Evaluating the Quality and Connectivity of Urban Green Space Networks for Biodiversity Planning in Canadian Cities: a Case Study in Surrey, BC

by

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Abstract

Urban green space networks play a vital role in increasing biodiversity in cities. However, not all green spaces are created equally. Planners must consider the quality of urban green space patches and the connection between them to effectively plan for biodiversity. Using the City of Surrey as a case study, this project set out to answer the following research questions: 1) What elements influence biodiversity in urban areas? 2) How can we assess overall Green Space Quality (GSQ) for wildlife, and, how does GSQ assessment influence connectivity analysis in urban green space networks? Open-source GIS connectivity models were used to apply a GSQ assessment framework to Surrey. It determined that parks within the City's green infrastructure network included 52% of elements known to increase biodiversity, the highest quality ranking park included 87.5% of elements. The inclusion of GSQ rankings did not influence the outcome of the connectivity analyses.

Keywords: Surrey; Urban Green Space; Biodiversity; Green Space Quality; Urban Green Space Network; Circuitscape

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List of Acronyms

BC	British Columbia
BCS	Biodiversity Conservation Strategy
CWD	Cost Weighted Distance
GIN	Green Infrastructure Network
GIS	Geographic Information System
GSQ	Green Space Quality
LCP	Least Cost Pathway

Chapter 1.

Introduction

Land use change is one of the leading drivers of climate change and biodiversity loss around the globe (IUCN, 2015). Balancing the need for development and the conservation of nature has become a challenging task for planners and other qualified environmental professionals. While cities have traditionally been viewed as centers of human activity intentionally separated from nature (Bush, 2020; Cazalis et al., 2023; Miller, 2005), the negative effects of fragmenting ecosystems in urban areas are more evident than ever. Research has shown that the preservation or reintroduction of nature has both direct and perceived benefits for people in cities, including but not limited to: mitigation of urban heat island effects, pollination services, improved air quality, flood prevention, improvements in human health and sense of well-being, and increases in environmental stewardship initiatives by residents via ‘cues to care’ (Aronson et al., 2017; Nassauer, 1995). Thus, it is important that planners consider the needs of people in concert with the need for nature to ensure the livability of cities for all – for now, and into the future.

Incorporating nature in cities through planning decisions has become a popular topic in recent years in both academic literature and professional practice (Bush, 2020; Lepczyk et al., 2023; Wellmann et al., 2020). Around the world, planners, urban foresters and ecologists have begun employing approaches such as Urban Green Space Networks (UGSNs)[1], Green Infrastructure Networks (GINs), and biodiversity planning to protect and/or reintroduce nature in new and existing developments (Aronson et al., 2017). However, the implementation of strong natural area protection planning policies and bylaws in Canadian cities has faced a variety of barriers, including the lack of robust spatial data (e.g. geographic information systems, land cover mapping) and expertise to make informed decisions (Wellmann et al., 2020). This project uses the City of Surrey as a case study for the assessment of how biodiversity planning can be further supported through urban green space quality assessments and the use of open-source

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[1] UGSNs are a series of habitat patches and connecting corridors in urban planning defined by the International Union for Conservation of Nature (IUCN) as “clearly defined geographical space that is governed and managed over the long term to maintain or restore effective ecological connectivity” (Beazley et al., 2023; Hilty et al., 2020)

GIS connectivity models. The City of Surrey's biodiversity conservation planning staff played a major role in the development of research objectives.

1.1. GIS and Planning

The benefits of enhancing UGSNs is widely understood in academic literature, yet there is a disconnect between academia and local government land use policy implementation (Haaland & van den Bosch, 2015; Scott, 2019; Wellmann et al., 2020). However, as noted there is a lack of strong planning policies aimed at protecting and restoring ecological connectivity through Canadian cities (Wellmann et al., 2020). In addition to this, there is a lack of standard definition around what constitutes a green space, and even less direction around how to plan for green spaces that contain high quality habitat. Therefore, it is important to ensure that land use planners and qualified environmental professionals are well equipped with the tools and knowledge to develop strong policies centered around protecting and connecting ecosystems in urbanizing landscapes.

While having the ability to interpret ecological data is seen as a crucial step to developing rigorous policy (Scott, 2019), the implementation of map-based tools in planning practice has not yet been harnessed to its full potential in North America (Wellmann et al., 2020). GIS-based models are powerful tools for assessing urban green space connectivity and can be used to effectively identify gaps for physical connectivity and quality. Spatial data analyses have been used extensively to study the benefits of green space connectivity in urban areas, particularly in China (Guo et al., 2018; Jiang et al., 2020; Wellmann et al., 2020). However, there has been comparatively little work in Canadian cities, even though many larger municipalities have begun developing biodiversity conservation strategies (e.g., City of Edmonton Natural Connections: Biodiversity Action Plan – 2009; City of Calgary Our BiodiverCity: Biodiversity Strategic Plan – 2010; City of Surrey Biodiversity Conservation Strategy – 2014; City of Vancouver Biodiversity Strategy – 2016; City of Toronto Wild Connected and Diverse: A Biodiversity Strategy for Toronto – 2019) . Uptake in using GIS models to assess UGSN is limited by access, cost of GIS software, and lack capacity (Wellmann et al., 2020). Thus, it is important that low-barrier GIS analyses to support biodiversity initiatives are explored.

1.2. Research Aim

The goal of this research project is to explore how quality assessments of UGSNs can be made more accessible to planners in Canada, irrespective of specialization. To achieve this, this paper aims to answer the following two questions:

1. What elements influence biodiversity in cities/urban area? And how can we assess overall Green Space Quality (GSQ) for wildlife?
2. How does GSQ assessment influence connectivity analysis in urban green space networks?

This paper will outline the elements of green spaces that have been identified to be the strongest indicators of increased biodiversity of terrestrial species in urban areas, the effects that poor-quality green space have on true UGSN connectivity, and how planners can harness the power of assessment frameworks to plan for better, more effective UGSN across Canada.

1.3. Document Structure

Research questions were first addressed through a literature review which investigated the intersection of two distinct bodies of research – urban ecology and urban green space planning. The findings from the literature review outlined the development of the Green Space Quality (GSQ) assessment framework, and detail how this framework was implemented into a field data collection application using ArcGIS Field Maps. From there, it details the methods used to run a connectivity analysis using Circuitscape, an open-source connectivity analysis software developed by McRae et al. (2016) that integrates with ArcGIS Pro. The methods describe how different GIS layer inputs have been integrated to include the in-situ GSQ assessments in the connectivity analysis. Finally, the results of the connectivity analyses are presented and discussed from both an ecological context and their wider planning implications, as well as recommendations for Surrey, and finally a conclusion.

Chapter 2.

Literature Review

2.1. Introduction to Urban Green Space

2.1.1. Evolving Role of Urban Green Space

More than 4.2 billion people live in urban areas (IPCC, 2023). Unsurprisingly, the migration to urban living has increased the need for built environments and the servicing infrastructure to support it. Towns and cities continue to swell beyond their initial borders, increasing pressure on the surrounding natural areas (Sandström et al., 2006). Anthropogenically driven land use change is one of the largest drivers of climate change, exacerbated by the fragmentation of green space (Haaland & van den Bosch, 2015; IUCN, 2015; Kong et al., 2010). The removal of functioning ecosystems from urban areas increases many negative impacts of climate change, including raising of ambient temperatures ("heat island effect"), more severe flooding events from increased impervious surfaces, and reduction in ecological services such as pollination, just to name a few.

Urban green space plays an integral role in promoting the health and wellness of human beings in cities. Contextualized through a western colonial lens, the concept of reconnecting human beings back to nature while surrounded by a dense urban matrix can be traced back to the work of Frederick Law Olmsted, Sr. in the nineteenth century (Eisenman, 2013). Olmstead's work focused on reintroducing natural elements to the city to alleviate the grievances of living in highly industrial urban areas, and to positively affect human living conditions. Since then, it has become increasingly evident that access to nature and high-quality green spaces is essential to the human experience. Research has shown that the perception of quality green space and reconnection with biodiversity can have positive psychological benefits for people, such as reducing stress and anxiety and benefits to physical health (Felappi et al., 2020). In addition, access to green space that supports high biodiversity promotes community conservation initiatives, or 'cues to care' (Nassauer, 1995; Swanwick et al., 2003). Meaningful stakeholder engagement is a critical step in developing effective urban conservation initiatives, and is essential for ensuring that future generations will be able to access nature outside their doorstep, no matter where their doorstep is (Aronson et al., 2017; Kirk et al., 2023; Swanwick et al., 2003).

Much of our present day understanding of the benefits that natural areas provide in cities are from a human-centric perspective. Yet, urban areas are crucial for biodiversity, as they are often home to a significant percentage of threatened and sensitive species, and in some cases provide preferential habitat (Ives et al., 2016; Pither et al., 2023). Many species have no choice but to select urban and sub-urban areas as habitat due to resource availability – referred to as urban avoiders or dwellers (Beninde et al., 2015) – while some species have adapted their behaviors and risk tolerance to thrive in human dominated environments – known as urban utilizers (Grade et al., 2022; Raymond & St. Clair, 2023). The interruption of landscapes due to human development has had a considerable impact on the ability of wildlife to move freely throughout regions, especially those that fall into the urban avoider or dweller designations, resulting in an increase in human-wildlife conflict and degradation of habitat quality (Apfelbeck et al., 2020; Grade et al., 2022; Raymond & St. Clair, 2023). The principles of landscape ecology dictate that the vast majority of species rely on a matrix of habitat ‘patches’ and ‘corridors’ in order to access different resources and enable gene dispersal throughout their life histories (Cushman et al., 2010). Wildlife in urban areas must depend on remnant habitat patches and corridors to survive.

Green space connectivity has been defined as the “degree to which the landscape facilitates or impedes movement among resource patches” and can be assessed by measuring the “probability of movement between all points or resource patches in the landscape” (Taylor et al., 1993). Thus, it is important that urban planners and other qualified environmental professionals begin to shift their understanding of ‘who’ or ‘what’ urban green space is planned for.

