WALK THE LINE: CONSEQUENCES OF LINEAR FEATURES TO EASTERN WOLVES (*CANIS LYCAON*)

By

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WALK THE LINE: Consequences of Linear Features to Eastern Wolves (*Canis lycaon*)

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ABSTRACT

Previous studies on wolves have reported conflicting evidence for both affinity and avoidance of linear features. This conflict may arise due to the nature and conditions of the features and circumstances of low human activity may allow animals to benefit from linear features. Using telemetry points (n = 51,515) collected from 28 GPS collared wolves in Algonquin Provincial Park (Ontario) over 4 years (2003-2006), I tested for wolf affinity or avoidance of linear features with randomization procedures applied to individual telemetry points and empirical estimates of home range. Significance was assessed by generating null distributions and applying a confidence interval procedure. Results indicated that linear features in this study system are not prohibitive to movement and can be used by wolves. Conservation initiatives within protected areas should therefore address the quantity and types of linear features since their use by predators may have cascading effects upon prey species and competitors.

ACKNOWLEDGEMENTS

Navigating through this thesis has been a tremendous adventure. From beginning to end, my studies have challenged me to explore new horizons, to grow and learn, and to expand my mind to encompass the implications of space and time. Throughout the adventure, I have been rewarded with great personal satisfaction, but perhaps more importantly, I was introduced to many new colleagues and reminded of how fortunate I am to be surrounded by my loving family and devoted friends. Thanking you all with characters on paper does not do justice to my appreciation; regardless I thank all of you for helping me to succeed.

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Dr. Brent Patterson of the Wildlife Research and Development Section of the Ontario Ministry of Natural Resources graciously provided me access to an invaluable data set of wolf locations. Having contributed to the collection of similar data for bears myself, I know that much of it was gained with blood, sweat and tears. As it stands, my project would not have been possible without these important data and I wish to thank him and all of his graduate students, especially Ken Mills and Karen Loveless, and colleagues for their hard work in collecting it. Dr. Dennis Murray of Trent University, Dr. Brent Patterson, and Dr. Martyn Obbard of the Ontario Ministry of Natural Resources along with Marie-Josée welcomed me under the umbrella of their investigation into Moose spatial ecology funded through an NSERC Strategic grant. I am grateful for the opportunity to contribute to this exciting project. My research was funded through both NSERC and PREA grants to Marie-Josée Fortin as well as student financial support from the University of Toronto.

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Diana, your steadfast love and support made me work harder and believe in myself. The countless times we had to spend apart were difficult, but our reunions reminded me of wolves, gathering with wagging tails after lengthy separation (on a road of course!). Our future is bright and I can’t wait for the next great adventure to begin. Thank you with all of my love for keeping the world at bay for me.

Finally, I would like to thank all the creatures and communities that formed the setting for my research, especially wolves. We are all fortunate that such species are still thriving in the wild and providing opportunities for us to learn more about their intricate secrets.

ASM

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THESIS INTRODUCTION

Settlement and industrial development over the past century has led to increasing demand for land modification and conversion from the natural range of variability. Concurrent to this process, we have set-aside protected areas and implemented stewardship initiatives to conserve biological diversity. Such conservation actions are likely due to the investment of value in native species and communities in terms of ecological services. In particular, the conservation of charismatic mega-fauna has likely been a driving force behind the creation of numerous parks, game reserves, policies and statutes.

Wolves in particular often invoke strong emotions about wildlife management. Across Canada and the rest of North America, much attention is being paid to the preservation of top-predators, especially in light of exploding ungulate populations (Cote et al. 2004, Ripple and Beschta 2007). In Ontario, the conservation of wolves and the role of protected areas in meeting wolf conservation targets have gained in importance. Specifically, the role of Algonquin Provincial Park in protecting Eastern Wolves (*Canis lycaon*) has been the focus of several research projects, reviews and new policies and regulations (Joslin 1967, Pimlott et al. 1969, Forbes and Theberge 1996, Algonquin Wolf Advisory Group 2000, Vucetich and Paquet 2000, Wilson et al. 2000, Theberge and Theberge 2004, Patterson et al. 2005; Appendix 1).

Recently, the consequences of human infrastructure, specifically roads, have been elevated in status in the discipline of ecology. The sub-discipline of road ecology has arisen within the fields of ecology and conservation and has highlighted the important role of roads in meeting conservation and management goals (Dyer *et al.* 2002, Forman *et al.* 2003, Forman 2004, Jaarsma *et al.* 2006, Ramp *et al.* 2006, Rico *et al.* 2007). In particular, many negative effects from roads have been demonstrated through studies on mortality rates, dispersal ability and isolation of sub-populations. In fact, the impacts from roads are often disproportionate to the area of land they are situated upon (Jackson 2006), making proper management of their effects key to success in conservation schemes. Probably due to Canada's sheer size and relatively low population size, there are more kilometers of roads per citizen here than in any other nation on earth (Forman *et al.* 2003); this coupled with relatively intact native communities of wildlife elevate the importance of roads.

Large bodies of work have been conducted determining the impacts from roads (Forman *et al.* 2003). Further questions remain, but ecology now comprehends the conditions in which roads and other linear features limit species, inhibit natural processes and disrupt behavioural patterns. Less is known about beneficial aspects of roads and other linear features; however several authors have attempted to investigate the importance of roads to wolves. In reviewing the large body of literature on linear features, it became apparent that two possible ecological scenarios could exist. Firstly, roads may act like a '*Picket Fence*' and divide populations, act as barriers to movement and behave generally as negative anthropogenic landscape features. Alternatively, linear features may become integrated with the surrounding habitat, be exploited by predator and prey species and facilitate movement of individuals across the landscape, acting more like a '*Garden Path*'. The intent of my research was to help to clarify which of these scenarios applies to wolves in Algonquin Provincial Park (APP), Ontario.

Wolves have been observed traveling on roads by many ecologists, naturalists and park personnel. Few authors, however, have empirically demonstrated an affinity between wolves and roads and anecdotal evidence suggesting a relationship may simply be due to a detection bias. In this thesis, I employ several spatial analyses to investigate whether wolves exploit linear features. Firstly, I assessed the nature of linear features found in a large protected area relative to adjacent private lands using a Geographic Information System. Subsequently, I investigated the proximity patterns between wolf telemetry points from APP between 2003 and 2006 and linear features using randomization procedures, non-parametric tests and confidence interval procedures. In addition, I investigate the role of linear features in determining the size and location of wolf home ranges.

Throughout, I presume that travel on linear features provides an energetic benefit for wolves. Since it likely requires less energy to travel down a road than it does to walk through a forest, I predict that wolves will make use of linear features to allow them to become more effective predators. If this is in fact true, then the configuration of linear features may play an important role in shaping the ecological communities of predator and prey to which wolves belong.

INTRODUCTION

Exploitation of natural resources and human land use can result in a variety of impacts on wildlife population dynamics and ecological communities (Brody and Pelton 1989, Alexander and Waters 2000, Fahrig 2002, Battisti 2003, Fahrig 2003). One source of impact is derived from the infrastructure required for the extraction (e.g. logging or mining) or utilization (e.g. outdoor recreation, human settlement) of natural resources (Forman and Alexander 1998, Switalski et al. 2004). As components of such infrastructure, roads and trails often become permanent additions to the landscape. Roads, active and abandoned railways, trails, hydro-electricity corridors and similar dissecting features, which I collectively refer to as *linear features* hereafter, may affect wildlife behaviour and survival (Mech 1989, Thurber et al. 1994, Stein 2000, Wielgus et al. 2002, Whittington et al. 2004, 2005, Ramp et al. 2006, Shepherd and Whittington 2006, Rico et al. 2007). These linear features may also act as significant barriers to the dispersal of recruits or immigration by adults into an area (Stein, 2000).

Although the impacts of linear features are highly variable, several authors have generalized them into four or more categories, including habitat loss, reduced habitat quality, enhanced mortality and reduced connectivity between populations (Forman *et al.* 2003, Jaeger *et al.* 2005, Jackson 2006). Clearly, linear features will affect species differently depending on their sensitivity to the above four effects as well as the magnitude of traffic volume, road size and avoidance tendencies (Jaeger *et al.* 2005). Some species may be able to tolerate or possibly exploit linear features provided the combination of species biology and the nature of the linear features in question falls below a critical threshold (Thurber *et al.* 1994). Therefore, effects from linear features may have important consequences for conservation or management actions.

The development of a sub-field of landscape ecology entitled *road-ecology* emphasizes the growing importance of linear-features in the grander context (Forman *et al.* 2003, Forman 2004, Jaarsma *et al.* 2006, Ramp *et al.* 2006). Many road-ecology studies have centered on the apparent negative impacts from linear-features, such as road kill, isolation of populations and avoidance behaviour (Forman and Alexander 1998, Forman et al. 2003, Mazerolle 2004, Jaeger et al. 2005). Some studies however, have demonstrated tolerance for linear features provided certain conditions, specifically related to human activity levels, are met (Thurber *et al.* 1994). Rouse (2006) found that a newly constructed multi-lane Highway did not inhibit movement of radio-equipped snakes prior to opening for vehicular traffic, however, subsequent to opening, mortality was high and likely influenced long term patterns in snake movement. This kind of evidence suggests that detrimental effects from linear feature construction, namely habitat loss, may not guarantee impacts for conservation, at least not immediately and not for all species. Rather it is the intensity of human activity on such features that often dictates the severity of impacts. Hence, roads, railways, and trails can have direct or indirect consequences of differing intensity according to the species biology in question (Oxley *et al.* 1974, Mazerolle 2004, Jaeger *et al.* 2005). Largely due to Canada’s pure magnitude, the country holds the world record for the number of kilometers of roads per capita (expressed as km per 1000 people) at 32 km / 1000 (Forman *et al.* 2003). Canada also lays claim to the longest paved road in the world in the Trans Canada Highway (Forman *et al.* 2003). Thus, I feel that identifying and studying the consequences of linear features upon species and ecological processes is an important step towards reaching sustained ecological integrity in Canada and Ontario specifically (Trombulak and Frissell 2000, Forman et al. 2003, Jaeger et al. 2005). Consequently, it is important to assess how linear features influence wildlife movement and survival to aid in the design of long-term conservation strategies, especially those for protected areas which often house relatively intact wildlife populations and sometimes contain expansive linear features.

Weaver *et al.* (1996) argue that mammalian carnivores are sensitive to landscape change due to low population densities, low fecundity, and limited dispersal abilities. This suggests that species like wolves may be useful as a model species in a regional conservation planning framework (see Carroll *et al.* 2001). Furthermore, using highly vagile species that require expansive spatial areas to survive may encapsulate the conservation requirements of species that require less area. Wolves, by their nature, are animals that move frequently and over great distances when foraging and while establishing and defending territories (Mech 1970, 1974). Wolves are also often impacted by human land use practices, as well as human exploitation and persecution, as witnessed by widespread eradication of this species across North America during the 19^{th} and 20^{th} centuries (Mech 1974, Thiel 1985, Stein 2000, Riley *et al.* 2004). Wolves are now commonly understood to be vital to the healthy functioning of many North American ecosystems and both conservation and re-introduction strategies are being enacted (Fritts and Carbyn 1995, Algonquin Wolf Advisory Group 2000, Musiani and Paquet 2004). Many investigations into the spatial requirements, natural history, ecology and genetics of wolves have helped to improve our collective understanding of their role in ecological communities (Pimlott et al. 1969, Mech 1970, 1974, 1989, Forbes and Theberge 1996, Algonquin Wolf Advisory Group 2000, Theberge and Theberge 2004, Gehring and Potter 2005, Ontario Ministry of Natural Resources 2005a, Patterson et al. 2005). Protection of mammalian carnivores, like wolves, via appropriate management of refugia which prevent population decline (Weaver *et al.* 1996) and increased knowledge of wolf behaviour in relation to humans (Thurber *et al.* 1994), may facilitate long term human-wolf coexistence.

Considerable effort has also been directed towards studying the relationship between roads and wolf persistence. Early research by Mech (1973) suggested a negative correlation between wolf abundance and rural road density. Namely, Mech (1973) suggested that the development of roads within an area occupied by wolves leads to persecution and exploitation of wolves and prevents the development of sizable wolf packs and thus limits total abundance. Other authors have documented appropriate levels of road density for continued wolf presence (Thiel 1985, Mech *et al.* 1988, Mech 1989, Merrill 2000).

Anecdotal observations of wolves traveling on linear features are common, but likely fraught with detection bias. Scats and tracks observed on linear features are probably far more detectable than those lying within adjacent forests. Determining whether wolves use road-less areas equally or more frequently than roads must rely upon more sophisticated means of observation. With that said, several authors have noted the presence of wolves on linear features (Pimlott et al. 1969, Voigt 1973, Musiani et al. 1998, Barja et al. 2004, Theberge and Theberge 2004). While such observations do not confirm a travel preference by wolves on linear features, they do compel me towards further study. Especially when one considers the rather large body of literature that has demonstrated that wolves are usually negatively impacted by roads (Mech 1973, Thiel 1985, Mech *et al.* 1988, Mech 1989). Mech (1989) concluded that wolves can be sustained in areas with high road densities provided they are situated adjacent to road-less refugia areas. Areas where human activity is variable or those that provide protection for wolves through legislation may mimic large road-less areas and allow for persistence of wolves despite high road densities. Central Ontario may be an example of this scenario with the vicinity of Algonquin Provincial Park acting as a wolf refugium adjacent to a heavily developed human landscape.

Drawing upon the work of Thurber *et al.* (1994), James & Stuart-Smith (2000) and others, my research aims to examine effects of linear features upon wolf movement within and adjacent to Algonquin Provincial Park (hereafter APP; 45° N, 78° W, Figure 1). APP provides an appropriate study system to examine the consequences of linear features given the juxtaposition of protected and public land and intense versus low levels of human activity in different temporal periods (seasons) within the park. APP has a long history of timber harvest, beginning prior to park establishment in the 1830's (Tozer & Strickland, 1991), accordingly, infrastructure for access to and extraction of harvested timber began to develop in the late 1800's (Tozer & Strickland, 1991). Currently, many of the linear features within the park are not maintained during winter months and recreational or timber activities vary in intensity depending on season and year (Algonquin Forest Authority, 2006; Ontario Ministry of Natural Resources, 1998). The nature of linear features within and adjacent to APP along with accompanying legal protection for wolves (Appendix 1) provides an unique opportunity to evaluate the findings of other authors (e.g. Thurber et al. 1994, James and Stuart-Smith 2000, Wielgus et al. 2002, Whittington et al. 2004, 2005) and extend our understanding of wolf ecology. Furthermore, there are a variety of types and intensities of land uses surrounding APP and future development of residential properties and associated infrastructure across the region is likely to continue in the coming decades (Carroll *et al.* 2004). The inclusion of a control study area, Wildlife Management Unit 49 (hereafter WMU 49; 45° N, 79° W, Figure 1) located to the west of APP will provide useful context for findings generated through analysis within the park. Thus, examining the effects of linear features now may identify important conservation issues for land managers in the future and provide useful context for the situation in APP.

Specifically, I aim to investigate wolf behaviour in relation to linear features using movement data collected from wild wolves. I hypothesize that anecdotal observations of wolves traveling on linear features may be indicative of a movement tendency. Such behaviour may be driven by energetic benefits associated with travel on linear features and therefore have cascading effects to prey species through predation. As a consequence, exploitation of linear features by wolves may affect other ecological relationships and species. In addition, variable levels of human activity on linear features will likely affect the expression of travel preferences in wolves, thus I propose the following hypothesis and predictions to investigate this ecological phenomenon:

Hypothesis 1: Wolves gain energetic benefit from traveling on or near certain types of linear features (e.g. those with temporally limited human activity) and therefore express a movement tendency for travel on suitable linear features.

Prediction 1.1: Telemetry locations of wolves should lie closer to suitable linear features than an array of random points.

Prediction 1.2: Telemetry locations of wolves should lie closer to linear features with less human activity than to those that are more heavily used by humans.

Relating to prediction 1.2, Table 1 presents the expected response of wolves in relation to specific classes of roads (see Methods: Linear Feature Data Section).

Table 1. Expected pattern of response between wolf distance to road and the three road classes found within the total study area. For primary roads, distant proximity to roads is interpreted as avoidance behaviour. The observed response to secondary roads is likely moderated by their proximity to primary roads thus the potential for variable response exists. For tertiary roads, close proximity to roads is interpreted as attraction. See Methods: Linear Feature Data Section for description of each road class.

Wolf Proximity to Road	Road Class		
	Primary	Secondary	Tertiary
Distant	X		
Moderate		X	
Close		X	X

To extend this investigation, I also propose that linear features may affect the territorial behaviour of wolves through the expression of effects on home range location and size. If hypothesis 1 holds true, then one could envision consequences for wolves which occupy areas of the landscape that are deficient in suitable linear features (e.g. none are present or only linear features with higher human activity are found there). Accordingly, investigating relationships between estimates of wolf home ranges and the linear features contained within them may lead to further knowledge about wolf movement behaviour. Therefore, I propose the following hypothesis and predictions to investigate the relationships between wolf home ranges and linear features:

Hypothesis 2: Assuming wolves can freely array themselves across the study area, wolf home ranges should contain more tertiary linear features than randomly sampled areas of equivalent size and shape.

Prediction 2.1: Wolf home ranges, when analyzed individually, will be situated in areas that contain more suitable linear features than what is generally available on the landscape.

Prediction 2.2: Wolf home ranges, when analyzed communally, will show a tendency for areas of higher suitable linear feature density but the effect will be moderated by the social structure of wolves in adjacent home ranges.

To permit these investigations, linear features will be studied at two spatial scales of inference: (1) the local scale (wolf home ranges within APP) will be used to quantify the relationship between wolf movements and linear features and test **hypothesis 1**.; and (2) the regional scale (APP, WMU 49 and a randomization zone surrounding them for a total area of 58,440 km^2) will be used to test **hypothesis 2** as well as to determine the degree, nature and effects of habitat dissection by linear features.

METHODS

Study Region

Ontario's vegetation is characterized by broad forest community bands that span the province in an east-west orientation (Wake 1997). The Great Lakes – St. Lawrence Forest Region (hereafter GFR; Figure 1) in central Ontario is an ecotonal region located between the boreal forest to the north and deciduous forests to the south (Clark and Wallace 1999). Specifically, the GFR lies immediately north of the Carolinian Forest Region, and immediately south of the Boreal Forest Region (Wake 1997). The GFR is also referred to as the Mixed Forest Region. Both coniferous and deciduous forests thrive in the warm summers and cool winters typical of this region (Clark and Wallace 1999). Due to the ecotonal nature of the region, numerous species reach the northern or southern limit of their geographical distribution across the GFR (Wake 1997). Much of the GFR lies to the lee of Lake Huron, and regional climate is greatly influenced by the proximity to Lake Huron and the surrounding Great Lakes (Crins *et al.* 2006). The Canadian Shield (geological feature of eroded Precambrian rock) underlies much of the northern portion of the region, and its substrates and elevation affect species composition (Wake 1997). The GFR provides an interesting location for studying wolf movements, as it encompasses gradients of environmental variables, floral and faunal communities and intensity of human land use.

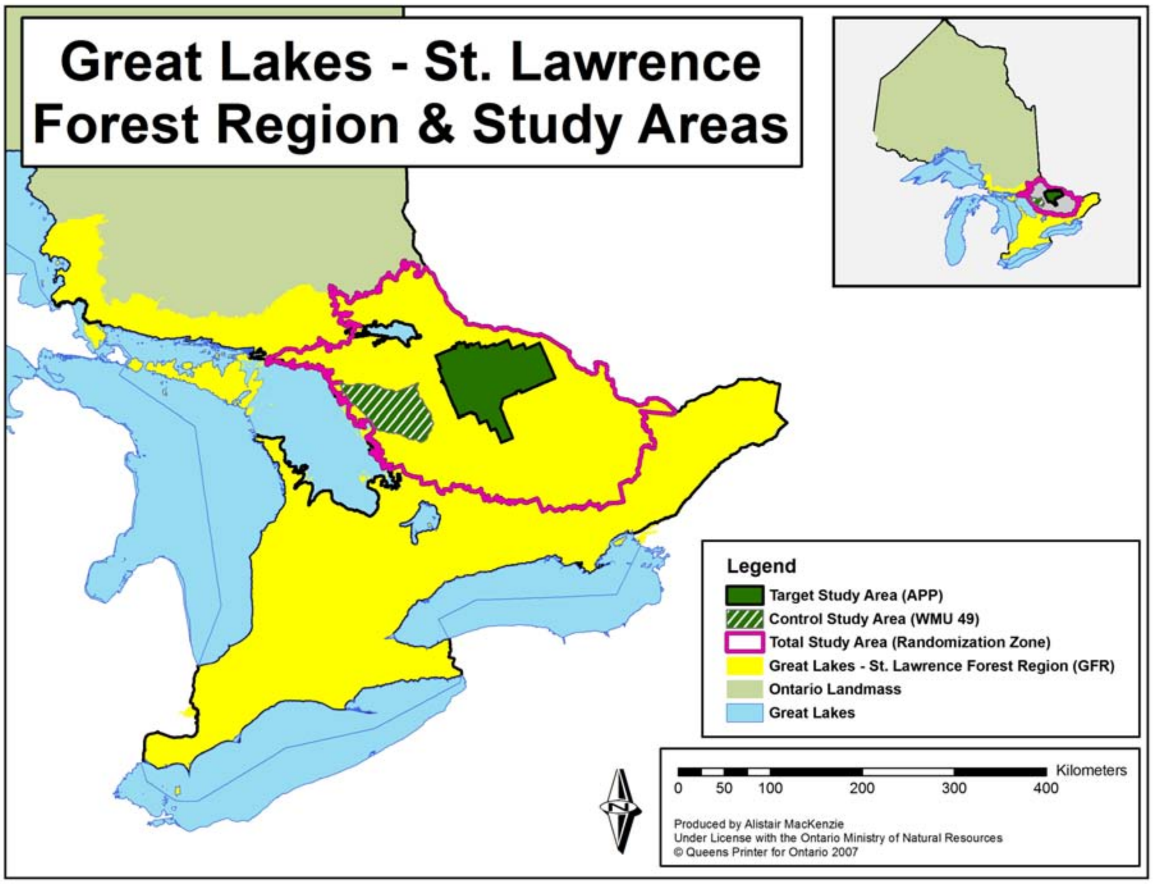

Figure 1. Ontario landmass with depiction of the approximate extent of the Great Lakes - St. Lawrence Forest Region (GFR) and the study areas evaluated herein (see Study Areas Section).

Climate

Climatic conditions in the GFR are affected by both elevation (Ontario Ministry of Natural Resources 1998) and proximity to the Great Lakes (Crins *et al.* 2006). Crins *et al*. (1997b) report a growing-season length of between 183 and 219 days and a mean annual temperature of 2.8 to 6.2 °C. Ahern (2006) reports temperature in terms of average growing degree days ((GDD); GDD = ((Tmax +Tmin)/2) – Tbase, where Tmax = daily maximum temperature, Tmin = daily minimum temperature and Tbase = a base temperature for the vegetative community being monitored), with the central region of the GFR exposed to between 1000 and 1500 GDD whereas the remaining study landscape experiences 1500 to 2000 GDD.

Precipitation is highly variable across the region and is affected by elevation and proximity to large bodies of water. The elevated Algonquin Dome (see Target Study Area) and westward to the shore of Georgian Bay receive between 550 and 600+ mm of precipitation during the growing season (average over period 1961-1990) (Ahern 2006). The eastern half of the GFR receives between 450 and 550 mm of precipitation during the growing season (Ahern 2006). This disparity in precipitation is largely due to the elevational gradient that air masses encounter as they move eastward across the region (Ahern 2006).

Flora

The study region is predominantly forested, which is in contrast to the adjacent Carolinian and Boreal Forest Regions that have been subjected to deforestation due to agriculture and urbanization, and forestry activities respectively (Figure 2). Current forest composition is the result of legacies of boreal disturbance regimes, including fire and insect outbreaks; more stable environmental conditions typical of southern deciduous forests; and human interactions with the environment. Some anthropogenic alteration of vegetation communities within the GFR has occurred, with selective timber harvest predominating in areas of the region lying on the Canadian Shield, and agricultural clearing occurring in many of the remaining area (Wake 1997).

Across the region, southern deciduous species abut against northern boreal species, with some inter-mixing of flora extending throughout the entire area(Jalava et al. 1997a). Consequently, forests are often composed of both deciduous and coniferous tree species including, but not limited to Balsam Fir (*Abies balsamea*), Sugar Maple (*Acer saccharum*), Yellow Birch (*Betula alleghaniensis*), White Birch (*Betula papyrifera*), American Beech (*Fagus grandifolia*), Tamarack (*Larix laricina*), White Spruce (*Picea glauca*), Black Spruce (*Picea mariana*), Eastern White Pine (*Pinus strobus*), Red Pine (*Pinus resinosa*), aspens (*Populus* spp.), cherries (*Prunus* spp.), and Eastern Hemlock (*Tsuga canadensis*) (Strickland 1989, Wake 1997, Ontario Ministry of Natural Resources 1998, Ahern 2006).

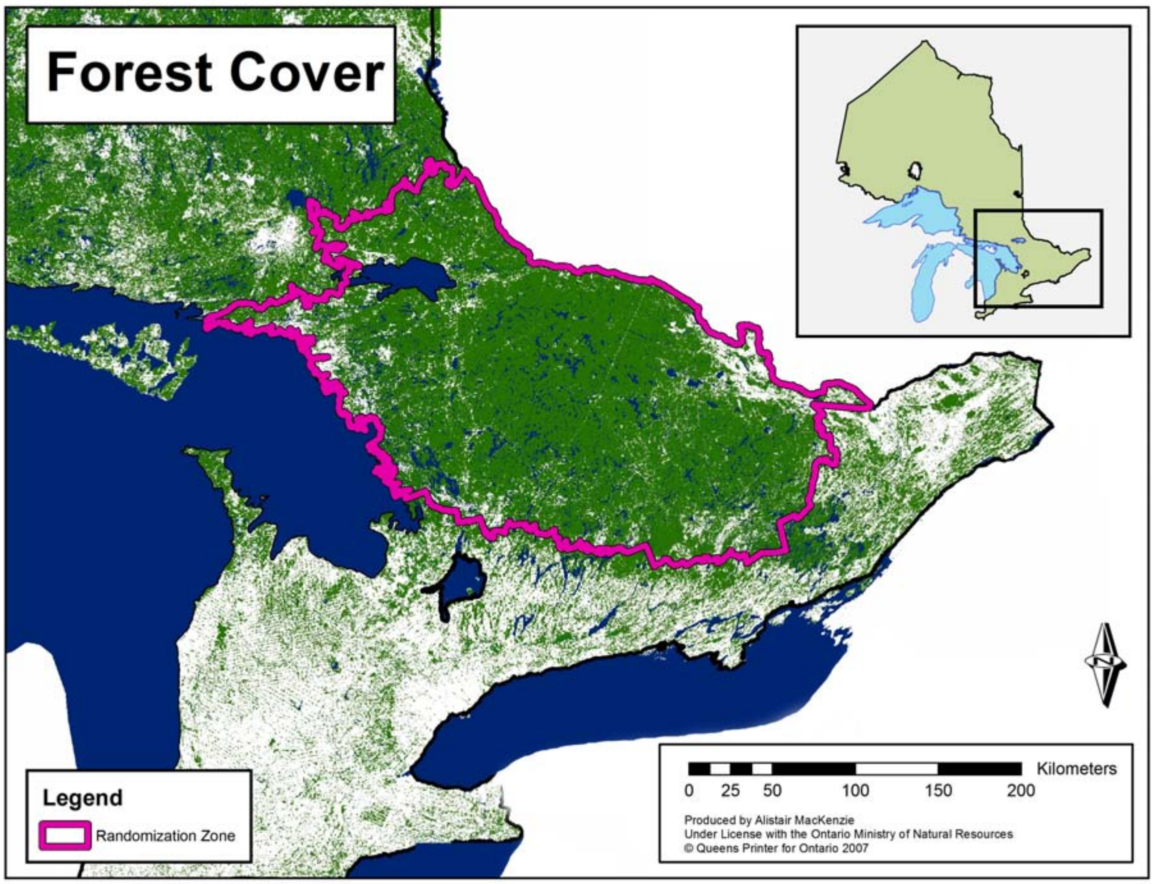

Figure 2. Forest cover of South-central Ontario derived from satellite imagery (Ontario Landcover 28). The pink line depicts the perimeter of the total study area (randomization zone, see Study Areas section). Green pixels indicate forested regions.

