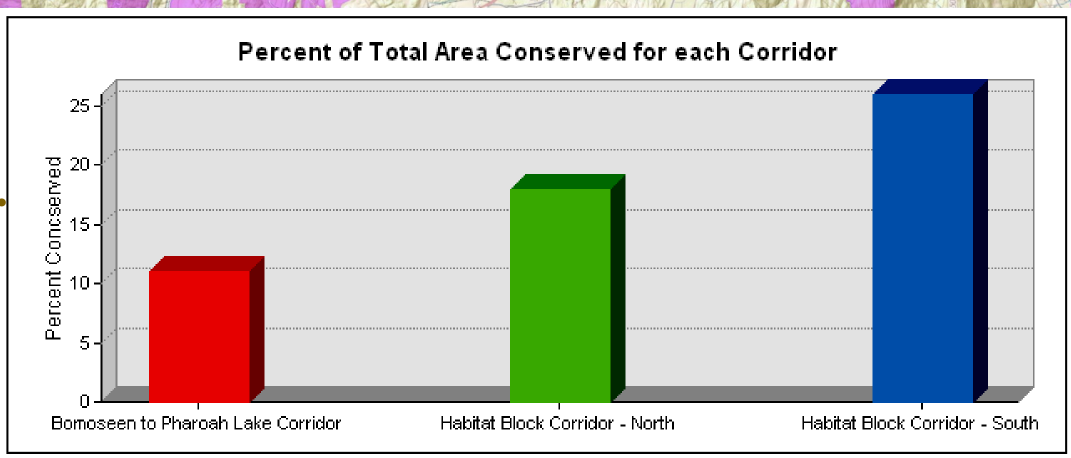
Conserved Land

Corridor Evaluation

Five landscape characteristics are presented in this section, while all 23 characteristics are depicted in Table 2. The results of additional modeling within the region can be found in the Appendix on pages 32-39. Corridor evaluation provides a comparison between alternative corridors, which will lead to more informed resource allocation decisions. Basis for comparison can vary depending on the end-user; for example, interests of conservation organizations versus interests of the department of transportation. The maps, tables, and statistics are meant to help guide the process of land conservation decision-making.

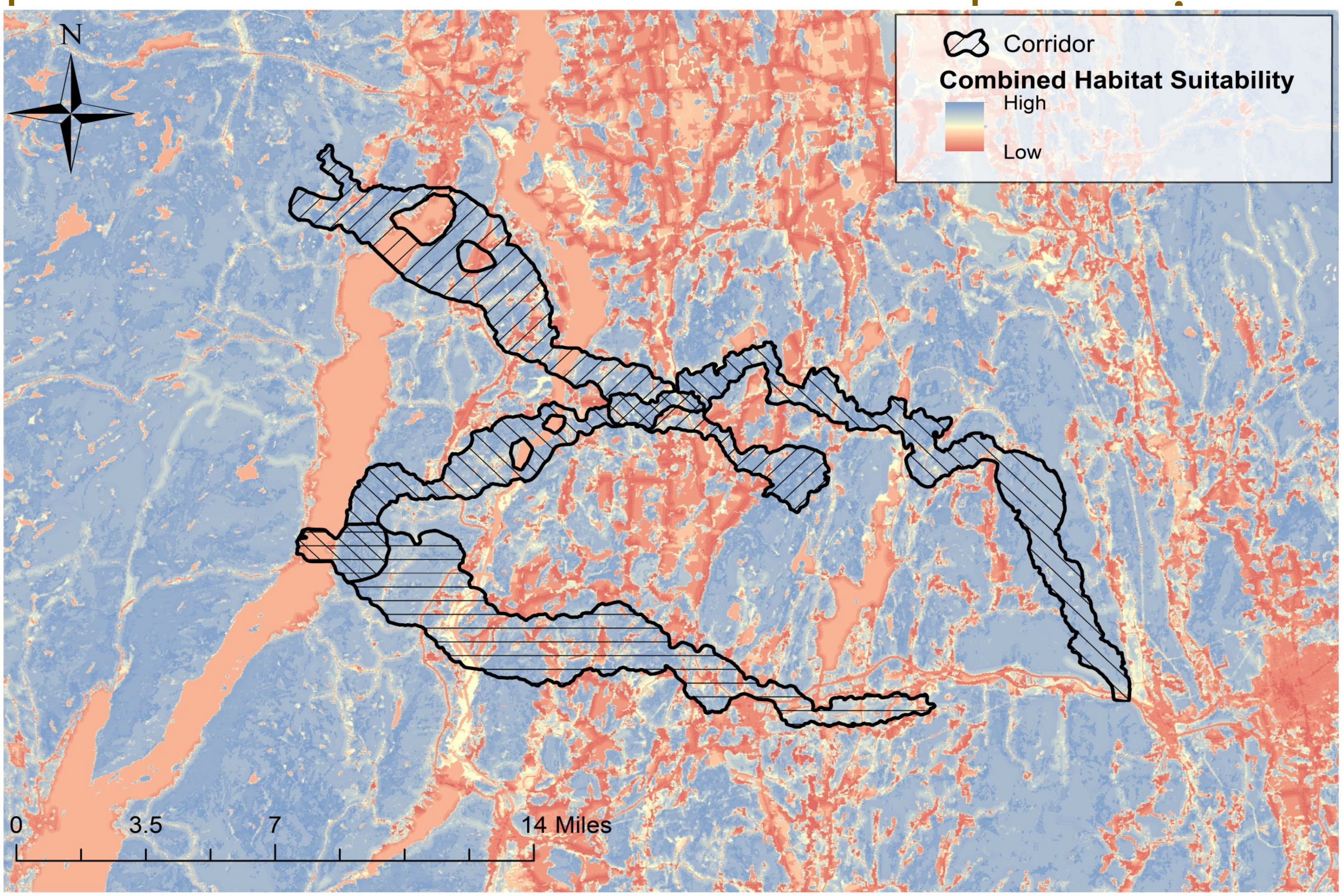
Figure 9: The first landscape characteristic reflects the distribution of conserved land (based on the Protected Area Database). It's important to take note of presently conserved land, as well as those areas that remain largely unconserved. This map will evolve over time and is subject to correction based on institutional knowledge.

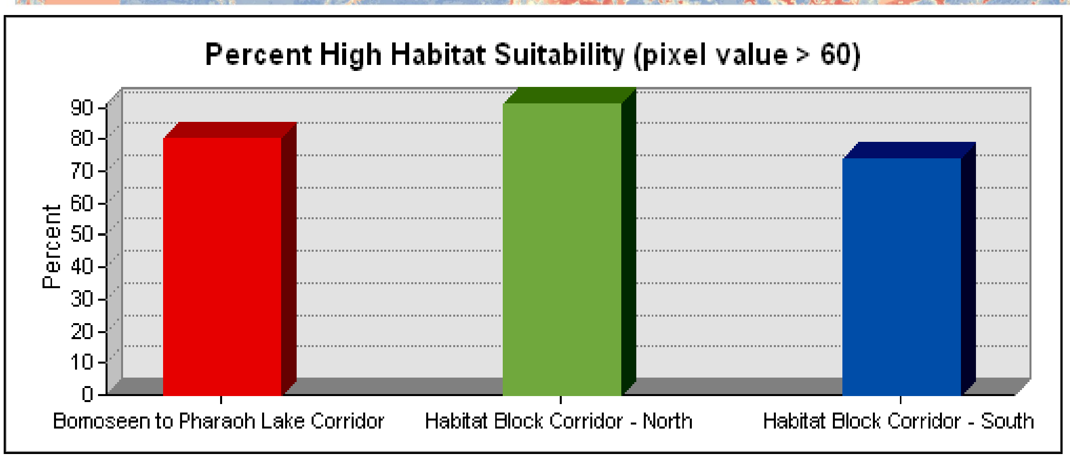




Habitat Suitability

Figure 10: This map incorporates all three habitat suitability models for black bear, bobcat, and fisher combined. Large regions of high suitability (displayed in blue) present potential habitat patches, while low habitat suitability (displayed in red) represent barriers to movement and potential "bottlenecks" within corridors.

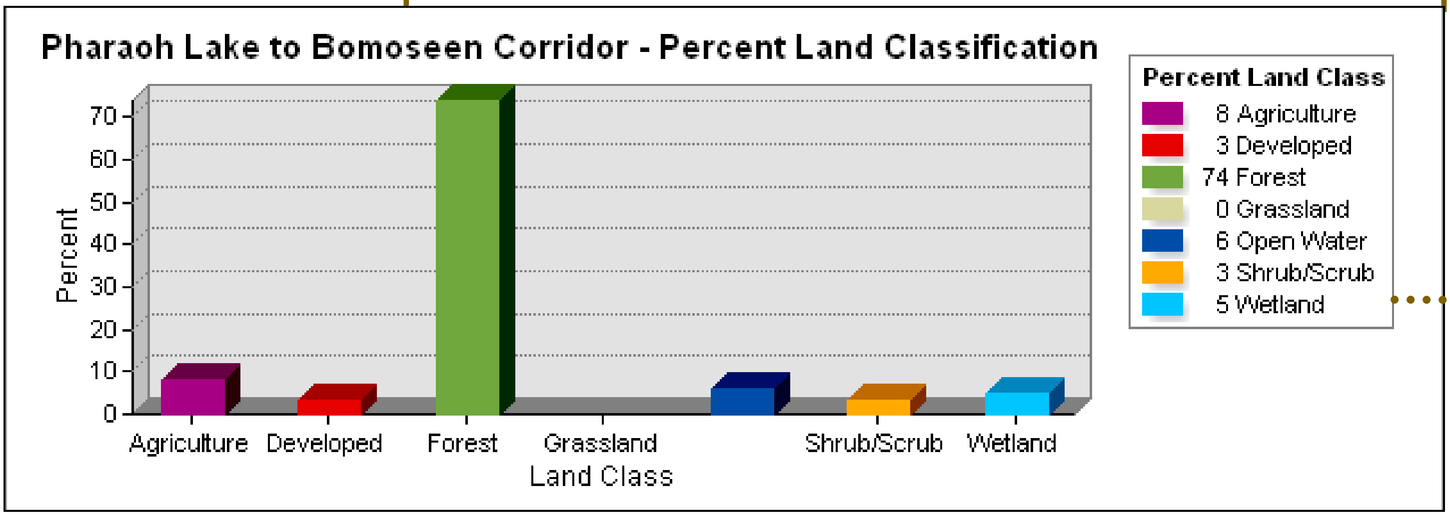


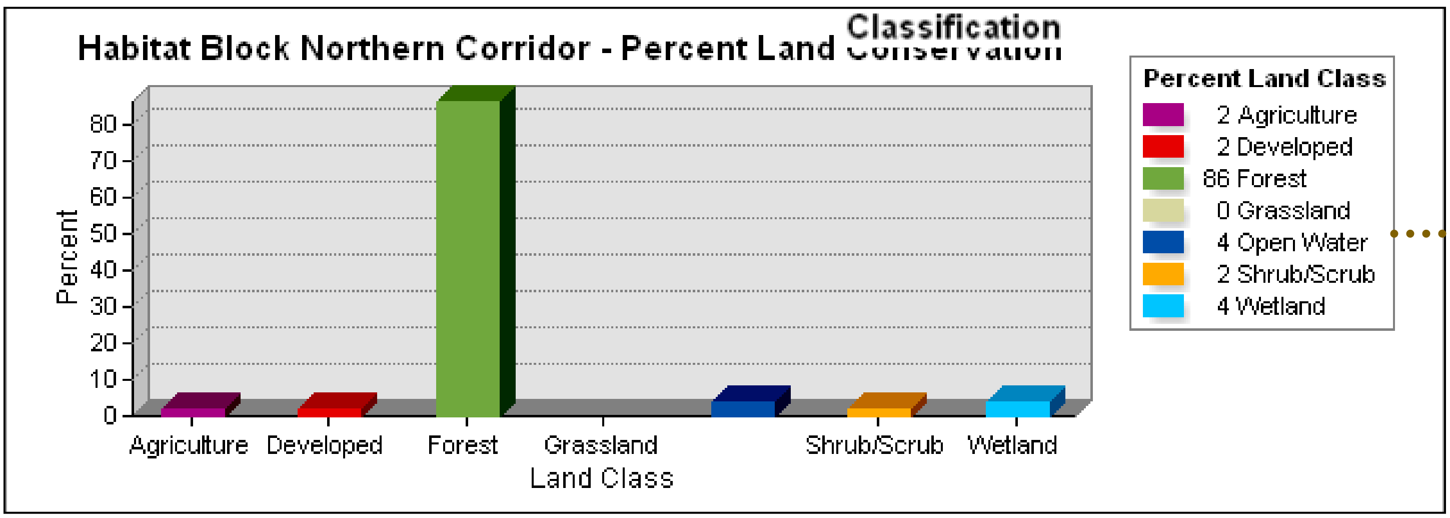


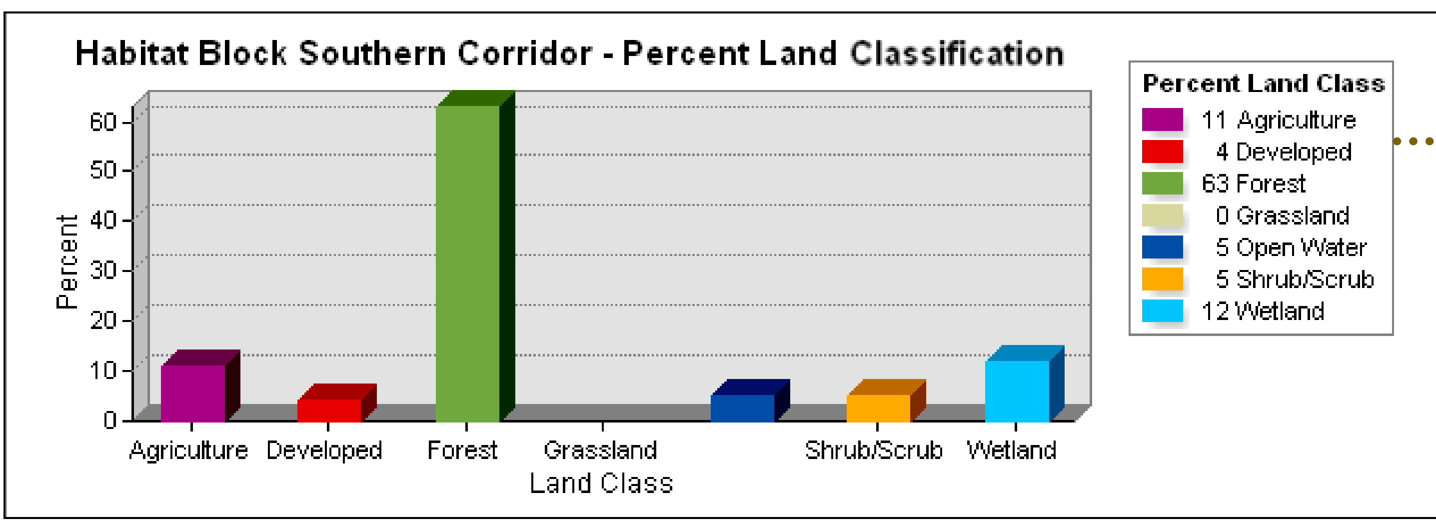
Land Use - Land Class

Land Use - Land Class (LULC) reflects landscape patterns driven by physical features (e.g. soil) and subsequent human use (e.g. agriculture). Furthermore, LULC constitutes the highest weighted factor for each focal species as determined by expert opinion and literature review, illustrating its significance to both structural and functional connectivity.

Figure 11 (a): Land Use - Land Classification as a percent of total area in each corridor. Data source: United States Geologic Survey (USGS): Land Use and Land Cover (LULC) Dataset - 2011 Edition (amended 2014)

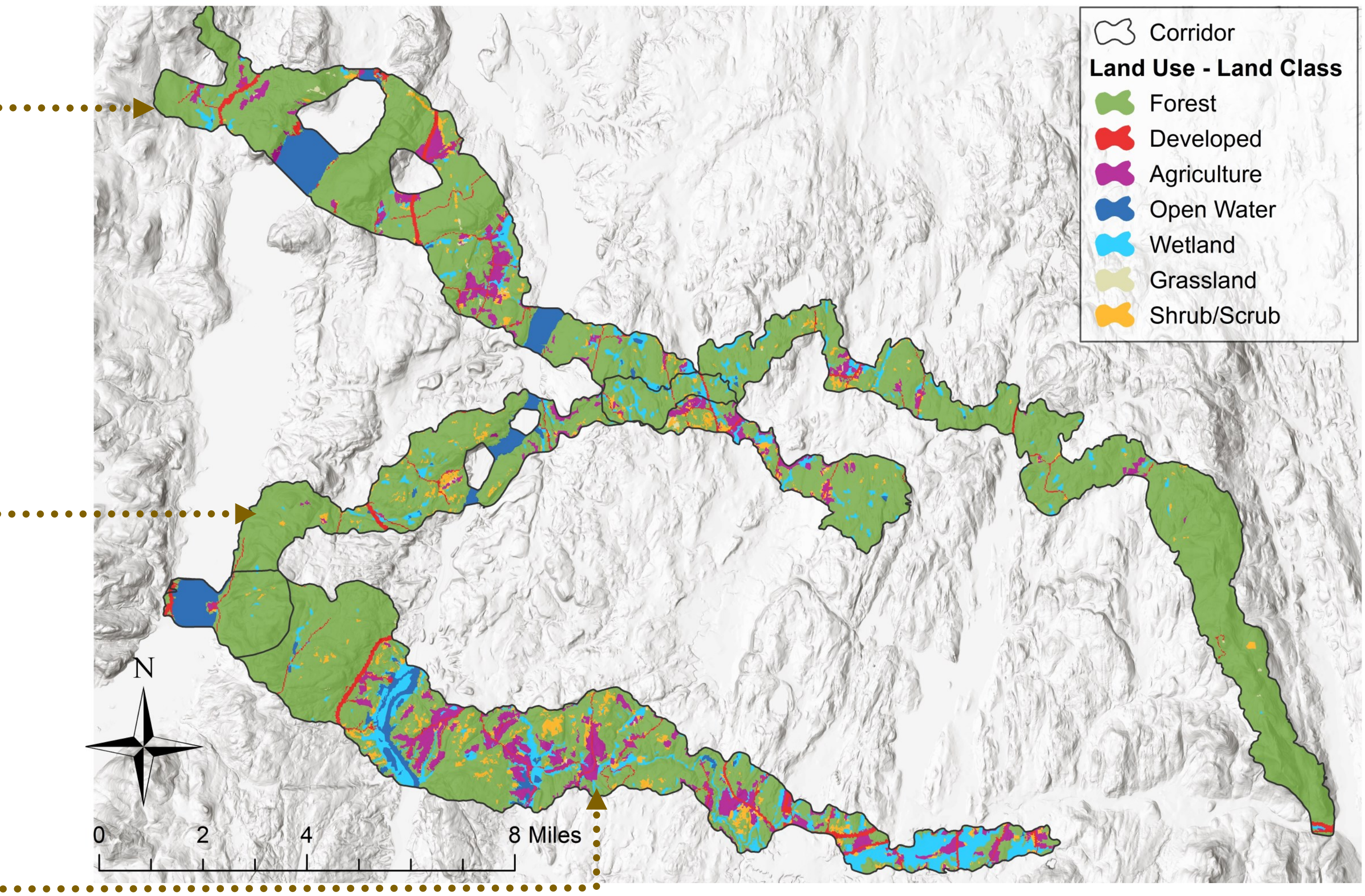






Land Use - Land Class

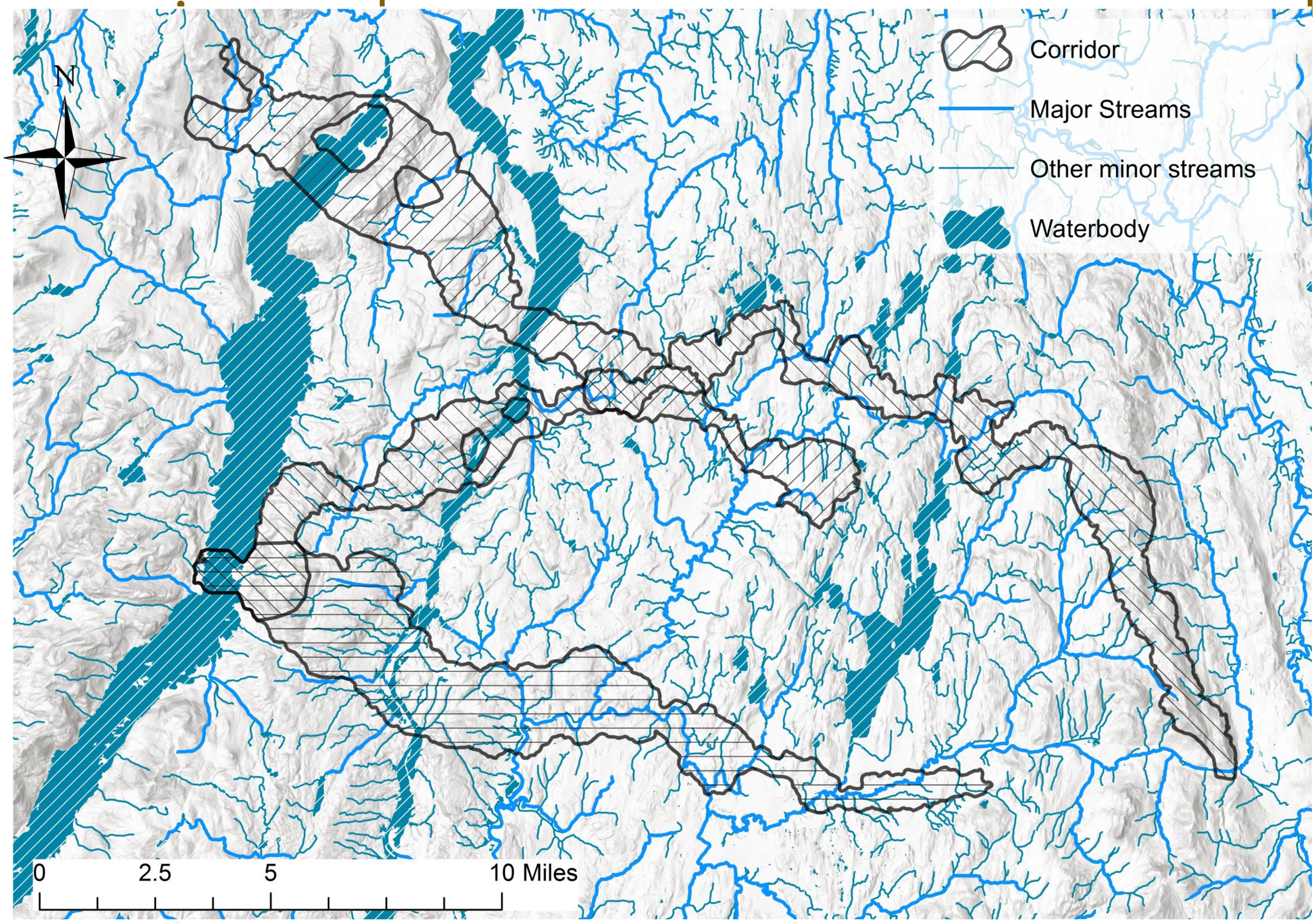
Figure 11 (b): Land Use - Land Class (LULC) within the corridors.
Data source: United States Geologic Survey (USGS): Land Use and Land Cover (LULC) Dataset - 2011 Edition (amended 2014)

