PEER REVIEW

Wildlife Habitat Linkages in the Eastern Adirondacks

Applying Functional Connectivity Modeling to Conservation Planning for Three Focal Species

By ROSE A. GRAVES and DEANE WANG

Abstract

As habitat loss and fragmentation increase across the northeastern United States, identifying and prioritizing connecting routes between protected areas has taken on new urgency. Protecting habitat linkages, or corridors, in which species can live and move between core habitats is a useful strategy for maintaining biodiversity, reducing the negative effects of habitat fragmentation, and potentially mitigating effects of climate change. Spatial models are an informative tool to predict the best locations for conservation corridors by incorporating specific landscape features and the available information on wildlife behavior and preferences. As large landscape conservation initiatives gain traction in the conservation community, conservation planners can use spatial tools to conduct connectivity analyses as opposed to creating conservation plans through ad-hoc methods.

Here we present a case study using CorridorDesigner, a free software program, and modeled landscape resistance surfaces based on expert knowledge to predict a habitat linkage location that could provide functional connectivity for three focal species: black bear (Ursus americanus), bobcat (Lynx rufus), and fisher (Martes pennanti) in the Split Rock Wildway conservation planning area (SRW) in Essex County, NY. The analysis area was limited to the SRW in order to provide comparison with an existing conservation effort. The methods described in this paper provide a cost-effective, science-based, and transparent way to assess habitat connectivity for conservation planning. This assessment: (1) provides a functional habitat linkage for three mammal species, (2) evaluates the uncertainty in resistance surfaces used to predict that habitat linkage, and (3) compares the predicted functional habitat linkage to an existing ad-hoc linkage effort in the same conservation planning area. In the SRW, our model suggests that the best functional habitat linkage for black bear, bobcat, and fisher is located south of a current ad-hoc initiative. This functional habitat linkage location differed significantly from the ad-hoc linkage in location as well as in the perceived resistance to movement for each species. Multiple model simulations tended to converge on the same functional habitat linkage. Our results suggest that the predicted functional habitat linkage should be included in conservation plans aimed at maintaining landscape connections between the Split Rock Wild Forest and the larger wild areas of the Adirondack Park.

Introduction

Over the last two decades, ecologists have recognized the importance of landscape connectivity as it relates to the conservation of biodiversity, mitigation of habitat fragmentation, and the potential for species to respond to changes in land use and climate (Bennett, 2003; Crooks & Sanjayan, 2006a; Ewers & Didham, 2006; Giles, 1998; Lindenmayer et al., 2008; Soule and Noss, 1998). Increased landscape connectivity can help prevent negative population-level effects due to isolation and could facilitate increased population sizes, viability, and dispersal of species (Crooks & Sanjayan, 2006b; Hanski, 1999; Harrison, 1992; Noss, 1983; Noss, 1987). It is generally assumed that connected reserves support larger populations that are less likely to succumb to local random extinction and that landscape connectivity facilitates movement of organisms among patches resulting in greater genetic exchange between populations and minimizing the loss of genetic variation. Conservation of habitat linkages or movement corridors has been recognized as one potential way to maintain habitat connectivity (Beier & Noss, 1998; Crooks & Sanjayan 2006a; Dixon et al., 2006; Driezen et al., 2007; Haddad et al., 2000; Huck et al., 2011). The connectivity of a landscape for wildlife can be described as: functional, referring to how a particular landscape's structure affects an animal's behavior; or structural, which refers to the spatial arrangement and proximity of habitat patches, regardless of an individual animal's perception. While many conservation scientists agree that connected landscapes are desirable, there is little agreement on how to measure and incorporate landscape connectivity into

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conservation plans (Berke, 2007; Kindlmann & Burel, 2008).

At the same time that landscape-level conservation strategies are increasingly encouraged (Bateson, 2005; Crooks & Sanjayan, 2006a; Hilty et al., 2006; Noss, 1987; Prato & Fagre, 2007), it has been recognized that systematic conservation planning is more effective than ad-hoc planning of the past (Chetkiewicz et al., 2006; Margules & Pressey, 2000; Noss, 2003). However, it is often difficult for small land conservation organizations to incorporate these ideas into their local work. Small land organizations often rely on connectivity analyses conducted by larger organizations, which may be inappropriate in scale and extent to allow for local identification and prioritization of land conservation projects (Berke, 2007; Groves et al., 2002). Conservation initiatives can be more successful by incorporating an understanding of animal movement across a landscape, but availability of empirical data can be a challenge for organizations with limited financial and human resources.

Connectivity conservation in the Northern Appalachian/Acadian ecoregion provides one example of this challenge. An ecoregional analysis conducted by Canadian and U.S. scientists working with the organization Two Countries, One Forest (2C1F) identified five top conservation priorities to maintain the ecological health and connectivity across the ecoregion (Bateson, 2005; Trombulak et al., 2008). They concluded that the link between the Adirondack Park and Vermont's Green Mountains was vital to the health of the Northern Appalachian/Acadian ecoregion and was likely to be compromised in the future; however, they did not provide specific actionable conservation priorities within that linkage. More recent analysis provided several possible linkages between the Adirondack and Green Mountains but remained focused on a regional scale (Baldwin et al., 2010).

The Split Rock Wildway Planning Area (SRW) located in Essex County, NY and within an area identified by 2C1F scientists as highly irreplaceable and highly threatened represents an opportunity to maintain an important steppingstone within this regional linkage area (Figure 1). Several local partners and conservation groups identified this area as a priority in which to restore and preserve habitat with the goal of linking wilderness areas in the northern Adirondack Park with the Champlain Lowlands and Lake Champlain to the east (Northeast Wilderness Trust, 2009). No systematic assessment of landscape

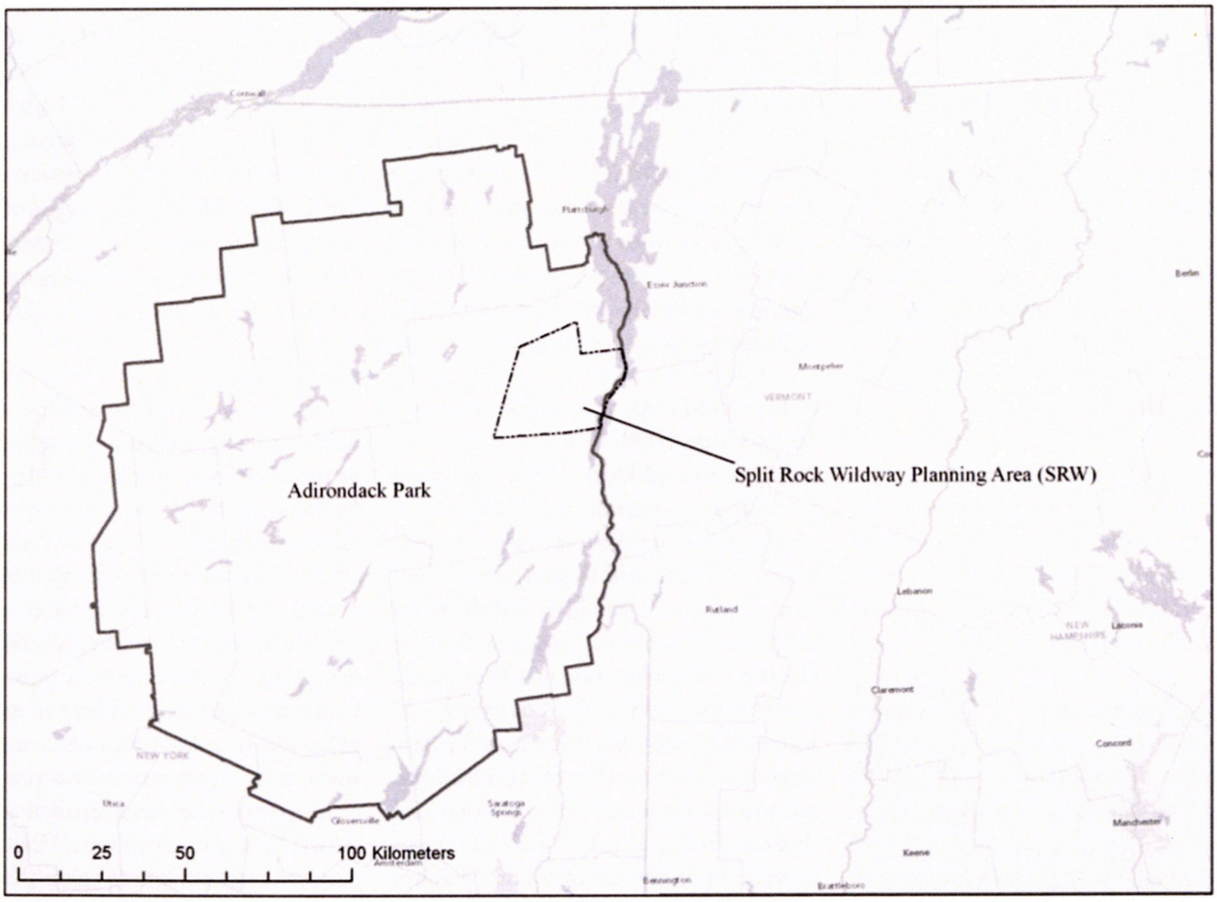


Figure 1. *The Split Rock Wildway Planning Area in Essex County, NY located at the eastern edge of the Adirondack Park. Inset shows Two Countries, One Forest in the northeastern United States and Canada, with arrows indicating wildlife corridor conservation priority locations (Trombulak et al., 2008).*

connectivity in the SRW has been conducted and GIS data identifying conservation priorities are at a scale of 10 km^2 or higher (Baldwin et al., 2010; Trombulak et al., 2008). Previous conservation planning within the SRW has been ad-hoc, has focused on structural connectivity to link previously conserved lands, and included the identification of an ad-hoc habitat linkage based on local conservationists' input (New York State Department of Environmental Conservation, 2005).

