Quantifying habitat effectiveness for bobcat (*Lynx rufus*), Canada lynx (*Lynx canadensis*), and eastern cougar (*Puma concolor couguar*) in Nova Scotia, Canada

ENVS 4902 Honours Thesis

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Chapter 1: Introduction

The Earth is currently facing a biodiversity crisis. The International Union for Conservation of Nature (IUCN) states that the extinction of species is occurring at a rate 1 000 times faster than would happen naturally (IUCN, 2010). Humans have been the dominant contributor to this issue through land conversion, overexploitation of species, and anthropogenically-driven climate change (IUCN, 2010). The consequences related to the loss of biodiversity will also greatly affect humans because we depend on the ecosystem services that are provided by a healthy ecosystem such as clean air, water, and food (Balvanera et al., 2006). Conservation efforts are therefore not only important to maintain diverse ecosystems, but also for human well-being.

Carnivores are necessary for the maintenance of healthy ecosystems as they exert top-down processes on lower trophic levels (Ford & Goheen, 2015; Miller et al., 2001; Ripple et al., 2014; Terborgh et al., 1999). Unfortunately, studies have shown that carnivore populations have declined globally, including in North America, since the 18th century (Estes et al., 2011; Miller, McLellan, & Derocher, 2013; Ripple et al., 2014). This decline is present in species historically found in Nova Scotia, including wold and wildcats: bobcat (*Lynx rufus*), Canada lynx (*Lynx canadensis*), and eastern cougar (*Puma concolor couguar*). Declines in wildcat populations are due to a combination of hunting and habitat loss and fragmentation from both the forest industry and other sources of land conversion (Mersey Tobeatic Research Institute (MTRI), 2008; Miller, McLellan, & Derocher, 2013).

Due to the importance and vulnerability of apex consumers such as carnivores, this study will assess whether there is sufficient effective habitat for the maintenance and/or recovery of bobcat, Canada lynx, and eastern cougar in Nova Scotia. In this study, habitat effectiveness is defined as a combination of habitat suitability and road density (acting as a proxy for human activity). Suitable habitat is that which theoretically could support a species based on habitat characteristics (land class type, prey availability, etc.; Atlantic Ecology Division, 2016).

Background

In North America, the decline of carnivore distribution and abundance began with European settlement (Miller, McLellan, & Derocher, 2013). These terrestrial mammals were targeted directly through hunting for pelts and to reduce the (perceived) threats to human life and livestock, as well as indirectly through land conversion and habitat fragmentation (Miller, McLellan, & Derocher, 2013). As such, serious conservation efforts for mammalian carnivores have been limited until recent decades (Treves & Karanth, 2003).

Measures to conserve and protect carnivores arose in the early-twentieth century and were ignited by the likes of Roosevelt, Leopold, and Muir in the United States (Miller, McLellan, & Derocher, 2013). Different motives for the protection of these species included maintaining populations for hunting and for their inherent value (Miller, McLellan, & Derocher, 2013). In addition, the protection of large areas in the form of national and provincial parks led to some recovery (Miller, McLellan, & Derocher, 2013). However, most of the carnivores never recovered to their full range or numbers (Miller, McLellan, & Derocher, 2013).

In Canada, the *Species at Risk Act* was introduced in 2002 (SARA, 2002). Under SARA, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) was created to examine species in Canada and establish their level of risk (SARA, 2002). A short-coming of this process is the unrealistic goal of characterizing the threat levels to all wildlife in Canada. Making rational and educated decisions on which species should be the focus of conservation strategies is thus important (Beazley, 1998).

One approach to conservation ecology is choosing focal species (Lambeck, 1997; Lindenmayer et al., 2014; Miller et al., 1998/1999). Focal species are the species that will be impacted the most by specific threats such as habitat destruction or fragmentation (Lambeck, 1997; Lindenmayer et al., 2014; Miller et al., 1998/1999). The rationale for this approach is that protecting the most sensitive species results in less sensitive species receiving benefits as well (Lambeck, 1997; Lindenmayer et al., 2014; Miller et al., 1998/1999). Carnivores are good candidates for focal species as they are often sensitive to habitat changes, have large ranges, and experience strong competitive pressure (Beazley & Cardinal, 2004; Carroll, Noss, & Paquet, 2001).

In addition, many mammalian carnivores are functionally-important species in terrestrial ecosystems as they initiate top-down regulatory processes that affect the entire food web (Ford & Goheen, 2015; Miller et al., 2001). Top-down processes are often called trophic cascades, a term that has been defined as "…indirect species interactions that originate with predators and spread downwards through food webs" (Ripple et al., 2016, p. 864). These trophic cascades allow for more diversity by suppressing strong competitors' abilities to competitively exclude weaker competitors through the predation of the strong competitors (Miller et al., 2001).

Members of the Felidae family (wildcats) should be considered for protection plans. These species can have a large impact on their ecosystem due to their ability to take down prey larger than them (Jackson & Norwell, 1996). In addition, these species have large home ranges and minimal critical areas, theoretically making them good umbrella species (Beazley & Cardinal, 2004). Umbrella species are often low-density, large-bodied species with large habitat requirements that encompass those of many other species that share similar habitat characteristics (Roberge & Angelstam, 2004; Wilcox, 1984). While none of the Nova Scotian species are listed as threatened or endangered on a national level, it is key to maintain genetic diversity throughout their range by having multiple, healthy populations (International Society for Endangered Cats [ISEC], 2016; Jackson & Nowell, 1996).

There are potentially three Felidae species found in Nova Scotia: bobcat, Canada lynx, and eastern cougar. Members of the Felidae family are hard to monitor due to their elusive nature, nocturnal behaviour, and low densities (Jackson & Norwell, 1996). The bobcat is Nova Scotia's (NS) most populous wildcat and is listed by SARA as being of least concern and not listed in NS's *Endangered Species Act* (ESA) (ISEC, 2016; NS Department of Natural Resources [NS DNR], 2017). The population estimate in Nova Scotia was 5, 170 to 9, 910 individuals in 2010 based on a harvest analysis (Roberts & Crimmins, 2010). Trapping for pelts is regulated in the province, with each licensed hunter being able to trap five bobcat per season (NS DNR, 2017). The number of bobcat trapped was 517 in 2016/2017 compared to 900 ten years before (NS DNR, 2017). This is the lowest number since the 1993/1994 season (NS DNR, 2017). There is little information on the current health of bobcat populations in the province.

Canada lynx is the only wildcat species with a recovery plan in Nova Scotia. While not listed by SARA, the NS ESA designated this species as endangered in 2002 (NS DNR, 2017; Nova Scotia Lynx Recovery Team [NS LRT], 2007; SARA, 2002). Breeding populations are believed to be extirpated on mainland Nova Scotia (NS LRT, 2007). The remaining Cape Breton population is genetically isolated due to the limited connection to the mainland (NS LRT, 2007). As such, it is important to examine whether habitat protection will be successful for the protection and/or recovery of lynx.

The presence of the eastern cougar in Nova Scotia is a complicated and controversial topic. Despite 315 reported sightings of cougar in Nova Scotia between 1970 and 1993, it's status under SARA has been classified as 'data deficient' in Nova Scotia since 1998 and remains unlisted in Nova Scotia's ESA (NS ESA; Nature Canada, n.d.; NS DNR, 1992; Stocek, 1995). While there have been recent studies reporting cougar in New Brunswick, there has been little scientific research conducted on mainland Nova Scotia (Bertrand et al., 2006; Lang et al., 2013). Therefore, determining the status of this species is paramount to conclude whether it persists in Nova Scotia and thus whether protection or recovery is required from a legal perspective. Regardless of legal requirements under SARA or NS ESA, apex consumers are important to ecological functioning, and thus restoration efforts for eastern cougar may be warranted for ecological health reasons, as well as their intrinsic value or inherent worth.

Summary of Literature and Knowledge Gaps

Systematic conservation planning is a holistic approach to conservation efforts (Margules & Pressey, 2000). One component is choosing species to focus upon for the development of conservation plans (Beazley, 1998; Noss et al., 1999). Nova Scotia's wildcats were determined to be appropriate focal species in an expert-based study and were further identified as important for conservation by members of the general public (Beazley, 1998; Beazley & Cardinal, 2004; Weiss Reid & Beazley, 2004).

Once focal species have been chosen, habitat modeling can be a useful tool to determine where effective habitat currently is and where it needs to be restored. It is also valuable for species like cats who are elusive and thus difficult to collect distribution or abundance data (LaRue & Nielsen, 2011; Woolf et al., 2002). Some habitat modeling has been conducted for wildcats; however, only Canada lynx have been assessed in Nova Scotia (Carroll, 2005; Hoving et al., 2005).

To accurately model effective habitat, the preferences and deterrents for bobcat, Canada lynx and eastern cougar need to be determined. Bobcat and eastern cougar are both habitat generalists while the Canada lynx is a habitat specialist (Hoving et al., 2005; ISEC, 2016; Loveless et al., 2016: Reed et al., 2017). All three of these species tend to avoid anthropogenically modified areas such as roads and urban areas (Donovan et al., 2011; Hoving et al., 2005; ISEC, 2016; Reding et al., 2013; U.S. Fish and Wildlife Service, 2010). Habitat effectiveness thus takes into consideration both suitable habitat, based on land cover, and road density, acting as a proxy for human impact.

Goals and Objectives

The goal of this study is to quantify the area of effective habitat for wildcat species in Nova Scotia. Is there sufficient effective habitat in Nova Scotia to maintain viable populations of native wildcats over short- and long-terms?

To achieve this goal, the following objectives are explored for bobcat, Canada lynx, and eastern cougar:

1. To identify the spatial distribution and area of habitat suitability using pre-established models;
2. To identify the spatial distribution and area of habitat effectiveness incorporating road density as a surrogate for human influence; and,
3. To estimate the population size of each species that can be supported in the effective areas to determine whether Nova Scotia has sufficient habitat to maintain viable populations.

This project thus aims to provide spatial and quantitative information for conservation and management of bobcat, Canada lynx, and eastern cougar in the province.

Summary of Approach

Nova Scotia's political boundary represents the geographic reach of this study. While it is noted that wild animals do not follow anthropogenic borders, it was determined to be important to assess these animals with regards to the unique features and threats in Nova Scotia. Nova Scotia is connected to continental North America solely by a narrow isthmus at the border with New Brunswick, thereby functioning ecologically much like an island.

The research is descriptive, quantitative, and cross-sectional in nature as it aims to quantify the amount of habitat that is currently present in Nova Scotia. Habitat suitability was derived using *a priori* criteria and pre-established models. Spatial data was retrieved from government databases (NS DNR, Climate Change Nova Scotia, and National Road Network). The criteria and data layers were put into ESRI ArcMap 10.5 and weighted according to established models. Outputs showed the spatial distribution of suitable habitat for each of the wildcat species. Road density was calculated for the province for all roads (including resource and recreational roads) and paved roads. Habitat effectiveness were derived from the combination of road density, acting as a proxy for human influence, and suitable habitat. The area of effective habitat was compared to the home range size of individual males and the number of males required for minimum viable populations to determine if Nova Scotia can support these species over the short (decades)- and long (centuries)-terms.

The following chapters present an in-depth literature review, explicit study methods, key results and their significance, and finally the main conclusions and recommendations the research has yielded.

Chapter 2: Literature Review

Introduction

This literature review introduces concepts inherent to strategic conservation planning, focal species, and habitat modeling, and then focuses on the habitat requirements for bobcat, Canada lynx, and eastern cougar in North America.

Key sources were found by searching bibliographic databases (i.e. Scopus, Web of Science, and Novanet). The keywords and phrases used included:

- Bobcat, cougar, lynx, wildcats
- Protected areas, conservation strategies
- Focal species
- Habitat modeling
- Habitat/range/territory
- Road density, road impacts; and,
- Population viability, minimum viable population

The revealed articles came from 24 scientific journals. The three most frequently selected journals were: Canadian Field-Naturalist, Journal of Mammalogy, and Journal of Wildlife Management.

The relevant articles produced from this search are used to discuss what conservation systems entail, the application of wildcats as focal species, habitat modeling, road density and the habitat and population viability requirements for the species in question. Throughout this chapter, discrepancies in the literature and knowledge gaps are identified which illuminates the need for this study.

Strategic Conservation Planning and Focal Species

An established approach to conservation is the creation of protected areas (Noss & Cooperrider, 1994). The IUCN defines a protected area as “a clearly defined geographical space, recognized, dedicated, and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values” (Dudley, 2008, p. 8). While the current goal of creating reserves is to increase the conservation of biodiversity, the conflict between protection and resource extraction has historically resulted in protected areas often being implemented in regions that do not fulfill the needs of species nor represent the highest priority areas for biodiversity conservation (Dudley, 2008; Margules & Pressey, 2000). In addition, the number and size of existing protected areas are not enough to support viable populations of the species they are meant to protect (Noss & Cooperrider, 1994). Often the reserves are not isolated from human activity, with many acting as popular camping or hiking destinations which causes direct and indirect negative effects for species sensitive to human activities or presence (Noss & Cooperrider, 1994). Despite problems with using only reserves for protection, they are one part of an effective conservation system (Margules & Pressey, 2000).

Systematic conservation planning has become a widely accepted approach to effective conservation efforts (Margules & Pressey, 2000). This method takes into consideration various components of biodiversity and their processes and aims to address the shortcomings associated with many existing protected areas (Margules & Pressey, 2000). The three-track method is one approach to systematic conservation planning to define areas for conservation. The three tracks in this approach are special elements, representation, and focal species (Beazley, 1998; Noss et al., 1999). Focal species are those species that should be the focus of conservation efforts due to their intensive or extensive habitat requirements, importance to their ecosystem, and/or a high level of sensitivity or vulnerability to human activities (Beazley, 1998; Noss et al., 1999). A benefit to the focal species approach is that it identifies the species that are most sensitive to the threats in a specific area (Lambeck, 1997). If threats do not exceed the minimum threshold for focal species, species with higher thresholds will also profit (Lambeck, 1997).

Cats are suitable focal species due to their disproportional effects on their ecosystem, their large home ranges, and their sensitivity to human activities such as landscape alteration (Beazley, 1998; Beazley & Cardinal, 2004; Carroll, Noss, & Paquet, 2001). In addition, wildcats have low fecundity and small populations (Carroll, Noss, & Paquet, 2001). A Nova Scotian study engaged 19 experts in a Delphi survey method to assess species relative to characteristics that make them appropriate focal species (Beazley, 1998; Beazley & Cardinal, 2004). Researchers concluded that all three-potential species of Nova Scotian wildcats (bobcat, Canada lynx, and eastern cougar) are appropriate focal species due to being regarded as keystone or functionally important, umbrella, flagship, vulnerable, and habitat quality indicator species (Beazley, 1998; Beazley & Cardinal, 2004). Canada lynx and eastern cougar were determined to be of the highest concern for the mammals included in the study (Beazley, 1998; Beazley & Cardinal, 2004). Despite bobcat not currently being listed as of concern in the province, researchers suggest that management attention should be given to maintain or improve their status so as to avoid their becoming at risk in the future (Beazley, 1998; Beazley & Cardinal, 2004).