A wide variety of herbaceous plants species are found in the GFR. Understorey assemblages vary depending on the site conditions and overstorey composition (Wake 1997). Common shrub species include, but are not limited to Striped Maple (*Acer pensylvanicum*), Mountain Maple (*Acer spicatum*), alders (*Alnus* spp.), Bearberry (*Arctostaphylos uva-ursi*), dogwoods (*Cornus* spp.), Beaked Hazel (*Corylus cornuta*), Labrador Tea (*Ledum groenlandicum*), honeysuckle (*Lonicera* spp.), Red-berried Elder (*Sambucus racemosa pubens*), Showy Mountain Ash (*Sorbus decora*), and blueberries (*Vaccinium* spp.) (Strickland and LeVay 1986, Legasy et al. 1995, Wake 1997). Similarly, some common wildflower species are Trout-Lily (*Erythronium americanum*), trilliums (*Trillium* spp.), Wild Sarsaparilla (*Aralia nudicaulis*), violets (*Viola* spp.), Wood Sorrel (*Oxalis montana*), Fringed Polygala (*Polygala paucifolia*), Twinflower (*Linnaea borealis*), Pickerel Weed (*Pontederia cordata*), Pitcher-plant (*Sarracenia purpurea*), goldenrods (*Solidago* spp.), and asters (Asteraceae) (Strickland and LeVay 1986).

Importantly, the species listed above represent a limited subset of the more than 40 species of trees, numerous shrubs and over 1000 forb species known from the region. Furthermore, other assemblages of grasses and sedges, ferns, mosses and liverworts, aquatic plants, lichens and fungi are also present in the GFR.

Fauna

Diverse assemblages of terrestrial and aquatic fauna are found in the GFR and, like the flora, they represent a combination of southern and northern species(Strickland 1990, Strickland and Rutter 1996, Jalava et al. 1997a, Ontario Ministry of Natural Resources 1998). Once again, many species reach their northern or southern limit of distribution here, and many of these boundaries co-occur with the southern boundary of the Canadian Shield (Wake 1997). The region is home to approximately 225 species of birds, 58 species of mammals, 20 species of amphibians, 24 species of reptiles, and 125 species of fishes (Wake 1997). Insect diversity is much more difficult to estimate, however, recent surveys report over 7000 species from within Algonquin Provincial Park alone (Marshall 1997).

Portions of the GFR (specifically Algonquin Provincial Park) have been the focal areas for several previous studies on wolves, beginning with the first provincial investigation of wolf biology between 1958 and 1965 by Pimlott, Shannon and Kolenosky (1969) and graduate students (Voigt 1973). Theberge and collaborators subsequently conducted research between 1987 and 1999 in what they term as the "longest intensive study [of wolves] in Canada to date" (Theberge and Theberge 2004). Since 2002, Algonquin has been the arena for investigations into wolf biology under the direction of Provincial Wildlife Research Scientist, Dr. Brent Patterson (Patterson *et al.* 2005).

In addition to pure and applied research on wolves, Algonquin Provincial Park is also famous for interaction between lay persons and wolves through public wolf howls conducted by the park's Natural Heritage Education staff (Ontario Ministry of Natural Resources 1998). The practice of broadcasting or imitating wolf howls was first initiated as a research tool by Pimlott *et al*. (1969), but subsequently became a popular activity for park visitors (Strickland 1992).

Study Areas

The original intent of this investigation was to examine wolf movements within the boundaries of Algonquin Provincial Park. However, upon examination of wolf telemetry data, it became apparent that wolves did not regard the park boundary as a barrier to movement and frequently ventured beyond it, most notably during winter months (Forbes and Theberge 1996, Theberge and Theberge 2004). Concurrent to this thesis, an investigation into Moose ecology along the southern periphery of their range of occupancy (including APP) was initiated by Trent University, University of Toronto and the Ontario Ministry of Natural Resources (hereafter OMNR Study). For the purpose of comparison between protected and unprotected areas, a wildlife management unit to the west of APP was included in the OMNR study design. Consequently, WMU 49 is included here to allow for inter-study comparison as well as to provide context for the findings from within APP in relation to environmental conditions and the nature of linear features. Furthermore, a larger area was established to encompass both APP and WMU 49 (Figure 1) to allow for spatial randomization of home ranges (see Spatial Randomization section).

Targeted Study Area: Algonquin Provincial Park

Algonquin Provincial Park (45° 27’ N 78° 27’ W) is the target study area for this research (Figure 3). As the first park in the Ontario Provincial Parks system, APP was created in 1893 for a variety of reasons, including “maintenance of water supply, preservation of primeval forest, protection of birds and animals, a field for experiments in forestry, a place of health resort, and beneficial effects on climate” (Ontario Ministry of Natural Resources 1998). Today, APP remains true to these objectives and my research takes advantage of both a supportive research arena as well as a functioning predator-prey species assemblage.

APP is situated in the heart of the GFR between provincial highways 7, 11 and 17. Highway 60 traverses the southwest corner of APP, separating the “Algonquin Panhandle” to the south and the “Park Interior” to the north. Since its creation, additional parcels of land have been added to Algonquin’s original boundaries, resulting in a total protected area of 7630 km^2 with a perimeter of 486 km.

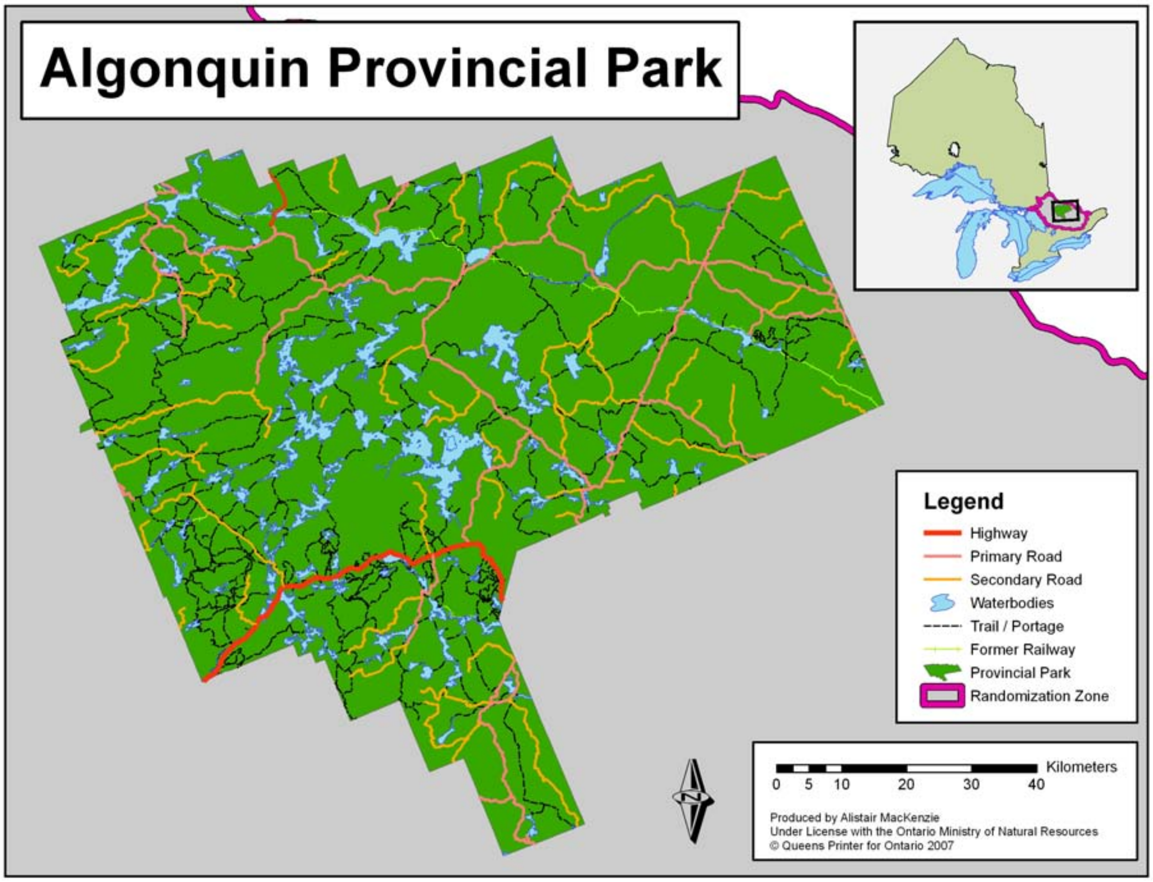

Figure 3. Graphical depiction of the target study area - Algonquin Provincial Park . The park is 7630 km^2 in total area. Rivers, streams and minor waterbodies as well as tertiary roads are not shown.

Much of Algonquin Provincial Park lies upon the Algonquin Dome, a geological feature having higher elevation (> 200m; Wake 1997) than the surrounding areas of the GFR (Ontario Ministry of Natural Resources 1998, Ahern 2006). Consequently, portions of Algonquin Provincial Park (especially Site District 5E-9, see Figure 5) have colder and wetter conditions than the surrounding areas of the GFR (Ontario Ministry of Natural Resources 1998). Prevailing westerly winds, along with the higher elevation of the Algonquin Dome, result in a gradient of precipitation from west to east. Forest composition within APP reflects this gradient, and forests on the western and eastern sides of the park take on characteristic species compositions (Ontario Ministry of Natural Resources 1998). Western portions of the park tend to be dominated by hardwood deciduous forest communities, whereas eastern portions have more coniferous cover (Ontario Ministry of Natural Resources 1998). The eastern half of APP has also been subjected to more frequent occurrences of fire and has a warmer, drier climate and sandy soils (Ontario Ministry of Natural Resources 1998).

APP is classified as a *natural environment* park in recognition of its outstanding recreational landscapes, natural features and historical resources (Ontario Ministry of Natural Resources 1998). Recreational opportunities can be generalized into those occurring along the Highway 60 corridor (campground and vehicular based) and those occurring in the interior (canoe, ski and pedestrian based). Not surprisingly, APP is a favourite travel destination for many visitors from Canada and beyond; an average of 900,756 annual visits (estimated human attendance) was recorded between 2003 and 2006 (Stronks 2007, personal communication). Unlike other protected areas (provincial and national parks) in Ontario, APP permits commercial harvesting of timber (on 78% of park's area; (Quinn 2004) and a system of infrastructure in the form of roads and gravel pits exists to support the extraction activities (Ontario Ministry of Natural Resources 1998, Quinn 2004). In contrast to roads and other linear features outside of APP, those inside are used by humans sporadically and may not have all of the associated negative consequences of roads typical of Ontario. The seasonal nature of road-use and specific restrictions on access result in reduced vehicular traffic both spatially and temporally. Recently, criticisms have been voiced over the quantity of linear features contained within the park boundaries (Perkel 2005).

APP is the largest protected area for Eastern Wolves in Ontario (Grewal *et al.* 2004, Patterson *et al.* 2005). Despite this, evidence derived from collared wolves that ventured outside the park during the 1980's and 90's documented losses due to human persecution, harvest and road mortality and raised concern about the efficacy of the park for wolf preservation (Patterson *et al.* 2005). Consequently, a ban on hunting and trapping of wolves in the 39 townships adjacent to the park's boundary was enacted by the Minister of Natural Resources in 2004 (Patterson *et al.* 2005; Appendix 1).

Control Study Area: Wildlife Management Unit 49

Often the density of linear features and the frequency of use differ between areas that are protected and those that are utilized for human settlement. Consequently, an area outside the boundaries of APP was selected to allow comparison and to provide context for results from within APP. Wildlife Management Unit 49 (45° 30' N 79° 46' W) is a provincial unit established to manage wildlife species in the province (Figure 4)(Ontario Ministry of Natural Resources 2005b). WMU 49 provides a contrast to APP in terms of human activity, road density, and wildlife habitat. WMU 49 lies at the same latitude as APP and within the range of occupancy of Eastern Wolves (Ontario Ministry of Natural Resources 2005a). WMU 49 contains small protected areas, but as a whole does not offer any kind of protection for wolves that is distinct from that of crown land in Ontario. WMU 49 is situated to the west of APP close to the shore of Georgian Bay and has an area of 3660 km^2 and a perimeter of 296 km. Provincial highways 400, 11, and 124 along with the Magnetawan River form the boundaries of the unit.

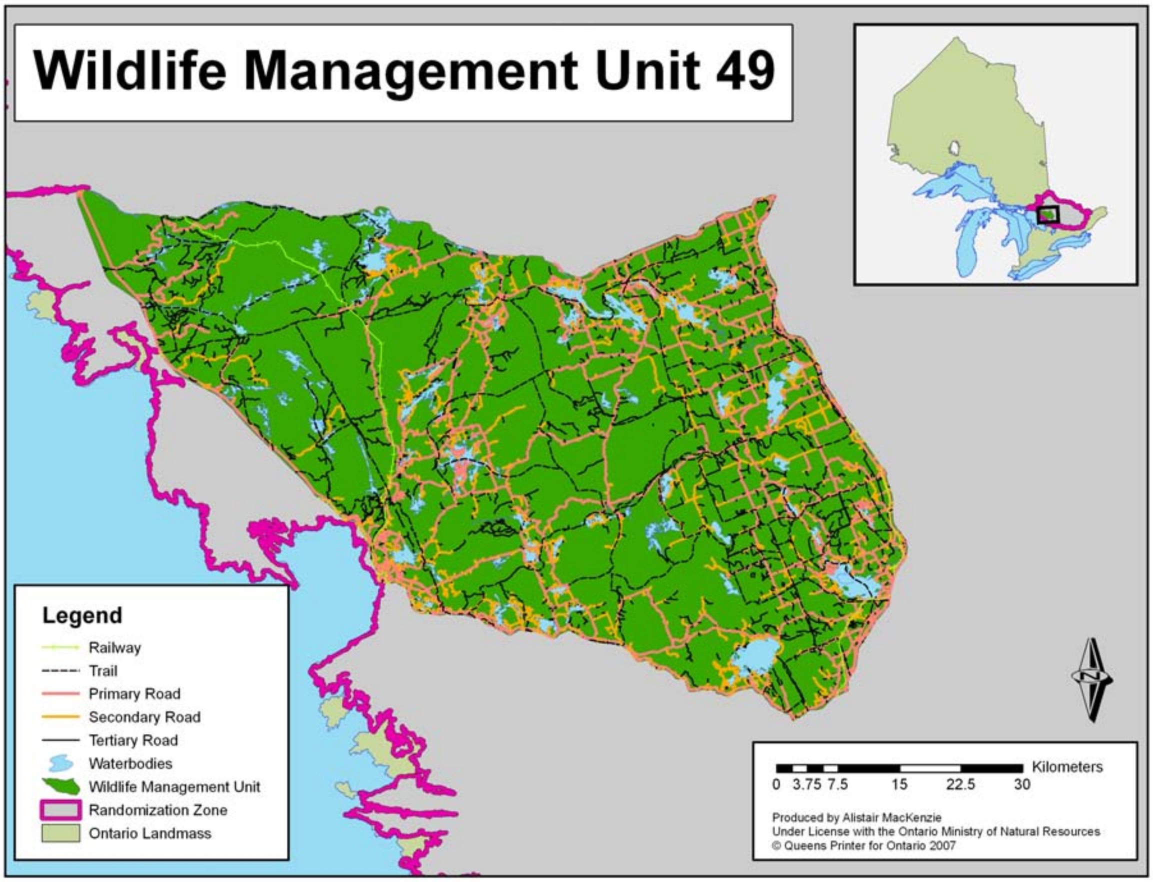

Figure 4. Graphical depiction of the control study area - Wildlife Management Unit 49 . WMU 49 is 3660 km^2 in total area. Rivers, streams and minor waterbodies are not shown.

Total Area: APP, WMU 49 and Surrounding Area

The total area studied (58,440 km^2 with a perimeter of 2740 km) includes both APP and WMU 49 and a surrounding area within the GFR used for spatial randomization procedures (see Spatial Randomization sub-section). The total area (hereafter referred to as the randomization zone) is roughly bounded by Georgian Bay (Lake Huron), in the west, Highway 17 to the north, Highway 7 to the south and the Ottawa River in the east. The boundaries of the randomization zone are defined on the basis of an ecological land classification system developed by Hills (1959) and revised by Jalava *et al.* (1997a)and Crins *et al*. (2006). The boundaries roughly coincide with the boundaries of proposed Ontario wolf ecological zone 5 (Ontario Ministry of Natural Resources 2005a). Hills' (1959) original work and subsequent revisions (Jalava et al. 1997a, Crins et al. 2006) rely upon a hierarchical system of landscape classification derived from physiographical and climatic attributes with the resultant expression of these through vegetation communities. The hierarchy consists of 6 levels - ecoprovince, ecoregion, ecodistrict, ecosection, ecosite and ecoelement. The levels of ecoregion and ecodistricts are of interest to this body of work. Ecoregions are unique areas of land and water defined by a range and pattern in climatic variables, including temperature, precipitation, and humidity as well as a broad vegetation type(Jalava et al. 1997a, Lee et al. 1998). Ecodistricts are sub-units within ecoregions, which are defined by a characteristic set of physiographic features, including bedrock, surficial geology, topography, water, flora and fauna(Jalava et al. 1997a, Lee et al. 1998). In both ecoregions and ecodistricts, climatic variables interact with biological processes to result in characteristic ecological communities.

The randomization zone is comprised of portions of both Site Region 5E (Georgian Bay Site Region) and Site Region 6E (Lake Simcoe --Rideau Site Region) (Figure 5). Specifically, the randomization zone includes Site Districts 5E-5, 5E-6, 5E-7, 5E-8, 5E-9, 5E-10 and 5E-11 in Site Region 5E and Site District 6E-16 in Site Region 6E. Site District 6E-16 was formerly considered to fall within Site Region 5E (previously Site District 5E-12); excluding Site District 6E-16 would result in a gap in coverage in the southeastern portion of the randomization zone.

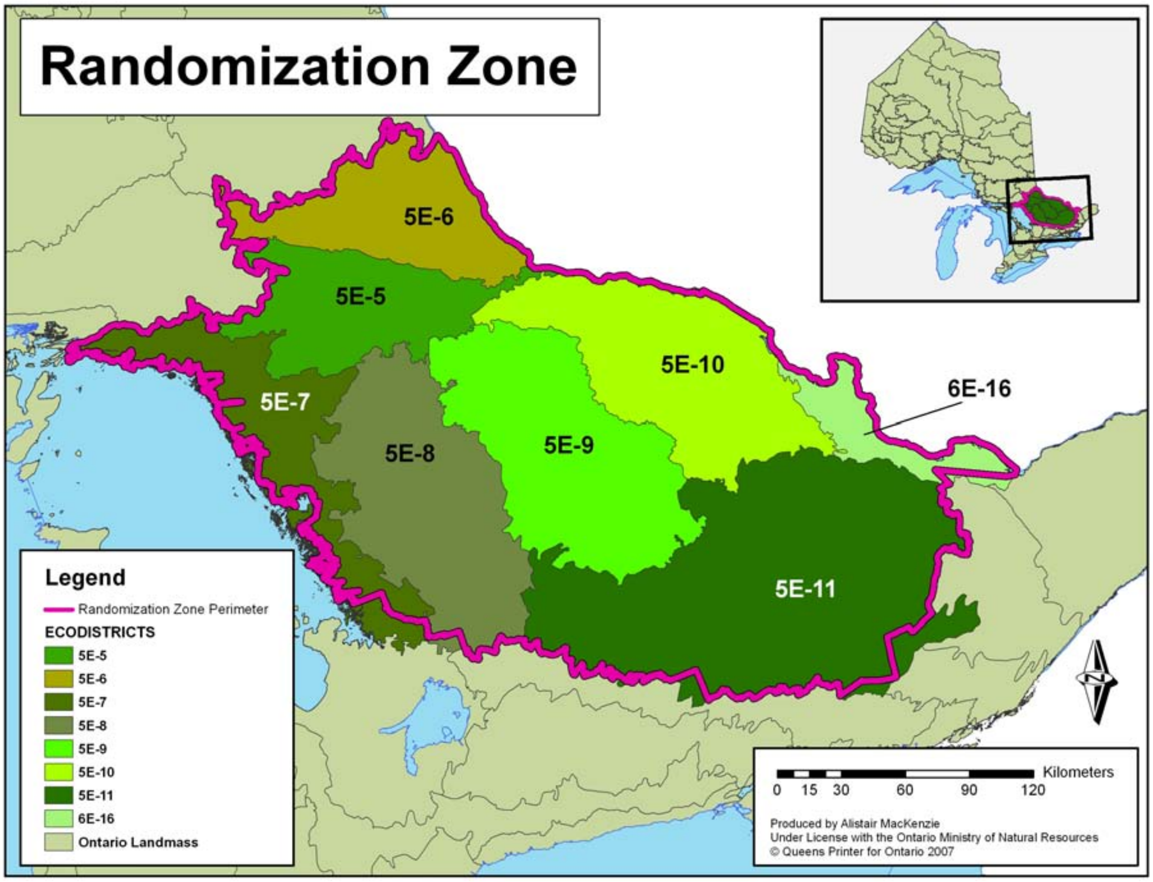

Figure 5. Spatial randomization zone comprised of ecological land classification units. Labeled ecodistricts were combined and their outer perimeter used to demarcate the boundary of the randomization zone which encompasses the target (APP) and control (WMU 49) study areas.

The Georgian Bay Site Region (5E) contains areas of silty sands, and clay and gravel deposits, which are interspersed with bedrock outcrops (~ 68% of land cover;Jalava et al. 1997a) and lower elevation areas having abundant water and water-laden soils (Hills 1959). Water covers approximately 10.6% of the total surface area of the region(Jalava et al. 1997a). Soils in the western portion of the site region were deposited by lacustrine processes, whereas those in the eastern portion were deposited by glaciofluvial processes (Hills 1959). The region is primarily forested, but contains open land areas (harvested/burned) and sand dunes (aeolian deposits). Cut-over areas may be under-represented in remote sensed data due to the shelter-wood selective harvesting techniques common to the area(Jalava et al. 1997a).

Study Organism

Most authorities believe that two species of wolves inhabit Ontario, namely, the Gray Wolf (*Canis lupus*) and the Eastern Wolf (*Canis lycaon*) (Ontario Ministry of Natural Resources 2005a). Much debate has ensued, however, regarding the taxonomic status of wolves in Ontario (see Wilson et al. 2000, Nowak 2002, Theberge and Theberge 2004, Kyle et al. 2006). Within the randomization zone, the Eastern Wolf is believed to be most common and accordingly is the focal species of this investigation. Throughout this document, the use of the terms wolf, Eastern Wolf, wolves or Eastern Wolves will refer to *Canis lycaon*. The southern boundary of the randomization zone is situated close the current southern extent of the area of occupancy for wolves in Ontario (Forsyth 1985, Ontario Ministry of Natural Resources 2005a). Wolves have been studied quite extensively in APP between 1958 and present (Pimlott et al. 1969, Forbes and Theberge 1996, Vucetich and Paquet 2000, Grewal et al. 2004, Theberge and Theberge 2004, Patterson et al. 2005, Mills et al. 2006), with specific research focus on taxonomy, ecology, natural history and forays out of the park by resident packs.

Eastern Wolves are medium-sized carnivores that are generally smaller and lighter in mass than Gray Wolves and have correspondingly smaller muzzles and a more slender appearance (Ontario Ministry of Natural Resources 2005a). Pimlott *et al.* (1969) reported a mean mass of males (n = 40) as 28 kg and females (n = 33) as 24.5 kg. Conversely, more recent mass estimates from APP are slightly higher with males (n = 24) at 30 kg and females (n = 32) at 25 kg (Patterson *et al*. unpubl. data, reported in Ontario Ministry of Natural Resources 2005a). Snout-to-tail length may vary between 100 and 200 cm (Forsyth 1985, Ontario Ministry of Natural Resources 2005a). Pelage varies in coloration, but individuals of *C. lycaon* tend to have tinges of red around the muzzle and ears (Ontario Ministry of Natural Resources 2005a). All-black and all-white morphs are not known to occur in Eastern

Wolves. Tails are bushy and usually held downward against the rump (Ontario Ministry of Natural Resources 2005a). Males reach maturity around 3 years of age, whereas females do so at 2; longevity is usually less than 10 years (Forsyth 1985).

Wild canids are highly social and Eastern Wolves are no exception to this rule (Mech 1970, 1974). Algonquin wolf packs vary in size depending on a variety of factors (recruitment, mortality, dispersal), but median pack size generally ranges from 4.5 to 5 animals (Patterson *et al.* 2005). Pack members communicate vocally using howls and barks (Mech 1974, Strickland 1992) as well as through scent marking (Mech 1974).

Wolves are believed to be obligate predators of ungulates and persistence in any given area depends on the presence of ungulate prey (Mech 1970). In APP, previous studies have documented that Eastern Wolves utilize White-tailed Deer (*Odocoileus virginianus*), and Moose (*Alces alces*) as their principle prey base; Beaver (*Castor canadensis*) and small mammals may act as supplementary prey (Pimlott et al. 1969, Theberge and Theberge 2004, Ontario Ministry of Natural Resources 2005a). Scat analysis, conducted by Theberge & Theberge (2004) reported an adjusted yearly percentage of biomass for deer as 41.3 % (adults and fawns combined), for Moose as 32.5 % (adults and calves combined), for Beaver as 22.4 % and other as 3.6%. Pimlott *et al.* (1969) report several methods for estimating prey selection (scat analysis, kill analysis) and deer consistently ranked highest amongst prey species. This is consistent with the attributes of proposed wolf ecological zone 5, where Eastern Wolves feed heavily on White-tailed Deer, but also utilize Moose and may prey upon recently re-introduced Elk (*Cervus elaphus*) (Ontario Ministry of Natural Resources 2005a). Prey selection is also influenced by the general abundance of prey across the spatial extent of the wolf population and the physical attributes of the wolf species or sub-species under study (Ontario Ministry of Natural Resources 2005a).

Density estimates for wolves vary depending on dominant habitat type, prey type and intensity of anthropogenic effects. Based on a literature review, the current estimate for wolf density in the APP region (proposed wolf ecological zone 5) is 28 wolves/1000 km^2 (Ontario Ministry of Natural Resources 2005a). Specific estimates from APP range from 1.5 to 2.9 wolves/100 km^2, which are roughly consistent with the estimate for zone 5 (Theberge and Theberge 2004, Ontario Ministry of Natural Resources 2005a, Patterson et al. 2005). Pimlott et al. (1969) estimated that there were 55 wolf packs within APP at the time of their study. More recent evaluation suggests approximately 30 packs reside within the park (Algonquin Wolf Advisory Group 2000). Examination of telemetry data (see home range analysis section) suggests a high degree of overlap amongst individuals and the number of discrete packs may be highly variable.

Wolves are a highly mobile species and travel frequently and over expansive distances (Mech 1970). Theberge &Theberge (2004) and Forbes & Theberge (1996) documented routine migrations of part or whole packs outside the boundaries of APP in response to winter aggregations of White-tailed Deer in yards. This phenomenon is most evident in the eastern half of the park, as it was not as apparent in studies carried out by Patterson *et al.* (2005) that focused on the western half of APP. It seems apparent that social factors, which are responsible for the establishment and maintenance of pack territories within the park, may be slackened in deer yards. Theberge & Theberge (2004) found a high level of tolerance for alien wolves by resident wolves in deer yards, as indicated by spatial and temporal overlap of telemetry data; data in this study seem to concur with this observation.

Hunting restrictions for wolves have recently been imposed in the townships surrounding Algonquin (Ontario Ministry of Natural Resources, 2005) and efforts are underway to develop a comprehensive provincial management strategy for the species (Appendix 1). Within provincial parks, wolves are provided hunting protection under the Provincial Parks Act (Ontario Ministry of Natural Resources, 2005).

Figure 6. Photograph of a chemically immobilized Eastern Wolf (*Canis lycaon*) during handling procedure to affix a telemetry collar. Photograph copyright Dr. B. Patterson.

Wolf Telemetry Data

Telemetry data for wolves, captured in APP between 2003 and 2006, were provided by Dr. Brent Patterson (Research Scientist with the Ontario Ministry of Natural Resources, OMNR). Mills *et al*. (2006) described how the animals were captured and outlined the immobilization protocol. A total of 56,751 telemetry locations were obtained from 186 wolves equipped with Very High Frequency (VHF) or Global Positioning System (GPS) model 4400 telemetry collars (Lotek Wireless Inc. 2007). VHF signals were located using a combination of aerial and ground-based telemetry. GPS collars were programmed to obtain satellite fixes at variable intervals throughout the course of the study. Of the total, GPS telemetry constitutes ~ 91% of the data set (51,515 locations) collected from a subset of 28 wolves (Table 2.); the remaining 9% is comprised of 1 kill site; 1 howling location; 6 mortality sites; 12 re-capture locations; 22 snow-tracking locations; 77 visual observations; 155 capture locations; 281 locations obtained from the ground; and 4681 locations obtained from the air. The bulk of analyses conducted herein utilized GPS data alone due to the inherently lower positional error. The telemetry data are spatially arranged across the target study area and the immediate surroundings (Figure 7).

Table 2. GPS telemetry data obtained from 28 Eastern Wolves captured in Algonquin Provincial Park during a collection period from 2003 to 2006. The ratio of males to females is 50 (*n* = 14):50 (*n* = 14).

