Modeling habitat connectivity and movement of Blanding's turtles (*Emydoidea blandingii*) across a fragmented landscape in Rouge National Urban Park, Ontario, Canada

ENVS 4902 Environmental Science Undergraduate Honours Thesis

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Abstract

Rouge National Urban Park is a highly fragmented park in Canada’s most populous city, Toronto, Ontario. Habitat fragmentation has been found to hinder conservation efforts due to the associated increased risks of species mortality when travelling between habitat patches. The park contains a population of endangered Blanding’s turtles (*Emydoidea blandingii*) augmented through a head-starting program that supplements wild populations by releasing captive raised young. Blanding’s turtle habitat size requirements are often underestimated, and little is known regarding the habitat selection of Blanding’s turtles in Rouge Park. This thesis examines the movement paths and habitat selection of Blanding’s turtles within the urban park. Blanding’s turtle habitat within the park was mapped using PlanetScope 3m Visible-Near Infrared remote sensing imagery. Habitat connectivity was modelled by completing a graph network and a least cost pathway (LCP) assessment. These assessments resulted in an evaluation of landscape connectivity and areas of facilitated turtle movement, as well as an LCP resistance map which identified discrete barriers to movement. Rouge Park contains 32 locations of road intersections along 16 paths of turtle movement, with a maximum of 4 road intersections per path. Although Rouge Park provides a less fragmented landscape than the surrounding area, there is only a moderate level of habitat connectivity within the park as a whole. It is anticipated that this model of turtle movement will help to target management and policy decisions, as well as habitat restoration efforts within Rouge National Urban Park and the surrounding area.

1.0 Introduction

1.1 Motivation

Habitat fragmentation resulting from anthropogenic development and urban sprawl is an increasing phenomenon globally (Irwin & Bockstael, 2007; Jaeger, Bertiller, Schwick & Kienast, 2010). This increase in edge space, or areas of discontinuity where a habitat abruptly ends (Temple, 1987), and lack of connectivity poses a threat to biodiversity for a number of reasons, including higher mortality (Concepcion et al., 2016) and higher rates of predation (Temple, 1987). In a Canadian context, an area of concern is Rouge National Urban Park (hereafter referred to as Rouge Park) in Toronto, which contains a population of Blanding's turtles (*Emydoidea blandingii*) (Toronto Zoo, n.d.). This species is listed as endangered both nationally by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC, 2016) and internationally by the International Union for the Conservation of Nature (IUCN) (van Dijk & Rhodin, 2011). Blanding's turtles are important because they are used as a model, or 'umbrella', species for wetland habitat conservation, as they are a long-lived species which moves extensively within their habitat (Herman et al., 2003). Habitat loss and accidental road mortality are listed as some of the top threats to Blanding's turtles (van Dijk & Rhodin, 2011), and it is for these reasons that research relating to the conservation of this species' habitat is valuable. By studying and protecting Blanding's turtle habitat, a number of other wetland species may also benefit, such as fish, amphibians, and waterfowl (Herman et al., 2003; Parks Canada, 2018). Although Rouge Park is intended as a refuge for rare wildlife and an area for habitat conservation (Parks Canada, 2017), it is highly fragmented (Wildlands League, 2018) and therefore conservation efforts may not be reaching their full potential. This thesis will examine the movement of Blanding's turtles within Rouge National Urban Park with respect to traversing areas of anthropogenic fragmentation. It is anticipated that the resulting model of turtle movement will help to target habitat restoration efforts within Rouge Park and the surrounding area, which will contribute to both habitat and species conservation efforts in Southern Ontario.

1.2 Background

With increasing global human populations and trends of movement toward urban centers (Satterthwaite, 2009), urban sprawl and the associated loss of habitat are increasing phenomena (Noss & Cooperrider, 1994; Jaeger et al., 2010). Urban sprawl is associated with habitat fragmentation, as well as decreases in the quality of ecosystems and landscapes (Jaeger et al., 2010), and loss of biodiversity (Fahrig, 2002). For example, populations of woodland caribou (*Rangifer tarandus caribou*) in Northern Ontario have declined due to development and the associated fragmentation of habitat (Miller, 2007). Specifically in Southern Ontario, wetland habitat is of high concern (Toronto and Region Conservation Authority, n.d.). In this region, the most concentrated areas of human development overlap with areas of wetland habitat, and the main cause of wetland loss in this region is anthropogenic land conversion (Ontario Ministry of Natural Resources and Forestry, 2017). Wetlands are highly productive, important, and valuable ecosystems. They are effective carbon sinks, and provide important habitat for a rich diversity of species (US Environmental Protection Agency, 2018).

Rouge National Urban Park is located in Ontario just outside of Toronto, and covers an area of 47 square kilometers (Figure 1). Located within the Park boundaries are over 1,700 species, 23 of which are at risk (Wildlands League, 2018). The Park also protects the lower Rouge watershed, which is the last entirely undeveloped watershed in the Western Lake Ontario region (Wildlands League, 2018). The Park is highly fragmented, with over 75 percent of its area having been altered by anthropogenic disturbances such as roads, housing developments, and agricultural lands (Parks Canada, 2017). Along with valuable habitats and rare species, the park aims to protect the areas of agriculture within its borders, as urban farmland is also considered a valuable resource (Parks Canada, 2017). In addition to the conservation efforts of Rouge Park, the Toronto and Region Conservation Authority (TRCA) is interested in wetland conservation and restoration. The TRCA is also interested in the creation of new wetlands in the Toronto area, as over 85 percent of the wetlands originally found in this area have been lost due to development (Toronto and Region Conservation Authority, n.d.).

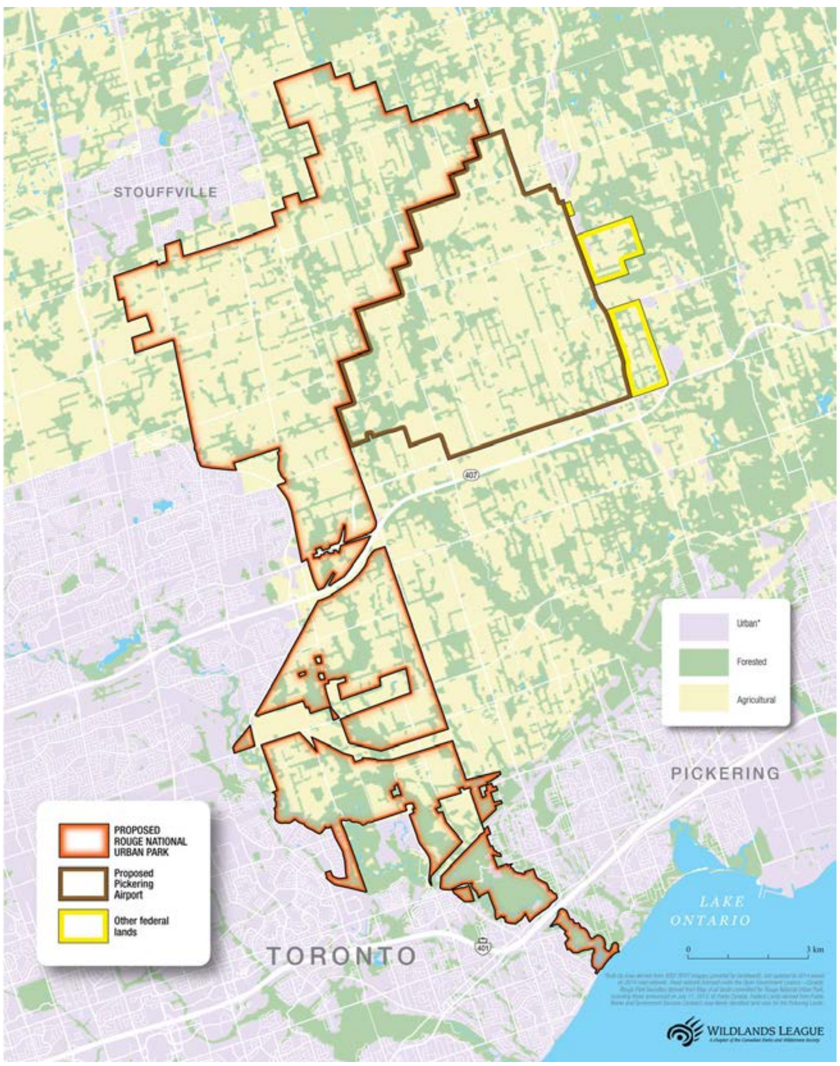

Figure 1. Location and boundaries of Rouge National Urban Park, along with neighbouring urban areas and indicators of fragmentation (Wildlands League, 2016).

Rouge Park contains a population of Blanding's Turtles that are of concern (Toronto Zoo, n.d.). Blanding's turtles are medium-sized, long-lived turtles, distinguishable by a bright yellow chin and throat, and domed black shell with yellow spots (COSEWIC, 2016). Their habitat consists of freshwater wetlands, where they spend the majority of their time (Refsnider & Linck, 2012). During nesting season, the turtles are quite mobile, traveling great distances away from their resident wetlands – from 100 metres to up to 2 kilometres (Congdon, Kinney & Nagle, 2011). The turtles prefer to nest in sandy, gravelly, or rocky terrestrial substrate, and tend to return to the general location annually (COSEWIC, 2016). There are two main Canadian populations of Blanding's turtles – one in the Great Lakes region of Ontario and Quebec, and one in Southern Nova Scotia (van Dijk & Rhodin, 2011; COSEWIC, 2016). They are considered to be endangered throughout their entire Canadian range (COSEWIC, 2016), as well as internationally (van Dijk & Rhodin, 2011). The sub-population of Blanding's turtles in Rouge Park is a conservation priority, as in order to reach suitable nesting habitat, they must traverse anthropogenic obstacles across a highly fragmented landscape, which consists of roads, housing developments, and agricultural areas (Parks Canada, 2017).

The Toronto Zoo has a Blanding's turtle conservation program, which involves the process of head-starting (Toronto Zoo, n.d.). Head-starting consists of collecting eggs from stable wild populations before they hatch in the fall season, then hatching and raising the juveniles in captivity. The juveniles are released into Rouge Park when they are large enough to avoid being consumed by predators such as raccoons. This occurs when the turtles are about the size of a medium potato (Toronto Zoo, n.d.). Before release into the wild, the juvenile turtles are fitted with radio transmitters to be used for movement tracking and monitoring (Toronto Zoo, n.d.) (Figure 2). By modeling the movement paths of Blanding's turtles, this project will assist in habitat restoration efforts within Rouge Park and the surrounding area. Locations and wetlands which are frequented by and desirable to the turtles can be targeted for conservation efforts. This will contribute to both habitat and species conservation efforts in Southern Ontario.

Figure 2. A juvenile Blanding's turtle from the Toronto Zoo head starting program with a radio transmitter attached to its carapace, before being released into Rouge National Urban Park (Pearce, 2017).

1.3 Summary of Literature

Tracking studies using radio telemetry data are a valuable resource for mapping and understanding a given species' spatial distribution and pathways of movement, along with a variety of other components. The majority of Blanding's turtle tracking studies have been performed on mature individuals and adults across their North American range (Rowe & Moll, 1991; Grgurovic & Seivert, 2005; Innes, Babbitt & Kanter, 2008; Schuler & Thiel 2008; Refsnider & Linck, 2012), with two studies performed on adult Blanding's turtles within Southern Ontario (Mui et al., 2016; Mui, Caverhill, Johnson, Fortin & He, 2017). While there are some studies that involve juvenile Blanding's turtle habitat selection (Pappas & Brecke, 1992) and more specifically, the tracking of head started juveniles (Morrison, 1996; Szymanski, 2016), the literature appears to be more focused on adult turtle tracking.

The scholarly community indicate that the body of knowledge on juvenile Blanding's turtle habitat remains incomplete (Beaudry, deMaynadier, & Hunter, 2009; van Dijk & Rhodin, 2011; COSEWIC, 2016). The Committee on the Status of Endangered Wildlife in Canada recognizes that the size of resident habitat ranges required by Blanding's turtles is likely underestimated by many studies (COSEWIC, 2016). Inaccuracies in habitat estimation may occur due to the lack of locational data for multi-seasonal turtle movement (COSEWIC, 2016). Additionally, while much is known about the general and overarching habitat preferences of Blanding's turtles, little is known regarding microhabitat selection, including individual vegetation species and substrate types (Hartwig & Kiviat, 2007). This thesis will contribute to the evolving body of knowledge on Blanding's turtles by providing a more focused look at the movement paths and habitat selection of Blanding's turtles within Rouge Park.