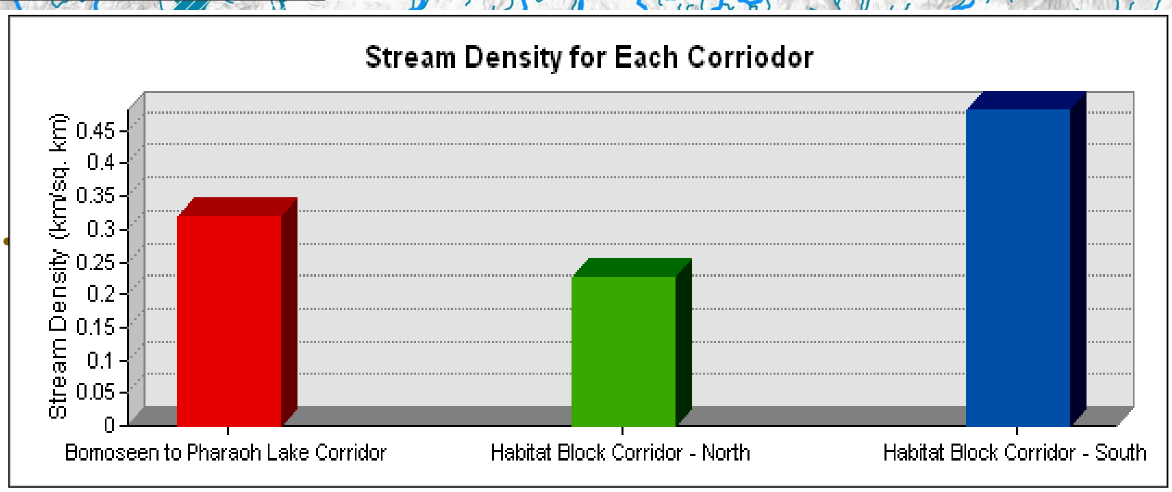


Streams

Waterways have the potential to foster or impede movement, depending on the inherent properties of a particular brook, stream, or river. For example, intact riparian zones provide vegetative cover and reduce movement cost parallel to the stream. However, depending on seasonal variations in water flow, wide streams may impede movement.

Figure 12: Streams and other waterbodies in the Lake George and southern Lake Champlain region
Source: United States Geologic Survey (USGS): Medium Resolution National Hydrography Dataset (NHD) - February 2015

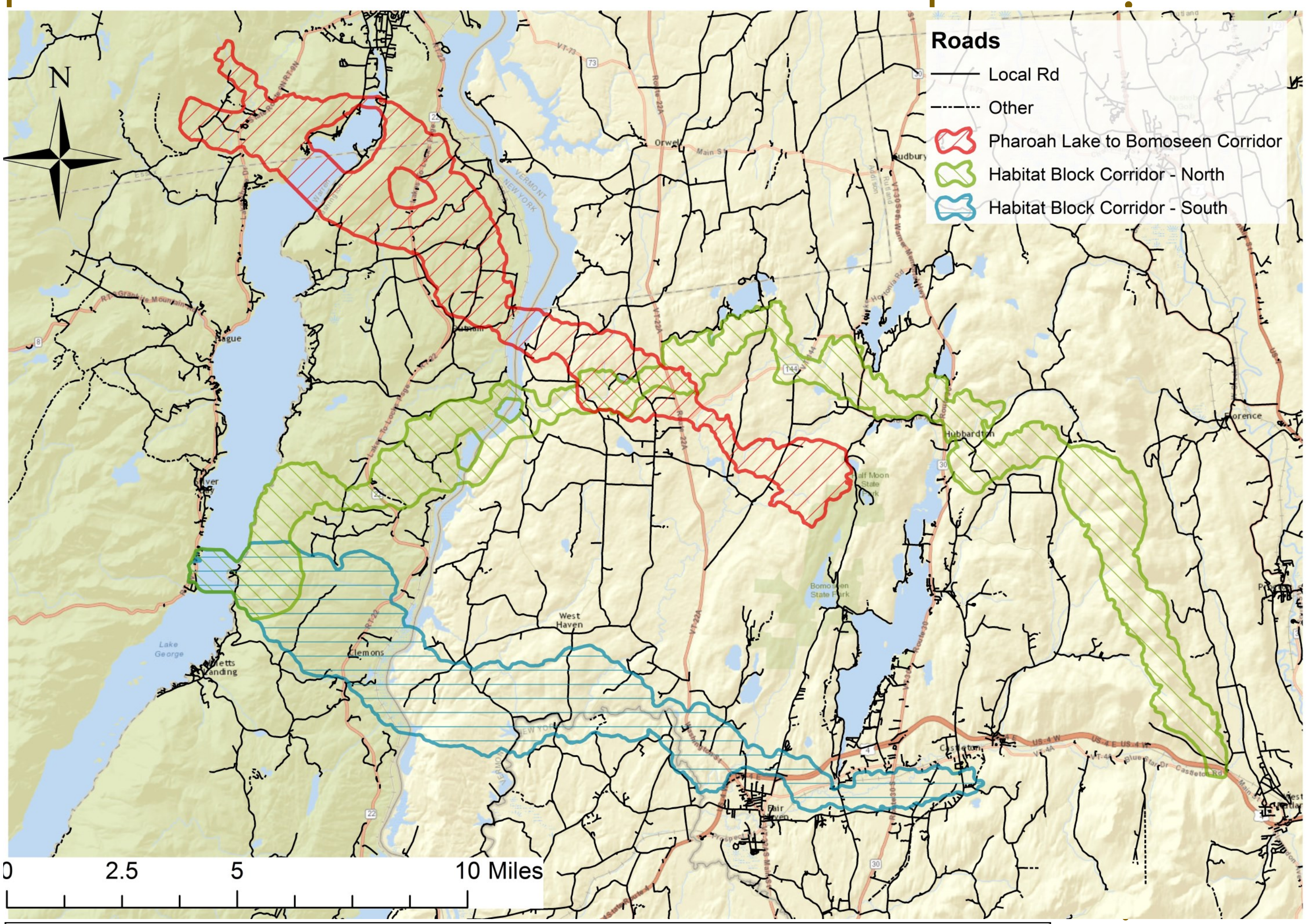




Roads lead to greater wildlife mortality and therefore present a greater cost than many other land features. Road density and number of road crossings are presented as basis for comparison (see Table 2). Not all roads result in barriers to wildlife movement. Specific characteristics, such as traffic levels and road structures, contribute to wildlife movement cost.

Roads

Figure 13: Roadways in the Lake George and southern Lake Champlain region
Source: United States Census Bureau: Transportation Investment Generating Economic Recovery (TIGER) Line Shapefiles - 2014



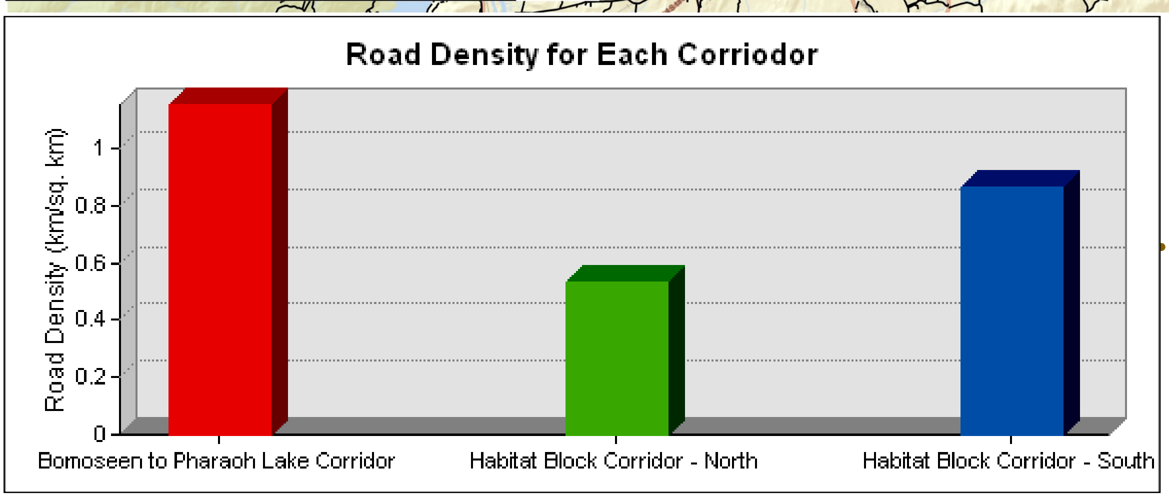


Table 2 Corridor Attributes—Although the list is not exhaustive, these characteristics form a basis for comparing one corridor to another.

Landscape Feature Class		Pharaoh Lake - Bomoseen Corridor	Vermont Habitat Block - New York Forest Matrix Block Corridor (North)	Vermont Habitat Block - New York Forest Matrix Block Corridor (South)	Total (*t*)
Total Length (km) (centerline of corridor)		29	54	31	114
Road Crossings (n)		14	16	14	44
Road Density (km/km^2) (secondary and local roads)		1.15	0.53	0.86	2.54
Stream Density (km/km^2) (medium resolution streams)		0.32	0.23	0.48	1.03
% High Quality Habitat (pixel value 60-100)	Black Bear	80	91	76	
	Bobcat	82	92	77	
	Fisher	75	88	68	
	Mean	79	90	76	245
% Low Quality Habitat (pixel value 0-40)	Black Bear	12	4	16	
	Bobcat	15	7	18	
	Fisher	17	7	20	
	Mean	15	6	18	39
Conserved Land (% total area)		11	18	26	55
Land Cover - Land Use					
Forest (% total area) (includes deciduous, conifer, and mixed)		74	86	63	223
Wetlands (% total area) (includes all types)		5	4	12	21
Agricultural (% total area) (pasture and cropland)		8	2	11	21
Developed (% total area)		3	2	4	16
Open Water (% total area)		6	4	5	15
Scrub-shrub (% total area)		3	2	5	10
Vermont Residential Building Density (cell count x density value)		552	901	1076	2529
Overlap with TNC Structural Pathway (% of total area)		35	45	25	105
VT Habitat Blocks (weighted by fragmentation threat)		326	758	477	1561
VT Habitat Blocks (weighted by conservation value)		347	909	451	1707
Rare Physical Landscapes (% of total area)		2	3	10	15
Riparian Connectivity (% of total area)		8	7	18	33
Connecting Lands (% of total area)		81	42	69	192
Connecting Blocks (% of total area)		10	21	13	44
Anchor Blocks (% of total area)		0	25	0	25
New York Matrix Linkage Zones (% of total area)		25	63	0	88

Table 3 Unweighted Normalized Scores (from 0 to 100)—Calculated by using the following steps: (1) Find total (*t*) for each of the landscape features by summing the values (*x*) for each corridor (from Table 2). (2) Calculate % of *t* of each corridor for each landscape feature class. In effect, the scores in every row of Table 3 shows the ratio of each value for a landscape feature class as a percent of the total. (3) To account for negative impacts (i.e. feature classes marked with a *) I calculated the scores in the same manner, except that *x* is equal to the difference between the original value and *t*.

Landscape Feature Class	Pharaoh Lake - Bomoseen Corridor	Vermont Habitat Block - New York Forest Matrix Block Corridor (North)	Vermont Habitat Block - New York Forest Matrix Block Corridor (South)
Total Length*	37	26	36
Road Crossings*	34	32	34
Road Density* (secondary and local roads)	27	40	33
Stream Density (medium resolution streams)	31	22	47
% High Quality Habitat (pixel value 60-100)	32	37	31
% Low Quality Habitat* (pixel value 0-40)	34	47	19
Conserved Land	20	33	47
Land Cover - Land Use			
Forest (includes deciduous, conifer, and mixed)	33	39	28
Wetlands (includes all wetland types)	24	19	58
Agricultural (pasture and cropland)*	31	45	24
Developed*	33	36	31
Open Water*	30	37	33
Scrub-shrub	30	20	50
Vermont Residential Building Density*	39	32	29
Overlap with TNC Structural Pathway	33	43	24
VT Habitat Blocks (weighted by fragmentation threat)*	40	26	35
VT Habitat Blocks (weighted by conservation value)	20	53	26
Rare Physical Landscapes	13	20	67
Riparian Connectivity	24	21	18
Connecting Lands	42	22	36
Connecting Blocks	23	48	29
Anchor Blocks	0	100	0
New York Matrix Linkage Zones	28	72	0
Total Score	**658**	**870**	**708**

Conclusion

As with any "abstraction and simplification of a real-world system" (Williams et al. 2002), inherent assumptions are used to produce model outputs that will guide future decisions. The main plausible assumption of the Corridor Designer approach is that individual wildlife movement through the landscape is based on a similar criteria as habitat selection (Beier et al. 2007). Habitat suitability as a proxy for resistance to movement has been employed throughout various geographic ranges and scales to model a variety of species movement (Kuemmerle et al. 2011 Rodríguez-Soto et al. 2013; Shakya et al. 2011; Graves and Wang 2012; Pullinger and Johnson 2010). This approach also reduces the "elusive parameters" associated with other methodologies, such as individual-based movement models (Beier et al. 2008).

This study utilized black bear (*Ursus americanus*), bobcat (*Lynx rufus*), and fisher (*Martes pennanti*) as focal species, which represent species that are wide-ranging, live at low densities, and occur within the analysis area. As an alternative to the cost and time prohibitive method of using empirical data as model parameters, I used a set of values established by Graves and Wang (2012), which were derived from expert opinion and literature review. The combined least-cost paths for each focal species were mapped by increasing width - representing a range of habitat suitability for potential wildlife movement between the respective set of habitat blocks. Three discrete corridors were defined based on model outputs (Figure 6):

- **Pharaoh Lake to Bomoseen Corridor**: This 29 km (18 mi) long corridor is the only defined corridor crossing between these two wildland blocks and shortest corridor in the study.
- **Habitat Block Corridor—North**: This corridor, at 54 km (34 mi) in length, reflects the longer of the two paths between the habitat blocks. It also has the highest normalized score in the evaluation (Table 3).
- **Habitat Block Corridor—South**: This path is much shorter than its counterpart, stretching 31 km (19 mi) across the landscape and is 8% more conserved. However, compared to the Habitat Block Corridor—North, this southern route contains a higher percentage of agricultural and developed land, and has much less overlap with modeling outcomes of other conservation organizations.

There are many considerations to account for when interpreting the final outputs of this modeling exercise. Least-cost path modeling will always result in a path, whether or not one exists in a particular landscape. This caveat highlights the importance of impermeable barriers within and around potential corridors. For example, Lake Champlain and Lake George provide unique examples of potential barriers to wildlife. Further empirical research should be conducted in the vicinity of these two water bodies to investigate home-range movement of local wildlife populations, specifically wide-ranging carnivores to determine how these waterbodies affect movement (for example, see LaPoint et al. 2013). Also, road ecology (such as crossing and structures) are an important feature to many conservation organizations, land managers, and the public.

The least-cost path method is particularly effective at pinpointing locations of bottlenecks, i.e. areas where crossing such barriers is more suitable, but surrounded by poor habitat, for the set of focal species (Long 2007; Beier et al. 2008). Therefore, end users should view these corridors at a number of scales in the context of many landscape layers. Some layers are depicted in this report on a landscape level, which should be augmented by a higher resolution perspective, such as town or community scale. For example, ownership records are one of the strongest informants of social influence on the landscape. Parcels can be used to infer potential for subdivision and fragmentation (for an example, see Host and Brown 2015). Large parcels containing unfragmented habitat are essential to sustaining wildlife corridors. However, the number of parcels in Vermont has increased by 42% between 1983 and 2008 (VNRC 2013) and their average size has reduced.

Besides least-cost path analysis based on expert opinion, additional methodologies could be applied within this region to address barriers, connectivity among several patches, and range-shift potential in the face of climate change. Circuit theory offers an approach that highlights barriers across a network of patches using resistance, current, and voltage to model movement (McRae et al. 2008). The landscape can also be modeled using a graph theory approach where multiple corridors (links) occur between multiple habitats (nodes), which reduces the effect of "forcing" a corridor through a particularly large scale region; this is also known as a stepping stone approach (Loro et al. 2015). In addition, the use of land facets, or “recurring landscape units of relatively uniform topography and soils”, can be used to compliment linkage design and emphasize resilient landscape characteristics in the face of climate change (Brost and Beier 2012).

Finally, this study identified 23 evaluation criteria to compare each corridor and apply regional context (Table 2 and Table 3; total score depicted in Figure 14). These landscape feature classes represent effects (either positive or negative) on wildlife movement and conservational value, or describe corridor traits, such as overall length. Nine of the criteria reflect similar studies performed in this region by various state and non-profit conservation organizations (see Appendix: pages 32-39).

Based on the outcome of the corridor evaluation and overlap with auxiliary model outcomes, I recommend that conservation planning and action be prioritized in the Habitat Block Corridor—North (shown in blue in Figure 14). This corridor shows considerable overlap with VT Fish & Wildlife/Vermont Land Trust connecting blocks and anchor blocks (page 35), TNC structural pathways (page 36), and NY Dept. of Environmental Conservation linkage zones (page 37). It also avoids main areas of residential density (page 38). In comparison, the Habitat Block Corridor—South traverses a high concentration of development south of Lake Bomoseen, including residential areas, quarrying activity, and major roadways (see Figure 1-C for aerial photo).

The outcomes of this study should be placed in the context of wildlife modeling efforts undertaken by the conservation community, and supplemented by institutional and residential knowledge of the region. Therefore, these corridors can be used to not only inform conservation and management decisions, but also enhance dialogue among partnering conservation organizations, land managers, and landowners.