Animal No.	Sex	No. of points obtained	Temporal period of data collection	No. of Julian Days between first and last GPS location.
W124	F	42	09/11/2004 -- 10/13/2004	32
W181	F	51	09/15/2005 – 12/12/2005	88
W114	M	166	07/11/2004 -- 08/18/2004	38
W091	M	153	02/12/2004 – 03/21/2004	38
W092	M	469	02/12/2004 – 07/10/2004	149
W134	F	581	02/10/2005 – 04/12/2005	61
W079	F	688	10/20/2003 – 01/31/2004	103
W083	M	702	10/24/2003 – 01/30/2004	98
W172	F	956	10/08/2005 – 01/22/2006	106
W077	F	1042	10/31/2003 – 08/14/2004	288
W184	F	1051	11/04/2005 – 02/02/2006	90
W186	F	1121	01/28/2006 – 03/12/2006	43
W014	F	1203	01/27/2006 – 05/24/2006	117
W187	M	1282	01/27/2006 – 05/23/2006	116
W050	M	1346	01/27/2006 – 05/24/2006	117
W132	F	1376	02/10/2005 – 02/28/2006	383
W180	M	1525	09/10/2005 – 02/16/2006	159
W035	F	1536	03/01/2006 – 04/20/2006	50
W036	F	1554	03/01/2006 – 05/23/2006	83
W190	M	1886	03/01/2006 – 05/24/2006	84
W129	M	2214	02/09/2005 – 09/11/2005	214
W133	F	2857	02/10/2005 – 09/26/2005	228
W175	M	2904	08/14/2005 – 05/14/2006	273
W119	M	3476	08/29/2004 – 07/06/2005	310
W024	F	3653	10/30/2003 – 08/31/2004	306
W117	M	4343	08/23/2004 – 08/07/2005	372
W080	M	5610	10/16/2003 – 11/03/2005	748
W084	M	7748	11/06/2003 – 05/23/2006	928

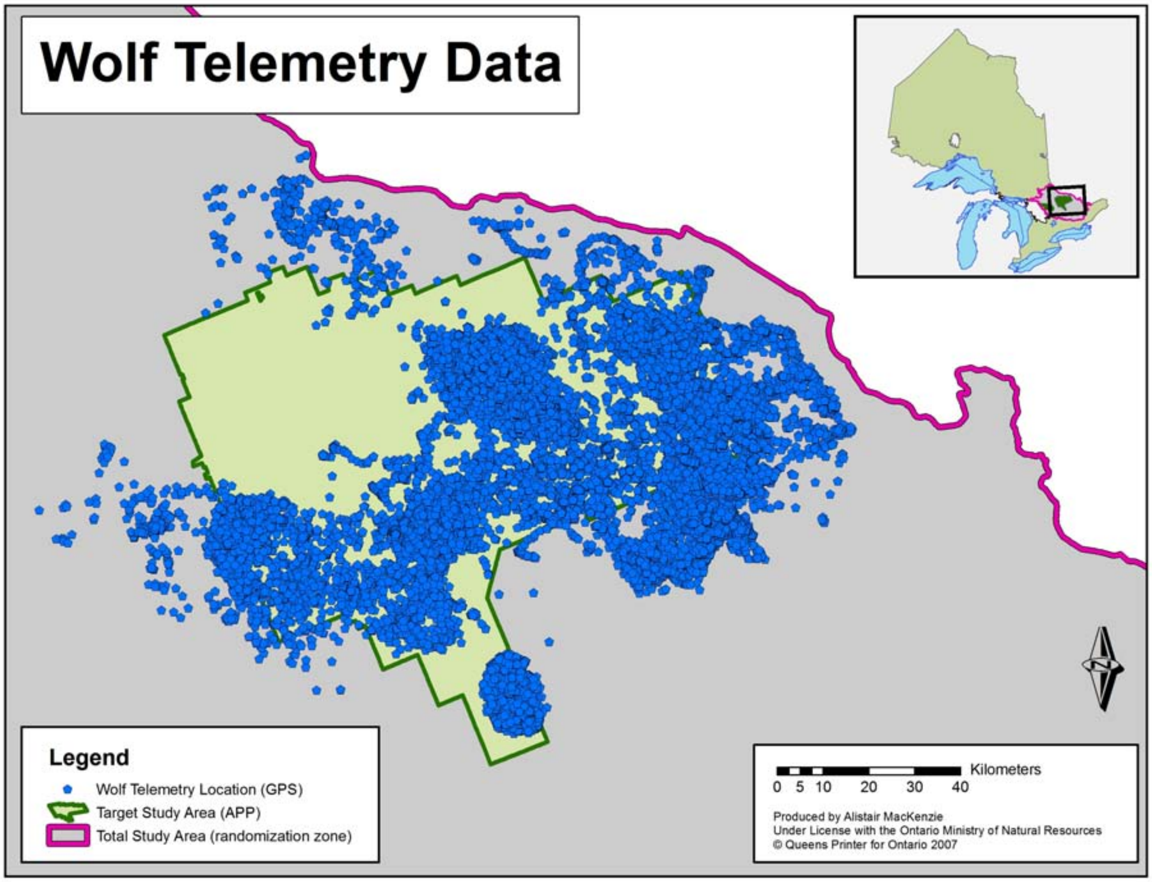

Figure 7. Spatial extent of wolf telemetry data obtained with Lotek GPS 4400 radio collars affixed to wolves in the APP region. Each symbol represents one GPS location captured automatically by the animal's collar.

The x-y coordinates of the telemetry data were imported into a geographical information system (GIS; ArcView 3.2; Environmental Systems Research Institute Inc. 1999) and converted into shapefiles (Environmental Systems Research Institute Inc. 2007). Data were subsequently converted to ArcInfo coverages to allow for manipulation within a GIS framework using AML (Arc Macro Language) (Environmental Systems Research Institute Inc. 2007) and Python scripting (Hetland 2005). Location data were collected in the field using a geographic coordinate system with locations recorded in decimal degrees. Subsequent analyses were conducted using one of two projected coordinate systems (Universal Transverse Mercator (UTM), Zones 17, 18, Units = metres & Canada Lambert

Conformal Conic, Datum NAD 83, Units = metres, False Easting = 930000, False Northing = 6430000, Central Meridian = -85.00, Standard Parallel 1 = 44.50, Standard Parallel 2 = 53.50, Latitude of Origin = 0.00000000).

GPS telemetry error is reported to be less than ± 10 meters (Patterson 2006, personal communication). This estimate is based upon field examination of kill site locations from which GPS telemetry fixes were obtained. Aerial and ground-based telemetry errors are likely variable, depending on azimuth, distance to the animal and signal strength. Tests using collars placed in known locations that were located by air and ground suggest that most locations are likely ± 200 m from actual locations of collared wolves (Patterson 2006, personal communication).

VHF collars were allocated to wolves opportunistically upon capture; animals deemed likely to disperse were assigned VHF collars (Patterson 2006, personal communication). GPS collars were strategically assigned to captured wolves that displayed evidence of breeding (lactating females, large males) in areas where packs were believed to reside (Patterson 2006, personal communication).

Linear Feature Data

Linear feature data was obtained under license from the Ontario Ministry of Natural Resources (Land Information Ontario, Ontario Parks (data for APP) and the University of Toronto Map and GIS library. Data were compiled into continuous coverages that spanned the entire randomization zone using GIS (ArcView version 3.2, ArcInfo version 9.2; Environmental Systems Research Institute Inc. 1999, 2007).

Roads

Road data created via Ontario Base Map (1:10,000 or 1:20,000) interpretation or direct GPS capture were obtained and categorized on the basis of road classification.

Accuracy of digital representations of road positions was not assessed. All roads were categorized into primary, secondary or tertiary roads as specified in the attributes (FMPDESG_CD or TYPE) provided with the obtained spatial data. Within APP, three classes of roads are specified within the park management plan (Ontario Ministry of Natural Resources 1998). Primary roads form a more or less permanent network of all-weather roads that provide access to crown land for a variety of purposes and usually have a life expectancy in excess of 15 years (Ontario Ministry of Natural Resources 1998). Similarly, secondary roads are intended for all-weather access and serve as branches of primary roads with a life expectancy of 5 to 15 years (Ontario Ministry of Natural Resources 1998). Finally, tertiary roads are constructed for the purpose of timber harvest and site renewal on a short term basis and eventually become impassable over time due to natural and directed reforestation (Ontario Ministry of Natural Resources 1998). Road allowance width within the park is constrained on the basis of road class to: 13.7 meters for primary roads, and 9.1 meters for secondary and tertiary roads. Photographic examples of the three classes of APP roads are shown in Figure 8.

Figure 8. Primary, secondary and tertiary road class examples obtained in APP. Note that the primary example is from Highway 60; not all primary roads are paved. Also note mammal tracks (mostly Moose) on the tertiary road class photo.

Roads outside APP are likely classed on the combined basis of road allowance width and traffic volume. Furthermore, it is unlikely that roads constructed on private or public lands outside APP are not maintained in some capacity and therefore likely have much greater life expectancies. It should be noted that the three road classes used here are the best available means to separate roads on the basis of their expected impact upon wildlife across the total study area with available data. It is possible however; that roads within APP and those in the surrounding randomization zone may not be appropriately categorized in relation to each other. Thus, primary roads within the park may or may not emulate primary roads outside the park boundary in terms of their impacts upon wildlife.

Road data were summarized on the basis of their spatial attribute tables using a GIS. Road lengths (km) and densities (km/km^2) were calculated for each study area as well as for wolf home ranges. Road length and density in wolf home ranges was assessed using the 95% Minimum Convex Polygon MCP (see Home Range Analysis) estimate of home range for each wolf. Using the 95% MCP here corrects for extreme outliers in the telemetry data set whilst maintaining a measure of conservatism in the estimation of home range (versus Kernel Density Estimates KDE – see Home Range Analysis). In addition, road density was assessed by generating line-density rasters. Vector road features for APP, WMU 49 and the randomization zone were used to create density rasters using a grain (cell size) of 1km x 1 km. Each cell in the raster was inventoried for the total length of road within and assigned a line density value (km of road per km^2 of area).

Railways

There are approximately 14 contiguous segments of railway line within the randomization zone surrounding the target and control study areas. Within APP there are two railway lines, both of which are no longer used for train transport and portions of each have been converted to recreation trails. Animals within APP are known to exploit these features for travel (personal observation; Theberge and Theberge 2004). Wildlife mortality attributable to railways may be high, especially when snow accumulation constrains animal movements and travel on railways offers energetic benefit (Wells *et al.* 2000). Accordingly, abandoned railways within APP are likely not comparable to active lines in the remainder of the randomization zone. Rather, these decommissioned lines may emulate roads or trails. There are 166.5 km of former railway lines in APP. WMU 49 is flanked on its east and west boundaries by active railways and contains 113.1 km of railway lines. The randomization zone contains a total of 2237.9 km of railway (or 1958.39 km exclusive of APP and WMU 49).

Trails

A variety of trails exist in the randomization zone. The term trail is used here to infer all linear features that are not roads or utility corridors. Within the bounds of APP, the majority of features are canoe portage routes, hiking trails and other recreational trails. Within the remainder of the randomization zone, snow machine trails may constitute a considerable portion of those presented. APP contains 2,470 km of trails while WMU 49 contains 912 km. The entire randomization zone contains 10,627 km of trails or 7,245 km exclusive of the two study sites.

Environmental Data

As with linear feature data, environmental data were obtained from the Ontario Ministry of Natural Resources and the University of Toronto Map and GIS library. As with previously mentioned data, environmental data were compiled into continuous coverages and raster grids that spanned the study area using GIS (ArcView version 3.2, ArcInfo version 9.2; Environmental Systems Research Institute Inc. 1999, 2007).

Hydrography

Central Ontario is densely populated with waterbodies and rivers. Water likely plays a significant role in the ecology of wolves and their prey in temperate regions with freeze/thaw cycles. Previous studies have demonstrated shifts in wolf locations towards lower elevation during winter (Pimlott et al. 1969, Kunkel and Pletscher 2001, Kuzyk et al. 2004). Three classes of hydrography data were compiled for the full extent of the randomization zone, namely: lakes, water and rivers. *Lakes* and *Water* are both polygonal (i.e. areas of water) features where lakes are waterbodies of extremely large extent and water represents all other polygonal water features. Rivers are line features. There are a variety of rivers of differing magnitude across the randomization zone; however,no distinction is made here between different classes of rivers.

Polygonal waterbodies and rivers were analyzed for each of the study areas as well as wolf home ranges. To permit this analysis, the provided waterbody GIS data were clipped to create coverages for each study area and wolf home range. Areas of polygonal waterbodies and lengths of rivers within each of the above areas were summarized using a GIS.

Temporal Assessments

Wolf movements may be affected by ice presence (Pimlott et al. 1969, Kunkel and Pletscher 2001, Kuzyk et al. 2004). To investigate this phenomenon, a database of ice formation and breakup dates available for the principle study area (APP) was used to establish an average temporal period of ice presence for the randomization zone. Beginning in 1964, and continuing annually till the present, ice breakup dates were recorded for Lake Opeongo, first by J. Fraser of the Harkness Fisheries Laboratory and later by R. Tozer of Ontario Parks. Similarly, ice formation data were tabulated annually by R. Tozer for Lake-of-Two-Rivers between 1972 and the present. Lake Opeongo and Lake-of-Two-Rivers are relatively large lakes that are both situated near the centroid of APP (~11.5 km and 24 km straight line distance respectively) and are likely representative of area lakes in terms of ice presence. Using 34 and 41 year cumulative means for ice formation and ice break-up respectively, an ice presence period between December 10th (julian = 344) and April 28th (julian = 118) was established. This temporal period was used to analyze telemetry data on the basis of ice presence to test for behavioural differences in relation to linear features. Additional periods based upon calendar month; the "wolf-year" using reproductive (May 1 through October 31) and non-reproductive periods (November 1 through April 30) and seasonally (summer versus winter) were also applied to location data using a GIS. Mean vector derived (see Point Based Movement Analysis) Euclidean distances from linear features were assessed in each period.

Wolf Movement

To investigate the hypotheses presented in the introduction, wolf movement behaviour was assessed using telemetry data and linear feature data obtained for APP, WMU 49 and the randomization zone. To begin, general comparisons between the target and control study areas were conducted to summarize linear features within each area using a GIS (Environmental Systems Research Institute Inc. 2007). Subsequently, wolf movement behaviour was assessed using point based movement analyses and home range analyses. An overview of the research design is shown in Figure 9.

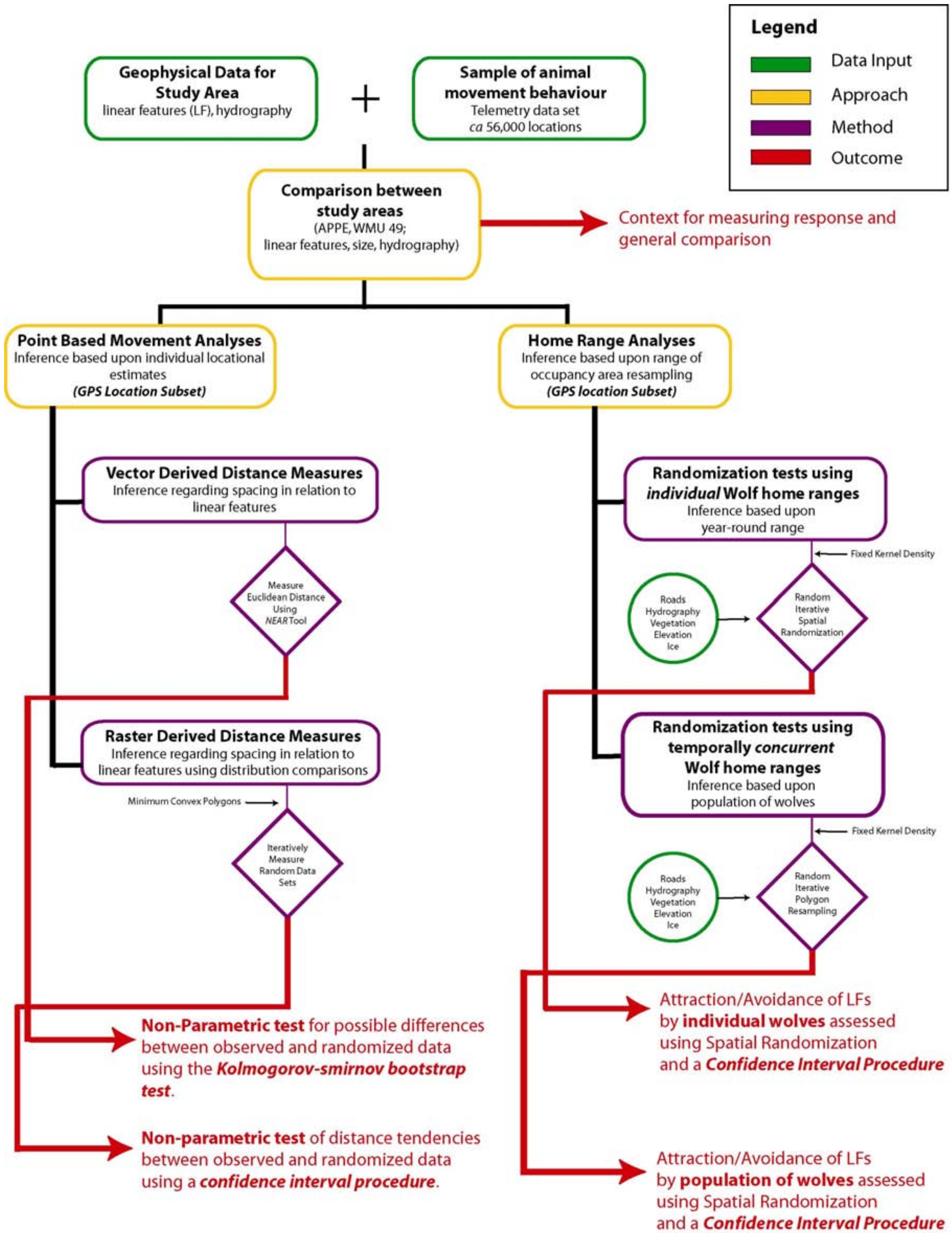

Figure 9. Overview of analyses conducted herein to evaluate the effects of linear features on wolf movement behaviour. Three general approaches were incorporated: Study Area Comparison, Point Based Movement Analyses and Home Range Analyses.

Point Based Movement Analysis

Animal movement patterns are often studied using telemetry observations taken at temporal intervals (Musiani et al. 1998, Wielgus et al. 2002, Patterson et al. 2005, Mills et al. 2006, Rouse 2006, Shepherd and Whittington 2006). Studies employing state of the art tools (e.g. GIS and spatial statistics) often join sequential telemetry locations with a straight-line estimate of the actual path taken by the study animal (Flamm et al. 2005, Bailey and Thompson 2006). Obviously, the more frequently locational estimates are captured, the closer one comes to modeling the actual path taken by the study organism. Other methods to evaluate animal movement patterns may also be applied. Specifically, analyses of animal paths themselves (i.e. path analyses) are commonly applied in ecology. Correlated Random Walk models (Zollner and Lima 1999, Bailey and Thompson 2006) and studies of path tortuosity (Whittington *et al.* 2004) have been used to study wolf movements using temporally successive location estimates and through direct tracking in snow respectively.

Whilst path analysis holds much promise to assist studies on movement behaviour, in this study I employ a measuring procedure using wolf location estimates to test for proximity patterns in relation to linear features. Analyzing movement data in terms of the proximity between linear features and wolves will help to improve our understanding of when such features exert repulsive versus attractive effects (Figure 10). In this study, observed wolf data are compared with a random set of locations stratified across the spatial extent of the observed wolf home ranges. I concentrate on linear features belonging to two categories, namely roads and trails; other linear features (e.g. hydro-electricity corridors) often have roads associated with them and are therefore assumed to be represented in the road data set. As presented in the introduction, hypothesis 1 predicts that wolf response to linear features may vary on the basis of road class. I interpret road class as a cumulative surrogate measure of human activity, vehicle velocity, noise pollution and other negative effects associated with linear features.

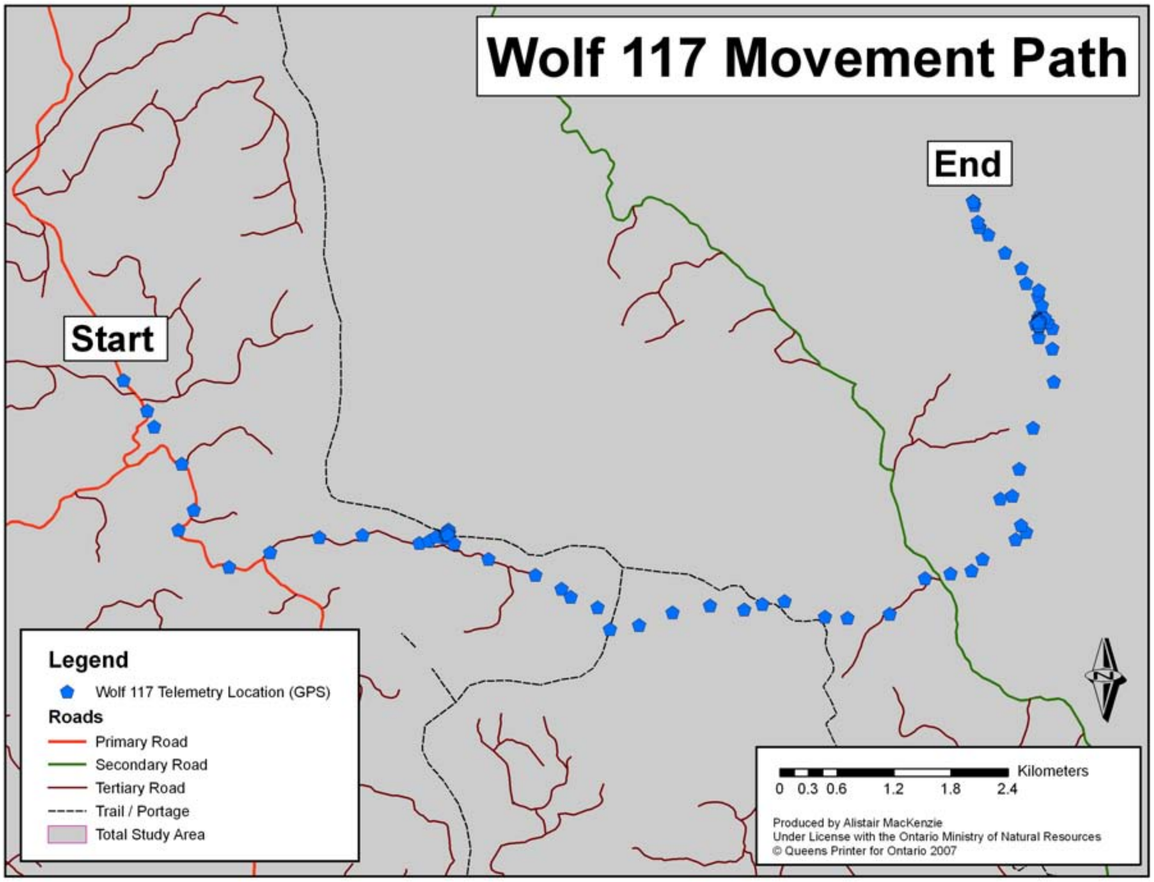

Figure 10. Wolf movement path for Wolf 117 collected on October 12, 2004 using 5 minute telemetry fix intervals. The depicted data are presented as an example of wolf telemetry in comparison to linear features (roads and trails). Note that in two instances, there appears to be a high degree of overlap between wolf locations and linear features.

Three classes of roads were analyzed: primary, secondary and tertiary (see linear feature data section). Primary roads likely have the greatest negative impact upon wolves due to the size of the features (i.e. road width), magnitude of human use, velocity of vehicles, amount of habitat loss and other generic negative pressures. Thus, wolf response to primary roads should clearly demonstrate repulsion or avoidance of these features. In contrast, tertiary roads, which are exploited by humans on an intermittent basis and are often decommissioned immediately following timber extraction, should offer significant energetic benefit to wolves which chose to travel on them with little corresponding negative effects attributable to humans. In the absence of human presence and noise pollution, one would expect tertiary roads to become similar to surrounding forested habitat in terms of deterrent effects. Consequently, the existence of tertiary roads should incite wolf use of the features and contribute overall to the movement behaviour of wolves. Secondary roads should likely exert intermediary effects on wolves between those of primary and tertiary roads. To clarify, secondary roads are expected to be used by wolves on the basis of their juxtaposition to primary roads and human developments, with secondary roads that are more distant to these being used more heavily. I expect that the observed data set should contain more data points that are closer to tertiary roads than that of a random data set. Furthermore, observed wolf telemetry should show strong repulsion from primary roads and intermediary repulsion from secondary roads.

Few authors have empirically investigated the impacts of trail systems upon wildlife. Papouchis *et al.*(2001) found that Big Horn Sheep (*Ovis canadensis nelsoni*) avoided trails more than roadways and postulated that the behaviour of human pedestrians on trails likely evoked a stronger repulsion of animals than that caused by vehicles on roadways. In addition, it has been suggested that learned behaviour regarding trails is likely passed on by adults to offspring since trail encounters with humans probably result in survival in most cases whereas animals that venture onto roadways are often killed. Consequently, in this study, I expect wolves to avoid trails, especially during temporal periods that correspond most closely to peak human activity in APP (May to October).

Two approaches were employed to test whether wolf spatial patterns were affected by linear features. First, Euclidean proximity distances for observed and random data were derived using a direct measurement of vector (e.g. arcs and nodes) data. Subsequently, a raster (e.g. grid cells) based approach compared observed and random data sets using a confidence interval procedure. Spatial analyses were performed using ArcInfo/ArcView (Environmental Systems Research Institute Inc. 1999, 2007) and the Python programming language (Hetland 2005) using Wing IDE 101 2.1 (Archaeopteryx Software Inc. dba Wingware 2006) on a windows-based personal computer. Additional data analyses were performed using Microsoft Excel.

Vector Derived Distance Measures

A vector based assessment of distances to roads was performed using observed wolf telemetry locations and a set of random locations. All observed wolf GPS telemetry locations (*n* = 51,515; for 28 individuals) were pooled and the number of locations per animal was used to derive a matching number of random locations equivalent in magnitude to the observed set for each individual (see Table 2). As outlined in greater detail below in the home range analysis section, estimates of home range can be generated using a variety of methods. One of the most simplistic is the minimum convex polygon (MCP) procedure. The MCP procedure joins the outermost telemetry locations to create a convex hull or polygon that encompasses the observations. The investigator can choose to eliminate outlying observations to generate MCP home ranges using subsets of the observations (see Home Range analysis section). In this case, MCPs generated using all observations (e.g. 100 % MCP) were used to constrain the placement of random data to an area of the landscape occupied by observed data. Random locations were generated using the *Generate Random Points* option within the Hawth's Analysis Tool Extension for ArcGIS (Beyer 2004).

The NEAR tool (ArcINFO; Environmental Systems Research Institute Inc. 2007) was used to derive the Euclidean distance between roads and both observed and random locations. A graphical representation of the NEAR procedure is depicted in (Figure 11). The tool appends a distance, in the unit of measure of the map (e.g. meters), into the spatial attribute table for each feature under evaluation. In this case, the road coverage used within the NEAR measurement procedure comprised all roads (cumulative set of all road classes) for the entire randomization zone. In this analysis, all data points in both the observed and random data sets were enumerated relative to vector representations for linear features. In this way, assessment of the proximity pattern for observed and for random data could be conducted to test for behavioural tendencies with regard to linear features.