1.4 Introduction to Study

The objective of this analytic cross-sectional study is to assess, characterize, and map where juvenile Blanding's turtles are moving within their habitat in Rouge Park with respect to crossing fragmented areas. For the purpose of this study, fragmented areas will be defined as areas of natural habitat which are isolated or interrupted by roads, fences, agricultural lands, or other human development which may pose as an obstacle to turtle movement (Mui et al., 2017). This analysis will be done through the use of geographic information system (GIS) spatial modeling and mapping software. This study will attempt to answer the following research question and sub-question:

What is the preferred habitat of Blanding’s turtles and the associated selection of pathways for movement across the fragmented landscape of Rouge National Urban Park? What is the level of habitat connectivity along these paths of turtle movement?

This study will test the following hypothesis:

Using computer mapping software, it will be possible to predict habitat connectivity and Blanding’s turtle movement within the study area.

This analysis will be performed using remotely sensed satellite imagery of Rouge Park and the surrounding area in Ontario, Canada.

1.5 Summary of Approach

To address the research questions, a three-year radio telemetry dataset containing the locational information of the Toronto Zoo’s juvenile head-started Blanding’s turtles from 2016 to 2018 will be examined. The tracked turtles range in age from two to five years, and have undergone the Zoo’s rearing program and subsequent release into Rouge Park (Toronto Zoo, n.d.). The data will be analyzed in ESRI’s ArcMap GIS software to assess where these juvenile turtles are travelling within their habitats by looking at the paths of movement. In congruence with this, remote sensing data will be used to characterize habitats within the National Park and the surrounding area. Along with this, remote sensing imagery will be used to assess, map, and quantify landscape connectivity and areas of anthropogenic fragmentation within the study area. Using this, an attempt will be made to assess and quantify the areas of fragmentation which are traversed by the turtles along their paths of movement.

2.0 Literature Review

2.1 Introduction

This chapter will assess the current state of knowledge on Blanding's turtles (*Emydoidea blandingii*) and studies of their movement, along with a discussion of the fragmentation and modeling of their habitat within Rouge National Urban Park (hereafter referred to as Rouge Park). Key scientific journals consulted for this literature review include *Conservation Biology*, the *Journal of Herpetology*, the *Canadian Journal of Zoology*, and *Urban Ecosystems*. This chapter will also serve to provide further background on the subject of Blanding's turtles, specifically within the context of Rouge Park. Details regarding Blanding's turtle life history, conservation status, and habitat selection will be reviewed, and background will be provided on Rouge Park and the urban landscape with respect to fragmentation and land-cover change. This literature review will also outline Blanding's turtle tracking and habitat modeling studies from the 1990's to the present, with a focus on juvenile head-started turtles. To conclude, current knowledge gaps will be addressed regarding the study and tracking of juvenile Blanding's turtles, Blanding's turtle habitat selection, and the temporal scope of turtle tracking research in general.

2.2 Blanding's Turtle Ecology

Much is known about the life history traits of Blanding's turtles. The species is most easily identified by a bright yellow chin and throat. The shell, high and dome-shaped, is black and covered with small yellow-brown dots (COSEWIC, 2016). Blanding's turtles are medium-sized (COSEWIC, 2016), with adult plastrons measuring between 140 and 190 millimetres, and display no sexual dimorphism (Gibbons, 1968). The species is extremely long-lived and late-maturing (Herman et al., 2003; COSEWIC, 2016), with individuals successfully reproducing at

75 years old (COSEWIC, 2016). Mating occurs in early spring, as well as between July and November (Power, 1989, and McNeil, 2002, as cited in Herman et al., 2003). Nesting and egg-laying season occurs in June (Gibbons, 1968; Herman et al., 2003), though the exact timing of the event is dependent upon the temperatures of the preceding months (Herman et al., 2003). Females migrate from 100 metres to up to 2 kilometres away from their resident wetlands to nest (Congdon et al., 2011), and lay 1 clutch of eggs every 1 to 3 years (COSEWIC, 2016). Clutch size ranges from 6 to 11 eggs (Carr, 1952, as cited in Gibbons, 1968). Hatchlings emerge from the nests in early fall, with incubation times ranging from 80 to 128 days (Herman et al., 2003). Blanding's turtles naturally have high rates of egg, hatchling, and juvenile mortality, which limits population growth (Congdon, Dunham & Van Loben Sels, 1993; Herman et al., 2003). Their predators include raccoons, skunks, foxes, crows, and coyotes, all of which typically prey on the eggs and hatchling turtles (Toronto Zoo, n.d.). Blanding's turtles are unique from other freshwater turtle species due to their slow life-history traits, which include a long lifespan, extended reproductive potential, and late maturity, as well as their extensive travel throughout their habitat.

Though different Blanding's turtle populations and individuals have varying habitat selections, there are several key uniform preferences. The turtles are semi-aquatic, and their habitat consists of freshwater wetlands, both in grassy and forested areas. Specifically, resident wetland habitats can include lakes, ponds, marshes, creeks, rivers, bogs, and ditches (Herman et al., 2003; COSEWIC, 2016). The species cycles through various habitats seasonally. Overwintering, or hibernating, typically occurs in a marsh. The turtles then transition to habitats with vernal pools in the spring in search of food, and to forested wetland areas as the vernal pools dry up in the summer. They then return to the marshes for the winter months (Klemens, 2000). The turtles tend to return to the same habitat sites annually (COSEWIC, 2016), which are known as their resident wetlands (Congdon et al., 2011). The habitat area of their resident wetlands can range in size from 0.6 hectares (Ross & Anderson, 1990, as cited in Schuler & Thiel, 2008) to 63 hectares (Piepgras & Lang, as cited in Schuler & Thiel, 2008). Nesting occurs on land in various substrates, including sand, gravel, cobblestone, organic soil, and within crevices of rock outcrops (COSEWIC, 2016). Successful nests tend to be located in areas with loose, well-drained substrate and minimal vegetation (Hughes & Brooks, 2006; Dowling et al., 2010, as cited in Mui et al., 2016). Though Blanding's turtles prefer shallow, freshwater wetlands for the majority of the year, during nesting season, the females select nesting locations with sandy, gravelly, or rocky substrates.

Blanding's turtles are a rare species throughout their range in North America, which consists of the central and eastern United States, and southern areas of Canada (Herman et al., 2003). There are two main Canadian populations of Blanding's turtles – one in the Great Lakes region of Ontario and Quebec, and one in Southern Nova Scotia (van Dijk and Rhodin, 2011; COSEWIC, 2016). The turtles are considered to be endangered throughout their entire Canadian range (COSEWIC, 2016), as well as internationally (van Dijk and Rhodin, 2011).

These turtles are considered to be an umbrella species due to their habitat requirements and life history traits. Umbrella species, also known as focal species, are a valuable conservation tool. Identifying umbrella species is an important approach to the holistic conservation of species and habitats (Lambeck, 1997; Lindenmayer et al., 2014). Umbrella species are selected because they represent the habitat and ecosystem requirements of multiple other species, and are also most sensitive to threats such as the destruction or fragmentation of habitat (Lambeck, 1997; Beazley, 1998; Lindenmayer et al., 2014). Therefore, protection of umbrella species results in the protection of other less sensitive species, which benefits the ecosystem as a whole (Lambeck, 1997; Lindenmayer et al., 2014). The Blanding's turtle is used as a model species for wetland habitat conservation due to its long life and extensive movement within its habitat, along with its preference for clean, productive, and interconnected freshwater wetlands (Herman et al., 2003; Edge, Steinberg, Brooks & Litzgus, 2010). Blanding's turtles also use a range of habitat types depending on the season and their life stage (Edge et al., 2010), resulting in a wide array of protected habitats from which a number of other species can benefit (Herman et al., 2003).

2.3 Land Cover Change and Fragmentation

Anthropogenic changes in land cover have a highly negative impact on biodiversity. Both the rate and amount of conversion from natural to anthropogenic land cover are increasing, significantly impacting ecosystem functioning and biodiversity (Turner II, Meyer & Skole, 1994; Sala et al., 2000; Lambin et al., 2001). In turn, habitat fragmentation resulting from anthropogenic development is increasing (Noss & Cooperrider, 1994; Irwin & Bockstael, 2007; Jaeger, Bertiller, Schwick & Kienast, 2010). When a habitat experiences fragmentation, the original expanse is reduced to isolated patches, separated by areas of inhospitable land or by barriers to movement (Mitchell & Klemens, 2000). The resulting reduction of habitat connectivity poses a threat to biodiversity due to a variety of factors, including increased mortality (Concepcion et al., 2016), increased rates of predation (Temple, 1987; Mitchell & Klemens, 2000), and an overall reduction in the quality of ecosystems and landscapes (Jaeger et al., 2010). Freshwater wetlands across North America have been altered, drained, and destroyed by humans since the 17th century with the onset of European colonization (Mitchell & Klemens, 2000). In the southern Ontario region specifically, the most concentrated areas of human development overlap with areas of wetland habitat, and the main cause of wetland loss in this region is anthropogenic land conversion (Ontario Ministry of Natural Resources and Forestry, 2017). The conversion of natural land cover to anthropogenic land cover results in losses of effective habitat and ecosystem functioning, leading to an overall negative impact on biodiversity.

Anthropogenic fragmentation in the form of roads, fences, agriculture, and housing developments has an overall negative effect on Blanding's turtle survivorship. Blanding's turtles are highly susceptible to negative effects from fragmentation due to their large habitat size requirements (Piepgras & Lang, 2000, as cited in Grgurovic & Sievert, 2005). The turtles use specific habitat corridors of movement when travelling between their resident wetlands and nesting sites (Herman et al., 2003), and anthropogenic obstacles such as roads along these paths can reduce reproductive rates and survivorship (Congdon et al., 1993; Steen et al., 2006; Szerlag & McRobert, 2006). Road mortality is among the greatest threats to Blanding's turtles (Gibbs & Shriver, 2002; van Dijk & Rhodin, 2011). The presence of roads in turtle habitat increases the risk of turtles being struck and killed by vehicles, in addition to facilitating illegal hunting and trapping of rare or valuable species. All of these are factors which lead to higher rates of mortality (Jalkotzy, Ross & Nasserden, 1997). Further, roads are considered to be ecological traps, as their gravel sides provide suitable yet unsafe turtle nesting habitat (Aresco, 2005; Coffin, 2007). This leads to a greater risk of mortality due to vehicle collisions for female turtles, hatchlings, and eggs (Gibbs & Steen, 2005; Steen et al., 2006). Rates of road mortality are especially increased in the fall during the hatchling emergence season, as the thermoregulation potential of pavement is an attractive feature to the newly hatched turtles as they leave their roadside nests (Ashley & Robinson, 1996). Agricultural and residential areas also present attractive nesting sites for Blanding's turtles as they are similar in habitat type to natural nesting areas (Mui et al., 2016). Nests in these sites are negatively impacted through reduced egg and hatchling development and success (Kolbe & Janzen, 2002, as cited in Mui et al., 2016), or even total destruction, due to the frequent anthropogenic disturbances which are characteristic of these areas, such as from agricultural machinery (Mui et al., 2016). Fragmentation of natural habitats poses a large risk to Blanding's turtles, especially in regards to paved roads and agricultural areas, which have the potential to greatly increase mortality and reduce reproductive potential.

2.4 Rouge National Urban Park

National Parks contribute to land conservation, providing protection for rare species and habitats (Noss & Cooperrider, 1994). They also, however, experience varying degrees of human activity in the form of hiking, camping, and vehicular transport. All of these activities can have both directly and indirectly negative impacts on the species within the Park, especially those which are rare or more sensitive to the presence of humans and anthropogenic disturbance (Noss & Cooperrider, 1994). Often nature reserve areas must compete with human developments for prioritization of land-cover, as natural areas may be considered by some to be obstacles to resource extraction and use (Margules & Pressey, 2000; Dudley, 2008). Although National Parks provide valuable protection of various lands and habitats from development, their exposure to human activity may pose a risk to sensitive species, and thus their efficacy as areas for rare species conservation is questionable.