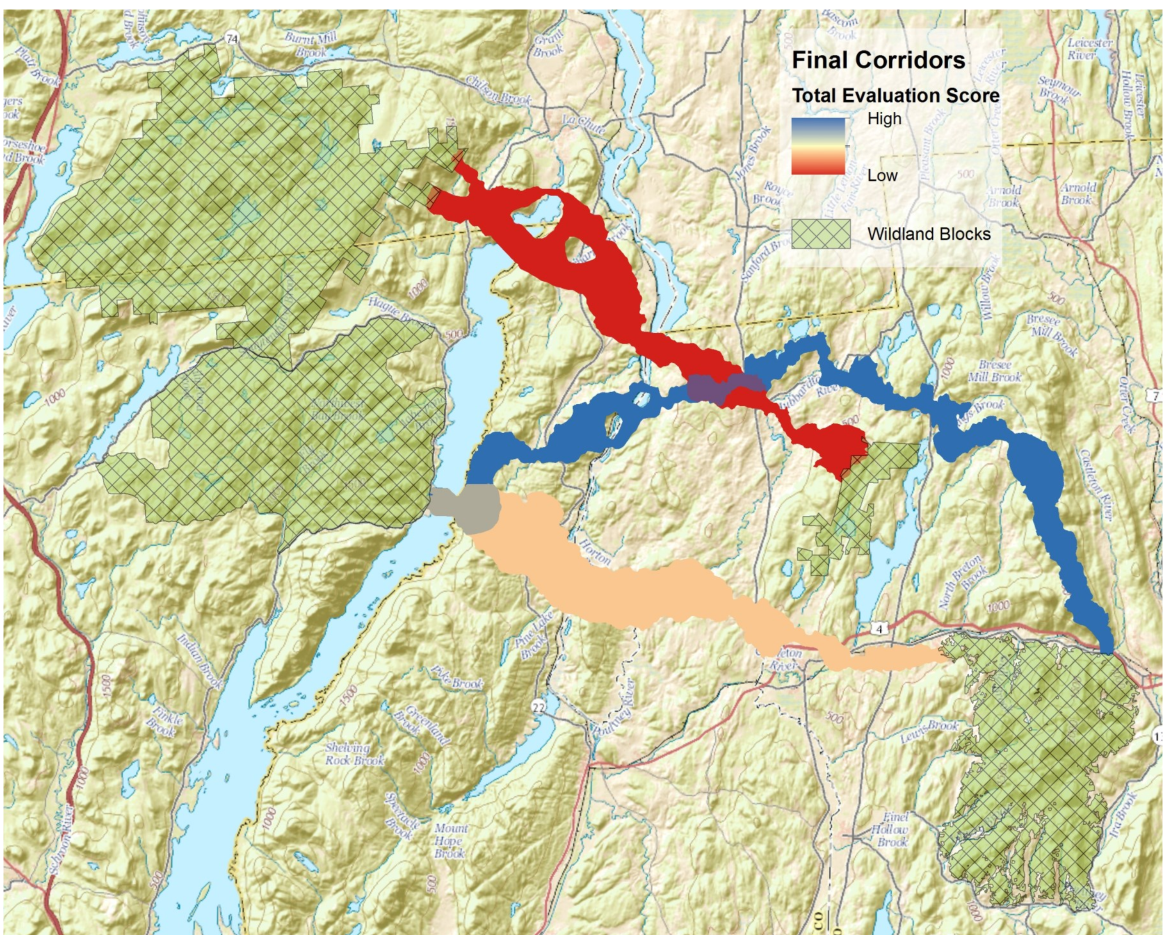


Figure 14: Final wildlife corridors depicted by total evaluation score, which is based on the landscape factors in Table 3. The total scores are: (1) Pharaoh Lake Corridor to Bomoseen= 658; (2) Vermont Habitat Block to New York Forest Matrix Block Corridor (North) = 870; (3) Vermont Habitat Block - New York Forest Matrix Block Corridor (South) = 708.

References

Ament, R., R. Callahan, M. McClure, M. Reuling, and G. Tabor. 2014. "Wildlife Connectivity: Fundamentals for Conservation Action." Center for Large Landscape Conservation: Bozeman, Montana.

Beier, Paul, Daniel R. Majka, and Wayne D. Spencer. 2008. "Forks in the Road: Choices in Procedures for Designing Wildland Linkages." *Conservation Biology* 22 (4): 836–51. doi:10.1111/j.1523-1739.2008.00942.x.

Beier, Paul, Dan Majka, and Jeff Jenness. 2007. "Conceptual Steps for Designing Wildlife Corridors." *CorridorDesign, Arizona, USA*.

Beier, Paul, and Reed F. Noss. "Do habitat corridors provide connectivity?." Conservation Biology 12, no. 6 (1998): 1241-1252.

Brost, B.M. and Beier, P. 2012. Use of land facets to design linkages for climate change. Ecological Applications, 22 (1), pp.87-103.

Caro, T. M. 2010. *Conservation by Proxy: Indicator, Umbrella, Keystone, Flagship, and Other Surrogate Species*. Washington, DC: Island Press.

Crooks, Kevin R., and M. A. Sanjayan, eds. 2006. *Connectivity Conservation*. Conservation Biology 14. Cambridge ; New York: Cambridge University Press.

Graves, Rose A., and Deane Wang. 2012. "Wildlife Habitat Linkages in the Eastern Adirondacks: Applying Functional Connectivity Modeling to Conservation Planning for Three Focal Species." Adirondack Journal of Environmental Science, 18.

Gilbert-Norton, Lynne, Wilson, R., Stevens, J.R. and Beard, K.H., 2010. A meta-analytic review of corridor effectiveness. Conservation biology,24(3), pp.660-668.

Host, G. and Brown, T., 2015. Quantifying parcelization potential of forest lands in Itasca County, north central Minnesota.

Jenness, J, D Majka, and P Beier. 2014. Corridor Designer Evaluation Tools: Extension for ArcGIS. Jenness Enterprises, Flagstaff, AZ, USA.

Kuemmerle, T., Perzanowski, K., Akcakaya, H.R., Beaudry, F., Van Deelen, T.R., Parnikoza, I., Khoyetskyy, P., Waller, D.M. and Radeloff, V.C., 2011. Cost-effectiveness of strategies to establish a European bison metapopulation in the Carpathians. Journal of Applied Ecology, 48(2), pp.317-329.

LaPoint, S., Gallery, P., Wikelski, M. and Kays, R., 2013. Animal behavior, cost-based corridor models, and real corridors. *Landscape Ecology*, *28*(8), pp.1615-1630.

Long, Robert. 2007. "Predicting Occurrence and Assessing Connectivity for Wide-Ranging Carnivores in the Greater Southern Lake Champlain Region of New York." The Nature Conservancy.

Loro, M., Ortega, E., Arce, R.M. and Geneletti, D., 2015. Ecological connectivity analysis to reduce the barrier effect of roads. An innovative graph-theory approach to define wildlife corridors with multiple paths and without bottlenecks. Landscape and Urban Planning, 139, pp.149-162.

Majka, D., J. Jenness, and P. Beier. 2007. CorridorDesigner: ArcGIS tools for designing and evaluating corridors. Available at http://corridordesign.org.

McRae, B.H., Dickson, B.G., Keitt, T.H. and Shah, V.B. 2008. Using circuit theory to model connectivity in ecology, evolution, and conservation.Ecology, 89(10), pp.2712-2724.

NYDEC. 2011. "New York State Strategic Plan for State Forest Management." New York State Department of Environmental Conservation. http://www.dec.ny.gov/docs/lands_forests_pdf/spsfmfinal.pdf.

Pullinger, M.G. and Johnson, C.J., 2010. Maintaining or restoring connectivity of modified landscapes: evaluating the least-cost path model with multiple sources of ecological information. Landscape Ecology, 25(10), pp.1547-1560.

Rodríguez-Soto, Clarita, Octavio Monroy-Vilchis, and Martha M. Zarco-González. 2013. "Corridors for Jaguar (Panthera Onca) in Mexico: Conservation Strategies." *Journal for Nature Conservation* 21 (6): 438–43. doi:10.1016/j.jnc.2013.07.002.

Shakya, Bandana, Kabir Uddin, Nakul Chettri, Birendra Bajracharya, and Eklabya Sharma. 2011. "Use of Geo-Spatial Tools in the Management of Potential Habitats Outside the Protected Areas in the Transboundary Brahmaputra-Salaween Landscape." *Contribution of Ecosystem Restoration to the Objectives of the CBD and a Healthy Planet for All People*, 98.

Sorenson, Eric, and Jon Osborne. 2014. "Vermont Habitat Blocks and Habitat Connectivity: An Analysis Using Geographic Information Systems." Vermont Fish & Wildlife Department.http://vtconservation.com/success/sites/default/files/Vermont_Habitat_Blocks_and_Habitat_Connectivity.pdf.

VT DFPR and VT ANR. 2015. "2015 Vermont Forest Fragmentation Report."

Williams, Byron K., James D. Nichols, and Michael J. Conroy. 2002. *Analysis and Management of Animal Populations: Modeling, Estimation, and Decision Making*. San Diego: Academic Press.

References - Spatial Data

Obtained from United States Geologic Survey (USGS)

Global Digital Elevation Model (GDEM) Version 2 - October 2011

Medium Resolution National Hydrography Dataset (NHD) - February 2015

Land Use and Land Cover (LULC) Dataset - 2011 Edition (amended 2014)

Protected Areas Database of the United States version 1.3 - November 2012

Obtained from United States Census Bureau

Transportation Investment Generating Economic Recovery (TIGER) Line Shapefiles - 2014

Obtained from New York Geographic Information Systems Clearinghouse (NYS GIS)

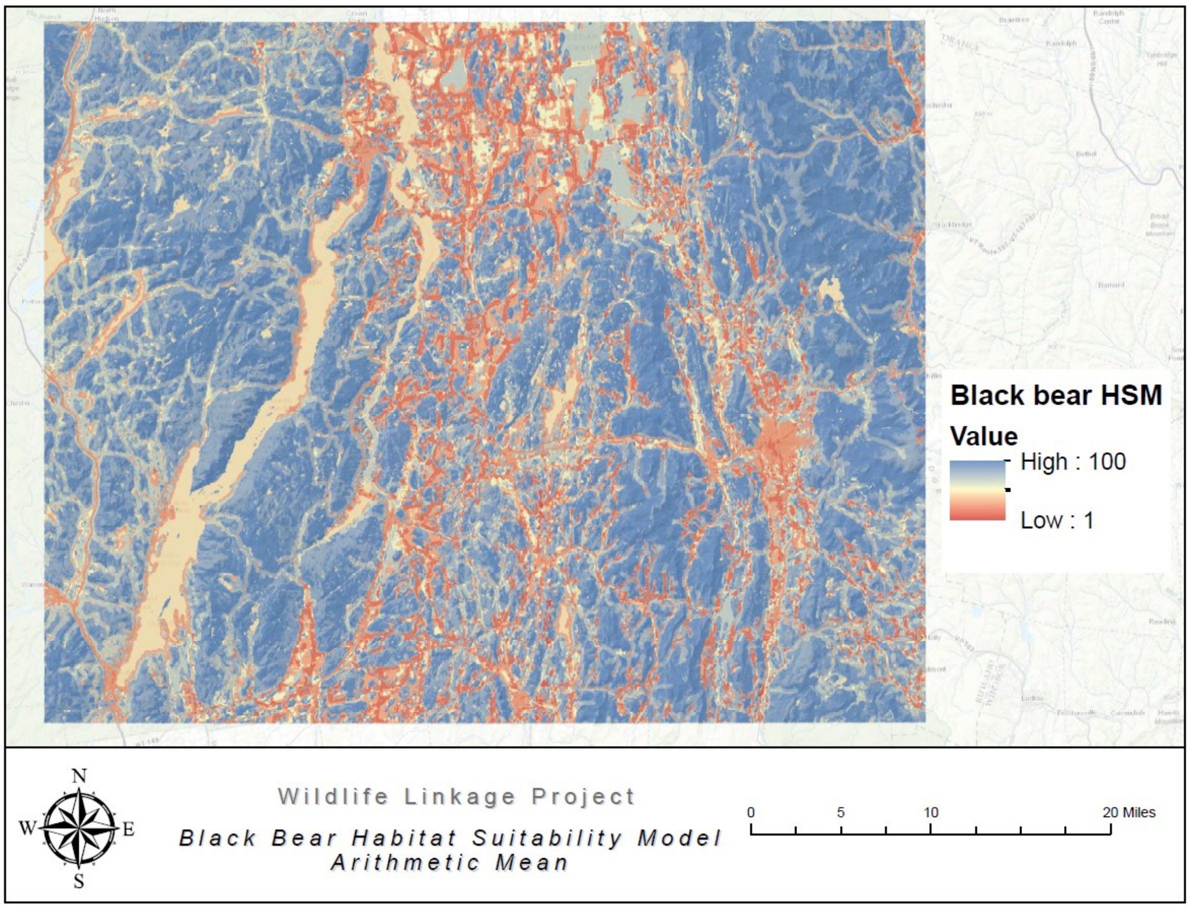
Matrix forest Blocks and Linkages - November 2012

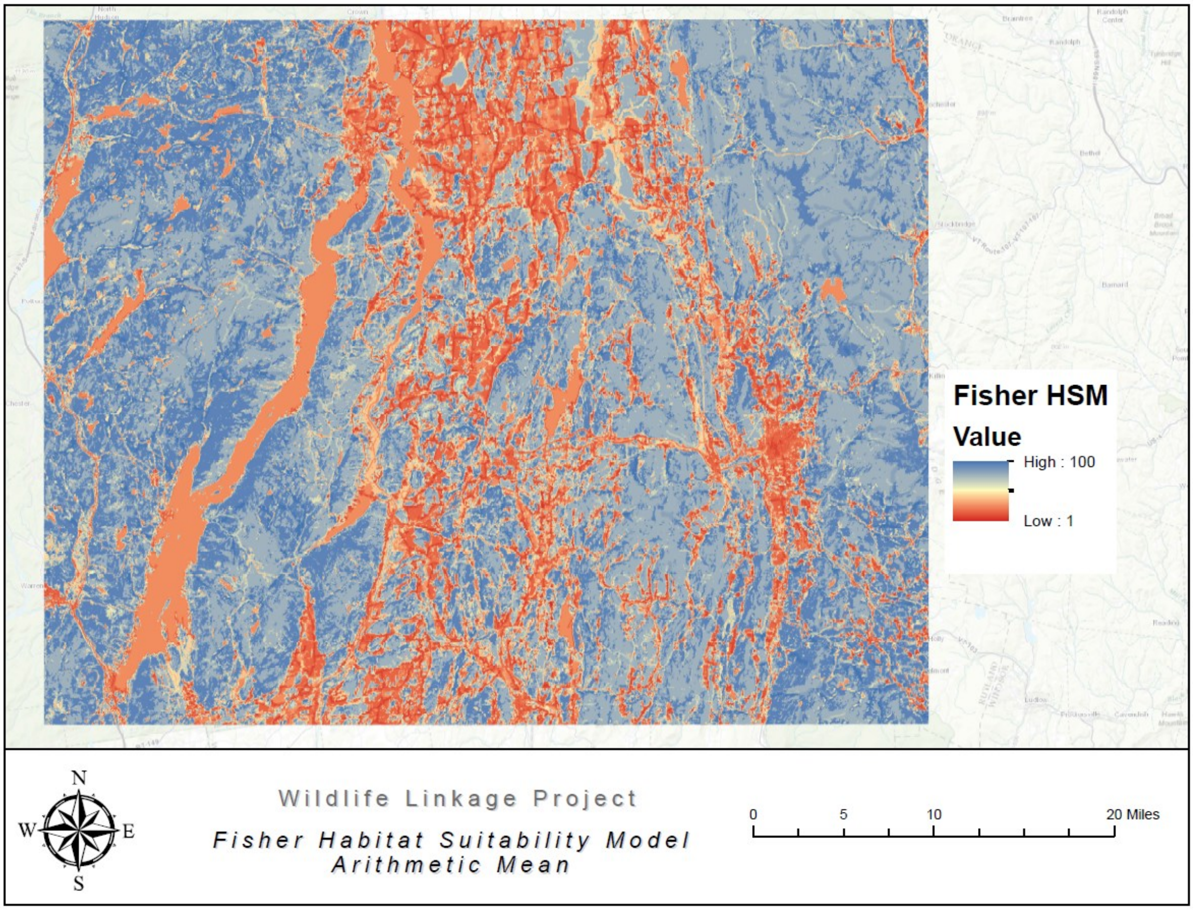
Obtained from the Vermont Center for Geographic Information (VCGI).

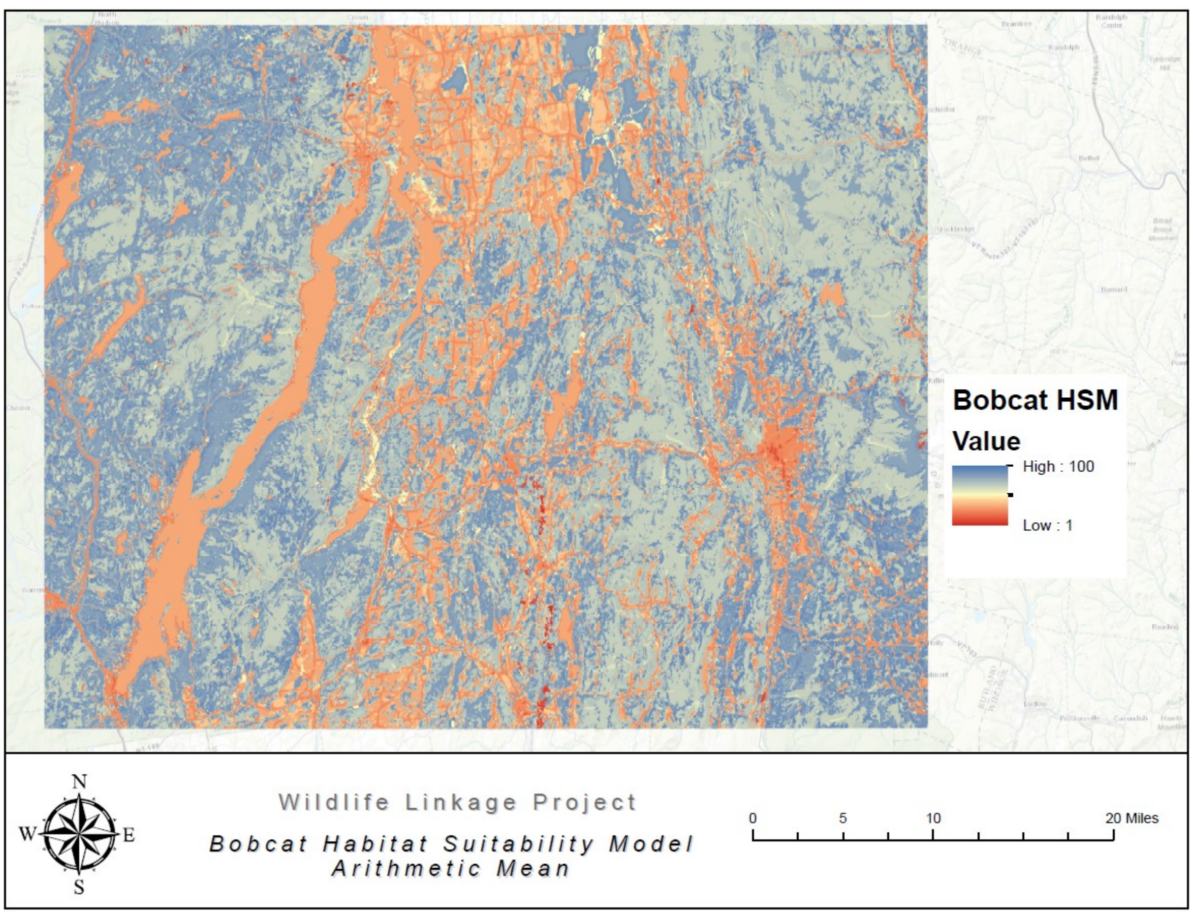
Vermont Habitat Blocks (VT F&W; VLT) - June 2011