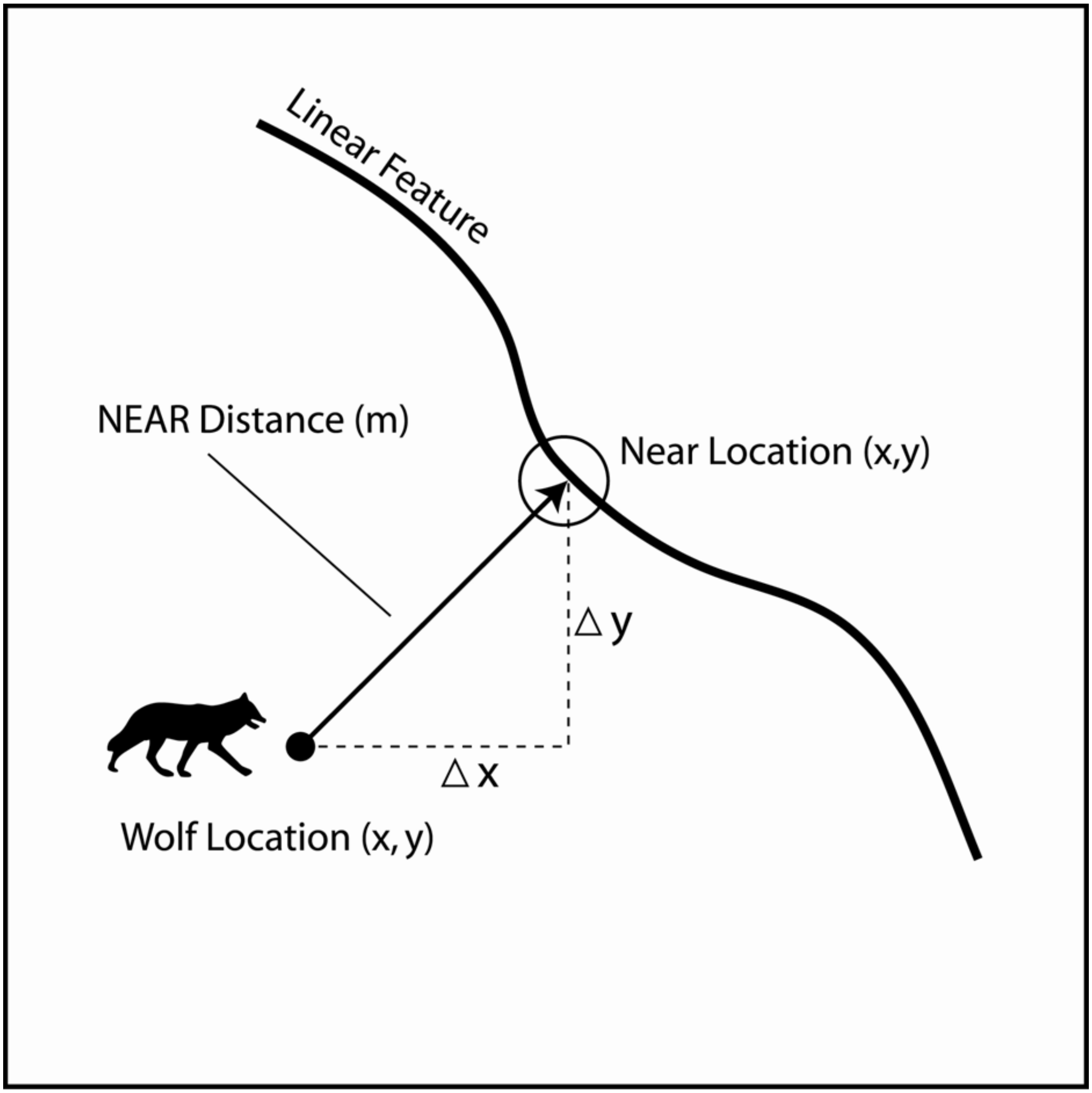

Figure 11. Graphical representation depicting NEAR measurement procedure. Euclidean distance between a point layer and an arc (line) layer is derived and the distance and location of the nearest arc is appended to the attribute table of the record under scrutiny.

Once Euclidean distances were calculated for both observed and random data sets, the resulting output was analyzed using the Kolmogorov-Smirnov (K-S) two-sample goodness-of-fit test (Zar 2004). Observed and random wolf locations were treated as two continuous samples and the test was applied to determine the probability that the two sets of observations were drawn from a common distribution. Assumptions of the K-S test are:

samples are drawn randomly from the population, the underlying distributions are continuous and the two samples are independent.

The K-S test determines the difference between the cumulative frequency distributions of the samples using the D statistic. The null hypothesis for the K-S test is:

$$H_0\text{: P = P}_0$$

the alternative hypothesis is:

$$H_1\text{: P ? P}_0$$

where P and P_0 are two unknown, continuous distributions. The D statistic is calculated using cumulative distribution functions (CDF); D represents the maximum difference between the two CDFs being evaluated (i.e. compare all differences between observed and expected CDFs and select the absolute largest difference).

Due to the presence of ties (i. e. many duplicate values) in the data series, the bootstrap K-S test was implemented in R statistical software program (Version 2.4.0, R Development Core Team 2006; Matching Package) to permit exact calculation of significance values (*p*-value). One thousand bootstrap iterations were performed when determining the exact *p*-value.

Raster Derived Distance Measures

Since the vector procedure relies upon only one random set of observations, a more rigorous assessment procedure for the pattern of wolf distance to linear features was developed. Specifically, a raster-based confidence-interval procedure using observed data and many sets of random data was developed. Once again, the numbers of observed wolf locations were used to derive equivalent sets (see Table 2) of random locations which were constrained by each wolf's 100% MCP, as in the vector derived procedure. In contrast to the vector derived distance measures, the random generation process in this case was repeated iteratively 1000 times to generate a null distribution (total of 51,515,000 random locations). To clarify, this represents 1000 sets of 51,515 random locations, each constrained to the spatial extent of each wolf's 100% MCP and equivalent in magnitude to the number of observed locations for each individual as presented in Table 2. Random locations were generated using the *Create Random Points* script within the Python programming language (Hetland 2005).

GIS vector data on linear features were used to create raster grids that summarized the distance from each cell in the raster to the nearest linear feature on the landscape. Each *distance raster coverage* was derived by calculating the Euclidean distance from each cell centroid to the nearest linear feature. Raster grids were generated with a grain (cell size) of 10 meters by 10 meters which was chosen partly on the basis of road allowance widths and also through interpretation of the resulting output. This process was repeated for all classes of roads (primary, secondary and tertiary) individually as well as for trails. An additional raster, which was derived on the basis of distance to secondary and tertiary roads combined, was also created. This resulted in five distance rasters for primary, secondary, tertiary, and secondary + tertiary roads as well as for trails.

Using the computer program Wing IDE 101 2.1, I applied a raster extraction script using Python that determined the cell value from the distance raster and appended it to the spatial attribute table for each randomized point (Figure 12.). This resulted in 51,515,000 random data points which each had an associated distance to the closest linear feature. The observed data set was subjected to the same enumeration and raster distance values were appended for each wolf location in the observed data set.

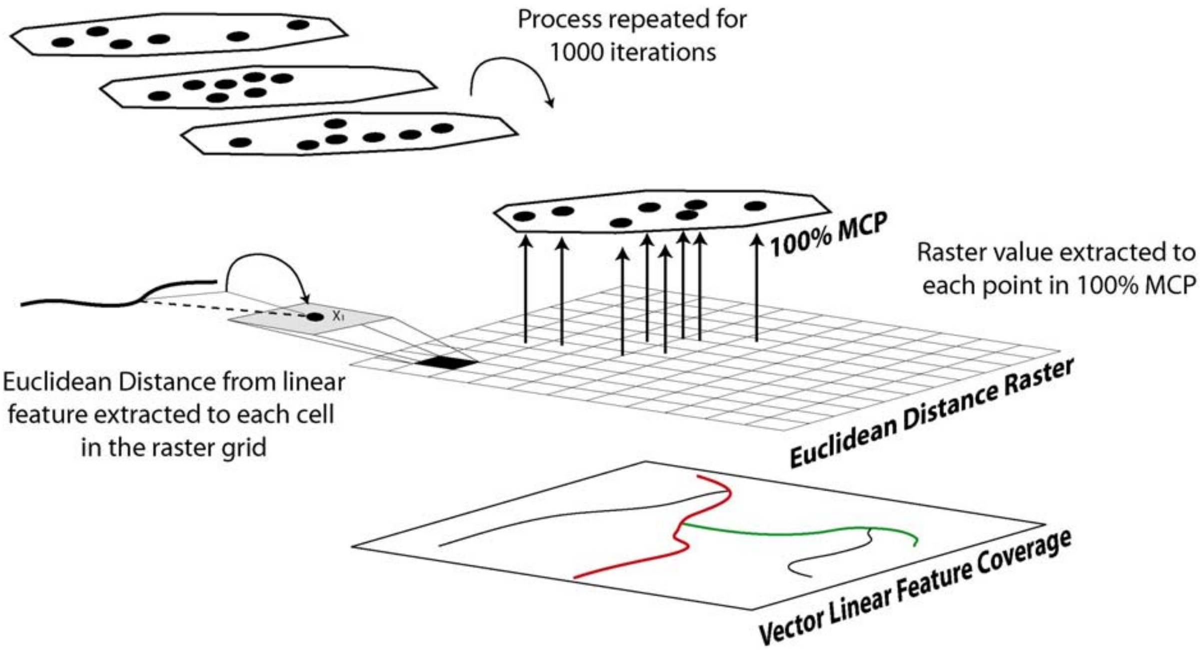

Figure 12. Graphical representation of the procedure used to assess the Euclidean distance to nearest linear feature for each point under evaluation. Vector based linear feature coverages were converted to raster grids by assigning the distance to the nearest linear feature to each cell in the raster grid. Subsequently, all points (observed and random data sets) were assigned a distance value by extracting the value from the underlying raster cell and appending it to each feature's spatial attribute table. The raster grain (cell size) is 10 meters by 10 meters. Raster distance values were expressed in meters, the spatial unit of measure for the vector linear feature coverage. The extraction of distance values was repeated for all 1000 iterations of the procedure.

Resultant data summaries were analyzed using distance classes derived to assess the pattern of observed and random locations. Distance classes were determined on the basis of the maximum observed home range width (derived using the 100% MCP), along with the minimum and maximum distance values for observed and random points. The resulting distance classes are shown in Table 3.

Table 3. Summary of distance classes used to assess the pattern of distance to linear features in both observed and random data sets. Distance classes were quantified in meters, the spatial unit associated with vector linear feature GIS coverages.

Distance Class	Distance Range (meters)
1	0 – 10
2	11 – 20
3	21 – 30
4	31 – 40
5	41 – 50
6	51 – 200
7	201 – 300
8	301 – 500
9	501 – 1000
10	1001 – 5000
11	5000 – 10000

Descriptive statistics were then determined in each distance class for both the observed (n = 51,515) and random (n = 51,515, 000) data sets using MS Excel pivot tables; these included: the arithmetic mean, the minimum distance, the maximum distance, the standard deviation, and the 5th and 95th percentiles.

Following the methodology of Pearl *et al*. (2007), the allocation of 1000 iterations of random points is assumed to approximate a true random distribution of distance measures between roads and all possible locations of wolves upon the landscape. In this manner, the distribution of distances to roads is generated on a wolf-by-wolf basis and assessed for each distance class shown in Table 3. The 5th and 95th percentile values for each distance class were then applied to evaluate the response of each animal in the observed data set. To clarify, the number of wolf locations in each distance class was assessed relative to the expected quantity of locations within the distance class as specified by the lower (5th percentile) and upper (95th percentile) limits. Observed quantities per distance class were then evaluated relative to this range and assigned to one of three assessment categories, namely *equal*, *fewer* or *more*. If the observed number of wolf locations per distance class fell between the lower (5^{th} percentile) and upper (95^{th} percentile) limits, I concluded that there was no significant effect of linear features upon wolf movement, or that this method was unable to discern an effect. These cases were labeled *equal* to the expected range. If there were *fewer* locations than expected, or the observed quantity fell below the lower limit (5^{th} percentile), then I concluded that the linear features were having a repulsive effect upon wolves. Should there be *more* locations than expected, or the observed quantity fell above the upper limit (95^{th} percentile), I concluded that roads were expressing an attractive effect upon wolves.

Home Range Analysis

Recall that if indeed there are benefits to traveling on linear features, there may be consequences for wolves who occupy areas of the landscape that are deficient in suitable linear features. Alternatively, wolves that learn to exploit suitable linear features may become more effective predators, attain better reproductive fitness and have greater overall survival. Furthermore, there may be other benefits to wolves when their home ranges contain linear features. Barja *et al.* (2004) found that crossroad areas of linear features provided benefit from a territorial marking perspective relative to the placement of scats. Thus, home ranges that contain linear features may aid in the establishment and maintenance of the territory through more effective scent marking. Here, I aim to investigate hypothesis 2 by using estimates of home range to assess the relative quantity of linear features within wolf home ranges versus that which is generally available in the randomization zone.

It is likely that many complex factors affect the size and location of wolf territories. For instance, competition, social dominance, recruitment, survival, prey distribution, habitat composition and quality, and human activity all likely play a role in the establishment and maintenance of home ranges. In this study, I investigate whether linear features can also be counted amongst the factors that influence home ranges.   In the context of multiple animal territories in socially regulated systems, such as in wolves, it is likely that socially dominant individuals or packs reside in areas of the landscape which have the highest net benefit to the individual, for instance in terms of prey capture opportunity. If certain classes of linear features within APP indeed provide benefit to wolves, then such features may play a role in how individuals/packs array themselves across the landscape, and thus drive territories to cluster around areas of higher density of suitable linear features. Not all linear features will provide benefit and larger linear features that are more heavily exploited by humans may result in net negative effects. Thus, it may be possible to use the location of home ranges to test for selective pressures of habitat components, such as roads and trails. If linear features indeed provide some kind of energetic benefit to wolves, then it is possible that they play a role amongst other factors in determining the size, density and stratification of home ranges.

In order to investigate this hypothesis, I employed wolf telemetry data to derive estimates of home range. Several procedures exist for determining the boundary and extent of an animal's home range and although the concept of home range is well established within ecology, the procedures used to derive estimates of home range remain active areas of investigation and refinement. The minimum convex polygon (MCP; or convex hull), first presented by Mohr (1947) has been widely applied for generating estimates of home range. It is a simplistic means of encircling telemetry locations to delineate the smallest area that encompasses all points using convex angles between adjacent sides. Criticism of the MCP estimation of home ranges (Horne & Garton, 2006; Lawson & Rodgers, 1997) warrants analysis with an additional estimation procedure. Thus, kernel density estimators (KDE)

(Worton 1989) will be used to derive statistically based estimates of the subject's utilization distribution. Girard *et al*. (2002) found that GPS telemetry generated more accurate estimates of home range than VHF telemetry. Thus, both MCP and KDE estimates of home range were generated using GPS telemetry data alone.

Minimum Convex Polygons (MCPs), using 100, 95, 75 and 50 per cent of available locations per individual wolf were generated using the Home Range Tools Extension (HRT) for ArcInfo (Rodgers and Carr 1998, Environmental Systems Research Institute Inc. 2007). MCP generation utilized the *Floating Mean* algorithm within HRT which calculates the mean of all points in both vertical and horizontal planes and removes the most extreme values until the requested percentage of points has been discarded. Importantly, following each discard, the mean of all remaining points is recalibrated, thereby removing the effect of the discarded points. The *Floating Mean* calculation procedure has the benefit that it does not rely upon the global mean of all points at the start of the calculation. This is in contrast to the *Fixed Mean* algorithm which presumably retains some residual effect from the discarded points. MCPs were projected using the Universal Transverse Mercator coordinate system (UTM zone 17,18; units of meters, datum of NAD83). Selecting variable percentages of points to incorporate in the calculation of the MCP results in variable sizes of resulting home range estimates (Figure 13). It is common practice to use 95 % MCPs since removing the outer 5 % of collected points minimizes the effects of extraneous movement. Consequently, the majority of analyses conducted here rely upon 95% MCPs which are shown in Figure 15. The allocation of random points discussed in the Point Based Movement Analysis section is an exception, where the 100 % MCP was used instead in an attempt to exert less bias on the allocation of random points. Allowing the random point generator to distribute random points within the 100 % MCP means that all possible locations where the wolf was observed to travel are available.

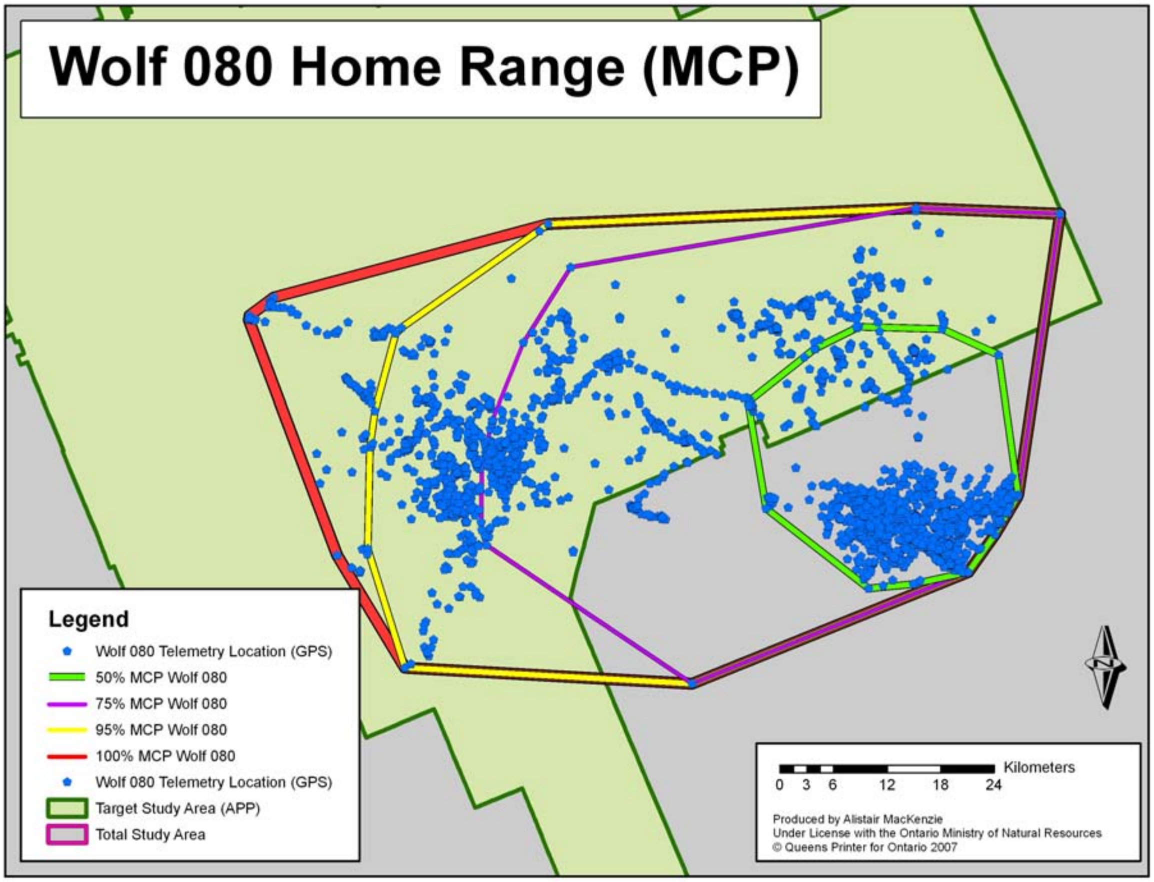

Figure 13. Minimum Convex Polygon home range estimates for Wolf 080. Example shown demonstrates the effects of limiting the percentage of total points included in home range calculations.

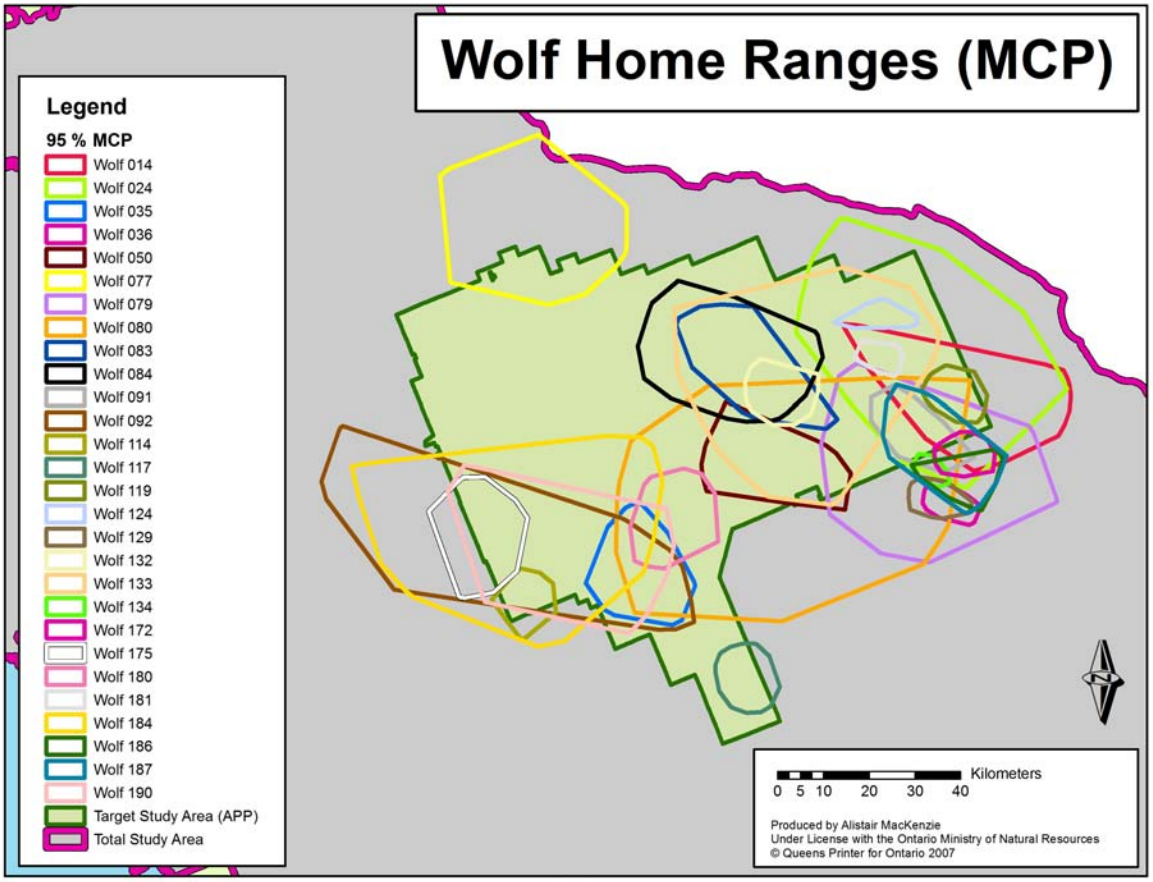

Figure 14. Minimum Convex Polygon (95 % MCP) home range estimates for all wolves (n=28) equipped with GPS collars. Depicted home ranges were generated using complete data sets for each wolf (i.e. all calendar years combined) and the 95 % MCP procedure was used to remove 5 % of outlying points.

Kernel Density Estimates (KDE) (Worton 1989) for all GPS telemetry were similarly calculated using the HRT extension for ArcInfo (Rodgers and Carr 1998, Environmental Systems Research Institute Inc. 2007). KDEs are believed superior to MCPs since they can accommodate activity clusters and are not influenced as heavily by outlying points (Hemson *et al.* 2005). The resulting output is often more meaningful than MCPs as it can graphically and statistically identify regions of highest concentration of locations (Figure 15). KDE procedures return volumes or densities of points in fractions of the collective data being analyzed. Consequently, unlike the MCP procedure where the operator can specify the percentage of outliers to exclude (e.g. 95 % MCP excludes 5 % outliers) the KDE procedure returns volume or density contours in variable increments. Thus I report the 90%, 75% and 50% volume contours of generated KDE polygons.

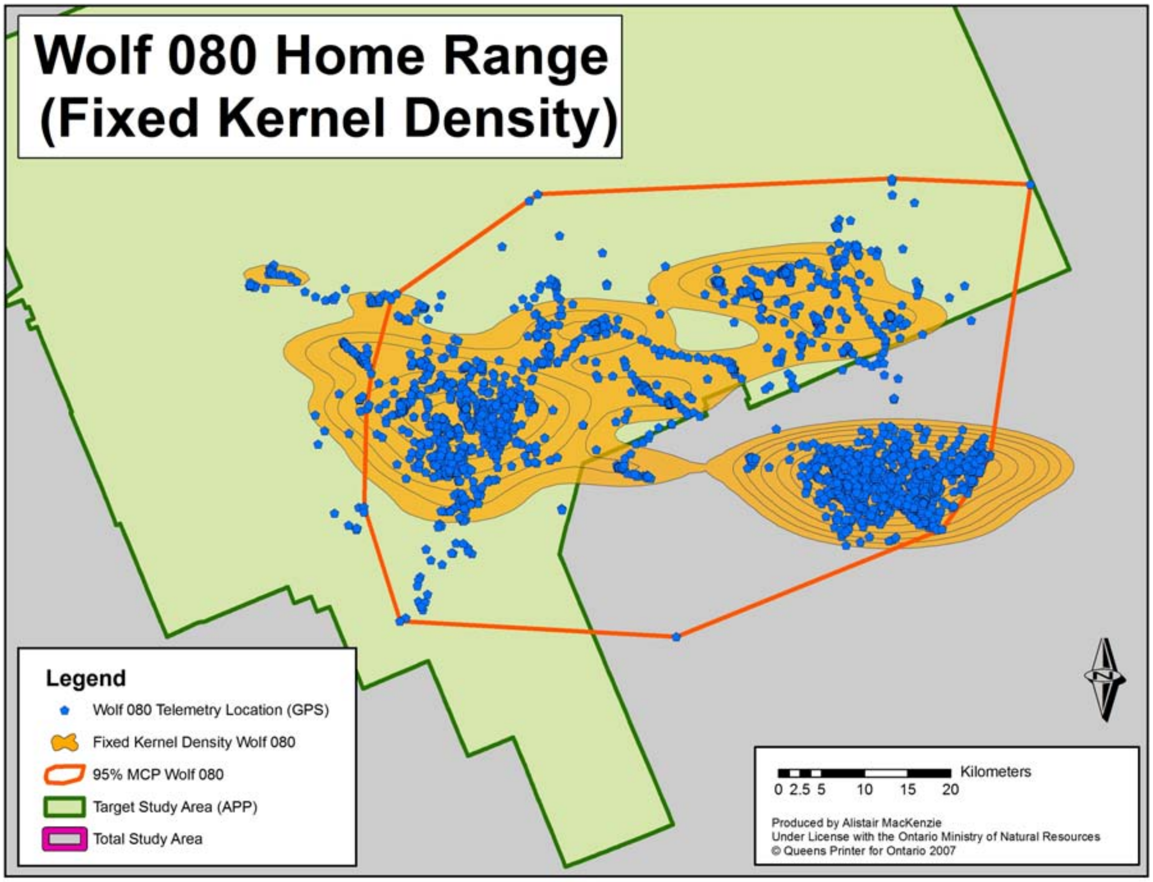

Figure 15. Fixed Kernel Density home range estimates for Wolf 080. Example shown depicts the 90, 80, 70, 60, 50, 40, 30, 20, and 10 % volume contours. The KDE procedure can identify multiple areas of activity and is less sensitive to outlying points than the MCP method. The 95% MCP home range boundary is included for comparison.

Generating estimates of an animal's utilization distribution (UD; the distribution of animal locations on the ground) (Worton 1989) requires the operator to choose a bandwidth (or smoother) for the kernel. Unfortunately, there is little consensus amongst ecologists regarding the appropriate procedure to employ when choosing a bandwidth (Rodgers and Carr 1998). Several authors recommend using the least-squares cross validation (LSCV) method to estimate the bandwidth. Hemson *et al.* (2005) however, reported that the LSCV method returned variable results and may not be appropriate for all studies. My own investigations using LSCV (*h-lscv*), the reference bandwidth (*h-ref*) and other methods of estimating the bandwidth (e.g. *root-n*) resulted in highly variable outcomes. I found that LSCV often returned under-smoothed home ranges and had computational difficulty with root-n due to extremely large sample sizes. Thus, KDEs were generated using the h-ref bandwidth smoother. Hemson *et al.* (2005) note that use of the h-ref bandwidth likely results in over-estimation of the true areal extent of the home range. I chose to err towards this bias and accept that home ranges within this study may be slightly larger than the true UD for each animal. To permit comparisons between study areas, KDE home range polygons were employed to assess hydrology and linear features within wolf home ranges, within study areas and within the randomization zone.