Rouge Park is the first and only National Urban Park in Canada (Parks Canada, 2018). The park was originally established in 1995 by the Province of Ontario (Garratt, 2000). In 2011, plans to establish a National Park in the Rouge Valley area were announced. The original Rouge

Park was officially designated as a National Urban Park in 2015 (Parks Canada, 2018). The Park spans from the Oak Ridges Moraine south to the shores of Lake Ontario (Toronto and Region Conservation Authority, 2018). Currently covering an area of 47 square kilometers (Wildlands League, 2018), the Park is expected to cover and protect 79.1 square kilometers of land once it is fully established (Parks Canada, 2018). Habitats contained within the Park boundaries include forests, meadows, rivers, wetlands, and agricultural areas (Parks Canada, 2018). Vegetation consists of Carolinian Zone species such as sugar maple (*Acer saccharum*), ironwood (*Ostrya virginiana*), black walnut (*Juglans nigra*), white pine (*Pinus strobus*), red pine (*Pinus resinosa*), common milkweed (*Asclepias syriaca*), and ostrich fern (*Matteuccia struthiopteris*) (Parks Canada, 2018). Restoration projects within the Park have resulted in the planting of over 65,000 native plant species, along with the restoration of over 42 hectares of wetland habitat and riparian zones (Parks Canada, 2018). Rouge National Urban Park serves as a refuge for biodiversity in a highly urbanized area, with efforts to improve rare species conservation despite the existing fragmentation.

Turtle head starting programs are a useful conservation tool which are utilized within Rouge Park. Globally, head starting efforts have resulted in conservation successes for a number of species, including the Northern red-bellied cooter (*Pseudemys rubriventris*) (Massachusetts Division of Fisheries and Wildlife, 2017), and the plains garter snake (*Thamnophis radix*) (King & Stanford, 2006). The process of head starting typically involves collecting turtle eggs or recent hatchlings from wild populations and raising them in captivity until they are one to two years old, when they are large enough to escape predation (Herman, 2003). Turtle head starting programs are typically based on the assumptions that mortality is greatest in the early stages of life, that captive rearing during the first several months or years of life helps to protect them from threats that are found in the wild, and that the released turtles will mature in the wild and be able to reproduce, thus ensuring a higher juvenile survival rate and increasing the wild population (Meylan & Ehrenfeld, 2000). Areas of concern regarding the head starting of turtles, however, include the question of potentially reduced survival in the wild due to artificial feeding and limited exercise during the captive rearing stage, as well as the potential exposure of wild populations to diseases acquired in captivity (Moll & Moll, 2000). To be successful, head starting programs must be implemented in conjunction with efforts to reduce adult mortality, such as habitat restoration (Frazer, 1992, as cited in Moll & Moll, 2000; Spencer, Van Dyke, & Thompson, 2017). Blanding’s turtles were historic inhabitants of the Rouge Valley area (Parks Canada, 2018), though they were nearly extirpated (Garratt, 2000). Captive Blanding’s turtles were imported and released into Rouge Park by the Toronto Zoo to increase the population (Garratt, 2000), but before the implementation of the head starting program, only seven Blanding’s turtles remained in the Park (Parks Canada, 2018). As of June, 2018, a total of 165 juvenile Blanding’s turtles have been introduced into Rouge Park through the Toronto Zoo’s head starting program (Parks Canada, 2018). The Blanding’s turtle head starting program is a promising conservation tool which, in combination with protection and restoration of habitat, may help to ensure a stable population within the Park.

2.5 Habitat Modelling

Habitat modelling is a key tool for species conservation endeavours. It allows researchers to determine areas of priority for both the study and protection of a species, while also assessing a larger area than could be covered by field research alone (Sanderson, Redford, Vedder, Coppolillo & Ward, 2002; Congdon, Kinney & Nagle, 2011; Mui et al., 2016). Modelling is a valuable tool for understanding the distribution and extent of a species within its habitat (Grgurovic & Sievert, 2005; Congdon et al., 2011; Mui et al., 2016). It can also be used to identify and target key areas of habitat or corridors of species movement for conservation (McRae, Dickson, Keitt, & Shah, 2008; Corridor Design, 2013). Modelling of landscape features and their connectivity is important for understanding both species movement and broader-scale ecological processes such as gene flow, community interactions, invasive species movement, and disease transmission (McRae et al., 2008; Beier, Spencer, Baldwin, & McRae, 2011; McRae, Hall, Beier, & Theobald, 2012). There are a number of different methods of habitat connectivity modelling, such as least cost pathway models, graph networks, and circuit theory models, which quantify landscape conductance and resistance to species movement (McRae et al., 2008). Areas of high conductance facilitate species movement, and areas of low conductance, or high resistance, hinder or prevent species movement (McRae et al., 2012). Locating and quantifying barriers which greatly reduce habitat connectivity, including highways, roads, fences, urban areas, or natural landscape features (Beier et al., 2011; McRae et al., 2012), is an important addition to landscape and habitat analysis, as these areas can be targeted for restoration (McRae et al., 2012).

The creation of accurate models of species habitat and movement is a difficult task, especially where there is little existing research on habitat selection. It is also difficult to account for all of the possible habitat features associated with a species (Corridor Design, 2013). Further, the creation of habitat and connectivity models requires the researcher to make decisions and assumptions about model selection, individual thresholds, resistance quantification, and a variety of other choices for which there are no clear best options, which may result in different model outcomes (Spear, Balkenhol, Fortin, McRae, & Scribner, 2010; Beier et al., 2011). Validation of the models presents another challenge due to complex logistics and large resource requirements. Field testing or ground truthing of habitat corridor models tends to occur only rarely due to the large spatial extents and various land ownerships or political borders within the corridors (Cushman et al., 2013). Overall, habitat modelling is a valuable tool for estimating the range and movement of a species, though the accuracy is dependent on the existing body of literature and research regarding the species in question.

2.6 Knowledge Gaps

Though much is known about adult habitat preferences, the body of knowledge on the habitat preferences and range of Blanding's turtles remains incomplete. There are no multi-seasonal or multi-year turtle movement studies, or long-term annual data on the same tracked individuals, which may lead to inaccuracies in habitat size, selection, and movement estimation (Beaudry et al., 2009; COSEWIC, 2016). According to the Committee on the Status of Endangered Wildlife in Canada, the size of resident habitat ranges required by Blanding's turtles is likely underestimated by many studies (2012). While much is known about the general and overarching habitat preferences of adult Blanding's turtles (Herman et al., 2003; COSEWIC, 2016), little is known regarding microhabitat selection of juveniles, including individual associated vegetation species and substrate types (Hartwig & Kiviat, 2007; Szymanski, 2016), though evidence from one study suggests that juvenile turtles tend to select both terrestrial and aquatic habitats rich in sphagnum moss (Morrison, 1996). Due to the temporal limitations of the locational data, the knowledge of Blanding's turtle movement throughout the habitat on a multi-year scale is limited.

Further, few studies have been conducted specifically focusing on juvenile head-started turtles, leading to gaps in knowledge of the movement and habitat selection of this subset of the turtle population. Tracking studies using radio telemetry data are a valuable resource for mapping and understanding a given species' spatial distribution and pathways of movement. The majority of Blanding's turtle tracking studies have been performed on mature individuals and adults throughout the species' range (Rowe & Moll, 1991; Grgurovic & Seivert, 2005; Innes, Babbitt & Kanter, 2008; Schuler & Thiel, 2008; Refsnider & Linck, 2012). Habitat studies which have been performed on juvenile Blanding's turtles are uncommon (Pappas & Brecke, 1992), with only two tracking studies having been previously performed on juvenile head started Blanding's turtles (Morrison, 1996; Szymanski, 2016). In one study, researchers tracked head-started juveniles within Kejimkujik National Park in Nova Scotia. This was a very small study, however, with a sample size of only 7 individuals which were only tracked from May to December in 1994 (Morrison, 1996). Though two tracking studies have been performed on adult Blanding's turtles in Southern Ontario (Mui et al., 2016; Mui, Caverhill, Johnson, Fortin & He, 2017), no previous studies have been published regarding the Blanding's turtles in Rouge Park. The lack of knowledge on the movement paths of Blanding's turtles provides opportunity for areas of research, specifically within the context of Rouge National Urban Park.

2.7 Conclusion

This literature review has described the impacts of habitat fragmentation on biodiversity, specifically with regard to Blanding's turtles. Background context was provided regarding ecological modelling and radio telemetry tracking research. Blanding's turtles are an extremely long-lived species, occupying freshwater wetlands and travelling great distances to nest. Habitat fragmentation is an increasing concern in the urban landscape, especially in the context of Rouge National Urban Park, due to the threats posed to Blanding's turtles. Finally, Blanding's turtle tracking and habitat modeling studies from the 1990's to the present were reviewed, with a focus on studies in Ontario and Rouge Park. This literature review has addressed the gaps in the current body of knowledge regarding the habitat modeling and tracking of Blanding's turtles. By contributing an analysis of turtle movement using GIS technology, these knowledge gaps may continue to be reduced.

3.0 Methods

3.1 Overview

This analytic cross-sectional study uses multiple methods of analysis to assess remotely sensed imagery for the purpose of mapping habitat and modelling landscape connectivity within Rouge National Urban Park (hereafter referred to as the park). Along with this, radio telemetry data of juvenile Blanding's turtles (*Emydoidea blandingii*) was plotted to assess the current location of the head started turtles. The data was collected by the Toronto Zoo from 2016 to 2018. The imagery was used to create a land cover map over the study area utilizing classes relevant to turtles. Habitat connectivity was then modelled by converting land cover classes to resistance values and completing a graph network and a least cost pathway (LCP) assessment. For the purposes of this study, fragmented areas were defined as areas of natural habitat which are isolated or interrupted by roads, fences, agricultural lands, or other human development which may pose as an obstacle to turtle movement (Mui, Caverhill, Johnson, Fortin & He, 2017). The objective of this study is to assess, characterize, and map pathways and corridors which Blanding's turtles are likely to utilize when moving within their habitat in Rouge Park.

3.2 Study Area

The study area of this project consists of approximately 760 square kilometers, which includes the boundaries of Rouge Park as well as the surrounding landscape (Figure 3). The park is located to the northeast just outside of Toronto and spans from the shores of Lake Ontario, north to the Oak Ridges Moraine, in Southern Ontario, Canada. The park covers an area of 47 square kilometers and contains over 1,700 species, 23 of which are at risk (Wildlands League, 2018). Along with valuable habitats and rare species, it aims to protect the areas of agriculture within its borders, as urban farmland is considered a valuable resource (Parks Canada, 2017). The park also protects the lower Rouge watershed, which is the last entirely undeveloped watershed in the Western Lake Ontario region (Wildlands League, 2018). Rouge Park is highly fragmented, however, with over 75 percent of its area having been altered by anthropogenic disturbances such as roads, pathways, fences, housing developments, and agricultural lands (Parks Canada, 2017; Wildlands League, 2018). The area surrounding the Park is highly urbanized, as it is adjacent to the cities of Toronto, Markham, and Pickering, which make up the largest metropolitan area in Canada (Parks Canada, 2018). Given the proximity to a large urban center, anthropogenically transported invasive species such as purple loostrife (*Lythrum salicaria*), garlic mustard (*Alliaria petiolata*), and reed canary grass (*Phalaris arundinacea*) are common, all of which may negatively impact the habitat quality for native species (Garratt, 2000). Although Rouge Park protects a large area of urban biodiversity, its potential to maximize rare species conservation, such as the Blanding's turtle, may be compromised due to the extensive anthropogenic fragmentation of the surrounding area.

