Opportunities for Wildlife Habitat Connectivity between Algonquin Park, Ontario and the Adirondack Park, New York

prepared by

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EXECUTIVE SUMMARY

The Wildlands Project (TWP) seeks to help minimize nature's short-term losses while working toward the long-term recovery of the natural landscape. Founded in 1992, TWP's mission is to help protect and restore the ecological richness and native biodiversity of North America through the design and implementation of a connected system of reserves. This report integrates the results of two separate studies designed to identify the most suitable wildlife habitat corridor between Algonquin Park in Ontario and the Adirondack Park in New York State, a region known as the Frontenac Link.

Given that it was impractical to assess the habitat requirements of all species native to the study area, we evaluated the region in terms of its ability to fulfill the habitat needs of a single umbrella species – the eastern timber wolf (*Canis lupus lycaon)*. A top carnivore, the wolf is a wide-ranging, habitat generalist that requires extensive areas of forested habitat for movement and foraging. Providing for the habitat requirements of the eastern timber wolf, therefore, will protect many other species with smaller, more restricted area and habitat needs. In addition, restoring functional connectivity between Algonquin, which currently supports wolves, and the Adirondacks, where potential wolf habitat has been identified, may facilitate future recolonization of the timber wolf throughout its former range.

Habitat suitability comprises habitat productivity (food resources) and habitat security (safety). For many of the larger carnivores, and especially habitat generalists like the wolf, habitat security is often a function of road and human density. It is important to note that this study primarily addresses habitat security, and is not a fine-scale habitat suitability analysis. Further examination of prey density would be necessary to analyze habitat suitability for wolves in the Frontenac Link.

Because road and human densities are high in many parts of our study area, recent attempts to identify a continuous linear area suitable as wolf habitat in this region have failed (see 4.4). This study, in contrast, attempts to answer the question: *If* wolves were to attempt dispersal between the Adirondacks and Algonquin Park, what would be their path of least resistance? This is an important question, especially when prioritizing protection and restoration efforts in developed landscapes.

The Priority Conservation Corridor was identified by developing a number of descriptive models and using geographic information systems (GIS) analyses. The models were used to assess and integrate variables that have been shown to influence the integrity and movement of wolf populations, including road density, presence of major roads, population density, land use and proximity to water. Raster-based path analysis techniques were then used to identify the most favorable paths between the parks and to assign path widths by evaluating the relative "cost" of moving any distance from the path.

By qualitatively evaluating various width corridors, we determined that the top 5% of cells identified along the best single cell path provide a better corridor design than those based on smaller or larger percentages. This model minimizes bottlenecks in northwestern New York and provides a continuous corridor throughout the remainder of the study area. The New York 5% corridor has a road density of 0.31 km/km^2, which is well below the threshold for suitable wolf habitat (0.70km/km^2). Thus, this model, with an area of 977 km^2, was chosen as the New York Priority Conservation Corridor. This Corridor provides equal or overrepresentation for most natural aquatic ecosystems present in the study area, but underrepresents many of the less common plant community types in the region. Using the 5% level and similar but slightly different methods, we also identified a Priority Conservation Corridor for the Ontario study area, with an area of 7,622 km^2. The highest quality wolf habitat within the overall study area is located in the northern half of the Ontario Priority

Conservation Corridor.

Based on our criteria, the Priority Conservation Corridor is the least degraded, continuous corridor linking the Adirondack Park with Algonquin Park, and allows managers, landowners, educators, municipalities, and land trusts to focus land protection strategies where they are most likely to benefit biodiversity.

1.0 INTRODUCTION

The Wildlands Project (TWP) seeks to help minimize nature's short-term losses while working toward the long-term recovery of the natural landscape. Founded in 1992, TWP's mission is to help protect and restore the ecological richness and native biodiversity of North America through the establishment of a connected system of reserves (The Wildlands Project 1995). The identification of areas with high conservation potential is critical to accomplishing this mission. These priority conservation zones can then become the targets of efforts to protect and restore the natural landscape.

This report integrates the results of two separate studies that were contracted by the Greater Laurentian Wildlands Project (GLWP), a regional effort of TWP working to design and implement an ecological reserve system throughout the Greater Laurentian Region. GLWP's work is primarily focused on New York, New England, and Canada's eastern provinces. The objective of these studies was to identify the best path for a priority conservation zone (linkage) between Algonquin Park in Ontario and the Adirondack Park in New York, a distance of approximately 270 km. The overriding goal of the project is to preserve and restore the natural connectivity of wildlife habitat between these parks.

The first of these studies identified and characterized a conservation zone between the Adirondack Park and the Thousand Islands area (Trombulak and Lane 1996). The second and latter study identified and characterized a complementary conservation zone between Algonquin Park and the Thousand Islands area (Quinby et al. 1998). The broad region between these two parks is the focus of a larger, collaborative conservation project called the Algonquin to Adirondack Conservation Initiative (A2A). The long-term goal of A2A is to link the two anchoring parks via landowner stewardship and official protection. This should provide habitat conditions that will be more likely to support natural levels of biodiversity, the movement of wildlife (individuals or populations), and long-term ecosystem integrity.

To perform an assessment of the study area based on the habitat requirements of all species native to the region is obviously impractical. Instead, we evaluated the region in terms of its ability to fulfill the habitat needs of a single species – the eastern timber wolf (*Canis lupus lycaon*). The timber wolf is a top carnivore that requires healthy populations of prey to survive. The wolf is also a wide-ranging, habitat generalist, requiring extensive areas of forested habitat. Providing for the habitat requirements of this species, therefore, should protect many other species with smaller, more restricted area and habitat needs and ideally will help to restore and maintain relatively intact and healthy ecosystems. This is known as an "umbrella" effect (see summary in Miller et al. 1998). Further, the timber wolf was formerly present throughout the study area, but is now extirpated throughout the southern half of the A2A region. Providing for functional connectivity between these two regions may allow for future recolonization of this species throughout its former range.

The criteria used to determine the location of the corridor included the demographic, biological, and geographical features of the region that are most likely to influence the movement of wolves. Habitat suitability comprises habitat productivity (food resources) and habitat security (safety). For many of the larger carnivores, and especially habitat generalists like the wolf, habitat security is often a function of road and human density in the region of interest (Fuller et al. 1992, Jensen et al. 1986, Mech 1989, Mladenoff et al. 1995, Thiel 1985, Thurber et al. 1994). It is important to note that this study is not a fine-scale habitat suitability analysis, but primarily addresses habitat security. Research suggests that the main factor limiting wolves *where they are tolerated by humans* is adequate prey density (Fuller et al. 1992). In our study, prey availability was considered only in terms of its indirect relationship to forest cover and distance to water bodies. Further examination of prey density would be necessary to analyze habitat suitability for wolves in the Frontenac Link.

A number of descriptive spatial models, each emphasising a different criterion or set of criteria, were developed using the following primary landscape features: road density, presence of major roads, population density, land use and proximity to water. These features, which have been shown to influence the integrity and movement of wolf populations in other regions (see 3.1.2), were analyzed using geographic information systems (GIS). The New York and Ontario studies were carried out independently, and while sharing a common goal, suffered from some variations in methodology – primarily as a result of differences in the data layers available for the two subregions.

2.0 STUDY AREA

2.1 The Greater Laurentian Region

This project is part of a larger effort to design a system of priority conservation lands in the Greater Laurentian Region of the U.S. and Canada (Fig. 1). The region includes the northern third of Pennsylvania and New Jersey, New York, New England, southern Quebec, eastern Ontario, and the southern Maritime Provinces. This region also includes the islands and banks of the continental shelf bordering the Gulf of St. Lawrence, the Gulf of Maine, and Long Island Sound. The southern border of the region roughly corresponds to the greatest southern extension of the Wisconsin Glaciers, which began to recede from this area about 14,000 years ago. Biologically, the terrestrial portion of the region is characterized by northern hardwood and spruce-fir forest communities. The flora and fauna are diverse, but are characterized by species that can tolerate hot, humid summers and cold winters.

2.2 Study Area

The study area on the Canadian side of the border was restricted to the eastern most portion of the Province of Ontario, which is approximately 75,000 km^2 in size and is covered by six National Topographic Series (NTS) data sheets. The New York study area focused on the northwestern portion of the state and is approximately 18,369 km^2 in size.

Most of the combined study area falls within a region known as the Frontenac Link (Fig. 2), a broad swath of land that connects Ontario's Algonquin Park to the Adirondacks and contains the Frontenac Axis, the least degraded north-south corridor across the St. Lawrence River (Keddy 1995). Approximately 12,000 years ago, the present St. Lawrence river region was covered by a glacial lake, while the more northern portion was tundra (Anderson 1989). Today, the Link lies near the continent’s northeastern limit of deciduous forest, thus providing a critical biogeographical connection between Canada’s Boreal Forest and the Northern Forest of the U.S. The wide array of

Fig. 1 The Greater Laurentian Region

environmental conditions and habitats, including interior forest, rock barrens and numerous wetland types, supports a rich and diverse range of species – many of which are rare. More than 50 mammal species occur in this region, with four (timber wolf, marten, lynx, and moose) having been extirpated or reduced to very small numbers in the southern portion. The cougar, wapati (elk), and wolverine have been extirpated from the entire Link. Nearly 200 birds may breed here, with the Link serving as a connection between their northern and southern ranges (Keddy 1995).

The importance of protecting the primarily forested Link is magnified by the destructive effects of human settlement on its surroundings. Deforestation, agriculture, commercial fishing, mining, water mills, and urbanization have transformed the natural ecosystem of the region, interfering with ecological processes as a result (Osborne, 1995). Keddy (1995) states: "While the less disturbed, more wooded landscape of the Frontenac Axis makes it stand out in sharp contrast to this landscape, the deterioration of its function as a significant ecological linkage due to threats from the major highway corridors, cottage and urban development and pollution of the St. Lawrence River, is currently of great concern." Anchored by two world class parks, the Link presents a strategically situated and ecologically valuable opportunity for re-establishing wildlife connectivity.

3.0 METHODS

3.1 New York

3.1.1 Identification of a Conservation Linkage

To identify the most suitable portion of the New York study area for a conservation linkage, several data sets were used that describe the demographic (human), biological, and geographical features of the region that are likely to influence the movement of wolves. These data sets were analyzed using ArcInfo GIS software. The goal was to identify the region in northwestern New York that best satisfies the habitat requirements of wolves. Five data sets were used to assess habitat suitability over a four-county target region that was divided into more than two million 90-m x 90-m cells.

3.1.2 Data Sets

3.1.2.1 Road Density Studies on wolves in western and midwestern North America indicate that the primary factor influencing the persistence of wolves in an area is the density of roads (Thiel 1985, Jensen et al. 1986, Mech 1989, Fuller et al. 1992, Thurber et al. 1994, Maldenoff et al. 1995). The greater the density of roads in an area, the less likely it is that wolves will be found there. This seems to be true for all kinds of roads, but is most severe for paved and multi-lane roads. It is not completely clear why roads influence the presence of wolves, but is likely to be related to the positive correlation between road density and road kill, ease of access by hunters and poachers, and increased chance of encountering humans. Roads data for the study area were acquired from US Census TIGER/Line 1994 road data base (Fig. 3), and converted from vector data to raster data for analysis.