Habitat Requirements

Bobcat

Bobcat have a wide species distribution, from northern Mexico to southern Canada (ISEC, 2016). Their individual ranges are dependent on their sex and the availability of prey in the area. Females can have ranges as small as 6 km^2 while male ranges can reach 325 km^2 (ISEC, 2016; Loveless et al., 2016). Female's ranges are smaller because they do not travel as far when they have kittens to care for (Donovan et al., 2011). In northwestern Vermont, an average home range of 45 km^2 was found (Donovan et al., 2011). Males bobcat average was 70.9 km^2 while females had a much smaller average range of 22.9 km^2 (Donovan et al., 2011). It is therefore the male bobcat range that should be taken into consideration when looking at available habitat for species as they have the greatest area requirements and will overlap their ranges with females but not with other males (Donovan et al., 2011).

Bobcat are generalists that are found in many different habitats including coniferous, deciduous, and mixed-wood forests, swamps, deserts, and scrublands (ISEC, 2016; Loveless et al., 2016; Reed et al., 2017). For forested land, bobcat may prefer areas with dense understories as they can support more prey (Donovan et al., 2011). Despite the habitat type holding little sway over this species, there are deterrents. Deep snow, heavily developed or roaded areas, and agricultural land are avoided by bobcat (Donovan et al., 2011; ISEC, 2016; Reding et al., 2013). Therefore, while bobcat can thrive in multiple habitat types, they tend to avoid anthropogenically-altered land.

A limited number of studies have been conducted in northeastern U.S. that support that bobcat prefer unaltered landscapes. In Iowa, radio trackers were placed on 23 individuals whose paths were recorded (Reding et al., 2013). It was found that the bobcat strongly preferred forest over other habitat types while moving through the landscape (Reding et al., 2013). This aligned with the findings of a New

Hampshire study that found that unfragmented forest and wetland were strong predictors of bobcat presence (Litvaitis et al., 2015).

Another New Hampshire study examined the habitat preference for bobcat on two scales (Reed et al., 2017). First, researchers used observational data to determine where bobcat were often reported as sighted compared to where they were never reported (Reed et al., 2017). For higher elevation and regions with low human density, remote-triggered cameras were used (Reed et al., 2017). Results of this supported that bobcat did not use high elevation areas that experienced deep snow in the winters (Reed et al., 2017). Second, the location of bobcat with GPS collars were recorded and models were generated to determine characteristics important to habitat suitability (Reed et al., 2017). This study found that bobcat preferred forest, shrubland, and wetland, and avoided agriculture, development, open water, high road density, and forest edge areas (Reed et al., 2017). Researchers also hypothesized that areas with both suitable habitat and high road density were potential population sinks because young bobcat may disperse to these areas and be involved in vehicular accidents (Litvaitis et al., 2015).

The combination of wide-scale distribution, large home ranges and the ability to use multiple habitats bodes well for conservation efforts for bobcat as they are not reliant on one habitat type. However, in Canada, the range of the bobcat overlaps with the most anthropogenically modified landscape (southern Canada) and the above studies have shown that these cats do not select for landscape characteristics such as high road density or agriculture (Litvaitis et al., 2015; Reding et al., 2013; Reed et al., 2017). Further research should be conducted on how bobcat adapt to land changes in southern Canada, northeastern U.S. and the Maritimes to see whether these cats can continue to survive and thrive in increasingly fragmented habitats.

Canada Lynx

Canada lynx are found throughout Canada's boreal forest and down to the southern border with the exception of parts of the prairies where intensive agriculture has drastically altered the land (Hoving et al., 2005; ISEC, 2016). Human development and climate change threaten the southern range of the Canada lynx and as such this portion of their range has shrunk in recent decades (Hornseth et al., 2014). Climate change is an issue because these cats require snowfall of 270 cm per year, which creates preferred habitat for snowshoe hare (*Lepus americanus*; lynx's key prey) and excludes competitors (ISEC, 2016). This problem is magnified in peripheral populations which are already more vulnerable to these changes because they are at the edge of their suitable range (Hornseth et al., 2014).

The home ranges of lynx are large and vary depending on the availability of snow. Male home ranges are between 29-522 km^2, and usually around 100 km^2 at the southern limits (Burdett et al., 2007; Hoving et al., 2005). Female ranges are much smaller, with a minimum of 5 km^2 and a maximum of 95 km^2 (Burdett et al., 2007; Hoving et al., 2005). Males increase their range during mating season while female ranges contract when they are raising kittens (Burdett et al., 2007). To further complicate the calculation of home ranges, snow-period home ranges are 2.7 times larger than snow-free ranges for females but snow-free ranges for males are 1.3 times larger than snow-period ranges (Vashon et al., 2008). It has thus been suggested that the 'core' home ranges (the parts that the cats inhabit year-round) should be focused on over the entire variable range of an individual (Burdett et al., 2007). In addition, it is important to distinguish studies being conducted at the southern-limit of the lynx range from those conducted in the northern portion because home-range characteristics of these populations differ (Vashon et al., 2008). Taking this into consideration, only studies looking at the northeastern U.S. and southeastern Canada are addressed in this literature review because they are more reflective of the Nova Scotia study area.

Scale matters when looking at habitat suitability. At a broad scale, deep snowfall is associated with lynx, but on a finer scale, forest successional stage is more important (Hoving et al., 2004). Beyond this level, Canada lynx are specialists and their habitat needs are close, but not identical, to their prey, the snowshoe hare (Fuller & Harrison, 2010; Fuller, Harrison, & Vashon, 2007). Suitable habitat has characteristics such as intermediate snowshoe hare density and easy access to and higher visibility of hares (Fuller & Harrison, 2010; Fuller, Harrison, & Vashon, 2007). Lynx also prefer less dense understory than hares as this helps with the latter two characteristics (Fuller, Harrison, & Vashon, 2007). Pregnant females and females with kittens chose more prey dense areas as they have higher caloric needs to meet (Fuller & Harrison, 2010). As Canada lynx are specialists, maintaining enough high-quality land to support a healthy population should be forefront for conservation efforts.

Multiple studies on Canada lynx have been carried out in Maine. This is beneficial as Maine is similar to Nova Scotia with an Acadian forest that has a history of intensive clear-cut (Simons-Legaard et al., 2013). While historic reports stated that lynx required mature forests, recent evidence suggests that this is not the case (Hoving et al., 2004). Researchers found that snowshoe hares had higher densities in conifer-dominated regenerating clear-cuts 15 to 35 years old compared to partially harvested stands that were 1 to 21 years old (Simons-Legaard et al., 2013). The difference in time scales between the two forest types is related to the changes in forestry practices in the area and is an issue for validity (Simons-Legaard et al., 2013). Hare density is important when looking for lynx occurrence as they preferentially select for habitat where hare density exceeds 1.5 hares per hectare and avoid areas with hare density of less than 0.5 hares per hectare (Simons-Legaard et al., 2013). Unfortunately, hare density information is not readily available in Nova Scotia and thus cannot be incorporated into this research.

A study conducted in northwestern Maine tracked six lynx and looked for evidence of their kills and resting beds over the course of two years and multiple forest stand types (Fuller, Harrison, & Vashon, 2007). The stands were mature forest, short regenerations, tall regenerations, recent partial harvests and established partial harvests (Fuller, Harrison, & Vashon, 2007). Researchers found higher lynx occurrence in tall regenerations and established partial harvests (Fuller, Harrison, & Vashon, 2007). There is therefore some controversy surrounding the impact of partial harvests on lynx occurrence and more research needs to be conducted in this area. Despite this, the findings of these studies suggest that lynx conservation and forestry may not have conflicting interests. If harvesting occurs in a manner that allows for large patches to be regenerated to an acceptable age (15 to 35 years) while others are being cut, harvesting could provide suitable habitat for lynx (Hoving et al., 2004).

There have been limited studies conducted on lynx in Nova Scotia. The Canada lynx is endangered in the province, with breeding populations only recognized on Cape Breton Island (NS LRT, 2006). Despite the species being provincially listed, there remains a severe lack of information around the species. For instance, the presence of lynx on mainland Nova Scotia is disputed. There are claims that the mainland population of lynx were extirpated in the 1950s (Poole, 2003), however, there is evidence of lynx crossing the Chignecto Isthmus in 2007 (MacKinnon & Kennedy, 2008). Maintaining lynx habitat along this piece of land is thus very important if recolonization of lynx on mainland Nova Scotia is to be supported. In addition, individuals may move from Cape Breton to mainland Nova Scotia (NS LRT, 2006). As the Nova Scotia Lynx Recovery Plan is now 11 years old, and lynx undergo cycles of 9 to 11 years, new information will hopefully be released surrounding the findings and impacts of the plan (NS LRT, 2006).

Eastern Cougar

Cougar have the largest range of any North American carnivore, stretching from the Yukon to southern South America (ISEC, 2016). The ability of the cougar to use a variety of habitats makes it a generalist (ISEC, 2016). The eastern cougar is a subspecies whose historic range included Ontario, Quebec, New Brunswick, and Nova Scotia in Canada and the area bordered by Michigan, Maine, South Carolina, and Tennessee in the U.S. (U.S. Fish and Wildlife Service, 2010). The home ranges of cougar are extremely variable and range from 65 km^2 to 1000 km^2 for males and about half that for females (Canadian Geographic, 2007). This huge range makes it difficult to determine whether cougar are present or absent from a region.

Despite having extremely large ranges and being generalists, there are certain habitats that are more conducive to cougar occurrence. Large tracts of forest habitat are often needed to support the cougar and their preferred prey, large cervids (ISEC, 2016; U.S. Fish and Wildlife Service, 2010). These forest tracts should be large enough to support non-overlapping male home ranges and hold little anthropogenic influence such as roads and developed areas (Glick, 2014; Kertson et al., 2011).

A study in Washington found that 60 percent of cougar kills were found to be within 100 meters of water (Kertson et al., 2011). Despite their common name 'mountain lion', this study also found that cougar were negatively correlated with elevation (Kertson et al., 2011). While there is a lack of scientific research on eastern cougar's habitat, there is no genetic difference between cougar found in the western versus eastern parts of Canada, and therefore, it can be presumed that the habitat requirements for the two groups are similar (Glick, 2014).

Nova Scotia may not have hosted breeding populations of eastern cougar since the early 1900s (Forbes, McAlpine, & Scott, 2010). While the on-going presence of the eastern cougar in NS is deemed unlikely by researchers (Bertrand et al., 2006; Forbes, McAlpine, & Scott, 2010; Glick, 2004), there have been 315 eyewitness reports filed between 1970 and 1993 (Lang et al., 2013). These sightings have been difficult to confirm since the cougar is so elusive (Lang et al., 2013). There has also been scientific evidence of cougar presence in the Maritimes. Bertrand et al. (2006) set up 12 traps in New Brunswick and Nova Scotia in parks and where reliable sightings were reported. Researchers found evidence of two cougar in New Brunswick, one of which was confirmed to be a North American cougar (Bertrand et al., 2006). Another study by Lang et al. (2013) set up 38 scratching posts in Quebec, New Brunswick, and Nova

Scotia. Evidence for cougar was found in Quebec and New Brunswick but not Nova Scotia (Lang et al., 2013). However, both studies only looked at Cape Breton and not mainland Nova Scotia.

Despite a high number of eyewitness accounts placing cougar in Nova Scotia, there is no scientific evidence placing cougar in the province at this time. That being said, as cougar are habitat generalists and efficient colonizers with extremely large ranges, it is very possible that cougar could recolonize the province if sufficient habitat remains (Bertrand et al., 2006; Glick, 2004).

Habitat Modeling

Habitat modeling is an important part of conservation system design as it acts as a valuable tool for determining where protection, maintenance, and/or recovery of habitat needs to occur. In addition, modeling can provide insight into the distribution and abundance of species which is especially useful when there is limited empirical data available (LaRue & Nielsen, 2011; Woolf et al., 2002). As this is the case for wildcats in Nova Scotia, habitat modeling is an appropriate approach. However, it is important to note that it is difficult to encompass all of the factors associated with a species in a model, and as such, models are often only 70 percent accurate (Corridor Design, 2013).

Bobcat

A habitat suitability index model for bobcat was developed by the U.S. Fish and Wildlife Services in 1987 for the southeastern U.S. This model does not include forested stands and bases the food availability solely on open, unaltered areas (U.S. Fish and Wildlife Services, 1987). Therefore, it was determined that this model was not appropriate for Nova Scotia as much of the province is forested. A more relevant model was created by Woolf et al. (2002) using data from sightings and satellite imagery in Illinois. They ran two separate models, one a canonical discriminant function and the other a stepwise logistical regression. These models were then validated against additional sightings. The final equation for habitat suitability was $\text{logit}(P) = -3.2 + 13.4\log_{10}(\text{grass fraction of area} + 1) + 26.1\log_{10}(\text{woods fraction of area} +$

1). Precise definitions of 'grass' and 'woods' were not provided, however there was a separate category for agriculture, so this was not considered 'grassland' (Woolf et al., 2002). Highly suitable habitat was considered P > 0.75, suitable habitat P > 0.50, and unsuitable habitat P < 0.50 (Woolf et al., 2002). When compared to the additional sighting data, 84 percent were found in P > 0.50 areas (Woolf et al., 2002). Using public sightings as presence data was also conducted by Reed et al. (2017). Researchers increased reliability by only using data with either in-depth description or photographic evidence and specific coordinates (Reed et al., 2017). Sighting data can be biased towards human-populated areas and roads, and thus may give information about dispersion paths instead of home ranges. In addition, sighting data is limited in Nova Scotia; the most complete data set is from trapping records at the county level for bobcat, making finer scale validation of models difficult.

Canada Lynx

A well-established habitat model was developed for the Canada lynx by Hoving et al. (2005) for eastern North America. They combined records from 1987 to 1999 of lynx sightings, roadkill, tracks, and incidental kills. Forest type per 100 km^2 and mean annual snowfall from a 10-year period were factored into the model. This produced the following optimal model where SNOW is the mean annual snowfall in each cell and DECIDUOUS is the percent of deciduous forest within 100 km^2 of the cell (equation 2.1).

$$(2.1)\ P_{LYNX} = \frac{e^{-12.78+0.046\mathrm{SNOW}+(-0.058)\mathrm{DECIDUOUS}}}{1+e^{-12.78+0.046\mathrm{SNOW}+(-0.058)\mathrm{DECIDUOUS}}}$$

This model resulted in 94 percent correct classification when compared to a reserved lynx presence dataset (Hoving et al., 2005). While it was suggested by Simons-Legaard et al. (2013) that 27 percent of a 100 km^2 area should contain suitable habitat, Hoving et al.'s (2005) model was found to be valid without incorporating this. This model was used for a habitat analysis in the northeastern U.S. and southeastern Canada where it was validated against trapping density data from Quebec (Carroll, 2005). Carroll (2005) found the only suitable habitat for Canada lynx in Nova Scotia to be in Cape Breton and that when snowfall predictions are forecast to 2055, this habitat disappears.