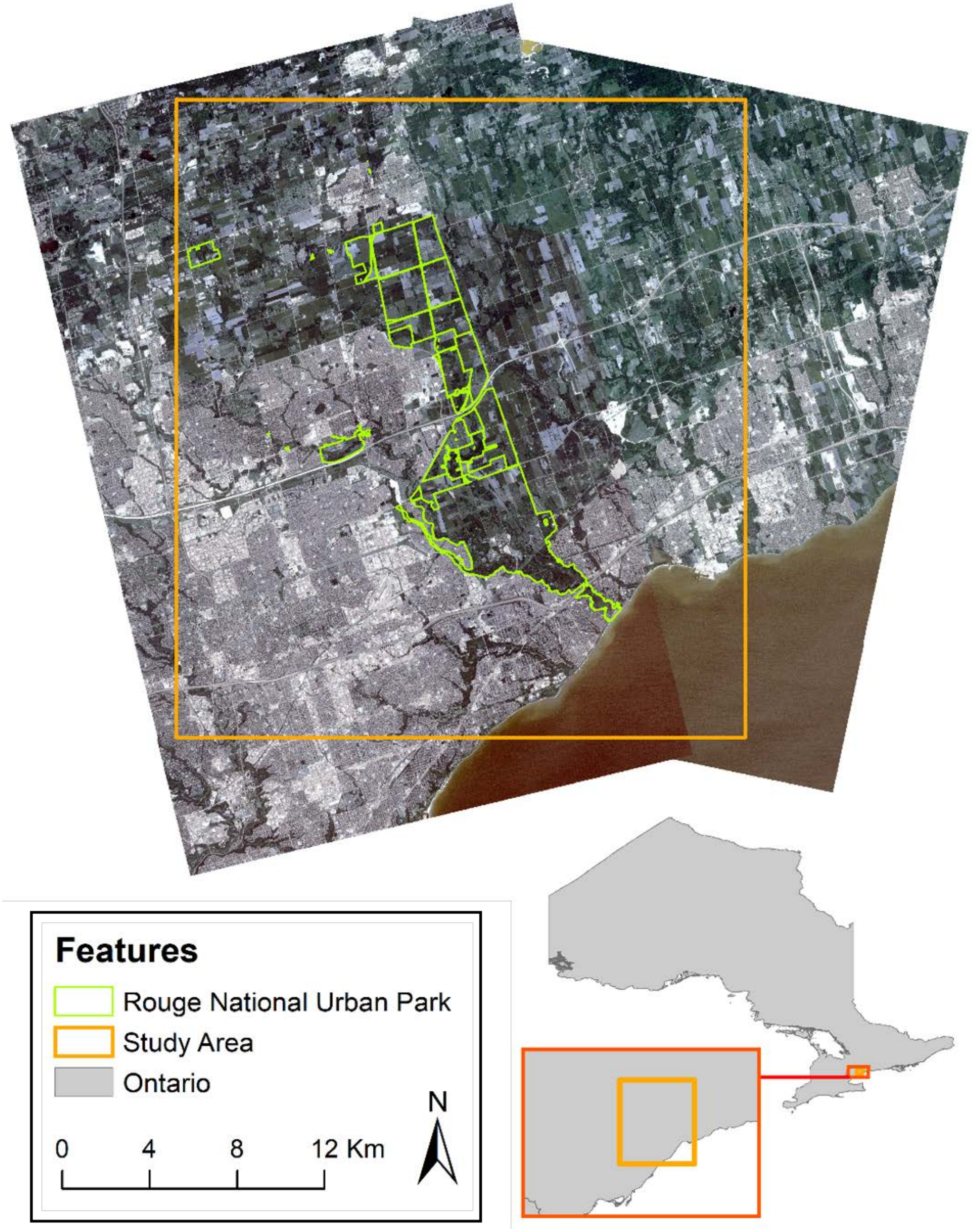

Figure 3. Map of the study area, which contains both the boundaries of Rouge National Urban Park and a portion of the surrounding landscape. Data sources: 3m 4 band VIS-NIR satellite imagery (Planet Labs, 2018), Ontario provincial boundary (Statistics Canada, 2011), Rouge National Urban Park boundaries (Toronto Zoo, 2007; Natural Resources Canada, 2016).

3.3 Sample Description

Locational data for the juvenile turtles was originally collected systematically by members of the Toronto Zoo from 2016 to 2018, as part of the Blanding's turtle head-starting program (Toronto Zoo, n.d.). Turtle eggs were collected from stable populations in other Ontario locations. The eggs were incubated and hatched at the Toronto Zoo, then raised in captivity until they were large enough to survive in the wild (Toronto Zoo, n.d.). Approximately 50 juvenile turtles were released annually into Rouge Park, each fitted with radio-transmitting devices on the rear marginal scutes of the carapace (Toronto Zoo, n.d.). Between June 1 and August 31 of 2016, 2017, and 2018, a total of 2941 juvenile turtle telemetry locations were collected.

Some pilot testing has been conducted using these techniques. Prior studies have been done in regards to tracking juvenile Blanding's turtles (Pappas & Brecke, 1992; Morrison, 1996; Szymanski, 2016), as well as assessing Blanding's turtle habitat use and connectivity in Southern Ontario (Mui et al., 2016; Mui et al., 2017). These studies were conducted in a different context, however, and no previous research has been done regarding the tracking and habitat modeling of Blanding's turtles in an urban park such as the Rouge Park.

3.4 Data Analysis

This study involves primarily qualitative analysis of data, with some quantitative analysis. The nature of this research involves qualitatively assigning raster land cover values for the LCP resistance map, which were decided upon by researchers based on previous knowledge of turtle behaviours. The model results are also interpreted based on qualitative spatial features. The quantitative portion of the analysis consists of assessing the mean distance between core wetland habitats, as well as counting the occurrences of turtle path intersections with roads.

3.4.1 Land Cover Maps

Multispectral satellite imagery of the Toronto area taken on July 20, 2018 was acquired from PlanetScope satellites for use in this analysis (Planet Labs, 2018). This imagery has 4 spectral bands (visible and near-infrared) and a resolution of 3 meters. Image processing was conducted using ArcMap (version 10.5; ESRI, 2016) GIS software. This imagery was used because it is the most recent available imagery, and fits the seasonal period in which live vegetation and land cover can be most easily identified. Further, historical weather data from the federal government was consulted to ensure that no droughts or prolonged periods of dry weather occurred during this temporal period (Agriculture and Agri-Food Canada, 2019), as this would influence the presence and accessibility of wetland areas to turtles, as well as the appearance of the satellite imagery.

Normalized difference vegetation index (NDVI) was calculated using satellite imagery to characterize live green vegetation canopy cover. NDVI values range from -1 to 1, with greater vegetation cover resulting in higher values. NDVI is calculated based on imagery pixel brightness values using the near-infrared (NIR) and visible (red) bands of the electromagnetic spectrum (Campbell, 2007; Rouse et al., 1974, as cited in Mui et al., 2016). The chlorophyll in the leaves of healthy, green plants absorbs red light, while infrared radiation is reflected. As a result, the ratio of infrared/red reflectance is quite high for actively growing vegetation. Alternately, this ratio is much lower for surfaces without vegetation or with dying vegetation (Campbell, 2007). Thus, NDVI is used as a measure of vegetation and habitat health. The formula for calculating NDVI is as follows:

$$NDVI = (NIR - red) / (NIR + red)$$

Land cover was classified from the satellite imagery using a maximum likelihood supervised classification method. Image classification is used to analyse the spectral values within the set of bands in the imagery, grouping pixels with similar values into distinct categories, or spectral classes (Campbell, 2007). The supervised maximum likelihood method was used to group pixels into informational classes of land cover. This method involves the creation of training samples by the researcher, which represent known land cover identities, and which are then used to classify the remaining unknown pixels into the pre-identified categories (Campbell, 2007). The maximum likelihood method was selected as it accounts for some variation within the spectral classes as well as overlap of some extreme spectral values within different classes (Campbell, 2007). Seven land cover classes were identified within the study area with the training samples: built; mixed forest; short vegetation (including meadows, residential lawns, and short agricultural crops); taller vegetation (including shrubland and taller, more fully grown agricultural crops); barren soil; river; and open water (Lake Ontario).

Several shapefiles were then acquired from various sources: one representing the Ontario road network (Ontario Ministry of Natural Resources, 2012), one representing rivers and watercourses within the study area (Toronto Zoo, 2012), and two representing wetlands within the study area which were merged together (Toronto Zoo, 2012; Ontario Ministry of Natural Resources, 2012). A buffer and dissolve were applied to both the road (6m) and river (3m) shapefiles to approximate the average width of these features. These shapefiles were then converted to raster files, and using raster algebra, were added into the output raster of the land cover classification to improve the accuracy of these classes. These layers were subsequently reclassified to supplement the existing river classification and to represent a new “road” classification type. This general process was repeated for the merged wetlands shapefile. First, the core habitat wetlands were isolated from the original shapefile. The criteria for a wetland to be considered a core habitat node were as follows:

- A wetland classified as either a swamp or marsh, as Blanding's turtles tend to prefer wetlands with clear water (COSEWIC, 2016).
- A wetland with an area of 10 hectares or greater. The minimum size of critical freshwater wetlands has previously been identified as 20 hectares (Anderson et al., 2006, as cited in Farrow & Nussey, 2017). In the fragmented landscape of Rouge Park, however, wetlands of this size are quite rare. There is also evidence that the juvenile Blanding's turtles in this study are thriving in smaller wetlands, as the complex into which they are released annually is only just over 10 hectares in size, thus this size was deemed an acceptable criterion.

The wetlands identified as core habitat nodes were exported as a new polygon shapefile. Then the remaining wetlands were added into the classified land cover raster following similar methodology as was used for the road and river files. The land cover raster was then reclassified to include a new "non-core wetland" classification type, for a total of nine land cover classifications. Finally, the GPS points of turtle telemetry locations were plotted onto the land cover maps in a GIS software.

3.4.2 Resistance Map

A resistance map was created using the classified land cover map. Land cover categories found in the study area were assigned and reclassified to values between 0 and 100, which relate to the Blanding's turtles' willingness and ability to cross various features (Mui et al., 2017). A value of 0 is associated with preferred habitat for Blanding's turtles, with the greatest ease of turtle movement. Higher values are associated with types of land cover that are more difficult or less favourable for turtles to traverse, with a value of 100 representing a complete barrier to turtle movement (Mui et al., 2017). Expert opinion is a common form of resistance value assignment (Spear et al., 2010, Mui et al., 2017). The resistance values used in this analysis (Table 1) were based on values generalized for adult Blanding's turtles, which were previously averaged from values provided by three experts with a prior knowledge of the Southern Ontario landscape and a combined 60 years of experience (Mui et al., 2017).

Table 1. Resistance values assigned to the nine land cover classifications in the study area of Rouge Urban National Park and the surrounding landscape. Values were based upon those previously used by Mui et al. (2017).

Land cover classification	Resistance value (summer)
Built	67
Road	92
Mixed forest	52
Short vegetation	50
Taller vegetation	66
Barren soil	61
River	30
Open water	1
Non-core wetland	10

3.4.3 Least Cost Pathway (LCP) Analysis

The LCP assessment was also conducted in ESRI's ArcMap software using a Linkage Mapper package (version 2.0.0; McRae & Kavanagh, 2017). This shows where obstacles or barriers may lie along turtle paths of movement. The underlying assumption of this analysis is that the animal has a knowledge of the landscape across which it is travelling, and that it will choose to move across the path of least resistance, with the fewest obstacles (Beier et al, 2009, as cited in Mui et al., 2017; McRae et al., 2008). This results in an output that shows single, discrete paths of turtle movement which traverse the lowest amount of resistance or obstacles. This aids in the identification of discrete barriers to movement, which is helpful from a management perspective as specific areas can be targeted for improvements (Beier et al., 2011; McRae et al., 2012; Mui et al., 2017). The inputs for this method of analysis were the resistance map and the core wetland polygons.

3.4.4 Graph Network Analysis

This is an alternate method of modelling turtle movement between and within habitat areas, which instead models conductance and resistance across the entire study area using circuit theory (McRae et al., 2008), and gives a broader sense of the landscape-level connectivity. It is used in addition to the LCP assessment, as individual turtles likely would not travel frequently along the same path, nor would they always travel the shortest route directly between two points (Mui et al., 2017). Additionally, this method includes a calculation of landscape features which may encourage or facilitate turtle movement (McRae et al., 2008; Howey, 2011, as cited in Mui et al., 2017). This approach is based on random walk theory, which models multiple pathways across a raster to assess what an animal may encounter when walking in any given direction (Mui et al., 2017). The underlying assumption of this approach is that the animal has no prior knowledge of the landscape (Mui et al., 2017), which is closer to what the juvenile head started turtles would likely experience upon being introduced to the park. This analysis was conducted using the Circuitscape package for ArcMap (version 4.0.5; McRae, Shah, & Mohapatra, 2014), using the same resistance map and core wetland habitat nodes as were used for the LCP assessment.