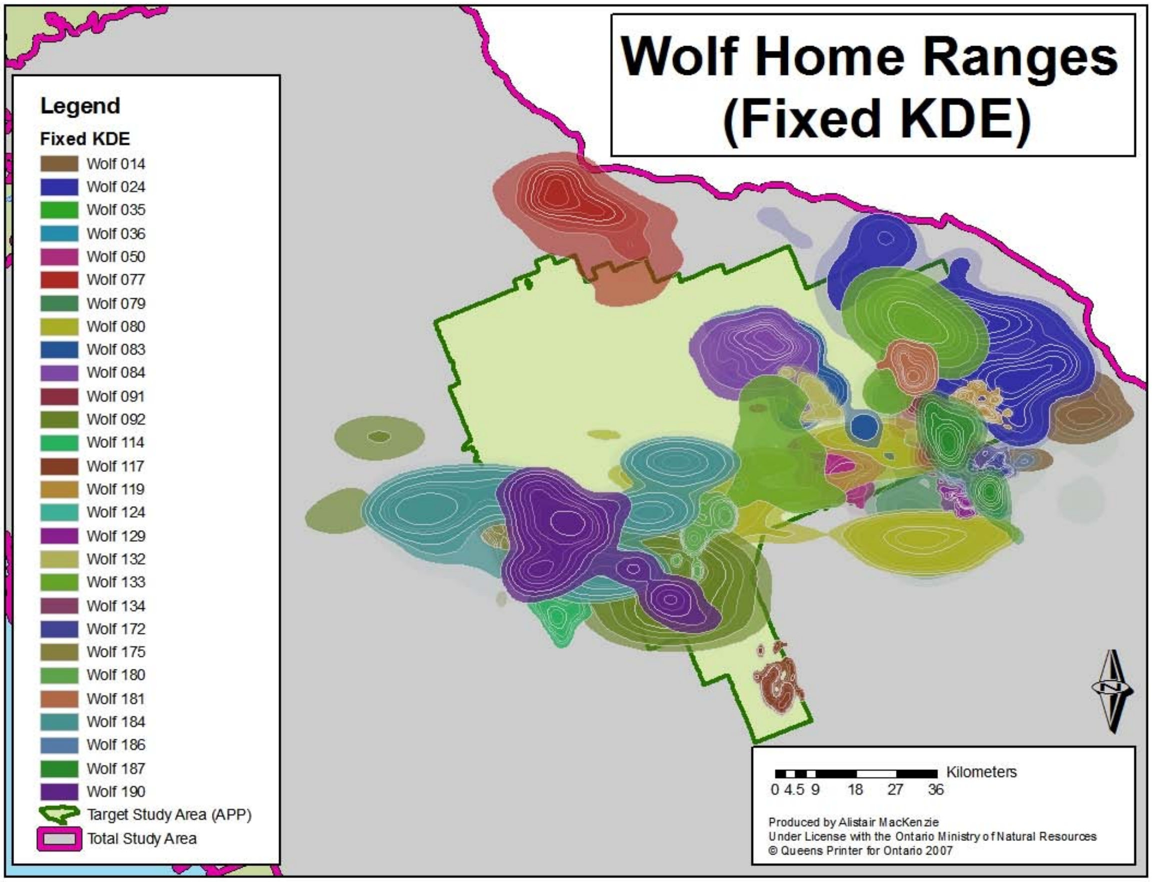

Figure 16. Fixed Kernel Density Estimates of home range for all wolves (*n*=28) equipped with GPS collars. Depicted home ranges were generated using complete data sets for each wolf (i.e. all calendar years combined). Home ranges shown were generated using the reference bandwidth estimator (smoother) h-ref. The fixed KDE procedure uses a constant bandwidth value for all points being analyzed, regardless of point density

Spatial Randomization

To assess whether linear features were affecting the location of home ranges, a restricted spatial randomization procedure was applied to move home range polygons. The observed location of the home range was spatially randomized iteratively across the randomization zone by applying a random shift and rotation (Figure 17 and 18). This procedure was repeated for one thousand iterations for each home range using the *Vector Geometry Random Iterative Spatial Resampling* (VGRISR) tool in the Hawths Tool Extension for ArcInfo (Figure 18). The randomization zone perimeter was used as an outer boundary for the allocation of randomized home ranges. If the VGRISR tool placed a randomized home range partially outside the boundary of the randomization zone, that iteration was removed and repeated to result in all randomizations being fully contained by the randomization zone.

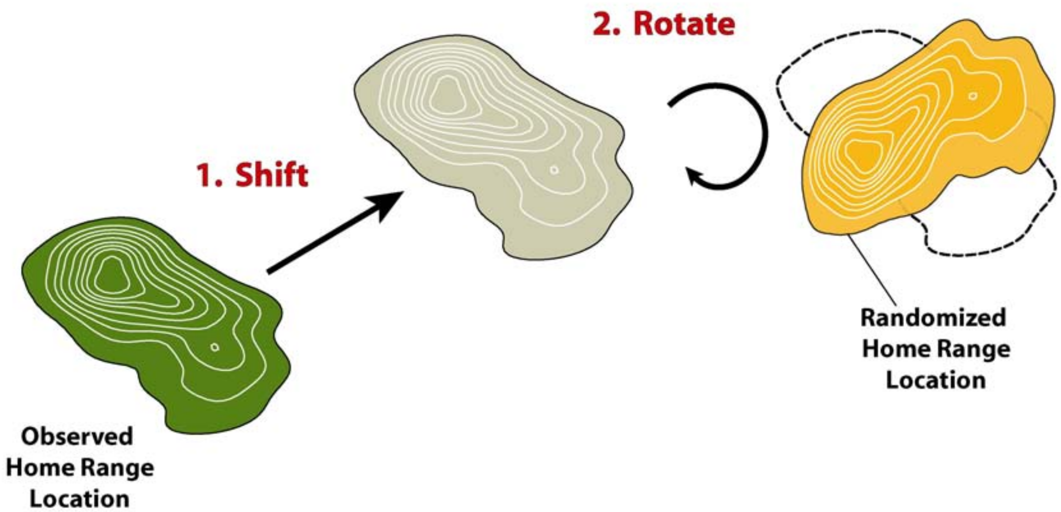

Figure 17. Graphical depiction of the randomization procedure applied to each wolf home range. Home range estimates were generated with the Fixed Kernel Density Estimation procedure. Randomization was accomplished through a two-step procedure using the *Vector Geometry Random Iterative Spatial Resampling* tool within the Hawth's Tools Extension for ArcInfo. For each home range, a specified number of iterations applied a shift of a random distance and a rotation of a random number of degrees.

Individual wolf home ranges as well as groups of home ranges were spatially randomized. Individual wolf home ranges were randomized to compare observed linear feature content with the general availability of linear features across the total study area. KDEs were employed in this instance since they most likely approximate the true utilization distribution more accurately than MCP estimates of home range. The outermost volume contour (90%) of each home range was selected and used as a perimeter for each home range during the randomization procedure. This procedure assessed each wolf independently from other wolves on the landscape. A sample of randomized home range polygons from one individual is shown in Figure 18. Conversely, analyzing groups of wolves collectively aims to maintain the social structure of adjacent wolf home ranges. Groups of home ranges were established on the basis of calendar year with individual wolves earning membership in a yearly grouping by having telemetry data collected for them within the year. Four temporally concurrent groups were established (e.g. 2003, 2004, 2005 and 2006) and the home ranges of all wolves within each group were randomized together as one entity. In wolves for which GPS locations were collected in multiple calendar years, the data was sub-sampled and new KDE home ranges were generated using only points collected during one calendar year period. To permit randomization of temporally concurrent groups of home ranges, the 90 percent volume contours (the outermost contour generated by the Fixed KDE procedure) were extracted from individual home ranges and merged to create one multi-part polygon. These polygons were then randomized across the landscape in a similar manner to that described above for individual wolves, once again employing one thousand iterations in the procedure.

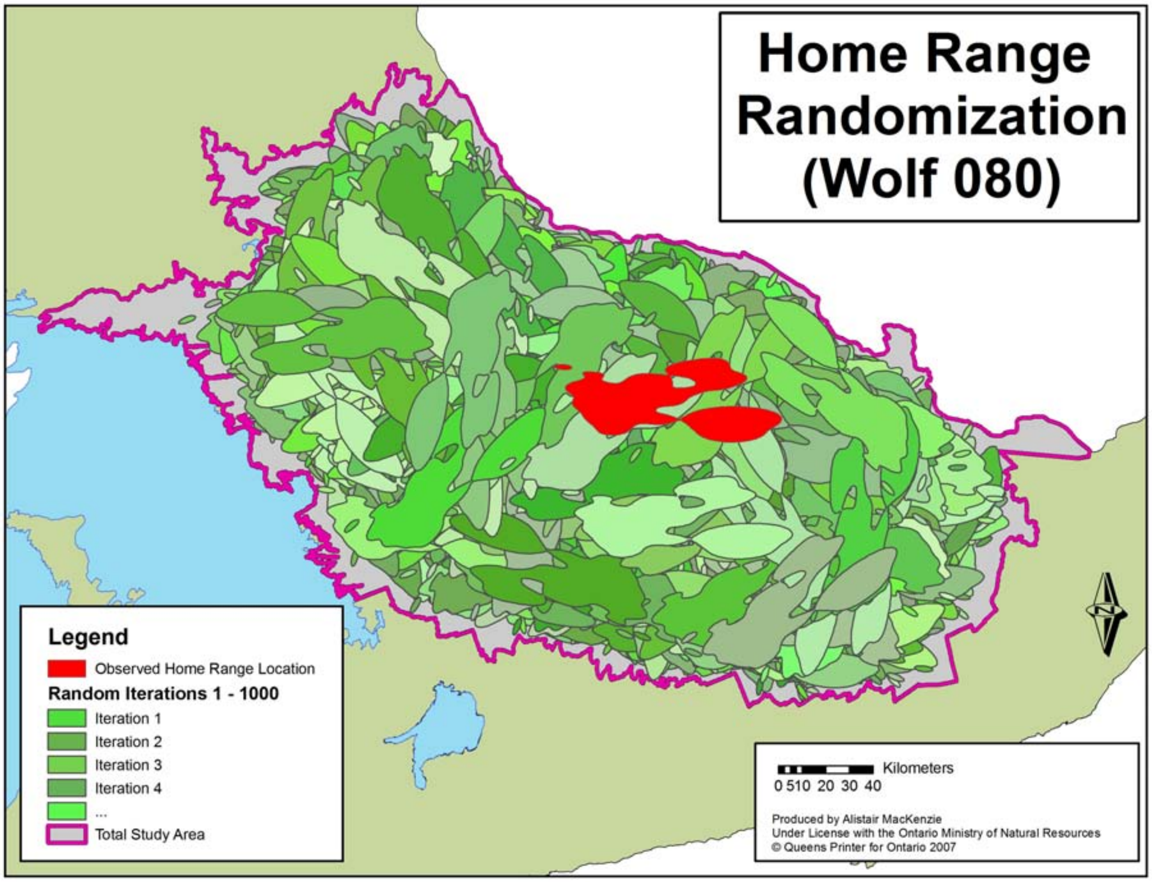

Figure 18. Output from home range randomization procedure showing observed home range location (red) and 1000 iterations of randomized home ranges that are rotated and shifted within the extent of the randomization zone (green shades).

Subsequent to the randomization procedure, an Arc Macro Language (AML) (Environmental Systems Research Institute Inc. 2007) script was written to extract linear feature attributes from each home range in both the observed and randomized data sets. The script was used for both individually randomized home ranges as well as temporally concurrent groups. Output from the script consisted of lengths for all arc (line) features of each class of road found within the home range being analyzed. Reported totals for each class of road were summarized using MS Excel and descriptive statistics were generated. Once again, the methodology of Pearl *et al*. (2007) was applied and the generated distribution of random home range road quantities was used to place the observed measures of linear features into context. To clarify, the arithmetic mean, the minimum, the maximum, the standard deviation, the 5th percentile and 95th percentile measures of length within each home range were computed and used to assess difference between observed and randomized home ranges.

RESULTS

Linear Feature Data

Roads

At the time of publishing, APP contained a total of 5488.02 kilometers of roads when all road classes were pooled. The park contains 592.87 kilometers of primary roads (FMPDESG_CD = "Highway", "Primary" and "Primary Out"); 667.57 kilometers of secondary roads (FMPDESG_CD = "Secondary" and "Secondary Out") and 4227.58 kilometers of tertiary roads (FMPDESG_CD = "Tertiary"). When all roads are pooled, APP has a cumulative road density of 0.72 km/km^2.

By applying the published road allowance values from the APP management plan (Ontario Ministry of Natural Resources 1998), habitat loss or conversion to roads in the park is as follows: 8.12 km^2 to primary roads or 0.1% of park area; 6.07 km^2 to secondary roads or 0.09% of park area; and 38.47 km^2 to tertiary roads or 0.5 % of park area.

The control study area, WMU 49, contained a total of 3762.22 kilometers of roads when all road classes were pooled. WMU 49 contained 1579.56 kilometers of primary roads (FMPDESG_CD = "Primary"); 1130.13 kilometers of secondary roads (FMPDESG_CD = "Secondary") and 1052.53 kilometers of tertiary roads (FMPDESG_CD = "Tertiary"). When all roads are pooled, WMU 49 has a cumulative road density of 1.00 km/km^2. Road densities assessed by generating line density rasters for the cumulative road data and each road class are shown in Figures 19, 20, 21 and 22.

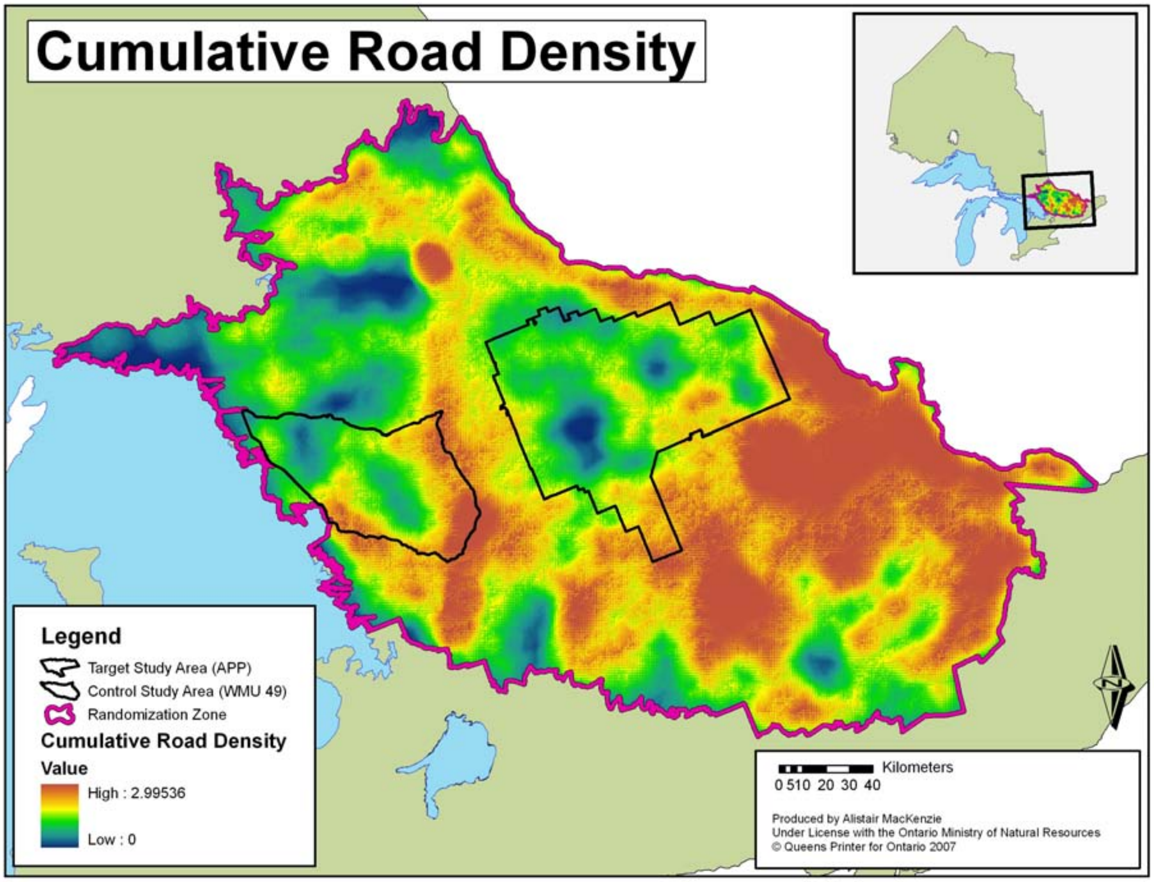

Figure 19. Cumulative road density (all road classes combined) calculated over the full extent of the randomization zone. The perimeters of the target (APP) and control (WMU 49) study areas are depicted in black. Areas of high road density are shown in red shades. Raster grain (cell size) is 1000m x 1000m (i.e. 1 km^2).

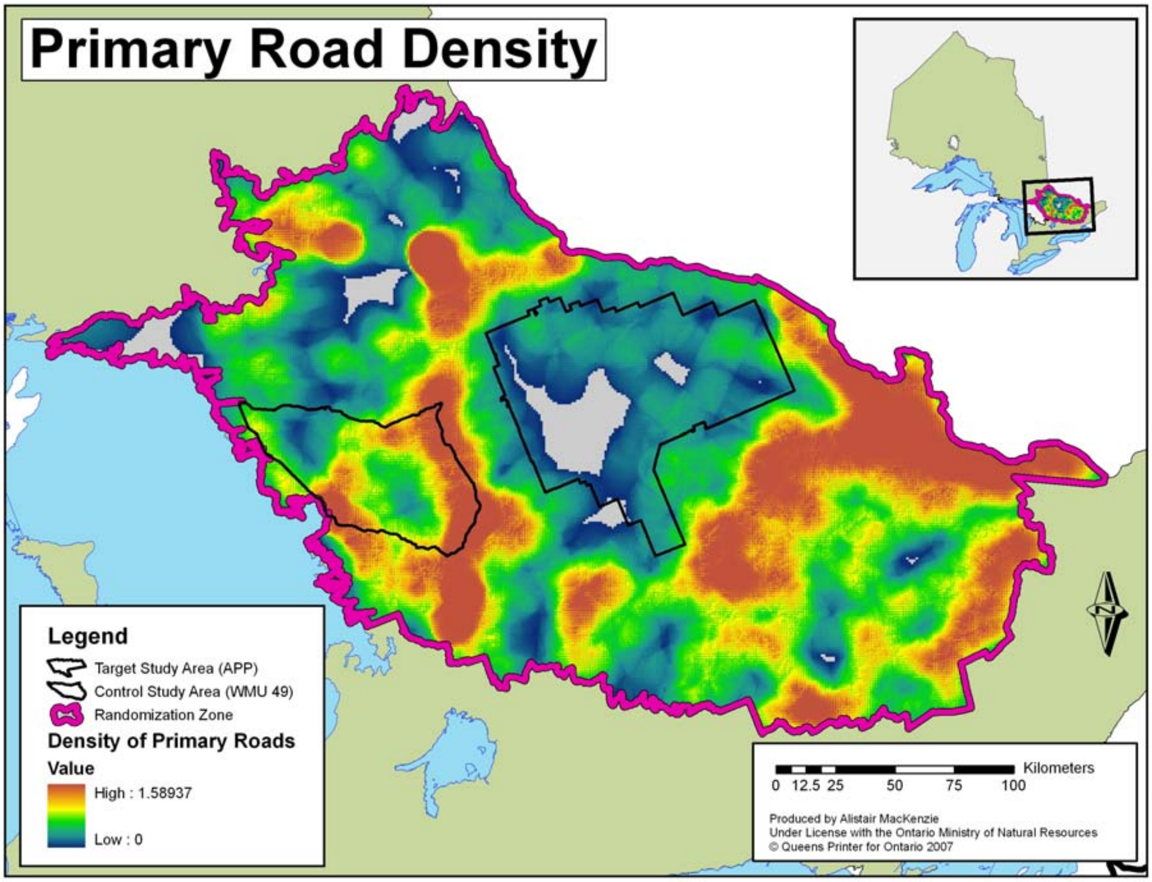

Figure 20. Primary road density calculated over the full extent of the randomization zone. Areas of high primary road density are shown in red shades. Areas depicted in gray represent regions of the randomization zone where no data values occur. Raster grain (cell size) is 1000m x 1000m (i.e. 1 km^2).

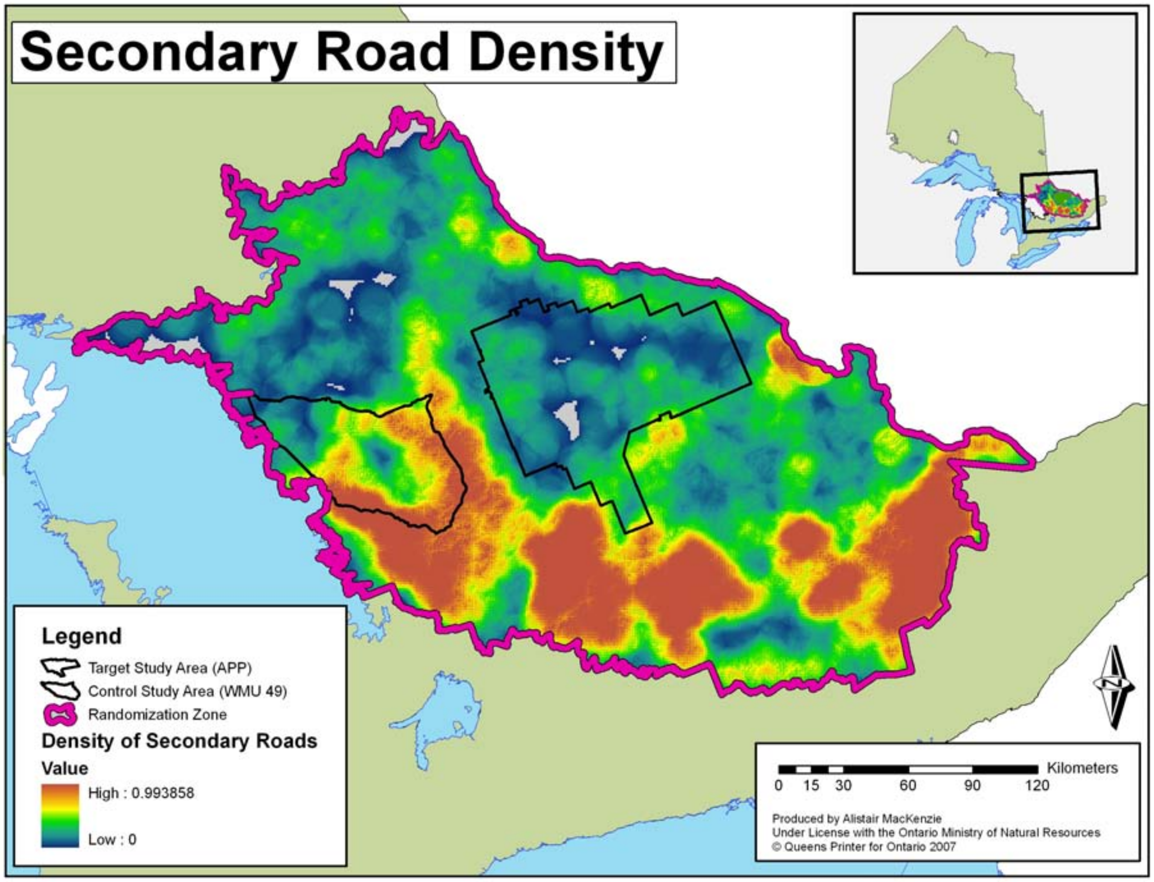

Figure 21. Secondary road density calculated over the full extent of the randomization zone. Areas of high secondary road density are shown in red shades. Raster grain (cell size) is 1000m x 1000m (i.e. 1 km^2).

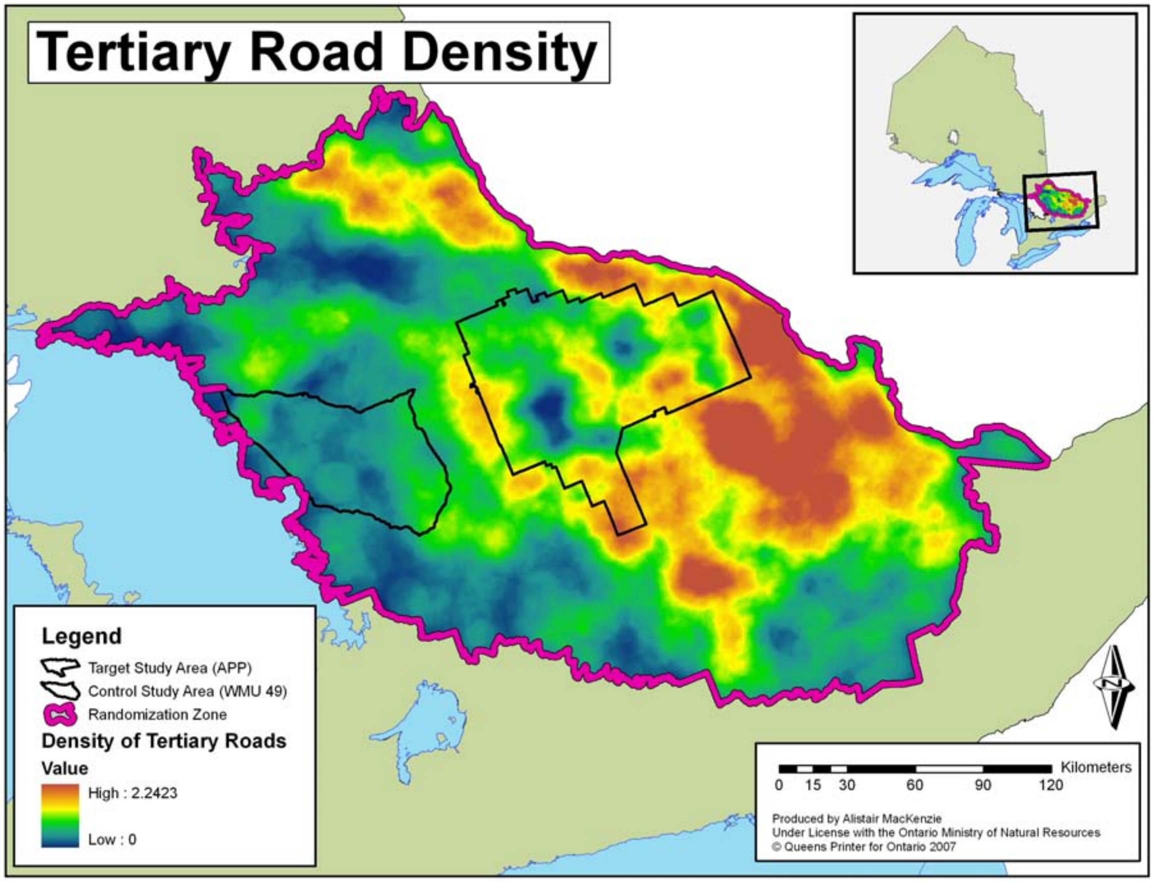

Figure 22. Tertiary road density calculated over the full extent of the randomization zone. Areas of high tertiary road density are shown in red shades. Raster grain (cell size) is 1000m x 1000m (i.e. 1 km^2).

Environmental Data

Hydrography

APP contains a total surface area of 871.78 km^2 of polygonal water (water and lakes combined) comprised of 7571 GIS features. This represents a surface area percentage of 11.43 of the total area of APP. The park contains 4773.03 kilometers of water courses at a density of 0.63 km/km^2. In contrast, WMU 49 contains a total surface area of 488.27 km^2 of waterbodies or 6.40 % of the total area. There are 1951.24 kilometers of watercourses in WMU 49 at a density of 0.53 km/km^2. Polygonal water covers a total of 7038.24 km^2 in the randomization zone or 8.0 % of the area. The randomization zone contains a total of 37845.45 kilometers of water courses at a density of 0.47 km/km^2.

Temporal Assessments

Euclidean distances determined using the NEAR vector procedure described above were assessed using the mean ice presence period (December 10th to April 28th) to test for changes in the distance between linear features and locational estimates obtained from wolves. In addition to this temporal assessment, NEAR proximity distances were also assessed on the basis of monthly periods; the "wolf-year" using reproductive (May 1 through October 31) and non-reproductive periods (November 1 through April 30) and seasonally (summer versus winter). Contrary to my expectations, no discernable patterns in distance from linear features could be found using any of the above mentioned temporal periods.

Point Based Movement Analysis

Vector Derived Distance Measures

Vector distance measures from roads for all observed GPS telemetry ranged between 0 and 8,897 meters. Random telemetry locations ranged between 0 and 10,117 meters from roads. The Bootstrap Kolmogorov-Smirnov (K-S) two-sample goodness-of-fit test found a significant difference (p-value < 0.001) between the Euclidean distance distributions of observed and random data points based on one thousand bootstrap iterations.

Raster Derived Distance Measures

An example output chart from the raster derived distance measurement procedure is shown in Figure 23. Divergence from the expected pattern of response was assessed using the bounds of the 5th and 95th percentile of observations. If the observed number of locations fell between these two bounds, I deemed there to be no significant difference between the observed data and the random data set (i.e. “equal” assessment category; E). Should the observed data for a particular distance class fall above the 95th percentile, I assumed that the wolf being assessed demonstrated a preference for that distance class (i.e. “more” assessment category; M). Conversely, if there were fewer observed points than the quantity of the 5th percentile, then I interpreted this to mean wolves were showing an aversion to this distance class (i.e."fewer" assessment category; F). Each wolf was assessed individually and results were pooled on the basis of distance class for all 28 individuals.