Geographic information system (GIS) and cost-distance models provide an opportunity to use species-specific information regarding habitat preferences "to identify critical corridors and permeable habitats" and to assess the functional connectivity of a landscape (Walker & Craighead, 1997). Cost-distance models, which represent landscape resistance by assigning an ecological cost to an animal crossing a particular landscape, have been used to describe connectivity for amphibians, birds, and mammals (see Sawyer et al., 2011). Many conservation organizations and government agencies have also used cost-distance modeling to guide conservation planning (Bates & Jones, 2007; Brown et al., 2010; Long, 2007; Singleton et al., 2002; Singleton & Lehmkuhl, 2001; Zeh & Marangolo, 2010). The difficulty and the financial and time costs associated with collecting empirical data on animal movement and genetic flow across a landscape make GIS models attractive to organizations interested in understanding functional connectivity in their conservation priority areas and several free software tools exist to help organizations do this (Calabrese & Fagan, 2004; Carroll, 2010; Majka et al., 2007; Shah & McRae, 2008; Theobald et al., 2006). Where detailed species and movement data are lacking, models based on expert knowledge, using peer-reviewed literature and personal communication with wildlife biologists, have been used in conservation designs and connectivity analyses (Beier et al., 2008; Chetkiewicz et al., 2006; Sawyer et al., 2011).

We used CorridorDesigner, a free GIS toolkit, and species-specific GIS models of landscape resistance to identify a functional habitat linkage within the SRW for three focal species: black bear (*Ursus americanus*), bobcat (*Lynx rufus*), and fisher (*Martes pennanti*). We chose these focal species based on the availability of literature on movement patterns and habitat use, their status as wide-ranging vertebrates with large area requirements, and their inclusion in existing conservation plans in the region (Brown et al., 2010; Long, 2007; Zeh & Marangolo, 2010). Black bear are wide-ranging mammals and are considered landscape species that require a variety of habitats to meet their life history requirements (Costello, 1992; Rogers & Allen, 1987; Schoen, 1990; Simek, 1995). Their seasonal movements, large home range sizes, and relatively low natural densities make black bears vulnerable to habitat fragmentation (Hammond, 2002; Lariviere, 2001). Bobcats are also described as sensitive to habitat fragmentation and urbanization (Crooks, 2002; Hansen, 2007; Riley et al., 2003). Connectivity of habitats may be particularly important for dispersing juvenile bobcats (Johnson et al., 2010). Fisher populations have been described as inherently unstable and subject to local extinctions and colonizations (Buskirk & Powell, 1994; Powell et al., 2003). While fisher are broadly described as forest carnivores sensitive to human development and disturbance, fishers fitted with global positioning system (GPS) collars in urban Albany, NY adjusted daily activity patterns but continued to select for connected forest habitat (LaPoint & Kays, 2011).

We sought to answer the following questions: 1) What habitat linkage provides the best functional connectivity for all three focal species within the SRW? 2) How does uncertainty in the model parameter values affect the landscape resistance models used to predict the habitat linkage? and 3) How does the predicted functional habitat linkage compare to an existing ad-hoc linkage effort in the same conservation planning area? Finally, we hope to illustrate a user-friendly method for assessing connectivity at a local scale within the budget of a small non-profit conservation organization.

Study Area

The study area encompasses approximately 900 km^2 of primarily forested and agricultural land in the western Lake Champlain Basin (Figure 1). Fully within the boundary of the Adirondack Park, it is a mosaic of public and private ownership containing a diversity of habitats ranging in elevation from 29 m at the Lake shore to 1,219 m at the top of Giant Mountain. Forests within the study area include spruce-fir (*Picea spp., Abies balsamea*), evergreen-northern hardwood, and mesic upland hardwoods dominated by sugar maple (*Acer saccharum*), American beech (*Fagus grandifolia*), and yellow birch (*Betula allegheniensis*) as well as patches of oak (*Quercus spp.*) forest and successional hardwoods. Non-forest communities include forested and open wetlands, open water, current and abandoned agricultural lands, and low- to medium-intensity development areas.

A 139-km^2 wildland block owned by the State of New York, including Jay and Giant Wilderness Areas and Hurricane Mountain Primitive Use Area, is located on the western side of the study area. The eastern side of the study area borders Lake Champlain and includes a second New York State–owned wildland block, Split Rock Wild Forest. The 15-km^2 Split Rock Wild Forest represents the largest block of undeveloped land on the western shore of Lake Champlain. The geodesic (non-Euclidean) distance between the Jay and Giant Wilderness Areas block and Split Rock Wild Forest is 21 km, and this area, referred to as the Split Rock Wildway conservation planning area, is intersected by one major interstate, three major state routes, and a multiple local roads. The identified ad-hoc habitat linkage follows a route southeast from the Jay Wilderness Area to Split Rock Wild Forest (Northeast Wilderness Trust, 2009) (Figure 2).

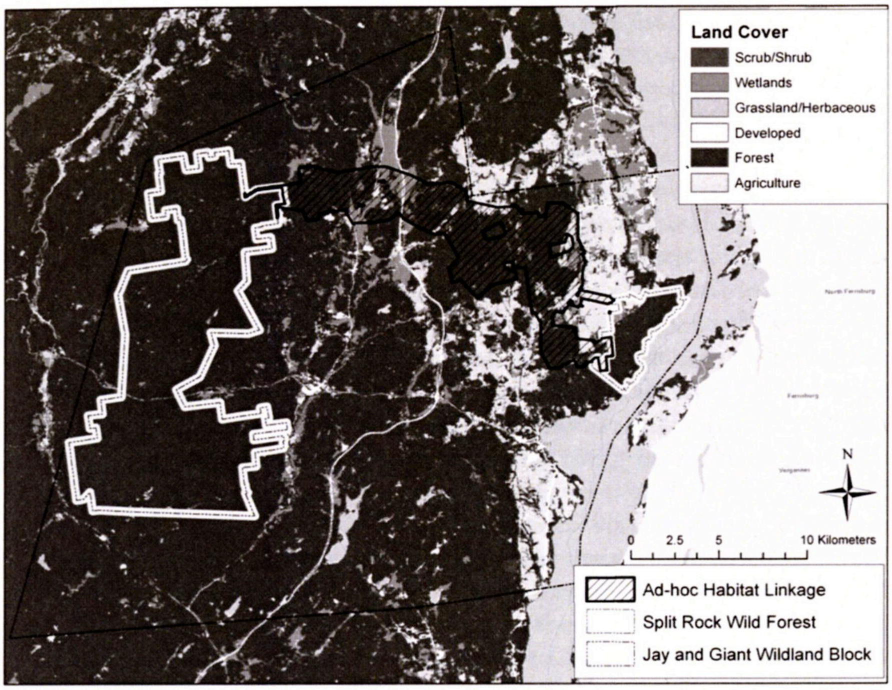


Figure 2. *The ad-hoc habitat linkage plan follows a route from the Jay Wilderness Area southeast to Split Rock Wild Forest, crossing forests, wetlands, and agricultural lands (Northeast Wilderness Trust, 2009).* (See p. 32 for color.)

Methods

Many approaches exist for modeling and identifying habitat linkages (Hargrove et al., 2004; Majka et al., 2007; Shah & McRae, 2008; Theobald et al., 2006; Urban & Keitt, 2001; Walker & Craighead, 1997). We chose to use CorridorDesigner to conduct cost-distance modeling to identify habitat linkages between habitat blocks (Adriaensen et al., 2003; Beier et al., 2008; Beier et al., 2006; Majka et al., 2007; Singleton et al., 2002). Cost-distance methods use GIS models of a species' perception of the landscape based on the known or assumed ability of that species to move across different landscape features (i.e., the *permeability* or *ecological cost* of those features) (Adriaensen et al., 2003; Kirk & Zielinski, 2010; Singleton & Lehmkuhl, 2001; Walker et al., 2007). Algorithms within CorridorDesigner calculate the minimum cost-distance paths across a modeled landscape wherein the cumulative ecological cost to move between two points is minimized (Majka et al., 2007). Identifying habitat linkages first required creating GIS models of landscape resistance for each of the focal species which were used in CorridorDesigner to calculate minimum cost-distance habitat linkages.