3.5 Limitations and Delimitations

One of the main limitations of this study lies in the process of assigning the values to the resistance map. All individual turtles vary in their habitat preferences and in their willingness to traverse various landscapes and barriers. As well, all landscapes vary in complexity and features. For these reasons, the values assigned for turtle ability and willingness to cross various landscape and obstacle types is an educated estimation, but not a guarantee. For instance, all roads likely do not pose the same level of risk to turtles, due to varying levels of traffic flow and speed limits. Previous research has noted that turtle mortality from vehicle collisions occurs more frequently on paved roads than on unpaved or gravel roads (Gunson & Schueler, 2012). Due to these factors, it is probable that not all roads within the study area truly represent a resistance level of 92, as was assigned in this analysis. Assignment of the values, however, is grounded in previous research and knowledge of general turtle behaviours so as to ensure appropriateness. It is also of note that these values were based on adult Blanding's turtles and not juveniles (Mui et al., 2017), which, due to difference in physical size or abilities, may experience different difficulties when crossing various landscapes.

Another important limitation to address is in regards to the wetland polygons used in the LCP and graph network analyses. These core wetland habitat nodes may not necessarily all be core turtle habitat. Though measures were taken to ensure that habitat which would presumably be the most appropriate was selected (see Section 3.5.1), this assumes that the original wetland shapefiles which were used represent accurate wetland shapes, sizes, and classifications. Further, some wetlands may be ephemeral, appearing in the spring but gradually disappearing as the season progresses and temperatures rise. This means that some important wetlands may be inaccurately included or omitted from the analysis. Further, as mentioned previously, individual turtles have varying habitat preferences, and the selected core habitat nodes are a best estimate. These wetland areas, however, would all likely be preferred over other habitat types, and still represent areas of facilitated turtle movement.

Finally, a limitation relates to the remote sensing aspect of this study. The level of detail and accuracy of the analysis is dependent on the quality and resolution of the satellite imagery that is used. It is also important to acknowledge the limitations associated with the validation of habitat corridor models in general (see Section 2.5).

4.0 Results & Discussion

4.1 Land Cover Maps

The normalized difference vegetation index (NDVI) calculation resulted in a range of values from -0.83 to 0.69 throughout the study area (Figure 4). Areas of extreme low values are seen throughout the area of Lake Ontario, with other low values throughout the highly urbanized portions of the study area, which indicate a lack of living vegetation. Areas of higher values are seen within the boundaries of Rouge Urban National Park and throughout surrounding agricultural areas, which indicate a greater presence of live green vegetation.

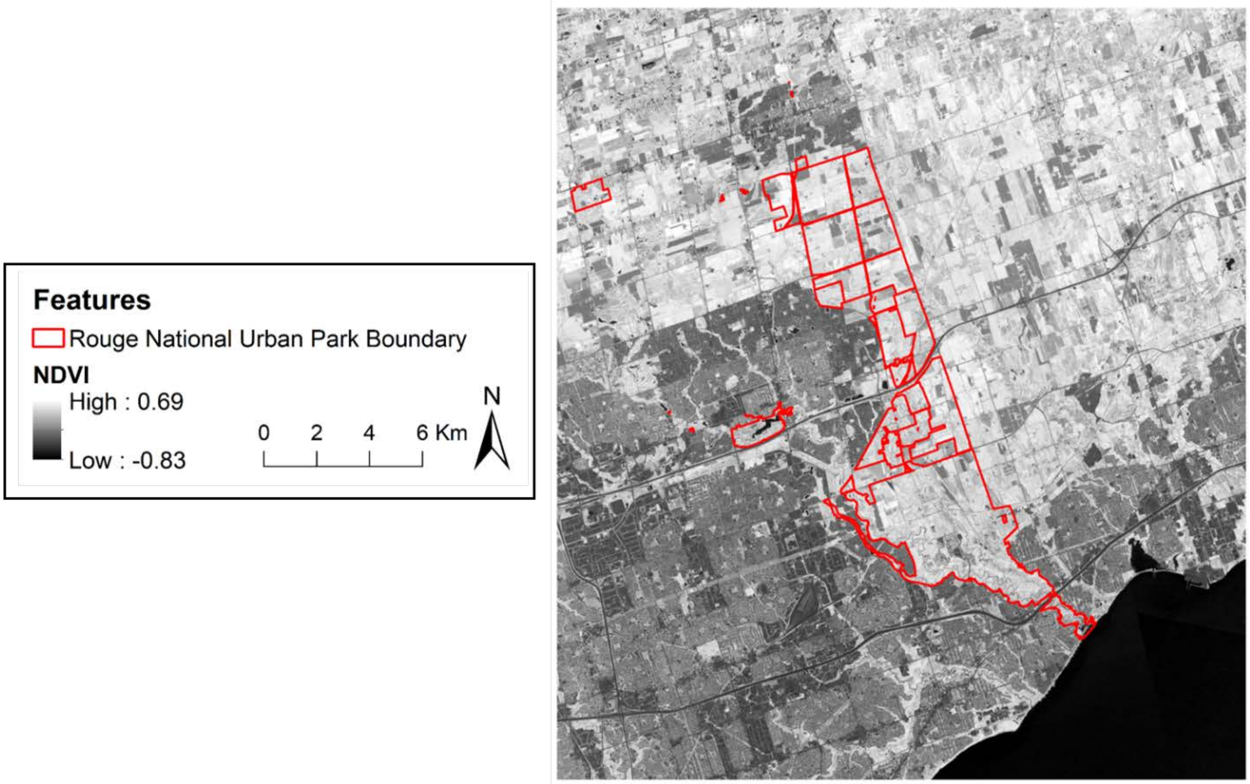

Figure 4. NDVI of the study area created from the red and near-infrared bands of the 3m resolution satellite imagery from July 2018 (Planet Labs, 2018). Low NDVI values are shown in darker colours, which represent a lack of vegetation, while higher values are shown in lighter colours, which indicate the presence of live green vegetation. Data sources: Rouge National Urban Park boundaries (Toronto Zoo, 2007; Natural Resources Canada, 2016).

Nine distinct land cover types were identified within the study area along with 44 areas of core wetland habitat, 7 of which are located within the boundaries of Rouge Park (Figure 5). Within the urban portion of the study area, the landscape is dominated by built areas, roads, and residential parcels with lawns ("short vegetation"). Rouge Park consists of forested areas, wetlands and rivers, and agricultural areas. The remainder of the study area was classified as "short vegetation", "taller vegetation", and "barren soil", all of which primarily represent agricultural land covers, though may also represent some meadows, shrubland, and natural exposed soil patches, respectively. A network of roads runs throughout the extent of the study area. A stratified random accuracy assessment of 215 points was performed on the classified land cover raster, which indicated an overall classification accuracy of 87% (kappa = 0.870141807; Appendix A).

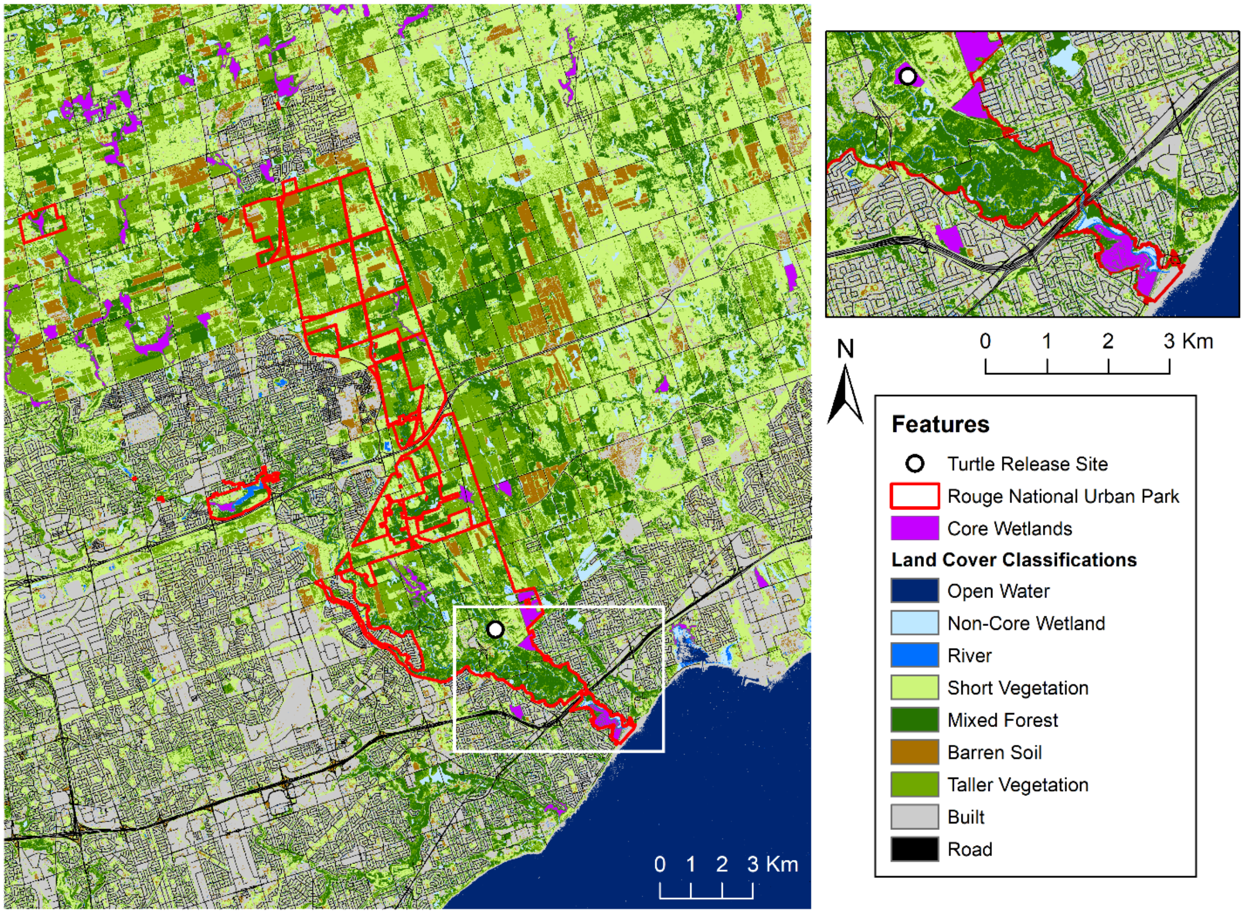

Figure 5. Land cover within the study area, including the location of the resident wetland complex into which the turtles tracked in the summers from 2016 to 2018 were released. The inset shows a finer scale view of the core wetlands and relatively contiguous forested habitat in the southern extent of the park, which extends to the shores of Lake Ontario. Data sources: 3m 4 band VIS-NIR satellite imagery (Planet Labs, 2018), Rouge National Urban Park boundaries (Toronto Zoo, 2007; Natural Resources Canada, 2016), Wetland polygons (Toronto Zoo, 2012; Ontario Ministry of Natural Resources, 2013), Ontario road network (Ontario Ministry of Natural Resources, 2012).

The identified core wetlands range in size from 10.3 hectares (ha) to 52.0 ha, with a mean size of 20.6 ha (±11.1ha). These wetlands appear to be primarily located in the northwestern corner of the study area, as well as in the southern end of Rouge Park. The mean Euclidean distance from the central point of one core wetland to the central point of another was found to be 3802.3 meters (±2598.3m). The mean Euclidean distance between the edge of one wetland to the edge of another is 2888.3 meters (±2509.8m). These distances are within the reported Blanding's turtle home range sizes of 0.6 to 63.0 ha (Ross & Anderson, 1990, as cited in Schuler & Thiel, 2008; Piepgras & Lang, 2000, as cited in Schuler & Thiel, 2008).

In an undisturbed landscape, Blanding's turtles prefer wetlands over upland areas and areas of flowing water, though these less-preferred areas may still be used as corridors for movement (Edge et al., 2010). In disturbed or fragmented landscapes such as that of Rouge Park and the surrounding area, however, high-quality and highly-preferred habitat may be rare or isolated (Gabor & Hellgren, 2000). Blanding's turtles are known to move extensively within their habitats, between and within wetlands, during all seasons, in both fragmented and pristine landscapes. If there is a low or limited number of suitable nesting sites within a habitat range, female turtles may move even more between wetlands (Edge et al., 2010). As well, with an increase of proximal urban areas and anthropogenic fragmentation of habitat, turtles may experience a number of negative impacts. These include a reduction in important vegetation species with replacement by non-native plants (Concepcion et al., 2016), as well as an increase in the occurrences of predation (Temple, 1987), and mortality related to roads and vehicle collisions (Aresco, 2005).