3.1.2.2 Presence of Major Roads Because of the high risk of mortality to wolves when crossing roads (Mech 1995), major roads were treated as a separate and independent factor that

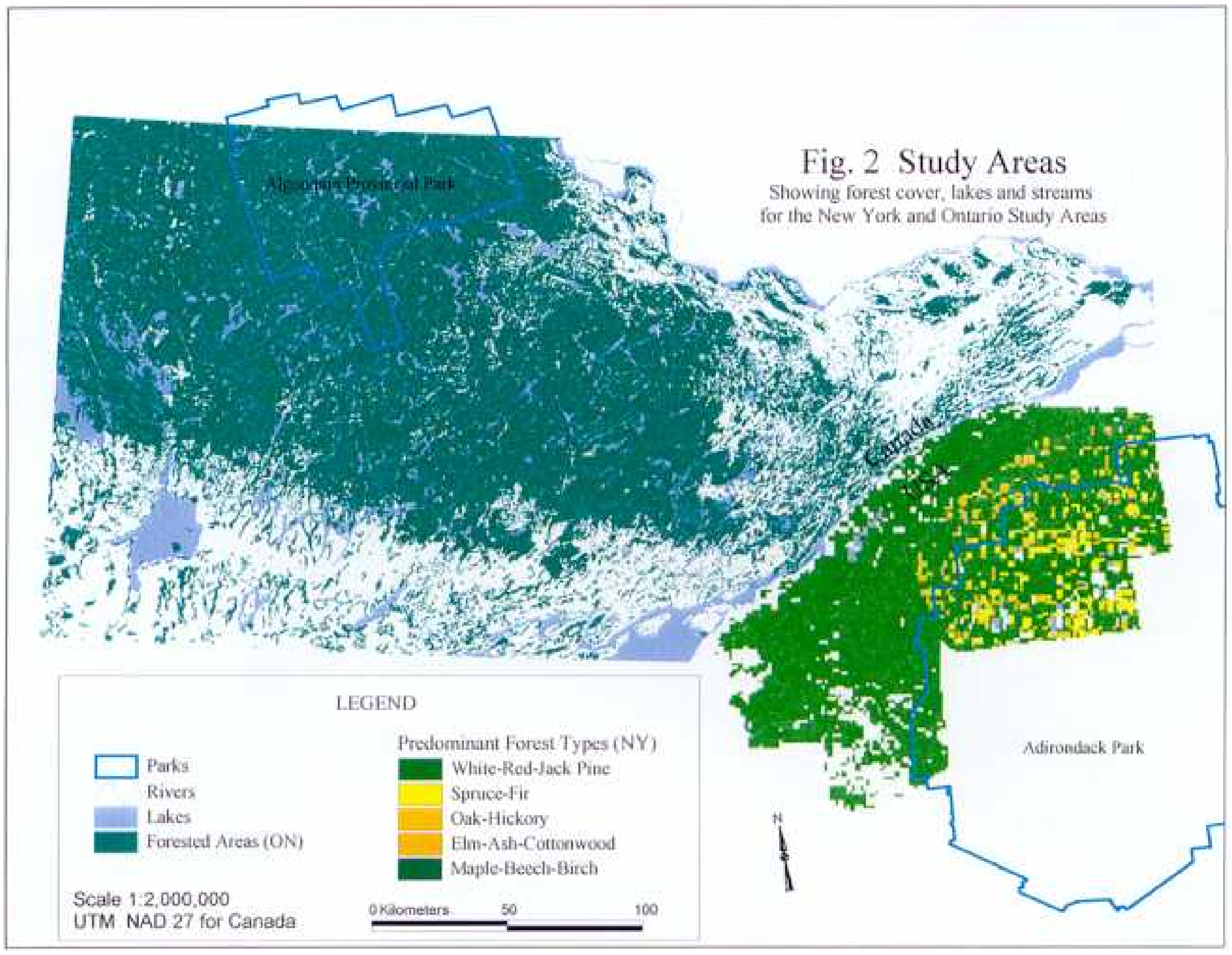

Fig. 2 Study Areas
Showing forest cover, lakes and streams for the New York and Ontario Study Areas

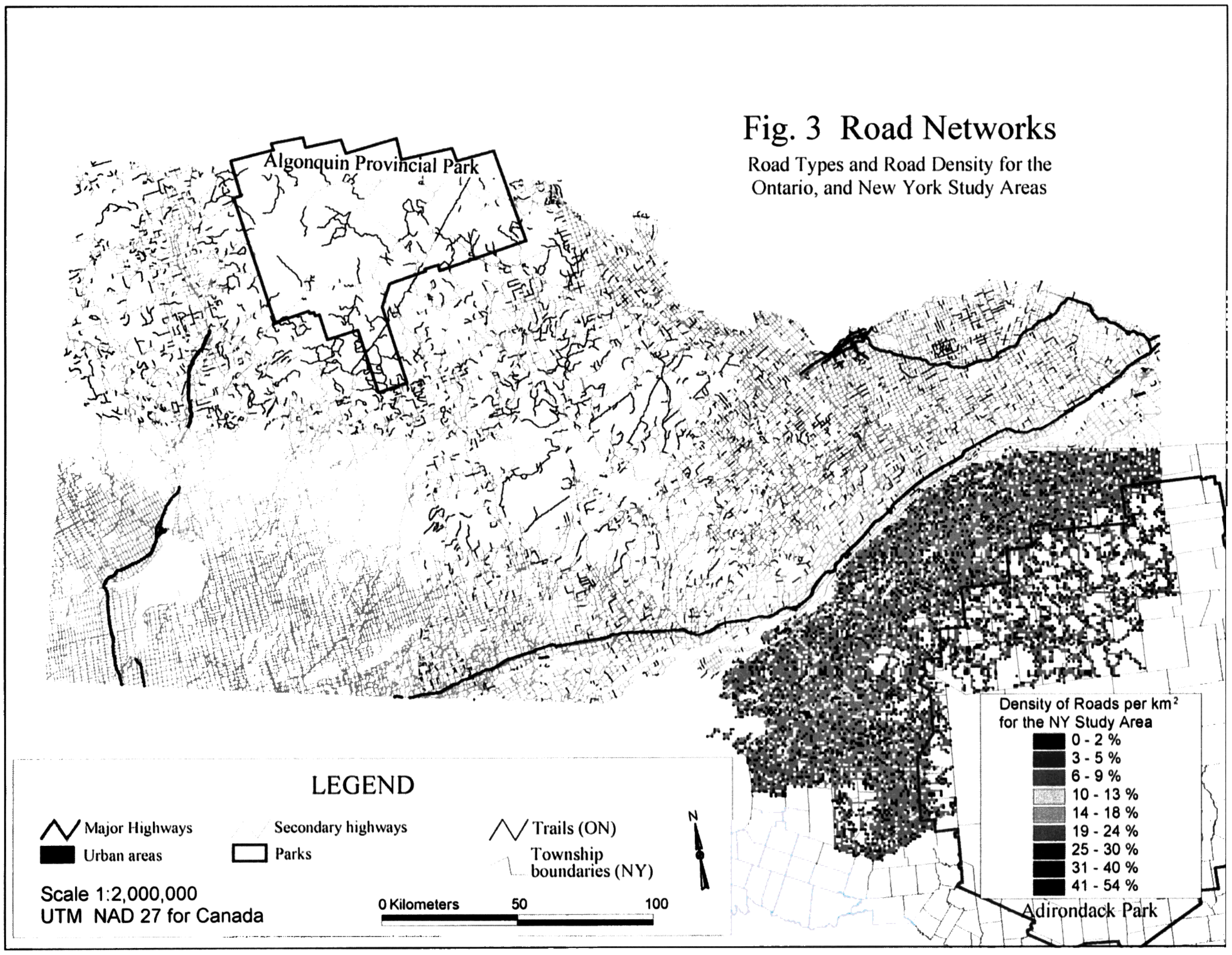

Fig. 3 Road Networks
Road Types and Road Density for the Ontario, and New York Study Areas

influences habitat suitability for wolves. Using the data set on road density, major roads included interstate and state highways because they are wider and have a higher volume of traffic than do other types, and therefore pose the greatest risk to animals that attempt to cross them.

3.1.2.3 Human Population Density Wolves tend to avoid areas with high human population densities (Fuller et al. 1992, U.S.F.W.S. 1992, Mladenoff et al. 1995, Boitani 1995). Thus human population density data acquired from the New York State Department of Environmental Conservation POP90 data were included in the analysis (Fig. 4). Each 90 m x 90 m cell within a township was assigned a value equivalent to the population density for that township.

3.1.2.4 Land Use Wolves likely respond to different types of land use in different ways. Using data from the U.S. Geological Survey on Land Use and Land Cover, the New York study area was classified by land use (30 categories) at a resolution of 90 m x 90 m (Table 1, Fig. 5). For each of the land use models (A, B, and C) shown in Table 1, the value for each land use category ranges between 0 and 100 and is inversely related to its assigned degree of habitat suitability. For example, the suitability of “residential” land in models A and C is the lowest possible, and is moderately unsuitable in model B. Model A maximizes the value of open and wild areas regardless of the potential for human interactions, model B minimizes the suitability of human interactions and rangeland, and model C further limits the suitability of human interactions. In all three models, water bodies are assigned the minimum values of suitability.

3.1.2.5 Proximity to Water Distance surfaces were generated around bodies of water and other hydrological features available from the U.S. Geological Survey DLG data set. The cells closest to water were considered most favorable to wolves and those furthest away from water were considered least favorable. Inclusion of this variable was based on the assumption that, all other parameters being equal, the availability of prey for wolves (deer, moose, beaver), and therefore the suitability for wolves, would be greater near bodies of water. Further, other large canids have been shown to move along and concentrate near water features (Harrison 1992). Water bodies themselves were treated as movement barriers.

3.1.3 Model Weighting Schemes

Using ArcInfo to analyze the five data layers (variables), cells were ranked according to how favorable they were for wolves based on a variety of weightings for the five habitat variables. Because there is no empirical evidence to suggest how these variables should be weighted with respect to one another, a combination of different weighting schemes were used to create a composite conservation corridor. In total, 15 weighting schemes were generated that systematically favored each single variable, combinations of two variables, and adjusted land use (Tables 1-3).

3.1.4 Corridor Analysis

For each model described in Table 2, each cell received a value for each parameter as set out by the model. The value for each parameter corresponded to the ability of that cell to provide suitable wolf habitat. ArcInfo was used to integrate the five parameters as determined by each model in order to identify the most suitable habitat for wolves between the Adirondack Park and the Thousand Islands area. As two separate analyses were used to identify the linkage between the two