Eastern Cougar

While there have been limited habitat models for eastern cougar, LaRue and Nielsen (2011) looked at potential habitat for cougar in midwestern U.S. The researchers could not use empirical data because it was limited and may have been from dispersing individuals which would not represent their habitat preferences (LaRue & Nielsen, 2011). Five factors (land cover, slope, human density, distance to roads, and distance to water) were weighted by experts for analysis (LaRue & Nielsen, 2011). Out of these five variables, land cover type was judged to be the most important indicator and distance to water the least important indicator of cougar presence (equation 2.2; LaRue & Nielsen, 2011).

$$(2.2)\ P_{EC} = 0.736(\text{land cover}) + 0.344(\text{distance to roads})$$

The model was validated against presence data from a known breeding population (LaRue & Nielsen, 2011). Researchers found that only three percent of the land contained highly connected, suitable habitat ($P > 0.75$), which indicated a need for a conservation strategy to be implemented if recolonization is deemed desirable in the region (LaRue & Nielsen, 2011).

Road Density

The presence of roads has an impact on the presence of wildlife, including wildcats. Roads are an issue for many reasons, including the fragmentation of habitat and the disturbance of connectivity (Reed, Johnson-Barnard, & Baker, 1996). In addition, roads lead to mortality through road kill and facilitating hunting and trapping of economically valuable species (Jalkotzy, Ross, & Nasserden, 1997). Due to the inverse relationship between presence of roads and ecological integrity, road density is an appropriate surrogate for human activity (Forman et al., 1997).

Road density thresholds have been suggested for wildcat species. All three species are sensitive to paved roads, with a suggested threshold of 0.6 km/km^2 (Hoving et al., 2005; Jalkotzy, Ross, & Nasserden, 1997; Poessel et al., 2014; Van Dyke et al., 1986). This threshold (0.6 km/km^2) was also identified for recreational and resource roads for Canada lynx and eastern cougar as there is evidence that these wildcats avoid such roads (Hoving et al., 2005; Jalkotzy, Ross, & Nasserden, 1997; Van Dyke et al., 1986). Some researchers have suggested that bobcat can thrive in areas with very high road densities (1.5 km/km^2, Jalkotzy, Ross, & Nasserden, 1997), while others have found that bobcat avoid paved roads to a similar degree as other wildcats (0.6 km/km^2, Crooks, 2002; Poessel et al., 2014).

Population Viability

The viability of a population needs to be considered when planning and implementing conservation strategies. One way to do this is to look at minimum viable population (MVP): the number of individuals required to persist over a specified period of time when faced with stochasticity and catastrophe (Shaffer, 1981). MVP encompasses the effective population, which is the number of randomly breeding individuals (Rai, 2003). Due to a lack of precise population viability numbers for most species, a generally accepted rule of thumb is often used in such estimates: 50 individuals for short-term (decades) and 500 individuals long-term (centuries) effective breeding populations, based on studies of inbreeding depression in domesticated animals (Franklin, 1980; Soule, 1980). The ratio of individuals in a population to effective breeding individuals is between 5:1 and 10:1 (Frankham, 1995; Waples, 2002). A meta-analysis of 141 sources found that the median long-term MVP was 4169 individuals (Traill, Bradshaw, & Brook, 2007). For mammals, the study found the median long-term MVP was 3876 individuals (Traill, Bradshaw, & Brook). While there has been some debate around whether MVP is a meaningful tool and which thresholds should be used, Brook et al. (2011) assert that having a quantitative goal is important.

As wildcat males have larger home ranges and do not overlap their ranges with other males but will with other females, sex ratios need to be known. These sex ratios will determine how much effective habitat is needed to support minimum viable populations. For bobcat, a study found that the three-year sex ratio on Cape Breton Island was 52 males to 48 females (Parker & Smith, 1983).. A similar study of Canada lynx carcasses on Cape Breton Island found a male to female ratio of 0.7:1 (Parker, 2001). There have been no sex ratio studies conducted in Nova Scotia for cougar, however this species usually has a ratio of male to female of 1:2 or 1:3 (Quigley & Hornocker, 2010).

Conclusion

This literature review has introduced information on conservation system planning and provided support for wildcats as appropriate focal species. It also summarized relevant habitat modeling, road density, general habitat and viable population requirements for the wildcat species present in Nova Scotia. Key research surrounding these cats in northeastern U.S. and the Maritimes has been identified and applied to the research area where applicable. There is an obvious dearth of scientific study about wildcat habitat in Nova Scotia, especially concerning bobcat and eastern cougar. As available and effective habitat is a major part of conservation strategies, my study will address whether Nova Scotia has sufficient effective habitat to support viable populations of these cats.

Chapter 3: Methods

Overview

This study investigates the spatial distribution and area of effective habitat for bobcat, Canada lynx, and eastern cougar in Nova Scotia. Indices of habitat suitability for each of the species were combined with road data to delineate remaining patches of effective habitat, using a computer-based geographic information system (GIS; ESRI ArcMap 10.5). Total area and patch sizes were compared with home-range sizes for males and the numbers of males that should be supported were calculated. These numbers were considered in relation to general guidelines or published estimates for viable population size for each species, with the objective of determining whether enough effective habitat remains in Nova Scotia for the maintenance and/or recovery of native wildcats.

Study Area

The political boundaries of Nova Scotia delineate the study area. Nova Scotia is Canada's second smallest province, with an area of 52 422 km^2 (Figure 3.1; Statistics Canada, 2005). It is part of the Acadian ecozone which encompasses the Canadian Maritimes and parts of Connecticut, Massachusetts, Vermont, New Hampshire, and the majority of Maine (NS DNR, 2016). Approximately 75 percent of the province is tree-dominant, a figure that includes regenerating areas following recent harvesting (NS DNR, 2016). The province's urban areas account for 2.8 percent of land while the transportation network (roads, rail lines, transmission, and pipeline corridors) outside of urban areas represent 1.1 percent of the land area (NS DNR, 2016).

This province was chosen because of the unique challenges it faces for the conservation of wildcats. Nova Scotia is nearly an island, with the only connection to the remainder of the continent via New Brunswick at the 23-km wide Chignecto Isthmus (Canadian Parks and Wilderness Society [CPAWS], 2005). This has implications for the genetic diversity of Nova Scotian populations of these cats as numbers need to be high enough to avoid inbreeding depression and other factors that affect population viability and persistence (CPAWS, 2005). In addition, Nova Scotia is located at the northern limit of the bobcat range and the southern limit of the Canada lynx range, which could make it an interesting case study for investigating the impacts of climate change on these species for future research (Hoving et al., 2005; ISEC, 2016).

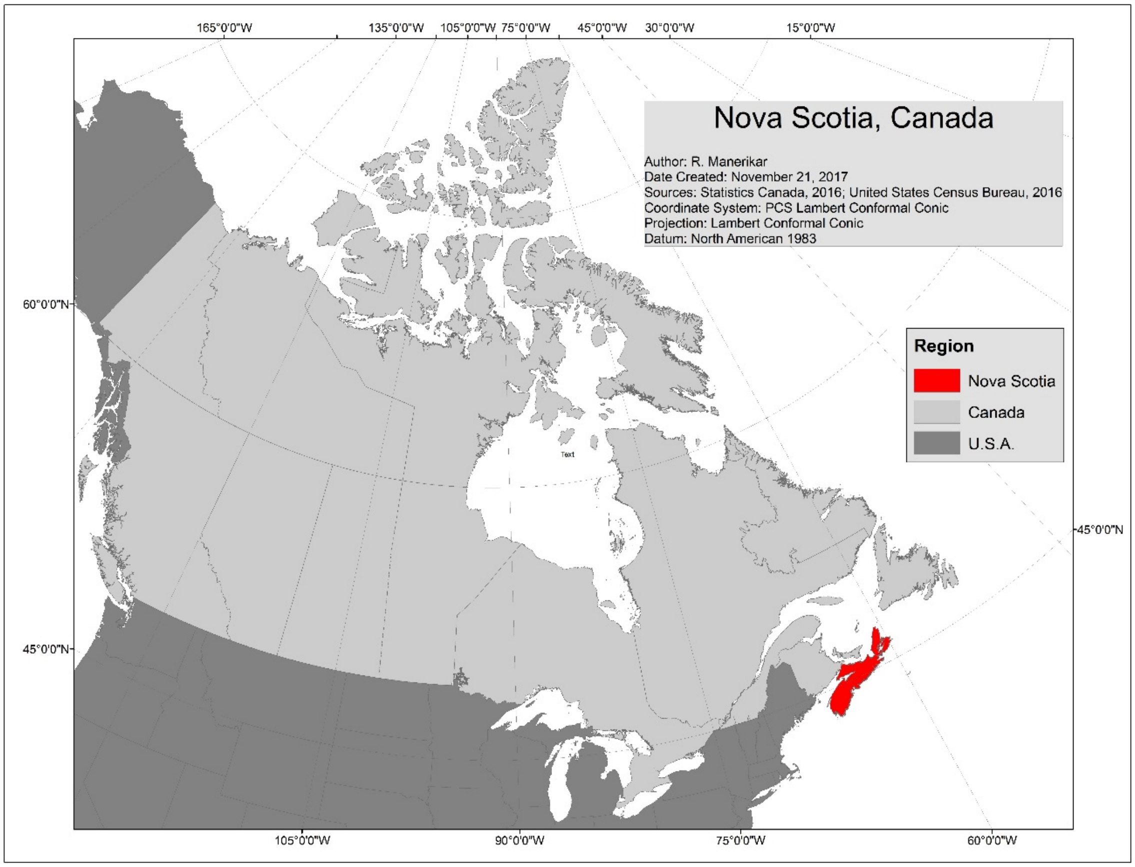

Figure 3.1 Map showing the location of the study area in relation to the rest of Canada.

Human impact has had an impact on these species. Hunting and trapping have been a part of Nova Scotian history and are still a threat to bobcat, and, through accidental trapping, lynx (NS DNR, 2017). The province has a long history of forestry which began in the early 17th century and carries on today (Bissix, 2010). The forest industry has changed the natural forests and has fragmented the landscape. Habitat conversion, degradation, and fragmentation caused by land-use and land-cover changes, including road, agriculture, forestry, mining, and urbanization have changed the landscape – thus potentially altering habitat effectiveness for wildcats. The assessment of habitat effectiveness is therefore important information for conservation planning for the maintenance and/or recovery of bobcat, Canada lynx, and eastern cougar in Nova Scotia.

Habitat Suitability

Pre-established habitat suitability models were used to identify and spatially delineate suitable habitat for each species of wildcat in Nova Scotia. Spatial data was acquired from the Nova Scotia Department of Natural Resource's Forest Inventory that contains information on land class type around Nova Scotia. The Forest Inventory's data ranges from 1995 to present day and are based mainly on aerial photograph interpretations with some limited satellite imagery and field data (NS DNR, 2015). This dataset was provided in Universal Transverse Mercator (UTM) zone 20 and this is the coordinate system that was used for this study. This spatial data was divided into files for each county in vector form, which was then merged into one dataset, excluding Sable Island, in ESRI ArcMap 10.5. The land class attributes were then split-by-attribute. Regions undergoing resource-extraction (clear-cutting, partial harvest, etc.) were included in the forested class as they represent potential habitat if restored/recovered. The home range sizes for each species are for males and based on findings reported in studies in similar habitats and latitudes.

Bobcat

Woolf et al.'s (2002) habitat suitability model was used for bobcat (equation 3.1). This model was developed for bobcat in Illinois and was thus determined to be more suitable for use in Nova Scotia than other models developed in southern U.S. (Woolf et al., 2002).

$$3.1)\ \text{logit}(P_{BOBCAT}) = -3.2 + 13.4\log_{10}(\text{grass fraction of area} + 1) + 26.1\log_{10}(\text{woods fraction of area} + 1)$$

The Forest Inventory's grass (brush) and woodland (any forest, including clear-cuts) land cover types were selected and then converted from vector to raster with 20 m by 20 m cells. The two land cover types were reclassified with 1 for presence and 0 for absence. Neighbourhood focal statistics with a five by five cell area were run on the grass and woodland datasets to calculate the percentage of each within a 10 m^2 area. The outputs from this operation were then inserted into the model (equation 3.1) using the raster calculator. As this model produced a logarithmic output, two further calculations needed to be performed to calculate probabilities (equation 3.2, 3.3).

$$3.2)\ \text{Odds} = \exp(\text{logit})$$

$$3.3)\ P_{BOBCAT} = \frac{odds}{1+odds}$$

The probabilities reflect the chance of bobcat being present in the cell area. Probabilities were then reclassified into two categories: unsuitable habitat ($p<0.5$), suitable habitat ($p\geq0.5$). The suitable habitat was converted back to vector polygons for area calculations to be performed using 'select-by-attribute'. A minimum male home range of 70.9 km^2 was used (Donovan et al., 2011; Woolf et al., 2002). Only areas equal to or larger than this size were considered suitable.

Canada Lynx

For Canada lynx, Hoving et al.'s (2005) habitat suitability model was applied (equation 3.3). As this model has been used in Nova Scotia before and was found to be 94 percent accurate in the region, it was deemed appropriate for this study (Hoving et al., 2005). This equation takes into consideration annual average snowfall, which must be above 270 cm, and deciduous forest cover (Hoving et al., 2005).

$$3.4)\ P_{LYNX} = \frac{e^{-12.78+0.046\text{SNOW}+(-0.058)\text{DECIDUOUS}}}{1+e^{-12.78+0.046\text{SNOW}+(-0.058)\text{DECIDUOUS}}}$$

Only the counties of Cape Breton, Inverness, Richmond, and Victoria received enough annual snowfall over the past ten years, thus the model was only applied to Cape Breton Island (Environment Canada, 2010). The deciduous forests were selected from the Forest Inventory if the first and second species were hardwoods and accounted for at least 50 percent of trees in a plot. While recent literature has shown that lynx may prefer regenerating stands 15 to 35 years after clearcutting, this study aims to inform management practices and thus is interested in any habitat that could be suitable (Simons-Legaard et al., 2013). This new dataset was then converted to raster with 100 m x 100 m cells and reclassified so that presence of deciduous forest was 1 and absence was 0. Neighbourhood focal statistics were run for a 100 km^2 (100 by 100 cells) area to determine percentage of deciduous forest around each cell. The values were then added to the model. The resulting probabilities were reclassified into two categories: unsuitable habitat ($p<0.5$) and suitable habitat ($p\geq0.5$). A minimum male home range of 100 km^2 was used (Burdett et al., 2007; Hoving et al., 2005). Only areas equal to or larger than this size were considered suitable.