Even agricultural areas, which are common throughout the study area, may present a threat to Blanding's turtles. Although they can have high temporary seasonal vegetation cover, thus providing adequate corridors for movement, agricultural fields may act as an ecological sink (Mui et al., 2016). In addition to altering hatchling sex ratios, they can be a source of significant juvenile and nest mortality, as females nest in the substrate only to have the nests destroyed by farm machinery (Mui et al., 2016). It is for these reasons that areas of contiguous suitable habitat, especially within areas intended for species protection and conservation, are important.

4.2 Least Cost Pathway Analysis

A resistance map with values ranging from 0 to 100 was created as part of the least cost pathway (LCP) analysis, with higher values represented by darker colours, indicating land cover types which are more resistant or difficult for turtle movement. Lower values are represented by lighter colours – these areas are less resistant to, and may facilitate, turtle movement (Figure 6). Areas of generally higher resistance tend to coincide with more urban areas, while the portions of the study area which tend to show lower resistance coincide with agricultural areas and park lands. Between the 44 core wetland habitat nodes, 110 least cost paths were calculated. It can be seen from these pathways of least resistance that the turtles prefer to stay in green, vegetated areas, with a clear avoidance of areas with urban land covers.

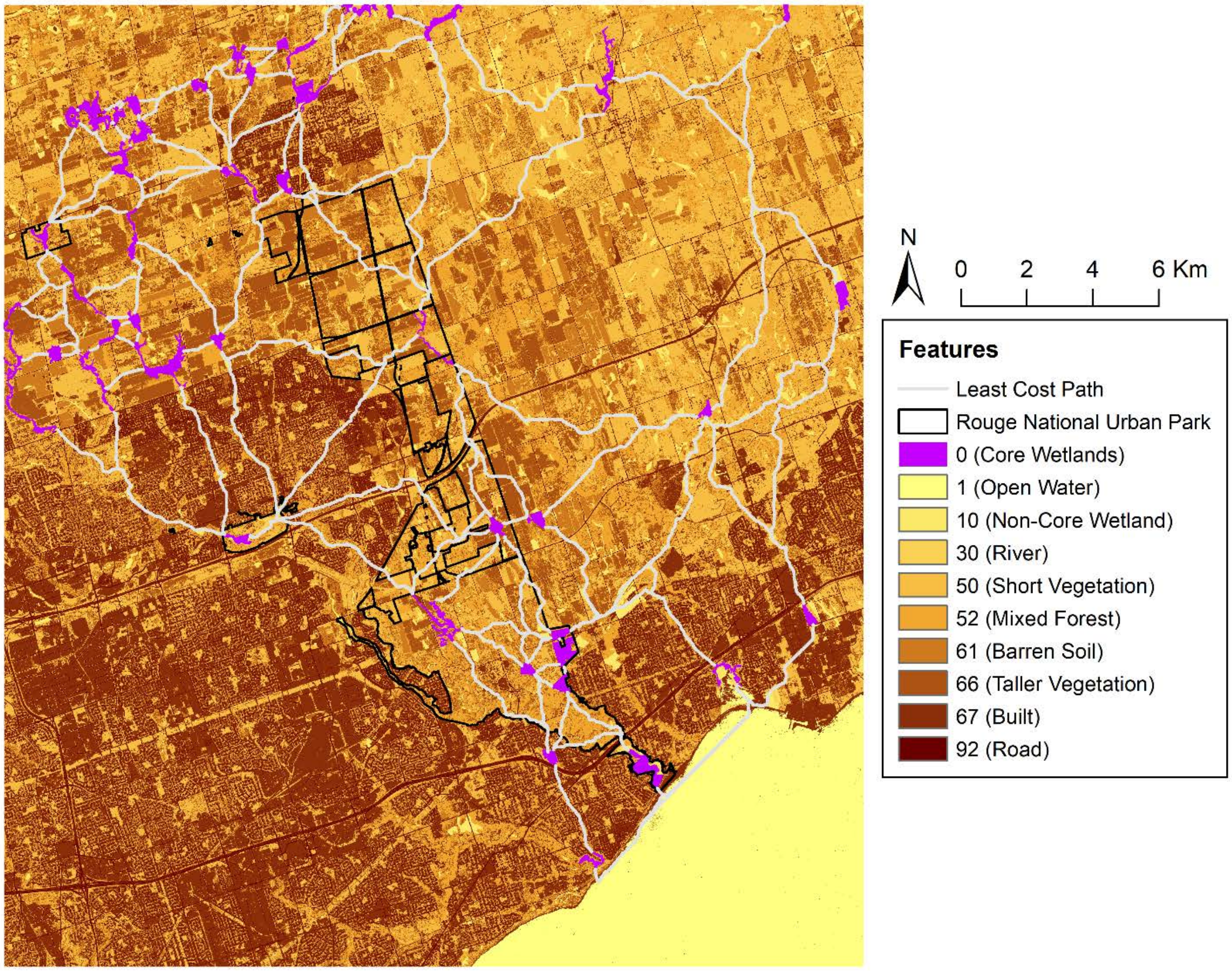

Figure 6. Map depicting the resistance values assigned to each land cover type, with darker colours indicating a higher level of impedance to turtle movement and lighter colours indicating less impedance. The least cost pathways connect each of the 44 core wetland nodes though areas of the lowest possible resistance values. Data sources: 3m 4 band VIS-NIR satellite imagery (Planet Labs, 2018), Rouge National Urban Park boundaries (Toronto Zoo, 2007; Natural Resources Canada, 2016), Wetland polygons (Toronto Zoo, 2012; Ontario Ministry of Natural Resources, 2013), Ontario road network (Ontario Ministry of Natural Resources, 2012).

The LCPs were intersected with the Toronto area road network to identify areas of overlap between these two features, which indicate potential areas that turtles would cross over a road in order to continue travelling along a certain path of movement to a destination wetland (Figure 7). Road-path intersections appear to be more numerous in urban areas, with fewer intersections in areas with more vegetation and a higher NDVI value, including agricultural areas. Intersections appear to be especially concentrated through Stouffville (Figure 7, A) and

Markham (Figure 7, B). Points of overlap located at the southern end of Rouge Park were excluded, as although the LCPs appear to intersect with roads in that location, the roads are actually part of a bridge that overpasses the waterway and core turtle habitat, and thus very likely do not obstruct turtle movement (see inset, Figure 7).

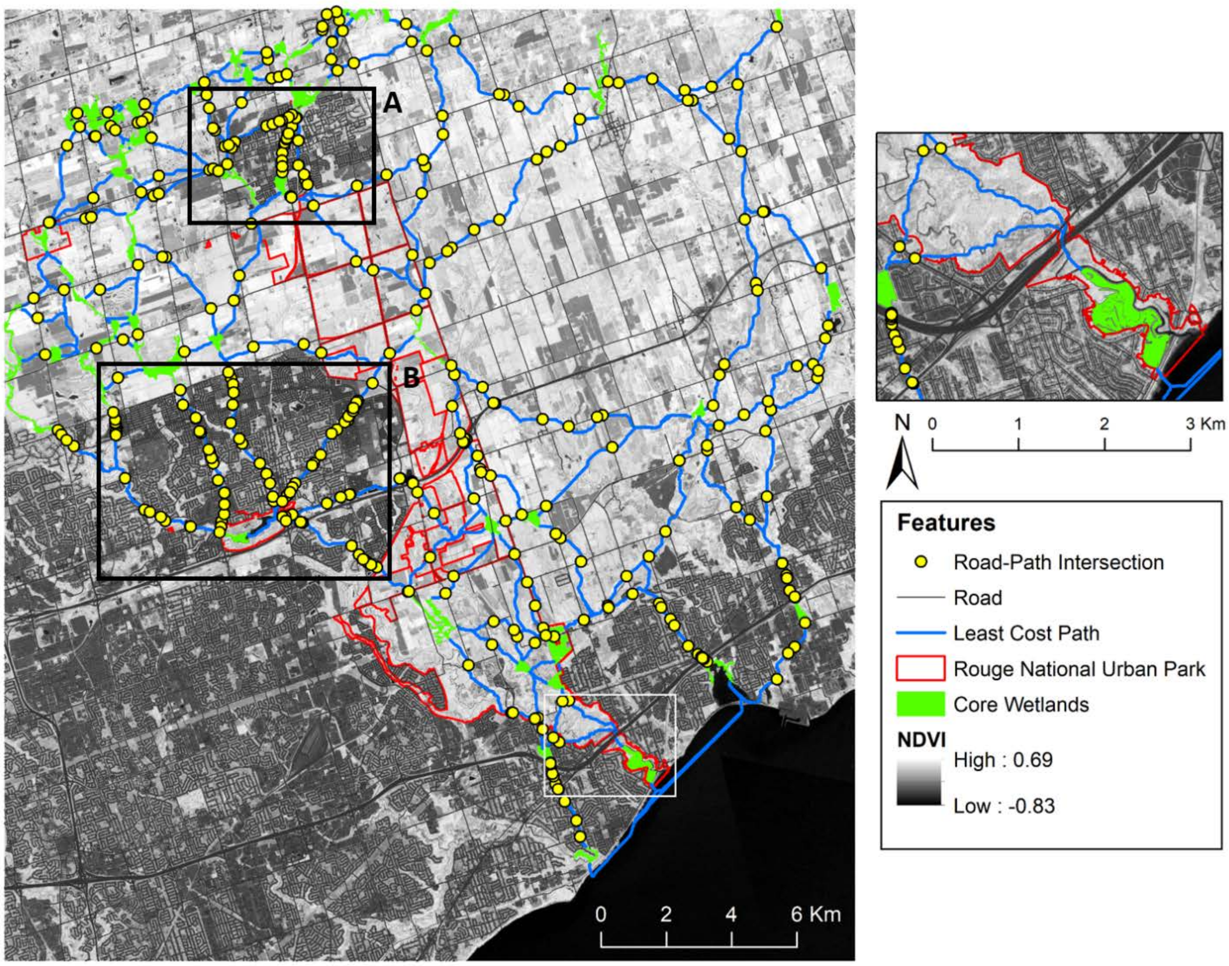

Figure 7. Locations where least cost paths between core wetlands intersect roads within the study area, with focus on areas of high intersection concentration in Stouffville (A) and Markham (B). The inset depicts an area in which a bridge crosses over the wetland habitat, and thus likely does not impede turtle movement. Data Sources: 3m 4 band VIS-NIR satellite imagery (Planet Labs, 2018), Wetland polygons (Toronto Zoo, 2012; Ontario Ministry of Natural Resources, 2013), Rouge National Urban Park boundaries (Toronto Zoo, 2007; Natural Resources Canada, 2016), Ontario road network (Ontario Ministry of Natural Resources, 2012).

In total, throughout the study area 479 road intersections were identified. 32 of these intersections were located within the boundaries of Rouge Park, which represent 6.7% of the total. The approximate density of these road-path crossings is 0.0053 intersections per hectare inside Rouge Park (area = 6093.0 ha), compared to 0.0063 intersections per hectare overall in the wider study area (area = 76022.4 ha). The number of roads crossed per least cost pathway was also calculated. Within the full study area, 94 of the 110 paths intersected a road in at least 1 location, with a range of 1 to 22 intercepts per path (Figure 8, A). Within the boundaries of Rouge Park, there were 16 paths which had at least one location of intersect with a road, with a much smaller range of 1 to 4 road intersections per path (Figure 8, B). The majority of the paths only intersected a road once.