Modeling Landscape Resistance

The process for developing a GIS raster (pixel) resistance surface followed three steps. First, we identified which landscape factors to include in the model and the factor weights in determining overall resistance. We then scored the classes within each landscape factor according to their permeability (e.g., a high permeability has a low resistance to movement). Third, we combined landscape factors using GIS to assign a score to each pixel (Beier et al., 2008; Beier et al., 2006; Sawyer et al., 2011). The first two steps of our landscape resistance models relied on expert-knowledge to assign parameters (Clevenger et al., 2002; Beier et al., 2008).

For each focal species, we reviewed the scientific literature associated with habitat requirements and movement patterns to develop species- and study area–specific models of resistance. Where possible we used studies locate in the northeastern United States, paying particular attention to studies o the focal species in the Adirondac Park of New York, and in the Champlain Valley and Green Mountains o Vermont. From this review, we selecte landscape factors that are most likely t influence movement of the focal species. Because of the prevalence of li erature describing habitat use and th corresponding lack of literature relate directly to animal movement or dispe sal, we followed the major assumptio that animals choose travel routes base on the same factors they use to selec habitat (Beier et al., 2008; Chetkiewic et al., 2006; Sawyer et al., 2011). Th most important landscape factors we not the same for all species. The fin landscape factors used in the mod were those identified in the literatu review as most important for determining species-specific landscape resistanc and also available or derivable as GI data. Some factors that likely influenc species movements across the landscap (e.g., density of conspecific competito or prey density) were not available i GIS data layers and thus not include in the model. The final selection o landscape factors was species-specifi and was reviewed by biologists wh studied the focal species.

For each species resistance mode the landscape factors were assigne a weight based on the relative impo tance of each factor in determining th resistance of any particular landscap pixel for the focal species (Table 1 Weights for a species summed to 100 Within each landscape factor include in a species model, we assigned a pe meability score to each class (e.g., deciduous forest or high intensity deve opment classes within the land cove landscape factor). Permeability score were set, based on our best estimate from the literature review and inpu by biologists, such that 0 indicated completely resistant (non-traversable unusable habitat and 100 represente optimal habitat. Scores were assigned a

Table 1. *Summary of habitat factor weights and data sources used in the habitat suitability model as well as the identified biologically plausible range for each weight. This range provided the basis for analyzing the uncertainty associated with the identified habitat linkages.*

Species	Landscape Factor	GIS Data Source	Landscape Factor Weight	Biologically Plausible Range	Relevant Citations
Black Bear	Land Cover	Land cover types for the study area were extracted from the National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center Coastal Change Analysis Program (C-CAP) Land Cover Layer. This layer was most recently updated in 2006 and contains 18 classes within the study area.	75	70–80	(Landers et al., 1979; Hall, 1981; Hugie, 1982; Rogers & Allen, 1987; Elowe & Dodge, 1989; Schoen, 1990; Costello, 1992; Boileau et al., 1994; McLaughlin et al., 1994; Schooley et al., 1994; Simek, 1995; Powell et al., 1996; McLaughlin, 1998; Lariviere, 2001; Hammond, 2002; Mitchell et al., 2002; Austin et al., 2005; Kart et al., 2005; Long, 2006; Reed, 2010)
	Distance to Roads (m)	Straight-line (Euclidean) distance to the nearest road was calculated for each pixel using GIS tools and the road data produced by the New York State Department of Transportation (NY DOT) in 2003.	20	15–30	(Lentz et al., 1980; Villarrubia, 1982; Rogers & Allen, 1987; Brody & Pelton, 1989; Beringer et al., 1990; Kasworm & Manley, 1990; Clark et al., 1993; Simek, 1995; Brandenburg, 1996; Fecske et al., 2002; Hammond, 2002; NY DEC, 2007)
	Topographic Position	Each 30m x 30m pixel was characterized as ridge, valley bottom, flat/gentle slope or steep slope using a GIS tool and elevation data from the National Elevation Dataset distributed by the United States Geological Survey (USGS).	5	0–10	(Simek, 1995; Hammond, 2002; Reed, 2010)
Bobcat	Land Cover	See above.	65	50–90	(Maclachlan, 1981; Livaitis et al., 1986; Morris, 1986; Boyle & Fendley, 1987; Livaitis et al., 1987; Fox, 1990; Lovallo & Anderson, 1996a; Sunquist & Sunquist, 2002; Woolf et al., 2002; Long, 2006; Tucker et al., 2008)
	Core/Edge Habitat	Data for this habitat factor were extracted from 30 m resolution C-CAP Land Cover (2006). We extracted and merged all forest types and forested wetlands and used ArcGIS tools to classify the pixels as edge (within 30 m of another habitat type), core (30–300 m), and deep core (> 300 m from edge).	15	10–30	(Abouelezz, 2009).
	Distance to Roads (m)	See above.	10	5–20	(Lovallo & Anderson, 1996b; Long, 2006; Abouelezz, 2009)
	Distance to Streams (m)	The Euclidean distance to the nearest stream was calculated for each pixel using a streams layer from the Adirondack Park Agency.	10	5–15	(Kolowski & Woolf, 2002; Tigas et al., 2002; Riley et al., 2003; Hilty & Merenlender, 2004)
Fisher	Land Cover	See above.	40	30–60	(Kelly, 1977; Allen, 1983; Arthur, 1987; Arthur & Krohn, 1991; Buck et al., 1994; Buskirk & Powell, 1994; Potter, 2002; Long, 2006; Lancaster et al., 2008)
	Canopy Cover (%)	The percent canopy cover was extracted from 2001 National Land Cover Dataset (NLCD) canopy density layer. This dataset is available from the Multi-Resolution Land Characteristics Consortium (MRLC).	40	20–60	(Coulter, 1966; Allen, 1983; Powell, 1993; Buck et al., 1994; Buskirk & Powell, 1994; Powell et al., 2003)
	Distance to Roads (m)	See above.	10	5–20	(Coulter, 1966; Buskirk & Powell, 1994; Dark, 1997; Fisher, 2004; Barnum et al., 2007)
	Distance to Streams (m)	See above.	10	0–20	(deVos, 1952; Allen, 1983; Aubry & Houston, 1992; Heinemeyer, 1993; Buck et al., 1994; Jones & Garton, 1994; Morse, 2010)

multiples of 10 with 10–30 representing strongly avoided habitat, 40–60 representing marginal habitat, 60–80 as suboptimal habitat, and 80–100 as strongly preferred habitat/completely traversable (Beier et al., 2008; Beier et al., 2009; Majka et al., 2007). After the factor weight and resistance scores were assigned for each landscape factor, we assigned a minimum and maximum possible value to provide an assumed biologically plausible range of uncertainty for each model parameter (Table 2) (Johnson & Gillingham, 2004). We based the final assignment of permeability scores on the available literature, existing habitat and connectivity models, and the opinions of species experts who reviewed our habitat suitability scores (Krohn, 2010; Marangelo, 2010; Morse, 2010; Reed, 2010).

Land cover was considered the most important landscape factor for all three species and received the highest weight in the models. Straight-line (Euclidean) distance to roads was included in all three resistance models. Other landscape factors included Euclidean distance to streams (bobcat and fisher), topographic position (black bear), percent canopy cover (fisher), and core/edge habitat (bobcat).

Black Bear. Based on the literature and expert opinion, black bear respond primarily to forest cover and human development, as well as the availability of foraging habitat (Table 1). Movements tend to be associated with food availability and with avoidance of certain features that can be captured in land cover data. Hammond (2002) suggested that black bears in Vermont avoid areas up to 200 m from roads during all seasons. Other studies have found road avoidance for black bears to range from 100 m to 1,000 m (Brandenburg, 1996; Brody & Pelton, 1989; Clark et al., 1993; Fecske et al., 2002; Kasworm & Manley, 1990; Lentz et al., 1980; Villarrubia, 1982). Roads contribute to mortality of black bears and were found to be the leading cause of non-hunter mortality in the central Adirondacks (Simek, 1995), thus distance to roads was included as a factor in the black bear landscape resistance model. Topographic position was also included in the model as black bears in regions similar to the study area may preferentially use ridgelines as travel corridors (Reed, 2010).