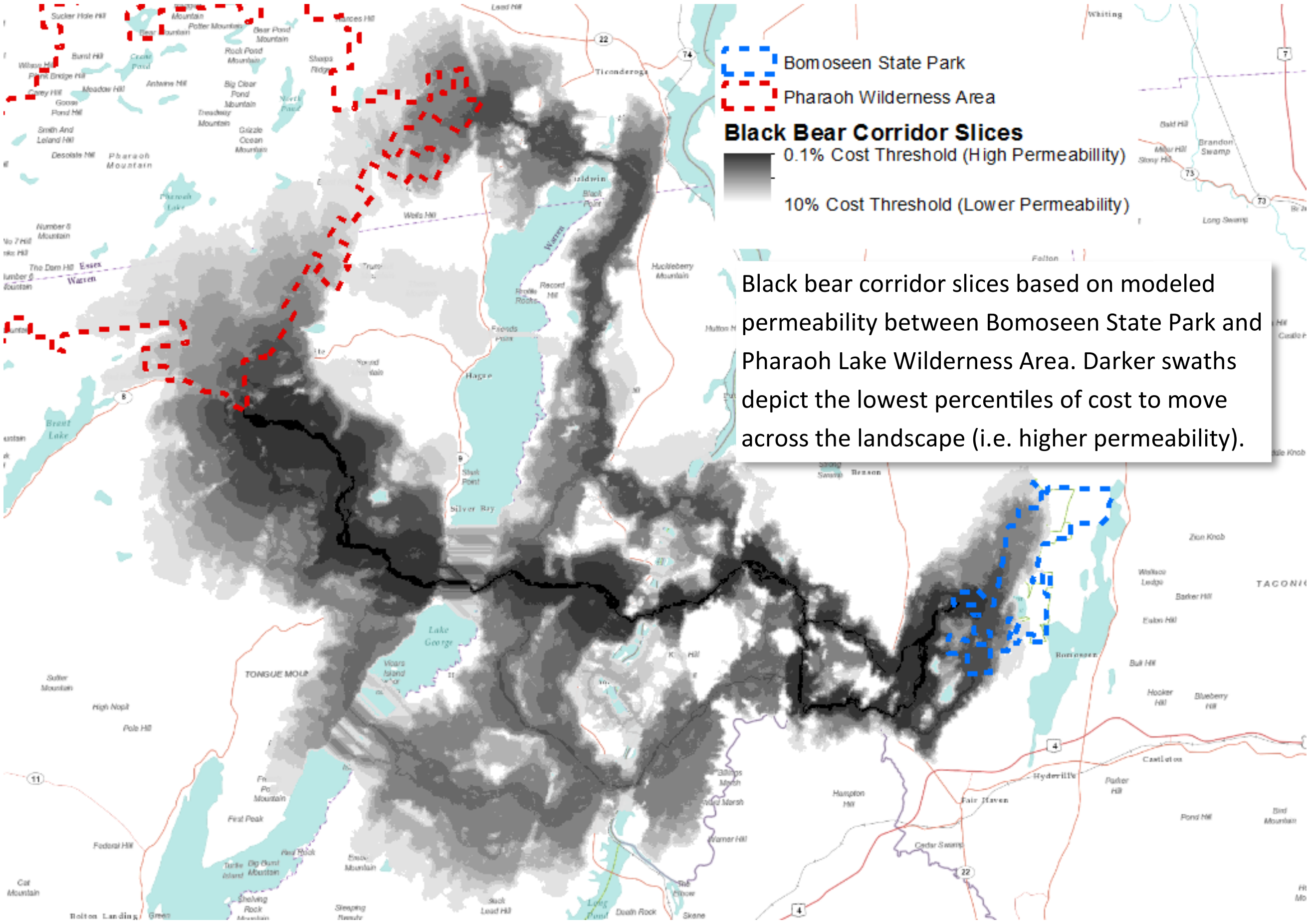
Census TIGER Road Centerlines - September 2008

Appendix

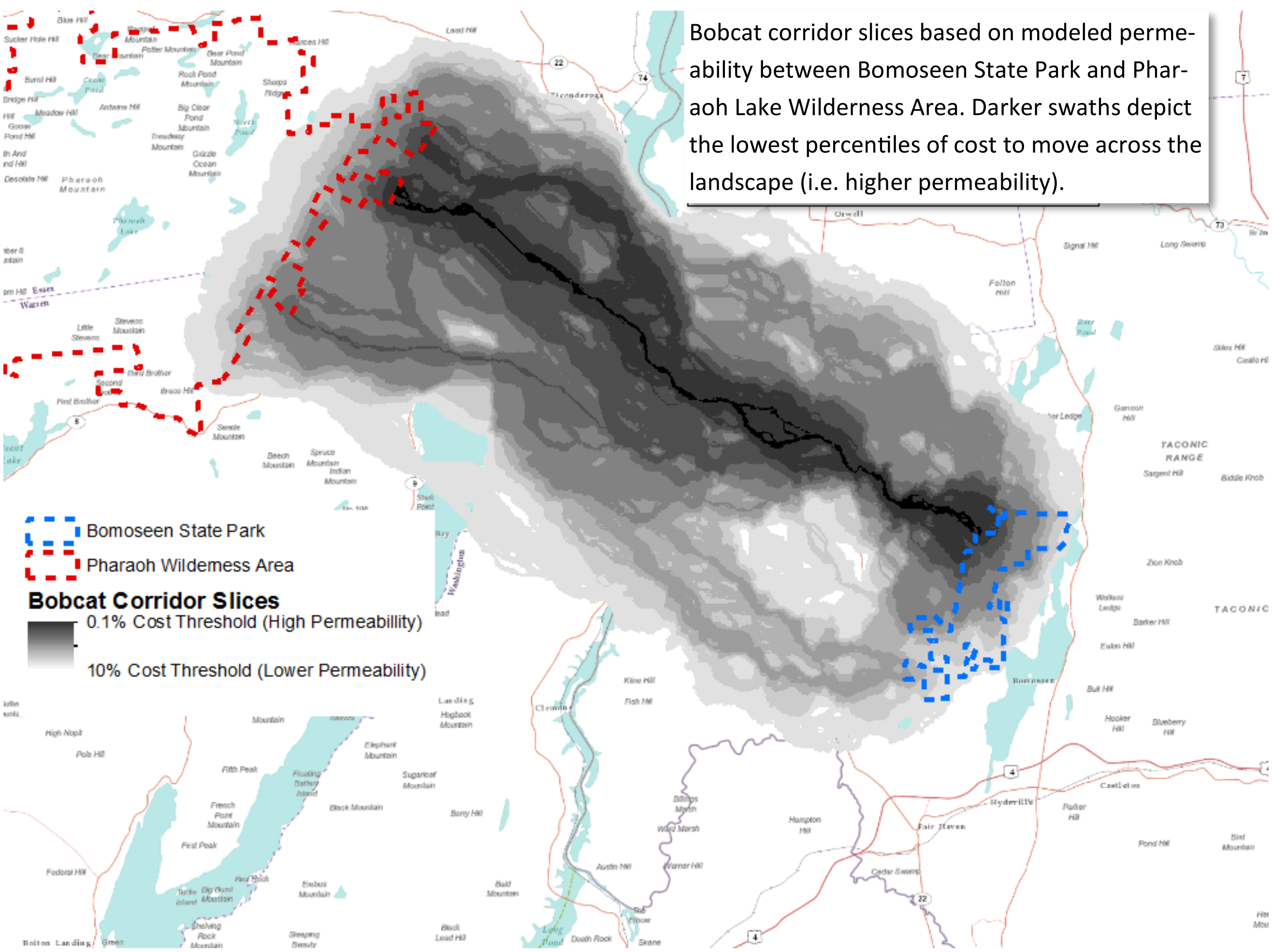

Black bear HSM
Value
High : 100
Low : 1
N
W
E
S
Wildlife Linkage Project
Black Bear Habitat Suitability Model
Arithmetic Mean
0
5
10
20 Miles


Fisher HSM
Value
High : 100
Low : 1
N
S
W
E
Wildlife Linkage Project
Fisher Habitat Suitability Model
Arithmetic Mean
0
5
10
20 Miles

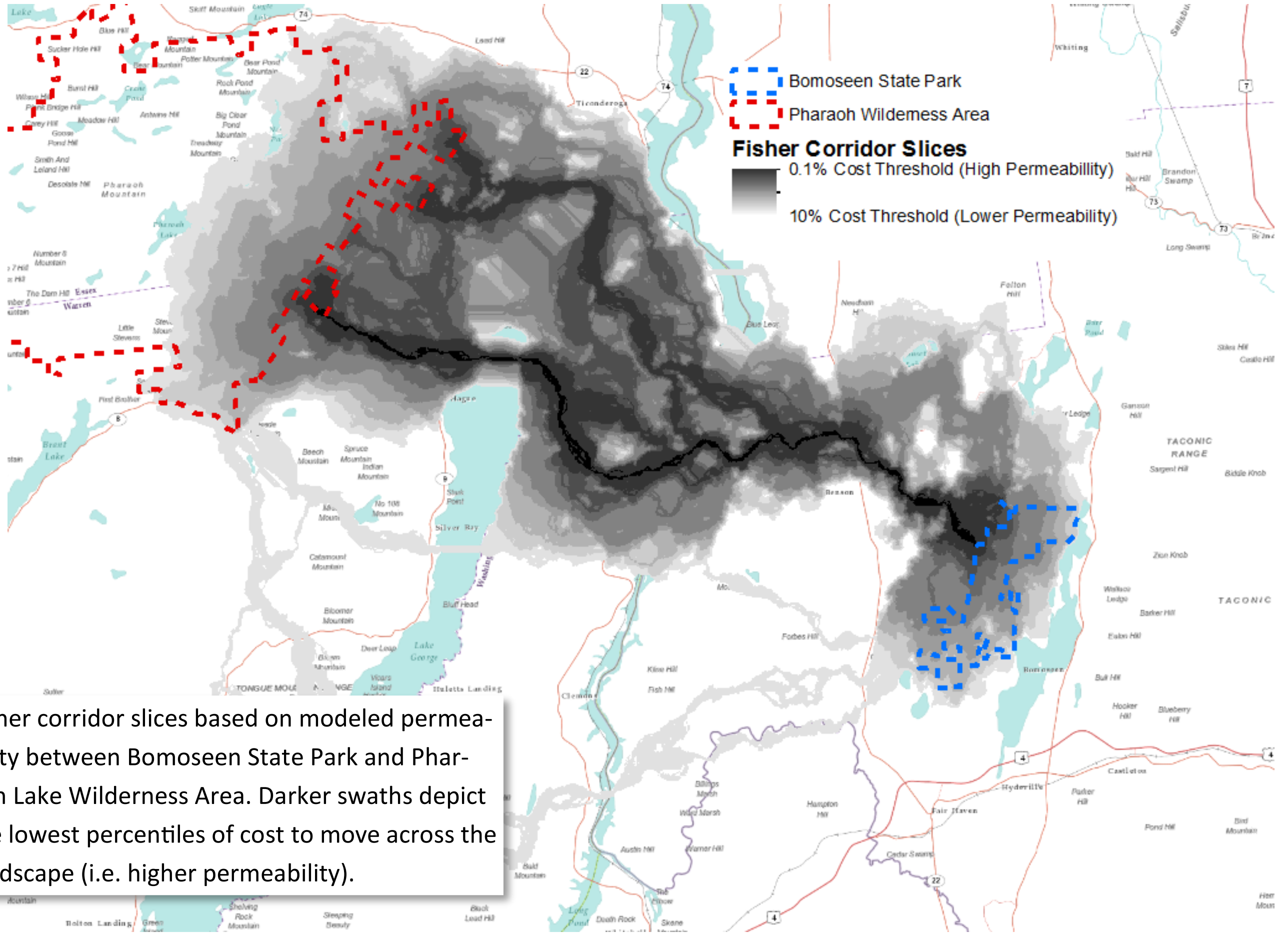

Bobcat HSM
Value
High : 100
Low : 1
N
S
W
E
Wildlife Linkage Project
Bobcat Habitat Suitability Model
Arithmetic Mean
0
5
10
20 Miles



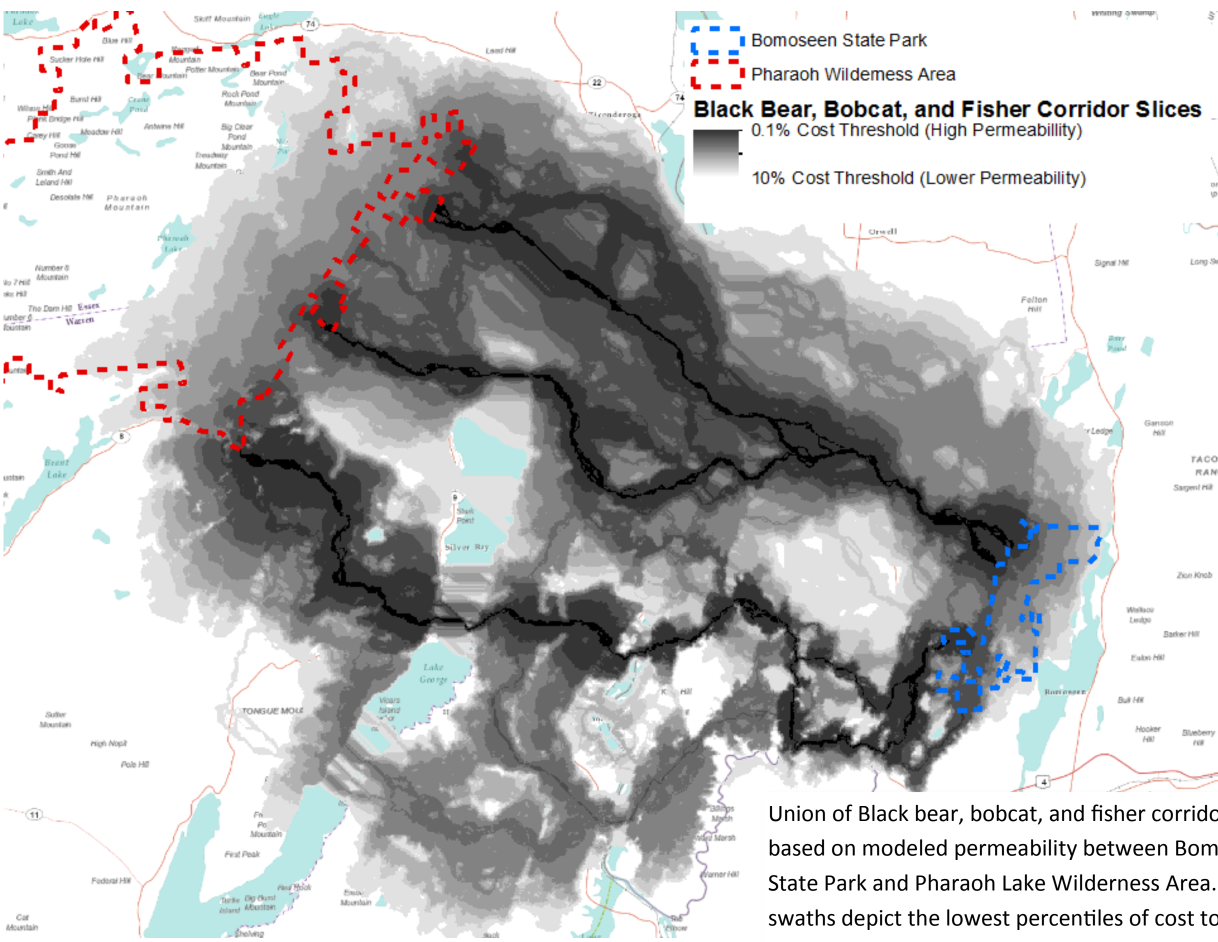
Black bear corridor slices based on modeled permeability between Bomoseen State Park and Pharaoh Lake Wilderness Area. Darker swaths depict the lowest percentiles of cost to move across the landscape (i.e. higher permeability).



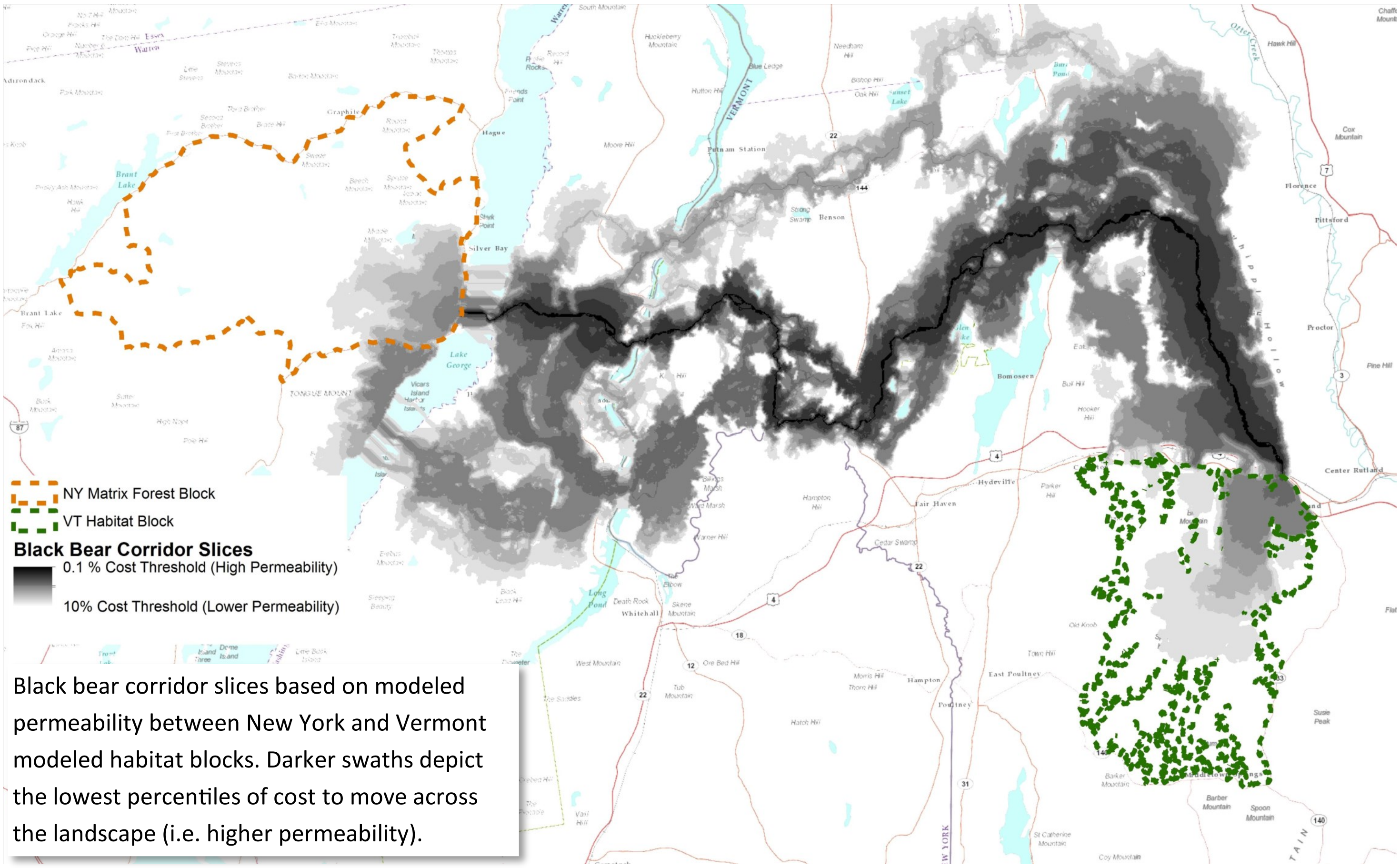
Bobcat corridor slices based on modeled permeability between Bomoseen State Park and Pharaoh Lake Wilderness Area. Darker swaths depict the lowest percentiles of cost to move across the landscape (i.e. higher permeability).