Eastern Cougar

LaRue and Nielsen's (2011) habitat suitability model was used for eastern cougar (equation 3.4). While this was developed in midwestern U.S., habitat suitability is assumed to be similar for this wide-ranging species and therefore it is appropriate for use in Nova Scotia.

$$3.5)\ P_{EC} = 0.736(\text{land cover}) + 0.344(\text{distance to roads})$$

Each of the land cover layers (see table 3.1) were converted to raster with 100 m x 100 m cells and reclassified so the presence equaled the weight of the class (LaRue & Nielsen, 2011). The raster layers were then combined using map algebra.

Table 3.1 Land cover type and weight based on LaRue and Nielsen (2011)

Land cover	Weight
Mixed wood	100
Deciduous	84
Evergreen	83
Shrubland	58
Wetland	35
Grass	32
Agricultural	15
Barren/urban	10

Road information was from Nova Scotia Road Network (2015) in the form of vector data. LaRue and Nielsen (2011) only factored paved roads into their model. Three buffers were created for roads: less than 0.3 km, 0.3-5 km, and over 5 km. These buffers were then converted to raster and reclassified based on their weights (Table 3.2).

Table 3.2 Distance from road and weighting based on LaRue and Nielsen (2011)

Distance from road (km)	Weight
<0.3	48
0.3-5	62
>5	100

The two components were then inserted into the model using the raster calculator. Probability outputs were reclassified as for the previous two species: unsuitable habitat ($p<0.5$) and suitable habitat ($p\geq0.5$). Suitable habitat was converted back to vector polygons for area analysis, where a minimum male home range size of 65 km^2 was used (Canadian Geographic, 2007).

Habitat Effectiveness

Habitat effectiveness is the combination of habitat suitability and human influence, here represented by road density. This study will look at the effects of all roads, including recreation and/or resource roads, as well as only paved roads. The road data was retrieved from Nova Scotia Road Network (2015) in vector form. It was divided into paved and unpaved roads using select-by-attribute. The km/km^2 density of paved, unpaved, and all roads were calculated using the line density tool.

All Roads - Bobcat

As bobcat were determined to react differently to the presence of paved and unpaved roads, a different layer was created for these species as opposed to Canada lynx and eastern cougar (Crooks, 2002; Jalkotzy, Ross, & Nasserden, 1997). Road density was classified as 0 when paved roads were below 0.6

km/km^2 and unpaved roads were below 1.5 km/km^2 and classified as 1 when the densities were above these thresholds (Crooks, 2002; Jalkotzy, Ross, & Nasserden, 1997). These layers were combined using map algebra to represent areas that had road presence above this threshold.

All Roads – Canada Lynx and Eastern Cougar

For Canada lynx and eastern cougar, the all road data was classified as 1 for under 0.6 km/km^2 and 0 for over this threshold (Hoving et al., 2005; Van Dyke et al., 1986).

Paved Roads – All Species

All three of the wildcat species have the same threshold for paved road densities: 0.6 km/km^2 (Hoving et al., 2005; Jalkotzy, Ross, & Nasserden, 1997; Van Dyke et al., 1986). As such the paved road densities were reclassified as 1 below this threshold and 0 above it.

Habitat Effectiveness

Map algebra combined the road density for (1) paved and (2) all roads with habitat suitability layers for each species. As the suitable habitat and the road densities below the established thresholds were denoted '1', this was a simple multiplication function (equation 3.5).

$$3.6)\ P_{SPECIES} = \text{habitat suitability x road density}$$

The resulting outputs that were 1 represented the areas with suitable habitat and road density beneath the thresholds. The outputs were then converted to vector polygons and the areas that did not meet the minimum male home range size for each species were removed (Table 3.3).

While the LaRue & Nielsen (2011) habitat suitability model for eastern cougar does use road data, the presence of roads is not weighted very heavily. A road being less than three kilometers away from a point would only reduce suitability by 16.5 percent. For this study, road density exceeding established the thresholds was determined to be equally as important as suitable habitat. Thus, a further calculation was required for eastern cougar habitat effectiveness.

Table 3.3 Minimum male home range size for bobcat, Canada lynx, and eastern cougar.

Species	Minimum home range (km^2)
Bobcat	70.9 (Donovan et al., 2011)
Canada lynx	100 (Burdett et al., 2007; Hoving et al., 2005)
Eastern cougar	65 (Canadian Geographic, 2007)

Population Viability and Minimum Critical Area Analysis

For each of the wildcat species, the number of males required to maintain a viable population was calculated and then the minimum critical area was calculated for males over the short- and long-term (Table 3.3, 3.4). Males have larger home ranges and will overlap with females but not other males (Burdett et al., 2007; Canadian Geographic, 2007; Donovan et al., 2011; Hoving et al., 2005). As such, enough male-supporting patches must be available to maintain a viable population. The definition of a viable population will be set at 50 effective (randomly breeding) individuals for the short-term and 500 effective individuals for the long-term (Franklin, Allendorf, & Jamieson, 2014; Franklin, 1980; Soule, 1980). For the purpose of this study, a ratio of 7.5:1 individuals to effective individuals will be used (based on Traill, Bradshaw, & Brook, 2007). The minimum critical areas take the proportion of males and multiplies the individual minimum male home range size by the short- and long-term population numbers (Table 3.5).

Table 3.4 Number of males required for viable short-term and long-term populations. Effective population numbers based on Franklin (1980) and Soule (1980). Ratio of individuals to effective individuals based on Traill, Bradshaw, & Brook (2007).

	Short-term				Long-term			
Species	Effective population	Proportion of Males	Census: Effective	Males Required	Effective population	Proportion of Males	Census: Effective	Males Required
Bobcat	50	0.5 (Parker & Smith, 1983)	7.5:1	188	500	0.5	7.5:1	1875
Canada lynx	50	0.41 (Parker, 2001)	7.5:1	154	500	0.41	7.5:1	1538
Eastern cougar	50	0.29 (Quigley & Hornocker, 2010)	7.5:1	109	500	0.29	7.5:1	1088

Table 3.5 Area required to support MVP over the short- and long-term.

	Short-term			Long-term		
Species	Male home range size (km^2)	Males required	Area required (km^2)	Male home range size (km^2)	Males required	Area required (km^2)
Bobcat	70.9 (Donovan et al., 2011)	188	13 329	70.9	1875	132 937
Canada lynx	100 (Burdett et al., 2007; Hoving et al., 2005)	154	15 400	100	1538	153 800
Eastern cougar	65 (Canadian Geographic, 2007)	109	7 085	65	1088	70 720

Population viability was evaluated based on the number of individuals that could be supported within areas of effective habitat (i.e. areas of suitable habitat with low road density) over the short- and long-term. These methods have been modified from Snaith et al. (2002) and Snaith & Beazley (2004), which respectively investigated (1) habitat suitability and effectiveness and (2) population viability for moose in Nova Scotia. In addition, manual visual analyses were conducted to identify whether connectivity was an issue. If patches were isolated and/or separated from other important areas by major roads, connectivity was determined to be poor.

Limitations and Delimitations

One of the biggest limitations of this study is the lack of relevant information. The NS DNR Forest Inventory does not contain all up-to-date data and thus the models produced may not reflect the current state of Nova Scotia. As forested land is being considered as suitable habitat for these species, the results are the best-case scenario and may overestimate the number of individuals that can be support in Nova Scotia.

There is also limited data to validate the habitat suitability and effectiveness models, with the best option being bobcat hunting records at the county level. In addition, the habitat suitability models may be valid where they were developed but may not accurately reflect habitat suitability in Nova Scotia.

A delimitation is the timeline of this project, which did not allow for consideration of each factor that may impact the wildcats' use of the land. This study will examine a few of these: forest type, snowfall, and road density. In addition, the state of the province's forests (i.e. clearcutting, stage or regrowth, etc.) were not taken into consideration for this project. Future research could take a more detailed approach to determining habitat effectiveness.

Another delimitation was the decision to use the UTM projection that the Forest Inventory was provided in. This projection maintains shape but does distort area. However, distortion within each zone is minimal and, as this project was focused on UTM zone 20, this was determined not to be an issue.

Furthermore, it is expected that climate change will alter the occurrence of effective habitat, which may benefit bobcat and further limit lynx. It is not in the scope of this project to examine the impacts of global warming on these species.

Chapter 4: Results

Introduction

Results were generated from habitat suitability models that were for bobcat, Canada lynx, and eastern cougar in Nova Scotia. The habitat suitability models produced the likelihood of finding the species in a given unit area (400 m^2 for bobcat, 1 km^2 for Canada lynx and eastern cougar). The resulting outputs were classified into two categories: unsuitable habitat ($p<0.5$) and suitable habitat ($p=0.5-1$) based on Woolf et al.'s (2002) classification. Only contiguous patches large enough to accommodate minimum male home range size for each species were considered suitable.

Road densities (acting as a surrogate for human influence) were calculated for Nova Scotia based on each species' threshold. This was done for all roads in the province, including resource and recreational roads, and only paved roads. Areas where road densities exceeded the threshold were deemed ineffective. The combination of low road density and suitable habitat model outputs produced areas of potentially effective habitat. To be considered effective habitat, these areas needed to be large enough to encompass the minimum male home range size for each species.

Analyses were conducted to see how many males of each species could be supported in effective habitat patches across all of Nova Scotia as well as how many males each effective patch could support.

Habitat Suitability

Bobcat and eastern cougar suitability models produced high amounts of suitable land in Nova Scotia (Table 4.1). Canada lynx had very limited habitat suitability, found only on Cape Breton Island.

Table 4.1 Breakdown of suitable areas for each species, males supported, and males required to maintain viable populations (Parker, 2001; Parker & Smith, 1983; Quigley & Hornocker, 2010).

	Suitable areas (km^2)	Males supported	Males required for short-term	Males required for long-term
Bobcat	49 318	695	188	1875
Canada lynx	4 627	46	154	1538
Eastern cougar	42 599	655	109	1088

Bobcat

The majority of Nova Scotia was found to be suitable based on Woolf et al.'s (2002) habitat suitability model (Figure 4.1). Based solely on this model, Nova Scotia has enough suitable habitat to support 695 males, which, if functioning as a meta-population, should be sufficient to support a viable population over the short-term (Table 4.1).

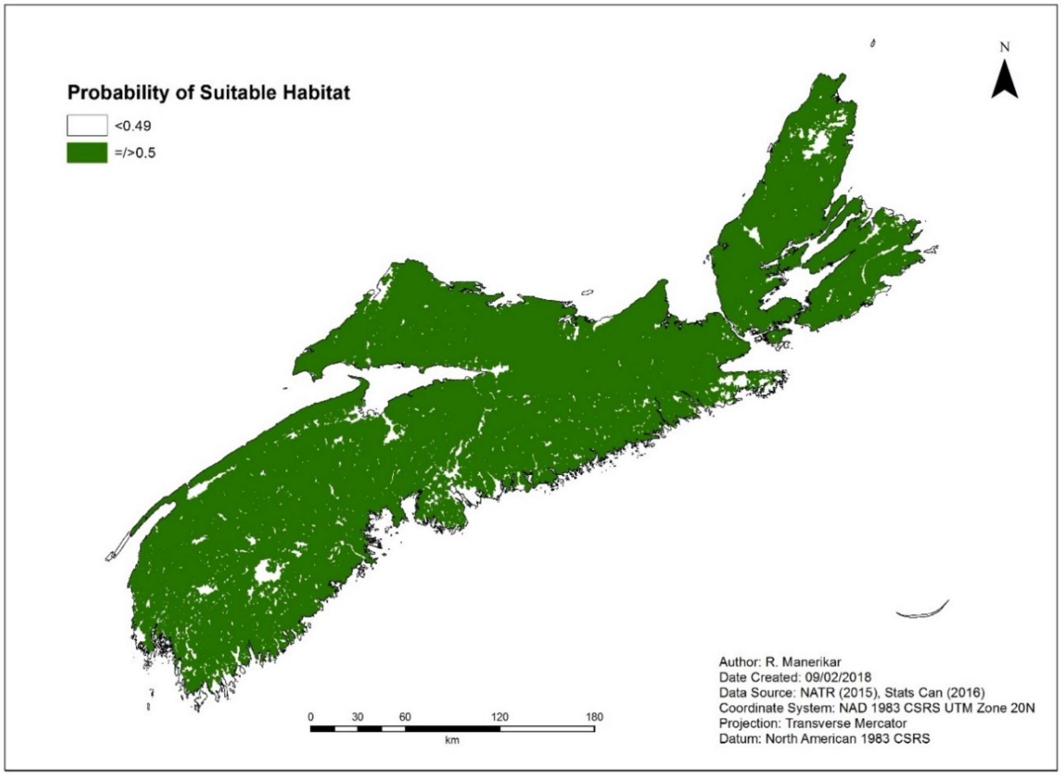

Figure 4.1 Probability of habitat suitability for bobcat in Nova Scotia. Based on Woolf et al. (2002) and assessed using 70.9 km^2 minimum male home ranges.

Canada Lynx

Due to the assumed requirements for snow (270 cm/year) by Canada lynx, the only suitable habitat according to Hoving et al.'s (2005) model was found on Cape Breton Island (Figure 4.2). This habitat was only moderately suitable with the highest probability of lynx presence being 67 percent. In addition, the habitat was patchy with poor connectivity. A maximum of 46 males could be supported in these patches, which even if they are functioning as a meta-population, is unlikely to be enough for short- or long-term population persistence (Table 4.1).