Bobcat. Land cover was identified as the most important factor influencing bobcat movement (Table 1). In addition, bobcats appear to avoid roads (Abouelezz, 2009; Long, 2006; Lovallo & Anderson, 1996b). Bobcats in the upper Champlain Valley and Green Mountains of Vermont tended to avoid "deep forest" (>300 m from edge) and used forest and wetland edge (0–30 m from edge) disproportionately, suggesting that forest edges, wetlands, and streams are important movement corridors to connect larger blocks of habitat (Abouelezz, 2009). We included a core/edge habitat landscape factor as well as a

Table 2. *Summary of landscape factor classes and the species-specific 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 as well as the compressed and dispersed values used to create alternate scenarios.*

Landscape Factor and Class	Permeability Score	Biologically Plausible Range	Compressed Value	Dispersed Value
Black Bear: Land Cover Classification				
Developed, High Intensity	10	0–30	30	0
Developed, Medium Intensity	30	0–30	30	0
Developed, Low Intensity	30	0–30	30	0
Developed, Open Space	30	0–40	40	0
Cultivated Crops	40	30–60	45	30
Pasture/Hay	10	10–50	45	10
Grassland/Herbaceous	40	20–50	45	20
Deciduous Forest	100	80–100	80	100
Evergreen Forest	80	60–80	60	80
Mixed Forest	90	80–100	80	100
Scrub/Shrub	90	80–90	80	90
Palustrine Forested Wetland	60	50–70	50	70
Palustrine Scrub/Shrub Wetland	60	50–70	50	70
Palustrine Emergent Wetland	60	50–70	50	70
Bare Land	0	0	0	0
Open Water	30	10–40	40	10
Mean Permeability Score	48			

Table 2. *(continued)*

Landscape Factor and Class	Permeability Score	Biologically Plausible Range	Compressed Value	Dispersed Value
Black Bear: Topographic Position				
Valley Bottom	50	40–70	58	40
Flat-gentle Slope	50	30–60	58	30
Steep Slope	50	20–50	50	20
Ridgetop	80	40–90	58	90
Mean Permeability Score	58			
Black Bear: Distance to Roads				
0–50 m	10	0–30	30	10
50–200 m	20	10–40	40	10
> 200 m	100	60–100	60	100
Mean Permeability Score	43			
Bobcat: Land Cover Classification				
Developed, High Intensity	10	0–30	30	0
Developed, Medium Intensity	30	0–30	30	0
Developed, Low Intensity	30	0–30	30	0
Developed, Open Space	30	0–40	40	0
Cultivated Crops	40	30–50	44	30
Pasture/Hay	30	20–50	44	20
Grassland/Herbaceous	40	30–50	44	30
Deciduous Forest	70	60–80	60	80
Evergreen Forest	90	80–100	80	100
Mixed Forest	100	80–100	80	100
Scrub/Shrub	80	60–100	60	100
Palustrine Forested Wetland	90	70–100	70	100
Palustrine Scrub/Shrub Wetland	60	50–80	50	80
Palustrine Emergent Wetland	60	40–70	44	70
Bare Land	0	0	0	0
Open Water	30	10–40	40	10
Mean Permeability Score	49			
Bobcat: Core vs. Edge Habitat				
Forest Core	30	20–60	48	20
Forest Intermediate	50	30–80	48	80
Wetland Core	30	20–60	48	20
Wetland Intermediate	50	30–80	48	80
Edge	80	40–80	48	80
Mean Permeability Score	48			
Bobcat: Distance to Roads				
0–100 m	30	10–50	50	10
> 100 m	90	40–100	60	100
Mean Permeability Score	60			
Bobcat: Distance to Streams				
0–30 m	90	50–90	73	90
30–75 m	70	50–90	73	50
> 75 m	60	30–90	73	30
Mean Permeability Score	73			

Table 2. *(continued)*

Landscape Factor and Class	Permeability Score	Biologically Plausible Range	Compressed Value	Dispersed Value
Fisher: Land Cover Classification				
Developed, High Intensity	10	0–30	30	0
Developed, Medium Intensity	30	0–30	30	0
Developed, Low Intensity	30	0–30	30	0
Developed, Open Space	10	0–40	37	0
Cultivated Crops	30	10–50	37	10
Pasture/Hay	10	5–40	37	5
Grassland/Herbaceous	30	10–50	37	10
Deciduous Forest	60	50–70	50	70
Evergreen Forest	100	90–100	90	100
Mixed Forest	100	90–100	90	100
Scrub/Shrub	50	40–60	40	60
Palustrine Forested Wetland	60	50–70	50	70
Palustrine Scrub/Shrub Wetland	60	40–60	40	60
Palustrine Emergent Wetland	60	30–60	37	60
Bare Land	0	0	0	0
Open Water	30	10–40	37	10
Mean Permeability Score	42			
Fisher: Canopy Cover (%)				
0–25	10	10–40	40	10
25–50	20	10–50	50	10
50–75	70	40–80	50	80
75–100	100	60–100	60	100
Mean Permeability Score	50			
Fisher: Distance to Roads				
0–50 m	20	10–40	40	10
50–100 m	40	10–60	53	10
> 100 m	100	40–100	53	100
Mean Permeability Score	53			
Fisher: Distance to Streams				
0–50 m	100	60–100	77	100
50–200 m	80	50–90	77	50
> 200 m	50	40–80	77	40
Mean Permeability Score	77			

distance to stream factor in the bobcat landscape resistance model.

Fisher. Habitat preferences for fisher vary regionally but can be generalized by habitat type; therefore, land cover was assigned as the most important landscape factor for fisher (Table 1). Allen (1983) suggested that optimal habitat was based on four variables: canopy closure, stand diversity, average size of stand, and percent deciduous cover. Based on the importance ascribed to canopy closure and fishers' often-cited avoidance of open areas, we chose to include a canopy cover landscape factor in the model. Fishers will travel through forested patches of non-preferred habitat to contiguous patches of preferred habitat and use riparian habitats as important travel corridors (Aubry & Houston, 1992; Buck et al., 1994; Heinemeyer, 1993; Jones & Garton, 1994). Thus we included distance to streams as an important landscape factor. Like black bear and bobcat, evidence suggests fisher avoid roads and roads in our study area contribute largely to the mortality of fisher (Coulter, 1966; Fisher, 2004; LaPoint, 2007).

For each species, GIS data layers were obtained for each landscape factor and transformed to Albers equal-area conic projection, 30 m x 30 m resolution raster layers using ArcMap 9.3.2. Using the CorridorDesigner toolbox for ArcGIS (Majka et al., 2007), we combined the landscape factors using a weighted geometric mean, as recommended by Beier et al. (2008), to produce an overall resistance score between 0 and 100 for each pixel (Majka et al., 2007).

Identifying Habitat Linkages

We used ArcGIS 9.3.2 and the CorridorDesigner toolbox (Majka et al. 2007) to identify habitat linkages in the SRW. CorridorDesigner allows planners to calculate the conditional minimum transit cost (CMTC), an extension of the minimum cost-distance, between two patches. CorridorDesigner requires inputs of landscape resistance layers and designated starting and ending patches (vector data layers). The tool randomly assigns multiple points within the starting and ending patches and calculates the pathways with the lowest cumulative resistance, or highest permeability, for each species (Majka et al., 2007; Pinto & Keitt, 2009; Sawyer et al., 2011).

We defined the starting and ending patches as the Jay and Giant Wilderness Areas block and the Split Rock Wild Forest, respectively. We constrained the program such that CorridorDesigner only chose starting points with a neighborhood (10 km^2) average suitability of 60 or greater. These criteria were chosen to ensure that sources within the starting and ending patches were large enough and of suitable habitat to support the focal species. We ran the CorridorDesigner toolkit for each species, setting a moving window of analysis of 200 m for black bear and 100 m for both bobcat and fisher. We required that the final path for each species meet the criteria of having an average width of over 1 km and a minimum width of 300 m (Beier et al., 2008; Majka et al., 2007). Finally, we merged the individual focal species paths to create a single functional habitat linkage for all three species in the SRW.

Alternate Scenarios

A major criticism of this habitat linkage modeling procedure involves the uncertainty surrounding landscape factor scores and weights (Beier et al., 2009; Clevenger et al., 2002; Sawyer et al., 2011). To examine the sensitivity of the resistance models (on which the habitat linkages are based) to changes in landscape factor weights and scores, we varied parameter inputs to create alternate scenarios for each focal species (i.e., black bear, 10; bobcat, 12; fisher, 12) following a methodology similar to Beier et al. (2009).

We varied factor weights and class permeability scores based on the biologically plausible range identified for each species (Tables 1 and 2). For each landscape factor, we determined the mean permeability score. We then created a compressed scenario for each landscape factor by reassigning the permeability scores to the value closest to the mean score while remaining in the biologically plausible range for each factor (Figure 3). Similarly, a dispersed scenario was