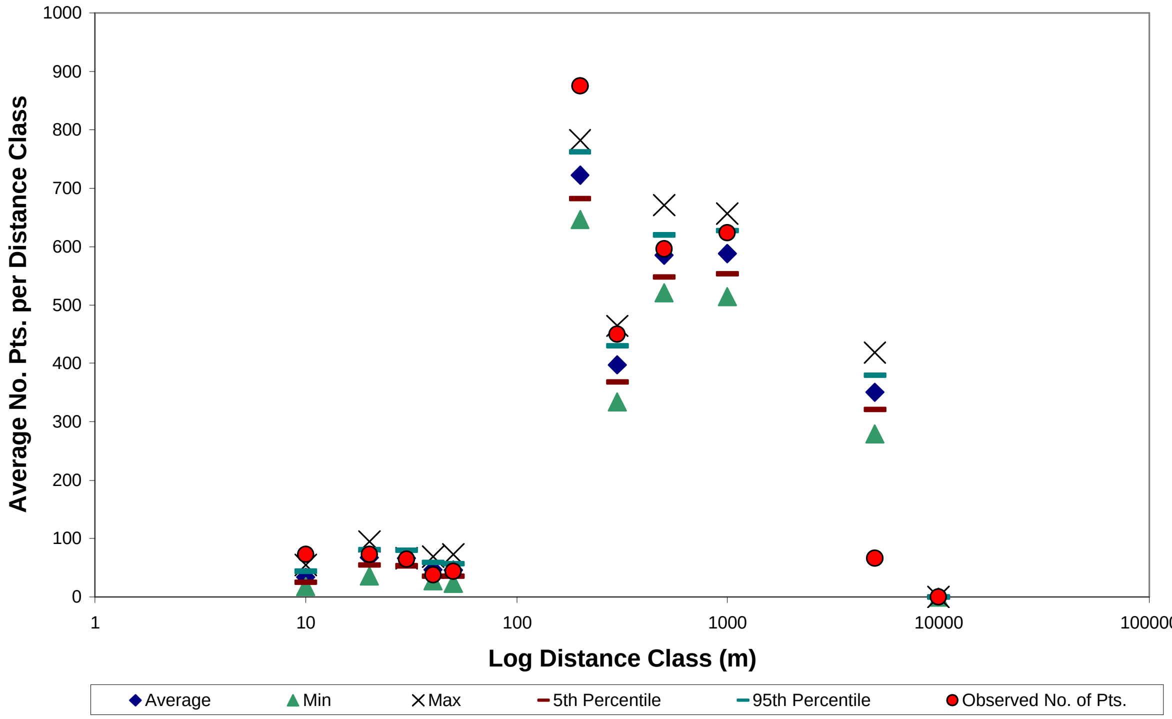

Figure 23. Sample output from raster derived distance measurement procedure for Wolf 117. For each animal, 1000 random sets of locations equivalent in magnitude to the observed data set were created and enumerated to provide the minimum, maximum, mean, 5th and 95th percentile of the quantity of points in each distance class. The observed number of wolf locations within each distance class is depicted in red.

Results of the raster derived distance measurement procedure for all roads combined are shown in Figure 24. For each distance class, totals of each assessment category were calculated. The prevailing trend in response is determined by the assessment category that contained the greatest number of animals. To clarify, the assessment category to denoted by the top-most symbol is what I interpreted as the prevailing trend in response.

In the case of all roads combined, the majority of individuals did not differ from what would be expected at random in distance classes 2, 3, 4, 5, 7, 9 and 11 (see Table 3). Wolves appeared to avoid distance classes 6 and 10. Fourteen out of twenty-eight wolves (14 More;

11Equal; 3 Fewer) assessed for distance classes 1 and 13 out of 28 (13 M; 7 E; 8 F) for class 8 show a tendency to use these classes more than you would expect by random. In distance class 6 the number of wolves having more points in each distance class is equal to those having fewer; in distance class 7 the number of wolves who have more than or an equal number of locations to random is identical. Since each wolf was assessed independently versus 1000 iterations of a matching number of randomly allocated data points, I see possible ecological significance in each red (more or attraction) and green (fewer or repulsion) data marker in Figure 24. It should be noted that although distance class 11 was included on the basis of home range width and maximum distances in the vector NEAR data set, not all wolves could attain a distance from any road that was this extreme. As such, the results of this distance class should be interpreted with caution as they may not reflect a true measure of an attractive or repulsive effect from roads.

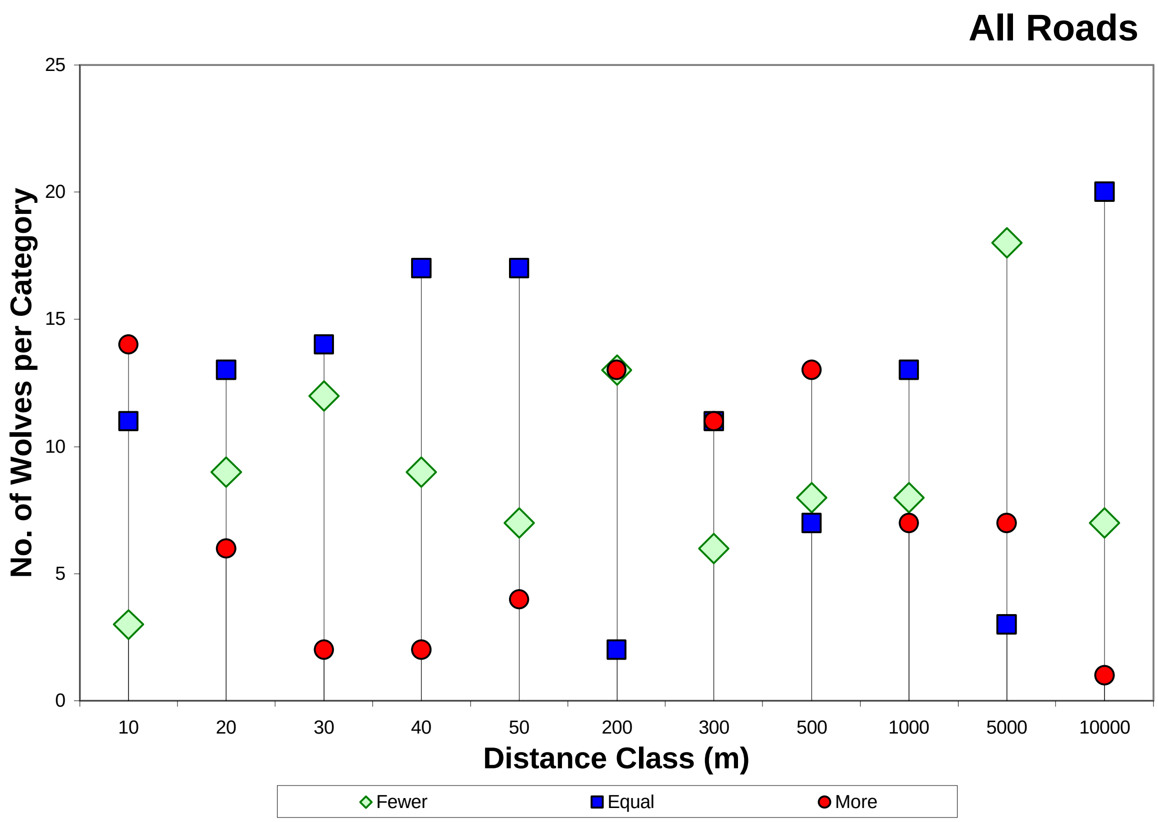

Figure 24. Summary counts of the number of wolves belonging to each assessment category when all roads were used to analyze distances between observed and random data sets. Distance classes were measured in meters.

Contrary to my expectations, tertiary roads did not cause a strong pattern of attraction at near distance classes. The data summary for tertiary roads is shown in Figure 25. Within 50 meters of a tertiary roadway (distance classes 1 to 5), five out of five distance classes predominantly showed no divergence from what would be expected by random. This result suggests that tertiary roads do not appear to exert a repulsive effect on wolves at these distances. Nor do they appear to be highly attractive given that only 6 wolves used the first distance class more than expected, 7 in the second, and three in the remaining three distance classes. Twelve, thirteen and eleven wolves in distance classes 7, 8 and 9 respectively were found there more often than expected.

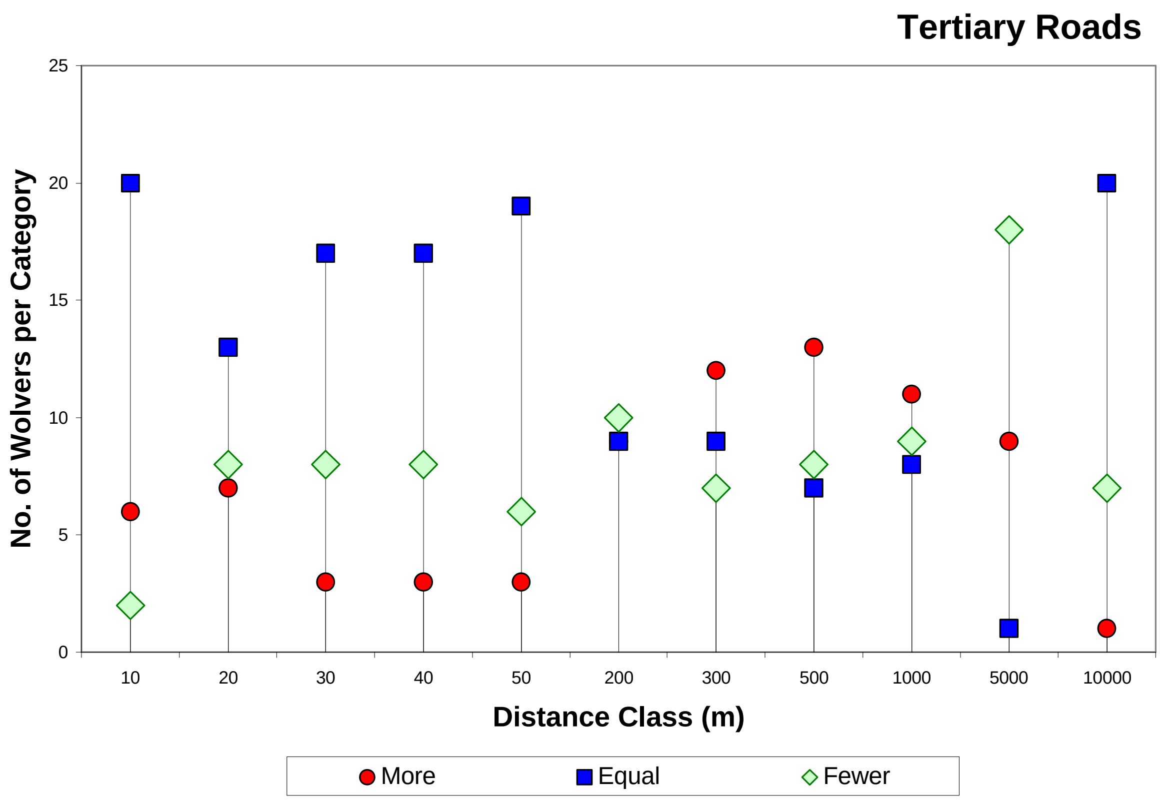

Figure 25. Summary counts of the number of wolves belonging to each assessment category when only <u>tertiary roads</u> were used to analyze distances between observed and random data sets. Distance classes were measured in meters.

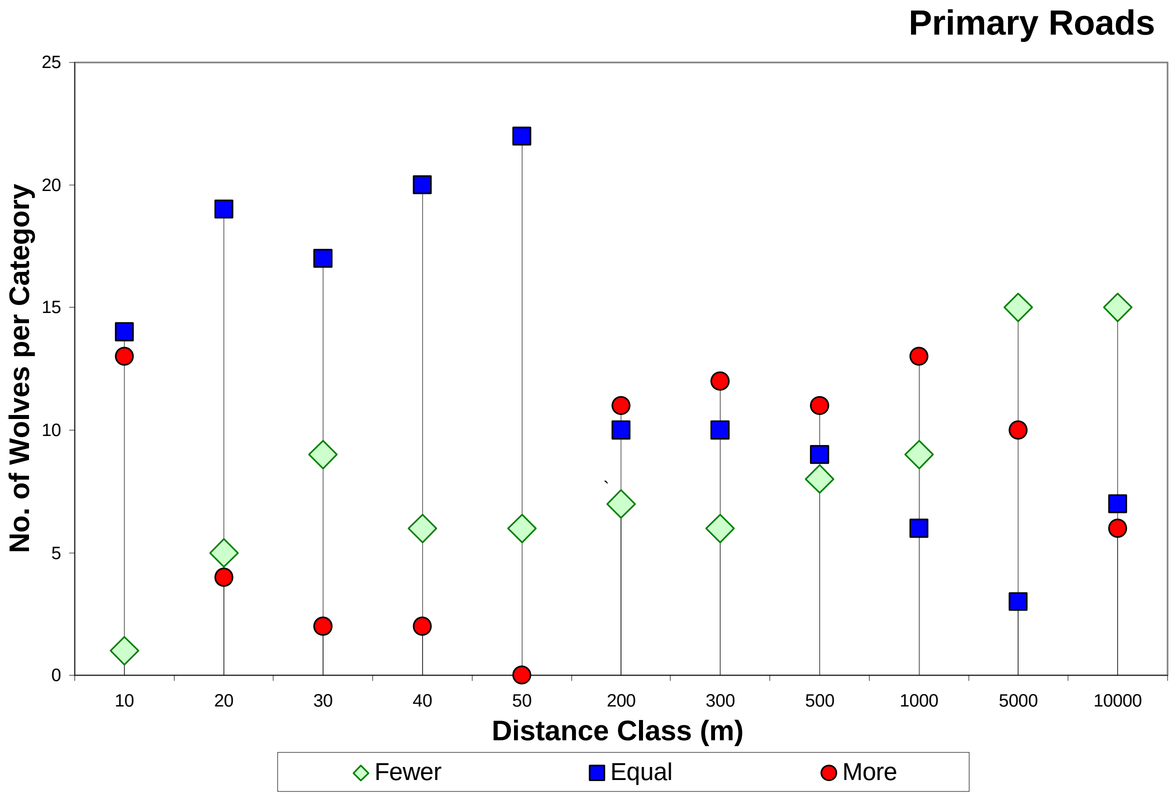

Figure 26. Summary counts of the number of wolves belonging to each assessment category when only <u>primary roads</u> were used to analyze distances between observed and random data sets. Distance classes were measured in meters.

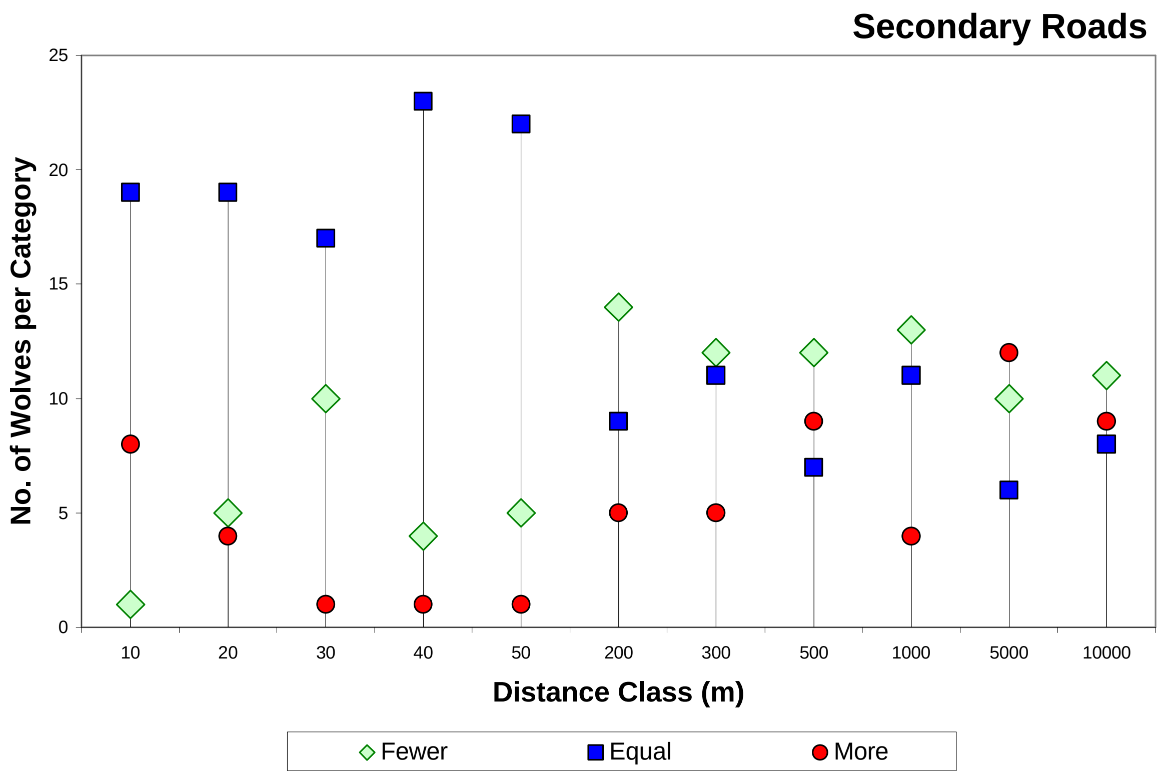

Figure 27. Summary counts of the number of wolves belonging to each assessment category when only <u>secondary roads</u> were used to analyze distances between observed and random data sets. Distance classes were measured in meters.

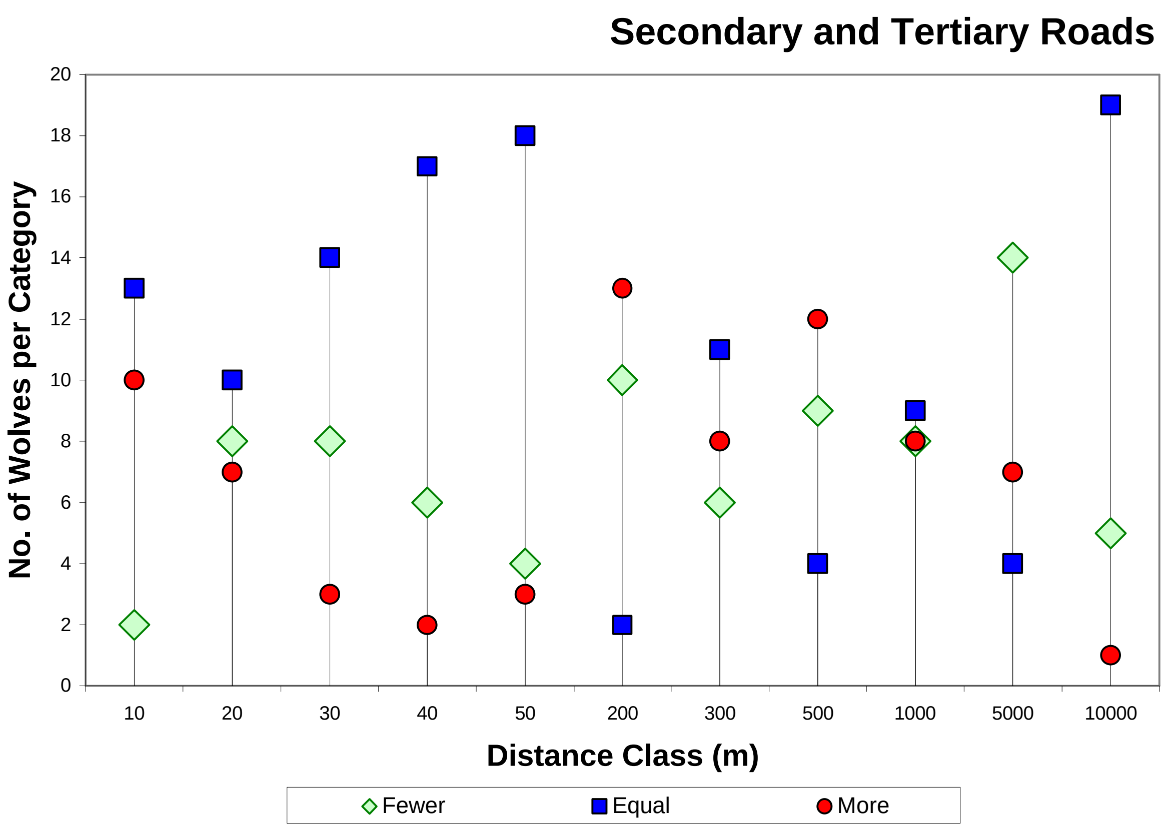

Figure 28. Summary counts of the number of wolves belonging to each assessment category when <u>secondary and tertiary roads</u> were collectively used to analyze distances between observed and random data sets. Distance classes were measured in meters.

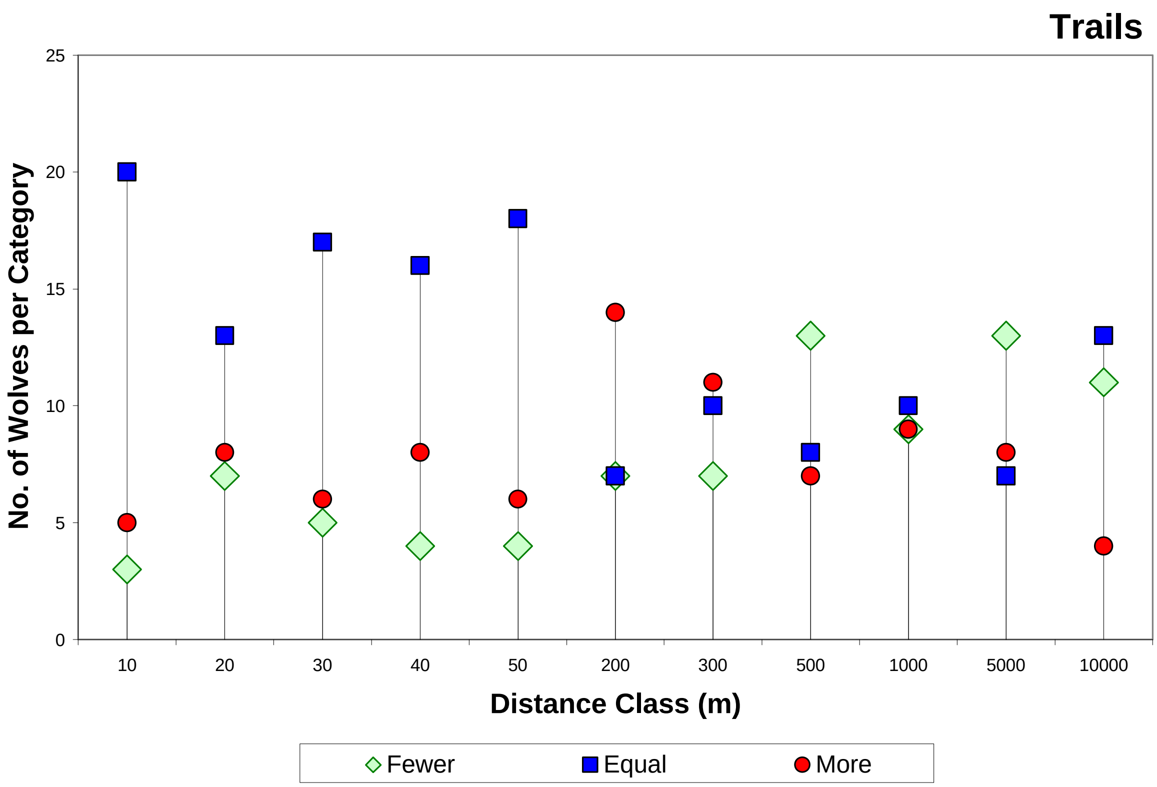

Figure 29. Summary counts of the number of wolves belonging to each assessment category when trails were used to analyze distances between observed and random data sets. Distance classes were measured in meters.

Home Range Analysis

Minimum Convex Polygon estimates of home range for all wolves are summarized in Table 4. As expected, 100 % MCP estimates of home range are highly variable with a minimum area of 49 km^2, a mean area of 1175 km^2, and a maximum of 4994 km^2. It is likely that these areas are influenced by extreme outliers in the point spatial data. Furthermore, they likely encapsulate areas that are not currently utilized by the animal but become part of the home range estimate due to the nature of the procedure (see Figure 13). Despite this weakness, the 100% MCP can be useful as a general indicator of the area over which habitual movement of an individual occurs.

Table 4. Descriptive statistics summary for Minimum Convex Polygon (MCP) Home Range Estimates generated for all GPS collared wolves (*n* = 28). % MCP specifies the percentage of points used to derive the home range estimate. Note that the estimates of home range shown below were derived using all available GPS data for each animal.

% MCP	Mean Area (km^2)	Standard Error	Minimum Area (km^2)	Maximum Area (km^2)
100	1175	255	49	4994
95	765	165	38	3353
75	374	104	23	2503
50	145	37	4	783

Fixed Kernel Density Estimates of home range for all wolves are summarized in Table 5. In comparison to the MCP estimates of home range, the KDE method generates more conservative mean area values.

Table 5. Descriptive statistics summary for Fixed Kernel Density Home Range Estimates (of the Utilization Distribution) generated for all GPS collared wolves (*n* = 28). Volume % specifies the percentage volume contour used to summarize the home range estimates.

% Volume	Mean Area (km^2)	Standard Error	Minimum Area (km^2)	Maximum Area (km^2)
90	618	122	38	2266
75	296	61	19	1272
50	159	34	10	719

Length and density of roads were assessed for each animal using the 95 % MCP. When all roads were enumerated, the mean length of road per home range was 1168.77 km. Of course, home range estimates vary significantly in area depending on the movement behaviour of the individual, resource density and other factors. Accordingly, measures of density are likely more meaningful than total length. Mean density of roads in wolf home ranges, when all classes were assessed cumulatively, was 1.04 km/km^2. Not surprisingly, the density of tertiary roads exceeded those of primary and secondary road since tertiary roads are intentionally densely allocated on the landscape to permit timber extraction. Namely, mean primary road density in wolf home ranges was 0.15 km/km^2, mean secondary road density was 0.12 km/km^2 and mean tertiary road density was 0.77 km/km^2. Secondary and tertiary road classes assessed cumulatively had a mean density of 0.89 km/km^2.

Ninety percent KDE volume contour estimates of wolf home ranges contained between 2 and 297 km^2 of polygonal water with a mean measure of 59 km^2 or 8.71 % of the area of the home range. In comparison to the percentage of surface area of APP covered by water, three of 28 wolves had a higher percentage of water body area (11.87, 13.11 and 13.46%) within their respective home ranges. Of the 28 home range estimates, the average length of water course was 289.07 km with a minimum of 9.92 km and a maximum of 1241.70 km. Mean density of water courses for wolf home ranges was 0.53 km/km^2.

Spatial Randomization

The results of the randomization procedure conducted using individual wolf home ranges are presented in Figure 30. In the cumulative road coverage (e.g. all roads) the majority of wolves (1 F; 17 E; 10 M) were categorized as equivalent to what you would expect by random placement of their home range within the randomization zone. Likewise, all three classes of roads analyzed independently did not differ from what you would expect by random; in primary, secondary and tertiary roads respectively, 24, 26 and 16 wolves out of 28 did not differ from random in terms of the length of road in the observed and randomized home ranges. Temporally concurrent groupings of wolves in all four calendar years (2003, 2004, 2005, and 2006) overall demonstrated a pattern of road length that matched what would be expected by random placement of the home ranges.

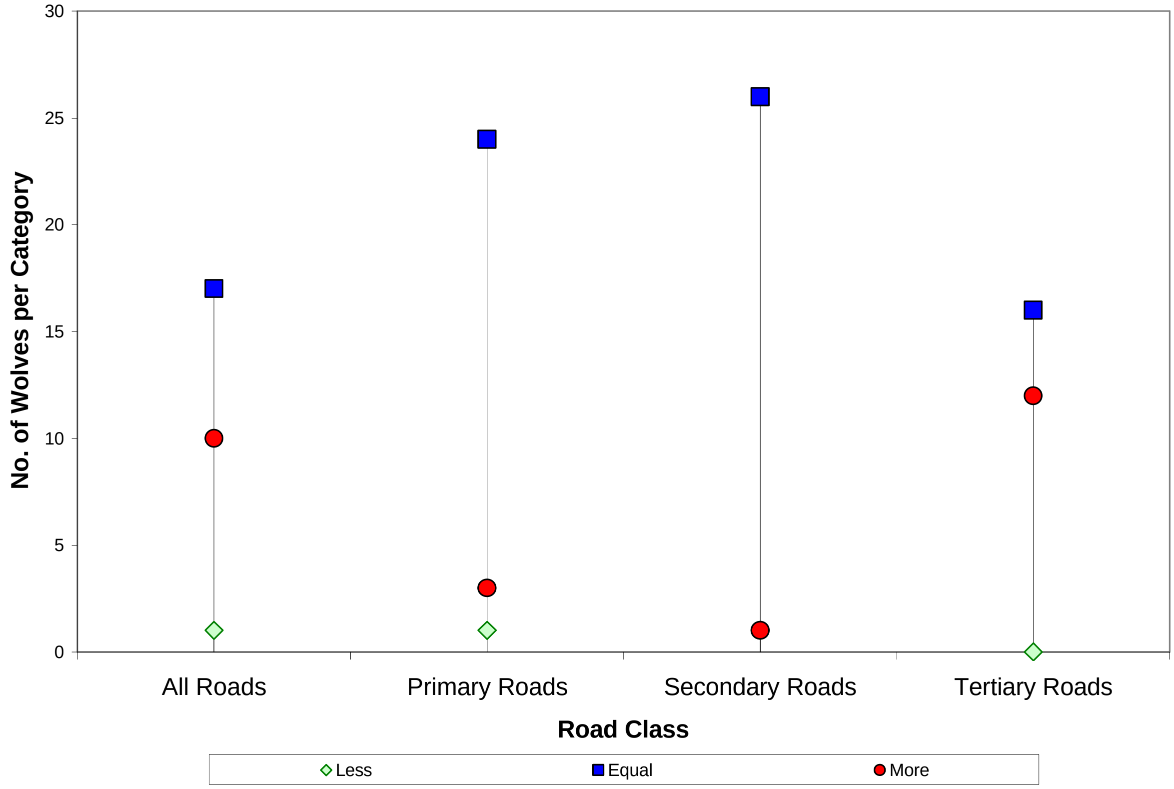

Figure 30. Results generated by the spatial randomization procedure performed on individual wolf home ranges (i.e. each wolf was assessed independent of the remainder in the data set). Results are summarized by road class. The number of wolf home ranges within each assessment category is shown on the y-axis. Wolf home ranges categorized as *fewer* contained less road length in the observed home range than you would expect following spatial randomization across the randomization zone. Wolves categorized as *equal* show no deviation from random in terms of the length of road within their observed home range. Wolves categorized as more contain a greater total road length than you would expect by random chance.