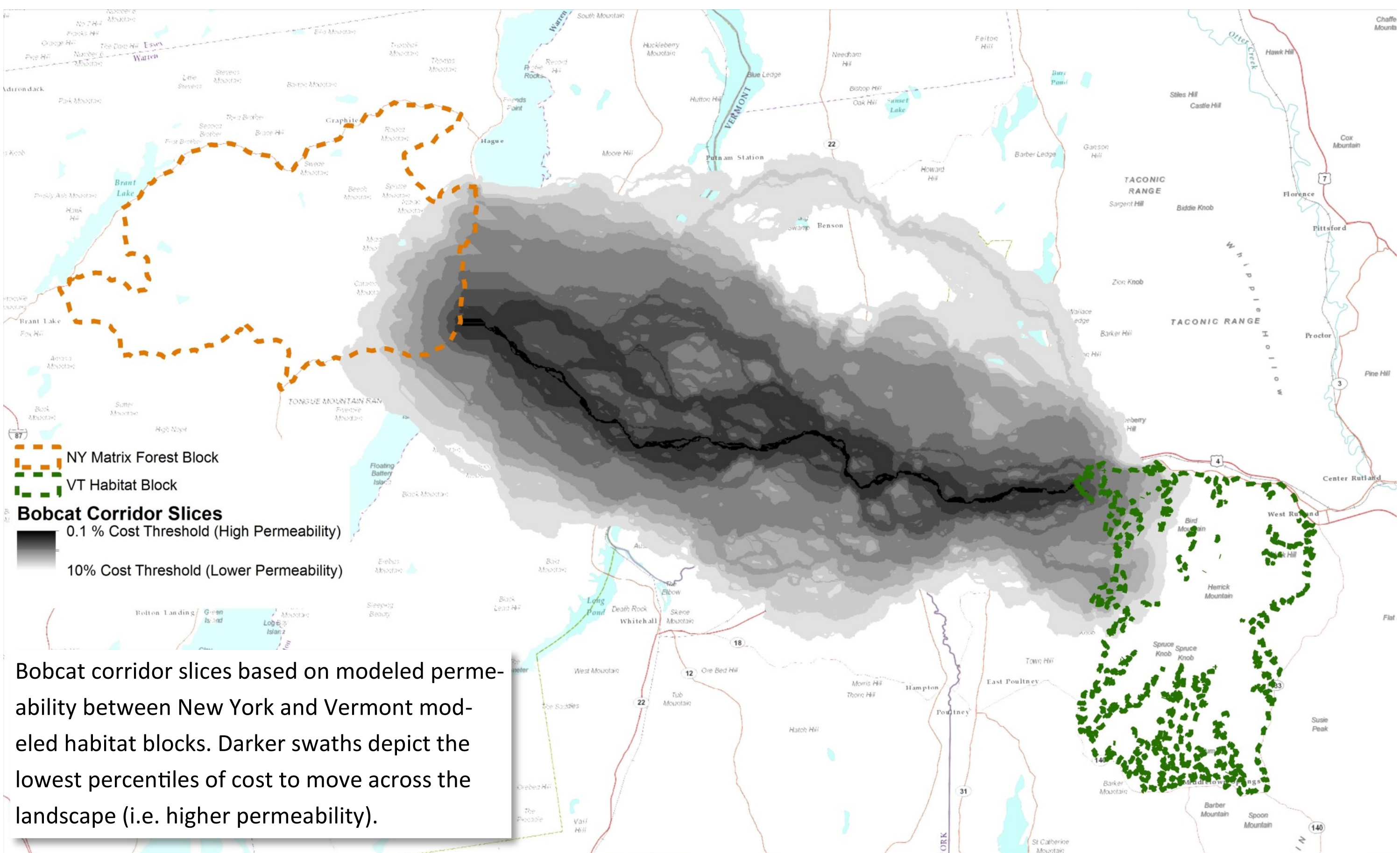
Fisher corridor slices based on modeled permeability between Bomoseen State Park and Pharaoh Lake Wilderness Area. Darker swaths depict the lowest percentiles of cost to move across the landscape (i.e. higher permeability).



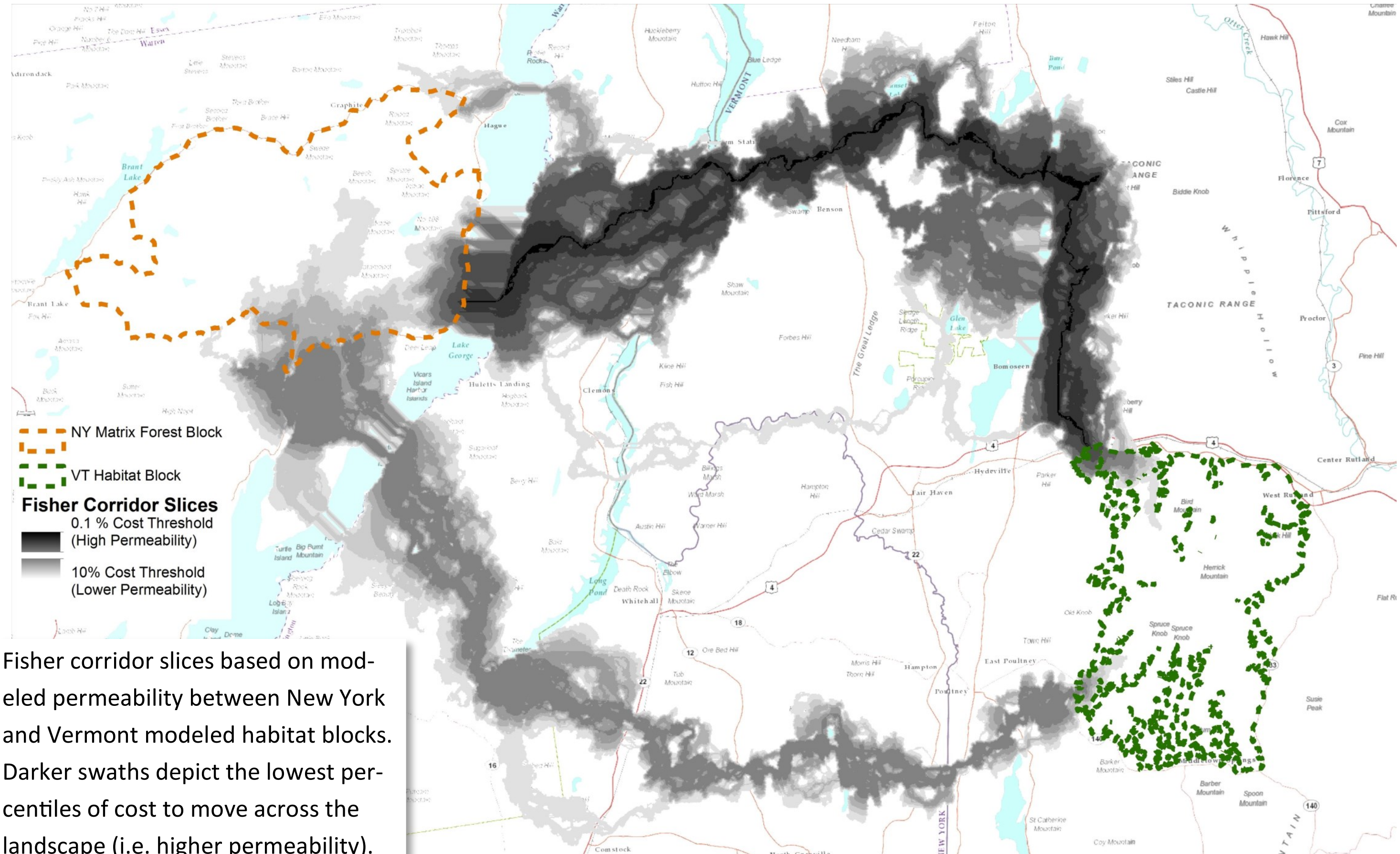
Union of Black bear, bobcat, and fisher corridor slices based on modeled permeability between Bomoseen State Park and Pharaoh Lake Wilderness Area. Darker swaths depict the lowest percentiles of cost to move across the landscape (i.e. higher permeability).



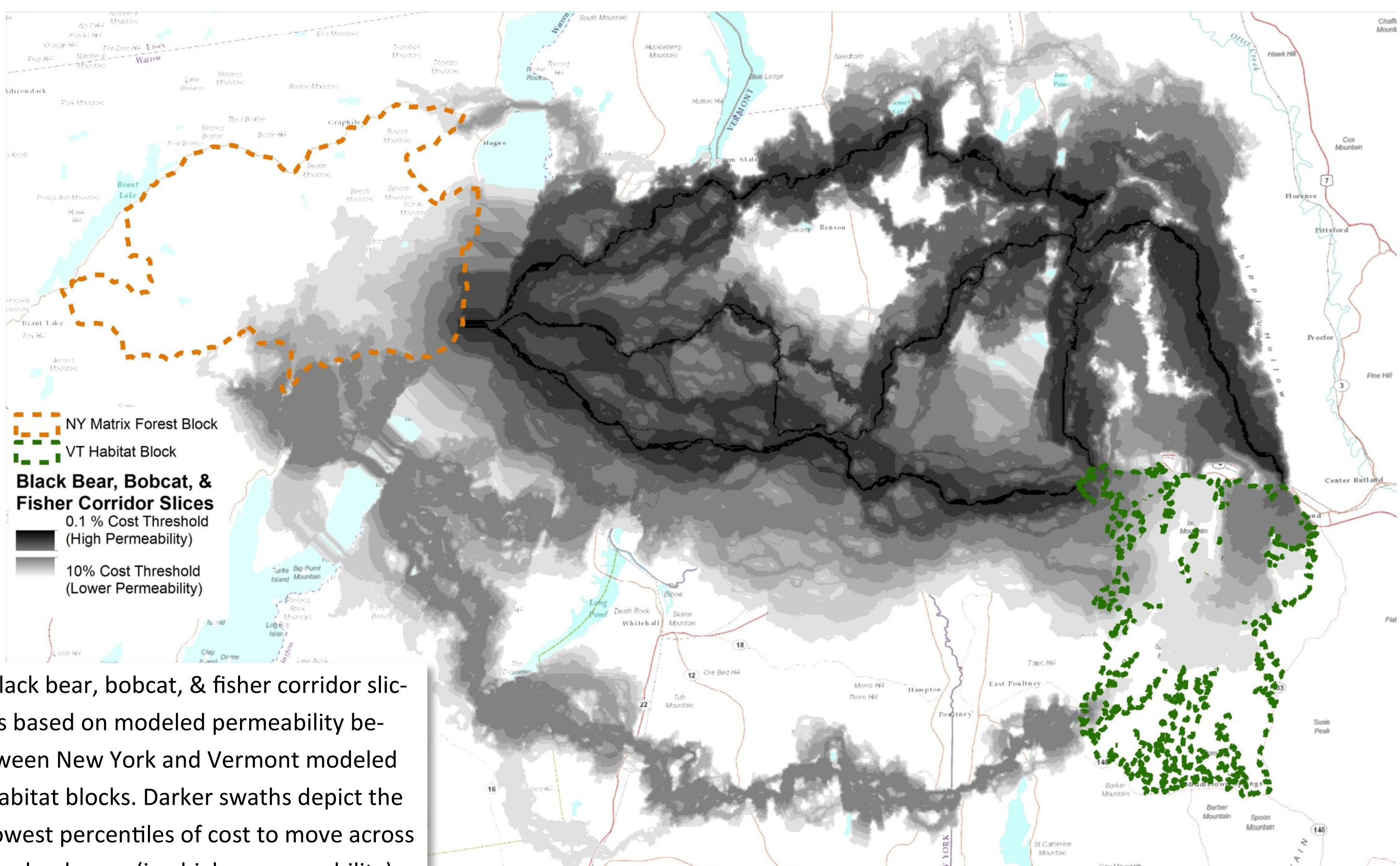
Black bear corridor slices based on modeled permeability between New York and Vermont modeled habitat blocks. Darker swaths depict the lowest percentiles of cost to move across the landscape (i.e. higher permeability).



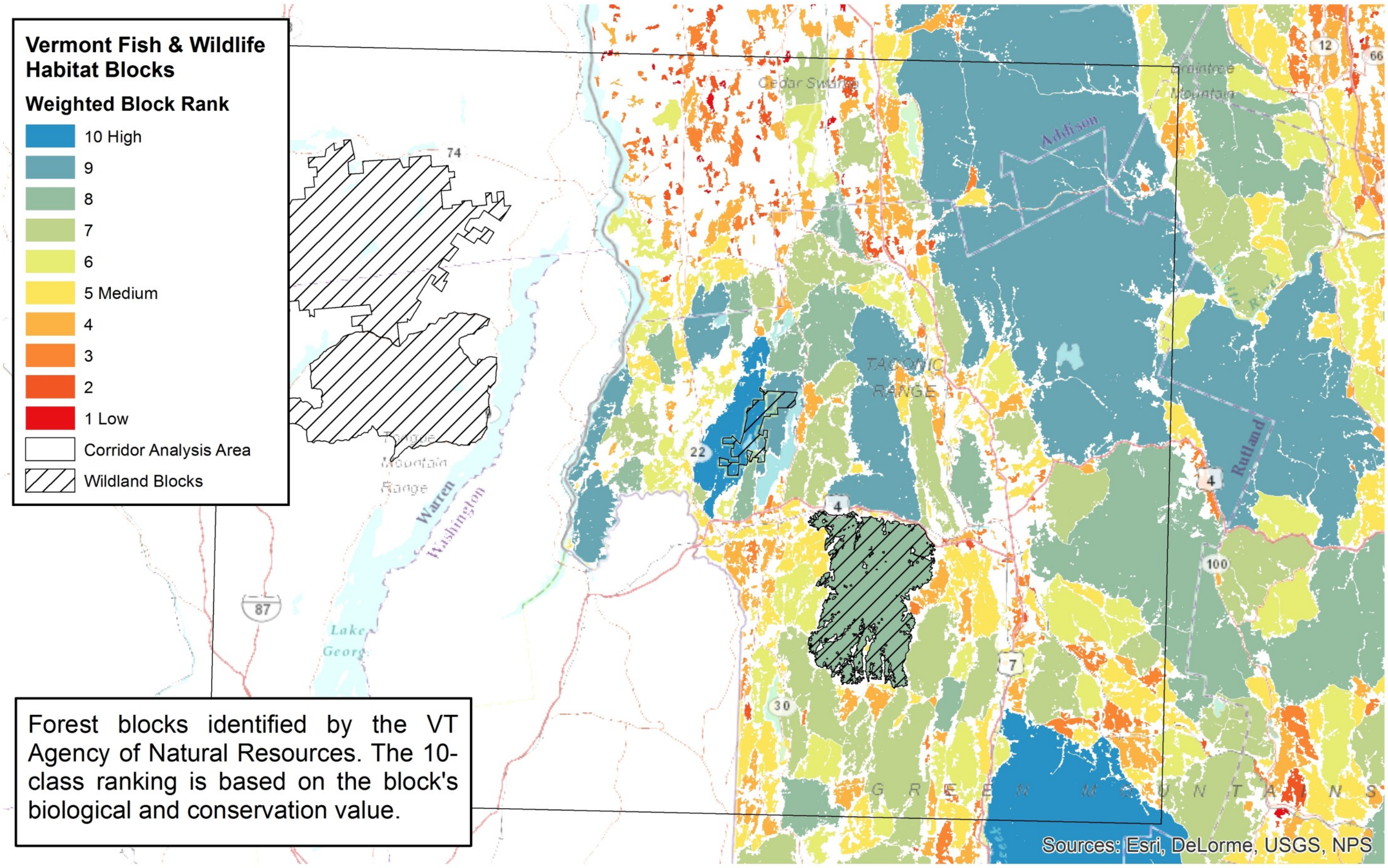
Bobcat corridor slices based on modeled permeability between New York and Vermont modeled habitat blocks. Darker swaths depict the lowest percentiles of cost to move across the landscape (i.e. higher permeability).



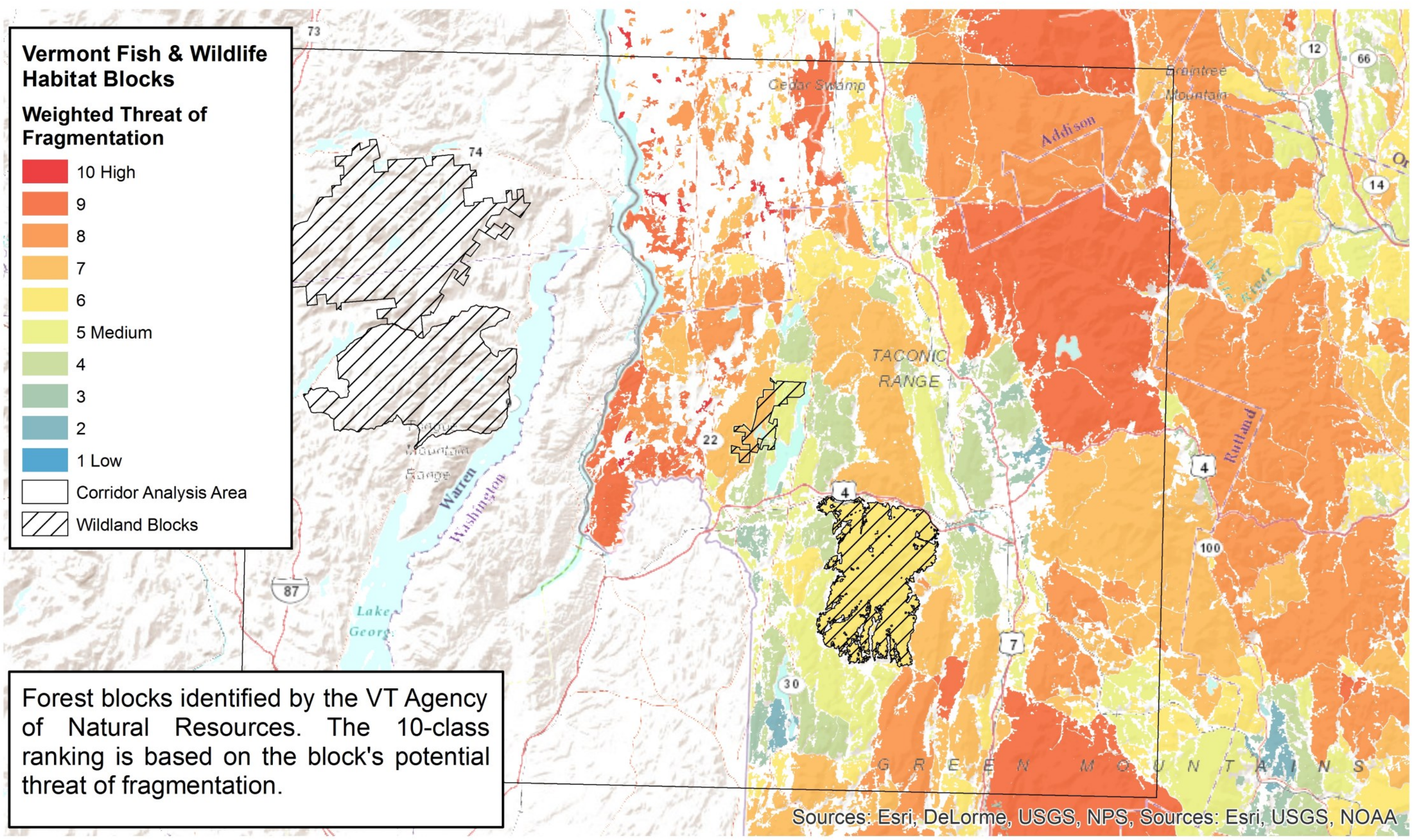
Fisher corridor slices based on modeled permeability between New York and Vermont modeled habitat blocks. Darker swaths depict the lowest percentiles of cost to move across the landscape (i.e. higher permeability).



Black bear, bobcat, & fisher corridor slices based on modeled permeability between New York and Vermont modeled habitat blocks. Darker swaths depict the lowest percentiles of cost to move across the landscape (i.e. higher permeability).