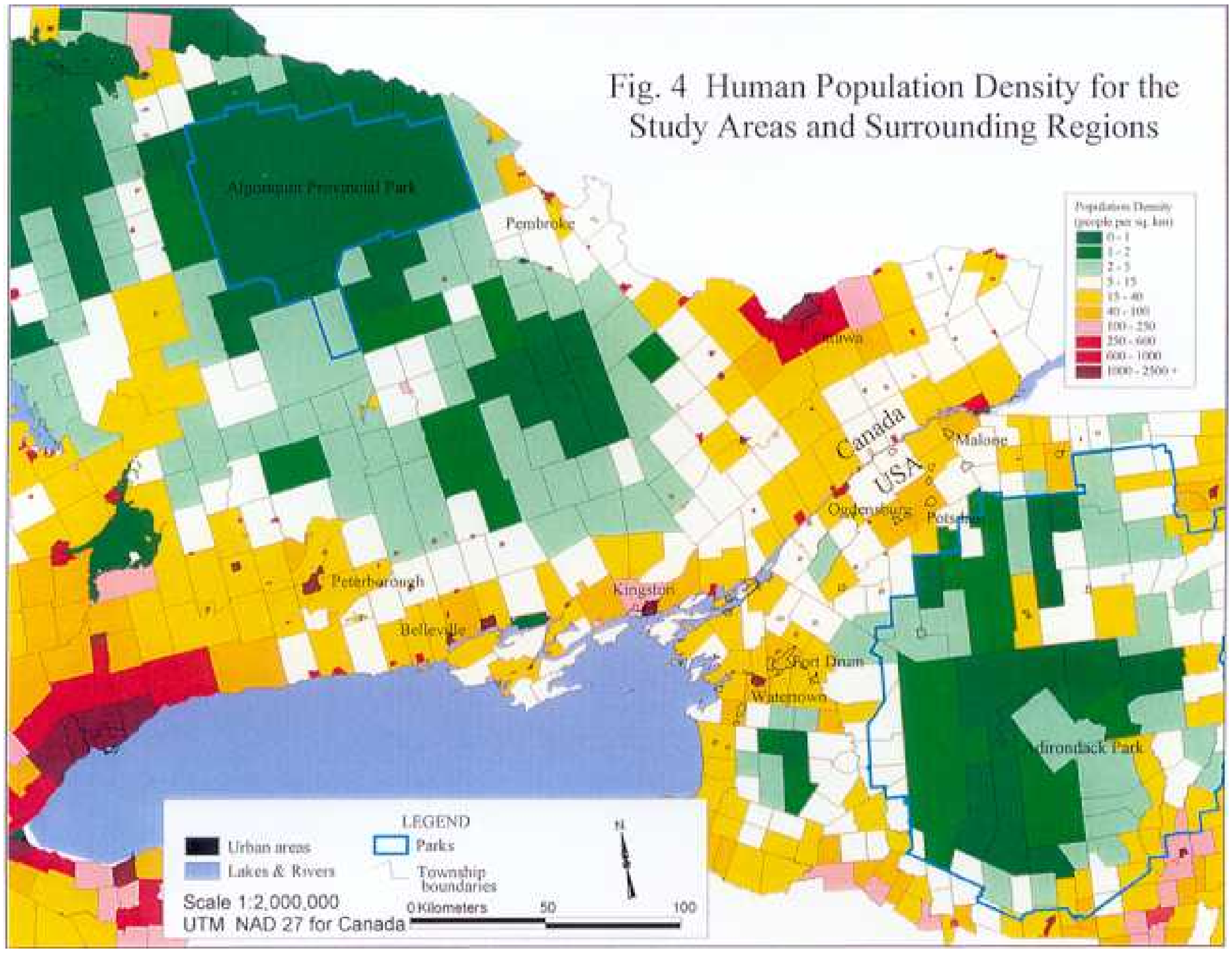

Fig. 4 Human Population Density for the Study Areas and Surrounding Regions

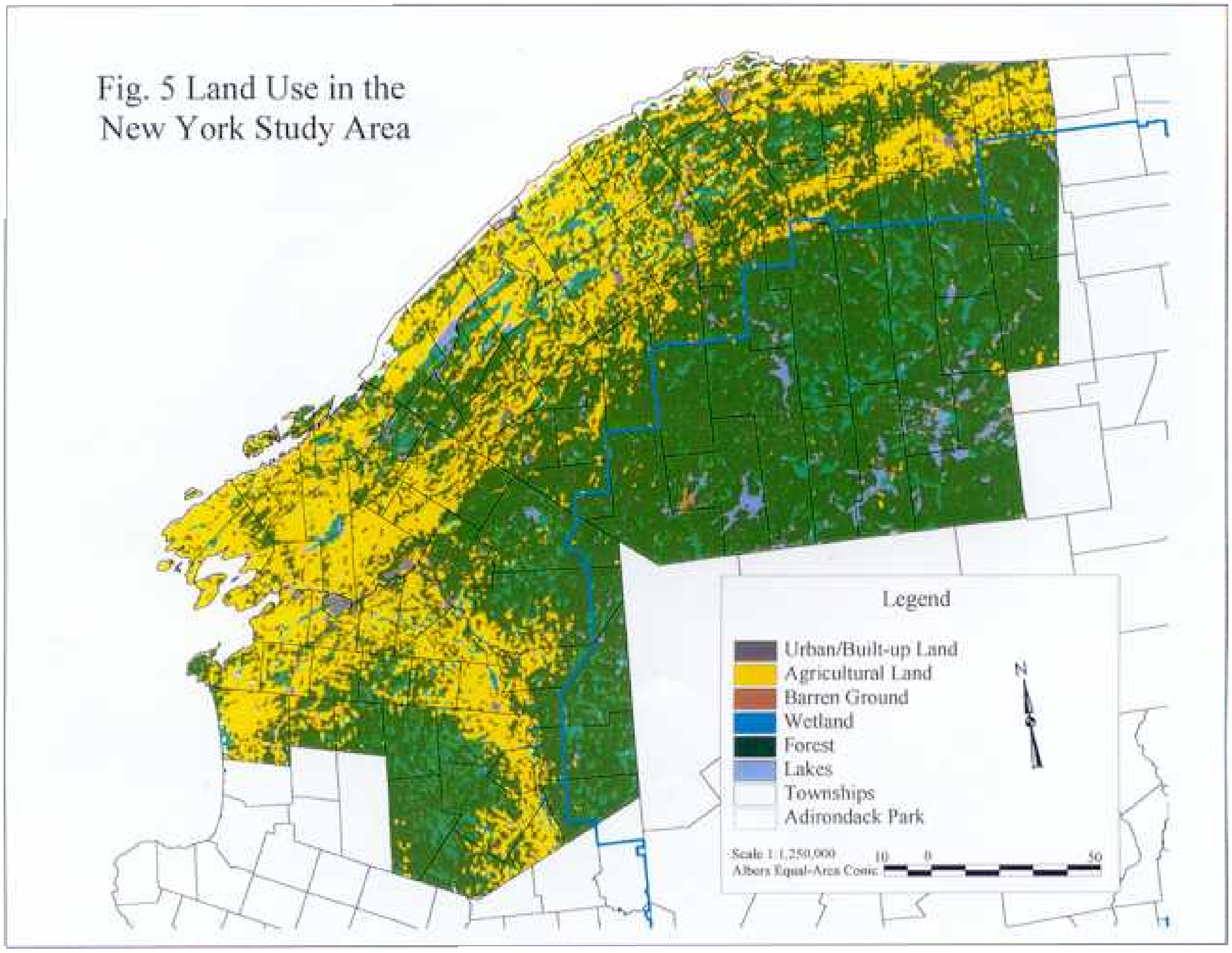

Fig. 5 Land Use in the New York Study Area

Table 1. **Weighting schemes used to assign relative habitat suitability to cells within the New York study area (value is inversely related to its suitability)**

Land Use	**A**	**B**	**C**
Residential	100	64	100
Commercial	100	100	100
Industrial	100	100	100
Transportation & Utilities	64	64	100
Industrial & Commercial	100	100	100
Mixed Urban	100	100	100
Other Urban	100	100	100
Cropland & Pasture	16	36	100
Orchards, Groves, & Gardens	36	36	100
Confined Feeding Operations	100	36	100
Other Agricultural	36	36	100
Herbaceous Rangeland	4	36	4
Shrub & Brush	4	36	4
Mixed Rangeland	4	36	4
Deciduous Forest	4	4	4
Evergreen Forest	4	4	4
Mixed forest	4	4	4
Streams & Canals	100	100	100
Lakes	100	100	100
Reservoirs	100	100	100
Bays & Estuaries	100	100	100
Forested Wetlands	16	16	16
Non-forested Wetlands	16	16	16
Dry Salt Flats	16	16	64
Beaches	16	16	64
Sandy Areas other than Beach	16	16	64
Bare Exposed Rock	16	16	16
Strip Mines & Quarries	100	64	100
Transitional Areas	36	36	36
Mixed Barren Land	36	36	36

Table 2. **Fifteen weighting schemes of the five parameters used to assess the suitability of each cell in the New York study area**

Parameter	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VIII**	**IX**	**X**	**XI**	**XII**	**XIII**	**XIV**	**XV**
Road Density	30	0	15	15	55	15	35	35	35	10	30	30	30	30	30
Presence of Major Roads	30	15	0	15	15	55	35	10	10	10	15	30	15	30	15
Population Density	15	55	15	0	15	15	10	10	35	35	15	15	15	15	15
Land Use	15	15	55	15	0	15	10	35	10	35	30	15	30	15	30
Proximity to Water	10	15	15	55	15	0	10	10	10	10	10	10	10	10	10
TOTAL	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table 3. **Explanations for each of the weighting schemes shown in Table 2**

Models I - XI use land use classification Model A
Models XII - XIII use land use classification Model B
Models XIV - XV use land use classification Model C
Models II - VI weighted one parameter favorably
Models VII - X weighted two parameters favorably
Models I, IX - XV adjusted the importance of land use for each land use model (A-C)

parks, each operating in its own portion of the study area, it was necessary to find a point on the U.S.-Canadian border where the linkages would most logically meet. The Thousand Islands area of the St. Lawrence River was chosen for three reasons: (a) it lies on a direct line between the two parks, (b) of the potential choices on the Canadian side, it was the least developed, and (c) its location is most conducive to facilitating wolf movement across the St. Lawrence River during winters with sufficiently low temperatures to cause the river surface to freeze.

Using the Thousand Islands area as the destination point for a linkage, and the Adirondack Park boundary as the origin, the “corridor” function in ArcInfo was used to identify the area between the origin and the destination that was best suited to supporting wolf populations. To do this, the weighted grids from each of the 15 models was used as a “cost surface” where the value of each cell became the “cost,” or impedance factor, for wolves to move through that cell. The area identified from the cost surface analysis was the most suitable wolf habitat (least costly for wolves to move through).

Thus, the corridor function produces a swath of cells that register below a certain cumulative cost. Taking into consideration the range of costs of the cells within the entire study area, it was possible to set the cost parameter for the corridor function at a level that would return a swath of cells, between the origin and the destination, that corresponded to the top 1% of cells that provide suitable wolf habitat. This 1% criterion was used for the generation of a 1% corridor for all of the 15 models. The cells returned from each iteration of the corridor function for each of the models were then amalgamated into what was labelled the "Top 1% Corridor". This process was repeated using 2%, 4%, 5%, 6%, and 10% criteria for the corridor function to generate the respective Top % Corridors.

3.2 Ontario

The purpose of the Ontario study was to identify a corresponding conservation linkage in Ontario using methods that mimicked those used in the New York study as closely as possible. Unavoidable differences in methodology arose, however, primarily due to the unavailability of matching digital data and slight differences between the ArcInfo and ArcView software. Those data sets for Ontario that most closely matched the data sets used in the New York study were obtained, including roads and trails, human population, vegetation, and water.

3.2.1 Data Sets

3.2.1.1 Roads and Trails The integrity and movement of wolf populations decreases as road density increases (Fuller et al. 1992, Jensen et al. 1986, Mech 1989, Mladenoff et al. 1995, Thiel 1985, Thurber et al. 1994). The roads and trails data set included all roads from multi-lane highways to single lane cart trails (Fig. 3). The roads and trails data were reasonably detailed and were stratified into three different themes. Each indicated a different direct or indirect pressure or effect on wildlife through habitat modification and allowed these different pressures to be differentially weighted in the analysis models (e.g. trails are likely an indicator of hunting pressure, while major highways and secondary highways act as movement barriers and indicators of human presence and activity).

