2012 NORTHEASTERN NATURALIST 19(2):147–156

Testing GIS-generated Least-cost Path Predictions for *Martes pennanti* (Fisher) and its Application for Identifying Mammalian Road-crossings in Northern New Hampshire

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Abstract - To mitigate the unintended consequences of roads and habitat fragmentation, biologists model wildlife corridors with least-cost path (LCP) analysis of spatial data managed with geographic information systems. However, the ability of LCP models to accurately predict preferred movement corridors remains questionable. We tested the effectiveness of an LCP model constructed using literature review, expert opinion, and the relative distribution of land-cover types present at roadside observations of *Martes pennanti* (Fisher). The model was then used to predict road-crossing corridors of Fishers, *Lynx rufus* (Bobcat), and *Ursus americanus* (American Black Bear) within our study area in northern New Hampshire. Roadside data were collected through track surveys from 5 Dec 2005–25 May 2006. Our analysis demonstrated that least-cost modeling successfully identified roadside wildlife corridors for Fishers and Bobcats, but not for American Black Bears.

Introduction

Roads can impede the movement of animals between resource patches, subdivide populations, increase the risk of mortality due to animal-vehicle collisions, and fragment connected habitats into isolated patches (Alexander et al. 2005, Forman and Deblinger 2000, Forman et al. 2003). To reduce these unintended consequences of roads, biologists are increasingly using least-cost path (LCP) analyses conducted within geographic information systems (GIS) to predict the most likely movement routes, which may then be used to prioritize locations for mitigation actions such as placement of wildlife bridges, tunnels, or overpasses (Adriaensen et al. 2003, Clevenger et al. 2002).

The ability of LCP models to accurately predict preferred movement corridors remains controversial, and there are few systematic tests of LCP predictions using empirical data (Driezen et al. 2007). Driezen et al. (2007) used radiotracking data on dispersing *Erinaceus europeaus* Martin (European Hedgehog) to test LCP model performance, and determined that model predictions were poor. LCP models also performed poorly at predicting movement

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paths when compared to actual movement paths in a study of *Ranger tarandus caribou* Gmelin (Woodland Caribou), where expert-based and resource-selection functions were incorporated into the model (Pullinger and Johnson 2010). Nonetheless, in the absence of better tools, least-cost corridor models are frequently advocated as a basis for land conservation, barrier mitigation, and land management practices (Beier et al. 2008).

Selecting species upon which to create corridors using LCP methods is also controversial (Noss and Daily 2006). Many LCP corridor models have focused on large carnivores (e.g., LaRue and Nielsen 2008, Rabinowitz and Zeller 2010, Singleton et al. 2002), but Beier et al. (2008) cautioned that when a corridor is designed for multiple species, they must share similar traits in terms of their habitat and movement. Beier et al. (2008) suggested against using wide-ranging carnivores as the focal species when a corridor is intended for other species with different degrees of habitat specificity or sensitivity or limited mobility. Reality, however, dictates that conservation managers focus their efforts on one or a small suite of species, and so Noss and Daily (2006) conclude that species most sensitive to habitat fragmentation should be given priority in corridor design. Beier et al. (2007) suggested six important characteristics that focal species may exhibit depending on the needs of the project at hand. These characteristics may include, but are not limited to: (1) area sensitivity, (2) habitat specialization, (3) short or habitat-restricted dispersal, (4) dispersal necessary for metapopulation persistence, (5) barrier sensitivity, and (6) ecological importance.

Martes pennanti (Fisher), a common wide-ranging mesocarnivore within our study area, meets all or many of these criteria, and is thus a suitable species with which to test LCP predictions. As mesopredators, Fishers serve various important ecological functions (Prugh et al. 2009), including predation on porcupines *Erethizon dorsatum* (Porcupine; Powell 1993), that in turn may influence vegetative structure. Fishers are also sensitive to fragmentation and disturbance (Linehan et al. 1995), and in the northeastern United States, select coniferous or mixed-hardwood forests over open areas and hardwood forests (Kelly 1977, Powell 1994, Thomasma et al. 1991). Juveniles disperse relatively short distances (approximately 10–20 km), and viable populations may be compromised in areas where habitat patches are small and poorly connected (Arthur et al. 1993, Powell et al. 2003). Radiotracking in the White Mountains of New Hampshire revealed home ranges that paralleled valleys and nearly always ended at streams (Kelly 1977); Linehan (1992) considered second-order and larger streams to be barriers to Fisher movement. Data on how roads influence Fisher movements, however, are lacking.