2.1.2. Green Space Networks – Connection is Everything?

While it is now well understood that access to green space in urban areas is essential for human and wildlife health alike, for wildlife there is a particular dependence on landscape connectivity for survival (Rudd et al., 2002; Sandström et al., 2006; Taylor et al., 1993). As green space has traditionally been planned for human use, urban planners often feel as though they do not have sufficient ecological knowledge to plan green spaces from a biodiversity centric approach (LaPoint et al., 2015), or that the trade-offs between planning green spaces that are effective for people conflict with wildlife needs (Garrard et al., 2018; Scott, 2019). Research suggests, however, that the composition of individual green space patches as well as their regional networks are not mutually exclusive, rather are complimentary, and that few trade-offs exist between the two (Aronson et al., 2017; Felappi et al., 2020; Garrard et al., 2018).

If we are to effectively support biodiversity within the city, we must focus on creating well connected UGSNs that facilitate wildlife movement while minimizing human conflict. Movement barriers can be defined as the inhospitable matrix that exists between habitat patches, or urban green spaces, including but not limited to roadways, dense building developments, and impervious surfaces (Kirk et al., 2023). Reducing movement barriers for wildlife – regardless of species, or their life history needs – is essential for maintaining the health and resiliency of regional populations of wildlife (Hanski & Thomas, 1994). The reduction of barriers can come in many forms, such as adding native vegetation to pathways between parks, installing wildlife over/under passes to major roadways, or restoring riparian corridors (Hilty et al., 2020). Reducing barriers and facilitating wildlife movement is of utmost importance to ensure that biodiversity can thrive in urban areas, as poorly connected networks reduce the ability of species to access various habitats that they may require throughout life stages, resource access, and the maintenance of genetic diversity, all of which may lead to local extinctions if not considered (Kirk et al., 2022, 2023).

2.1.3. Planning for Wildlife – Who, what, where, when, and how?

Ensuring that planners have the base knowledge of how to assess natural assets without requiring expert elicitation is key (Kirk et al., 2021, 2022; Sandström et al., 2006). In an ideal scenario, all planning teams would be comprised of interdisciplinary subject matter experts enabled by comprehensive regulatory tools surrounding environmental protection. This is, however, unrealistic in Canada's present socio-political environment, especially for smaller communities with limited resources. The development of urban green space quality and connectivity assessment tools that require minimal technical expertise is a way to reduce the barriers of implementation and promotes more frequent UGSN assessments – a crucial way to monitor the status of UGSNs as urbanization continues to fragment natural areas.

2.1.4. Urban Green Space Network Assessments

Network assessments can be completed through assessing individual green space patches across a network, a network connectivity analysis, or ideally both. Tools that assess individual green space patches include the popular tools such as the Green Factor Tool (Juhola, 2018), the Biodiversity Sensitive Urban Design (BSUD) framework (Garrard et al., 2018; Kirk et al., 2021), or the City Biodiversity Index (Chan et al., 2021). These tools can be used proactively or reactively – for example, the BSUD framework can be employed with development proposals to assess project build sites and determine if habitat conservation goals can be achieved alongside development needs. While these tools have been used to assess individual green space patches and determine habitat quality, the authors suggest that a network analysis should also be completed to obtain a comprehensive view of green space networks across an urban area.

Habitat connectivity analyses have long been employed by researchers in landscape ecology to better understand how species move through space to access resources and spread genetic diversity (Deslauriers et al., 2018; Guo et al., 2018; Taylor et al., 1993). They are essential for a comprehensive overview of how green space networks can better support wildlife. A commonly employed technique for assessing the degree of connection between habitat patches is circuit theory, which assesses physical barriers to movement to a species through a landscape matrix. This is achieved by viewing landscapes as if they are electrical circuits, determining which ‘least-cost’ pathway that an electrical current – or species – would preferentially select to access various habitat patches (see Figure 1) (Dickson et al., 2019; B. H. McRae et al., 2008).

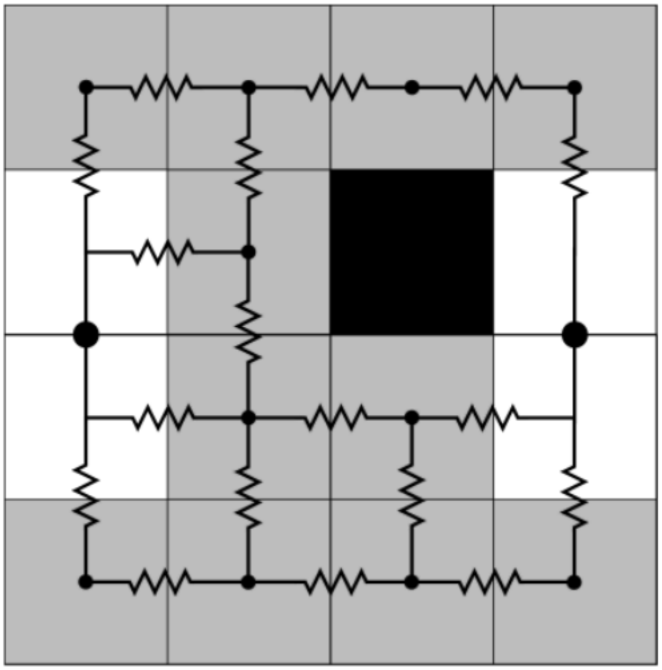

Figure 1. **A simplified landscape matrix detailing least cost pathways through Circuit Theory. The dots represent habitat 'nodes', or patches, that have minimal resistance surrounding them (large) or moderate resistance (small). The white grid cells represent non-resistant landscapes (high quality habitat), the grey cells represent moderately resistant landscapes (modified habitat), and the black cell represents a completely resistant landscape (unsuitable or inaccessible habitat).**

Source: McRae et al. (2008). Figure reproduced in accordance with the terms of SFU's CRKN license with Wiley Publishing.

Landscape resistance and connection between patches is determined by combining multiple raster[2] layers that have had resistance values assigned to them based on movement sensitives from one or more species (Pither et al., 2023), including but not limited to: land cover classifications, density of linear disturbances such as roadways, density of the built up environment, habitat patch sizes, etc. Assigning resistance values can be a complicated task, as movement barriers may depend on the size, mobility, and urban tolerance of the focal species3 (Kirk et al., 2023). To resolve this, many connectivity analyses focus on assigning resistance values based on only one or two focal species[3] – typically one avian and one terrestrial – that researchers have determined to be reflective of the movement patterns of most

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[2] A raster layer is a matrix of pixels organized into rows and columns that represent a surface. Each pixel contains a numerical value that represents information about the surface. A common example of a raster-based layer is an aerial image or a digital elevation model.

[3] Focal species are species whose habitat requirements and movement capacities are considered to be representative of all species that persist within a study area.

species within the defined area. However, recent studies have shown that connectivity analyses that consider multiple species (more than two) and generalize their movement sensitivities are just as effective in determining overall landscape connectivity, as evidence suggests that many species will likely use the same least cost pathways (Pither et al., 2023; S. L. R. Wood et al., 2021).

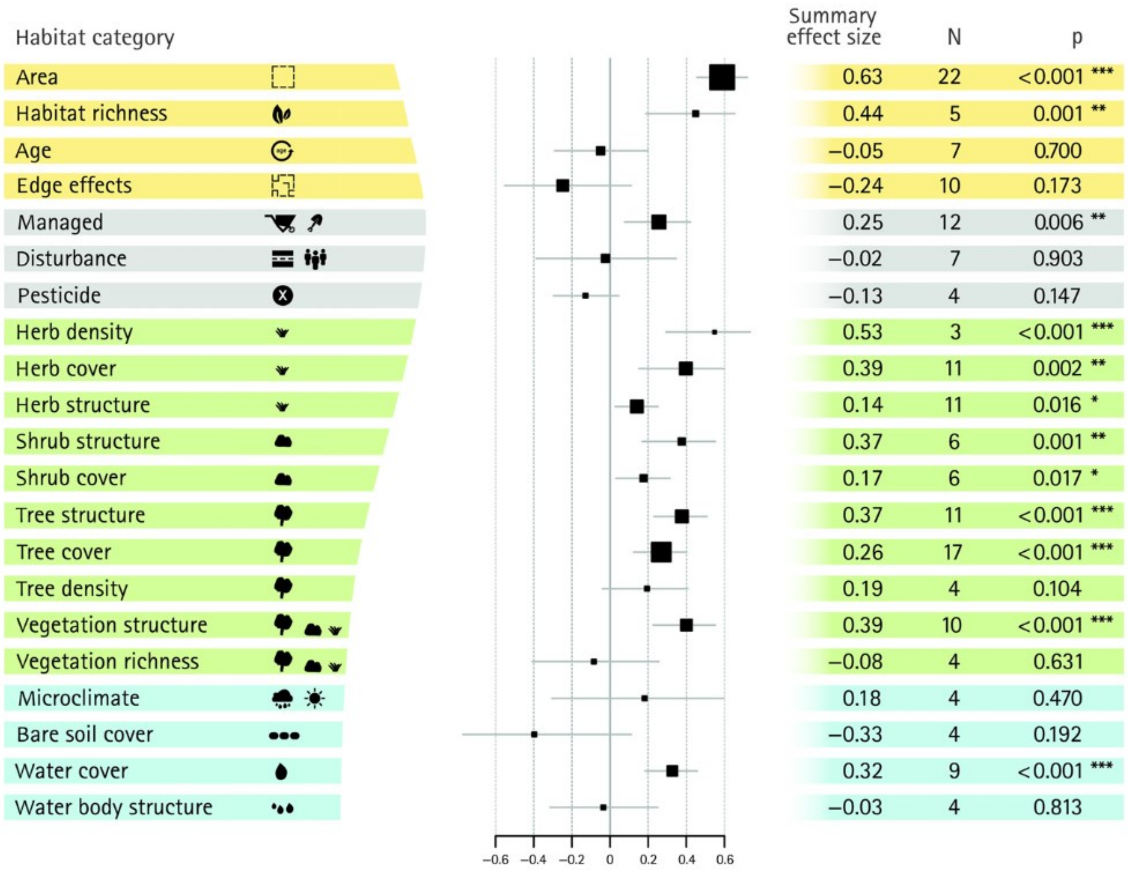
Many of these analyses are still unavailable to planners and other qualified environmental professionals, even if they have the expertise to use them. Model scripts may not be made publicly available, or parameters are too location specific to be easily replicated elsewhere. There are a few connectivity software packages that have been published for out-of-box use, namely Circuitscape (B. McRae et al., 2016), Conefor, Zonation, and Linkage Mapper (a subsidiary of Circuitscape). Unfortunately, these tools typically require expertise in GIS software and/or ecology to use them effectively. Because of this, although they recognize the need, many planners and natural asset managers feel as though they do not possess the necessary knowledge to conduct these assessments themselves (Sandström et al., 2006).