In contrast with the New York study, the distance to roads rather than road density was used. This was done because (1) road density does not reflect the relative difference in value between road-free cells, and (2) the resolution of the road data was such that even in areas with many roads, the density of roads was not likely to change much between cells using a cell size of 90-m x 90-m. With such a fine resolution grid size, road density usually does not change significantly from one cell with roads to another cell with roads, but does shift dramatically to zero as soon as a cell becomes road-free. Thus, a cell without a road that is located contiguous to a cell with a road would be assigned the same value in a road density grid as the value of a road-free cell situated 10 km away from a road. The "distance to roads" variable assumes that a cell 10 km away from any roads provides better wolf habitat than a road-free cell located contiguous to a cell with roads. Each roads theme could also be weighted separately in the analysis and included the following:

> **Major highways** These roads are equivalent to the state and interstate highways used in the New York study. These correspond to 400 series highways and are generally multi-laned and paved with speed limits of 100 km/hr.
>
> **Secondary highways** These roads correspond to the 80 km/hr highway network. They are generally two lanes and paved.
>
> **All roads and trails** This data layer comprises all roads and trails of any kind from major and secondary highways to single lane dirt trails. This road layer combines all roads to

match the road density data set used in the New York study.

3.2.1.2 Human Population Humans have been shown to be the major source of wolf mortality (Fritts and Mech 1981, Fuller 1989). Thus, wolves tend to be associated with low human population densities (Fuller et al. 1992, U.S.F.W.S. 1992, Mladenoff et al. 1995, Boitani 1995). To account for this in our analysis, we obtained 1991 human population data from Compusearch (Toronto, Ontario). The study area is sparsely populated throughout most of the region, resulting in low values in most regions except the immediate vicinity of Ottawa and a few smaller towns (Fig. 4). Human population within the study area is subject to drastic seasonal changes due to the abundance of second homes and cottages. In the summer, the populations of many small towns increases significantly, however, these seasonal fluctuations are not represented in the data set which provided only average population densities for each county within the study area. These data were converted to a 90-m x 90-m grid so that each cell would have a value reflecting the average population density. In order for these cell values to be appropriately weighted in our model analyses, an "inverse" population grid was calculated using the following equation:

Inverse (population) =(population grid values - maximum population value) * (- 1)

The purpose of such a transformation is to establish a consistent meaning between values of different data themes so that the meaning of high cell values in one data theme corresponds to the meaning of high cell values in another data theme.

3.2.1.3 Vegetation Wolves require extensive core areas of forested habitat for cover, denning, and access to prey (Jensen et al. 1986, Fuller et al. 1992, Mladenoff et al. 1995, Harrison and Chapin 1997, 1998). Unfortunately, the digital data for land cover in Ontario is less detailed than it is for New York. Therefore, in the Ontario study area, vegetation replaced the land use categories used for the New York study. The vegetation theme simply identified areas that are wooded as opposed to non-wooded areas (Fig. 2). In the analysis, the "inverse" distance to vegetation (inverse function defined in 3.2.1.2) was used as an indicator of habitat fragmentation. Non-wooded cells located far from a wooded area received a lower cell value than a non-wooded cell that was adjacent to a wooded cell. While this is a crude way of estimating forest fragmentation, it was assumed to be some measure of the suitability of a cell as wolf habitat.

3.2.1.4 Water As in the New York analysis (see 3.1.2.5), we assumed that wolf movement and prey densities would be highest near bodies of water. To incorporate this variable into the analysis, the lakes and rivers data sets were combined to create a theme of water features (Fig. 2). Lakes were masked out of the analysis so that they would not be identified as wolf habitat. The inverse distance to water (see 3.2.1.2) was used for analysis.

3.2.2 Model Weighting Schemes

Distance grids for each theme were normalized on a scale from 1 to 100, and 15 different models based on different theme weightings were generated, each resulting in a new grid reflecting the combination of theme weightings. Weighting schemes for the Ontario models (Table 4) were similar to those in the New York study, but were not identical because the data used for the two studies differed. We emphasized roads by including three roads themes because roads appear to be the single most important and useful indicator of wolf habitat (e.g. Mladenoff and Sickley 1998). Roads allow access for a variety of human activities, such as off-road vehicle use, which may compromise optimal wolf habitat.

Table 4. Weighting schemes for the 15 models used in the mosaic calculations and analysis models for the Ontario study area

	Model Type and Number																
Habitat Variable	**Dominant**						**Co-Dominant**					**Road Reduced**			**Natural**	**Other**	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Dist. to Road &Trail	**50**	10	10	10	10	10	**30**	10	10	10	10	0	0	0	5	100	16.6
Dist to Major Hwy	10	**50**	10	10	10	10	**30**	**30**	**30**	**30**	**30**	15	15	15	5	0	16.6
Dist to Secondary Hwy	10	10	**50**	10	10	10	10	**30**	10	10	10	15	15	15	5	0	16.6
Population Density	10	10	10	**50**	10	10	10	10	**30**	10	10	**40**	15	15	5	0	16.6
Dist to Vegetation	10	10	10	10	**50**	10	10	10	10	**30**	10	15	**40**	15	**40**	0	16.6
Dist to Water	10	10	10	10	10	**50**	10	10	10	10	**30**	15	15	**40**	**40**	0	16.6
Total percent	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

3.2.2.1 Models 1 - 6: Dominant Weightings Each of these models favored only one of the six themes at 50% while the rest of the themes were weighted at 10% each. This allowed each theme to exert a dominant influence over the other themes.

3.2.2.2 Models 7 - 11: Co-dominant Weightings These models represented a co-dominant weighting with two themes receiving a weight of 30% and the remaining themes each receiving a 10% weighting. Performing calculations on all possible co-dominant combinations (15) was prohibitive, therefore, the major highways theme was chosen as the most significant factor affecting wolf habitat and was used as one of the co-dominants in each of the five models. Each of the other themes was then used as the other co-dominant theme.

3.2.2.3 Models 12 - 14: Reduced Roads Weightings Because there were three different road themes, roads received significant emphasis in most of the models despite individual road themes receiving little weight. Models 12 - 14 were designed to reduce the importance of roads in the analysis by assigning the roads and trails theme to zero. Road influence was not completely eliminated from these models, however, because of the influence of both secondary and major highways on the models. Neither of these themes dominate the weightings in these models. Rather, each of the population, vegetation, and water themes was, in turn, weighted at 40%, with the other themes weighted at 15%, and roads and trails at 0%.

3.2.2.4 Model 15: Natural Features Model Because of the high weightings assigned to the road and human population themes, models 1-14 represented conditions in which human influence was substantial. In contrast, model 15 was designed to allow the “natural” features of water and vegetation to dominate the selection of favorable wolf habitat. In this model, water and vegetation themes were weighted at 40%, while the remaining themes received a weighting of 5% each.

3.2.2.5 Model 16: Roadless Areas Model This model, which only considered the absence of major highways, was not used in the mosaic analysis but was used in the cost surface and cost path analyses.

3.2.2.6 Model 17: Equal Weighting This model was used only for descriptive purposes in the display of the final corridor. The equal weighting of all themes was used to color-shade the final proposed composite corridor to show a gradient of composite wolf habitat suitability. Many additional models could be generated using different weighting schemes, but time and resource limitations necessitated selecting a few models that best represented the spectrum of possibilities.

3.2.3 Mosaic Analysis

Each of the first 15 models generated a grid where cell values reflected their suitability as wolf habitat. The top 1, 2, 4, 5, 6, 10, 25, and 50th percentiles were determined for the entire study area for each of the 15 models. This resulted in the identification of those areas considered as suitable habitat by each model, with no consideration of the linkage between the Thousand Islands area and Algonquin Park.

For the New York study area, the mosaic analysis method resulted in the identification of a continuous conservation zone. However, the extremely high suitability of wolf habitat in the northern part of the Ontario study area compared to the southern parts, resulted in the higher percentile mosaic areas being located almost exclusively in the northern portion of the Ontario study area. The lack of high quality wolf habitat in the southern portions precluded the identification of linkages using this method. Thus, additional analyses were required to find the most suitable wolf habitat in the southern portions of the Ontario study area.

3.2.4 Cost Surface and Cost Path Analyses

The model grids are weighted distance grids that have low values in cells identified as favorable wolf habitat. The cost surface analysis produces a weighted grid, assigning a “cost” to each cell that determines movement through that cell from a source to a destination. The path analysis was carried out using an Avenue program (ArcView programming language) that minimized the cost of moving from the source to the destination.

The cost path analysis has a tendency to minimize path cost by choosing the straightest line possible from source to destination. To dampen the shortest distance effect, and to ensure that the features of a given theme were recognized in the cost path analysis, it was necessary to increase the range of the cell values used in the weighting models using the following formula.

$$\text{New Cell Value} = (\text{Old Cell Value}/10)^{n}$$

With increasing values of n, this equation was first applied to the distance to road and trails grid to test the method. The results from each output grid were observed and a decision was made to run the output grid through the equation until the resulting change in path location was minimal to none from one iteration to the next. An exponent of 5 was required to reach a stable location for the roads and trails grid.

Also, to improve calculation efficiency of the cost surface and cost path analyses, a 500-m x 500-m cell size (resulting in a total of 300,000 cells) was chosen, as speed of calculations provided greater freedom to experiment with the analysis and did not compromise the quality of the output. Smaller cell sizes (127-m x 127-m; 180-m x 180-m) increased calculation times considerably and did not greatly change the path location.

Finally, a subset of the 15 models was selected for cost surface and cost path analyses that reflected the full range of possible corridor routes. Models 1 and 16 were chosen because roads are thought to be the most significant component of potential wolf habitat, and model 15 was chosen because this model represented the natural features (forest and water) that significantly influence the suitability of habitat for wolves. While other models were subjected to the cost surface and cost path analyses, only models 1, 15, and 16 are presented in the results because other models were not based on variables with significant regional variation (e.g. human population density), or did not deviate appreciably from the paths generated by models 1, 15 and 16.

3.2.5 Adding Width

Once the paths were established, it was necessary to define the corridor width that was established by combining criteria similar to those used in the mosaic analysis with the cost surface and path analysis. New cost surface grids were generated for models 1, 15 and 16 using the paths generated on those grids as the source and evaluating the cost distance to each cell in the entire study area grid. The cost surfaces generated were then queried for the top 1, 2, 4, 5, 6, and 10 percentiles of cells. The corridor area determined by models 1, 15 and 16 were then combined to form a composite corridor for each percentile.

4.0 RESULTS & DISCUSSION

4.1 New York

As there are no empirical data that address the question of corridor design for wolves, we can only assess the suitability of these corridor designs qualitatively. The Top 1% Corridor (Fig. 6) is not continuous from the Thousand Islands area to the Adirondack Park, and is therefore insufficient by itself to ensure functional connectivity. The Top 2% Corridor (Fig. 7), while continuous across its southern edge, is extremely narrow in many places, and is likely to present problems for dispersing wolves as they try to move through these bottlenecks. The Top 4% Corridor (Fig. 8) widens these bottlenecks in most places, but is still constricted on both its southern and northern edge near the Thousand Islands area. The pocket of low suitability cells in the center of the northwestern end of this corridor reflects the presence of a cluster of agricultural land and water bodies.