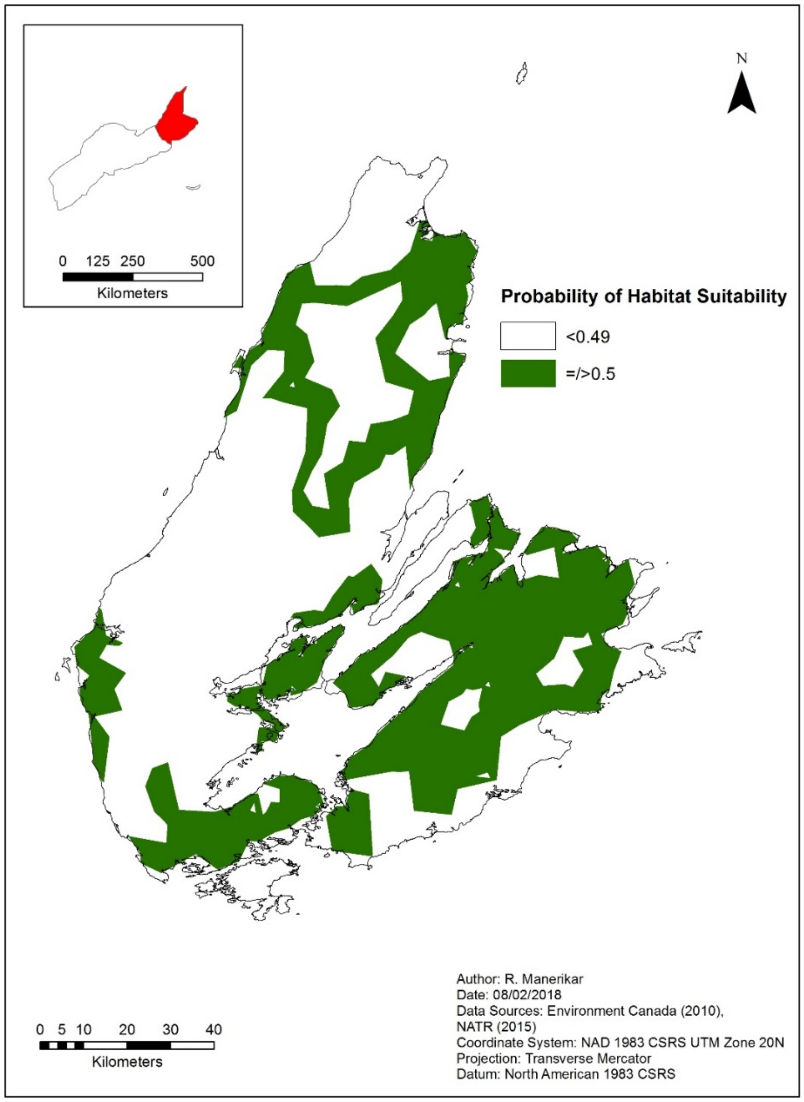

Figure 4.2 Probability of habitat suitability for Canada lynx on Cape Breton Island. Based on Hoving et al. (2005) and assessed using 100 km^2 minimum male home ranges (Burdett et al., 2007).

Eastern Cougar

Suitable habitat for eastern cougar was widespread throughout Nova Scotia based on LaRue & Nielsen's (2011) model (Figure 4.3). The habitat was well-connected throughout the province. These patches should support 655 males, which if functioning as a meta-population should be sufficient for short-term population viability but not for long-term (Table 4.1).

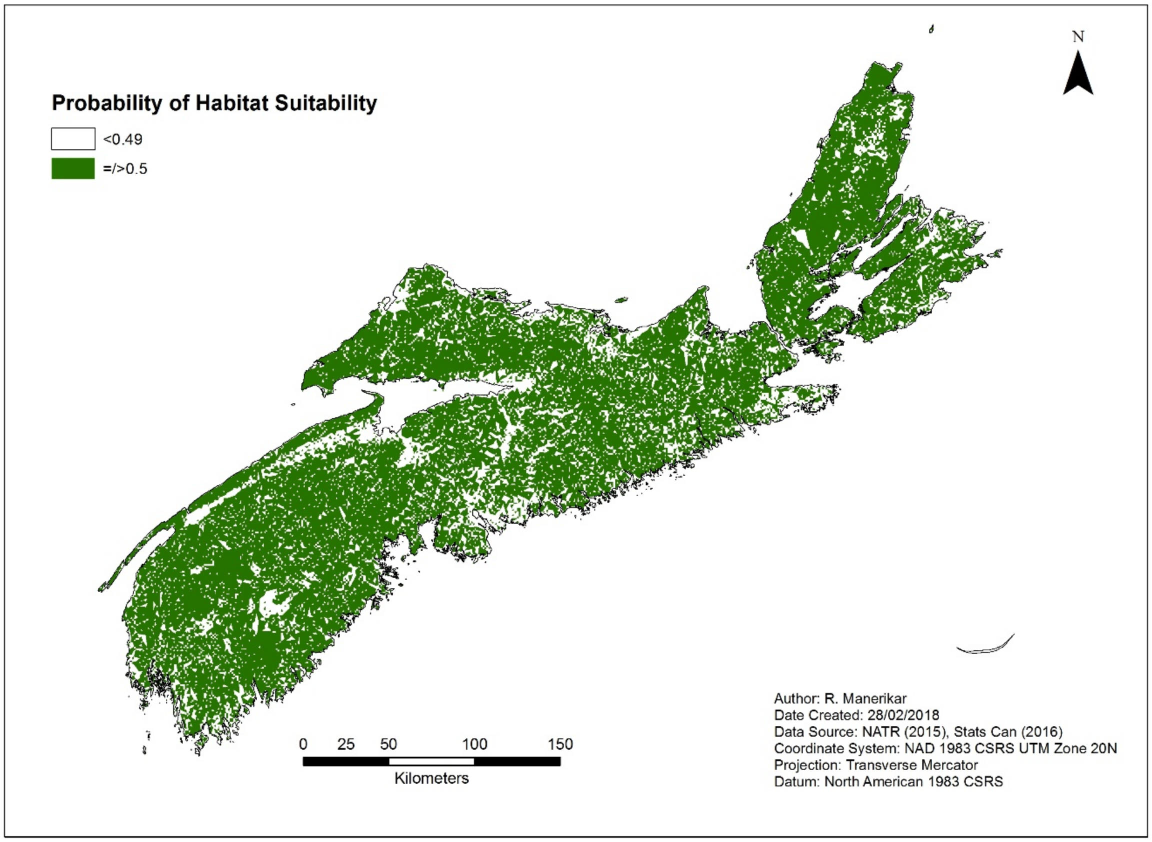

Figure 4.3 Probability of habitat suitability for eastern cougar in Nova Scotia. Based on LaRue & Nielsen (2011) and assessed based on 65 km^2 minimum male home ranges (Canadian Geographic, 2007).

Road Density

There is an abundance of roads cross-cutting the province of Nova Scotia (Figure 4.4, 4.5, 4.6). Paved roads are mainly found along the coastline, Annapolis Valley, the Halifax Regional Municipality, and other urban centers. When taking into consideration recreation and resource roads, Nova Scotia exhibits many more areas that exceed the established thresholds for road density.

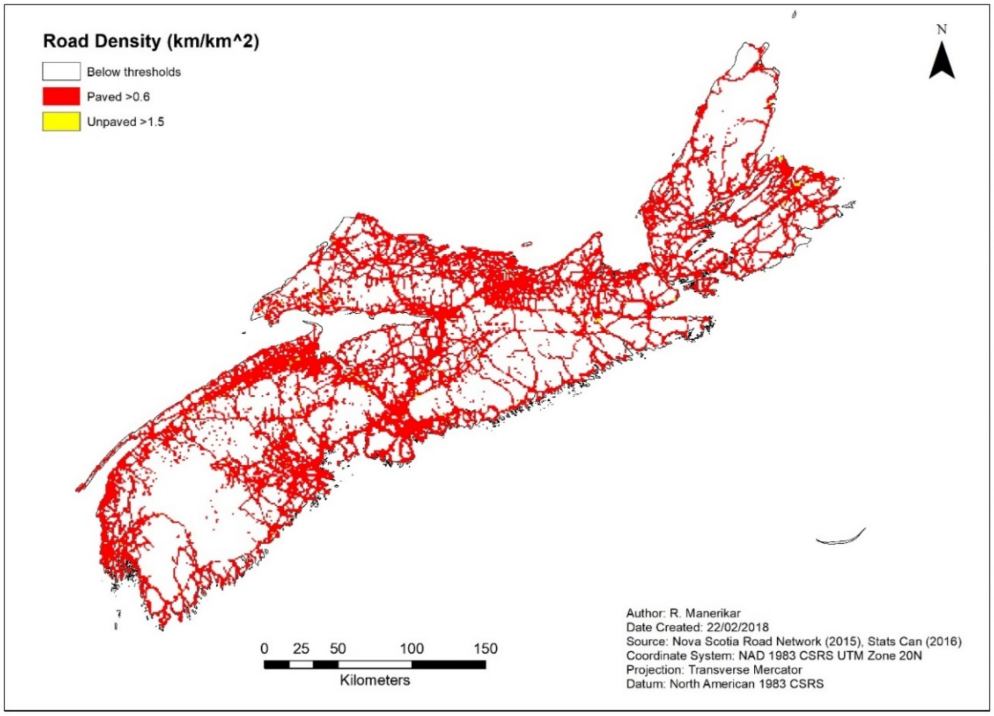

Figure 4.4. All roads above established thresholds for bobcat in Nova Scotia. For bobcat, the paved threshold was 0.6 km/km^2 while the unpaved threshold was 1.5 km/km^2 (Crooks, 2002; Jalkotzy, Ross, & Nasserden, 1997).

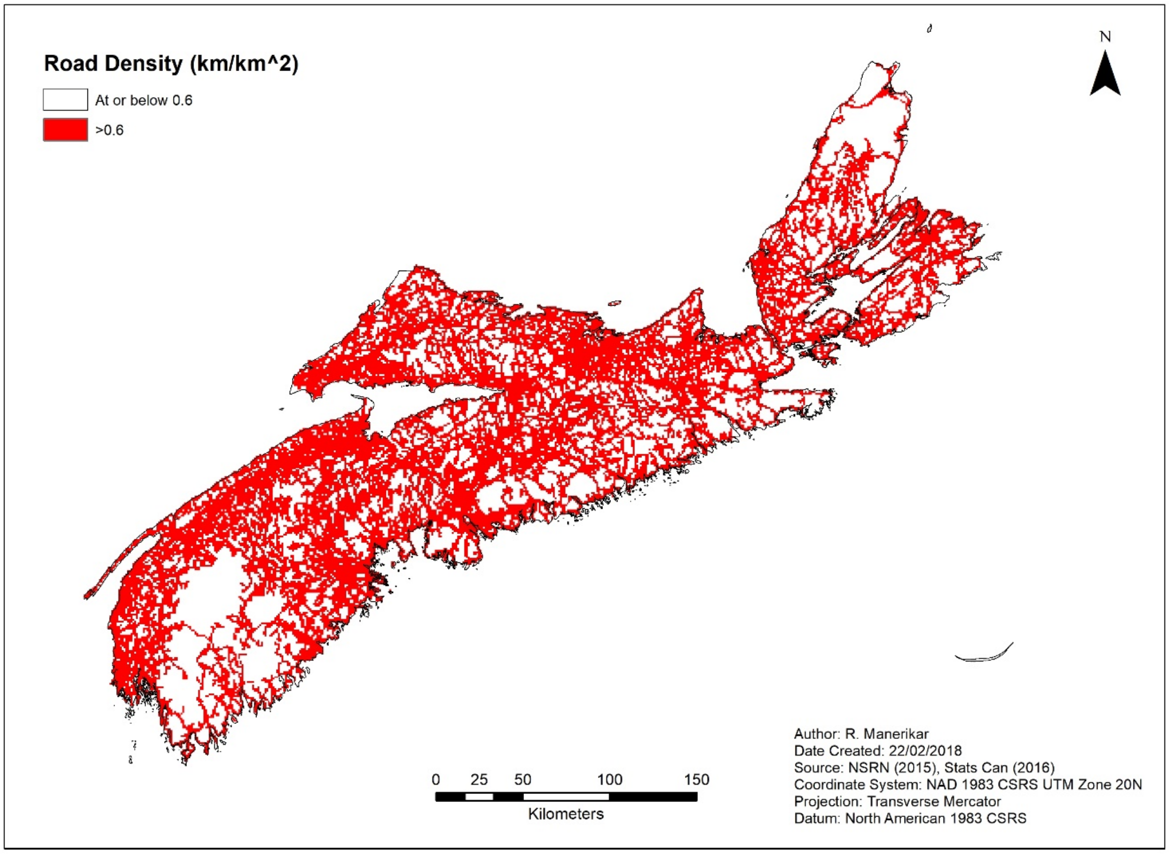

Figure 4.5 All roads above the established threshold (0.6 km/km^2) for Canada lynx and eastern cougar in Nova Scotia (Hoving et al., 2005; Thiel, 1985; Van Dyke et al. 1986).

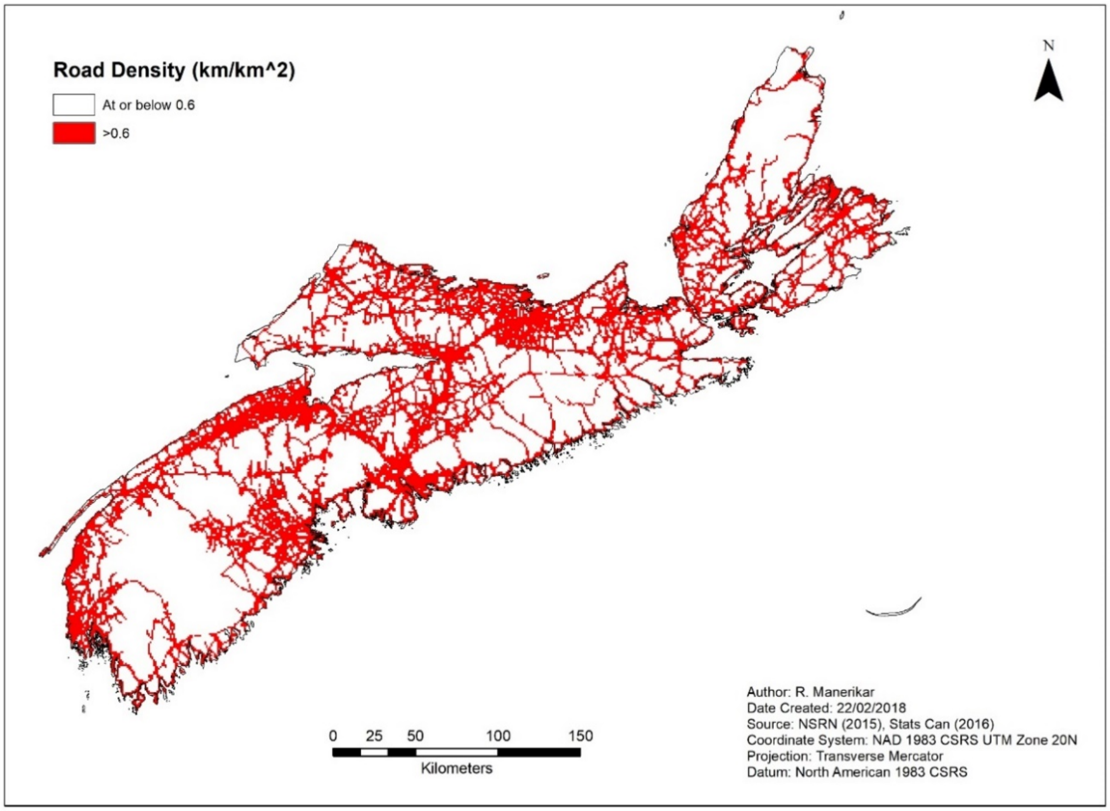

Figure 4.6 Paved road densities above threshold (0.6 km/km^2) for bobcat, Canada lynx and eastern cougar in Nova Scotia (Jalkotzy, Ross, & Nasserden, 1997; Hoving et al., 2005; Thiel, 1985; Van Dyke et al. 1986).