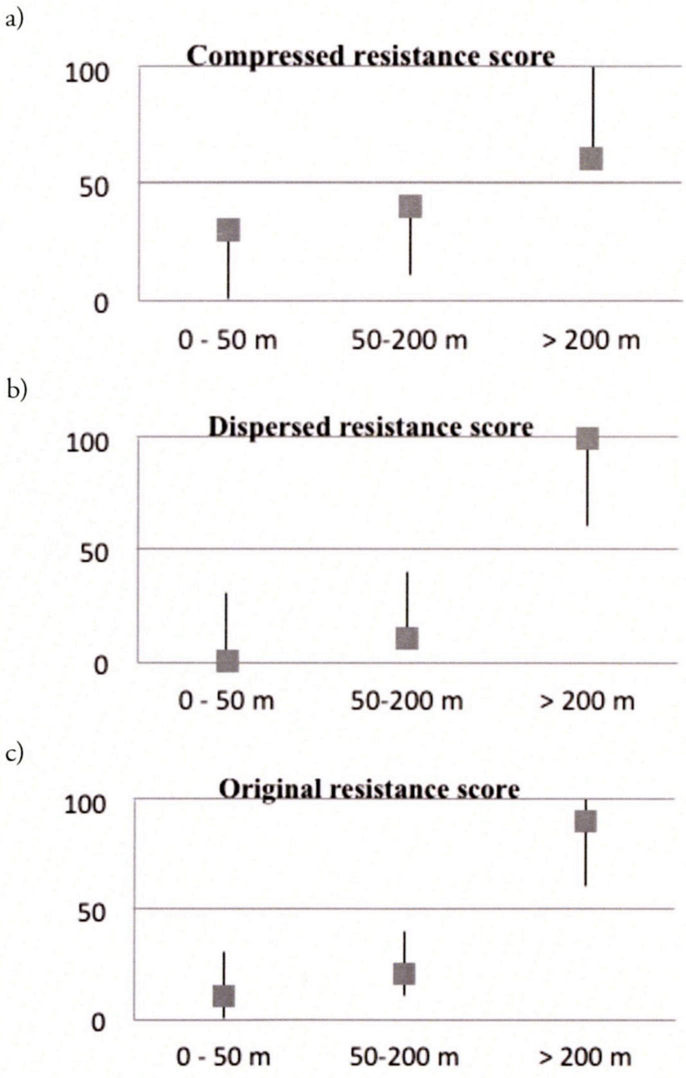


Figure 3. *Visual representation of (a) compressed and (b) dispersed permeability score scenarios for black bear landscape factor "distance to roads." The bars indicate the plausible biological range for each class within the landscape factor and the boxes indicate the permeability score. Note that the compressed permeability scores are more similar across all classes while the dispersed permeability scores are more spread out than the (c) original permeability scores.*

created for each landscape factor where the permeability scores were set to the value within the biologically plausible range, which maximized the difference from the mean score. We varied each factor's permeability scores while keeping the other factors constant and created two scenarios where we altered all of the landscape factors at once either compressing or dispersing all scores (Table 2). Finally, we created two alternate scenarios for each species wherein the weights of the landscape factors were either compressed or dispersed. For each scenario, we followed the procedure described above to create GIS raster layers of landscape resistance. The resistance surfaces calculated from these alternate scenarios were the same extent and spatial scale as the original resistance surfaces.

Each model run produced a map containing one observation per 30 m x 30 m pixel with a unique score, resulting in extremely large datasets (n > 990,000). To assess how each change in the parameter values affected the resulting resistance surfaces, we performed pixel-by-pixel comparisons using a Kappa test which provided an index that accounted for agreement due simply to chance between the alternate resistance surface models and the original resistance surface model (King, 2004; Levine et al., 2009; Monserud & Leemans, 1992). Generally, Kappa values closer to 1.0 indicate high agreement between two scenarios with 0.80–1.0 indicating almost perfect agreement and 0.01–0.20 indicating only slight agreement (Viera & Garrett, 2005). For each species, we also calculated the percent overlap between the alternate scenario habitat linkages and the predicted functional habitat linkage using spatial analysis tools within ArcGIS.

Comparison of Functional and Ad-hoc Habitat Linkages

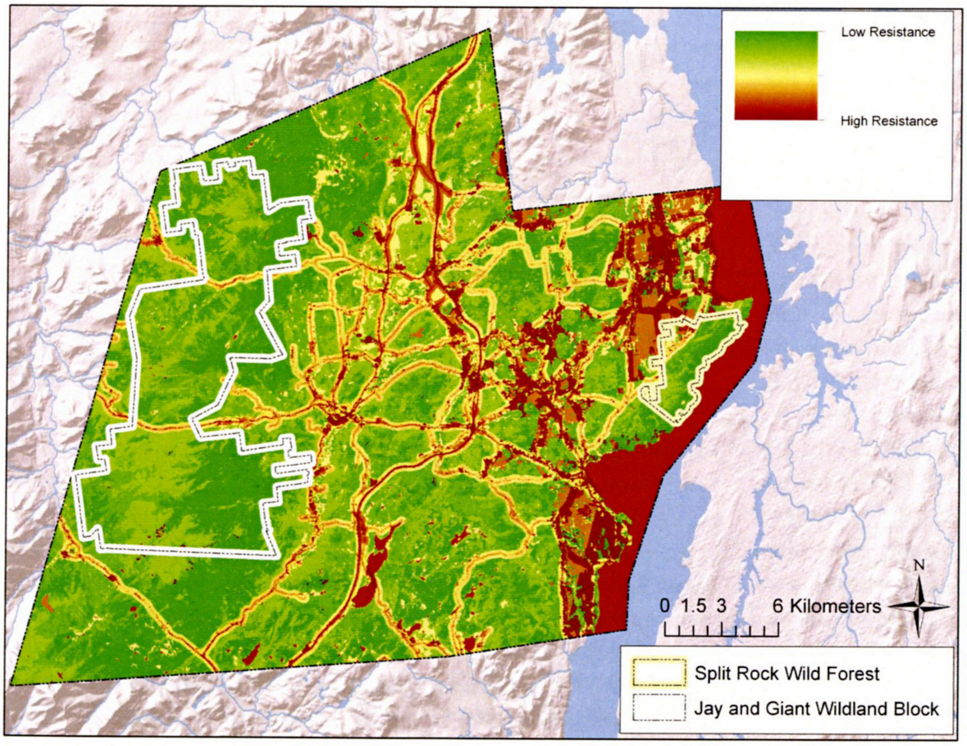
To assess differences between the functional habitat linkage and a previously identified ad-hoc habitat linkage (Northeast Wilderness Trust, 2009), we compared several landscape characteristics including the habitat quality for each species as described by the modeled landscape resistance surface (Beier et al., 2008). We assumed that areas modeled as low resistance corresponded to high habitat quality and vice versa (Beier et al., 2008; Beier et al., 2009; Majka et al., 2007). Using ArcGIS 9.3.2, we calculated the proportion of each habitat linkage within the major landcover classes, the proportion permanently conserved (GAP status 1–3; http://gapanalysis.nbii.gov/), the proportion within four habitat quality classes (i.e., avoided, marginal, sub-optimal, and preferred habitat) as defined in the landscape resistance model above, the road density within each habitat linkage, and the number of road crossings (defined as Class I–III roads completely crossing a linkage). These landscape characteristics allowed for qualitative comparison between the modeled functional habitat linkage and the ad-hoc habitat linkage.

Results

Expert Knowledge-based Resistance Surfaces

For each focal species, the modeled landscape resistance was low throughout

a)