From a qualitative perspective, the Top 5% Corridor (Fig. 9) and Top 6% Corridor (Fig. 10) appear to be better corridor designs than those based on smaller percentages. The bottlenecks on the northwestern end are virtually eliminated and the corridor is continuous across a wide portion of the landscape. The pockets of low suitability are not completely eliminated, but that does not occur even in the Top 10% Corridor (Fig. 11), so this seems to be a permanent constraint. Although the Top 6% Corridor would, by virtue of its larger size, be better for wolf movement than the Top 5%

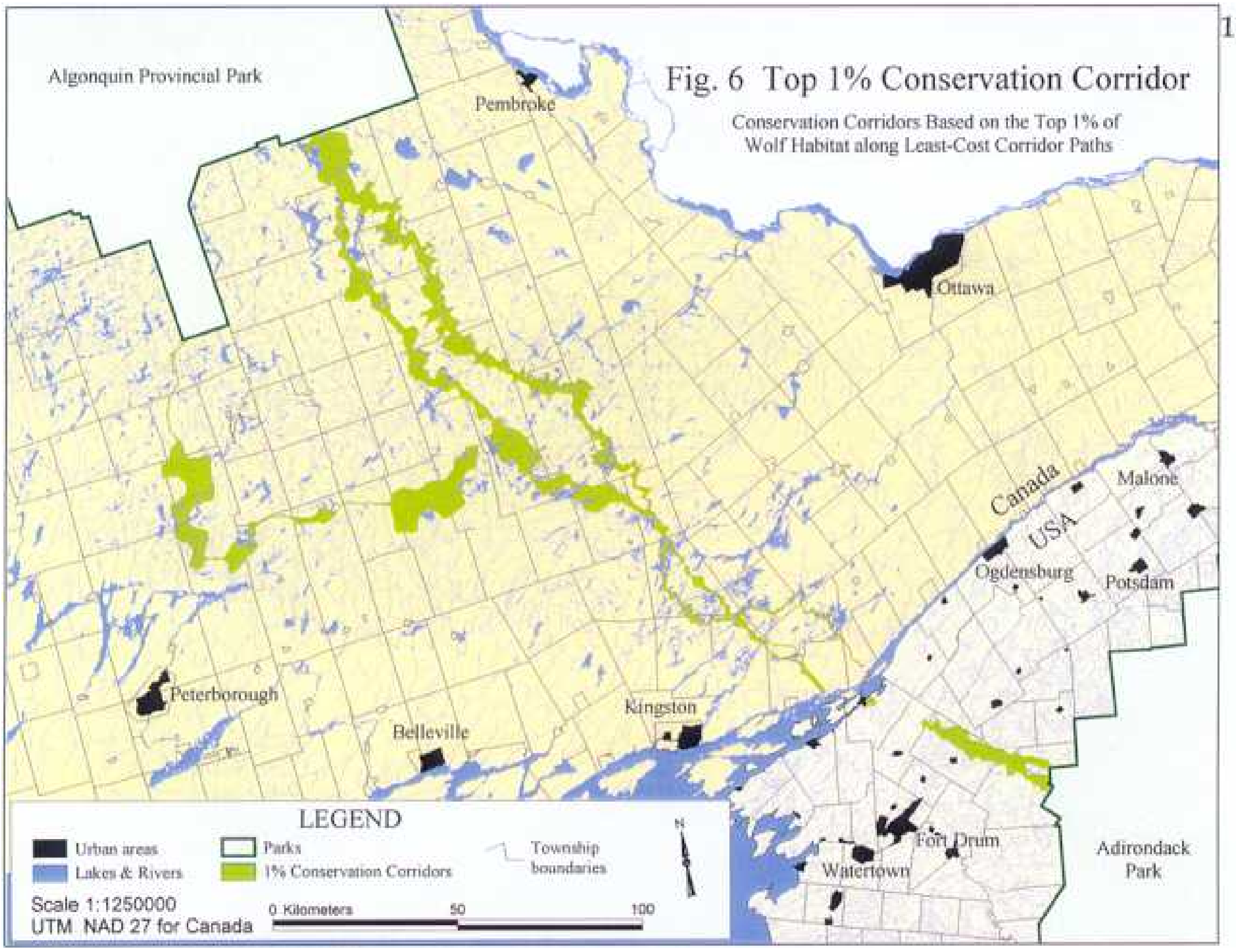

Fig. 6 Top 1% Conservation Corridor

Conservation Corridors Based on the Top 1% of Wolf Habitat along Least-Cost Corridor Paths

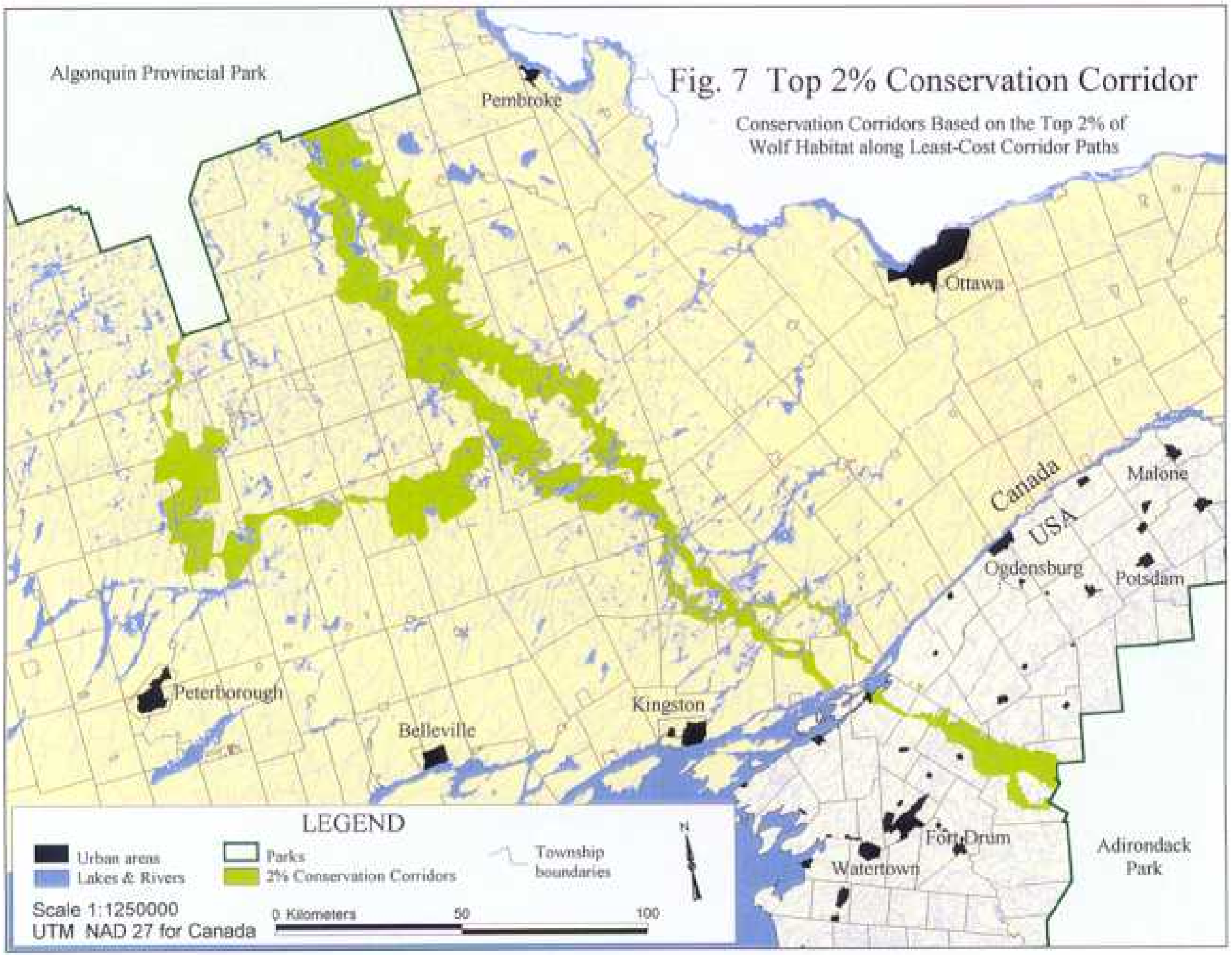

Fig. 7 Top 2% Conservation Corridor

Conservation Corridors Based on the Top 2% of Wolf Habitat along Least-Cost Corridor Paths

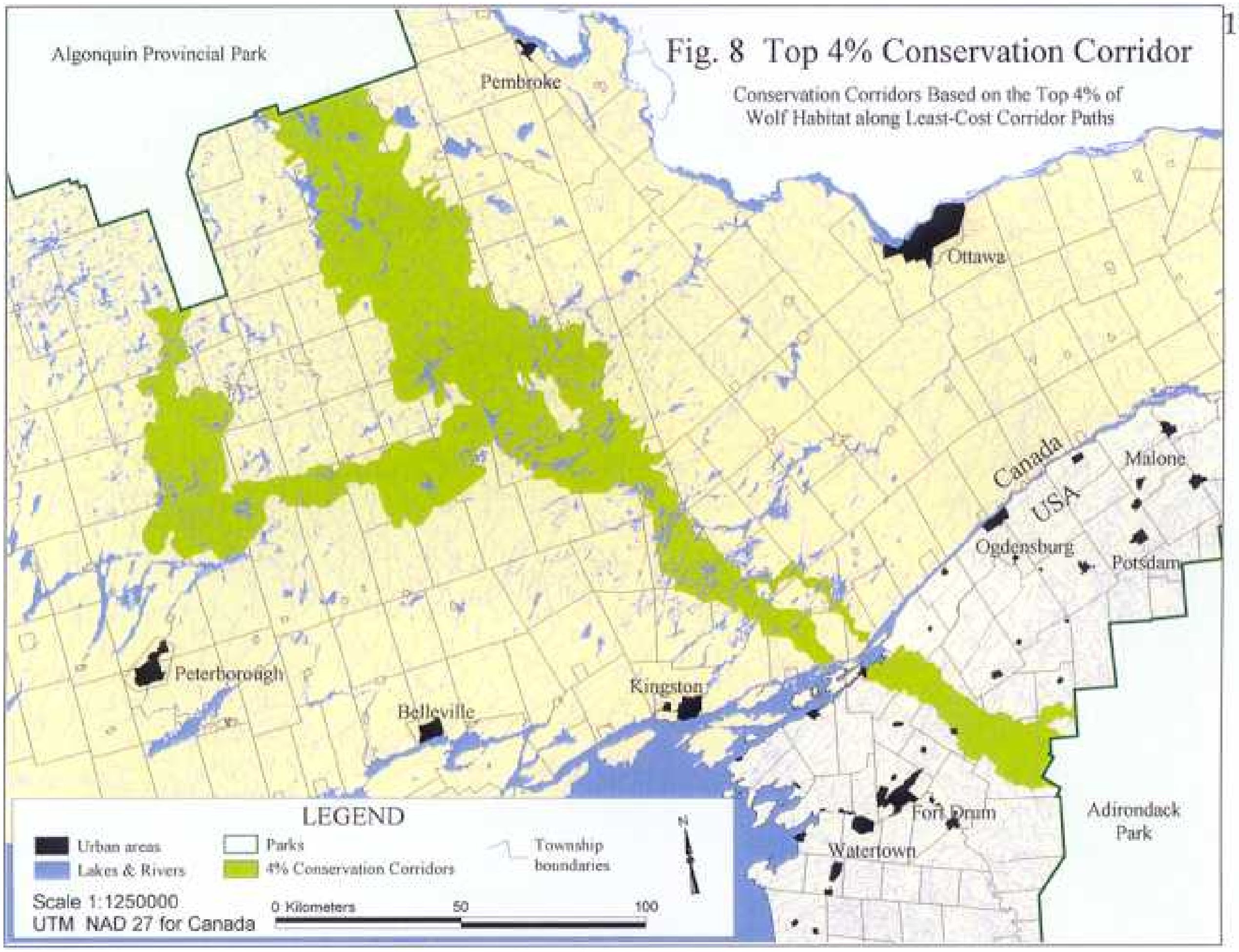

Fig. 8 Top 4% Conservation Corridor

Conservation Corridors Based on the Top 4% of Wolf Habitat along Least-Cost Corridor Paths