Researchers have also recommended protecting roadside habitats selected by Fishers because these locations may serve to identify and protect the movement corridors of a range of wildlife species (Linehan et al. 1995). Here, we developed a least-cost corridor model for Fisher based on literature review, expert opinion, and land-cover types found adjacent to roadside sites where Fishers were detected in northern New Hampshire (Barnum et al. 2007). We used roadside tracking data to test whether Fishers and other wide-ranging mammal species thought to be sensitive to fragmentation, such as *Lynx rufus* (Bobcat; Crooks 2002) and *Ursus americanus* (American Black Bear; Kindall and van Manen 2007), were detected more frequently at locations where LCP corridors intersected roads as compared to roadside locations that were not intersected by the LCP corridors. We also examined whether the Fisher-based LCP corridors provided roadside movement corridors for a range of wildlife species by evaluating whether more species were recorded within these corridors as compared to random locations outside of the corridors.

Methods

Study area

The study area was located along Route 2 (17.9 mi/27.9 km) and Route 115 (5.9 mi/9.8 km) in the northern New Hampshire towns of Jefferson and Randolph (Fig. 1). These road sections traverse valley bottoms of the White Mountain region of the state. The study area extended 2 km (1.2 mi) beyond the roads' edges in either direction and encompassed 111.6 km^2 (43.1 mi^2) in total. A large majority of the landscape was managed as national forest; the remainder of the study area included patches of low-density development, pasture, and hay fields (Barnum et al. 2007). A detailed description of land-cover types within the study area is presented below.

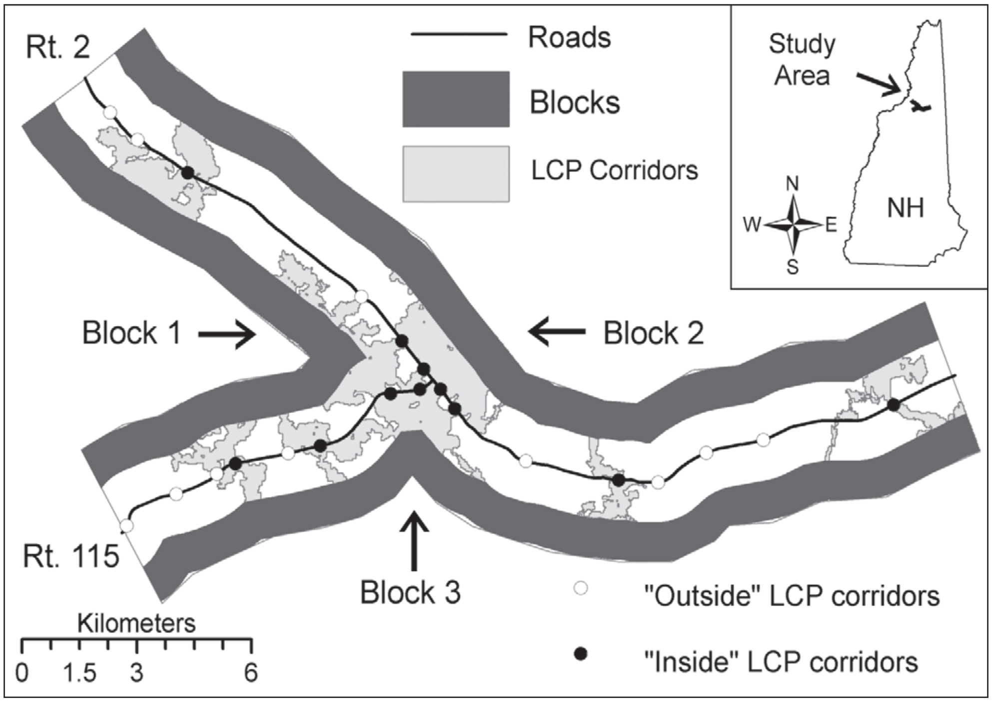

Figure 1. Study area in northern New Hampshire, including locations of corridor endpoint blocks (1 km from road edges), least-cost path corridors based on land-cover types found adjacent to roadside Fisher observations, and point locations (250-m road sections) defined as being "inside" or "outside" the LCP corridors.