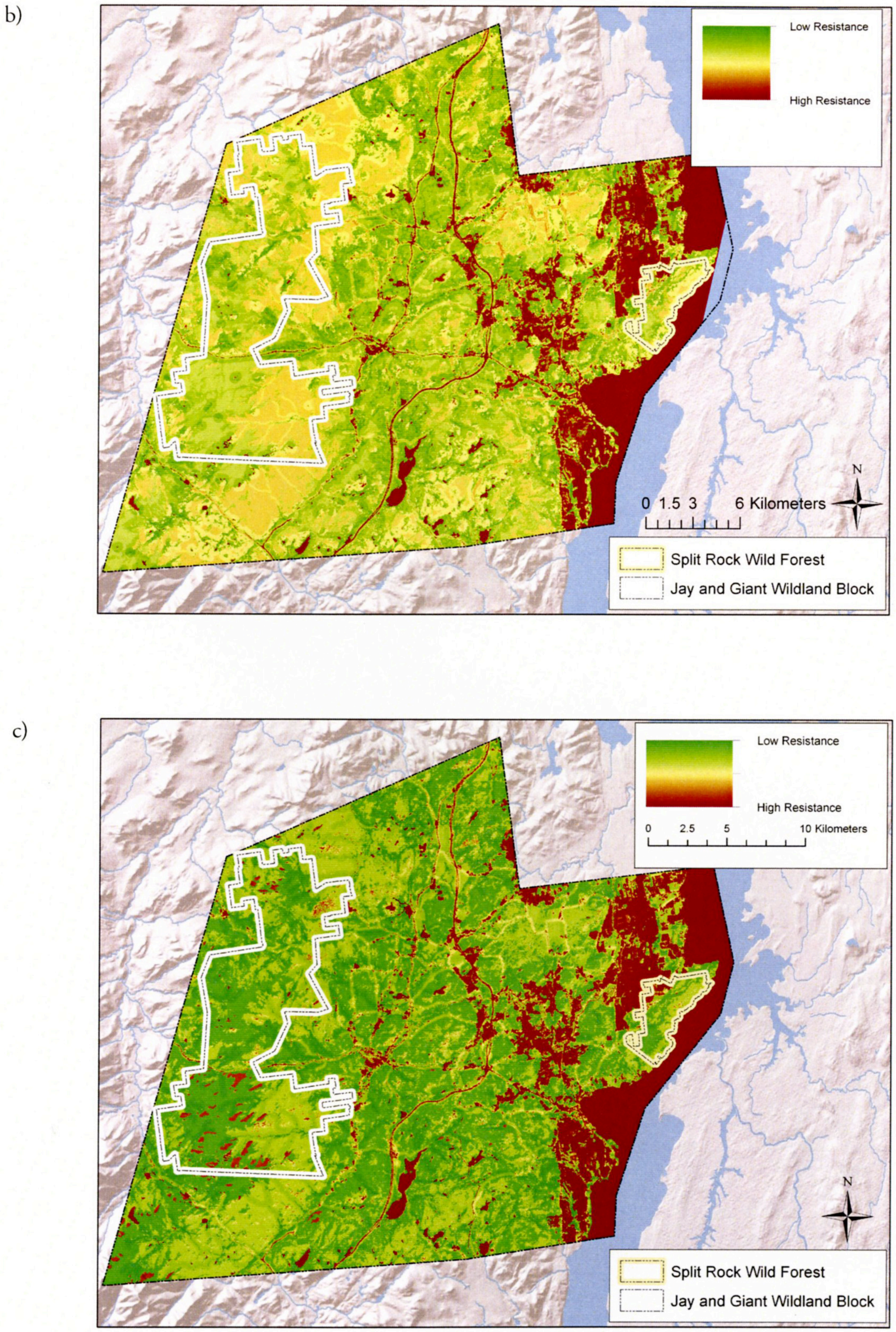


Figure 4. *Resistance surfaces for three focal species (black bear, bobcat, and fisher) developed using literature review and expert opinion. Dark grey to black indicates high resistance to movement. Light grey to white indicates lower resistance (high permeability) to movement.*

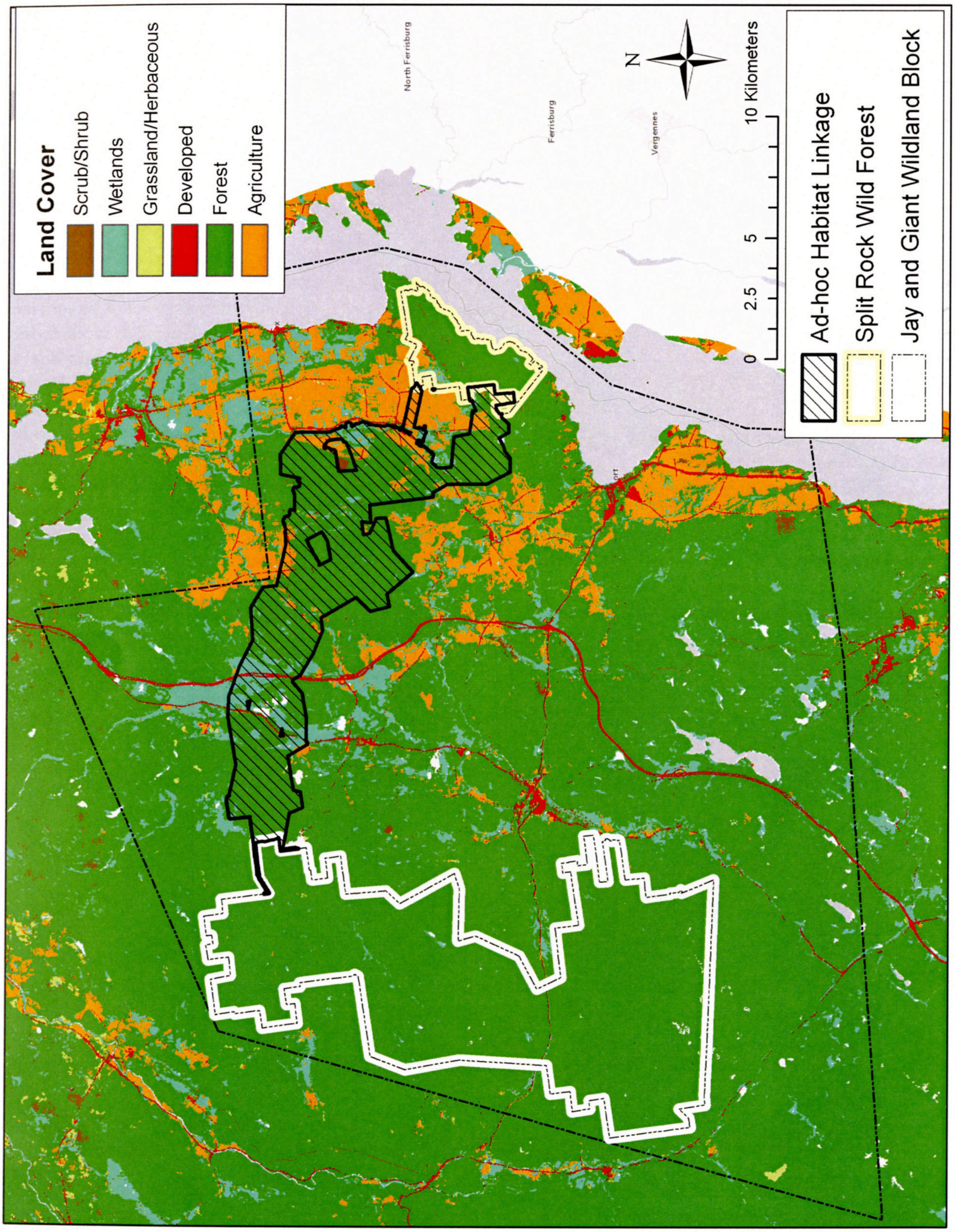


Figure 2. (first referenced on p. 23) *The ad-hoc habitat linkage plan follows a route from the Jay Wilderness Area southeast to Split Rock Wild Forest, crossing forests, wetlands, and agricultural lands (Northeast Wilderness Trust, 2009).*

the study area (Figure 4). Over 75% of the study area was predicted to be high quality habitat with low resistance and therefore highly traversable for all three species.

Identifying Habitat Linkages

Predicted habitat linkages for all three species, based on the species-specific landscape resistance surfaces, followed a route from the Jay and Giant Wilderness Block to Split Rock Wild Forest, and were merged to create a single functional habitat linkage (Figure 5). The functional habitat linkage is 21 km in length, running northeast from Giant Mountain Wilderness Area to Split Rock Wild Forest, with an average width of 2 km. The total area included in the functional habitat linkage is 93 km^2. It crosses Route I-87 southeast of Elizabethtown, NY and then passes through a large, roadless area before narrowing to 800 m outside of Westport, NY.

Alternate Scenarios

We produced ten black bear or twelve bobcat and fisher alternate scenario resistance surface models depending on the number of landscape factors included. For all three species, the agreement between alternate scenarios and the original landscape resistance model was very high (Table 3). Kappa agreement was substantial to almost perfect for most alternate scenarios; in only one scenario for fisher, compressed permeability score inputs for canopy cover resulted in moderate agreement. However, when the landscape permeability score inputs were compressed for all landscape factors in concert for all three species, there was less agreement between landscape resistance surface maps (4–52% overlap). These results suggest the models are insensitive to changes in assigned permeability scores of any one parameter but are sensitive to scenarios that diminish the differences between classes of all landscape factors. In other words, results differed most from the original resistance model when parameter estimates underemphasized a focal species' perception of the difference in resistance across a landscape (Beier et al., 2009).

Species-specific habitat linkages generated by CorridorDesigner using the alternate scenario resistance surfaces generally overlapped with the functional habitat linkage. The modeled