2.2. Green Space Quality – Not all Green Space is Created Equal

It is not enough to simply increase the connectivity between green space patches to better support wildlife in cities. Quality of green space is just as important to the success of increasing the effectiveness of UGSNs, and cannot be a secondary consideration. The composition of individual green space patches can significantly affect how and which species use those patches, with mammals being particularly sensitive to the presence or absence of specific features (Gallo & Fidino, 2018). If land use decision-makers are serious about supporting wildlife in urban areas, understanding what elements create a ‘quality’ green space is key to sustaining biodiversity.

As discussed, a major barrier to the mainstreaming of biodiversity and connectivity planning throughout Canada is the perception that biological assessments require a team of experts or a well-stocked interdisciplinary planning team (Aronson et al., 2017). While there are considerable benefits to ensuring that planning teams are comprised of interdisciplinary experts, there are accessible tools to assess the effectiveness of UGSNs for wildlife and identify linkage gaps. An important step in reducing barriers for planners and other qualified environmental professionals for implementing UGSN quality assessments is clearly identifying what combination of elements actually increase habitat quality. In their 2015 paper, Beninde et al.

conducted the first ever meta-analysis of urban green space compositions across the globe with the goal of identifying which elements have the strongest impact on species richness and abundance within urban green space. Species richness can be defined as the number of different species reported at a given site, whereas abundance is defined as the count of individuals regardless of species (Thompson & Starzomski, 2007). These dynamics are important to consider in green space assessment as they provide performance metrics for habitat quality. By assessing a wide range of taxa, their results indicate that some generalizations can be made about the absence or presence of natural elements within urban green spaces that influence higher rates of biodiversity (see Figure 2) (Beninde et al., 2015). This is important for planners as many connectivity and biological assessments require target species selection, which is typically conducted by biology professionals and increases the barriers to implementation (Diamond Head Consulting, n.d.; Solstice Environmental Management, 2017).



Habitat category	Summary effect size	N	p
Area	0.63	22	<0.001 ***
Habitat richness	0.44	5	0.001 **
Age	−0.05	7	0.700
Edge effects	−0.24	10	0.173
Managed	0.25	12	0.006 **
Disturbance	−0.02	7	0.903
Pesticide	−0.13	4	0.147
Herb density	0.53	3	<0.001 ***
Herb cover	0.39	11	0.002 **
Herb structure	0.14	11	0.016 *
Shrub structure	0.37	6	0.001 **
Shrub cover	0.17	6	0.017 *
Tree structure	0.37	11	<0.001 ***
Tree cover	0.26	17	<0.001 ***
Tree density	0.19	4	0.104
Vegetation structure	0.39	10	<0.001 ***
Vegetation richness	−0.08	4	0.631
Microclimate	0.18	4	0.470
Bare soil cover	−0.33	4	0.192
Water cover	0.32	9	<0.001 ***
Water body structure	−0.03	4	0.813

Figure 2. Summary effect sizes of random-effect models for all local factors calculated for species richness; size of square of summary effect corresponds to sample size of model. design variables (yellow highlight); management variables (grey highlight); biotic variables (green highlight); and abiotic variables (blue highlight).

Source: From Figure 3 from Beninde et al. (2015). Figure reproduced in accordance with the terms of SFU's CRKN license with Wiley Publishing.

2.2.1. Vegetation Composition

Urban tree canopies are a popular topic in planning research (Wolch et al., 2014). Many urban biodiversity strategies have a strong emphasis on protecting and enhancing canopy coverage in pursuit of increasing biodiversity. Although tree canopy coverage does play an important role in reducing the heat island effect in cities (Deilami et al., 2022; Ibsen et al., 2022; Westendorff, 2020), increases in canopy coverage does not necessarily correspond to an increase in habitat patch selection by species (Beninde et al., 2015; Grade et al., 2022; Rogers, 2022; Threlfall et al., 2016, 2017). This is not to suggest that tree canopy coverage is not important in increasing the quality of a green space patch – in fact, increasing the percentage of native trees within urban areas has been seen to increase selection of that patch by native wildlife (Berthon et al., 2021). However simply increasing the density of trees in a city, even in parks, will not increase biodiversity. A typical urban park full of large mature trees with expansive turf ground cover represents low quality habitat for many mammals (Gallo et al., 2017).

A diversely vegetated low to mid-level canopy is a strong indicator of increased animal biodiversity in UGSNs (Beninde et al., 2015). Low to mid canopy can be defined as shrubbery or low-height herbaceous plants, such as multi-stem short woody vegetation or tall native grasses, respectively. Herbaceous and shrub density, cover, and structure were found to be statistically significant for predicting species richness within green space patches. The structural diversity of these vegetation elements – mid to low canopy thickness, height differentials, etc. – provide essential foraging spaces for smaller species of birds and mammals and play a critical role in providing refuge and camouflage (Raymond & St. Clair, 2023). Herbaceous and shrub coverage provide essential structural diversity for wildlife that is reflective of natural forested areas, which increases niche availability required by the various life stages across a diversity of species.

The importance of vegetation structural diversity does not end with living plant material – land cover consisting of woody debris deadfall (logs, twigs, mulch, etc.) and leaf litter also play an important role in influencing species richness in urban green space (Grade et al., 2022). The presence of leaf litter and woody debris are reported to increase the abundance and richness of bird species in urban green space as the structural diversity of land cover increases foraging habitat, due largely to these elements increasing the abundance and richness of insects (Shwartz et al., 2013). Leaf litter helps to retain soil moisture that is essential throughout various life stages of pollinators, and provides wintering habitat (Shwartz et al., 2013). In addition, the presence of deadfall and leaf debris in urban green spaces is typically indicative of a reduction in human interference within the habitat patch, which coincides with increases in biodiversity.

2.2.2. Wetlands and Waterbodies

The presence of wetlands within green space patches has a strong influence on increasing biodiversity (Beninde et al., 2015). Wetlands are areas that experience permanent or seasonal water retention or ground saturation characterized by distinct plant species and soil compositions (Environment and Climate Change Canada, 2007). Examples of wetlands present in Canada include swamps, bogs, fens, sloughs, seasonally flooded forests, and fresh or saltwater marshes. Wetlands can also be comprised of open waterbodies, such as permanent or semi-permanent lakes and streams (Environment and Climate Change Canada, 2007). The inclusion of wetlands within urban green space increases the habitat availability for species that require aquatic access throughout their life stages – such as waterfowl (Rogers, 2022), amphibians (Beninde et al., 2015), and semi-aquatic mammals like muskrat and beavers (Diamond Head Consulting, n.d.). Some studies identified the presence of water to be more influential for pollinator species presence than woody debris (Shwartz et al., 2013), and has been shown to influence denning locations for urban mammals like coyotes due to hydration needs during pupping season (Raymond & St. Clair, 2023).

The presence of wetlands and other aquatic habitat is also an equally important element for climate proofing cities by attenuating storm water flows and filtering contaminant run-off (Lehmann, 2021). Open water features may also increase the abundance and richness of predatory avian species, such as hawks and eagles (Rogers, 2022), due to the increase in waterfowl and other prey species. Waterbodies are not, however, beneficial for all species – for those with limited mobility, large waterbodies can act as a barrier to movement (Kirk et al., 2021). Thus, while it is important to increase or preserve wetlands within urban green space patches, other considerations need to be taken to ensure that movement is not impeded for smaller and non-aquatic animals.

2.2.3. Native Vegetation vs. Novel Ecosystems

The debate of reinstating native vegetation versus planting exotic flora in urban areas is a contentious topic in UGSN design. One would assume that increased native vegetation would coincide with increased animal and pollinator biodiversity, however others suggest that cities should be treated like novel ecosystems given their inherent departure from natural systems (Aronson et al., 2017; Lepczyk et al., 2023). An example of this is the argument that certain native trees are considered a nuisance for maintenance and human health due to pollen production, regardless of their ecological importance (Coutts & Hahn, 2015). Whilst there is some truth to novel ecosystems having a positive impact on native species like pollinators (Shwartz et al., 2013), there is overwhelming evidence that increasing native vegetation land cover significantly increases wildlife richness and abundance within urban green space patches (Beninde et al., 2015; Berthon et al., 2021).

In a literature review investigating the role that ‘nativeness’ plays in increasing biodiversity in cities, it was found that 43% of publications studying the success of native vs.

non-native vegetation determined that native vegetation outperforms exotic counterparts (Berthon et al., 2021). The same review found that non-native animals respond negatively to increased native vegetation land cover, suggesting that restoring native vegetation in urban green spaces may have positive implications for invasive species management. In a study investigating the response of various bat, bird, and insect species to native vegetation in Australia, it was found that a 30% increase in native vegetation resulted in between 10 to 140% increases in species abundance across all study sites (Threlfall et al., 2017).

2.2.4. Human Intervention/Maintenance

Unsurprisingly, heavily maintained urban green space patches do not create desirable habitat for urban wildlife. Maintenance can be described as any interference with the natural processes within urban green space patches, such as mowing, raking, vegetation removal, etc. Interventions can increase stress on urban wildlife residing in the patch, reduce access to resources, and often lead to patch abandonment or increases in human-wildlife conflict (Beninde et al., 2015; Lehmann, 2021; Raymond & St. Clair, 2023; Uchida et al., 2021). This presents a challenge urban planners and natural asset managers as many urban green space designs are centered around human use (Masood & Russo, 2023). A balance between human recreation and areas set aside for conservation is important to achieve biodiversity goals. (Aronson et al., 2017).