Field data

Track and sign observers, tested in the field and certified by Cybertracker Conservation (Elbroch et al., in press; Evans et al. 2009), conducted track surveys on 51 days from 5 Dec 2005–25 May 2006 (Barnum et al. 2007). Observers drove slowly (<16 kph [10 mph]) along the roads, stopping frequently to record species when tracks were encountered within 10 m of the road. Because surveys were conducted between 48–72 hrs after new snow events, and the same observers repeated surveys, old tracks were not recounted. Bridges and culverts were also surveyed each field session. In spring, after the snow season, track surveys for bears and *Alces alces* L. (Moose) were conducted on foot for the entire road system twice each week. Observers erased all tracks as they were recorded to ensure they were not recounted during future sampling. GPS data loggers (TDS Recon and Trimble® GeoExplorer) equipped with the data collection software Cybertracker (www.cybertracker.org) were used to record locations where tracks were found.

GIS methods and study design

Least-cost corridors were delineated in ArcGIS® 9.2 using the extension CorridorDesigner (Beier et al. 2007; www.corridordesign.org). The CorridorDesigner extension delineated the most permeable swath of pixels, considered to represent the lowest cumulative resistance between two endpoint blocks, by calculating "cost distance" for each pixel. For instance, a pixel score of 100 would equal zero resistance to travel by Fishers, while a pixel score of 1 would indicate 99% resistance to travel. The inverse of a habitat suitability raster created a resistance map that was used as the basis for identifying the LCP corridors analyzed in this study.

We used the 2001 New Hampshire Land Cover Assessment raster (30-m x 30-m pixels; www.granit.unh.edu), containing 15 habitat classifications, as the basis for the habitat suitability raster (Table 1). The majority of resistance values, intended to reflect how each land-cover type might impede Fisher movement (Adriaensen et al. 2003), were based on comparing roadside land-cover types present near Fisher observation localities to the overall availability of each roadside land-cover type in the study area. Because roads produce significant ecological effects that extend >100 m from the road's edge (Forman and Deblinger 2000), Fisher localities were delineated by creating 125-m buffers around all sites where the species was recorded crossing the road (n = 117). We assumed that Fishers would select preferred crossing locations based on the roadside land-cover types within 125 m of the road. Boundaries between the resulting buffers were dissolved to create 36 discrete polygons reflecting areas of known Fisher activity. The land-cover data was then extracted based on the boundaries of these polygons. We then calculated the sum of 30-m x 30-m pixels for each land-cover type within buffers, and compared this information to the sum of 30-m x 30-m pixels for a 125-m buffer of Route 2 and 115. This represented the available land-cover types adjacent to the road within the study area.

In response to potential inaccuracies in the fine-scale land-cover classifications (Table 1, user's accuracy), we consolidated beech/oak, paper birch/aspen, and other hardwoods as "hardwoods"; white/red pine, spruce/fir, and hemlock as "conifers"; and open wetland and forested wetland as "wetland". We then scored the following land-cover categories according to whether the data indicated preferential use by Fishers (Table 1). To translate the preferential use into weightings for the computation of the LCP, we imposed a scheme in which proportional use equated to a weight of 50; strong positive preference was weighted as 100, and strong negative preference was 1. Weights were assigned by expert opinion of the authors, and a review of Fisher habitat selection literature (Allen 1983, Arthur et al. 1989, Kelly 1977, Thomasma et al. 1994) provided additional guidance to the land-cover scores below.

Three land-cover types clearly showed disproportional use compared to their availability; these were given resistance values of either 100 ("conifers" and "mixed forest") or 1 ("hay/pasture"). Land-cover types that showed approximately proportional use, such as "hardwoods" and "other cleared", were scored as 50. Wetlands were given scores of 75, because they were used slightly more than they were available, and Kelly (1977) found that Fishers chose to inhabit wetland-associated forests in northern New Hampshire. Although "open water", "disturbed land", "residential/commercial/industrial", and "transportation" showed nearly proportional use to availability, we considered them to be unsuitable habitat, and assigned them scores of 1.

Table 1. Land-cover classification scores for the habitat suitability index were used in conjunction with the 2001 New Hampshire Land Cover Assessment raster (www.granit.unh.edu) to create a habitat suitability raster, which was used as the resistance layer for the corridor model. Land-cover scores were based according to whether they evidenced preferential use by Fishers. Hardwood, conifer, and wetland groups were created to account for inaccuracies in the fine-scale land-over classifications (user's accuracy).