Habitat Effectiveness

The amount of effective habitat was greater for calculations only including paved roads when compared to calculations including all roads (Table 4.2, 4.3, 4.4). Very few patches support more than 10 males of any of the species (Table 4.4). No single patch could support short- or long-term populations of any of the three species (Table 4.3).

Table 4.2 Amount of effective habitat and total number of males supported for each species for all roads and paved roads.

		Total effective habitat (km^2)	Males supported
Bobcat	All roads	25 632	340
	Paved roads	26 701	353
Canada lynx	All roads	1 669	7
	Paved roads	2 953	13
Eastern cougar	All roads	6 564	87
	Paved roads	20 234	268

Table 4.3 Breakdown of how many effective habitat patches are large enough to support each category of numbers of males for all roads and paved roads effective habitat. No patches supported > 125 males.

		Number of patches large enough to support categories of numbers of males						
		1-25 males	26-50 males	51-75 males	76-100 males	101-125 males	Total Patches	Total Number of Males
Bobcat	All Roads	47	1	1	0	1	50	340
	Paved Roads	46	1	1	0	1	49	353
Canada Lynx	All Roads	4	0	0	0	0	4	7
	Paved Roads	7	0	0	0	0	7	12
Eastern Cougar	All Roads	32	1	0	0	0	33	87
	Paved Roads	60	1	1	0	0	62	286

Table 4.4 Breakdown of how many effective habitat patches are large enough support each number of males (under 10) for all roads and paved roads.

		Number of patches large enough to support each category of males										
		1 male	2 males	3 males	4 males	5 males	6 males	7 males	8 males	9 males	10+ males	Total Patches
Bobcat	All roads	21	10	4	3	0	4	1	0	1	6	50

	Paved roads	21	9	4	3	0	3	1	0	0	8	49
Canada lynx	All roads	3	0	0	1	0	0	0	0	0	0	4
	Paved roads	4	1	1	1	0	0	0	0	0	0	7
Eastern cougar	All roads	15	10	4	2	0	1	0	0	0	1	33
	Paved roads	30	12	5	3	0	1	1	1	0	9	62

Bobcat – All Roads

The amount of effective habitat for bobcat when incorporating all roads was nearly half (49 percent) the suitable habitat (Table 4.1, 4.2). While the suitable habitat is well-connected, the effective habitat is patchy, with limited connection between patches (Figure 4.7). Out of the 50 patches, 21 support only one male (Table 4.4). Six out of 50 patches would support 10 or more males, with only three of these supporting 26 or more, and with the largest of these patches in southwestern Nova Scotia supporting 103 males (Appendix 1). While none of the patches could support a viable population, collectively the province has enough effective habitat for 340 males, which if functioning as a meta-population would maintain a short-term viable population but not a long-term population (Table 4.1, 4.2).

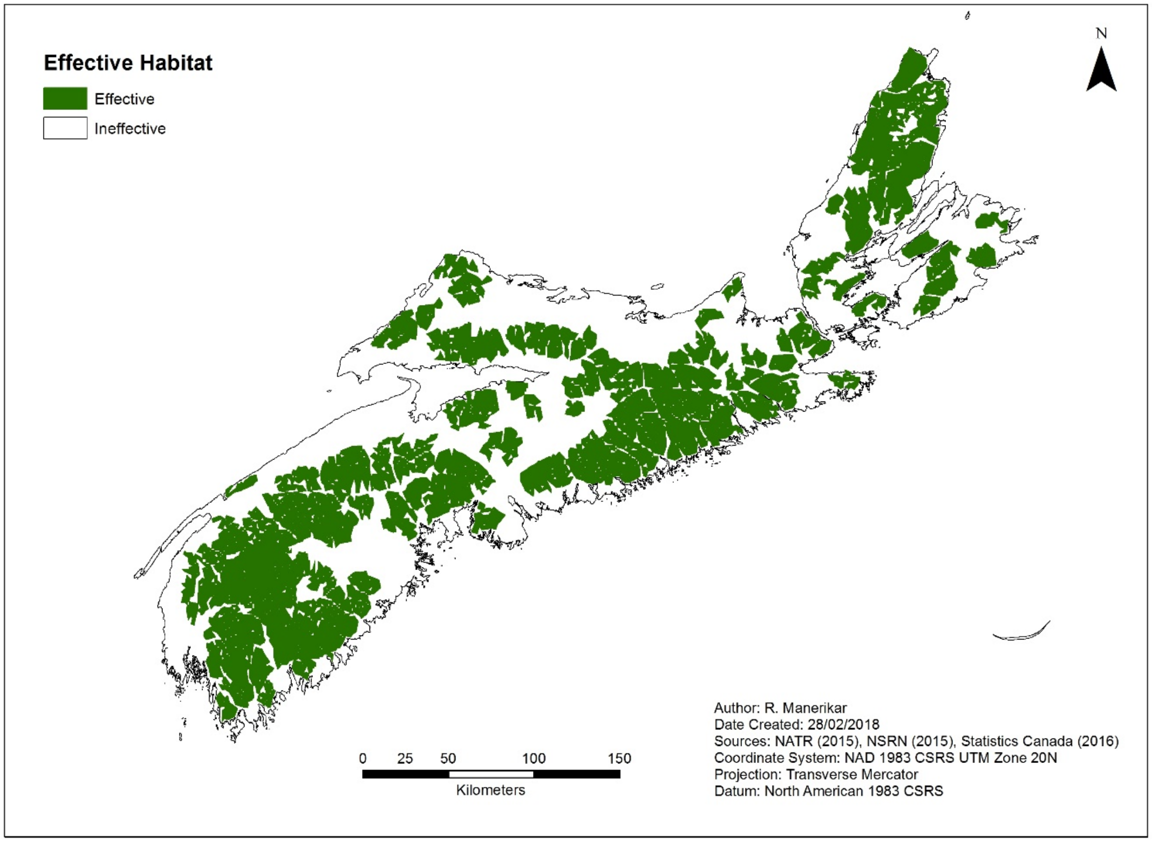

Figure 4.7 Habitat effectiveness in Nova Scotia for bobcat. Based on Woolf et al.'s (2002) habitat suitability model and road density for all roads (paved <0.6 km/km^2 threshold; unpaved <1.5 km/km^2 threshold; Crooks, 2002; Jalkotzy, Ross, & Nasserden, 1997).

Canada Lynx – All Roads

Canada lynx effective habitat was only 36 percent of the suitable habitat when considering all roads (Table 4.1, 4.2). The four effective patches were limited to the Cape Breton Highlands and an isolated area to the southeast (Figure 4.8). Three of these four patches are only large enough to support one male, while the other patch can support four males (Table 4.4). There is enough effective habitat to support seven males on Cape Breton Island which is not enough to maintain short- nor long-term viable populations (Table 4.1).

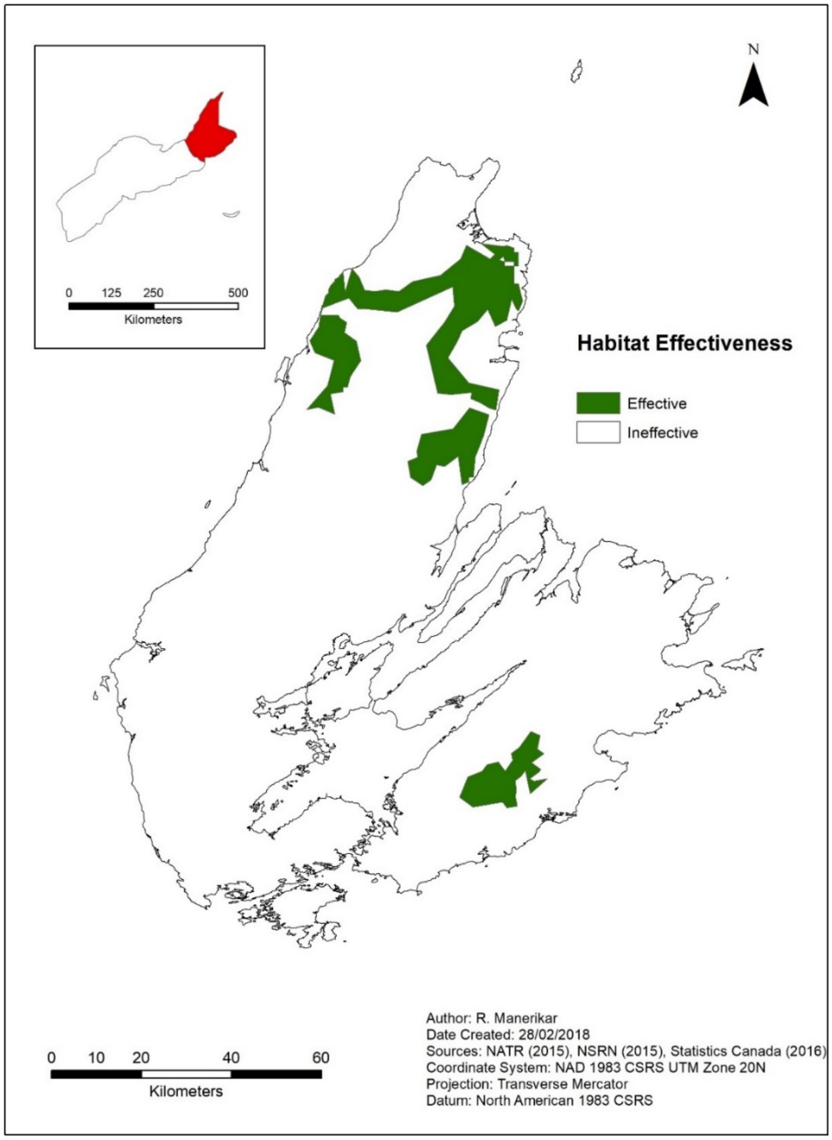

Figure 4.8 Habitat effectiveness in Nova Scotia for Canada lynx. Based on Hoving et al.'s (2005) habitat suitability model and road density for all roads (<0.6 km/km^2 threshold; Thiel, 1985; Van Dyke et al. 1986).

Eastern Cougar – All Roads

Incorporating all roads had a dramatic impact on eastern cougar effective habitat. Only 15 percent of the suitable habitat was found to be effective (Table 4.1, 4.2). In addition, the effective habitat is patchy and dispersed (Figure 4.9). Out of the 33 effective patches, 15 support only one male and 10 support two males (Table 4.4). The largest patch is found in southwestern Nova Scotia and should support 26 males. Nova Scotia has enough effective habitat for 87 males, which will not maintain short- nor long-term viable populations of eastern cougar (Table 4.1, 4.2).

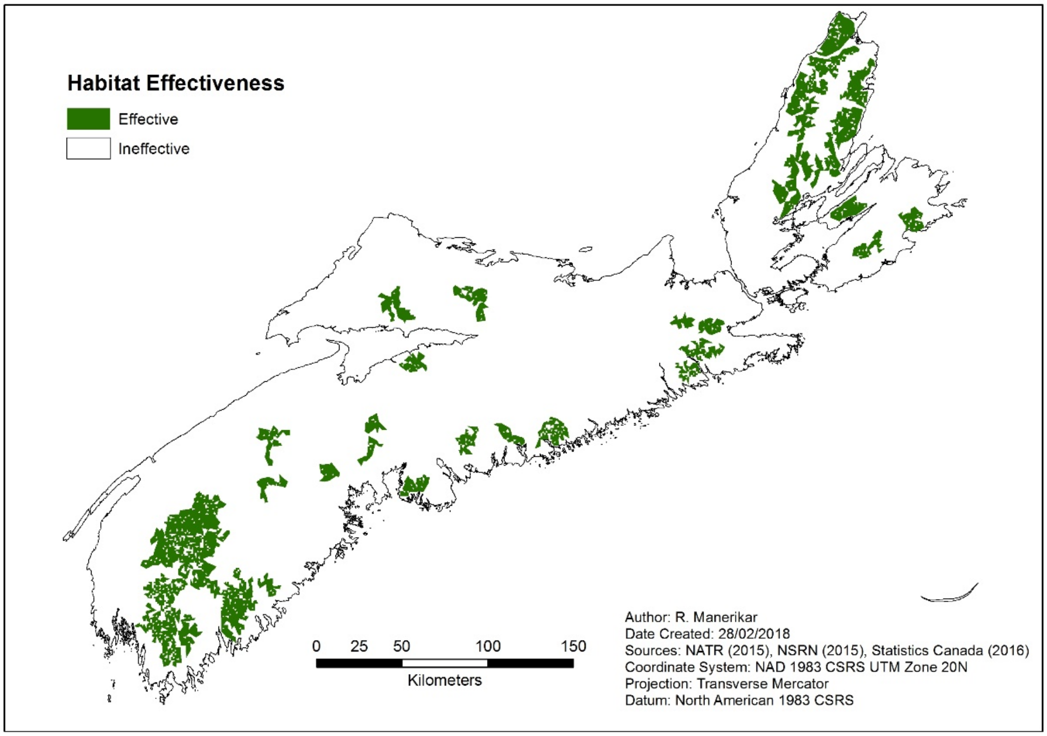

Figure 4.9 Habitat effectiveness in Nova Scotia for eastern cougar. Based on LaRue & Nielsen's (2011) habitat suitability model and road density for all roads (<0.6 km/km^2 threshold; Thiel, 1985; Van Dyke et al. 1986).

Bobcat - Paved Roads

As bobcat had a higher tolerance for unpaved roads than Canada lynx or eastern cougar, the effective habitat incorporating only paved roads was similar to the one incorporating all roads (51 percent, Figure 4.10). There was the same number of one-male patches (21) for both effective habitat models (Table 4.4). In general, the patches supporting over 26 males increased in size when only incorporating paved roads (Appendix 1). The largest patch supported 105 males. This effective habitat model shows Nova Scotia supporting 353 males, which if functioning as a meta-population is enough to support a short-term viable population, but not a long-term viable population, if connectivity is improved (Table 4.1, 4.2).