DISCUSSION

Wolves are a very interesting species to study; they display social cooperation within family groups, yet aggressively defend territory against conspecifics (Mech 1970, 1974, Mech 1994, Forbes and Theberge 1996, Ciucci et al. 1997, Cook et al. 1999, Theberge and Theberge 2004). Their movement behaviour is complex and influenced by a myriad of factors including seasonality, prey distribution, territorial defense, competition, and reproduction. It would be optimal to study wolf movement using comprehensive data and complex models that incorporate the many variables which collectively influence the footsteps of a wolf. Herein, I chose to investigate one possible influence on wolf movement behaviour: linear features. More specifically, the bulk of this thesis investigated the role of roads in determining how a wolf moves and where they situate their home ranges.

The results presented above demonstrate several interesting and perhaps surprising patterns. When you stroll down examples of the different road classes within APP, it seems evident that tertiary roads are quiet and narrow components of the landscape, at least from a human perspective. In contrast, primary and secondary roads bear the weight of park vehicles, recreational visitors, logging machinery and road maintenance equipment more frequently than do tertiary roads. Thus, when I framed my questions in terms of road impacts to wolves, I expected tertiary roads to be most attractive and primary roads to be most repulsive.

In comparison to the control study area, APP has an overall lower density of roads and fewer kilometers of primary and secondary roads. Not surprisingly, due to the extraction of timber within APP, tertiary roads are more plentiful there than in the control study area. Whilst this may seem initially concerning, recall that the tertiary roads in APP have access limitations (Ontario Ministry of Natural Resources 1998) and so consequentially may not have all of the inherent negative effects typically associated with roads. Furthermore, the reduced amount of primary and secondary roads in APP relative to the control area likely moderate the overall effects of roads since primary and secondary roads likely have greater negative consequences for wildlife.

Concerns have been raised regarding the long term persistence of wolves in APP (Appendix 1). Road density could play a role in maintaining the integrity of the APP population of this species. Thiel (1985) concluded that wolf persistence in a given area is negatively related to road density; specifically, he felt that there is a threshold at 0.58 km road/km^2 area exists, above which long-term wolf persistence is less likely. Recall that APP currently has a cumulative road density of 0.72 km/km^2. It should be noted, however, that Thiel (1985) did postulate that areas with appropriate levels of access control (i.e. gating) may be able to sustain wolves at densities above the recommended threshold. Importantly, road density and traffic volume do not exist on a one-to-one ratio and so interpretations based solely on density may exclude scenarios where roads are dense, but traffic volume is low. Furthermore, Thiel's work was conducted outside of the spectrum of protected areas and many of the impacts associated with high road density were attributable to human persecution of wolves. Given that APP affords appropriate protection for wolves through legal protection, my results suggest that the observed road density may not be of conservation concern. Evidence to support this idea may be found in the observed densities of roads within wolf home ranges in this study. As previously mentioned, mean road density in the 28 wolf home ranges, when all road classes were assessed cumulatively, was 1.04 km/km^2. In fact, all 28 individual home ranges had road densities which fall above Thiel's threshold. Given that the majority of wolf home ranges in this study are situated in the eastern half of APP, where tertiary road densities in particular are higher than in much of the western portion (see below), I believe that tertiary roads likely contribute most to the overall density of roads in wolf home ranges. There are also other examples where road densities above the recommended threshold (Thiel's; 0.58 km/km^2) for wolf persistence permit sustained wolf presence. Merrill (2000) reports successful breeding of wolves at a density of 1.42 km/km^2 and further recommends a distinction be drawn between road density and traffic intensity. Merrill (2000) conducted their research adjacent to a protected area subjected to a variety of land use practices.

Tertiary roads likely have the lowest consequences for wolves in terms of road mortality relative to other road classes. This does not however imply that they do not contribute to habitat fragmentation. The act of constructing roads, regardless of their category results in habitat dissection and habitat loss. Habitat loss or conversion to another state, should not be under estimated in terms of possible impacts to this study system. Reduced habitat availability, secondary re-growth along roadsides or within cut-blocks (Theberge and Theberge 2004) and avoidance of features (James and Stuart-Smith 2000) could alter several equilibria between predator and prey. In fact, Fahrig (2003) found that habitat loss often has greater consequences to biodiversity than does habitat fragmentation. At the time of analysis, APP has a maximum area of habitat loss due to roads of 52.66 km^2 calculated using length of road and road allowance widths. Assessing the impact of this degree of habitat loss and its associated fragmentation require further study. I suggest that further investigations into the consequences of elevated road densities and the effects of the related habitat fragmentation and loss be conducted.

The cumulative road density depicted in Figure 19 shows that much of the eastern portion of the randomization zone contains relatively high road densities. Additional areas of high road density correspond with the major transportation corridors (Highway 11 and Highway 17) and urban centres (e.g. North Bay, Ontario). APP stands out as an area with relatively low road density in comparison to the entire randomization zone. The "Algonquin Panhandle" (southern projected portion of the park) bears higher road density as do two areas found in the south eastern portion of the park interior and two areas lying on the eastern and western park boundaries. With these results in mind, assessment of the individual road class densities (primary, secondary and tertiary; Figures 20, 21 and 22) helps to clarify the sources of road density in the cumulative road density raster. APP is relatively devoid of primary roads, with two areas that roughly correspond with the large wilderness zones in the park bearing no primary road features at all. Secondary roads follow a similar pattern, however occur in slightly higher density than primary roads. Evaluation of the tertiary road density raster output seems to indicate that much of the cumulative road density in APP is attributable to the tertiary road class. A similar pattern of high road density can be found between the cumulative and tertiary rasters. APP likely serves as an important refuge for wolves given that the maximum density of roads (cumulative road density) within APP is 1.69 km/km^2 relative to the cumulative density outside the park which peaks at 2.99 km/km^2.

The line density rasters presented above provide useful information about areas of the park that are impacted more heavily by road construction consequences. Specifically, greatest habitat loss attributable to road construction should correspond with the areas of peak road density. Interestingly, one high road density area seems to correspond with a documented migratory corridor used by wolves moving from APP to an adjacent deer yard. Cook *et al.* (1999) documented migration of wolf packs during winter from the southeastern corner of APP towards the Round Lake area deer yard. The correspondence between this observed migratory behaviour and the elevated road density suggest that the roads in this area within APP are likely not a barrier to movement by wolves. In context to the results from this study, roads that lie in juxtaposition to such deer yarding areas outside the perimeter of APP may be serving as travel conduits that facilitate wolf movement. Obviously, the availability of prey at relatively high densities likely attracts wolves to the area of the yard, the linear features however may be facilitating their movements to and from such areas. Further research into the energetic considerations of travel by wolves on linear features, such as that conducted by Musiani *et al.* (1998), who found that wolves could attain higher rates of travel on forest roads and trails, may help to clarify the importance of linear features to both wolf and prey management and conservation.

I expected trails to exert a significant repulsive effect upon wolves given the findings of Papouchis *et al.* (2001). The results presented above suggest that trails do not in fact deter wolf use as evidenced by the fact that, in most distance classes, the majority of wolves either have an equivalent or greater number of data points than you would expect by random chance. It is possible that deterrent effects observed elsewhere (Papouchis *et al.* 2001) may only manifest during periods of high human activity as I did not correct for seasonal variation in human activity on trails in this analysis. It is also possible that wolves traveled on or close to trails during the night and thus were not affected by human presence during the day. Ballard *et al.* (1991) found that wolf activity peaked at night during summer, which would correspond to peak levels of daytime human activity in the case of APP. Furthermore, the study area described in Papouchis *et al.* (2001) may not be as densely vegetated as that of APP. Thus wolves may be less affected by human presence on trails due to denser vegetation cover and consequentially reduced line of sight distances.

As shown by assessment of the hydrological features found in the total area, APP has a relatively higher surface area of waterbodies than what is generally found within the randomization zone. This result is not surprising given that the abundance of water was one of the factors responsible for the establishment of APP in 1893. Interestingly, APP has an higher percentage area coverage of polygonal water than most of the wolf home ranges contained within. As reported in the results above, several temporal windows were applied to assess Euclidean distances between linear features and wolf locations. None of the constructed windows (e.g. ice presence, seasons) indicated a clear change in behaviour in relation to linear features. This was somewhat surprising given that wolves are often observed traversing frozen lakes during winter and ungulate kills are often on or close to such features. I maintain that the degree of water surface area may play a role in the selection of home range location and size. The data analyzed here do not appear to support this belief and such selection may be outweighed by prey distribution, terrestrial habitat type and social factors amongst wolves. With that said, further and more sophisticated temporal assessments are warranted to investigate this issue.

Similarly, APP also scores highest in terms of density of water courses in comparison to the control study area and the total area. Once again, I assumed that water course availability might play a role in home range selection given that such natural corridors may naturally funnel movement by wolves. The data presented here suggest that wolves do not tend to select regions with higher water course density given that the mean density of water courses within their home ranges falls below the APP average value. With that said, the range of values for water course density within wolf home ranges is quite variable, suggesting that some wolves may take advantage of such features when they are present or that stream characteristics are variable in relation to the degree of friction they pose to animal movement. Furthermore, it is possible that inherited home ranges or learned behaviour may be variable in regard to the importance of water courses and thus affect expression of selection for such features.

When I began to study the telemetry data set, I was convinced that the presence of ice may affect the movement behaviour of wolves in relation to linear features. This conviction was based on personal observation as well as references from the literature (Pimlott et al. 1969, Kunkel and Pletscher 2001, Kuzyk et al. 2004). I predicted that wolf proximity to linear features would decrease when ice was present since frozen lakes would facilitate travel (Musiani *et al.* 1998) without the possible negative effects of linear features. Furthermore, in the winter period (herein approximated by the ice presence period) deciduous undergrowth would be less inhibitive to travel due to leaf-fall and thus decrease the benefit of traveling on linear features. The results of my analyses do not uphold these predictions since the distance between wolf locations and linear features did not differ when ice was present or absent. Possible explanations for this result are numerous. Perhaps most importantly, I did not explicitly evaluate if wolf locations demonstrated any changes in proximity relative to water bodies alone. Rather, I used proximity to linear features to test for a locational shift towards water bodies and away from linear features. I further suspect that wolf movement behaviour in winter is strongly correlated with ungulate prey distribution (Cook *et al.* 1999) and this may be a superseding factor relative to the benefit of travel on frozen lakes and rivers.

Point Based Movement Analysis

Hypothesis 1 is partially supported by the results of the point based movement analyses. To begin, the vector based assessment demonstrated that the distribution of observed data differs significantly ($p < 0.001$; K-S Bootstrap) from a random distribution of points constrained within the home range. Whilst these results are meaningful, and served as a step towards further study with the raster derived measures, they simply identify that the pattern of proximity, as measured through vector Euclidean distances, was not due to random chance. The intervals generated by the minimum and maximum NEAR distances suggest that the observed data set is closer to Linear features than the randomly generated point locations, this could be attributable to differences in the variance of distances between the two distributions. Regardless, it offers partial support for prediction 1.1.

Subsequent analyses using the raster derived distance measures were more robust in my opinion than the vector derived measures since they rely on many iterations of a matching random data set and allow more detailed interpretation. The results of the raster procedure show that wolves behave in a manner that is not supported by random movement, at least in certain distance classes.

Very interesting results were obtained relative to different classes of linear features. To begin with, prediction 1.2 was not upheld. When all roads were analyzed together, the first distance class showed a strong response in terms of preference in some individuals. When individual classes of roads were assessed, I attributed the observed response in all roads to the pattern of response seen in primary roads alone. This was contrary to my expectations since I expected the short temporal period of human use, low traffic volume and narrow width to make tertiary roads far more attractive than primary roads. In addition, I expected the negative aspects of larger Linear features to exert a greater deterrent effect that would lead to greater avoidance of such feature classes. On the contrary, primary roads did not seem to deter wolves at close proximities. In the first five distance classes (i.e. within 50 m of a road) the majority of individuals either had a greater or equivalent number of locations to what you would expect at random. I was initially buoyed by the finding that wolves in the first distance class had more points than you would expect, I interpret these results to suggest that some wolves do in fact show a preference for primary roads, demonstrated by a non-random pattern of use in the first distance class. This observation may be supported by the findings of Barja *et al.* (2004) who found that deposition of wolf scats, presumably for the purpose of territory marking, was more common at the intersections of larger road features.

If some individuals do in fact spend more time within 10 meters of a road, it is likely that they are indeed on the road or in the immediate vicinity of the shoulder. Perhaps more important however is the lack of repulsion in the five most proximate distance classes, suggesting that primary roads in APP do not inhibit wolf use of an area. When I assessed the results obtained from tertiary road analysis, which I expected to show the strongest attraction, they seem somewhat counter-intuitive. Whilst tertiary roads did not repel wolves in the first

5 distance classes, they did not attract them either since the majority of individuals did not differ from random in terms of the number of locations.

In Prediction 1.2, I expected tertiary roads to be strongly selected for, given their attributes. The results from the point based movement analyses do not support this prediction. There are two possible explanations for this result: a) all road categories in APP are below an unknown threshold which causes repulsion and b) the physical nature of the road segment and not the classification dictates the observed response. To clarify, it is possible that all of the roads in APP are *suitable* from the perspective of a wolf given the seasonal nature of use and the restrictions on human access to the road network. These results concur with those of Thurber *et al.* (1994) who found that gated roads were used by wolves. Furthermore, Thurber *et al*. (1994) postulated that the degree of human activity and not the nature of the linear feature likely dictated wolf response. Thus primary roads may not possess some of the negative aspects that I expected given the degree of access control in APP. As well, the displacement distance afforded by the road may be more important in determining if wolves chose to travel on it than its classification. Tertiary roads are short and narrow by nature to permit timber extraction. Primary and secondary roads however tend to connect disparate sections of the park since they are relatively long and straight. From a wolf's perspective, it may be more beneficial to travel along portions of primary roads, allowing them to traverse a greater portion of their home range in a shorter period of time than what could be attained on tertiary roads. Other road classes and combinations of them (i.e. secondary and tertiary) did not demonstrate strong selection preferences in the measured number of locations per distance class.

Why is travel on linear features important from an ecological perspective? I suspect that the key to this question lies with energetic considerations of travel in temperate forests.

Furthermore, there may be consequences for resource partitioning between individuals and amongst packs of wolves. If an individual is able to traverse their home range on a linear feature using less energy than what would be required if traveling cross country through the forest, there would likely be energetic consequences. Expending less energy for travel may affect an individual's condition during periods when resources are limited. Furthermore, energetic savings may allow an individual to become a more effective predator when chasing or capturing a prey item. In relation to individuals who do not express a propensity to travel on linear features or inhabit an area without linear features, wolves that do exploit linear features could be more effective predators.

Musiani *et al.* (1998) observed that wolves traveling on forestry roads and trails moved faster than when traveling through forested areas. The ability to traverse ones home range likely has consequences for conspecific interactions related to territorial boundaries and competition. It is also possible that an increased frequency of patrol around the entire spatial area of a home range would affect predatory success thjrough increased prey encounters. Theberge & Theberge (2004) report that wolves occupying younger areas (tree age between 20 and 24.9 years) of APP have smaller home ranges. Since the dominant cause of forest renewal in APP is timber extraction, I postulate that these younger areas likely have more linear features than older areas. If wolves can indeed traverse areas faster using linear features, they may require a smaller territorial area. Furthermore, areas that are more recently logged likely have a greater amount of re-growth and can therefore support more ungulate prey.

Why are linear features important in a conservation framework for Eastern Wolves? I propose that use of linear features by wolves may be changing the point of equilibrium between wolves and their prey species in terms of their respective abundance. James &

Stuart-Smith (2000), who conducted a similar study to the one presented here, also suggested possible increases in predation pressure on their prey if in fact wolves do travel on linear features. If wolves are more effective predators because of linear features then, it is possible that they are exerting a top down effect which lowers total prey abundance relative to what could be sustained by the habitat. On the contrary, it may also be possible that prey species are also gaining benefit by feeding along or traveling on linear features. Recently, steps were initiated to review the ecological footprint associated with APP logging. Amongst many recommendations, the document (Appendix 2) recommends a reduction in the total area where logging is permissible along with reductions in the extent and nature of the road network through decommissioning. It is unlikely that decommissioning of roads will involve complete removal of the features, rather access will be further limited through the removal of water crossings and addition of gates. Thus, the linear connectivity of roads will persist and traffic related negative effects will be removed allowing wolves to continue to travel along such features.

Home Range Analysis

The randomization of wolf home ranges sought to evaluate if linear features were exerting any kind of effect on the spatial selection of home range locations. The selection, maintenance and orientation of home ranges is likely the result of a complex social and ecological process, guided by many intrinsic and extrinsic factors. Spatial randomization of individual wolf home ranges artificially released them from the restrictive effects of social and ecological processes and permitted them to orient themselves anywhere within the randomization zone. By doing so, I hoped to assess whether the nature of linear features within the observed home ranges were unique in terms of their compositions or magnitude in relation to what was generally available on the landscape. The results suggested several outcomes. Firstly, since there appears to be no difference between the observed and random home ranges in terms of quantity or composition of linear features, it is likely that these features do not influence home range selection. Either that or perhaps other forces (e.g. prey distribution or social dominance amongst wolves) over-ride the effects of good versus bad configurations of linear features within a home range. Secondly, it could be that the entire randomization zone is more or less equally covered by linear features, meaning that wolves do not have a choice in terms of the composition of linear features in their home range. Visual interpretation of linear features and line density rasters for the randomization zone suggested that although density varies across the zone, there are relatively few locations that are devoid of linear features. Consequently, this methodology may be more applicable where a road-less area abuts against an area with roads. Given the rather unique nature of APP (i.e. logging within the bounds of the park), other protected areas may offer a more suitable study area for investigations of this nature. In addition, measures of road length or density may not be accurate measures of the true impacts from linear features given that road access is limited within APP but not in the remainder of the randomization zone. Thus, the results described above may indicate that the condition of linear features in much of the randomization zone do not preclude wolf home ranges from being found there, rather the associated human activity (vehicular traffic and persecution) dictates whether wolves can survive in those areas.

Model Species Considerations

Another possible factor to consider when applying home range randomization methodology in Ontario is the demonstrated hybridization between Coyotes (*Canis latrans*) and Eastern Wolves (*Canis lycaon*) (Kyle *et al.* 2006). It is likely that *C. latrans* is more tolerant of linear features (or more tolerant of human activity on said features), thus in areas outside APP but within the randomization zone, the expression of tolerance for linear features may vary. In addition, we should consider the long-lived nature of wolves and high degree of parental input. It may be possible that expression of preference or avoidance of areas with linear features may be a learned behaviour. Parents of offspring who have learned to derive benefit from certain configurations of linear features will likely intentionally or un-intentionally pass such knowledge on to their offspring who may then express it. Alternatively, those who are not exposed to linear feature use by their parents may inherently avoid linear features. Furthermore, wolf capture locations were generally close to access roads (Patterson pers. Comm.2005) and this may be a potential source for bias towards animals that tend to travel close to roads in the sample data.

Spatial Randomization

Given the advancements of computer technology, employing randomization procedures, such as those presented here, may hold tremendous value for other ecological studies. The nature of ecological data often makes analyses using more traditional parametric-based statistical tests difficult, or can result in lower statistical power (Fortin 2002). Thus the use of generated null distributions and the described confidence interval procedure may allow studies, particularly those with a spatial component, to assess the significance of their results more effectively. By using scripting languages such as Python (Hetland 2005) many iterations of spatial analysis procedures may be computed with relative ease. Therefore, the potential for this type of analyses to be further developed and applied to other study systems is high. In the context of this type of ecological study, being able to randomize matching data sets over spatial extents that correspond to the observed data set permits analyses that are highly specific to the investigation in question. Overall, I feel coupling of spatial analyses and randomization procedures hold significant promise for ecology.

Future Research

Whilst I feel that significant value can be found in this body of research, there is obviously potential for further work on the focal research questions. Specifically, the investigation as presented here examines wolf behaviour independently from other species. Incorporating the spatial arrangement and movement behaviour of principle prey species for wolves, and perhaps competitors, will likely clarify our overall understanding of the role of linear features in animal movement. With this said, the OMNR/Strategic NSERC study is presently tracking the whereabouts of both Moose (*Alces alces*) and Black Bears (*Ursus americanus*) concurrent to acquiring further wolf telemetry data across both APP and WMU 49. It is possible that prey movement behaviour may be over-riding the effects of linear features at all distance classes, however, given the observed response data, I suspect that prey may exert significant effects on wolf behaviour.

There are also other means to study animal movement, namely through the establishment of movement paths that link successive telemetry locations. Given the high quality of this data set, and the short interval between successive locations, there is tremendous potential to investigate how estimates of the paths taken by an animal correspond with linear features. Determining whether wolves travel perpendicularly or parallel to linear features may shed more light on the importance of such features in the overall movement behaviour of wolves.

There is also tremendous potential to further investigate changes in wolf behaviour in different temporal periods. Changes in wolf behaviour between day and night; winter and summer; and breeding and non-breeding periods may help to parse out the role of linear features in determining the overall movement behaviour of wolves. The high quality of the wolf data set in terms of positional accuracy and frequency of fix intervals will permit more sophisticated assessment of habitat selection by wolves in context to linear features. Thus, analyses incorporating sequentially connected points or couplets of positions could be used to compare wolf travel trajectories with linear features.

Cushman *et al.* (2005) demonstrated that spatial autocorrelation signals from wildlife telemetry data could be used to decipher ecologically important periods or resources. I maintain that the presence of ice likely plays a role in the movement behaviour of wolves and their prey. Assessing autocorrelation signals when solid ice is present versus absent may be one means of studying this idea given the complexity of possible factors dictating the behaviour of individuals.

CONCLUSION

Recall that linear features can exert two ecological functions. They may act as '*Picket Fences*' or alternatively as '*Garden Paths*'. This investigation tested which of these two functions is at play in the APP ecosystem. The consequences of these two functions are varied and relate to wolf conservation, protected areas management, resource exploitation and scientific knowledge. Specifically, research on the impacts of linear features helps advance the discipline of road ecology, lately generalized to traffic ecology, and more importantly aides in conservation of wolf populations.

The APP study system is well suited towards an investigation of this nature. The gradients of linear features and temporal variation in human activity permit useful comparisons using APP, WMU 49 and the randomization zone. To address whether linear features were promoting or inhibiting wolf movement I devised a series of assessment methods. Whilst these methods have inherent strengths, weaknesses and limits to the extrapolation of their findings, they nonetheless help to clarify our understanding of the interaction between wolves and linear features.

Not surprisingly, APP has fewer kilometers of primary and secondary roads than the adjacent control study area. Furthermore, as expected, there are more tertiary roads in APP than in the control area. Whilst the combined density of roads in APP exceeds a published threshold for wolf population stability, it is likely that other attributes of APP, specifically the intensity of human use and the degree of legal protection for wolves, alter the level of this threshold. Furthermore, several published exceptions to the threshold have been reported. Regardless, conservation managers may wish to further evaluate the issue of road density in the context of wolf conservation and timber harvest infrastructure. Addressing regions of the park where road density peaks and maintaining areas with lower road density should be considered when planning future development and assessing wolf conservation.

Habitat loss due to road construction is estimated above by applying reported road allowance widths to the measured lengths of roads within APP. At present, relatively low percentages of the total area of APP are under conversion to roads; the ecological consequences of such conversion may not relate to surface area on a one-to-one ratio however, so these low percentages should not be prematurely dismissed. Despite evidence from elsewhere to suggest that trails influence wildlife movements, no evidence to support this could be found in the data set. It is possible that the temporal nature of human and wolf behaviour in APP modify the expected response. From a conservation standpoint, ensuring a temporal separation between human and wolf use may be important, this of course assumes that wolves and humans partition time (e.g. day versus night) when using trails in the same periods.

Somewhat surprisingly, wolves do not seem to be seeking out areas with greater surface areas of water. In retrospect, this probably makes sense, since water or frozen lakes may only become important features once a prey chase sequence is initiated. Habitat quality or prey distribution likely plays an over-riding role in home range selection rather than water surface area. Similarly, despite predictions to the contrary, ice presence does not appear to be affecting wolf movement behaviour. Although the assessment procedure used here may not be the most appropriate and more sophisticated measures of proximity to water, frozen or otherwise, may be warranted.

The point based assessment of wolf proximity to linear features returned interesting findings. Perhaps most importantly, my results demonstrate that in general wolves in APP are not deterred by roads. The common response of wolf points occurring in proximate distance classes at an equivalent frequency to randomly generated points suggests that roads in APP are not significant barriers to wolves. Moreover, for some individuals, there is a tendency to occur in close distance classes with greater frequency than due to random chance. Specifically, this result was most prevalent when all road classes and primary road classes were assessed respectively. It is thus likely that roads in APP all fall below a threshold that would prevent wolf use given the tendency for some individuals in the population to exploit specifically primary roads which are expected to carry the greatest net detriment to wolves.

Home range randomization similarly suggests that linear features are not a prohibitive component of the APP landscape, neither are they specifically selected for, given that the majority of individuals do not select areas of the landscape that have unique densities of roads (e.g. high or low). Perhaps road density across the region is relatively similar and thus the home range randomization procedure I implemented is not sensitive to subtle wolf selection.

Overall, there is clearly much more work to be done to fully address the question of whether or not wolves exploit linear features. My results do however lead me to favour the '*Garden Path*' model of interaction between wolves and the landscape. The apparent lack of repulsive effects for many of the individuals suggests that linear features in this study system do not deter movement as observed in other systems. In addition, the lack of specific selection for areas of low road density in relation to home range selection once again suggests that roads are not prohibitive to wolf movement here. It is possible that the unique nature of APP, in terms of human activity and the legal protection of wolves, disassociates the negative consequences of traffic intensity from road density. Thus wolves are able to thrive in this area with elevated road density.

THESIS CONCLUSION

Wolves are inherently vulnerable to impacts from linear features given the low population densities and relatively large home ranges commonly expressed by the species (Callaghan and Paquet 1999). Wolves also provide ecological services as top-predators and hold inherent value for large portions of the human population (Fritts and Carbyn 1995). Thus, adequate comprehension of the role of linear features may be crucial to the success of conservation initiatives. This investigation establishes several interesting findings in the context of the Algonquin Provincial Park ecosystem.

Importantly, wolf locations were not distributed randomly with respect to linear features (also see James and Stuart-Smith 2000). Thus, it is likely that these features are exerting some kind of effect on the movement of wolves. Given the variable nature of animal behaviour, it is likely that previous exposure, parental teachings and the general availability of the linear features in an individual's home range likely affect the observed response. Regardless, in support of my predictions, several individuals in the data set demonstrated a preference for proximate distance classes or demonstrated no net repulsion from said features. Somewhat surprisingly, primary roads did not deter wolves as I expected and actually wolves showed a relatively strong positive response in relation to other categories of linear features. Contrary to my predictions, tertiary roads did not exert a strong attractive effect on wolf locations. I hypothesize that these results occurred due to the relatively poor net displacement potential (i.e. ability to translocate from one area to a distant area with ease) afforded by tertiary roads and consequently, wolves chose to travel on other classes of roads that permitted gross displacement more easily. Regardless of response (e.g. attraction vs. repulsion), roads are likely a contributing factor to the spatial arrangement of wolves across the landscape (Thurber et al. 1994, James and Stuart-Smith 2000).

Trails did not seem to affect wolf behaviour as assessed through point pattern analyses. It is likely that temporal or spatial separation of wolves and humans on trails resulted in the lack of response seen in other studies.

The randomization procedures used here to examine wolves hold promise for other investigations of wolf behaviour and that of other species as well. Restricted randomization of species observations within the extent of home range estimates permits the investigator to test for non-random patterns over an explicit spatial area. The expanding computational powers of computer hardware and software will likely permit further refinements to this method. Testing predictions relative to random data sets comes with freedom to adapt procedures to the specific needs of the investigation in question. This is not intended to imply the lack of statistical constraints, further work to define the limitations of these types of methods will be required. Coupling randomization with the powers of Geographical

Information Systems will help ecologists to continue to incorporate space and time in their research. Randomization of home range polygons allows the investigator to remove the observed data from the context in which it was situated and permits comparisons with other data or in other spatial configurations. The ability to constrain the randomization of spatial data within the confines of other areas while specifying the number of iterations holds tremendous promise for more sophisticated spatial procedures. The potential exists to incorporate several factors which would constrain the randomization procedure, for instance on the basis of prey distribution or land cover type.