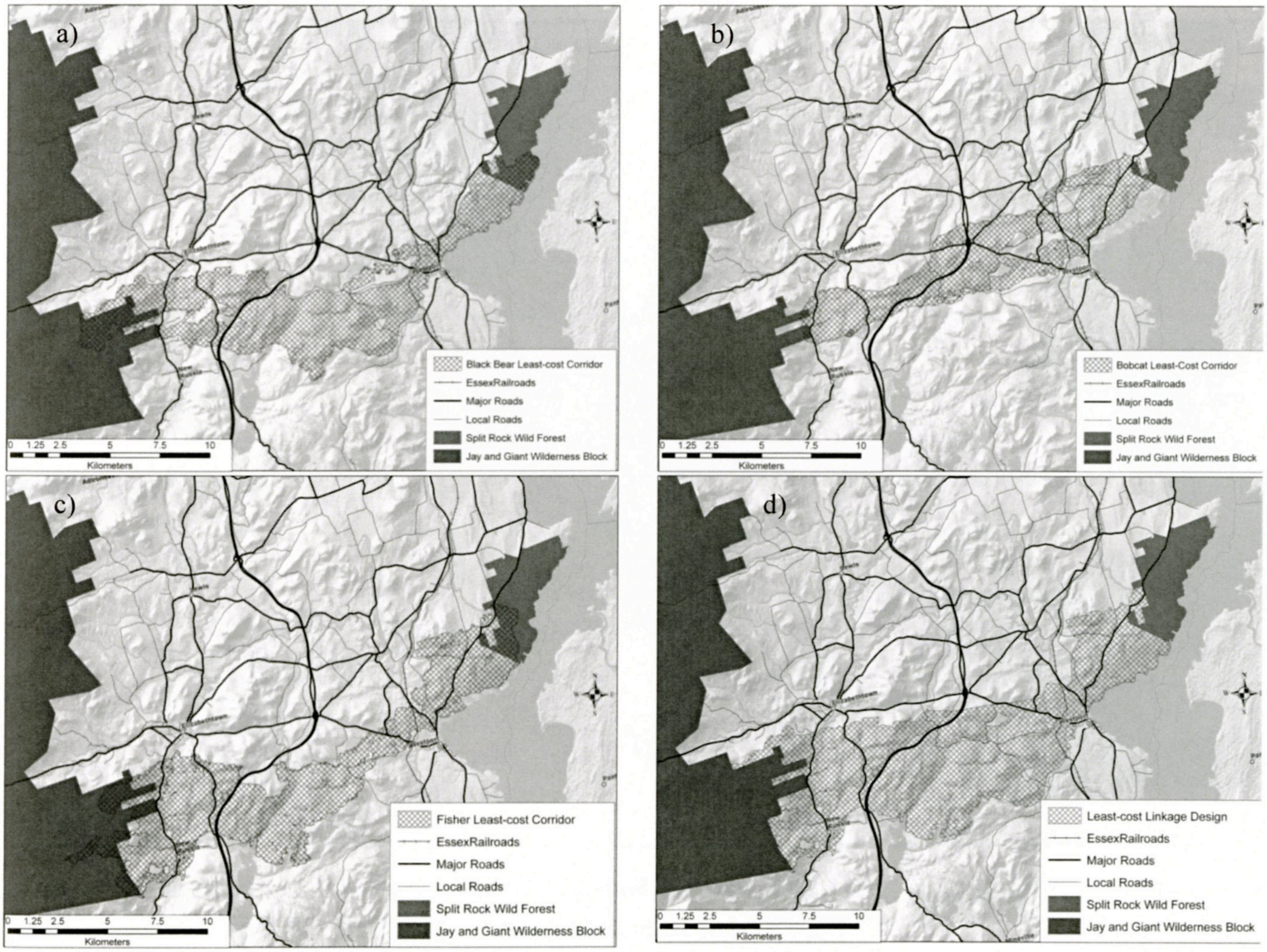


Figure 5. *Minimum cost-distance habitat linkages for (a) black bear, (b) bobcat, and (c) fisher. These were merged to create the functional habitat linkage (d).*

habitat linkage location for black bear remained stable as factor weights and permeability scores were changed, with greater than 50% overlap in all scenarios (Table 3). Habitat linkage locations for fisher tended to be stable; however, when all parameters were compressed, the habitat linkage location overlapped by only 7%. Bobcat habitat linkage locations predicted by alternate resistance surfaces were more variable. The lowest overlaps occurred when the permeability scores for the landscape factor representing core and edge habitats was changed or when all landscape factor scores were compressed, indicating that the location of bobcat habitat linkages is sensitive to the core/edge habitat parameter and to overestimates of the importance of each landscape factor class.

Comparison to Ad-hoc Habitat Linkage

Only 4% of the functional habitat linkage intersects with the ad-hoc habitat linkage (Figure 6). In comparison to the previous ad-hoc habitat linkage, the functional habitat linkage has a lower road density, larger area, and shorter length (Table 4). The amount of permanent conservation land (GAP status 1–3; http://gapanalysis.nbii.gov/) is greater in the functional habitat linkage, both in total acres conserved and percent of the total habitat linkage conserved. The distribution of habitat quality for the three focal species in both habitat linkages tends toward preferred habitat (Figure 5). In all cases, the functional habitat linkage has a higher proportion of preferred and highly traversable habitat. Conversely, the ad-hoc habitat linkage has a higher proportion of avoided habitat for all three species.

Discussion

The functional habitat linkage generated by this study gives one option for prioritizing areas that could ensure long-term connectivity for wide-ranging mammals within the SRW between the Adirondack Mountains and the Champlain Valley. For three focal species, the landscape resistance models indicated that there is a high-level of connectivity and high-quality habitat for the three focal species in the mostly forested landscape of the SRW. Minimum cost-distance models predicted a functional habitat link-

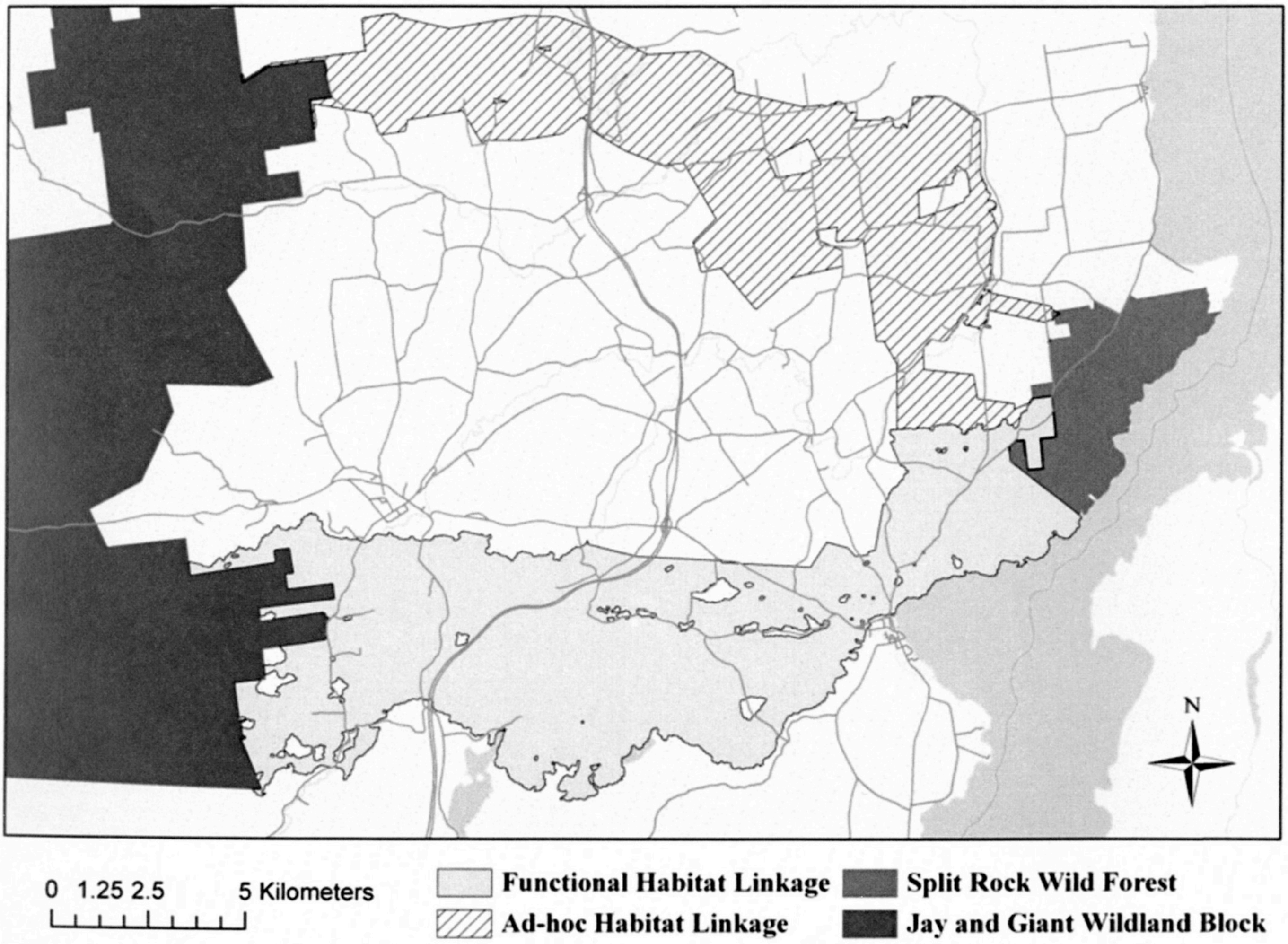


Figure 6. *The functional habitat linkage generated by minimum cost-distance and landscape resistance models is located south of the ad-hoc habitat linkage (Northeast Wilderness Trust, 2009).*

Table 3. *Summary of the Kappa statistic pixel-by-pixel comparison of alternate landscape resistance surfaces for each focal species with the original landscape resistance surface model for each species showing the Kappa statistic value, lower confidence interval (LCI), upper confidence interval (UCI), and the agreement interpretation, as well as the percent overlap of habitat linkages predicted by the alternate scenarios with the habitat linkage predicted from the original model.*