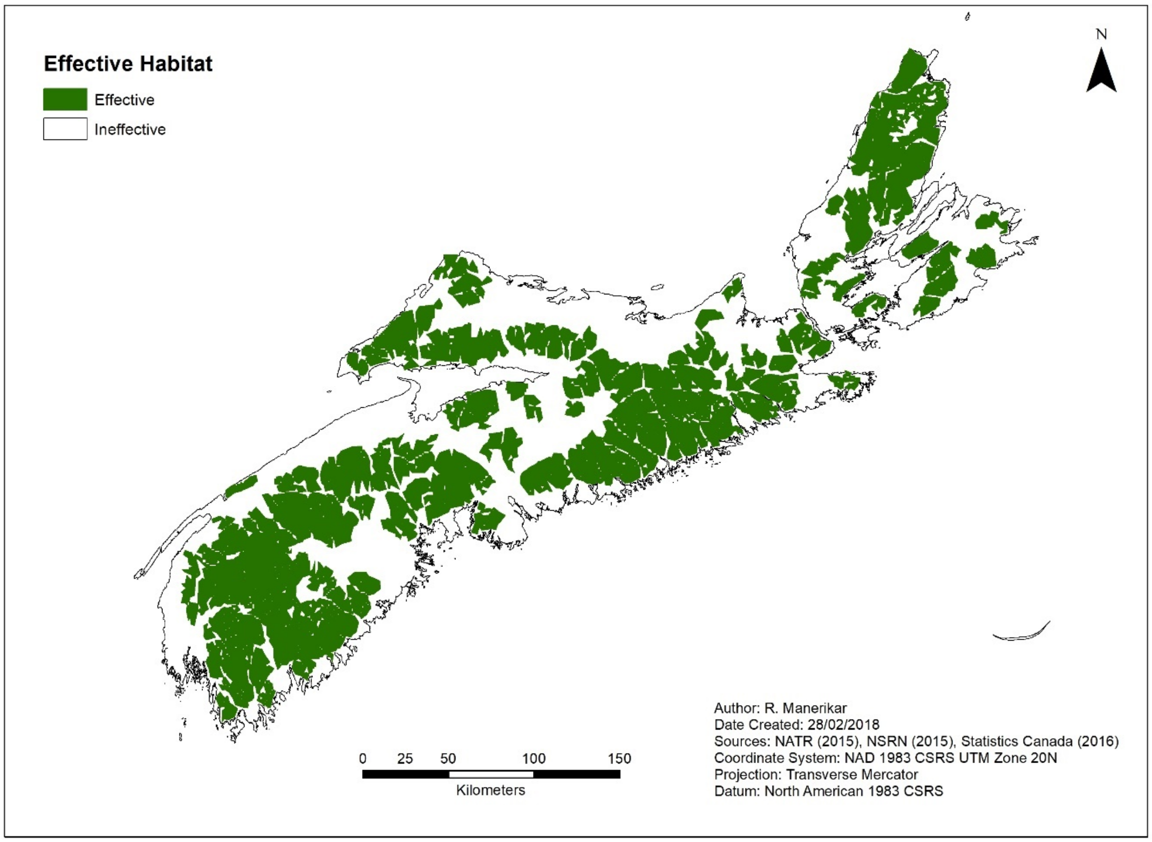

Figure 4.10 Habitat effectiveness in Nova Scotia for bobcat. Based on Woolf et al.'s (2002) habitat suitability model and road density for paved roads (paved <0.6 km/km^2 threshold; unpaved <1.5 km/km^2 threshold; Crooks, 2002; Jalkotzy, Ross, & Nasserden, 1997).

Canada Lynx – Paved Roads

Considering paved roads alone resulted in much more effective habitat area for the Canada lynx (Figure 4.11): 64 percent of the suitable habitat was found to be effective using this method (Table 4.5). There were seven patches compared to only four, however, none of the patches supported more than four males (Table 4.2, 4.3). Lack of connectivity is an issue, especially between the Cape Breton Highland patches and those towards the southeast. A total of 13 males could be supported on Cape Breton Island, which is not enough to support short- or long-term viable populations (Table 4.1).

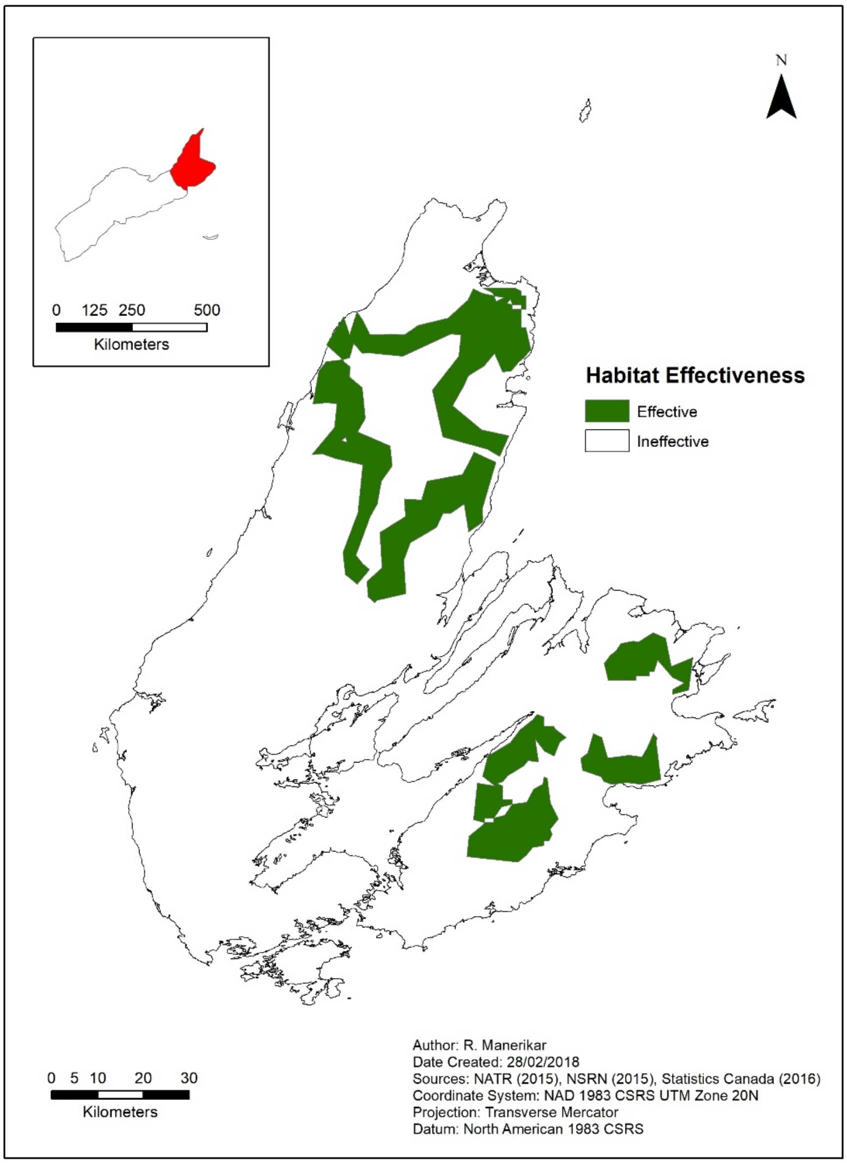

Figure 4.11 Habitat effectiveness in Nova Scotia for Canada lynx. Based on Hoving et al.'s (2005) habitat suitability model and road density for paved roads (<0.6 km/km^2 threshold; Thiel, 1985; Van Dyke et al. 1986).

Eastern Cougar – Paved Roads

Assessing habitat effectiveness using only paved roads resulted in more effective habitat for eastern cougar (47 percent of suitable habitat; Table 4.2, 4.3). Habitat was still highly fragmented, with very little effective habitat in the center of the province (Figure 4.12). The majority of patches still only held one or two males (42 out of 62 patches; Table 4.2, 4.3). However, the number of patches supporting 10 or more males increased (from one to nine). The largest patch held 74 males. In total, Nova Scotia could support 268 males when considering only paved roads (Table 4.2). If functioning as a meta-population it should be sufficient to support a short-term viable population but not a long-term viable population (Table 4.1).

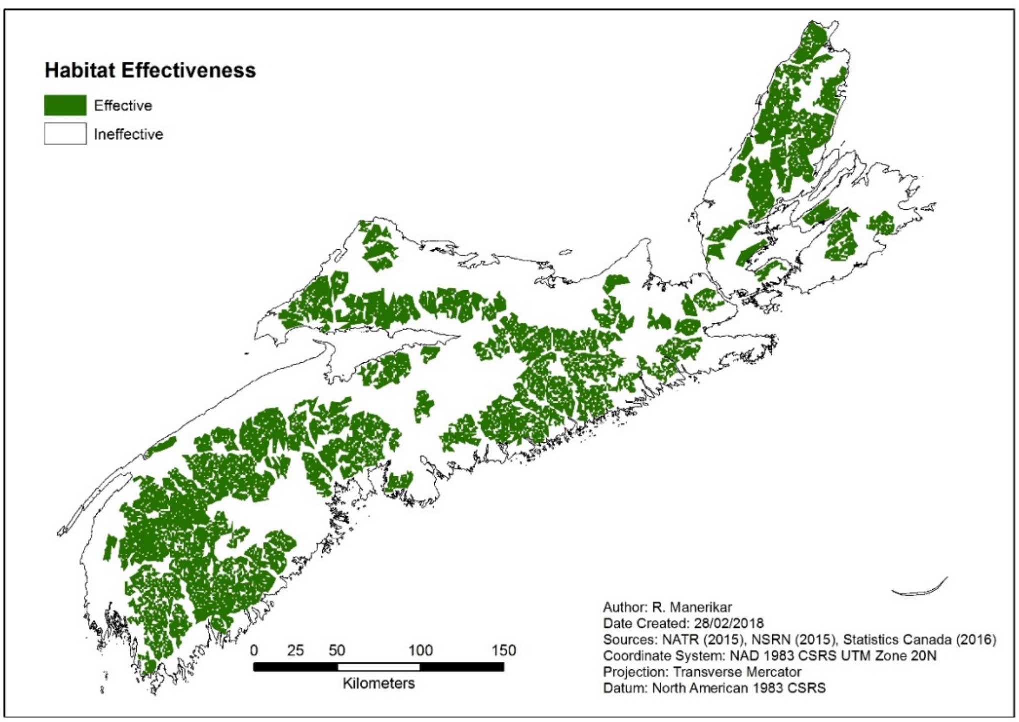

Figure 4.12 Habitat effectiveness in Nova Scotia for eastern cougar. Based on LaRue & Nielsen's (2011) habitat suitability model and road density for paved roads (<0.6 km/km^2 threshold; Thiel, 1985; Van Dyke et al. 1986).

Chapter 5: Discussion

Nova Scotia does not have sufficiently connected areas of effective habitat for populations of bobcat, Canada lynx, or eastern cougar to persist over the long-term. For the short-term (< 100 years), bobcat could be supported, however, habitat patches would need to be connected. Eastern cougar has potential effective habitat to support a short-term population if some unpaved roads are decommissioned and connectivity is improved. Canada lynx is in a dire situation with limited habitat and the threat of global warming expected to reduce this further in the future.

Habitat Suitability

As bobcat and eastern cougar are both generalists, it was predicted that there would be large amounts of suitable habitat for these species in Nova Scotia (ISEC, 2016; Loveless et al., 2016; Fuller, Harrison, & Vashon, 2007). This was found to be the case. While a high percentage of the province was found to be suitable (94 percent for bobcat, 81 percent for eastern cougar), 75 percent of Nova Scotia is potentially tree-dominant, which is one of the preferred habitats for both species (ISEC, 2016; Loveless et al., 2016; Reed et al., 2017; NS DNR, 2016; U.S. Fish and Wildlife Service, 2010). Habitat suitability has not been quantified for these species in Nova Scotia before and thus local comparisons cannot be made.

Canada lynx are specialists (Fuller & Harrison, 2010; Fuller, Harrison, & Vashon, 2007). Their minimum snow requirement resulted in them being isolated to Cape Breton Island. These results were in agreement with Hoving et al.'s (2005), whose model was used. The extent of suitable habitat in Nova Scotia differed slightly from Hoving et al.'s (2005) study, which may be attributed to snowfall patterns changing and/or a different landcover dataset being used. Hoving et al. (2005) found 4 538 km^2 of suitable habitat on the island, whereas this study found 4 627 km^2.

Habitat Effectiveness

Roads greatly impacted the amount of effective habitat in Nova Scotia for all three species. While suitable habitat was widespread for both bobcat and eastern cougar, once roads were factored in, the landscape became highly fragmented. As expected, incorporating all roads resulted in less effective habitat compared to incorporating only paved roads for all wildcat species.

For eastern cougar, the LaRue and Nielsen (2011) habitat suitability model did factor in distance to roads. However, based on this model, the greatest reduction in habitat suitability would have been 16.5 percent (if a road was present within three kilometers). If the surrounding land class was considered to have a suitability of 66.5 percent or greater, the presence of roads would not reduce suitability below the 50 percent threshold. In the habitat effectiveness model, road density was weighted as equal to habitat suitability. Therefore, if roads were present in a density over the established threshold, the habitat was not considered effective.

Roads are of concern for numerous reasons. First, they disrupt the continuity of habitat and restrict the movement of individuals due to the barrier effect (Chen & Koprowski, 2016). This is of high concern for native wildcats as they are solitary and require dispersal networks to establish their own home ranges (Beckmann & Hilty, 2010; Burdett et al., 2007; Donovan et al., 2011; Kertsen et al., 2011). In addition, the creation of roads equals the loss or conversion of habitat (Jalkotzy, Ross, & Nasserden, 1997). This loss is not restricted to solely the road but also the area around the road that has been modified (Jalkotzy, Ross, & Nasserden, 1997). When there is limited suitable habitat initially, roads further compound the issue.

Another problem is the fragmentation of a population into smaller and more vulnerable local groups (Beckmann & Hilty, 2010). The most frequent patch size for all three wildcat species only supported one male. Smaller populations are more susceptible to environmental, genetic, and demographic stochasticities, as well as natural catastrophes (Hanski, 1998; Shaffer, 1981). Variations involving habitat and other species, including diseases, represent environmental stochasticity factors (Shaffer, 1981). Demographic stochasticity is the variability in birth and death rates of a population (Shaffer, 1981). This is tied in with genetic stochasticity which focuses on genetic phenomenon such as inbreeding effect and genetic drift (Reed, Nicholas, & Stratton, 2007). The lack of genetic variations in a small population can result in lower fecundity for individuals, which is further detrimental to conservation efforts (Reed, Nicholas, & Stratton, 2007). If populations of wildcats are isolated, there will be a dearth of new genetic material to diversify the gene pool, which makes the population more susceptible to chance events. Finally, natural catastrophes, such as extreme weather events, that drastically reduce populations have a greater impact on smaller populations than larger ones (Lande, 1993). With global warming predicted to increase the amount of natural disasters, having populations large enough to survive an increasing frequency of catastrophes is important if persistence of these species is desired (van Aalst, 2006).