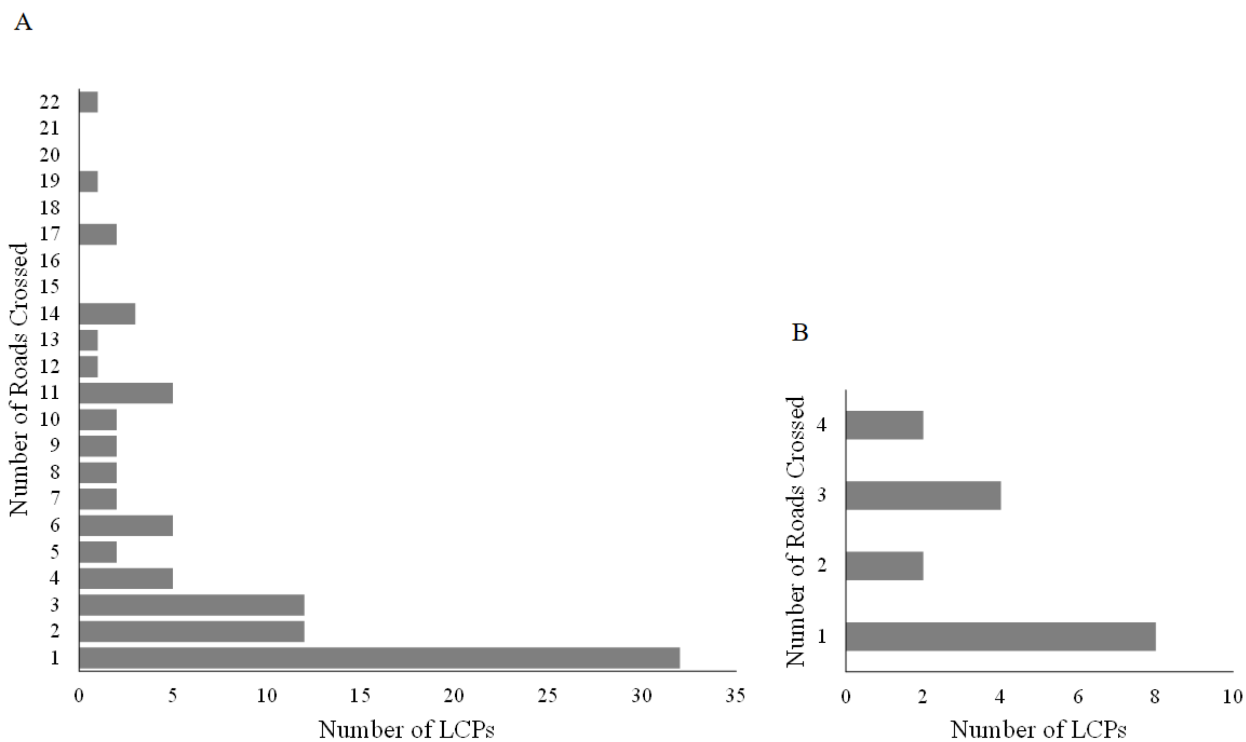

Figure 8. The number of LCPs with each amount of road-path intersections in both the full study area (A) and within Rouge Park (B). In both areas, the majority of paths were only intersected by a road at one location. In Rouge Park, 8 paths had 1 location of intersection with a road, while only 2 paths each had 4 road intersections. Within the broader study area, 32 paths had 1 road intersection, with one path intersecting 22 roads.

One weakness of the LCP assessment is that it will calculate a path even if it is very unlikely that a turtle would travel or even survive along it. This means that in areas of especially concentrated road-path intersections, the chance that a turtle would actually travel along that path is very unlikely. Further, it is not feasible to ground truth the entire LCP output to verify which paths are actually travelled by turtles. Analyzing the intersection locations, however, allows for the estimation of which LCPs are more likely to be used in reality. Turtles do not usually survive being struck by a vehicle, and roads which travel near or through wetlands are a source of significant turtle mortality (Aresco, 2005). Crossing even just a single road poses a risk to an individual turtle's survival. The more road intersections along a path of turtle movement, the less likely a turtle might be to take it, however if the turtle does travel along that path, the less likely it is to survive. When travelling between wetlands, even if a turtle is successful in crossing a road along its path once, it is highly probably that the turtle will travel back along a similar path and will be at risk by crossing the road again (Aresco, 2005). Because of this, it is highly important to minimize the number of times a turtle may encounter a road within its habitat.

Based on this assessment, it appears that the park is serving its conservation purpose in terms of limiting anthropogenic habitat fragmentation by roads and by limiting turtle road encounters, when compared to the surrounding area. To improve the park's conservation potential, however, mitigation measures should be implemented to further reduce the number of road encounters along these paths and enact policies to prevent further road development. At a minimum, this could involve vehicle road signage warning about turtle crossings in the areas near the identified path intersections. This is a relatively inexpensive and easily installed method which could serve to increase driver awareness of turtles along certain roads (Gunson & Schueler, 2012). Unfortunately, the efficacy of this method in actually reducing wildlife mortality rates is not well understood (Huijser et al., 2007), appearing to depend highly upon the location of the signage (Gunson & Schueler, 2012). Further, simple signage is easily stolen, and turtle crossing signs appear to have a high rate of theft (Gunson & Schueler, 2012). A more effective mitigation measure would be the installation of permanent ecopassages at important path-road intersections. This method can include various forms and combinations of tunnels, culverts and barrier fences, all of which serve to redirect the turtle under the road instead of over it (Aresco, 2005; Heaven, Litzgus, & Tinker, 2019). Some drawbacks to this method, however, include holes or failures in the fencing system due to wear and reluctance of turtles to travel through the culverts or underpasses (Aresco, 2005; Baxter-Gilbert, Riley, Lesbarreres, & Litzgus, 2015; Heaven et al., 2019). Although Blanding's turtles have been documented travelling through semi-submerged hydrologic culverts with a diameter of 1.22 meters (Heaven et al., 2019), overall these culverts provide only a low level of habitat connectivity, and the installation of ecopassages specifically designed for turtles should be prioritized (Baxter-Gilbert et al., 2015; Huijser, Gunson, & Fairbank, 2017). Recently, a new ecopassage system was engineered which involves precast tunnels with grated tops, which integrates more natural light, moisture, and temperature conditions within the tunnel while still diverting turtles under roads (Heaven et al., 2019). The implementation of a combination of these signage and ecopassage methods would likely provide the most benefit for reducing the threat of road mortality along paths of turtle movement within Rouge Park.

4.3 Graph Network Analysis

Landscape conductivity within the study area was plotted using a graph network approach and overlaid with the LCP output and the NDVI to assess overall landscape connectivity and facilitation of turtle movement (Figure 9). Here, dark areas show locations of low habitat connectivity, which represent values below the mean connectivity value (0.15) as calculated by the graph network output. Areas of moderate connectivity consist of values between the mean and 1 standard deviation (0.08) above the mean connectivity value, while areas of high connectivity represent areas over 1 standard deviation above the mean (0.23), though the actual numbers assigned to landscape connectivity in this output are arbitrary. The majority of the discrete pathways are located in areas of moderate to high connectivity. Areas with less vegetation appear to have a greater number of road-path intersections. Rouge Park appears to provide moderate connectivity between wetland areas overall, with a higher level of connectivity in the southern portion of the park.

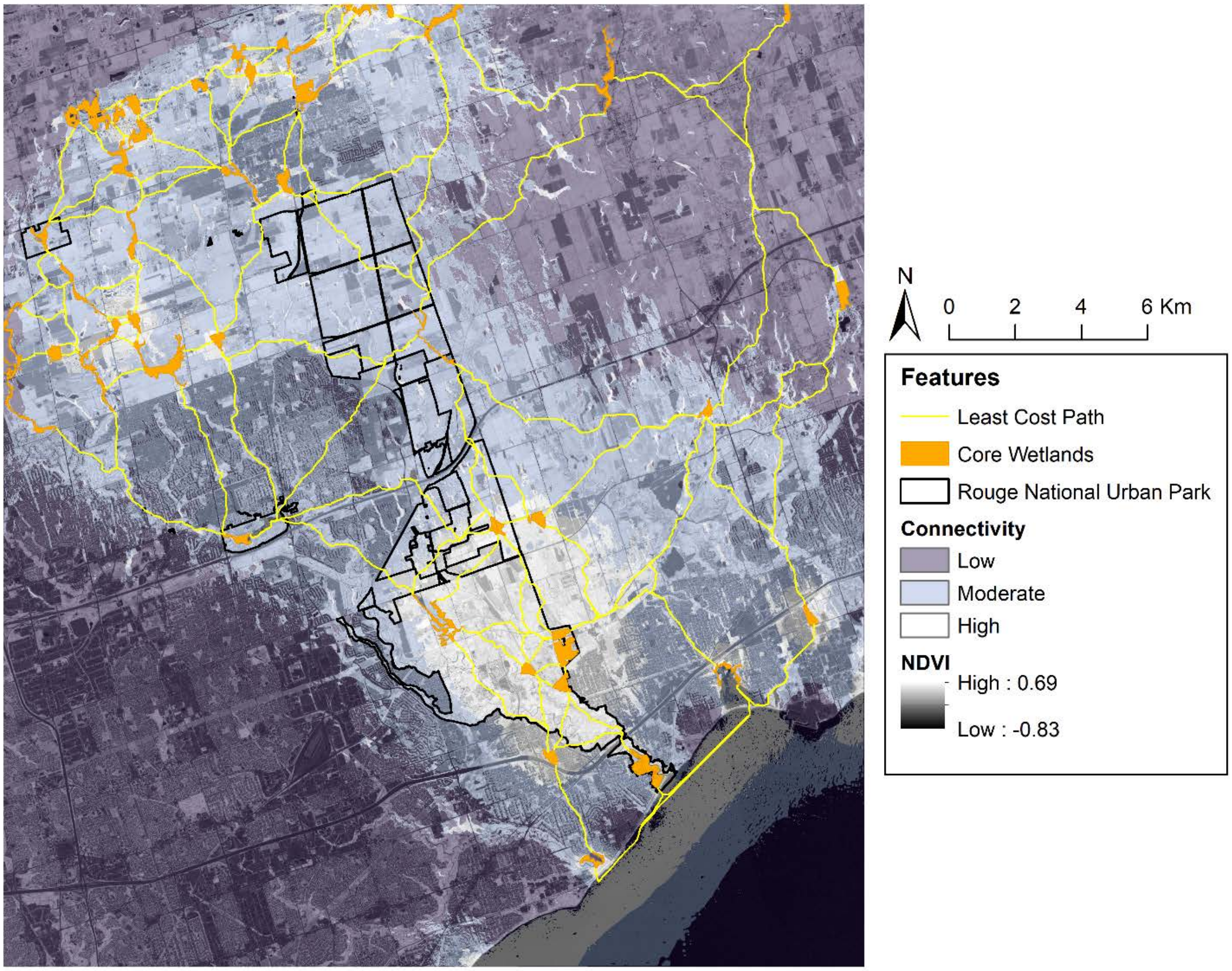

Figure 9. The range of landscape connectivity throughout the study area, along with least cost pathways and path intersections with roads. Areas of low connectivity (dark purple) represent values below the mean of the graph network output. Areas of moderate connectivity (pale blue) represent values between the mean and 1 standard deviation above the mean of the graph network output. Areas of high connectivity (white) represent areas above the identified connectivity threshold. Data sources: 3m 4 band VIS-NIR satellite imagery (Planet Labs, 2018), Wetland polygons (Toronto Zoo, 2012; Ontario Ministry of Natural Resources, 2013), Rouge National Urban Park boundaries (Toronto Zoo, 2007; Natural Resources Canada, 2016).

The area of relatively high connectivity (over 1 standard deviation above the mean connectivity) was set as a threshold for landscape connectivity, which represents the area of highest conductance to turtle movement. Habitat connectivity and conductance between core wetlands appears to be relatively high in the southern extent of Rouge Park, though the northern portion of the park, as well as the remainder of the study area, appear to have low conductance and habitat connectivity (Figure 10) There are also patches of well-connected wetland habitats in the northwestern portion of the study area, though these patches are not contiguous. As evidenced by comparison with the NDVI, the majority of land within the connectivity threshold consists of areas with high vegetation cover.