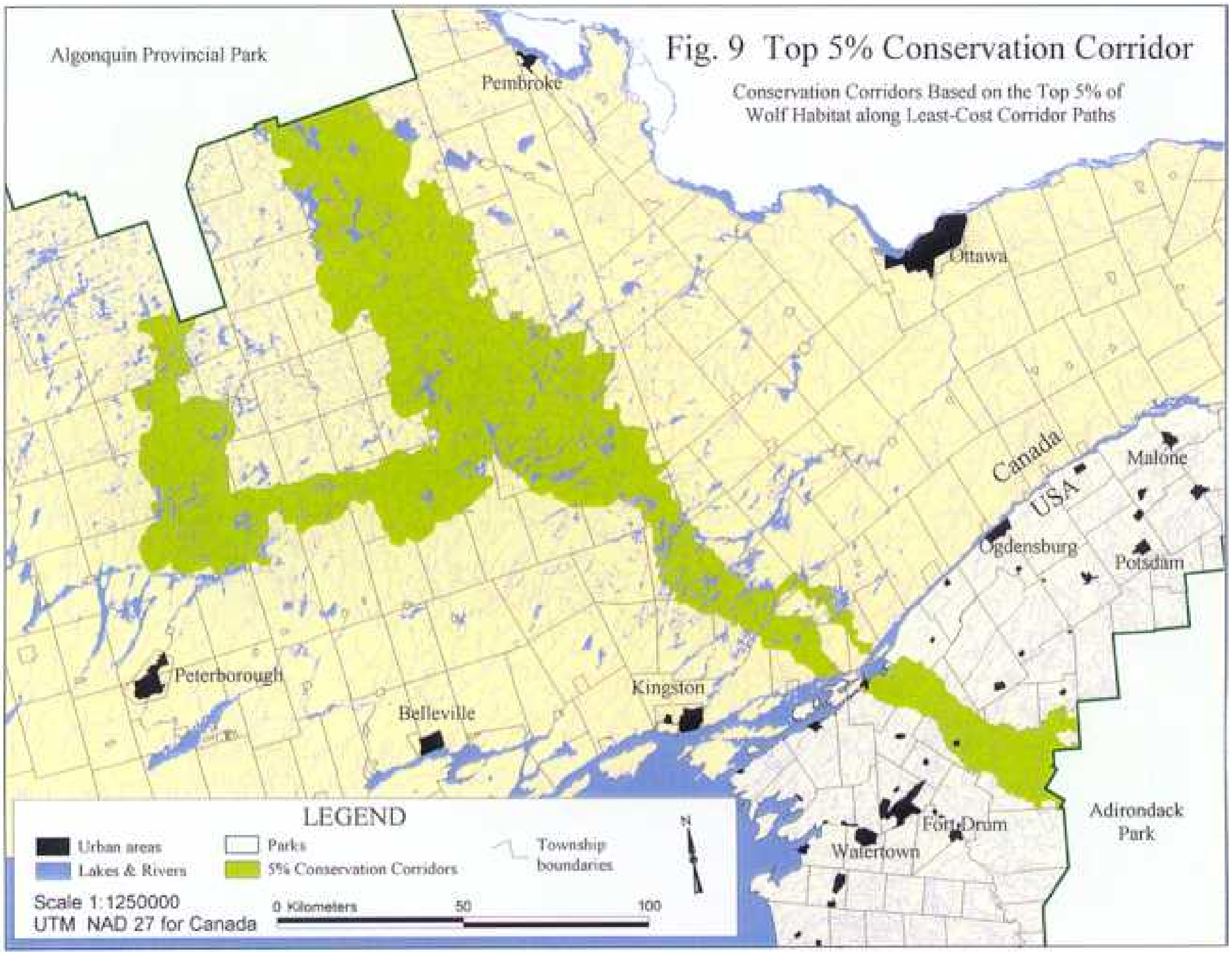

Fig. 9 Top 5% Conservation Corridor

Conservation Corridors Based on the Top 5% of Wolf Habitat along Least-Cost Corridor Paths

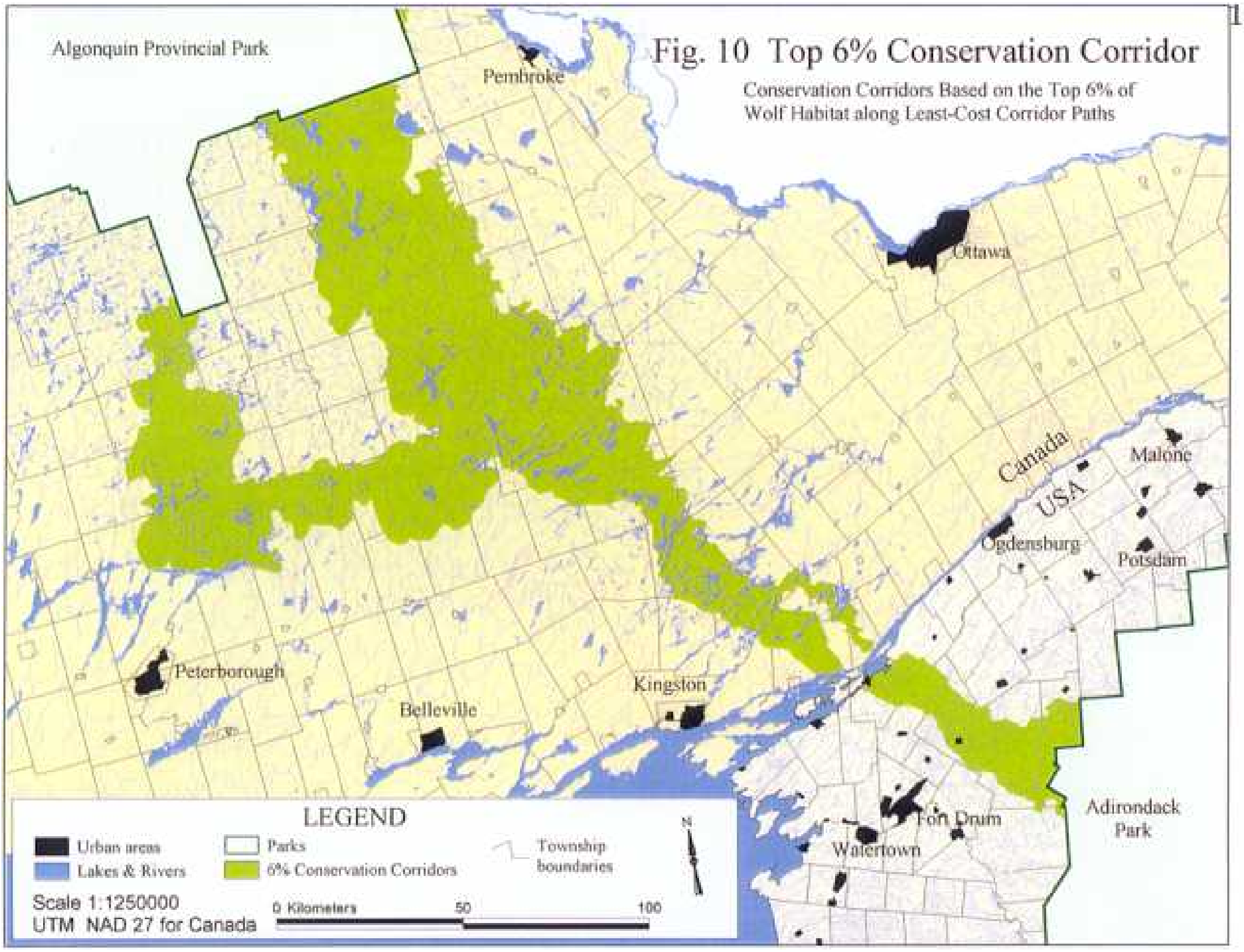

Fig. 10 Top 6% Conservation Corridor

Conservation Corridors Based on the Top 6% of Wolf Habitat along Least-Cost Corridor Paths

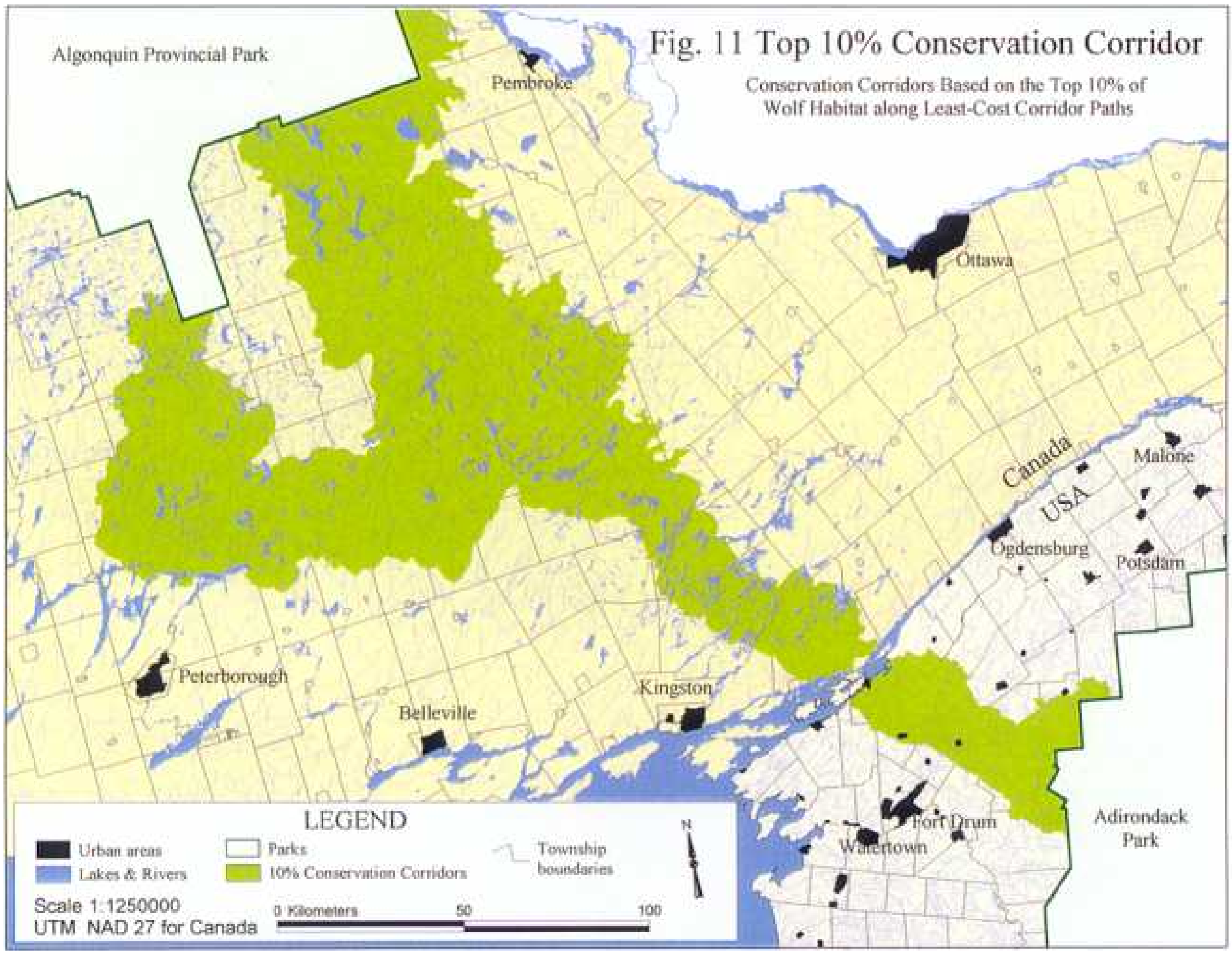

Fig. 11 Top 10% Conservation Corridor

Conservation Corridors Based on the Top 10% of Wolf Habitat along Least-Cost Corridor Paths

Corridor, it may or may not be incrementally better. Therefore, we suggest that the Top 5% Corridor should be considered the Priority Conservation Corridor (Fig. 12), with the additional land in the Top 6% Corridor being of lesser importance.