Direct mortality from vehicular collisions is an issue, especially for Canada lynx and eastern cougar (Parker, 2001; Vickers et al., 2015; White, 2017). Thus, deterrents for crossing roads should be implemented in high mortality areas and safe passage (such as underpasses) should be facilitated in key areas.

Roads (even unpaved ones) allow for humans to access otherwise unreachable areas where noise and hunting activities may have negative impacts on wildlife (Jalkotzy, Ross, & Nasserden, 1997). Bobcat are the only wildcat species that may be legally trapped and/or hunted in Nova Scotia, however, there have been accidental Canada lynx kills (NS DNR, 2017). Old logging roads should be decommissioned and reclaimed to deter such activities in key areas. Permits for bobcat and other hunting and trapping that may result in Canada lynx bycatch should be prohibited or restricted. This would not only reduce the amount of trapping/hunting in populated regions, but also help with connectivity, especially for Canada lynx and eastern cougar, by reducing barriers and increasing amount of effective habitat. Reducing access to and maintenance of logging roads in lynx habitat would also decrease coyote and bobcat access, increasing lynx competitive advantage by decreasing competition for key prey.

Evidently, roads are of concern for Nova Scotian wildcats for numerous reasons. In order for a viable population to be supported either solely in the province or as part of a larger metapopulation, connectivity needs to be improved and threats need to be mitigated.

Improving Connectivity

A major issue for all wildcat species is the lack of connectivity between patches. As mentioned above, small populations have a greater risk of extinction and the majority patches for each of the species support less than ten males. For the patches to be able to function as a metapopulation, increasing habitat connectivity to facilitate safe movement is required. Ideally, connectivity would be improved between all patches. In reality, patches that are close together and can be connected through a relatively 'easier' solution, such as voluntary restrictions in access, discontinued road maintenance, decommissioning and/or reclamation of roadbeds, represent more politically acceptable means of restoration.

In addition, there are three major areas of concern for connectivity on mainland Nova Scotia (Figure 5.1). Highways 101 and 102 connecting Halifax to the Annapolis Valley and Truro areas isolates south western habitat patches and populations of bobcat and eastern cougar from the rest of the province. There is also a major barrier from Truro to New Glasgow along Highway 104 that hinders movement of individuals from Nova Scotia into the Cobequid Hills and beyond, into New Brunswick and vice versa. As there is already not enough effective habitat to support persisting populations of wildcats in Nova Scotia alone, the impediments to connection to NB is a significant problem.

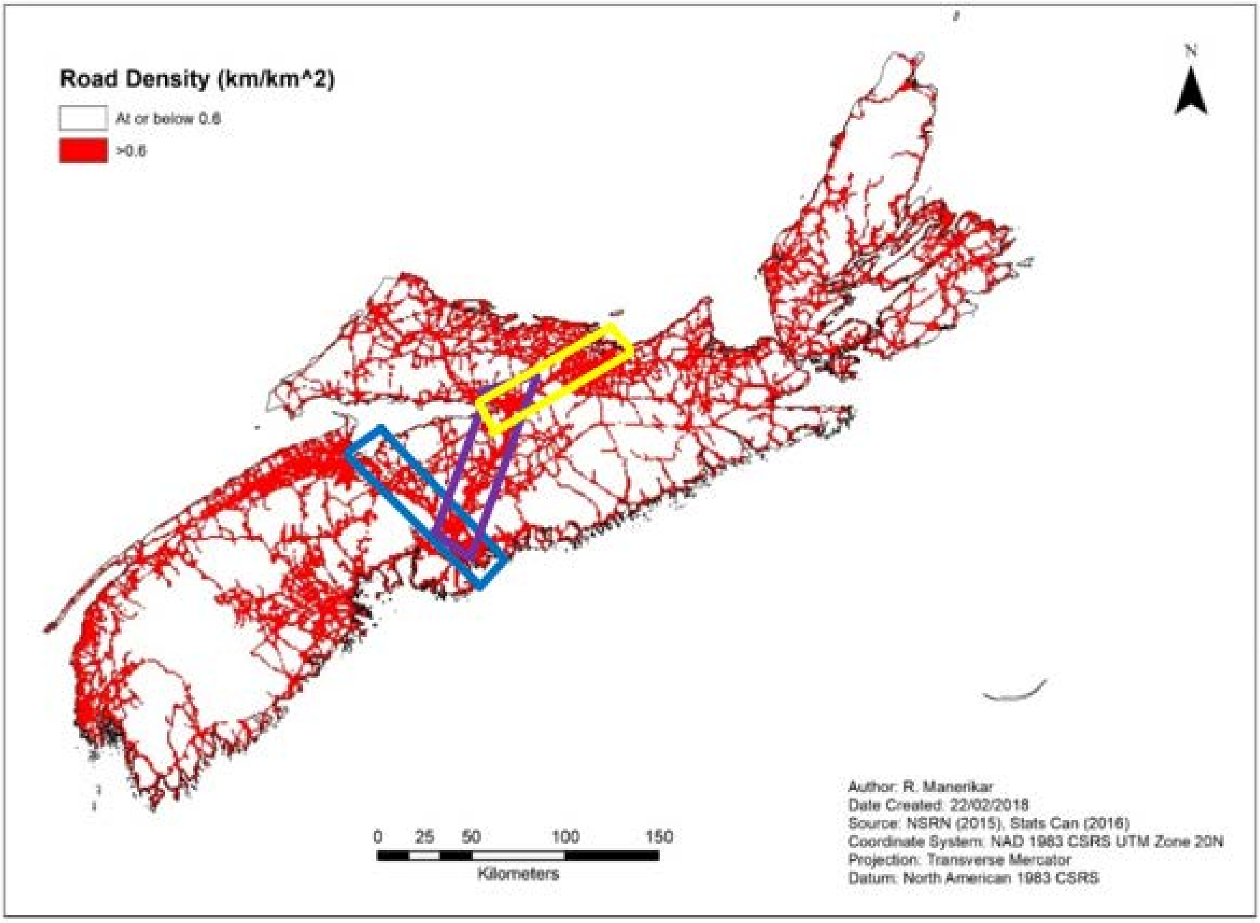

Figure 5.1 Map showing paved road density exceeding 0.6 km/km^2 in Nova Scotia. Key areas indicated in boxes (blue = Highway 101, purple = Highway 102, yellow = Highway 104).

There is currently a culvert intended to serve as a wildlife underpass under Highway 104, but between 2015 and 2016 no bobcat used it (White, 2017). However, a study conducted in Banff National Park found that cougar were using open-span underpasses more than other types of crossing structures (culverts, creek bridges, overpasses; Gloyne & Clevenger, 2001). Underpasses have also been found to be effective for bobcat and cougar in Florida (Foster & Humphrey, 1995). As underpasses are working in other areas, there is a possibility of them being successful in Nova Scotia. White (2017) suggested that underpasses should have native vegetation funnel leading to the entrances, as well as within the underpasses. In addition, White (2017) suggests that wildlife fences be placed on either side of the entrance. Making these changes and installing multiple wildlife crossings along highways and other primary roads would hopefully facilitate movement of wildcats.

If connectivity is improved, bobcat can be expected to persist as a subpopulation in Nova Scotia over the long-term. There is also the opportunity for eastern cougar to recolonize the province, and have, at a minimum, short-term population viability in NS, and long-term viability if connectivity with New Brunswick is restored.

For Canada lynx, connectivity should be improved in the Cape Breton Highlands. The current lack of effective habitat in the region does not bode well for the species. The Nova Scotia Lynx Recovery Team (2006) identified the importance of connecting Cape Breton to New Brunswick via the Cobequids and Chignecto Isthmus, however they also recognized that the feasibility of recovering Canada lynx in Nova Scotia was uncertain. Based on this study, the short-term and long-term persistence of the Canada lynx is in question and would require serious attention to decreasing road density.

This study may overestimate the amount of suitable and effective habitat within Nova Scotia as it counted forested land as forest. In addition, there may have been minimal distortion in area sizes from the choice of conformal projection (UTM). Despite these limitations, this study shows the importance of not relying solely on suitable habitat when making planning and management decisions. The suitable areas did not account for roads and other aspects of human influence and fragmentation of the landscape to a sufficient degree and thus drastically overestimated the amount of available habitat for wildcat species in Nova Scotia. In addition, in land planning and resource management there is a general lack of accounting for the extensive population and habitat areas required to maintain and restore viable populations of species over short- and long-terms. Thus, habitat effectiveness, minimum viable population, and minimum critical area sizes all need to be taken into consideration when making conservation decisions.

Chapter 6: Conclusion

This study has quantified the effective habitat for native wildcat species in Nova Scotia. As these species are considered appropriate focal species, these results can be used to guide conservation and other land planning and management efforts. They represent important foci of conservation because of their (1) current and/or potential at-risk status in Nova Scotia, (2) important function as apex consumers in healthy ecosystems, (3) large- and wide-ranging habitat requirements, which if conserved would capture many other sympatric species and ecosystems with smaller area requirements, (4) sensitivity and vulnerability to human influences, and (5) public appeal as charismatic or flagship species (Beazley & Cardinal, 2004; Estes et al., 2011; Ripple et al., 2014; Weiss-Reid & Beazley, 2005).

Nova Scotia alone does not have enough effective habitat to support long-term viable populations of bobcat, Canada lynx, or eastern cougar. If connectivity is improved within the province, populations of bobcat and eastern cougar could persist over the short-term. However, for long-term maintenance of these species the movement of individuals to and from New Brunswick is required. Due to currently limited habitat, high fragmentation and increasing threats from climate change and bobcat and coyote competition, the survival of Canada lynx on Cape Breton is in question.

Future research should be directed at validating the habitat effectiveness models used in this study. Observational studies involving the tracking of individuals would be informative and would further conservation plans. Nonetheless, the results show that consideration of habitat suitability alone, without adequate consideration of its effectiveness in terms of minimizing human influences, is insufficient. Habitat suitability alone provides an incomplete picture of the ability of wildlife to use the habitat and to survive over time. Habitat suitability alone often results in the identification of sink habitat. When effective habitat is taken into account, a dramatically reduced habitat area is identified, often insufficient in size and connectivity to support viable populations of wide ranging species sensitive to human activities. Habitat effectiveness needs to be more systematically incorporated into land use, transportation, and resource planning and management (including forestry and wildlife management and recovery of species at risk).

Efforts should be made to obtain more accurate information on population numbers for bobcat in Nova Scotia. The current practice of distributing bobcat hunting/trapping licenses without knowing the state of the species has the potential to reduce their numbers to below a viable population level. The number of licenses allocated should be based on scientific data and analyses that ensure a healthy population can persist. No bobcat licenses should be issued for regions in proximity to lynx habitat.

Logging companies and other managers of unpaved roads should decrease access to and maintenance of these roads, and increase the abandonment and reclamation of roadbeds in wildcat-populated regions. Passable roads contribute to mortality through ease-of-access for hunters and trappers, coyotes and other competitors and predators, and act as impediments to wildcat movements.

Opportunities for enhancing safe passage for wildlife across major highways throughout the province should be identified and mitigation measures implemented. This will facilitate the movement of individuals between effective patches within the province and beyond, into New Brunswick, for both short- and long-term population viability for wildcats and other species.

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Appendix 1: Areas of effective habitat for bobcat, Canada lynx, and eastern cougar based on all roads and paved roads.

All Roads						Paved Roads					
Bobcat		Canada Lynx		Eastern Cougar		Bobcat		Canada Lynx		Eastern Cougar	
Patch	Area (km^2)	Patch	Area (km^2)	Patch	Area (km^2)	Patch	Area (km^2)	Patch	Area (km^2)	Patch	Area (km^2)
1	72.12	1	126.79	1	67.27	1	72.12	1	112.54	1	65.71
2	72.26	2	144.52	2	67.33	2	72.42	2	123.30	2	66.66
3	72.42	3	159.19	3	73.46	3	76.13	3	159.88	3	70.43
4	75.99	4	474.5	4	74.04	4	77.85	4	187.84	4	71.14
5	76.13			5	74.64	5	78.58	5	288.15	5	71.94
6	77.85			6	80.93	6	83.24	6	299.21	6	74.46
7	79.62			7	84.74	7	90.20	7	494.48	7	75.18
8	80.10			8	86.18	8	94.50			8	75.41
9	86.36			9	97.84	9	96.62			9	76.90
10	96.62			10	98.86	10	98.18			10	77.37
11	98.18			11	100.19	11	102.13			11	77.60
12	99.99			12	102.69	12	104.11			12	79.04
13	102.13			13	112.48	13	104.50			13	79.45
14	104.11			14	114.35	14	111.99			14	81.17
15	110.78			15	117.68	15	113.10			15	82.87
16	111.99			16	139.21	16	119.33			16	84.25
17	115.06			17	141.68	17	121.14			17	91.26
18	120.46			18	144.55	18	123.73			18	94.81
19	122.64			19	149.39	19	123.73			19	100.64
20	123.73			20	152.95	20	124.93			20	100.82
21	124.93			21	156.88	21	127.23			21	102.36
22	155.44			22	173.74	22	160.51			22	102.38
23	160.51			23	179.76	23	166.51			23	108.19
24	164.22			24	182.44	24	169.73			24	112.71
25	171.05			25	185.61	25	171.05			25	114.26
26	179.96			26	211.49	26	180.01			26	118.87
27	180.10			27	219.18	27	186.10			27	120.16
28	186.56			28	245.21	28	188.94			28	124.48
29	203.14			29	255.63	29	204.75			29	127.47
30	203.73			30	265.41	30	205.19			30	128.10
31	208.29			31	281.12	31	254.59			31	135.34
32	239.85			32	389.75	32	267.30			32	137.29
33	251.66			33	1737.14	33	277.37			33	139.84
34	260.11					34	278.43			34	140.59
35	274.91					35	303.35			35	141.33
36	303.35					36	329.47			36	145.74
37	314.80					37	351.36			37	154.33
38	348.99					38	455.66			38	157.64
39	442.74					39	458.20			39	158.44
40	444.18					40	461.15			40	178.94
41	449.85					41	523.88			41	179.70

42	459.92					42	759.46			42	188.41
43	518.97					43	786.20			43	212.74
44	676.76					44	787.92			44	216.08
45	738.06					45	1093.41			45	229.05
46	1043.29					46	1319.08			46	238.87
47	1075.67					47	2935.42			47	256.47
48	2917.06					48	3764.76			48	266.50
49	3702.83					49	7506.28			49	272.73
50	7332.82									50	297.82
										51	426.79
										52	466.39
										53	570.64
										54	658.43
										55	676.85
										56	703.82
										57	784.98
										58	854.30
										59	867.66
										60	879.88
										61	1918.46
										62	4822.09