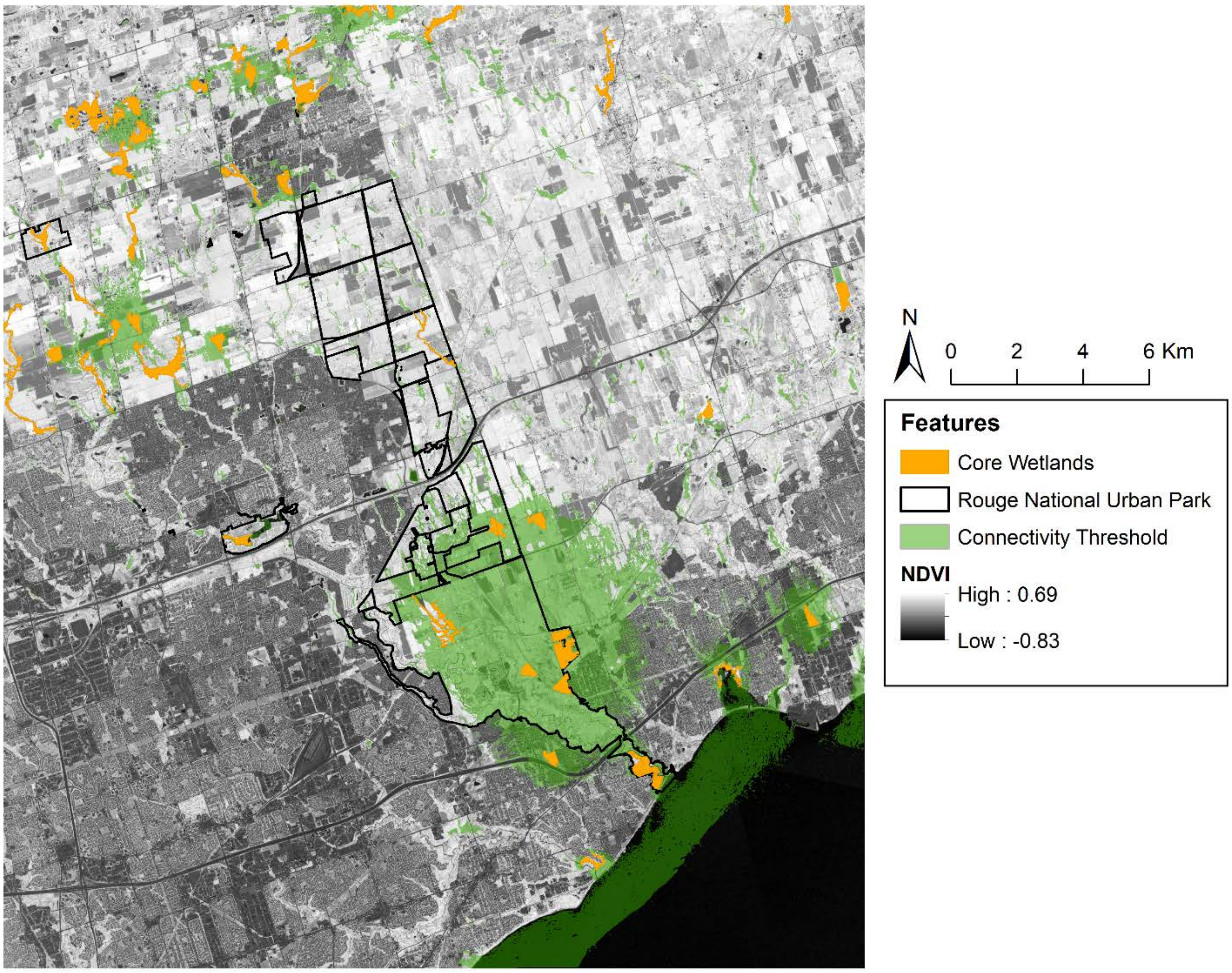

Figure 10. Areas of relatively high landscape connectivity (areas greater than 1 standard deviation above the mean connectivity value) between core wetland habitats within the study area. The normalized difference vegetation index (NDVI) suggests that areas of high connectivity are coincide with areas of high vegetation cover and lower built features. Data sources: 3m 4 band VIS-NIR satellite imagery (Planet Labs, 2018), Wetland polygons (Toronto Zoo, 2012; Ontario Ministry of Natural Resources, 2013), Rouge National Urban Park boundaries (Toronto Zoo, 2007; Natural Resources Canada, 2016).

Within this identified threshold of habitat connectivity, or the area of relatively high conductance for turtles moving through the landscape, proportional land cover type was assessed. The raw pixel counts within the area of the threshold were examined and compared to those of the wider study area excluding the threshold (Table 2). Within the threshold of habitat corridors, excluding core wetlands, over 50% of the land cover is natural (consisting of wetlands, water features, and forested areas), compared to only 23% in the remainder of the study area. Also, only 10% of the land cover within the threshold is anthropogenic (roads and other built areas), versus almost 30% outside of the threshold. Areas of taller vegetation, short vegetation, and barren soil represent a combination of natural and anthropogenic (predominantly agricultural) land covers (Figure 11). This further highlights the importance of natural and vegetated areas within turtle habitat.

Table 2. Raw counts of the number of pixels of each land cover type, as identified in the classified land cover raster, within the habitat connectivity threshold and throughout the entire study area with the exclusion of the threshold.

Land cover type	Pixels within threshold	Pixels outside of threshold
Built	58197	19630308
Road	10170	4582555
Mixed forest	109802	3788974
Short vegetation	153121	26148684
Taller vegetation	71449	10271445
Barren soil	14517	10685594
River	8080	430146
Open water	122864	6232704
Non-core wetland	82583	2080919

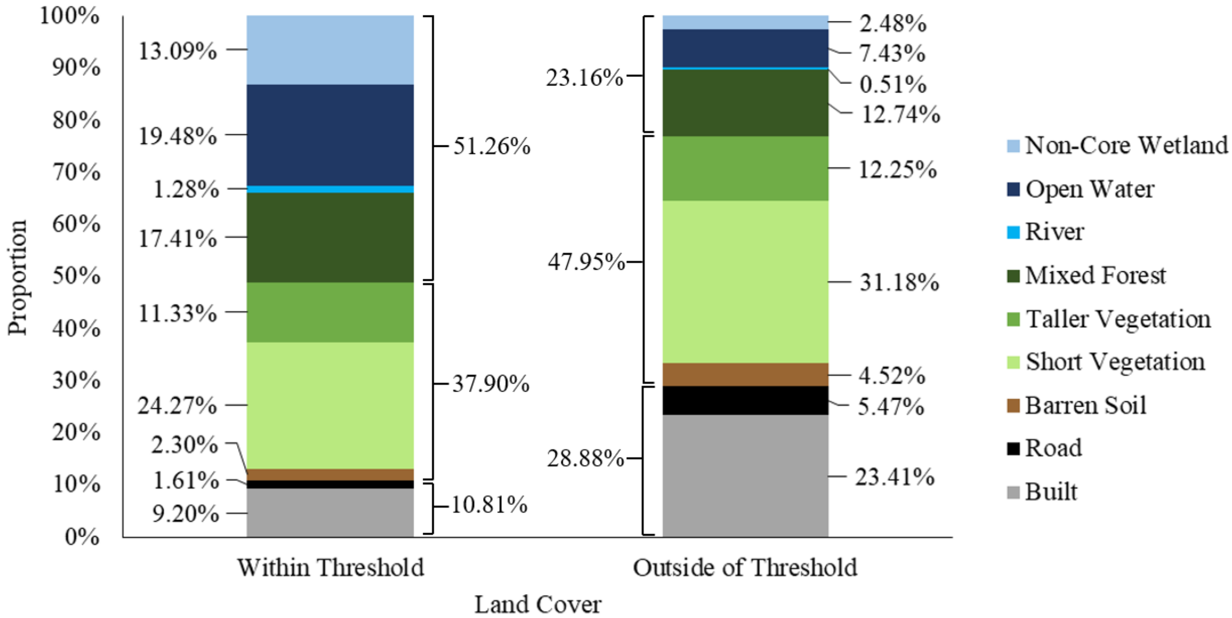

Figure 11. Comparison of proportional land cover type that falls within the threshold of habitat connectivity and within the wider study area, excluding the threshold. Natural land covers are grouped at the top of the bars and anthropogenic land cover types are grouped at the base of the bars. The middle grouping consists of land cover which represent both natural and anthropogenic (agricultural or residential) types.

Based on this assessment, the middle section of Rouge Park appears to be an important conduit for turtle movement north through the park. The upper left portion of the study area between Stouffville and Markham contains sections of high connectivity, as well as primarily agricultural land cover which appears to facilitate turtle movement. Therefore, it is possible that turtle habitat suitability could be maximized if wetland and connectivity restoration and management efforts are prioritized in this area. Peri-urban areas and other areas along urban margins, such as Stouffville and Markham, tend to experience rapid change and growth. These types of areas are difficult to manage, due to the balance between pressure of urban development against the pressure for preservation of undeveloped and rural areas. (Bourne, Bunce, & Luka, 2003). Urban development in Toronto will likely continue, and Rouge Park will likely serve as an important stronghold for biodiversity, which will hopefully encourage turtle movement to the north instead of east or west into populated areas. From 2011 to 2016, Stouffville experienced a population growth of 21.8%. During this same period, the population of Markham increased by 9.0% (Statistics Canada, 2016). With further growth, Markham may continue to expand northwards, and Stouffville may expand outwards in all directions. Because the area between these two towns contains a number of important wetlands, and also has potential to serve as a habitat corridor, it is important to target this passage for conservation to limit urban development in this area and to preserve turtle access to these wetlands. This would require considerable coordination between a number of stakeholders, including politicians, municipal governments, and organizations such as the Toronto and Region Conservation Authority (TRCA), Parks Canada, and the Toronto Zoo. In the future, if these upper wetlands are able to be connected to those in the lower portion of the study area by Rouge National Urban Park, the Toronto Zoo may be able to assess new areas for future juvenile head started turtle releases. It is possible that the Zoo could release the juvenile turtles in a more northern location, which would both encourage use of the habitat areas in this upper range while also bypassing some of the roads and path intersections in the southern extent of the park.

5.0 Conclusion

As an endangered species which is highly sensitive to anthropogenic habitat fragmentation, Blanding's turtles (*Emydoidea blandingii*) face a number of obstacles to movement within the fragmented landscape of Rouge National Urban Park. These include over 32 potential areas of road crossings along paths of movement, as well as only moderate levels of landscape-level habitat connectivity within much of the park. Though the park does provide more suitable turtle habitat and facilitated movement compared to the landscape outside of the park boundaries, there are still improvements which can be made. Recommendations for park management include the installation of ecopassages at likely turtle path-road intersections, as well as the prioritization of new land acquisition and wetland restoration in the area between Stouffville and Markham. Both of these measures would serve to improve turtle habitat connectivity and conductance at the landscape level.

In the end, it is anticipated that this model of Blanding's turtle habitat may help to inform management decisions within Rouge Park, as well as to target habitat restoration and acquisition efforts. This, in turn, will contribute to both habitat and species conservation efforts in Southern Ontario, in addition to contributing to the growing body of knowledge on Blanding's turtle habitat selection. Currently, the juvenile turtles are primarily confined to a single wetland complex in the southern extent of the park, and likely will not start to increase their range until they are larger and more mature (McMaster & Herman, 2000). Therefore, there is potential for the landscape within the park boundaries to be considerably improved with regard to the facilitation of turtle movement by the time these juveniles mature in the future.

Recommendations for further study include analyzing the locations of observed turtle road mortality incidents to assess where best to target areas for ecopassage installation, as well as further study of urban and peri-urban growth projections of Stouffville and Markham. An in-depth assessment of the logistics and implications of land conservation efforts in the potential corridor area targeted for land acquisition, with a focus on municipal and organizational jurisdictions and priorities, would also be highly valuable.

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Appendix A

Table 3. Confusion matrix for the supervised maximum likelihood classification of PlanetScope 3m 4 band VIS-NIR satellite imagery (Planet Labs, 2018), consisting of 215 stratified random accuracy assessment points over 9 land cover classes.

OID	ClassValue	C_1	C_6	C_10	C_30	C_50	C_52	C_61	C_66	C_67	C_92	Total	U_Accuracy	Kappa
0	C_1	15	0	0	0	0	0	0	0	0	0	15	1	0
1	C_6	0	0	0	0	0	0	0	0	0	0	0	0	0
2	C_10	0	0	10	0	0	0	0	0	0	0	10	1	0
3	C_30	0	0	0	3	0	0	0	0	7	0	10	0.3	0
4	C_50	0	0	0	0	58	3	0	1	0	0	62	0.935483871	0
5	C_52	0	0	0	0	0	22	0	4	0	0	26	0.846153846	0
6	C_61	0	0	0	0	1	0	7	0	2	0	10	0.7	0
7	C_66	0	1	0	0	0	2	0	21	0	0	24	0.875	0
8	C_67	1	0	0	0	1	0	0	0	45	0	47	0.957446809	0
9	C_92	0	0	0	0	0	0	0	0	0	11	11	1	0
10	Total	16	1	10	3	60	27	7	26	54	11	215	0	0
11	P_Accuracy	0.9375	0	1	1	0.966666667	0.814814815	1	0.807692308	0.833333333	1	0	0.893023256	0
12	Kappa	0	0	0	0	0	0	0	0	0	0	0	0	0.870141807