Many studies from the western and midwestern U.S. indicate that the threshold value of road density above which wolves cannot persist is between 0.45 and 0.70 km/km^2 (Fuller et al. 1992; Jensen et al. 1986; Mech 1989; Mladenoff et al. 1995; Thiel 1985; Thurber et al 1994). Within the Top 5% Corridor, the road density is 0.31 km/km^2, well below the threshold, indicating that, with respect to this important parameter, the proposed Priority Conservation Corridor currently satisfies the conditions for wolf movement.

4.2 Ontario

4.2.1 Mosaic Analysis

The results of the Ontario mosaic analysis (Fig. 13) identified a patchy network of suitable wolf habitat, but failed to identify a linkage between the Thousand Islands area and Algonquin Park. The top 5% mosaic of the 15 scenarios shows the beginning of a potential corridor in the northern portion of the study area along the eastern boundary of Algonquin Park. It also shows a zone of suitable habitat stretching southward, however, continuity in this zone is lost about halfway to the Thousand Islands area. This result was not surprising due to the high road and human population density of that region.

4.2.2 Cost Surface and Cost Path Analysis

The cost surface and cost path analyses identified a continuous or unbroken corridor across the study area (Fig. 14). It is interesting to note, however, that none of the initial 15 path analysis models linked the Thousand Island area to the “pan handle” (most southerly extension) of Algonquin Park. Only the roadless areas model used in the cost path analysis identified this additional path.

4.2.2.1 Path Analysis Model 1 (Roads & Trails Model) The path analysis for model 1 exits the Thousand Islands area at its southernmost point, taking a relatively straight path to its destination at Algonquin Park, 29 km west of the southeastern corner of the park (Fig. 14 Roads & Trails path in pink). The total path length was 226 km and deviated from its axis (a straight line joining its start and finish points) by no more than 23 km.

4.2.2.2 Path Analysis Model 15 (Natural Features Model) The path analysis for model 15 exits the Thousand Islands area 6.5 km from its northernmost point and had the same destination point as the model 1 path. The path deviated most notably in the southern one-third of its length, indicating significantly different wildlife values in this section when compared with the other two models (Fig. 14; Natural Features path in green). The total path length was 249 km and deviated from its axis by no more than 22 km.

4.2.2.3 Path Analysis Model 16 (Roadless Areas Model) The path generated for model 16 exits the Thousand Islands area at its southernmost point in the same location as model 1. It follows the model 1 pathway closely for the first one-half of its length and just north of the halfway

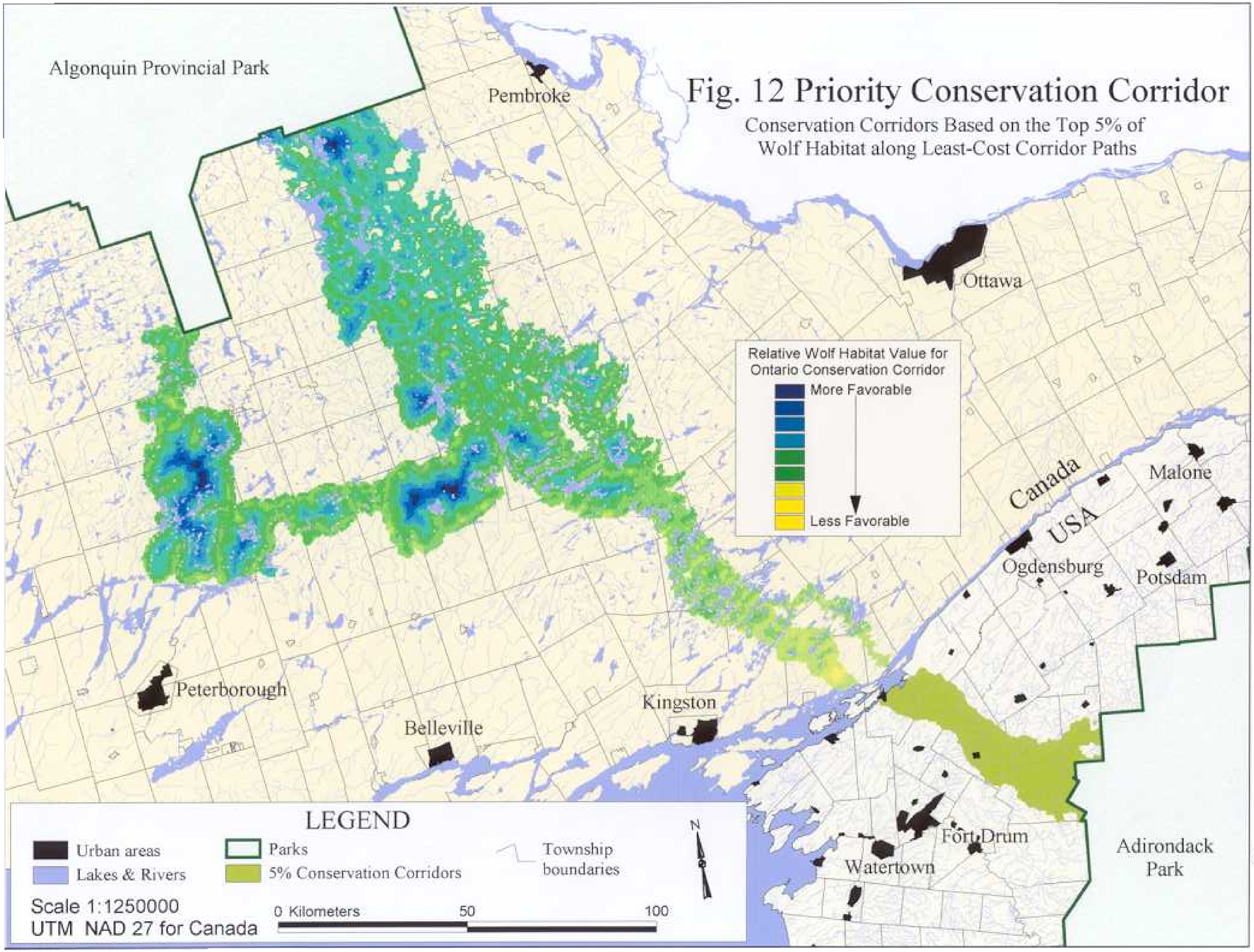

Fig. 12 Priority Conservation Corridor

Conservation Corridors Based on the Top 5% of Wolf Habitat along Least-Cost Corridor Paths

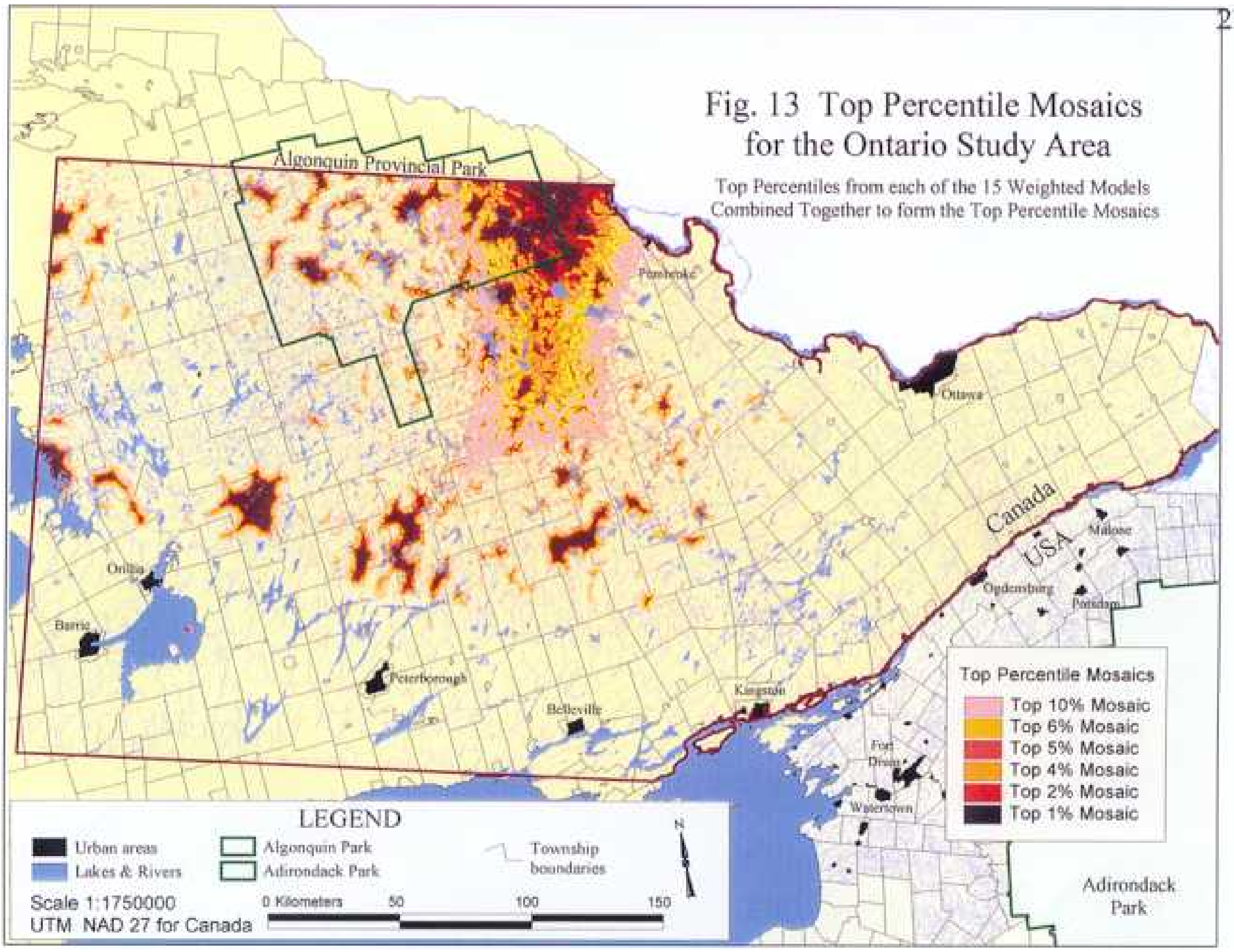

Fig. 13 Top Percentile Mosaics for the Ontario Study Area

Top Percentiles from each of the 15 Weighted Models Combined Together to form the Top Percentile Mosaics