2.2.5. Patch Sizes and the Built Environment

How habitat patch configuration influences species richness and abundance is a wider topic throughout biological sciences. The ‘Single Large or Several Small’ (SLOSS) conservation area structure debate dates back to the 1970’s with the publication of island biogeography theory. The debate details the differences in conservation science on whether wildlife responds better to having access to one large, protected area, or several smaller areas that they can disperse between. In their meta-analysis, Beninde et al. (2015) conclude that large green space patches are a highly influential component to increasing biodiversity within cities. They suggest that larger green space patches provide greater niche availability for species, and that large patches inherently reduce edge effects as there is more habitat availability away from the perimeters of the patch. Other studies have also found similar results that patch size was a major indicator in predicting increased avian species richness (Plummer et al., 2020; Rogers, 2022; Zambrano et al., 2022), and that small tree mammals such as squirrels preferentially select habitat that is inland from green space perimeters (Kay et al., 2023). In short, larger urban green spaces are more likely to host a larger variety of wildlife – however, there are other dynamics of the city environment that are likely to be affecting these findings.

First, urban green spaces are typically surrounded by built-up urban land cover, such as buildings, roads, and other inhospitable elements. It is more likely that urban wildlife will select larger urban green space patches due to space availability. Interestingly, mammalian species richness has been found to increase as one moves away from the urban core, peaking in suburban areas (Grade et al., 2022). This is likely due in part to suburban areas having more green space availability in general due to the presence of private yards, something that is often lost with densification in the urban core (Apfelbeck et al., 2020). While the answer may seem obvious – simply increase the size of urban parks to increase biodiversity – planners are stuck with the challenging task of balancing the social needs of their communities (e.g., the right to housing and other amenities) with the needs of urban wildlife. Access to larger green spaces also brings a host of social justice issues such as gentrification and inequitable nature access across cities (Fidino et al., 2021). Creating multiple, smaller, well-connected green spaces that incorporate smaller steppingstone parks may be a better method for increasing niche availability and access for urban wildlife while also responding to human needs.

2.2.6. Comprehensive, Quality UGSN

Equitable access to quality green space is an issue for both city dwelling humans and non-humans alike. While research shows that large, less anthropogenically managed habitat patches are the best indicators for increasing wildlife biodiversity in cities, it is unrealistic to expect urban planners to prioritize wildlife needs over human in every greenspace. However, it is increasingly evident that access to high quality green space is essential to the health and well-being of people, and access can be appropriately designed through a well-planned UGSN (Beninde et al., 2015). Connectivity can and will look different depending on the species. For example, birds have greater mobility across the landscape as compared to small terrestrial species, such as shrews or amphibians (Kirk et al., 2022; Zambrano et al., 2022). Connectivity can, however, be strategically generalized across multiple species (Pither et al., 2023). Failing to address the quality of connection throughout the network inherently limits movement potentials for many species, and therefore is not reflective of a truly well-connected network (Felappi et al., 2020). It is crucial that urban planners employ connectivity and quality assessment tools in concert with one another that can address the habitat requirements and movement patterns of multiple species.

Chapter 3.

Methods

The purpose of this chapter is to outline the methods used to develop the Green Space Quality (GSQ) Assessment Framework and connectivity analysis, to answer the following questions: What elements influence biodiversity in cities/urban area? And how can we assess overall Green Space Quality (GSQ) for wildlife? And how does GSQ assessment influence connectivity analysis in urban green space networks?

Surrey, BC represents the study area used to answer these questions. This includes the methods used to develop the GSQ Assessment Framework, and its subsequent implementation through field data collection. Finally, we will examine the methodology used to run a connectivity analysis for Surrey's GIN, and how individual green space quality assessment scores were incorporated into the analysis.

3.1. Study Area: Surrey, BC

The City of Surrey is approximately 30km from Vancouver in BC's lower mainland and is situated on the traditional unceded territories of the Coast Salish Peoples, including the land-based nations of the q̓ic̓əy̓ (Katzie), q̓ʷɑ:n̓ƛ̓ən̓ (Kwantlen), and səmyámə (Semiahmoo). It is the second largest municipality by population in the Metro Vancouver region, with approximately 610,500 residents, and is the largest municipality by area (316.4km2). The city is bounded by the Fraser River to the north, the Washington State border and Boundary Bay in the south and shares boundaries with the cities of Delta, White Rock and the Township of Langley (City of Surrey, 2019b). Surrey is home to a wide variety of land use types, including high density urban developments, industrial parks, active agricultural land, suburban, and rural residential. It is also one of the fastest growing municipalities in Canada (City of Surrey, 2020), which has resulted in a challenging balancing act between natural area conservation and urban development.

The City of Surrey was the first city in BC to have a council-endorsed Biodiversity Conservation Strategy (BCS) in 2014. The goal of the strategy is to recognize the importance of biodiversity across the city, document and measure the current state of biodiversity and habitat availability, set conservation targets, and recommend policies and procedures that can be used to support biodiversity initiatives. This innovative strategy sets the stage for balancing ongoing urban development with natural area conservation. It provides land use decision makers with a roadmap for developing stronger biodiversity protection policies and management approaches. Complimentary to the BCS is the more recent Biodiversity Design Guidelines (2021), which outline site-level considerations to incorporate biodiversity-friendly principles into various forms of land use and development One of the major components of the BCS is the identification of a GIN, a 39.0 km2 network that includes secured or protected natural areas, parks, greenways, foreshore areas, and other natural corridors throughout the city (City of Surrey, 2019a).. The GIN weaves its way throughout the entirety of Surrey, connecting biodiversity hotspots called "hubs" and "sites", via "corridors" to create a comprehensive ecological network (see Fig. 3).

Private lands encompassed by the GIN that would not fall under legislated protection mechanisms e.g., upland forests or other natural areas, including designated critical habitat for species at risk that do not have riparian areas, streams and wetlands, are vulnerable to development unless dedicated to or acquired by the city for parkland. Any development within 50 metres of the GIN triggers Surrey's Sensitive Ecosystem Development Permit Area (SEDPA), a special development permit area designation created through an amendment to the City's Official Community Plan (OCP) in 2016. Development and rezoning applications in the SEDPA require an ecosystem development plan and must follow SEDPA guidelines. Surrey's tree protection bylaw can be used to leverage the protection or replacement of individual significant trees or specific stands of trees within the GIN. However, as noted, trees on their own do not equate to intact, connected ecosystems. The city can require that developers implement wildlife-friendly landscaping and other approaches to mitigate biodiversity loss (e.g., follow the Biodiversity Design Guidelines) in areas of the GIN impacted by development that do not trigger provincial or federal legislation.

While some adjustments have been made over time, Surrey has not undertaken a comprehensive update to the GIN since it was endorsed in 2014. Consequently, the GIN map layer in the City's GIS system applied for land use planning does not reflect many areas in the GIN moved for or lost to development. Not having the current spatial extent and location of the GIN has implications for the development permit review process and ongoing decisions involving the GIN (e.g., density bonus and green space transfers). This is especially relevant for corridors. Similarly, using out-of-date data can affect informed decision making for parkland acquisition.

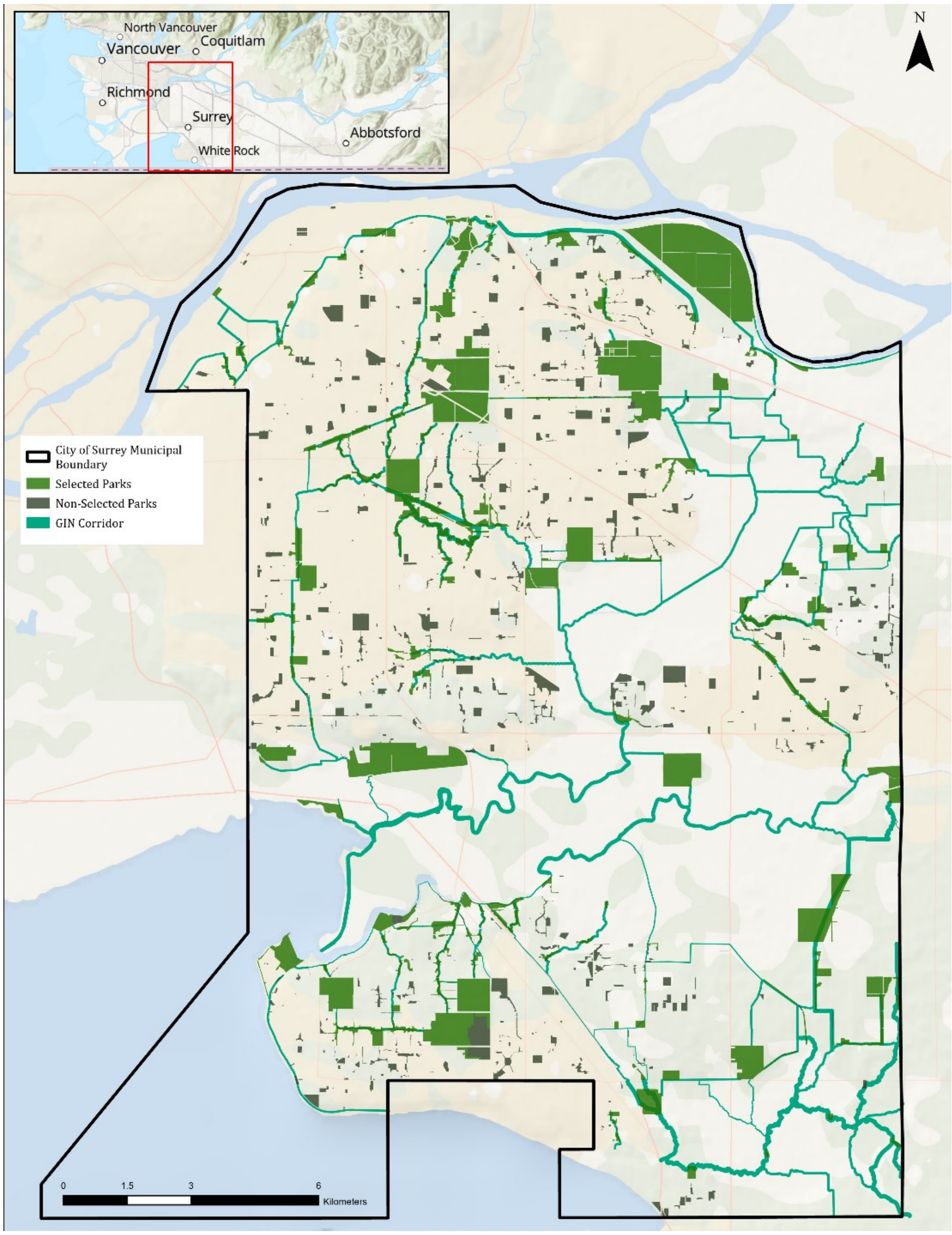


Figure 3. **Study Area Map detailing the City of Surrey's Park and Green Infrastructure Network (GIN), detailing the parks selected for this study based on the intersection of the GIN.**

3.2. Quality Assessment Framework

There are currently few green space quality assessment tools for planners that are specifically designed to assess green spaces on their ability to support wildlife (Knobel et al., 2019). In understanding the importance of reducing barriers for understanding what constitutes a high-quality green space, a green space quality assessment framework that was designed to be adapted to GIS software and mobile data collection applications for ease of spatial analysis.