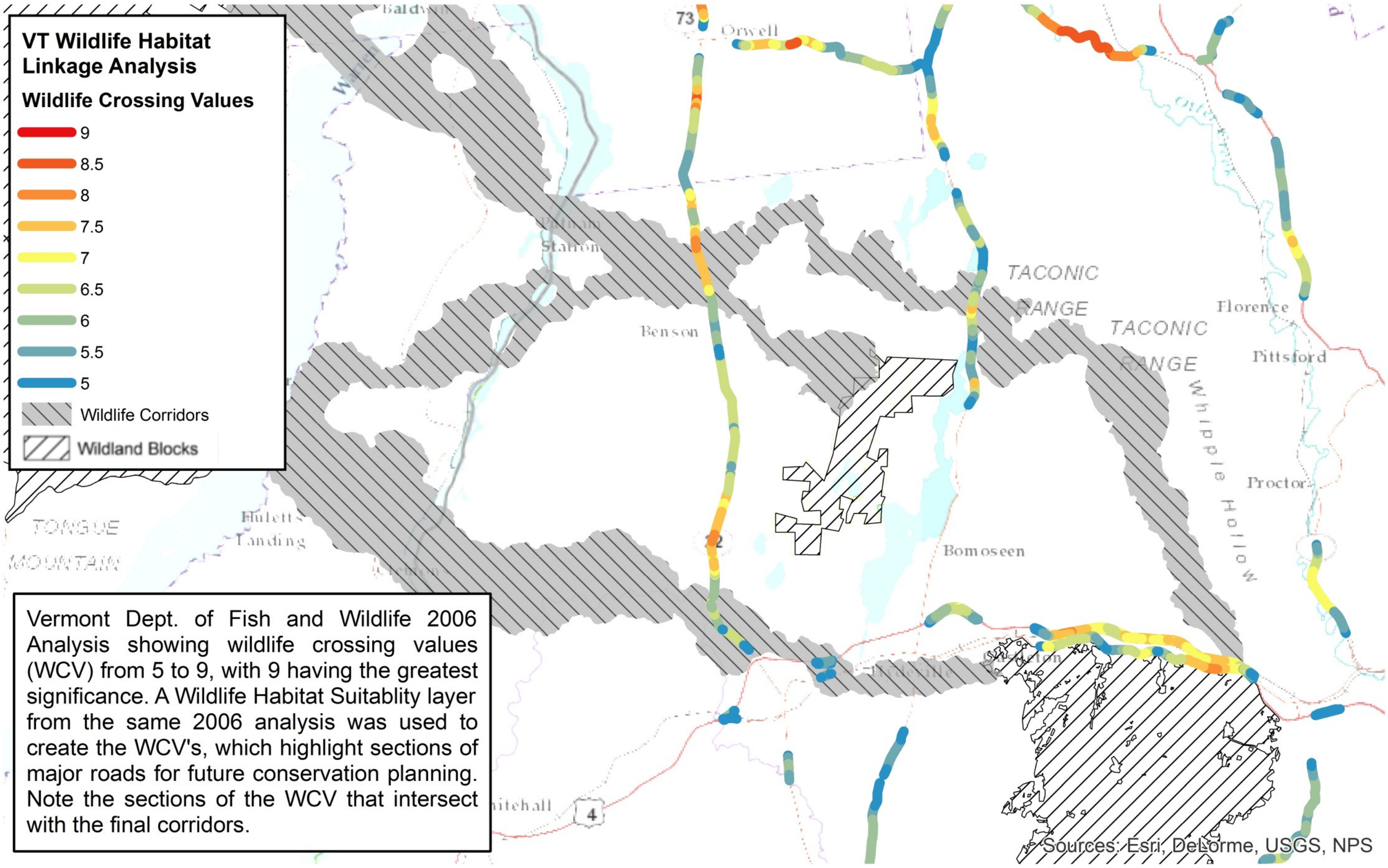


Forest blocks identified by the VT Agency of Natural Resources. The 10-class ranking is based on the block's biological and conservation value.

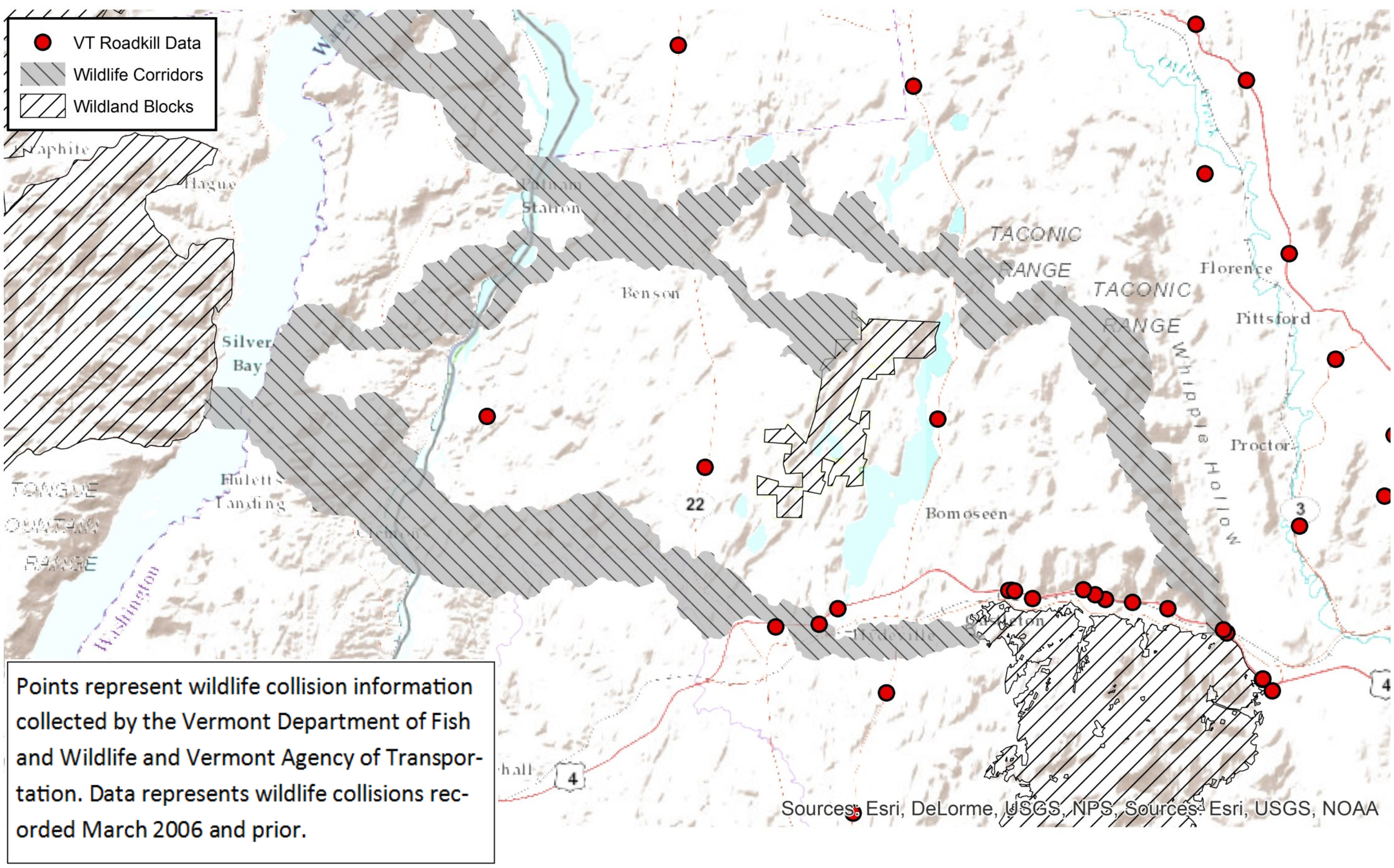


Forest blocks identified by the VT Agency of Natural Resources. The 10-class ranking is based on the block's potential threat of fragmentation.

(Source: Vermont Habitat Blocks and Wildlife Corridors: An Analysis using Geographic Information Systems, Vermont Fish & Wildlife Department, 2011, by Eric Sorenson - Vermont Fish & Wildlife Department and Jon Osborne - Vermont Land Trust)

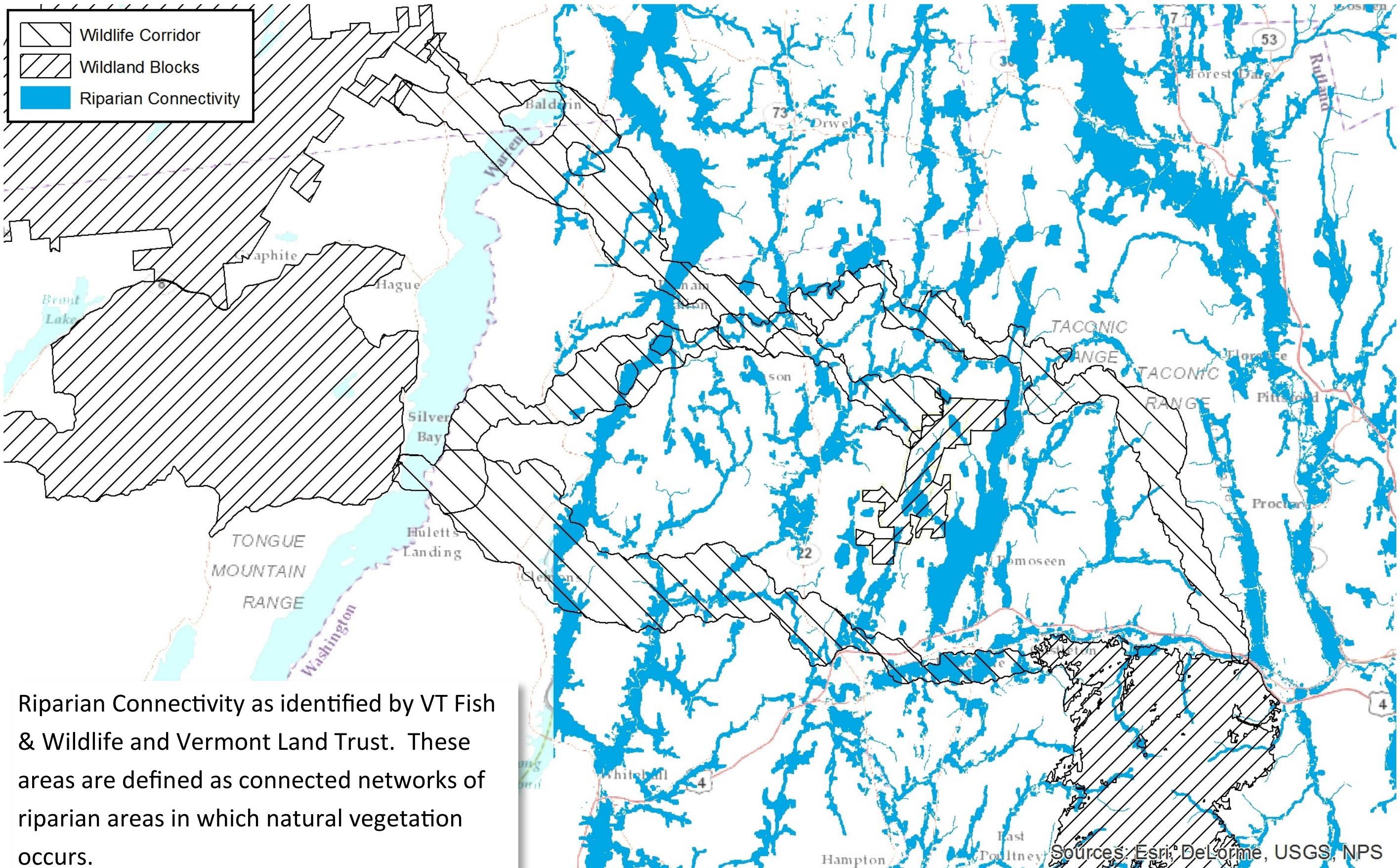


Vermont Dept. of Fish and Wildlife 2006 Analysis showing wildlife crossing values (WCV) from 5 to 9, with 9 having the greatest significance. A Wildlife Habitat Suitablity layer from the same 2006 analysis was used to create the WCV's, which highlight sections of major roads for future conservation planning. Note the sections of the WCV that intersect with the final corridors.

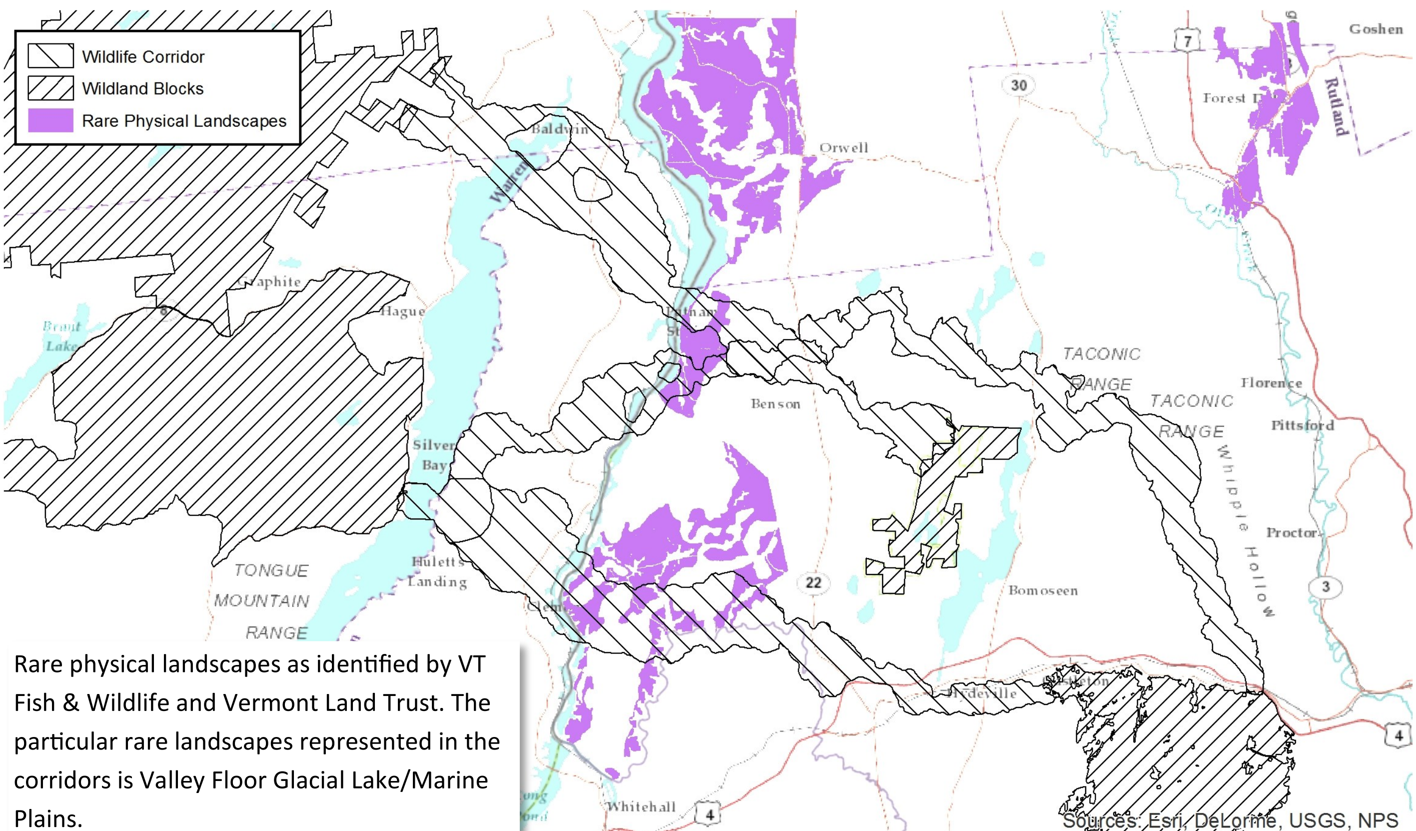


Points represent wildlife collision information collected by the Vermont Department of Fish and Wildlife and Vermont Agency of Transportation. Data represents wildlife collisions recorded March 2006 and prior.

(Source: 2006 Vermont Department of Fish and Wildlife and Vermont Department of Transportation: Wildlife Linkage Habitat Analysis)

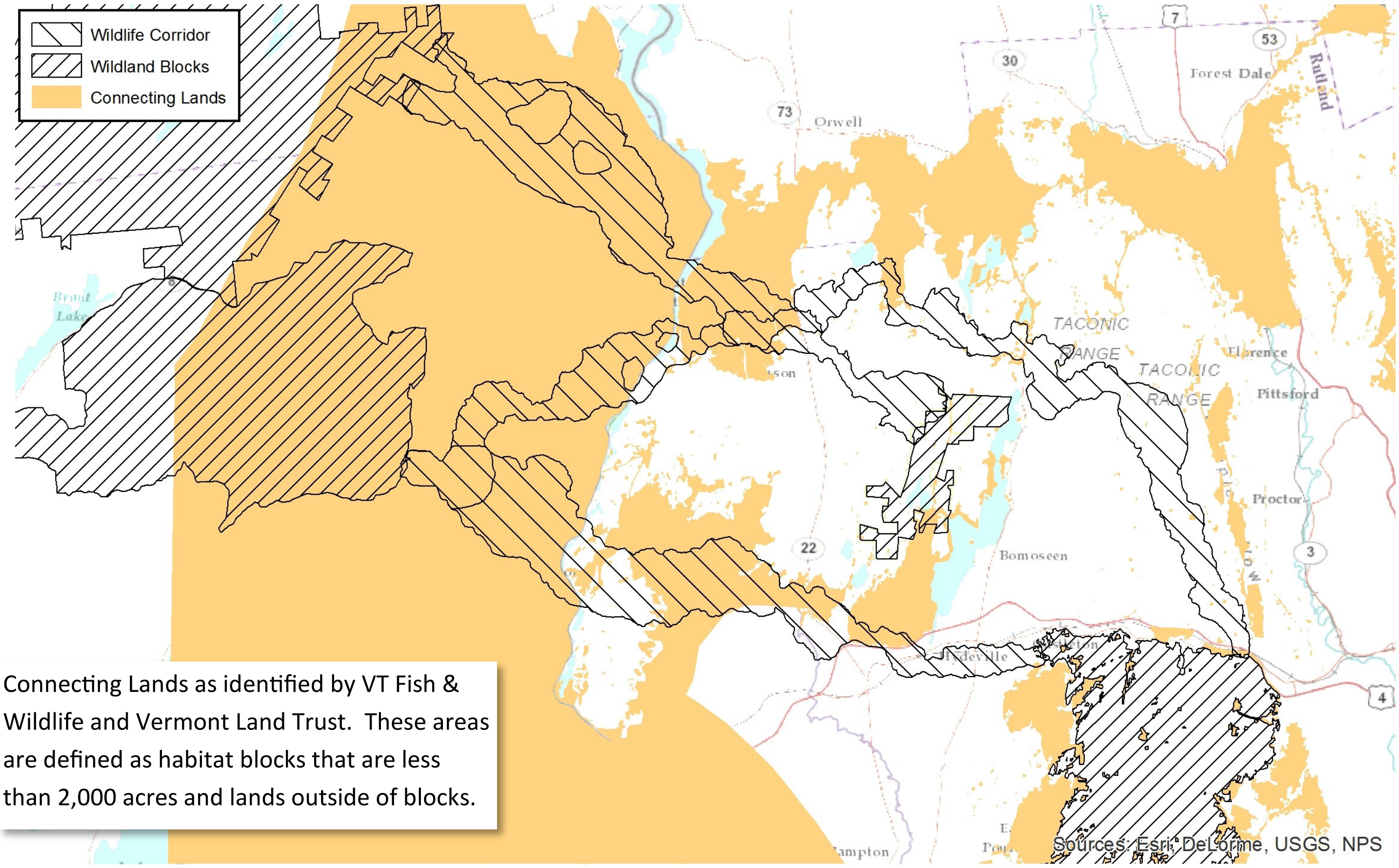


Riparian Connectivity as identified by VT Fish & Wildlife and Vermont Land Trust. These areas are defined as connected networks of riparian areas in which natural vegetation occurs.