The confidence interval methods used herein and others (Pearl *et al.* 2007) hold promise for evaluating the results of spatial randomization procedures. The ability to compare observed data with constructed null distributions derived using randomly generated data permits analyses when little is known about the underlying statistical distribution of the data. Furthermore, current computing advancements will permit ecologists to advance the sophistication of these procedures and thus generate more useful findings.

Inherent to the study site are many attributes that proved valuable to this investigation. The ability to make comparisons between protected and private lands, typical versus atypical traffic volumes, large versus smaller roads and variable intensities of human activity in general along with the high quality data collected on wolf movements suggest further investigation into the realm of linear feature to wolf interaction is warranted in APP. Contained herein are several important findings related to the density and configuration of roads within APP that will likely guide management operations. Furthermore, the findings that primary roads appear to be most closely related to observed wolf point patterns in a large portion of the sample size suggest that management actions should be cognizant of the configuration of these features in particular. Tertiary road densities may be affecting the overall habitat quantity or quality available to wolves.

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Appendix 1

Ontario Environmental Registry

Amend regulations under the Fish and Wildlife Conservation Act, 1997 to enhance wolf conservation in specific Wildlife Management Units (WMUs) by creating: wolf/coyote seasons, the requirement for a wolf or coyote game seal, and annual mandatory reporting of wolf or coyote hunting activities.

EBR Registry Number: RB04E6012

Ministry of Natural Resources

Date Proposal loaded to the Registry: November 25, 2004

Wildlife Section
MNR Fish and Wildlife Branch
5th Floor, North Tower, 300 Water Street
Peterborough Ontario
K9J 8M5
Phone: (705) 755-1940
Fax: (705) 755-1900

MNR has amended regulations to require a wolf/coyote game seal and annual mandatory reporting. The decision to proceed with the proposal to establish a closed wolf/coyote hunting and trapping season was originally posted on March 10, 2005 and the closed season took effect on April 1, 2005.

MNR has proceeded with the amendment of O. Reg. 670/98 (Open Seasons) to establish a closed hunting and trapping season in 2005 from April 1 to September 14 for wolves and coyotes in WMUs 1A, 1B, 1C, 1D, 2, 3, 4, 5, 6, 7A, 7B, 8, 9A, 9B, 10, 11A, 11B, 12A, 12B, 13, 14, 15A, 15B 16A, 16B, 16C, 17, 18B, 18A, 19, 20, 21A, 21B, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 46, 47, 48, 49, 50, 53A, 53B, 54, 55A, 55B, 56, 57 and 58. This area can generally be described as central and northern Ontario.

The closed season will protect wolf pups and adults during the pup rearing season through to the beginning of the pups' fall dispersal period. The closed season took effect on April 1, 2005, and will extend from April 1 to September 14 each year. In the WMUs not listed in this paragraph (parts of Southern and Central Ontario) populated mainly by coyotes, the season will remain open all year except in the townships located in and around Algonquin Provincial Park in WMUs 48, 50, 53A, 54, 55, 56, 57 and 58. In those townships the season remains closed all year. A list of the townships is provided in the 2005 Hunting Regulations Summary.

The closed season applies to resident hunters and trappers, and to non-resident hunters. The resulting open season allows for the opening of wolf and coyote hunting and trapping at the same time that a number of small game seasons are opening in September, while also allowing for some late winter hunting/trapping.

The regulation amendment does not affect the right of a landowner to defend his or her property from wolves or coyotes, or to use an agent to do so, during the closed hunting and trapping season.

The proposal was implemented by an amendment to O. Reg. 670/98 (Open Seasons - Wildlife) by O. Reg. 62/05. This regulation was filed with the Registrar of Regulations on February 28, 2005 and was published in the March 19, 2005, edition of the Ontario Gazette.

MNR has also amended O. Reg. 665/98 (Hunting) to require game seals for wolf/coyote hunters. Holders of resident and non-resident small game hunting licences in the WMUs where the April 1 to September 14 closed season applies are now required to possess a wolf/coyote game seal in addition to their licences to enable them to hunt wolves and coyotes. Hunters are required to attach a seal to each wolf or coyote taken in the manner prescribed on the seal, and are limited to a maximum of 2 seals per year. The fee for the wolf/coyote game seal has been established at $10.00 for residents and $250.00 for non-residents.

MNR has also amended O. Reg. 665/98 (Hunting) to require hunters of wolves and coyotes in the WMUs where the April 1 to September 14 closed season applies to report their annual wolf/coyote hunting activity and harvest to MNR by January 15 following the year of the hunt. Landowners, and their agents, who destroy a wolf or coyote in defence of property such as livestock under Section 31 of the Act are also required to report their kills to MNR.

The above regulatory measures provide a mechanism for the ministry to collect the vital information on wolf harvest that will enable the ministry to make future conservation decisions. The regulatory measures take effect on September 15, 2005.

The proposals were implemented by an amendment to O. Reg. 665/98 (Hunting) by O. Reg. 276/05. This regulation was filed with the Registrar of Regulations on June 10, 2005 and was published in the June 25, 2005, edition of the Ontario Gazette.

Comments Received on the Proposal: 871

Public Consultation on the proposal for this decision was provided for 40 Days, from November 25, 2004 to January 04, 2005.

As a result of public consultation on the proposal, the Ministry received a total of 871 comments: 871 comments were received in writing and 0 were received online.

Additionally, a copy of all comments is available for public viewing by contacting the Contact person listed in this notice.

Effect(s) of Consultation on this Decision:

871 responses were received during the proposal notice period, with many respondents providing comments on several of the proposals in the posting.

Overall the comments offered support for the proposed closed season as an initial step in improving wolf conservation; however, specific concerns were expressed regarding the proposed length and geography of the closed season. A number of comments were made about expanding the area affected, making the season shorter, permanent closure of parks and protected areas, excluding agricultural areas and excluding coyotes.

In response to the comments received on the geographical area of the closed season, the ministry excluded WMUs 43A, 43B, 44 and 45 from the area where the closed season applies.

Overall, the comments received on the seal requirement, mandatory reporting for hunters and landowners were in support of the proposal. Specific comments/concerns received included:

- no proven need for seals;

- the administrative costs of seals, fees for the seals;

- having a limit on the seals;

- possible reduced ability of livestock owners to use hunters as agents in protection of property;

- reporting should be voluntary or not required in agricultural areas; and

- cost of implementation.

These regulatory provisions do not affect landowners' rights or their agents to protect their property such as livestock by killing wolves or coyotes under Section 31 of the Fish and Wildlife Conservation Act.

MNR has taken into consideration issues such as livestock predation, and is not considering any changes to the provisions under the Act that will affect the ability of landowners to protect their property.

Overall the comments expressed support for inclusion of coyotes; however, specific concerns were also expressed: coyotes have no need of protection from hunting and trapping; hunters and trappers can differentiate coyotes from wolves in the wild; and the reduction in coyote harvest opportunities may lead to increased populations and increased predation on livestock and wild prey.

Appendix 2

RECOMMENDATIONS OF THE ONTARIO PARKS BOARD LIGHTENING THE ECOLOGICAL FOOTPRINT OF LOGGING IN ALGONQUIN PROVINCIAL PARK

Executive Summary

The Minister of Natural Resources (the Minister) asked the Ontario Parks Board of Directors (the Board) to provide advice on how to lighten the ecological footprint of logging in Algonquin Provincial Park (Algonquin) in April 2005. The Board accepted the assignment and subsequently gathered input, advice and technical support from the Ministry of Natural Resources (MNR) and the Algonquin Forestry Authority (AF). The Board prepared and presented to the Minister in January 2006 an initial concept for lightening the footprint, which called for 128,000 hectares to be added to protection zones. Subsequently, the Board considered alternative concepts based on input received input from MNR and the AFA.

The Board has developed three recommendations for the Minister:

1. Protection zones should be expanded by 241,032 hectares to include a total of 409,482 hectares or 54 % of the park.

2. The Ministry and AFA should develop an action plan with targets to reduce the impacts of logging operations considering the 7 strategies outlined in Table 4, including a review of roads standards, aggregate use, size of pits, and use of temporary bridges.

3. The Ministry should partner with the AFA in a pilot project to test the effectiveness of more detailed forest resource inventory and a spatial computer modeling to enhance the accuracy of planning and better integrate the protection and harvesting objectives where logging continues.

These zoning proposals will provide substantial benefits including:

• Enhanced protection of 214 self-sustaining brook trout lakes and associated nursery stream habitat, 1,374 campsites, 1,481 km of canoe routes and 463 portages, old growth forest stands and representative ecosystems;

• Protected zones would increase from 168,450 hectares constituting 22% of the park to 409,482 hectares constituting 54% of the park;

• The recreation/utilization zone where logging is potentially allowed is reduced from 594,860 hectares constituting 78% of the park reduced to 353,828 hectares constituting 46% of the park.

In implementing the expanded protection zones in accordance with Recommendation 1, and focusing the areas where logging continues, the Board recommends that:

1. The Minister directs MNR/AFA to initiate appropriate consultation with potentially affected aboriginal peoples, and with the public through the park planning and forest planning process;

2. Forest management should continue according to the existing Algonquin Forest Management Plan until its normal date of 2010, but where harvest areas identified by the plan overlap with the recommended protected zones, and it is necessary[1] to harvest those areas to meet wood supply commitments, particular care should be taken to minimize impacts, such as use of single tree selection harvest or shelter wood harvesting that retains most forest cover;

3. While consultation is underway, the AFA should use the new protected zoning recommended by the Board as a basis for forest management planning for periods beyond 2010, subject to modifications that may arise from the consultation and planning process;

4. Since practical road access to the remaining wood supply in the managed forest is important, zoning of new protected areas and road strategies should provide for practical road access to future harvest areas;

5. The recreation/utilization zone should be mapped as to the areas where logging may continue and areas of the recreation-utilization zone that are not part of the managed forest – water bodies, wetlands, rock barrens and Area of Concern (AOC) Reserves – should be incorporated into protection zones;

The Board believes that Algonquin is an essential part of Ontario's heritage, and will prove of even greater value and importance in the future. Consequently, the Board reiterates its support for a strategic review of the future of this provincial treasure.

This review would include the park's role in the protected areas network, goals and objectives, how the park is managed, governance and its legislative framework. In the interim, the Board believes that implementation of these recommendations will substantially lighten the impact of logging on Algonquin, increase ecological representation, enhance the wilderness values and experience, and respond to initial concerns about short term wood supply and gaps in ecological representation within the protected zones of Algonquin.

Necessity should be documented and determined through an MNR process that requires consultation with the Algonquin Park Superintendent and public notice.

Background

The Board of Directors provided the Minister of Natural Resources with advice about proposed parks and protected areas legislation on February 11, 2005. The Board's advice addressed 8 legislative proposals for new legislation that the Ministry of Natural Resources had used in the fall of 2004 as a basis for public consultation. One of the proposals was that industrial uses, including commercial logging, should be prohibited in provincial parks and conservation reserves, with the exception of the recreation/utilization zone of Algonquin, where commercial logging could continue. The Board endorsed this legislative proposal with some reservations. With respect to the future of Algonquin the Board's recommendation was that:

> *The Minister should commission an independent review of Algonquin Provincial Park including the park's role in the protected areas network, the management and goals of the park, and the park's legislative and governance framework. The Board recommends this review be initiated within one year in light of current pressures on the park.*

On April 26, 2005 the Minister met with the Board's Chair to discuss future tasks for the Board. The highest priority task identified was for the Board to provide advice about how to lighten the ecological footprint of logging in Algonquin Provincial Park. In September 2005 the Board met in Algonquin to learn about logging in the park. Presentations were provided by representatives of MNR and the AFA, the Crown agency that manages logging in the park under the terms of the Crown Forest Sustainability Act. The Board was also provided with a tour of forest management operations. At this meeting the Board established a sub-committee to work on the task.

This subcommittee included:

- Ric Symmes (Chair)
- Bill Calvert
- Jennifer East
- Stewart Elgie
- David Earthy
- Gerry Killan

The sub-committee reviewed information provided by MNR and the AFA. Based on this review the Board endorsed a provisional concept for lightening the footprint that would see the area available for logging – the park's recreational/utilization zone – reduced from about 78% of the park to about 50% without reducing wood supply significantly. The Board's view that this was possible was based primarily on the pattern of average harvest levels well short of the allowable cut, and actual harvested areas well below the planned harvest area each year. At the Board's request MNR prepared a map of the park that identified proposed new "protection" zones totaling about 128,000 hectares where logging would not occur. The Board's concept for more protection zones focused on internationally significant brook trout lakes, establishment of larger core wilderness areas and enhancing the wilderness character of canoe routes. The Board also identified in a preliminary way some measures that would reduce the impacts of logging where it did occur.

On October 25, 2005 the proposed parks and protected areas legislation – *Bill 11: The Provincial Parks and Conservation Reserves Act* – was introduced in the Ontario Legislature for First Reading. When introducing the Bill the Minister stated that the Board was going to provide advice about how to lighten the footprint of logging in Algonquin. On January 11, 2006 the Board's Chair and other members met with the Minister and MNR's Deputy Minister. The Board's provisional concept for lightening the footprint was presented. At this meeting the Minister expressed interest in the provisional concept and requested that the Board develop the concept more fully. It was agreed that further development should include an analysis wood supply impacts and discussions with MNR and the AFA about how to mitigate any potential impacts on wood supply.

Consequently, the Board's sub-committee had three meetings with MNR and AFA representatives: an initial meeting in May, a two-day workshop in June and a follow-up workshop in July. In developing Preliminary Proposals the Board used an iterative approach. MNR provided wood supply, ecological and recreational assessments of the Board's provisional zoning concept (the "128,000 hectare" concept presented the Minister in January). Subsequently the Board revised its provisional zoning concept in response to MNR and AFA input. The extent and location of proposed protection zones was reduced and revised significantly, with the intention of minimizing impacts on wood supply commitments and optimizing ecological benefits. MNR provided assessments of this revised zoning concept. The Board commissioned an independent qualified consultant to review the MNR wood supply analysis.

The Preliminary Proposals were presented to the Minister on October 27, 2006. The Minister asked the Board to work with MNR and the AFA to develop final recommendations and submit them to him on or about December 4th. Subsequently, the Board held a teleconference and a meeting with MNR/AFA representatives to explore how the preliminary proposals might be modified to reduce wood supply impacts and enhance protection of natural values. The Board's Chair and sub-committee appreciated the spirit of cooperation and professionalism exhibited by MNR and AFA employees throughout this exercise. The maps, assessments and input provided by staff helped immeasurably in the development of a realistic proposal.

The Board's Vision of Algonquin

Algonquin plays a unique and important role in Ontario's system of provincial parks and conservation reserves. Ontario's third largest park, after Polar Bear and Wabakimi, Algonquin takes in 763,310 hectares of land and water. Algonquin is by far the largest protected areas south of the French and Mattawa rivers. French River Provincial Park with 73,530 hectares is the next largest in this respect, but is less than 10% the size of Algonquin. Indeed, Algonquin dwarfs all other protected areas in central and southern Ontario. The park plays a proportionately large role in the lives of Ontarians. Over the years hundreds of thousands of visitors have enjoyed their first taste of wilderness travel in the park. Many more enjoy car camping, hiking and picnicking along the heavily used Highway 60 corridor. The park's recreational and natural attractions have made Algonquin one of Ontario's premier tourist destinations, together with Niagara Falls, Toronto and Ottawa. Algonquin plays a dominant role in the regional tourism economy. However, many Ontarians value the park mainly as a natural area, a place where nature operates on a large scale. The scientific value of the park is well established – a large volume of natural science research takes place in the park. All of these benefits – recreational, tourism, scientific and natural heritage – are becoming increasingly important as the land east, west and south of the park becomes more heavily used and developed, and as the population of southern Ontario within a 3 hour drive of the park increases.

TABLE 1 – EXISTING ZONING PER PARK MANAGEMENT PLAN

Zone	Area (hectares)	% of Park Area
Nature Reserve	39,250	5.1%
Wilderness	90,475	11.9%
Natural Environment	13,765	1.8%
Historical	1,680	0.2%
Development	22,545	3.0%
Access	735	0.1%
Recreation/Utilization including:	594,860	77.9%
Managed Forest	(424,550)	(56%)
Other[2]	(170,310)	(22%)
Total	763,310	100.0%

Nevertheless, since commercial logging was halted in Lake Superior Provincial Park in the 1980s, Algonquin is the only provincial park where logging continues. Ontario's flagship provincial park is the sole holdout from the "multiple use" era of park management. "Other" includes areas within the R/U zone that are not subject to logging, such as akes, wetlands, rock outcrops and Area of Concern Reserves.

The Board recognizes that logging in the park is managed effectively by the AFA. The AFA ensures that forest management in the park meets the standards established under the Crown Forest Sustainability Act. Yet, a fundamental question must be asked. Should 78 %f Algonquin be zoned to allow logging that is conducted in much the same way it is conducted on Crown land outside the park?
The Board does not believe this approach is appropriate. Logging, and in particular the construction, maintenance and use of an extensive network of primary, secondary and tertiary roads, inevitably has significant impacts on the park environment. Some of the physical impacts include:

- The footprint of roads, and the impact of road construction;
- Habitat fragmentation;
- Creation of edge habitat, and changes in species balance and forest composition;
- Mining of large quantities of aggregate for construction and maintenance of roads;
- Introduction of invasive non-native species;
- Pollution (noise, exhaust emissions, sediment, dust, oil and fuel leaks/spills, etc.)
- Animal mortality including species at risk such as wood turtle;
- Impairment of hydrological function;
- Sedimentation of stream and lakes;
- Opportunities for unauthorized public access to fish and game.

There is also a social and spiritual cost associated with logging in Ontario's flagship provincial park. This is hard to quantify, but for many Ontarians it is significant. The Board recognizes the importance of the Algonquin wood supply for the region's economy and understands that a complete cessation of logging is not practical at this time, without serious social and economic fallout. The Board believes actions can be implemented to lighten the ecological footprint of logging in the park while maintaining an adequate regional wood supply. Consequently, the Board is making recommendations to lighten the footprint of logging under three headings:

1. Protection zones should be expanded by 241,032 hectares to include a total of 409,482 hectares or 54 % of the park.
2. The Ministry and AFA should develop an action plan with targets to reduce the impacts of logging operations considering the 7 strategies outlined in Table 4, including a review of roads standards, aggregate use, size of pits, and use of temporary bridges.
3. The Ministry should partner with the AFA in a pilot project to test the effectiveness of more detailed forest resource inventory and a spatial computer modeling to enhance the accuracy of planning and better integrate the protection and harvesting objectives where logging continues.

Enlargement of Protection Zones

The Board recommends that portions of the current recreation/utilization zones (where logging may be permitted) be rezoned as protection zones (where logging may not be permitted). The Board has identified 5 components for inclusion in protected zones:

- Component 0 – Areas identified to protect representative ecosystems;
- Component 1 – Core areas to connect and expand existing protection zones;
- Component 2 – 200 m setbacks for key self-sustaining brook trout lakes and primary canoe routes (including lakes);
- Component 3 – 120 m setbacks for remaining canoe routes (including lakes) and remaining self-sustaining brook trout lakes;
- Component 4 – Additional setbacks of 200 to 500 m for high priority areas and creation of blocks to connect and expand existing protection zones;
- Component 5 – Areas within remaining recreation/utilization zone (i.e. after Components 0 through 4 are incorporated in protection zones) that would not be subject to logging (lakes, wetlands, rock outcrops, Area of Concern Reserves, etc.)

Current Situation

R/U Zone :78%
Protection Zones: 22%

Board Recommendation

R/U Zone: 46%
Protection Zones: 54%

Benefits of the Enlarging Protected Zones

Implementation of the recommendation would increase protected zones to 54% of the park's area from 22%, and reduce the recreation/utilization zone to 46% of the park from the current 78%. While protected zones would be increased by 241,032 hectares, only 70,722 hectares would be removed from the managed forest, a reduction of 17%. The bulk of the area added to protection zones would consist of lakes, wetlands, other non-forested landscape elements, and Area of Concern Reserves not subject to logging.

The recommendation will enhance protection of:

- 214 self-sustaining brook trout lakes and associated nursery stream habitat;
- 1,374 campsites;
- 1,481 km of canoe routes;
- 463 portages;
- Old growth forest stands; and
- 6,288 hectares of under-represented terrestrial ecosystems.

The Board gave considerable weight to the protection of self-sustaining brook trout lakes. The Board believes that it is prudent and necessary that additional protection be given brook trout lakes and tributaries, consistent with the principle that ecological integrity is the first priority for management of protected areas. As noted above, for many visitors Algonquin is primarily about wilderness canoeing. Yet many canoe routes are within recreation/utilization zones, while many campsites and portages are in close proximity to roads and logging operations. The term “managed forest” is used in this report for simplicity sake in place of the technically correct term “available managed Crown production forest”.

The Board believes it is important to protect the wilderness character of canoe routes and has included these in recommended protected zones. MNR/AFA expressed concern that inclusion in protection zones of some areas scheduled for harvest per the 2005 – 2010 Forest Management Plan (FMP) would have significant short term impacts on wood supply (especially hardwood sawlogs) that could not be fully mitigated. Mitigation, where feasible, would require amendment of the FMP, a complex and time consuming process. In response, the Board dropped from recommended protection zones two areas near Lake La Muir and Lake Louisa totaling 3,646 hectares. MNR developed for the Board’s advice zoning considerations aimed at achieving established natural heritage protection objectives. These considerations differed in some respects from the Board’s preliminary proposal. Most significantly MNR identified areas intended to fill ecological representation gaps. The Board identified in its preliminary proposal a 3,000 hectare “budget” to be used in the future to fill these gaps.

The Board has now included recommended protected zones the areas required to fill representation gaps and dropped the recommendation regarding a 3,000 hectare budget. Consequently, in eco-district 5E-9 (west side the park and surrounding area) 67 under-represented landform/vegetation associations with 1,926 hectares would be protected. In eco-district 5E-10 (east side of park and surrounding area) 80 underrepresented landform/vegetation associations with 4,362 hectares would be protected. In implementing the expanded protected zones and focusing the areas where logging continues, the Board recommends that:

1. The Minister direct MNR/AFA to initiate appropriate consultation with potentially affected aboriginal peoples, and with the public through the park planning and forest planning process;

2. Forest management should continue according to the existing Algonquin Forest Management Plan until its normal date of 2010, but where harvest areas identified by the plan overlap with the recommended protected zones, and it is necessary[6] to harvest those

areas to meet wood supply commitments, particular care should be taken to minimize impacts, such as use of single tree selection harvest or shelter wood harvesting that retains most forest cover;

3. While consultation is underway, the AFA should use the new protected zoning recommended by the Board as a basis for forest management planning for periods beyond 2010, subject to modifications that may arise from the consultation and planning process; [6]

Necessity should be documented and determined through an MNR process that requires consultation with the Algonquin Park Superintendent and public notice.

4. Since practical road access to the remaining wood supply in the managed forest is important, zoning of new protected areas and road strategies should provide for practical road access to future harvest areas;

5. The recreation/utilization zone should be mapped as to the areas where logging may continue and areas of the recreation-utilization zone that are not part of the managed forest – water bodies, wetlands, rock barrens and Area of Concern (AOC) Reserves – should be incorporated into protection zones;

Wood Supply Impacts

The Board fully recognizes MNR/AFA concerns about future wood supply. The Board's view is that at a gross scale, withdrawal of 17% of the managed forest need not jeopardize long term regional wood supply commitments. This is because on average only 56% of the planned harvest area was actually harvested each year, between 1995 and 2005. The Board also believes that there are opportunities to enhance harvest levels on public and private lands outside the park. At the request of the Board, MNR undertook a Wood Supply Analysis of the preliminary proposal using a computer model (Strategic Forest Management Model or SFMM) generally used for this purpose in Ontario. This analysis concluded that if implemented the proposal would have impacts on product-based commitment volumes and would potentially affect certain mills. The Board requested an independent consultant (KBM Forestry Consultants Inc.) to review the MNR Wood Supply Analysis. The consultant verified that the MNR Analysis was sound but that the inputs and assumptions were conservative. Conservative approaches are the industry norm due to the large uncertainties arising from the low reliability of inventories at the stand level and model errors associated with variation in growth, yield and natural events such as blowdowns. The consultant also noted that an alternative "spatial" computer model might provide more accurate modeling of the Board's proposal and that Forest Resource Inventory (FRI) data was coarse and that a more thorough inventory would provide more reliable results. The possibility of limited impacts on wood supply dependent mills is recognized because of uncertainty, however the Board believes that the impact can be mitigated over the long term, both within Algonquin and on surrounding lands. As noted above, the Board has made recommendations that will allow wood supply commitments to be met during the course of the current Forest Management Plan.

Reducing the Impacts of Logging Operations

The Board discussed with the AFA and MNR proposals for reducing the impact of logging operations in areas where it continues. Many of these proposals were suggested by the AFA. They are to a large extent "operational" in nature and can be implemented independently of the Board's proposes for enlarging protection zones. Proposed actions and their benefits are listed below in Table 4. Protection of species at risk should be a priority when planning and undertaking logging operations. For wood turtles this means in essence the protection of watercourses and associated habitat. Per #7 referenced in Table 4 below, practices should have particular regard for maintenance of ecological integrity, including protection of species at risk.

Pilot Project to Enhance Forest Management Planning

KBM Forestry Consultants Inc, when reviewing MNR's Wood Supply Analysis, noted that an alternative spatially-based computer model known as Patchworks has potential to more adequately support decision making in the park. This would need to be supported by enhanced forest inventory. The Board recommends that a pilot project be undertaken for a portion of Algonquin by conducting a more thorough forest resource inventory and applying the Patchworks computer model (or an equivalent spatial model) to test the potential for enhanced, more iterative forest management planning. Possible benefits of such an approach include:

- Increased certainty of wood supply while reducing impacts on sites with high natural and recreational values;
- Increased ability of Algonquin and AFA staffs to integrate decision making and cooperation;
- Opportunities to protect some sites without withdrawing them entirely from the managed forest.

In making this proposal the Board is not suggesting that Ontario's forest management regime is inadequate. Algonquin is a special place, and logging in the park requires special care.

TABLE 4 – PROPOSED ACTIONS TO REDUCE IMPACTS OF LOGGING OPERATIONS

Proposed Action Benefits

1. Complete application of the Forest Access Management (FAM) Zone concept to the park, whereby the managed forest is broken into zones with local access/egress from the park and hauling of timber across the park is minimized (i.e. including the permanent elimination of the Crow River bridge crossing). Minimizes traffic through the park and wear and tear on park logging roads. Algonquin and AFA staffs are working together to finalize a roads strategy that will implement the FAM Zone approach. The decommissioning of roads also reduces the risk of culvert failure and environmental damage, as well as reducing unauthorized access to the Park interior.
2. Integrate the management of aggregate use, supply and pit rehabilitation into the FAM zone concept and minimize use of aggregate on roads, especially on in the east portion of the park, by developing new road standards (i.e. narrower 4.8 m wide running surface) and modifying practices (i.e. less hauling during wet seasons). Reduced number and size of aggregate pits.
3. Develop more rigorous standards for aggregate pits (i.e. reduced maximum size of pits) and their rehabilitation (i.e. progressive, active rehabilitation rather than relying on natural succession). Reduced ecological impact from aggregate extraction.
4. Use temporary portable bridges more widely for stream crossings, in place of culverts and permanent bridges (e.g.. Daventry). Reduced disturbance of stream habitats (placement and

removal of culverts, and erosion culvert ends, can have significant local impacts on stream habitats).
5. Manage logging roads more actively by using old roads where possible, rehabilitating abandoned roads, decommissioning roads that will not be used for 10 years or more, etc. Reduced overall impacts from road network.
6. Where forest management activities occur during the June to October period, enhance planning of operations, communications between AFA and MNR regarding use patterns, and consider options for quieter equipment and modified practices. Improved recreational experiences and reduced logging – recreation conflict.
7. Review forestry practices with an eye to reducing impacts and supporting ecological integrity (i.e. leave more slash and cull on the forest floor, consider use of environmental friendly lubricants and fluids, increase winter logging). Reduced impact from forest operations.

Next Steps

The Board is aware of the potential interest the public, stakeholders and aboriginal communities have in the future of Algonquin. Changes in park management and zoning would have to be addressed through park planning process with appropriate consultation. Any changes would have to be reflected in a new Forest Management Plan. The Crown's obligation to consult regarding any ramifications with respect to aboriginal and treaty rights would need to be met. The Board would be available to assist provide the Minister with further support and advice for communications once a course of action is decided.