3.2.1. Literature Review

A literature review was conducted in two parts to support the development of a quality assessment framework. The first part of the literature review was conducted to determine the key determinants of habitat quality for urban green space. Two distinct pillars of literature were identified to investigate the interplay between biodiversity and urban planning. Using the search engine Scopus, two searches were conducted using the key terms “urban” + “green space” + “quality” + “wildlife”, and “urban” + “green space” + “quality” + “biodiversity”, yielding 157 and 99 documents, respectively. Search results were restricted to published peer reviewed studies originating from Canada, the United States, United Kingdom, Australia, and New Zealand due to comparability of species, existing research, and policies and governmental structures. Search results were manually screened for relevancy as only peer reviewed journals that considered green space design requirements for terrestrial animals were reviewed. This resulted in n= 44 papers reviewed for biodiversity.

The second part of the review was conducted to investigate current tools available to planners for green space quality assessments and planning for biodiversity. This research was also conducted on Scopus, using the key terms “urban” + “planning” + “biodiversity” + “tool” and was restricted to the same geographical parameters as the biodiversity searches, as well as limited to publications from ‘Urban Planning’ journals. Search results yielded 52 documents. Results were manually selected for relevancy for terrestrial wildlife, and to avoid duplication of selected papers originating from the biodiversity key term search. This resulted in an additional n= 12 papers reviewed.

3.2.2. Framework Development

The green space quality assessment framework draws from the findings of Beninde et al.'s (2015), paper titled: Biodiversity in cities needs space: a meta-analysis of factors determining intra-urban biodiversity variation. Through literature review, a pattern of influence was identified, placing the results of Beninde et al. (2015) as a key marker in GSQ assessment work. Their work holds significance as it was the first ever meta-analysis that compared different green space elements on their effectiveness for increasing biodiversity across multiple and different taxonomic groups globally. The quality assessment framework consists of 10 elements identified by Beninde et al. (2015) with some categories condensed for clarity. These categories were then confirmed by subsequent studies that appeared in the results of the literature review, as well as prominent literature that cited Beninde et al. (2015). the elements were reviewed by the City of Surrey's Biodiversity Conservation Planner, a Registered Professional Biologist to confirm relevancy and evaluation strategies. The 10 categories included in this study are: vegetation coverages, leaf litter and deadfall, water presence, native vegetation presence, patch size, anthropogenic elements and interventions, and connectivity in relation to the existing green infrastructure network (GIN), as seen in Table 1.

Elements are assessed based on presence or absence in the location of the collected data point, denoted by a non-weighted binary value assignment of 1 or 0, respectively. Each element from the framework was collected via a pre-configured fillable form on Esri FieldMaps to ensure consistency of data collection across the entire study area. The point data collected in FieldMaps was then populated into the polygon layer of surveyed parks, which was then rasterized for implementation into Circuitscape.

Table 1. Green Space Quality Assessment Elements

GSQ Elements	Articles	Summary of Effect	Notes
Vegetation Cover/Density - Low to Mid-Level	Beninde et al. (2015), Threlfall et al. (2017), Threlfall et al. (2016), Raymond & St. Clair (2023), Grade et al. (2022), Rogers (2022)	Increasing the structure and diversity of low to mid canopy vegetation (shrubbery, herbaceous plants) has been seen to increase the richness and abundance of wildlife across all taxa. Strong effects on the increases in wildlife presence with dense herbaceous plants. Suggested that diverse mid-level vegetation increases shelter opportunities for a wide array of species, and increases food availability for species such as bats and birds. May also increase nesting opportunities and food sources for insects.	Statistically significant across all categories from the Beninde analysis with the strongest effect from herb/shrub/structure diversity elements. Has also since been proven to increase species richness and abundance across multiple studies.
Vegetation Cover - Canopy/Trees	Beninde et al. (2015), Threlfall et al. (2017), Threlfall et al. (2016), Grade et al (2022), Rogers (2022)	Presence or absence of canopy trees within urban green space influences the abundance of species. Variable results on if presence increases species richness, however increased tree densities have been reported to have either a null effect on species richness and abundance or a negative effect (Threlfall et al. 2017). Tree cover is not a universal indicator of an increase in species richness.	Some reports of increasing richness and abundance with tree presence but has in many of the studies proven to be a non-significant indicator. Tree density has not been shown to have a significant impact across multiple studied taxa.
Deadfall/Leaf Litter	Beninde et al. (2015), Shwartz et al. (2012), Grade et al. (2022), Kirk et al. (2021)	Deadfall and leaf structural diversity provides increased foraging opportunities for species. Increased shelter and hides for smaller invertebrates. Increased deadfall and leaf litter may also indicate reduced management interventions and are more reflective of natural systems. Increases denning habitats for coyotes and can reduce mammalian conflict with people as it provides refuge and camouflage.	Large indicator of invertebrate and foraging bird presence. Increases shelter and food availability across many taxa. Deadfall has also been shown to increase denning selection.
Wetland/Waterbody	Beninde et al. (2015), Shwartz et al. (2012), Raymond & St. Clair (2023), Rogers (2022)	Increased habitat for aquatic or semi-aquatic species across all taxa, increased hydration opportunities for mammals including denning species that had lactation requirements, decreases urban heat effects and provides refuge. Water was seen as one of the second strongest indicators of avian richness in Rogers (2022) study.	Shown to increase habitat availability and food web facilitation.

GSQ Elements	**Articles**	**Summary of Effect**	**Notes**
%Native Vegetation	Beninde et al. (2015), Berthon et al. (2021), Shwartz et al. (2012), Kirk et al. (2021), Threlfall et al. (2017)	Native vegetation has been reported to have significant impacts on the abundance and species richness within green spaces. Berthon et al. ran a comprehensive literature review and were able to determine that native plants outperformed non-native in 43% of the published studies. Papers also discuss how the use of native vegetation may be an important mechanism for invasive management as native species outperform invasive species in predominantly native habitat patches. Threlfall et al. (2017) found that increasing native vegetation up to 30% within their study area increased species abundance from 10-140%.	Reports of significant increases in native biodiversity and implications that native vegetation may decrease the likelihood of invasives.
Patch Size	Beninde et al. (2015), Shwartz et al. (2012), Rogers (2022), Plummer et al. (2020)	Patch size did have some effect in the presence of species abundance and richness in urban green spaces, but it was not a universal indicator. Rogers found that there was a predictable increase, but other studies suggest that it must be in combination with increased habitat elements and connectivity. Beninde's study did find that there was an overall positive effect on the patch sizes for increasing biodiversity through a physical increase in niche partitioning.	Some increases in biodiversity with increased habitat size but unclear on if patch size alone is a good indicator. Wrapped up in quality of construction as well as distance and accessibility to other green spaces. Conflicts arise in acquiring large patch sizes in highly dense or rapidly urbanizing municipalities.
Human Intervention	Beninde et al. (2015), Kirk et al. (2021), Aronson et al. (2017), Lehmann (2021) *SOME RATIONALE*	Increased management and maintenance of green space patches have been found to decrease the richness and abundance of wildlife. Mowing regimes create physical and audio disturbances that reduce habitat selection for many pollinators, birds, and some mammals.	Decrease in human management allows for rewilding and natural behaviours of urban wildlife. Increases movement potential in and out of urban areas and reduces potential roadway mortalities and other conflicts

GSQ Elements	Articles	Summary of Effect	Notes
Degree of Connection	Fidino et al. (2021), Kirk et al. (2021), Rogers (2022), Beninde et al. (2015), Felappi et al. (2020), Zambrano et al. (2022), Grade et al. (2022), Metrovan (2018), *SLOSS Debate*	Increased availability of green space within a 1km buffer of other patches was a strong indicator of species richness from Beninde's study, and an increase in connectivity has been noted to increase the viability of species due to an increase in dispersal and genetic movement.	Increased connection increases movement potentials and habitat access throughout all life stages of wildlife.
Building Density	Fidino et al. (2021), Kirk et al. (2021), Kay et al. (2023)	Building density adjacent to green space has been noted as a potential barrier for wildlife as increases in human wildlife conflict have been reported, and increasing the 'landscape of fear'.	Dependent on the building type and activity levels, and presence of private green space. Some indication that building density decreases biodiversity but general building construction may not. Some preferential selection of suburban areas for opportunistic species.
Roadway Impacts/Edge Effects	Kirk et al. (2021), Kay et al. (2023)	Perception of risk and increased offspring mortality association with roads can increase the stress on urban wildlife and have shown to decrease abundance and richness in green spaces that do not have roadway buffers	Suggestions that roads create physical movement barriers and may shift wildlife behaviours to avoid mortality for themselves and offspring. Well known to reduce the movement capacity of species in urban areas.

3.3. GIS Analysis

3.3.1. Existing GIS Datasets

Vector and raster based spatial data was obtained from the City of Surrey to conduct the green space connectivity analysis. Shapefiles for current parks, green infrastructure network (GIN), core habitat areas, known species ranges, natural areas, etc. were obtained in a file geodatabase format and analyzed using ArcGIS Pro. A 2020 land classification layer used to develop a resistance raster was obtained from the Metro Vancouver open data portal, which was then clipped down to the City of Surrey municipal boundary. For a complete list of data obtained, see Table 2.

Table 2. Acquired data layers. Asterisk indicates layers that were used for reference or visual purposes, but not included in Circuitscape.