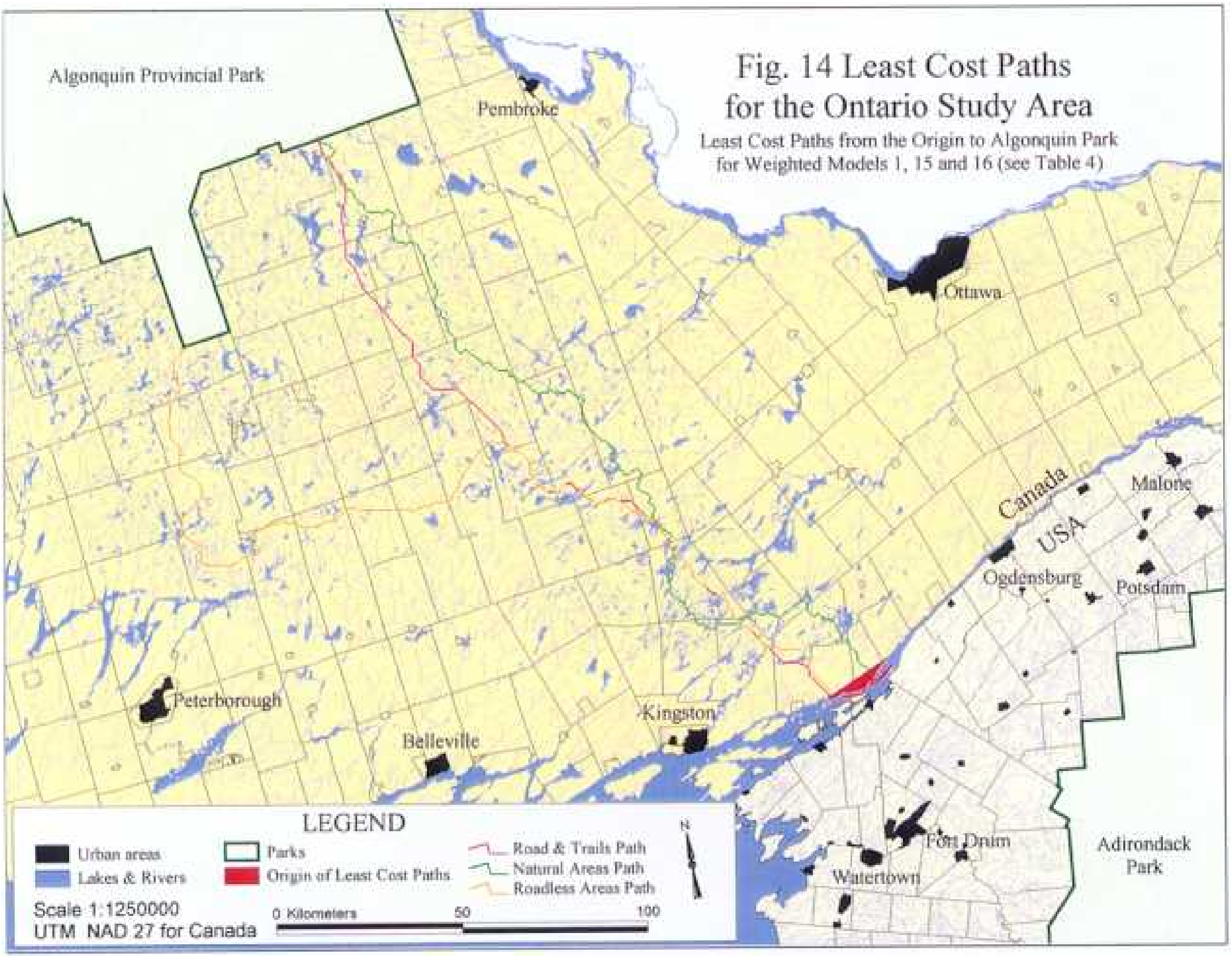

Fig. 14 Least Cost Paths for the Ontario Study Area

Least Cost Paths from the Origin to Algonquin Park for Weighted Models 1, 15 and 16 (see Table 4) point it deviates markedly towards the west and then turns north eventually entering Algonquin Park near the southernmost part of the pan handle (Fig. 14; Roadless Areas path in orange). It is worth noting that this was the only model that identified a least-cost path that joined the Thousand Islands area with the pan handle of Algonquin Park. Despite the fact that this particular model weighted all data themes other than roads and trails at 0%, it is proposed as an important corridor because it links large roadless areas deserving consideration in the development of any conservation strategy. These roadless areas should to be identified as priorities for conservation immediately in order to preserve future conservation options.

4.2.3 Adding Width

The three separate 5% corridors from the cost-surface analyses were merged into a composite corridor for the entire corridor length corridors (note: 5% was used to maintain consistency with the New York study). This composite corridor represented the Priority Conservation Corridor for the Ontario study area. It has a total area of 7,622 km^2, and comprises approximately 10.2% of the total study area, which is less than the 15% that would be expected if there were no overlapping areas among the 5% corridors. Starting with the natural features corridor at 5% of the study area, the addition of the road and trails corridor increases the total to about 7.8% of the study area, and finally the addition of the roadless areas corridor brings the Priority Conservation Corridor up to 10.2% of the study area.

At its widest, the Corridor measures 43 km. It is narrowest at the southern limit, where the wide branch connecting to the Thousand Islands area is 5.3 km and the narrow branch is only 2.3 km. This is not surprising as this region was identified in all 3 models as having poor habitat values, with cell values not making it into the top 50th percentile of favorable habitat conditions. It was, therefore, extremely “costly” to add width to the Corridor in this region. In total, the Priority Conservation Corridor contains 34% of the top 10% of suitable wolf habitat in the study area, amounting to 59% of the Corridor area.

The northern half of the Priority Conservation Corridor encompasses much more suitable wolf habitat, making up 33.8% of the top 10% of suitable habitat conditions in the study area. This is a total of 4,486 km^2,or 58.8% of the Corridor.

4.3 Conservation Values of the Proposed Priority Conservation Corridor

4.3.1 New York

Additional analyses of the New York study area addressed the issue of ecological representation, including plant communities, water bodies, and habitat fragmentation, within the Priority Conservation Corridor. These types of features likely affect the conservation value of the Corridor and should be noted.

4.3.1.1 Plant Communities Plant community data at a 1.5 km x 1.5 km resolution were obtained for the New York study area from the U.S. Forest Service Southern Forest Experiment Station. Compared to the entire New York study area, the Priority Conservation Corridor overrepresents the maple-beech-birch forest type and underrepresents all others (Table 5). Further, the Corridor fails to represent the rare elm-ash-cottonwood forest type, which is restricted to central St. Lawrence County. Underrepresented plant community types, however, may be protected within the nearby Adirondack Park.

Table 5. Frequencies of each plant community type in the Priority Conservation Corridor for the New York study area

Forest types	Total Study Area		Priority Conservation Corridor	
	Area (km^2)	Frequency	Area (km^2)	Frequency
White-Red-Jack Pine	693	0.38	11	0.011
Spruce-Fir	805	0.044	1	0.001
Oak-Hickory	848	0.046	11	0.011
Elm-Ash-Cottonwood	19	0.001	0	0.000
Maple-Beech-Birch	13,876	0.756	940	0.970
Non-forest, water, or unclassified	2,116	0.115	6	0.006

4.3.1.2 Water Bodies Compared with the frequency of water bodies in the entire four-county study area, the Priority Conservation Corridor represents most natural types of water bodies (lakes and wetlands) at or above their natural level (Table 6). Bays and estuaries are underrepresented, as only a small part of the Corridor abuts the St. Lawrence River. We believe that the estimates of streams and canals throughout both the study area and the Corridor are biased as a result of the coarse resolution of the data layers (90 m) relative to the size of a stream, and therefore little can be said about this type of water body. Reservoirs are underrepresented in the Corridor relative to the study area, but the overrepresentation of lakes may offset this. The Corridor contains 723 km, or slightly more than a proportionate amount, of the area's 13,546 km of rivers and streams. Generally, therefore, the proposed Priority Conservation Corridor likely contains a proportional amount of the region's aquatic ecosystems.

Table 6. Frequencies of each type of water body in the Priority Conservation Corridor for the New York study area

	Four-county area		Priority Conservation Corridor	
Water bodies	Area (km^2)	Frequency	Area (km^2)	Frequency
Streams and canals	6	0.004	0	0.000
Lakes	198	0.131	19	0.250
Reservoirs	307	0.204	1	0.013
Bays and estuaries	10	0.007	0	0.000
Forested wetlands	917	0.608	52	0.684
Nonforested wetlands	70	0.046	4	0.053

4.3.1.3 Degree of Fragmentation Within the study area, excluding the Adirondack Park, landscape fragmentation outside of the Priority Conservation Corridor was compared with landscape fragmentation within the Corridor. This analysis assumes that major roads are the primary source of fragmentation, and that the patterns of distribution of other sources of fragmentation (e.g. minor roads, urbanization) are correlated with these major roads. The size of fragments within the Corridor are not significantly different from those in the target area as a whole (average size within Corridor = 82.9 km^2, SE = 26.3, n = 17; average size in target area = 151.1 km^{2,}, SE = 34.0, n = 128; t = -0.73, df = 143, P = 0.47), indicating that the Priority Conservation Corridor captures roadless areas of a size similar to those available throughout the study region outside of the Adirondack Park.

In summary, within the New York Study area, the Priority Conservation Corridor underrepresents many of the less common plant community types in the region, provides equal or overrepresentation for most natural aquatic ecosystems present in the region, and contains unfragmented areas similar in size to those in the region as a whole.

4.3.2 Ontario

The area within the Ontario Priority Conservation Corridor was identified using analysis of natural features, roadless areas, and a combination of all themes weighted for roads and trails. The branched design provides two routes for approximately half of its length (northern portion), resulting in redundancy that may serve as an ecological safety net. To illustrate the gradient in wolf habitat suitability within the Corridor, its area was color-shaded by evenly weighting all the data themes used in the study (Fig. 12; see inset legend).

The Corridor identified from these analyses includes regions of relatively intact wolf habitat in the northern areas, as well as regions with high degrees of fragmentation and disturbance in the south. The proposed corridor routes are the best routes through this highly heterogeneous landscape based on the digital data used in the study, and can provide the geographical focus for maximizing habitat connectivity between Algonquin Park and the Thousand Islands area of Ontario.

4.3.3 The Corridor in Relation to Other Species

As noted in 2.2, the Frontenac Link, with its wide array of environmental conditions and habitats, supports a rich and diverse range of species – many of which are rare. Among the rarest are other wide-ranging species including the marten, lynx, and moose, and extirpated species such as the cougar, elk, and wolverine. Many of these species, because of their sensitivity to human disturbance, trapping, road mortality, and other anthropogenic factors, would be expected to benefit from both the core and dispersal habitat resulting from the protection of the identified Priority Conservation Corridor. Further, species that have an affinity for interior forest habitats, such as some songbirds, would also be likely to benefit from such a corridor.

4.4 Results Relative to Other Wolf Habitat/Suitability Studies in the Northeast

The Adirondacks have been identified as potential core habitat for wolf recovery (USFWS 1992, Harrison and Chapin 1997, 1998, Mladenoff and Sickley 1998). Recent research suggests that, although wolves are physically capable of doing so, the likelihood of their dispersing from extant populations in Ontario into the previously occupied habitat of the northeastern U.S. is uncertain because of potential physical barriers (e.g. the St. Lawrence River) and isolation of suitable habitat (Harrison and Chapin 1998, Wydeven et al. 1998). As Wydeven et al. (1998) point out, however, bi-national efforts to protect biotic corridors representing significant zones of connectivity may increase the potential for wolf recovery in New England *and* serve to protect overall biodiversity in the region.

5.0 SUMMARY

By analyzing habitat suitability for wolf movement in the study areas, we identified a Priority Conservation Corridor for eastern timber wolves between the Adirondack Park, New York, and Algonquin Park, Ontario (Fig. 12). The Corridor encompasses 977 km^2 in New York and 7,622 km^2 in Ontario and may provide a starting point to restore functional connectivity for wolf recovery and protection of other special elements and natural communities. Furthermore, presuming the criteria used in the analysis are meaningful for many species, we believe the corridor offers the best opportunities for wildlife habitat connectivity between Algonquin Park and the Adirondacks.

At an early stage in the ecological design process, GIS analysis is a valuable tool that can be used to identify potential conservation zones, particularly when working with large regional landscapes. A major advantage of using GIS techniques is that they allow the for the iterative refinement of reserve designs as new data and improved methods become available. Future studies should be undertaken to fully examine the potential values of the Priority Conservation Corridor, and to adapt it accordingly. Meanwhile, these preliminary findings may help to guide managers, landowners, educators, municipalities, and land trusts in focusing land protection strategies where they are likely to be most beneficial to biodiversity.

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