		Pixel-by-pixel comparison to original landscape resistance model				
	Scenario	Kappa	LCI	UCI	Kappa Agreement Interpretation	% Overlap of predicted habitat linkage
Black Bear n = 995,273	All Permeability Scores Compressed	0.18	0.15	0.21	Slight	52%
	All Permeability Scores Dispersed	0.76	0.73	0.79	Substantial	91%
	Land Cover Permeability Scores Compressed	0.61	0.58	0.64	Substantial	85%
	Land Cover Permeability Scores Dispersed	0.95	0.92	0.98	Almost perfect	86%
	Road Distance Permeability Scores Compressed	0.66	0.62	0.67	Substantial	75%
	Road Distance Permeability Scores Dispersed	0.97	0.93	1	Almost perfect	100%
	Topographic Position Permeability Scores Compressed	0.98	0.95	1.01	Almost perfect	100%
	Topographic Position Permeability Scores Dispersed	0.86	0.83	0.89	Almost perfect	100%
	Factor Weights Compressed	0.93	0.9	0.96	Almost perfect	100%
	Factor Weights Dispersed	0.96	0.93	0.99	Almost perfect	96%
Bobcat n = 991,285	All Permeability Scores Compressed	0.39	0.35	0.42	Fair	4%
	All Permeability Scores Dispersed	0.77	0.74	0.81	Substantial	78%
	Edge vs. Core Habitat Permeability Scores Compressed	0.87	0.83	0.9	Almost perfect	6%
	Edge vs. Core Habitat Permeability Scores Dispersed	0.71	0.68	0.74	Substantial	43%
	Land Cover Permeability Scores Compressed	0.54	0.51	0.57	Moderate	68%
	Land Cover Permeability Scores Dispersed	0.79	0.76	0.83	Substantial	87%
	Road Distance Permeability Scores Compressed	0.92	0.89	0.96	Almost perfect	86%
	Road Distance Permeability Scores Dispersed	0.85	0.82	0.89	Almost perfect	92%
	Stream Distance Permeability Scores Compressed	0.81	0.78	0.84	Almost perfect	90%
	Stream Distance Permeability Scores Dispersed	0.7	0.67	0.73	Substantial	75%
	Factor Weights Compressed	0.85	0.82	0.88	Almost perfect	78%
	Factor Weights Dispersed	0.76	0.73	0.8	Substantial	90%
Fisher n = 996,007	All Permeability Scores Compressed	0.04	0.01	0.06	Slight	7%
	All Permeability Scores Dispersed	0.93	0.9	0.97	Almost perfect	100%
	Canopy Cover Permeability Scores Compressed	0.42	0.39	0.46	Moderate	67%
	Canopy Cover Permeability Scores Dispersed	0.99	0.95	1.02	Almost perfect	100%
	Land Cover Permeability Scores Compressed	0.87	0.83	0.9	Almost perfect	99%
	Land Cover Permeability Scores Dispersed	0.79	0.76	0.83	Substantial	100%
	Road Distance Permeability Scores Compressed	0.86	0.82	0.89	Almost perfect	92%
	Road Distance Permeability Scores Dispersed	0.96	0.93	0.99	Almost perfect	100%
	Stream Distance Permeability Scores Compressed	0.87	0.84	0.9	Almost perfect	88%
	Stream Distance Permeability Scores Dispersed	0.9	0.86	0.93	Almost perfect	100%
	Factor Weights Compressed	0.95	0.91	0.98	Almost perfect	99%
	Factor Weights Dispersed	0.77	0.74	0.81	Substantial	100%

Table 4. *Summary of landscape characteristics comparing the Split Rock Wildway Planning Area, functional habitat linkage, and ad-hoc habitat linkage. High and low quality habitat percentages were calculated using the landscape resistance models from this study, conserved land percentage was calculated using the Protected Areas Database and the National Conservation Easement Database, and land cover type percentages were calculated from the NOAA C-CAP dataset (NCED, 2011; USGS National Gap Analysis Program, 2011).*

	Split Rock Wildway Planning Area (including wildland blocks)	Functional Habitat Linkage	Ad-hoc Habitat Linkage
Total length (km)	n/a	22.3	27.2
Total area (km^2)	896.4	93.2	70.3
Road crossings (n)	n/a	7	12
Road density (km/ km^2)	0.62	0.66	0.89
% High quality habitat (pixel values 60–100)			
Black bear	76%	85%	81%
Bobcat	85%	95%	90%
Fisher	82%	92%	88%
% Low quality habitat (pixel values 0–40)			
Black bear	13%	4%	7%
Bobcat	10%	2%	3%
Fisher	17%	6%	10%
Conserved Land (% of total; area) (GAP status 1–3; http://gapanalysis.nbii.gov/)	41% (367.5 km^2)	29% (27.0 km^2)	22% (15.5 km^2)
Land Cover Composition (% total; area)			
Forest (includes deciduous, conifer, and mixed woods)	84% (754.0 km^2)	90% (83.9 km^2)	82% (57.5 km^2)
Wetlands (includes all wetland types)	6% (54.3 km^2)	5% (4.4 km^2)	9% (6.7 km^2)
Agricultural (includes pasture and cropland)	8% (68.2 km^2)	3% (3.0 km^2)	7% (5.0 km^2)
Developed (includes low-, med-, and high-density)	2% (13.4 km^2)	2% (1.4 km^2)	1% (0.8 km^2)
Grasslands	<1% (1.1 km^2)	<1% (<0.1 km^2)	<1% (<0.1 km^2)
Scrub-shrub	<1% (4.0 km^2)	<1% (0.6 km^2)	<1% (<0.1 km^2)

age across a southern route from Giant Wilderness Area to Split Rock Wild Forest suggesting the best location for a habitat linkage intended to maintain connectivity for black bear, bobcat, and fisher based on this dataset and weighting scheme (Figure 6). Areas outside the SRW, and outside the scope of this paper, may also provide connectivity for these species between the Adirondack Mountains and the Green Mountains (Long, 2007; Zeh & Marangolo, 2010). This study area was chosen to provide a comparison between a functional habitat linkage and an existing ad-hoc habitat linkage plan.

Of particular note to conservation planners is that the functional habitat linkage had very little overlap with an ad-hoc habitat linkage planned for the northern part of the study area. Additionally, the functional habitat linkage has a larger area presently conserved and less area in land-use types (e.g. developed and agricultural land) that may require mitigation in order to remain permeable to wildlife movement. The functional habitat linkage is larger which could imply that it would be more expensive to conserve. However, the combination of more area presently conserved and a smaller area in less permeable land-use types suggests that the functional habitat linkage provides a more feasible option for maintaining connectivity across the SRW. Further studies should focus on validation of the models presented in this study.

Validation of model results is often difficult and costly (Beier et al., 2008; Sawyer et al., 2011). Uncertainty analyses (cf. Beier et al. 2009, Ray & Burgman 2006) capture a range of model outcomes given parameters defined by data and/or expert knowledge. Multiple model simulations using varied parameter estimates reflecting the uncertainty of our model tended to converge on the same functional habitat linkage. Our results suggest that the predicted functional habitat linkage should be included in conservation plans aimed at protecting the existing connectivity between the High Peaks of the Adirondacks and Lake

Champlain. Maintaining landscape connections between the Split Rock Wild Forest and the larger wild areas of the Adirondack Park may provide a stepping stone connecting the Adirondack Park with the greater Northern Appalachian/Acadian ecoregion thereby adding to a network of core reserves, matrix lands, and corridors believed to be critical to the long-term health of both the Adirondack Park and the greater ecoregion (Trombulak et al., 2008).

We have presented one example of systematic conservation planning that incorporates scientific understanding of focal species and their needs in a particular landscape and that is a defensible alternative to ad-hoc conservation planning. However, it is important to recognize the assumptions and specific objectives of the analysis. Our analysis models the best habitat linkage for the three focal species based on the available data. While the vagility and large area requirements of these species make it possible for them to serve as umbrella species (i.e., protecting habitat for them would have the side benefit of protecting habitat for many other facets of biodiversity), the inclusion of other focal species or focal ecosystem characteristics could result in a different habitat linkage (Roberge & Angelstam, 2004; Thorne et al., 2006). For example, the ad-hoc linkage has a larger wetland area and might overlap with a functional habitat linkage based on the requirements of wetland obligate species. The functional habitat linkage presented here can provide a guiding tool for organizations determining where best to spend their financial and human resources if connectivity of wide-ranging mammals is a priority. Organizations that prioritize other conservation values can use similar analyses to generate systematic conservation plans incorporating those goals, including recreational access, aesthetic values, and water quality (Margules & Pressey, 2000).

Conclusions

Connected landscapes provide wildlife and natural processes the flexibility to respond to both natural and human-created disturbances. While most researchers agree that the identification of habitat linkages should be based on empirical evidence such as movement of radio-tagged animals, population studies, or estimates of genetic distance, the availability of empirical data is limited and often expensive (Bates & Jones, 2007; Brown et al., 2010; Crooks & Sanjayan, 2006a; Feinberg, 2007; Long, 2007). The modeling framework used in this study provides an example of how land managers can incorporate existing knowledge and GIS data to create science-based functional connectivity models at a scale useful to local conservation planning. It allows and encourages conservation planners to be explicit about what they are trying to achieve and intentional about the information that they use to develop conservation plans. The modeling framework also provides insight into conservation values that highlight areas not previously considered high priority and allows for transparent consideration of multiple alternatives. With the advent of easy-to-use and low cost toolkits, these analyses help us to promote accountability in decision-making, transparency in conservation decisions, and efficiency in the allocation of financial and human resources.

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