Landcover class	% used	% available	Score	User's accuracy (%) [A,B]
Residential/commercial/industrial	5.3	6.0	1	88.3
Transportation	17.6	16.3	1	85.0
Hay/pasture	2.9	11.7	1	91.7
Beech/oak	1.0	1.9		53.3
Paper birch/aspen	9.7	8.3		28.6
Other hardwoods	14.4	15.0		70.0
Hardwoods grouped	25.1	25.2	50	N/A
White/red Pine	1.7	1.3		81.7
Spruce/fir	7.1	3.8		80.4
Hemlock	1.5	1.0		65.0
Conifers grouped	10.3	6.1	100	N/A
Mixed forest	13.4	8.7	100	62.5
Open water	0.2	0.2	1	100.0
Forested wetland	0.4	0.1		86.7
Open wetland	1.7	1.7		75.0
Wetlands grouped	2.1	1.8	75	N/A
Disturbed land	0.2	0.1	1	90.0
Other cleared	22.9	23.9	50	93.3

[A] User's accuracy indicates what percentage of the time a particular land-cover type on the map was actually determined to be that type of land-cover on the ground (Globe 2009).

[B] University of New Hampshire, EOS-Webster Earth Science Information Partner.

The CorridorDesigner extension offered two algorithms to calculate pixel scores for the habitat suitability raster. We used the weighted arithmetic mean algorithm because none of our resistance values equaled 0. The math behind the arithmetic mean algorithm was: suitability equals = $\sum(S_n * W_n)$, where each S_n is the score for factor n and W_n is the weight for that factor (Beier et al. 2007). The corridor model used the habitat suitability raster as the resistance layer. These steps produced at least three LCP corridors between each of three 1-km-wide blocks of potential habitat that paralleled the roads; block 1 was southwest of Route 2 and northwest of Route 115, block 2 was primarily north of Route 2, and block 3 was south of Route 2 and southeast of Route 115 (Fig. 1).

Mammal track-point locations were classified relative to their occurrences along road sections located inside, or outside, the LCP corridors (Fig. 1). Eleven road sections >150 m in length fell within areas identified as LCP corridors; "inside" roadside track points were defined as those falling within 125 m of the centroids of these road sections. "Outside" mammal track points were defined as those falling along 11 randomly placed, 250-m road sections located outside the LCP corridors. We selected 250-m road sections as the basis of our analysis following Alexander et al.'s (2005) conclusion that tracks of the same species separated by distances >250 m could be treated as independent observations.

We used one-tailed Fisher's exact tests to examine whether Fishers, Bobcats, and American Black Bears were detected more often inside LCP corridors compared to along road segments falling outside the identified corridors. Wilcoxon rank-sum tests were used to compare the median number of species present in road segments inside vs. outside of the LCP corridors. All statistical tests were performed using JMP 7 (JMP, Version 7. SAS Institute, Inc., Cary, NC).

Results

In total, 7151 observations were collected where wildlife either crossed or approached the road. For this analysis we used 7099 observations, representing 21 mammal species (Table 2). We eliminated tracks representing the subfamily *Sciurinae* Hemprich (tree squirrels, flying squirrels and relatives; *n* = 10), domestic animals (*n* = 12), *Meleagris gallopavo* L. (Wild Turkey; n = 29), and *Bonasa umbellus* L. (Ruffed Grouse; *n* = 1). One record of an unknown fox species was included under *Vulpes vulpes* (Red Fox), and 4 unknown weasel species were included under *Mustela erminea*(Ermine).

The frequencies of Fisher detection vs. non-detection was significantly greater at road segments within LCP corridors compared to road sections outside these corridors (*P* = 0.015); similarly, Bobcat detection was significantly greater within the LCP corridors (*P* = 0.006). There was no difference (*P* = 0.707) in the frequencies of American Black Bear detection vs. non-detection along road segments inside vs. outside the LCP corridors (Table 3). Additionally, there was a significant difference (Z = -2.746, *P* = 0.006) in the number of species found along road segments within LCP corridors ($\bar{x}$ = 7.36, *n* = 11) versus road segments outside these corridors ($\bar{x}$= 4.45, *n* = 11).

Discussion

Empirical tests of least-cost path corridors based on Fisher habitat resistance values derived from field tracking data indicated there was a greater diversity of mammal species found inside LCP corridors, and Fishers and Bobcats were detected more often within corridors compared to random locations. Detection frequencies of American Black Bears did not differ inside versus outside the corridors. Corridor delineation was based entirely on available land-cover maps of 30-m x 30-m resolution. Habitat suitability rankings reflected that three main land-cover types (hay/pasture, conifers, and mixed forest) were disproportionally used or avoided by Fishers relative to their availability in the landscape.