Layer Name	Data Type	Year	Resolution	Source
Parks	Polygon	2022	N/A	City of Surrey
BCS Hubs	Polygon	2020	N/A	City of Surrey
GIN Corridors	Polygon	2014	N/A	City of Surrey
Natural Areas *	Polygon	2022	N/A	City of Surrey
Habitat Types *	Polygon	2023	N/A	City of Surrey
Municipal Boundary	Polygon	2014	N/A	City of Surrey
Critical Habitat for Federally Listed Species at Risk *	Polygon	2019	N/A	iMap BC
Road Centrelines	Polyline	2022	N/A	City of Surrey
Land Cover Classification	Raster	2020	5m	Metro Vancouver Open Data Portal
Orthophoto *	Raster	2022	10cm	City of Surrey

3.3.2. Green Space Selection

There are 862 individual city-owned parks within the City of Surrey. For scope, 158 patches were identified for analysis. These green spaces were selected based on the following criteria: individual patches intersected or were within 100m of the GIN, were ≥1ha in size, and were not classified as an athletic park. Of the identified green space patches, only 78 were assessed due to access restrictions such as private property, constructed barriers (e.g., fencing), and sensitive habitat closures.

3.3.3. Field Data Collection & Visualization

The GSQ assessments were completed using ArcGIS Field Maps, a mobile data collection application developed by Esri. The absence or presence of GSQ elements were recorded using point data on the Field Maps application on a basis of absent or present, represented numerically by 0 or 1, respectively. Based on the GSQ Assessment Framework the following green space elements were evaluated in each green space patch: Grass Coverage, Tree Coverage, Shrub Coverage, Understory (Structural Complexity), Leaf Litter Presence, Wetland Presence, Waterbody Presence, Management Regime, and Management Type. Building density, roadway impacts, and degree of connection were factored in using a land classification and connectivity analysis in later steps. The degree of nativeness for vegetation was not assessed due to fieldwork being completed in January. A minimum of one data point was collected per green space, however multiple data points were collected approximately every 200 meters, or if a new GSQ element was identified. A total of 213 individual data points were collected.

Following the completion of field data collection, data points were exported to an excel worksheet. GSQ elements across the points were then averaged and collated into a single representative value for an overall quality score per park. The combined GSQ values were then re-symbolized as a point layer and appended to the corresponding green space polygon. Polygons were then symbolized based on the combined value to represent the overall quality of the patch, ranging from 0 to 1, representing a low quality to high quality habitat patch, respectively.

3.3.4. Resistance Raster Development

The current state of connectivity of the GIN was determined by conducting an updated connectivity analysis using Circuitscape. This software package was selected due to its integration with ArcGIS Pro, previous use in urban green space connectivity modeling in the literature, and its non-reliance on node placement, which is ideal for land use planning purposes as connectivity is equally evaluated across the inputted surface (Solstice Environmental Management, 2017).

The Polyline to Raster tool in ArcGIS Pro was used to convert the road layer into a usable raster format, using a cell size threshold of 40. The Surrey Parks layer was converted into a raster using the Polygon to Raster tool. The GSQ polygon layer was categorized into 5 quality score ranges using Natural Breaks (Jenks), and then converted into a raster also using the Polygon to Raster tool in ArcGIS Pro. All resistance rasters were clipped to the Surrey municipal boundary polygon. Resistance values for each category per layer were assigned based on values used in the 2018 Regional Connectivity Report and adjusted based on findings from Beninde et al. (2015), as can be seen in Table 3.

Two resistance rasters were created using the clipped 2020 Metro Vancouver Land Cover Classification (LCC), the GSQ polygon layer, the City of Surrey road network, and the City of Surrey parks layer. The resistance layers were calculated using SUM, which can better account for compounding disturbances from multiple layers without double counting them – for example, road disturbances received a compounding disturbance output in combination with the ‘paved’ land classification layer, which is likely more representative of disturbances from highways versus parking lots. The two resistance rasters created were: All Parks, and All Parks + GSQ. Both resistance rasters include the 2020 LCC and road network resistance values, and subsequently include the additional resistance/non-resistances of Surrey parks, and Surrey parks + quality ranking scores, respectively.

Table 3. **Resistance Values used for developing the respective resistance rasters for the connectivity analysis**

Data Layer	Class Description	Extra Info	Resistance
LCC	Buildings	MetroVan 2020 LCC	50 – *Highest Resistance*
LCC	Paved	MetroVan 2020 LCC	40
LCC	Other Built	MetroVan 2020 LCC	40
LCC	Barren	MetroVan 2020 LCC	20
LCC	Soil	MetroVan 2020 LCC	20
LCC	Conifer	MetroVan 2020 LCC	2
LCC	Deciduous	MetroVan 2020 LCC	2
LCC	Shrub	MetroVan 2020 LCC	3
LCC	Modified Grass/Herb	MetroVan 2020 LCC	10
LCC	Natural Grass/Herb	MetroVan 2020 LCC	3
LCC	Non-photosynthetic Veg	MetroVan 2020 LCC	20
LCC	Water	MetroVan 2020 LCC	10
LCC	Conifer/Paved	MetroVan 2020 LCC	5
LCC	Deciduous/Paved	MetroVan 2020 LCC	5
Roads	Highway	Surrey Road Network 2022	50 – *Highest Resistance*
Roads	Arterial	Surrey Road Network 2022	40
Roads	Collector	Surrey Road Network 2022	40
Roads	Local	Surrey Road Network 2022	40
Parks	City	All Surrey Parks	1
Parks	Community	All Surrey Parks	1
Parks	Nature Preserve and Habitat Corridors	All Surrey Parks	0
Parks	Neighbourhood	All Surrey Parks	1
Parks	Provincial	All Surrey Parks	0
Parks	Regional	All Surrey Parks	0
Parks	Urban Forest	All Surrey Parks	0
Parks	Unspecified	All Surrey Parks	0
GSQ Ranking	GSQ: 0.00 - 0.25	GSQ Score Layer	4
GSQ Ranking	GSQ: 0.26 - 0.438	GSQ Score Layer	3
GSQ Ranking	GSQ: 0.439 - 0.563	GSQ Score Layer	2
GSQ Ranking	GSQ: 0.564 - 0.675	GSQ Score Layer	1
GSQ Ranking	GSQ: 0.676 - 0.875	GSQ Score Layer	0 – *Lowest Resistance*

3.3.5. Linkage Mapper and Least Cost Pathway (LCP) Identification

The Build Network and Map Linkages tool from the Circuitscape Linkage Mapper ArcGIS Toolbox (v 3.1.0) (herein referred to as Circuitscape) was used to run the connectivity analysis and determine the Least Cost Pathways (LCP) between terrestrial hubs in Surrey. An LCP can be defined as the ‘easiest’ route of travel through an area, or the preferential movement pathway between important habitat patches that determine the quality of connection throughout a landscape. LCP ratios calculated by Circuitscape are determined per pathway and appear in the attribute table for each analysis. Two separate connectivity analyses were completed based on the two resistance rasters, as detailed in the previous section. The City of Surrey Terrestrial Hubs layers were used as the Core Area Feature Class for all connectivity analyses. The Cost-Weighted & Euclidean option was used for the Network Adjacency Method based on recommendations and lessons learned in the Circuitscape instruction manual. LCP’s that were less than 100m in length were filtered out for visual clarity.

Chapter 4.

Results

The purpose of this section is to answer the second research question: what elements influence biodiversity in cities/urban areas? And how can we assess overall Green Space Quality (GSQ) for wildlife? This question was answered through conducting two connectivity analyses in Surrey, BC, Parks Only and Parks + GSQ, using Circuitscape. Surrey was selected as a recognized leader in municipal biodiversity planning, but it has not conducted connectivity analyses that includes field assessments of green space quality. Surrey also has an existing GIN, which could be compared against the connectivity analysis results to determine how well the existing network aligns with the analysis. This chapter will first present the results of the GSQ field data collection and quality ranking system. It will then present the results of the two connectivity analyses – Parks Only and Parks + GSQ. Both analyses include the Metro Vancouver land classification, Surrey roads, and Surrey parks layer as base information, with the GSQ layer included in the Parks + GSQ analysis. The BCS hub layer was used to designate terrestrial hubs for both analyses, as required by Circuitscape. The connectivity analyses are then used to examine differences in Least Cost Pathways (LCP), intersections between LCP and the GIN, and the overlap between LCP and known critical habitat for federally listed threatened and endangered species at risk within Surrey.

4.1. GSQ Quality Assessment Results

The GSQ assessment reviewed 78 parks that intersected or were within 100m of Surrey's existing GIN networks. Final quality scores were assessed based on the presence or absence of GSQ elements identified from the literature, highlighted by the findings of Beninde et al. (2015). At the time of survey, the maximum GSQ score from the field data analysis for selected parks in Surrey was 0.875, with the highest-ranking green space being Tynehead Regional Park (see Figure 4), which is a designated terrestrial biodiversity hub in Surrey. The lowest ranking park was Mound Farm Park with a score of 0.0 (see Figure 4). This park is also a terrestrial biodiversity hub, but the park is dominated by an extensive tilled agricultural area and surrounded by intensively farmed blueberry monocultures. At the time of assessment, the only accessible area of Mound Farm Park that could be assessed was a bare agricultural plot. The average GSQ ranking for all assessed parks was 0.52. Average to higher ranking green space patches were evenly distributed throughout Surrey, with no distinct patterns of GSQ distribution throughout the selected parks (see Figure 5).

Figure 4. **Highest and lowest ranking parks from the GSQ assessment in Surrey, BC. The image on the left was captured of Mound Farm Park during field data collection. The image on the right depicts Tynehead Regional Park, image courtesy of Vancouver Trails.**

Shrub coverage was the most commonly present GSQ element, recorded in 71 of 78 assessed parks. The second most common element was tree coverage, appearing in 64 parks, followed closely by grasses, recorded in 63 parks. For grasses, however, 6 of those parks were noted to be native wet meadows and 9 were non-mowed grasses. Additionally, 59 parks were observed to have low to mid forest canopy coverage, indicating forest structural diversity was present, which corresponded with 60 parks observed to have dense leaf litter coverage and/or deadfall, which serves as important habitat for invertebrates in winter months. Interestingly, only 48 parks were observed to have obvious signs of intensive human management regimes, with 38 of those parks having signs of mowing patterns and 4 with manicured flora. While 12 of the parks showed signs of vegetation removal, which was almost exclusively recorded in Utility Right-of-Ways (ROWs). The most commonly absent GSQ element was wetlands and/or open waterbodies, with 49 assessed parks containing a wetland, open waterbody, and/or creeks and stream. Interestingly, only 34 assessed parks contained a wetland and/or open waterbody if creeks and streams were ignored[4]*. Anecdotally, it was noted that a variety of waterfowl and wetland dwelling species were present in nearly all parks with open waterbodies, regardless of location, and in one instance a coyote was observed following a creek bed.