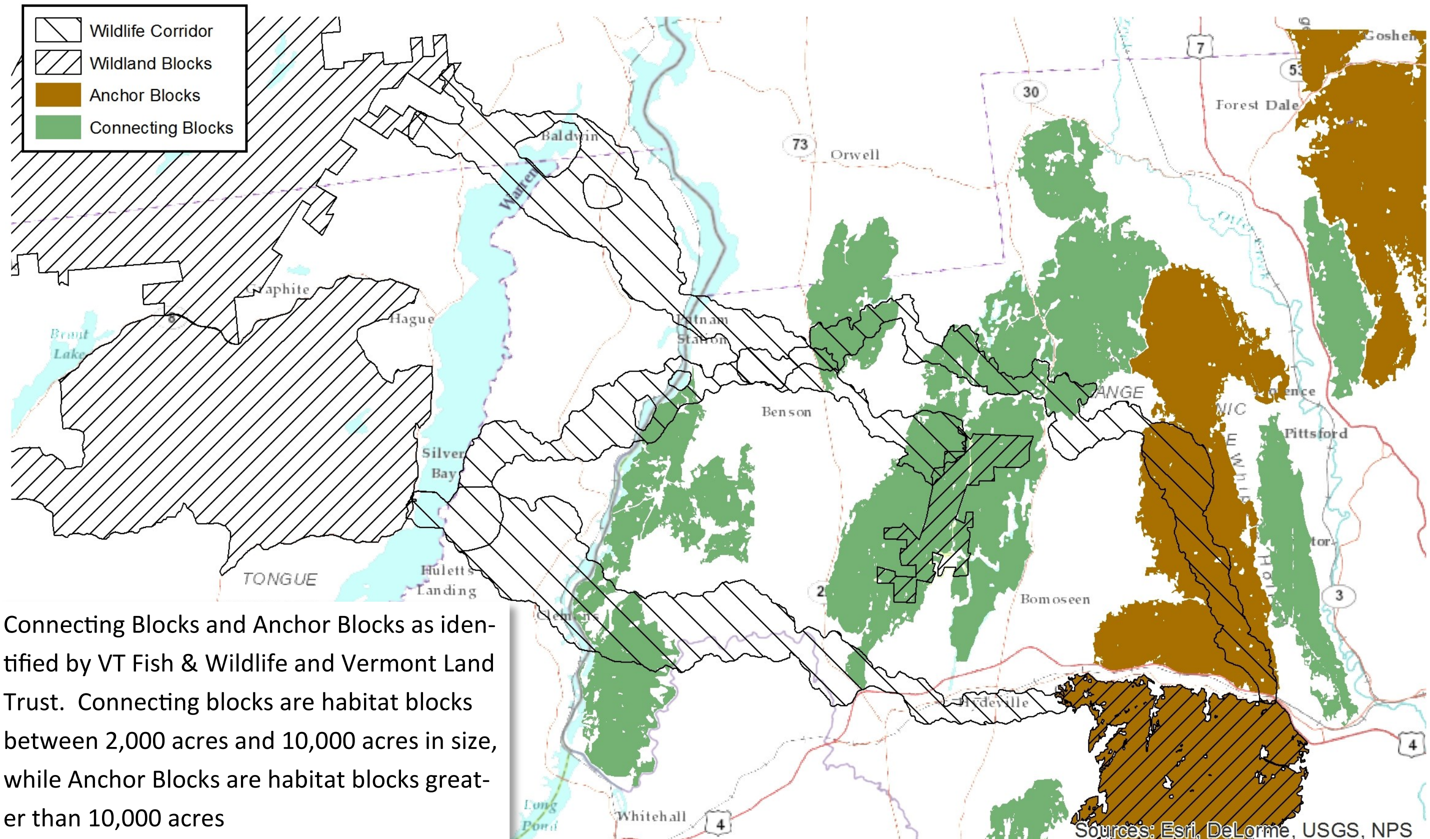


Rare physical landscapes as identified by VT Fish & Wildlife and Vermont Land Trust. The particular rare landscapes represented in the corridors is Valley Floor Glacial Lake/Marine Plains.

(Source: Vermont Conservation Design: Maintaining and Enhancing an Ecologically Functional Landscape, 2015. Produced by Eric Sorenson, Robert Zaino, and Jens Hilke - VT Fish & Wildlife; Liz Thompson - Vermont Land Trust)

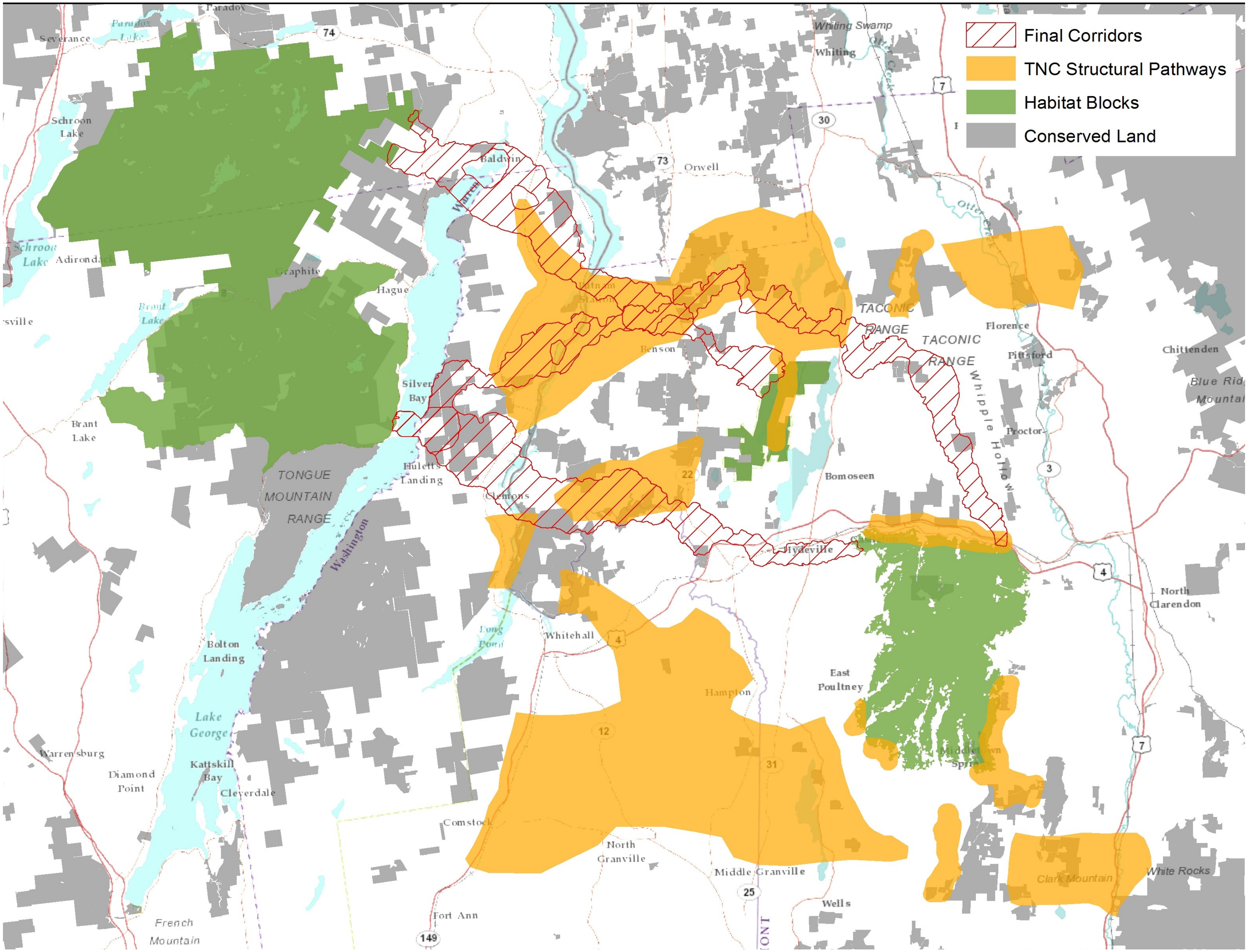


Connecting Lands as identified by VT Fish & Wildlife and Vermont Land Trust. These areas are defined as habitat blocks that are less than 2,000 acres and lands outside of blocks.

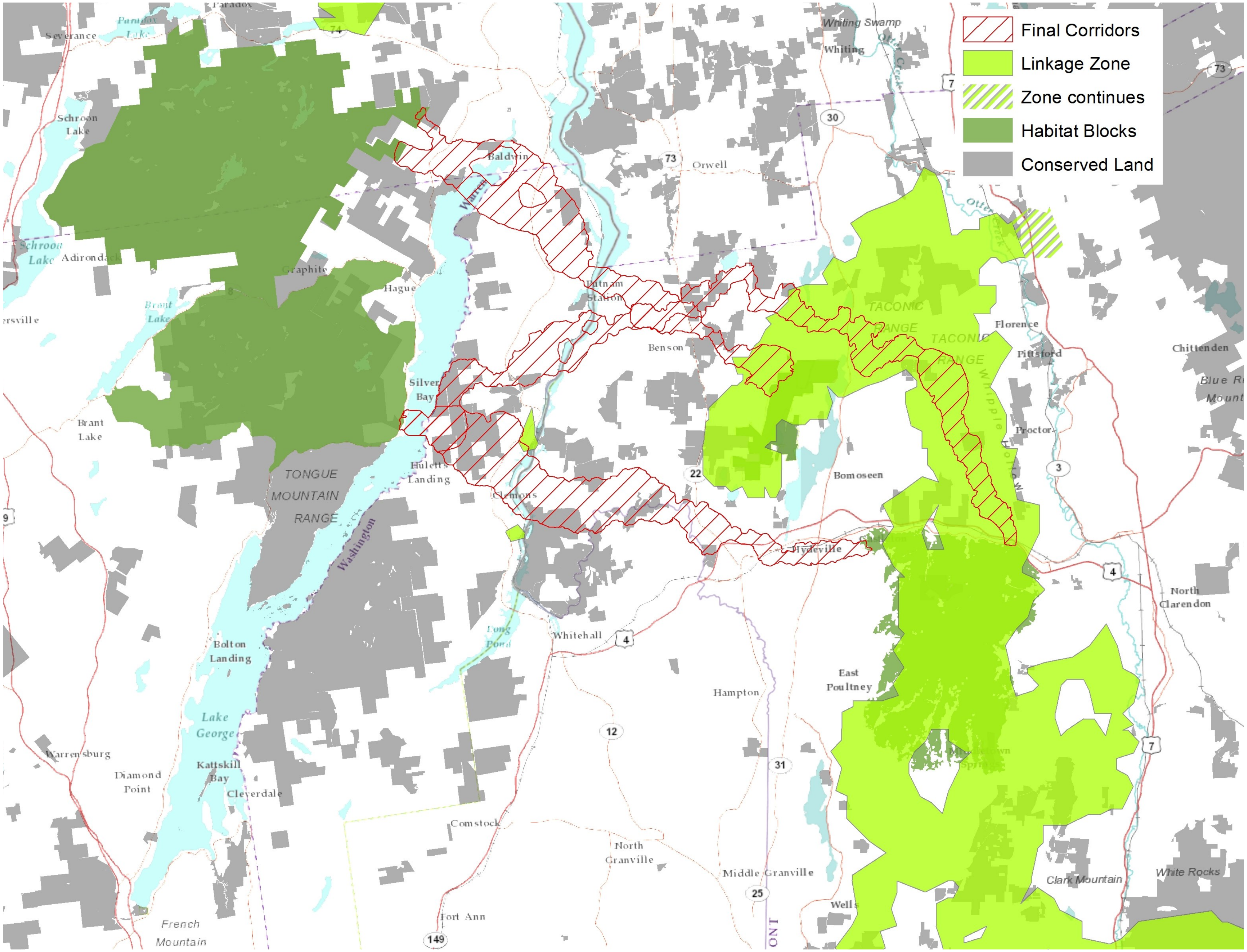


Connecting Blocks and Anchor Blocks as identified by VT Fish & Wildlife and Vermont Land Trust. Connecting blocks are habitat blocks between 2,000 acres and 10,000 acres in size, while Anchor Blocks are habitat blocks greater than 10,000 acres

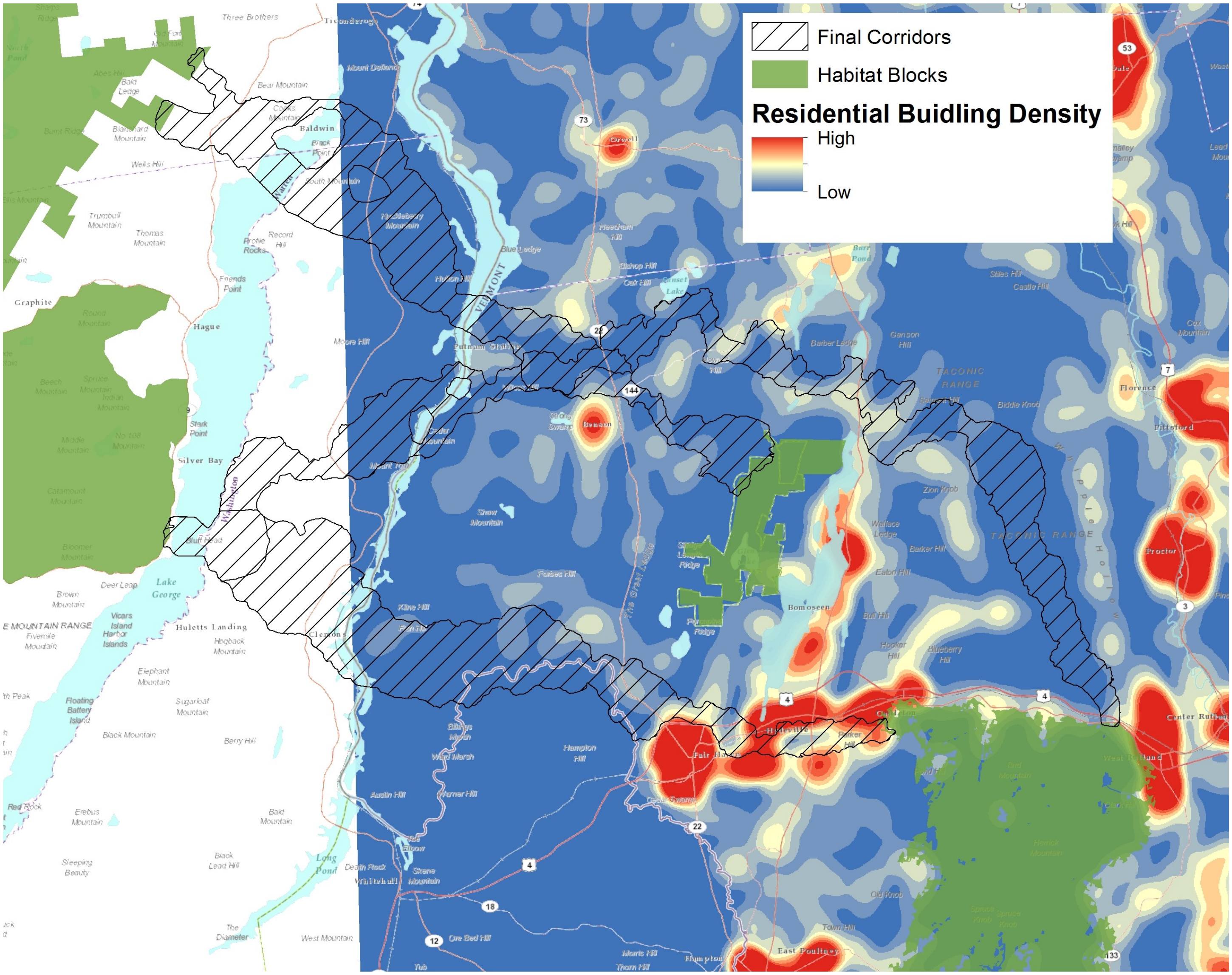
(Source: Vermont Conservation Design: Maintaining and Enhancing an Ecologically Functional Landscape, 2015. Produced by Eric Sorenson, Robert Zaino, and Jens Hilke - VT Fish & Wildlife; Liz Thompson - Vermont Land Trust)



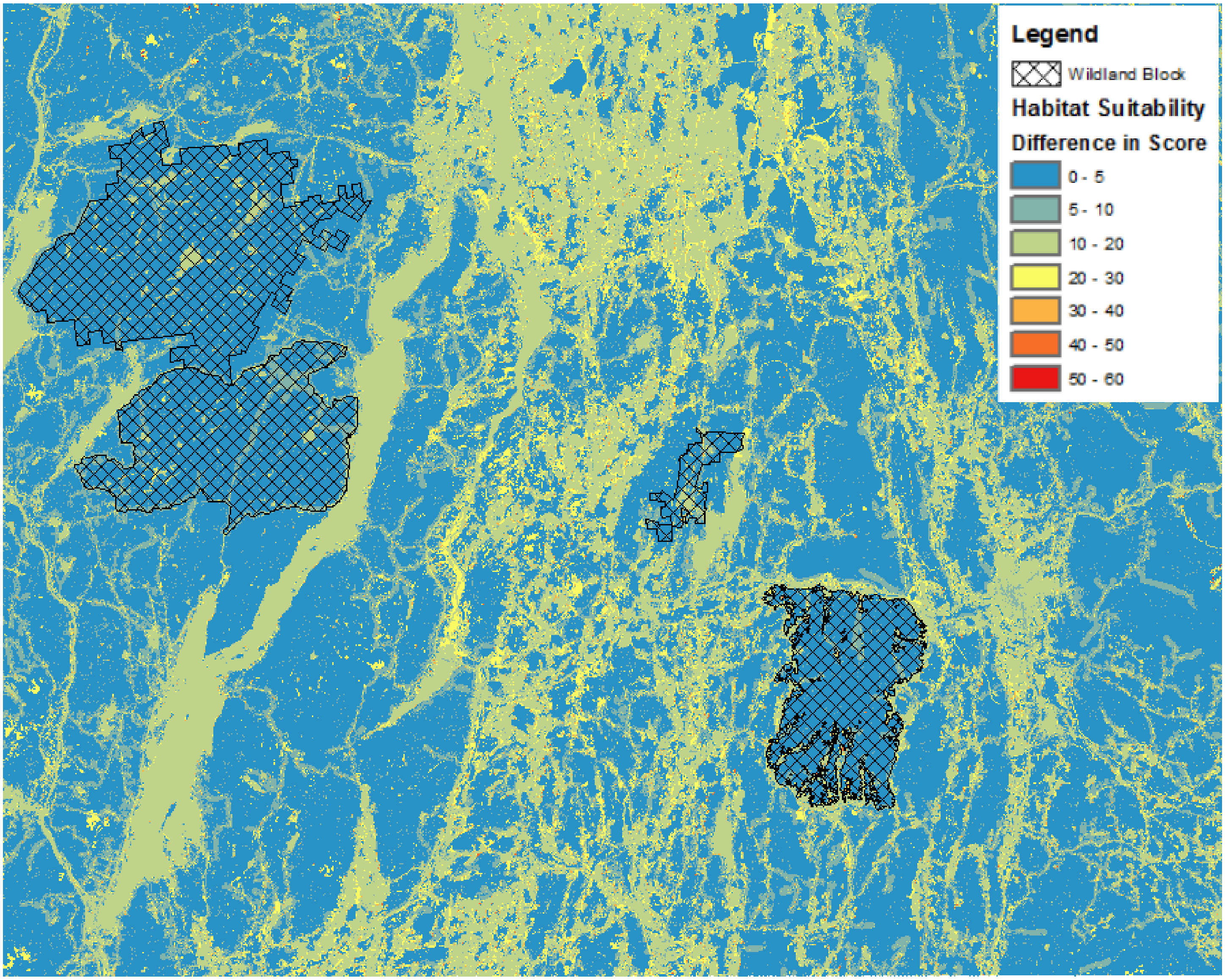
Map depicting the three corridors defined in this study in relation to corridors defined in a Nature Conservancy study conducted in 2013.



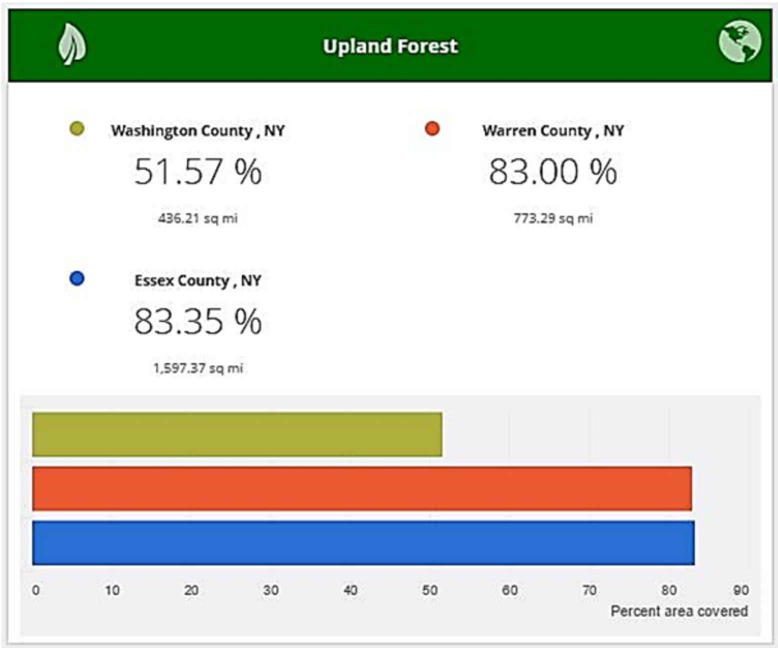
Map depicting the three corridors defined in this study in relation to corridors defined by The New York Department of Environmental Conservation for their 2011 strategic plan for state forest management.