Table 2. Total number of individual tracks of species documented during the field surveys and those that were contained within LCP corridors.

		n		
Scientific name	Common name	Total	LCP corridors	% from total
Ursus americanus Pallas	American Black Bear	42	6	14
Martes americana Turton	American Marten	6	0	0
Castor canadensis Kuhl	Beaver	4	0	0
Lynx rufus Schreber	Bobcat	32	14	44
Lynx canadensis Kerr	Canada Lynx	1	0	0
Canis latrans Say	Coyote	662	169	26
Mustela erminea L.	Ermine	36	7	19
Martes pennanti Erxleben	Fisher	117	35	30
Urocyon cinereoargenteus Schreber	Gray Fox	217	20	9
Mustela frenata Lichtenstein	Long-tail Weasel	77	14	18
Mustela vison Schreber	Mink	92	11	12
Alces alces L.	Moose	2590	666	26
Ondatra zibethicus L.	Muskrat	3	0	0
Erethizon dorsatum L.	Porcupine	6	2	33
Procyon lotor L.	Raccoon	48	20	42
Vulpes vulpes (L.)	Red Fox	1862	242	13
Lontra canadensis Schreber	River Otter	3	1	33
Lepus americanus Erxleben	Snowshoe Hare	132	31	23
Mephitis mephitis Schreber	Striped Skunk	11	0	0
Didelphis virginiana Kerr	Virginia Opossum	1	0	0
Odocoileus virginianus Zimmermann	White-tailed Deer	1157	128	11
Total		7099	1366	19

Table 3. One-tailed Fisher's exact tests compared detection vs. non-detection data "inside" and "outside" LCP corridors for three species.

Species	Sample	*n*	Present	Absent	Probability
Fisher	Inside LCP	11	8	3	
	Outside LCP	11	2	9	0.015
Bobcat	Inside LCP	11	6	5	
	Outside LCP	11	0	11	0.006
American Black Bear	Inside LCP	11	2	9	
	Outside LCP	11	2	9	0.707

We found that the LCP corridor design for Fisher performed well in identifying areas used by a number of other mammal species within our study area. Fifteen out of the 21 (71%) mammal species documented during the study were found within LCP corridors (Table 2). This result may be due to the selection of a focal species that is sensitive to habitat fragmentation (Noss and Daily 2006), or because roadside land-cover types selected by Fishers did identify movement corridors for a range of wildlife species (Linehan et al. 1995). It is also possible that Fishers and other mammals within the study area travel in coniferous cover types in winter because snow crust is harder and depths are lower there (Raine 1983). In Massachusetts, Bobcats selected coniferous and mixed cover types in winter because higher densities of prey items were found there (McCord 1974), and this may be another reason why they and other mesocarnivores were detected frequently in LCP corridors.

Black Bears were dormant during the winter months until early spring, and they showed no preference towards LCP corridors during the short period of time they were sampled. However, they may use the predicted corridor locations more frequently during other seasons when different food sources become available. Due to the temporal scale of this study being confined to winter and spring, we are unsure whether or not the diversity and frequency of mammalian road-crossings at the LCP corridors will remain the same year-round.

Some uncertainties and concerns still remain. For instance, the land-cover raster from 2001 may be different than the actual land-cover of 2005–2006 when the field data were collected. The land-cover raster was the only factor used in this modeling exercise, and changes in forest composition (land cover) due to the influences of climate change or habitat destruction may make model predictions irrelevant in the future. Furthermore, terrain has frequently been used as a predictive factor in other studies (Beier et al. 2006); future research should explore the outcome of corridor models that couple this factor to information about land cover.

A further test of our LCP model would be to use it to identify corridors in other locations in northern New England, and to then gather track data on varied species to see if corridor predictions proved accurate. Radio-telemetry studies may also be used to test whether an animal is using the entire length of an LCP corridor (Noss and Daily 2006); however, our snow-tracking method documented Fishers at predicted corridor locations, as well as provided information on additional species that occurred at the roadside (Barnum et al. 2007). Multiple species "linkages", as suggested by Beier et al. (2008), based on a variety of habitat-suitability models joined together to form one corridor, may prove superior to single-species corridor designs, but our study provided evidence that single-species LCP models are still a valuable tool in conservation planning.

Acknowledgments

The data used in this study was collected, and generously shared, by NH Audubon, under grants from by NH Fish and Game, the NH Department of Transportation, and the Merck Family. Thank you to Rose Graves for assistance in data collection.

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