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[4] Due to data collection being conducted in the winter months and often during periods of heavy rain and snow. Unnamed creeks observed in the field may or may not be the result of vernal flooding, thus the results reported took this into consideration.

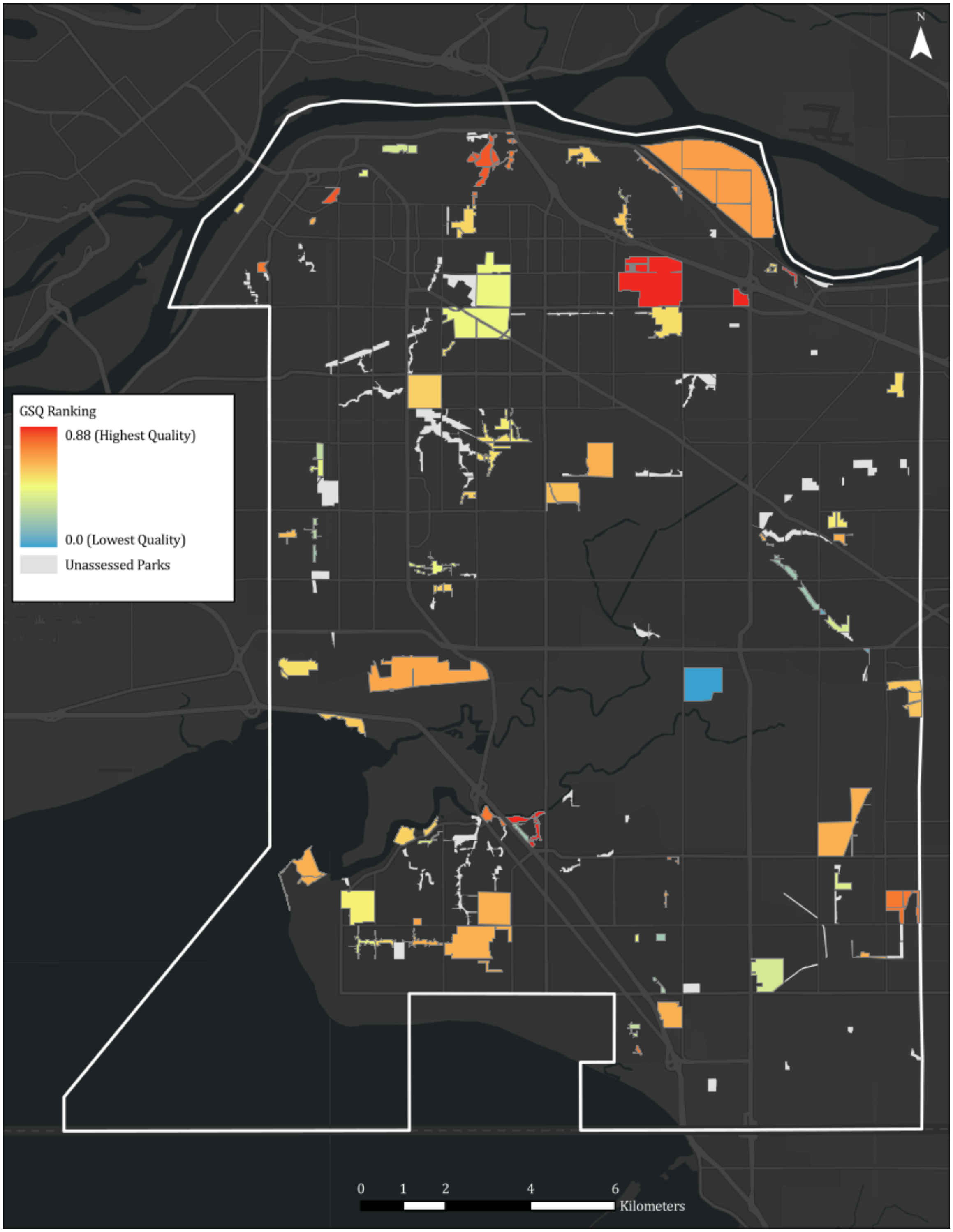

Figure 5. Final Green Space Quality (GSQ) assessment rankings for identified parks in Surrey, BC. Coloured polygons correspond to the overall quality score based on the application of the GSQ framework. Black outlines represent identified parks from the Green Infrastructure (GIN) network.

4.2. Connectivity Analysis

4.2.1. Differences in Least Cost Pathways

The Circuitscape results indicate that the inclusion of GSQ assessments in connectivity analyses identify differences in Least Cost Pathways (LCP) between terrestrial hubs in Surrey. The results of the connectivity analysis determined that the Cost-Weighted Distance (CWD) to Euclidean distance ratio for *Parks + GSQ* ranged from 4.21 (least-barriered movement) to 29.88 (most-barriered movement), and the ratios for the CWD to Path Length distance ranged from 3.18 to 16.98. For the *Parks Only* analysis, ratios ranged from 4.21 to 29.71, and 3.18 to 16.89, respectively. A Paired t-test was used to compare the ratios for both CWD to Euclidean and Path Length ratios, however the results for both were statistically insignificant ($p = 0.8907$, $p = 0.9830$, respectively). For a summary of the statistical analyses, please see Tables A1 and A2 and Figure A1 in the Appendix. For both analyses, the LCP with the highest CWD to Euclidean distance ratios were primarily found in north Surrey, with the most barriered LCP connecting Green Timbers Urban Forest to Hawthorne Park terrestrial hubs (n = 29.88 and n = 29.71 for *Parks + GSQ* and *Parks Only*, respectively). Tynehead Regional Park also presented high ratios for all LCP with the exception of the LCP connecting Tynehead to Port Kells Park terrestrial hub (see Figure 6). For a complete breakdown of the CWD to Euclidean and Path Length ratios for matching LCPs, please see Figure A2 and Table A3 in the appendix.

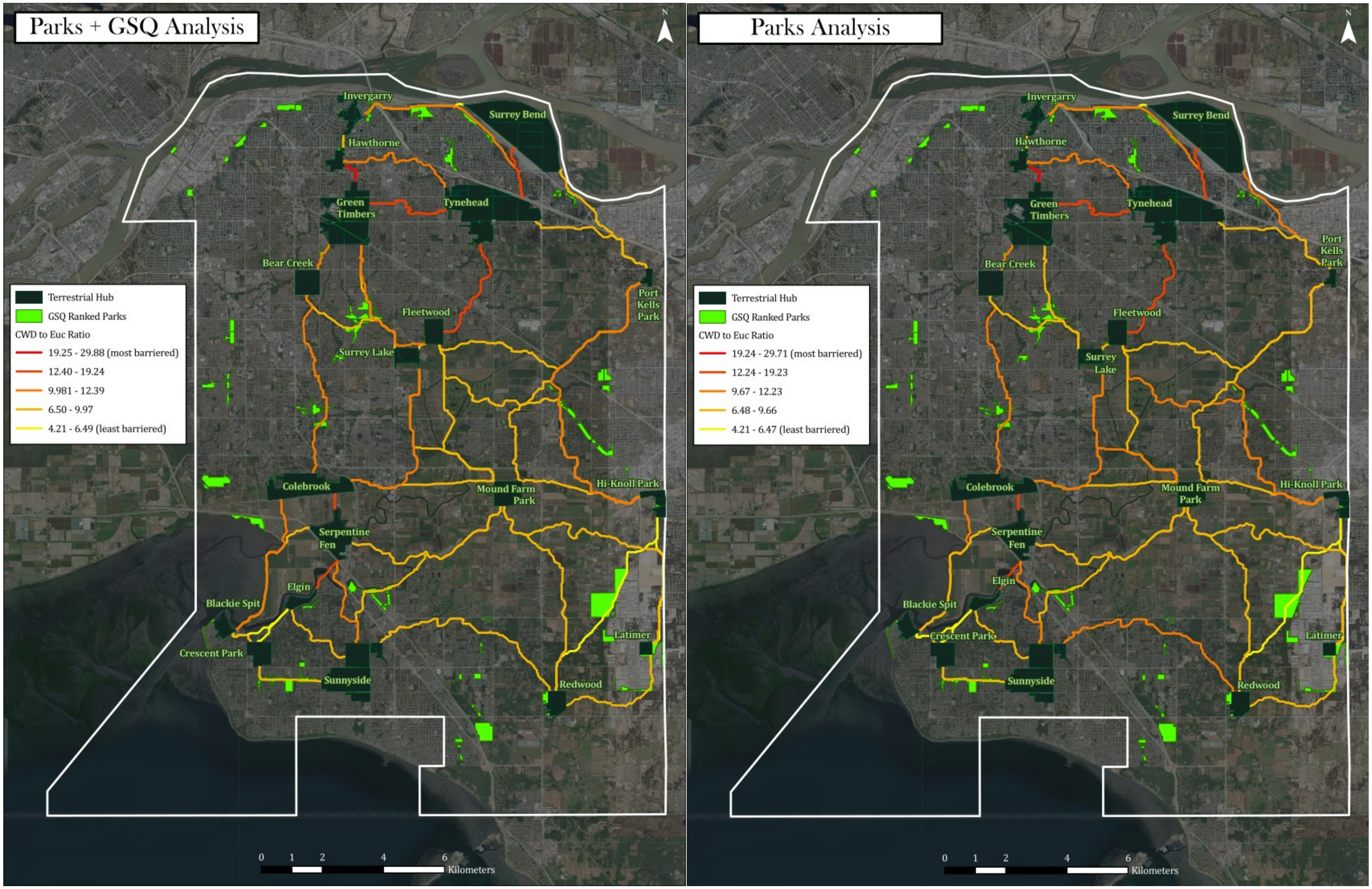

Figure 6. CWD to Euclidean Distance ratios for the Parks + GSQ and Parks Only analysis. Results indicate that the most barriered movement pathways exist in north Surrey.