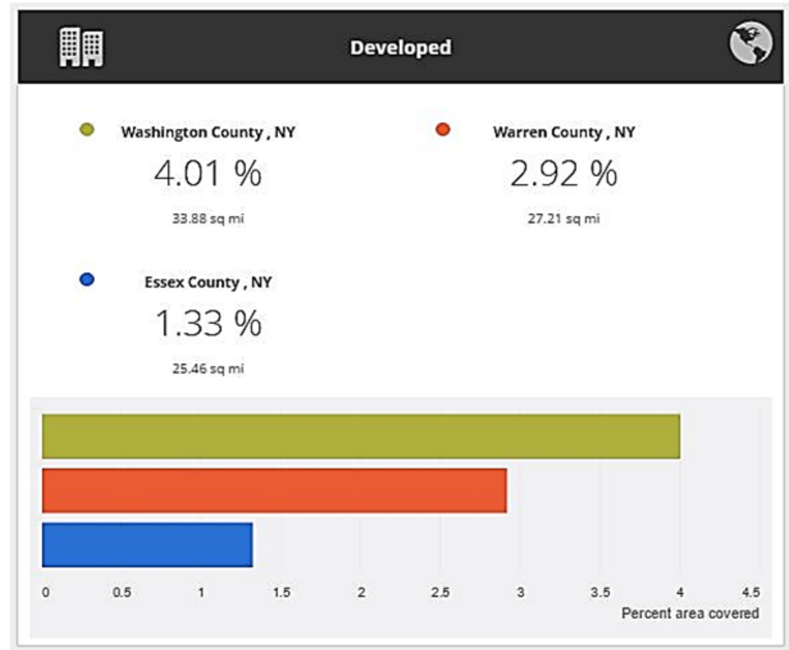


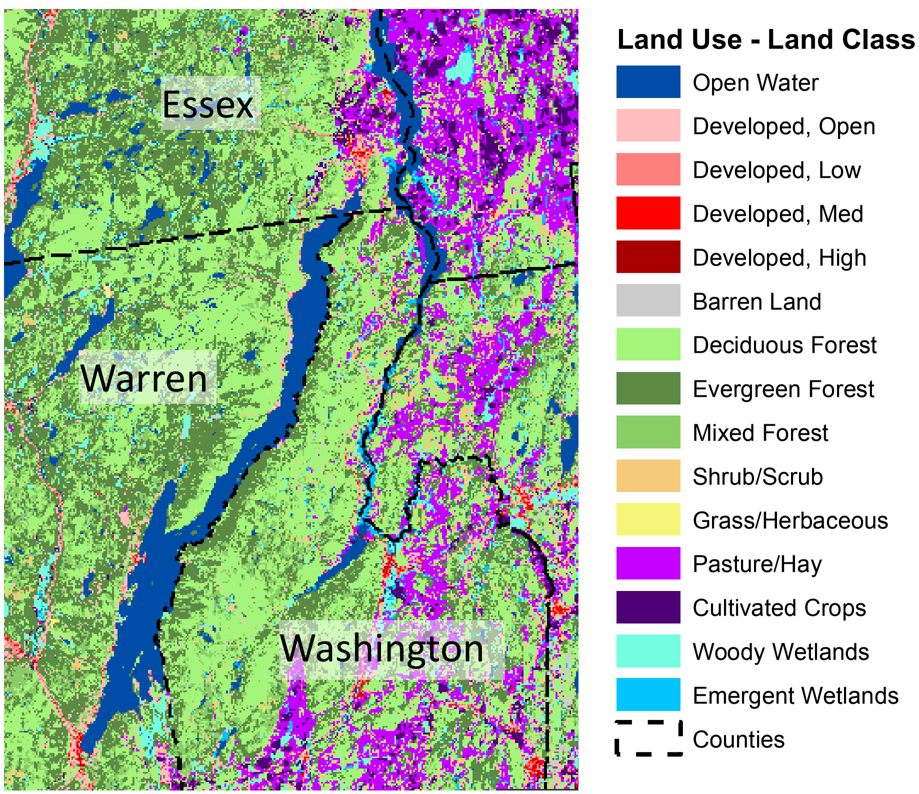
This map depicts the three final corridors and residential density. The Vermont building density model was developed by the VT Center for Geographic Information in 2008. Residential buildings are defined as any structures identified as year round dwellings

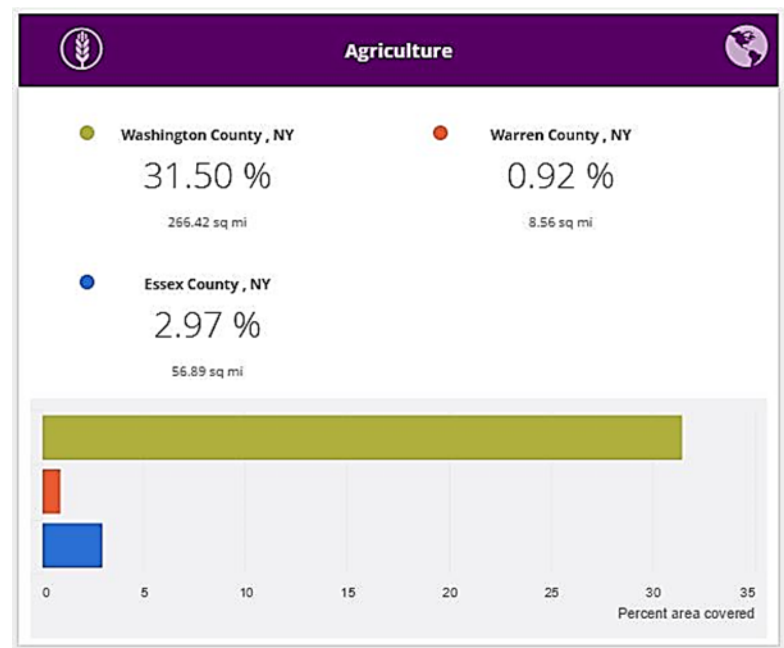


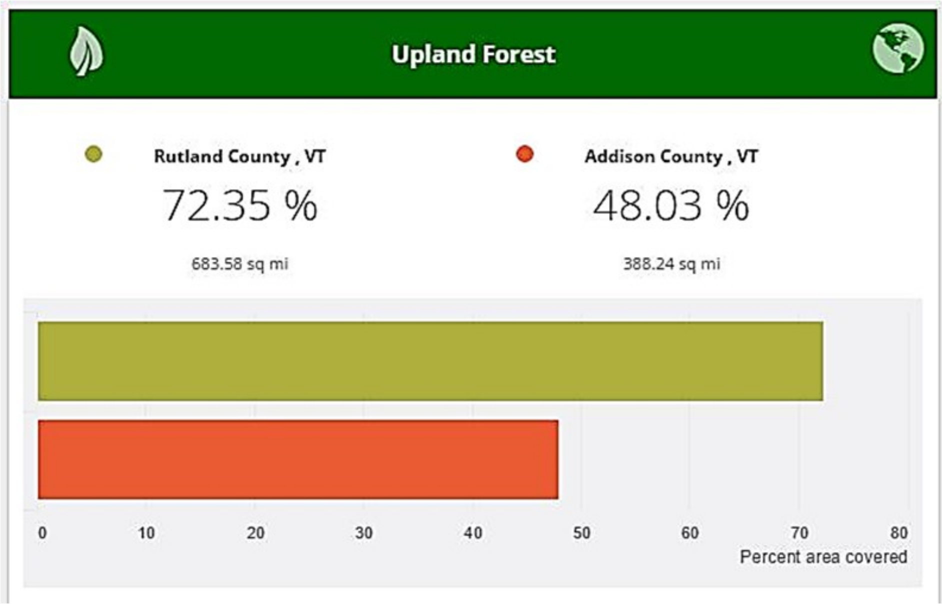
This map depicts the difference (in absolute value) between model outputs using arithmetic mean and geometric mean to derive habitat suitability models. A greater degree of difference occurs were habitat is lower quality (e.g. near roads, development, etc.). This study utilized the arithmetic mean to combine landscape factors. In corridor design, it is important to take note of such decisions and how they lead to separate understandings of the landscape.

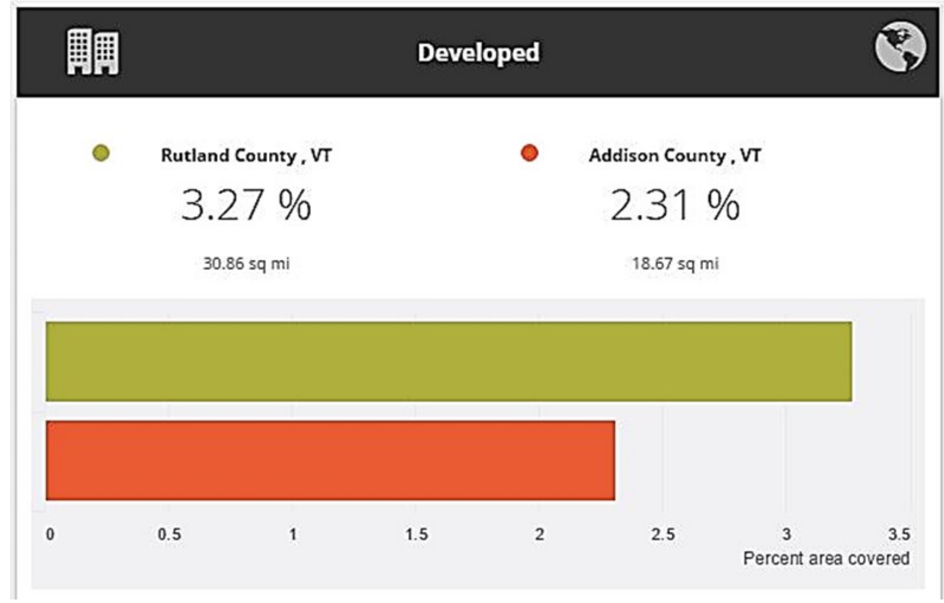

Upland Forest
Washington County, NY
51.57 %
436.21 sq mi
Warren County, NY
83.00 %
773.29 sq mi
Essex County, NY
83.35 %
1,597.37 sq mi
0 10 20 30 40 50 60 70 80 90
Percent area covered

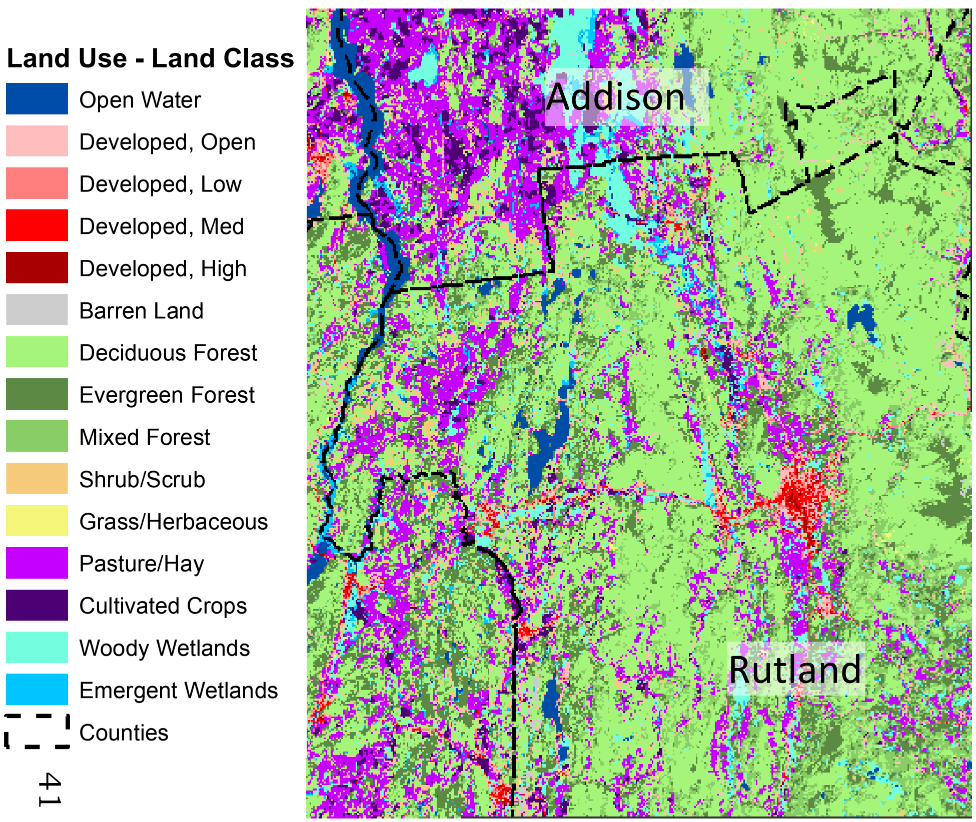

Developed
Washington County, NY
4.01 %
33.88 sq mi
Warren County, NY
2.92 %
27.21 sq mi
Essex County, NY
1.33 %
25.46 sq mi
0 0.5 1 1.5 2 2.5 3 3.5 4 4.5
Percent area covered

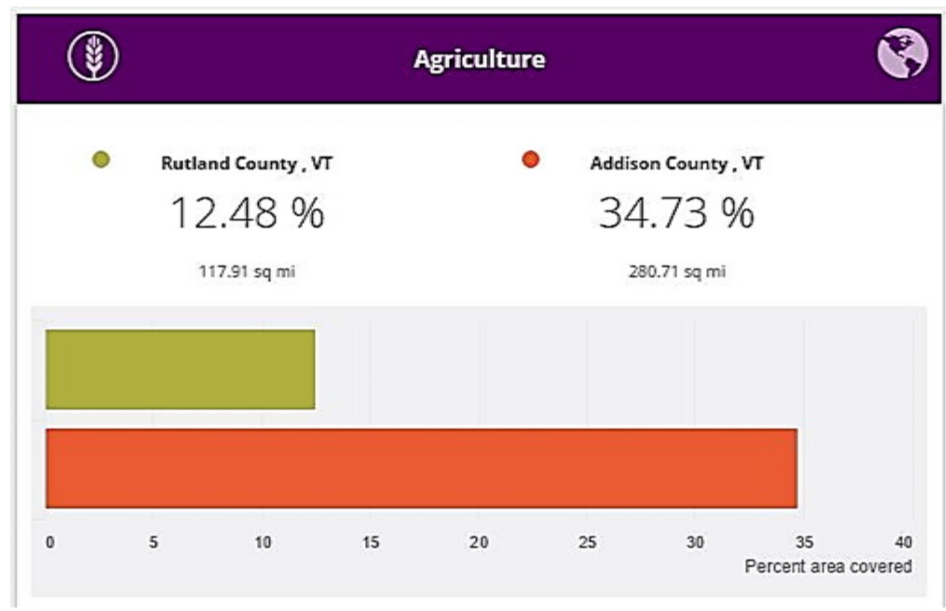

Essex
Warren
Washington
Land Use - Land Class
Open Water
Developed, Open
Developed, Low
Developed, Med
Developed, High
Barren Land
Deciduous Forest
Evergreen Forest
Mixed Forest
Shrub/Scrub
Grass/Herbaceous
Pasture/Hay
Cultivated Crops
Woody Wetlands
Emergent Wetlands
Counties


Agriculture
Washington County, NY
31.50 %
266.42 sq mi
Warren County, NY
0.92 %
8.56 sq mi
Essex County, NY
2.97 %
56.89 sq mi
0 5 10 15 20 25 30 35
Percent area covered


Upland Forest
Rutland County , VT
72.35 %
683.58 sq mi
Addison County , VT
48.03 %
388.24 sq mi
0
10
20
30
40
50
60
70
80
Percent area covered


Developed
Rutland County , VT
3.27 %
30.86 sq mi
Addison County , VT
2.31 %
18.67 sq mi
0
0.5
1
1.5
2
2.5
3
3.5
Percent area covered


Land Use - Land Class
Open Water
Developed, Open
Developed, Low
Developed, Med
Developed, High
Barren Land
Deciduous Forest
Evergreen Forest
Mixed Forest
Shrub/Scrub
Grass/Herbaceous
Pasture/Hay
Cultivated Crops
Woody Wetlands
Emergent Wetlands
Counties
Addison
Rutland


Agriculture
Rutland County , VT
12.48 %
117.91 sq mi
Addison County , VT
34.73 %
280.71 sq mi
0
5
10
15
20
25
30
35
40
Percent area covered

Landscape Factor and Class	Permeability Score	Biologically Plausible Range
	Black Bear: Land Cover Classification	
Developed, High Intensity	10	0 - 30
Developed, Medium Intensity	30	0 - 30
Developed, Low Intensity	30	0 - 30
Developed, Open Space	30	0 - 40
Cultivated Crops	40	30 - 60
Pasture/Hay	10	10 - 50
Grassland/Herbaceous	40	20 - 50
Deciduous Forest	100	80 - 100
Evergreen Forest	80	60 - 80
Mixed Forest	90	80 - 100
Scrub/Shrub	90	80 - 90
Palustrine Forested Wetland	60	50 - 70
Palustrine Scrub/Shrub Wetland	60	50 -70
Palustrine Emergent Wetland	60	50 - 70
Bare Land	0	0
Open Water	30	10 -40
Mean Permeability Score	48	
	Black Bear: Topographic Position	
Valley Bottom	50	40-70
Flat-gentle Slope	50	30-60
Steep Slope	50	20-50
Ridgetop	80	40-90
Mean Permeability Score	58	
	Black Bear: Distance to Roads	
0 - 50 m	10	0-30
50-200 m	20	10-40
> 200 m	100	60-100
Mean Permeability Score	43	

Summary of landscape factor classes and the black bear permeability scores assigned to each class (i.e., 0 indicates a completely resistant or completely unusable class and 100 represents completely traversable, optimal habitat) including the biologically plausible range for each score. (Source: Graves and Wang (2012))

Landscape Factor and Class	Permeability Score	Biologically Plausible Range
	Bobcat: Land Cover Classification	
Developed, High Intensity	10	0 - 30
Developed, Medium Intensity	30	0 - 30
Developed, Low Intensity	30	0 - 30
Developed, Open Space	30	0 -40
Cultivated Crops	40	30 - 50
Pasture/Hay	30	20 - 50
Grassland/Herbaceous	40	30 - 50
Deciduous Forest	70	60 - 80
Evergreen Forest	90	80 - 100
Mixed Forest	100	80 - 100
Scrub/Shrub	80	60 - 100
Palustrine Forested Wetland	90	70 - 100
Palustrine Scrub/Shrub Wetland	60	50 - 80
Palustrine Emergent Wetland	60	40 - 70
Bare Land	0	0
Open Water	30	10-40
Mean permeability value	49	
	Bobcat: Core vs. Edge Habitat	
Forest Core	30	20 - 60
Forest Intermediate	50	30 - 80
Wetland Core	30	20 - 60
Wetland Intermediate	50	30 - 80
Edge	80	40 - 80
Mean permeability value	48	
	Bobcat: Distance to Roads	
0 - 100 m	30	10-50
> 100 m	90	40 - 100
Mean permeability value	60	
	Bobcat: Distance to Streams	
0 - 30 m	90	50 -90
30 - 75 m	70	50 - 90
> 75 m	60	30 - 90
Mean permeability value	73	

Summary of landscape factor classes and the bobcat permeability scores assigned to each class (i.e., 0 indicates a completely resistant or completely unusable class and 100 represents completely traversable, optimal habitat) including the biologically plausible range for each score. (Source: Graves and Wang (2012))

Landscape Factor and Class	Permeability Score	Biologically Plausible Range
	Fisher: Land Cover Classification	
Developed, High Intensity	10	0-30
Developed, Medium Intensity	30	0-30
Developed, Low Intensity	30	0-30
Developed, Open Space	10	0-40
Cultivated Crops	30	10-50
Pasture/Hay	10	5-40
Grassland/Herbaceous	30	10-50
Deciduous Forest	60	50-70
Evergreen Forest	100	90-100
Mixed Forest	100	90-100
Scrub/Shrub	50	40-60
Palustrine Forested Wetland	60	50-70
Palustrine Scrub/Shrub Wetland	60	40-60
Palustrine Emergent Wetland	60	30-60
Bare Land	0	0
Open Water	30	10-40
Mean permeability score	42	
	Fisher: Canopy Cover (%)	
0-25	10	10-40
25-50	20	10-50
50-75	70	40-80
75-100	100	60-100
Mean permeability score	50	
	Fisher: Distance to Roads	
0 - 50 m	20	10-40
50 - 100 m	40	10-60
> 100 m	100	40-100
Mean permeability score	53	
	Fisher: Distance to Streams	
0 - 50 m	100	60-100
50 - 200 m	80	50-90
> 200 m	50	40-80
Mean permeability score	77	

Summary of landscape factor classes and the fisher permeability scores assigned to each class (i.e., 0 indicates a completely resistant or completely unusable class and 100 represents completely traversable, optimal habitat) including the biologically plausible range for each score. (Source: Graves and Wang (2012))