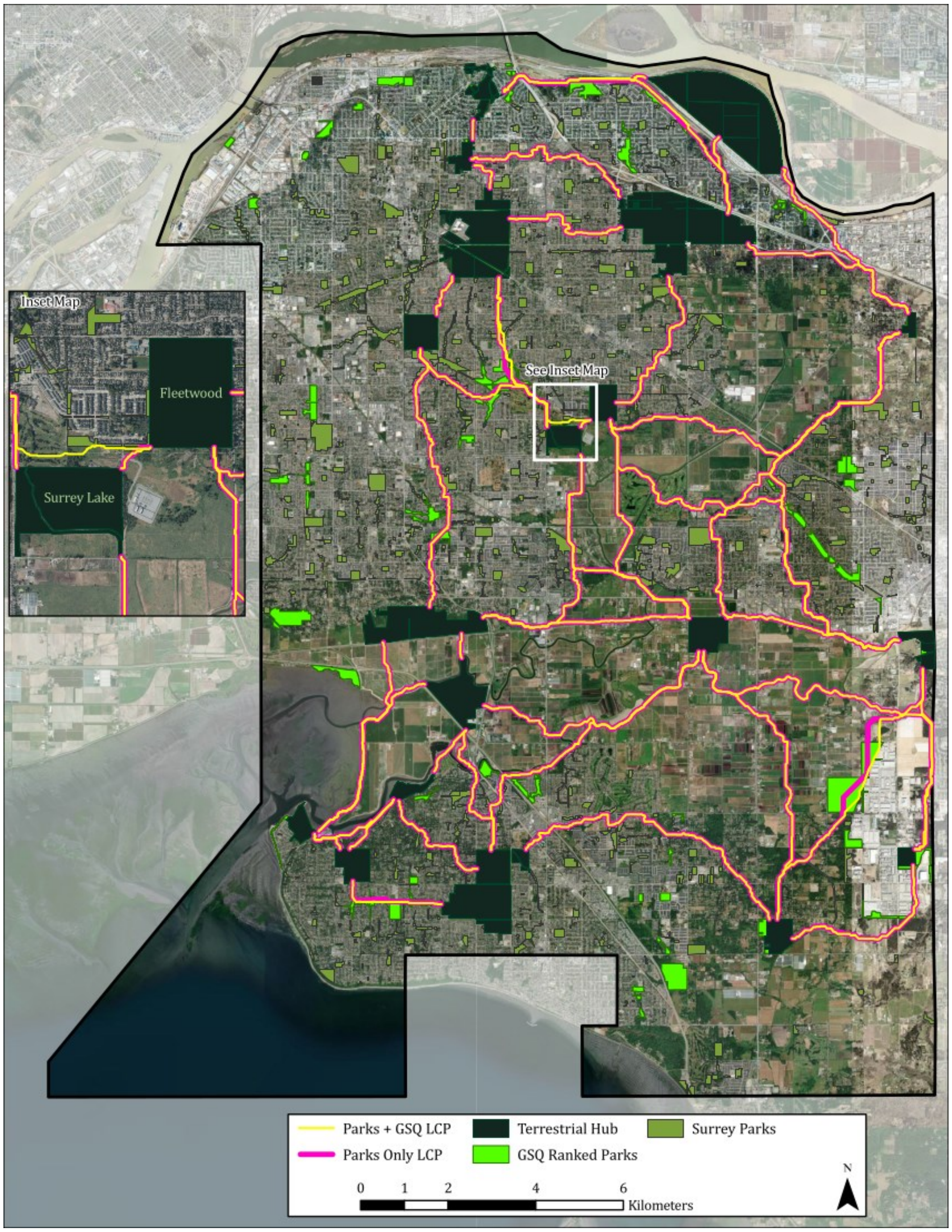

Figure 7. **Least Cost Pathways (LCP) identified from Circuitscape analysis. Yellow lines represent the results of the Parks + GSQ analysis, and pink lines represent the results of the Parks Only analysis. Inset map depicts an additional LCP identified from the Parks + GSQ analysis for the connection of Surrey Lake and Fleetwood Park.**

From a qualitative standpoint, the connectivity analyses revealed some differences in LCP identification, as highlighted in Figure 7. An additional LCP connecting Surrey Lake and Fleetwood Park was identified in the *Parks* + *GSQ* analysis that utilizes a golf course and utility ROW. Additional variation in LCP from the analyses were observed in the southeast and southwest regions, however both pathways utilize different portions of the same green space, therefore variation is likely due to the variations in analysis parameters.

4.2.2. LCP and GIN Intersection

The results of the Parks Only and Parks + GSQ connectivity analyses indicate that there is a considerable amount of overlap between the identified LCP and Surrey's existing GIN. The overlap of identified LCP from the Parks Only and Parks + GSQ connectivity analyses was 52.2% and 52.8%, respectively. This indicates that the Parks + GSQ analysis resulted in a marginally better alignment with Surrey's current GIN. As seen in Figure 8, several LCPs for both Parks Only and Parks + GSQ show near-identical pathways to the GIN – namely, along the Nicomekl River, Boundary Bay, corridors in the northeast, and in the southwest. Interestingly, no LCPs were identified that correspond to the GIN in the northwest part of the city.

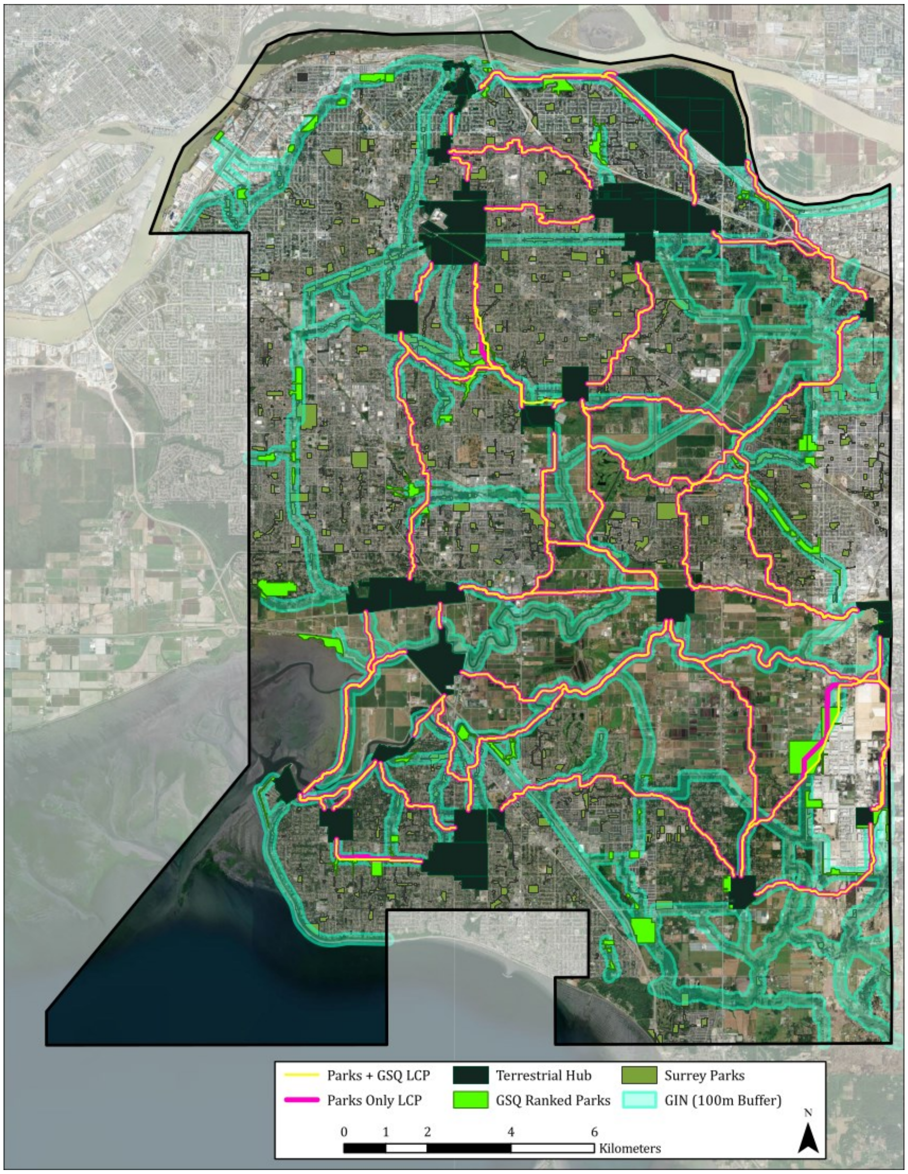

Figure 8. Comparison of Surrey's existing Green Infrastructure Network (GIN) with the outputs from the Circuitscape connectivity analyses. Pink lines represent the Least Cost Pathways (LCP) for the Parks Only analysis, and yellow lines represent the LCP for the Parks + GSQ analysis.

4.2.3. Least Cost Pathways and Critical Habitat Overlap

The City of Surrey contains habitat ranges for 6 federally listed species at risk: Audion’s Night-Stalking Tiger Beetle, Oregon Forest Snail, Pacific Water Shrew, Western Painted Turtle, Barn Owl, and Streambank Lupine. The results of the connectivity analysis suggest that identified LCP have considerable overlap with the known critical habitat ranges, with *Parks Only* and *Parks + GSQ* results demonstrating a 47.3% and 46.7% overlap, respectively (see Figure 9). The most prominent overlap is with the Barn Owl range, with nearly 100% of intersecting LCP being identified within their reported habitat. This was expected, however, due to their extensive range within Surrey. The critical habitat for the Pacific Water Shrew intersected with approximately 11% of the LCP for both *Parks Only* and *Parks + GSQ* analyses, and approximately 6% of the habitat for the Western Painted Turtle. Overlap with the Audion’s Night-Stalking Tiger Beetle, Oregon Forest Snail, and Streambank Lupine were minimal.

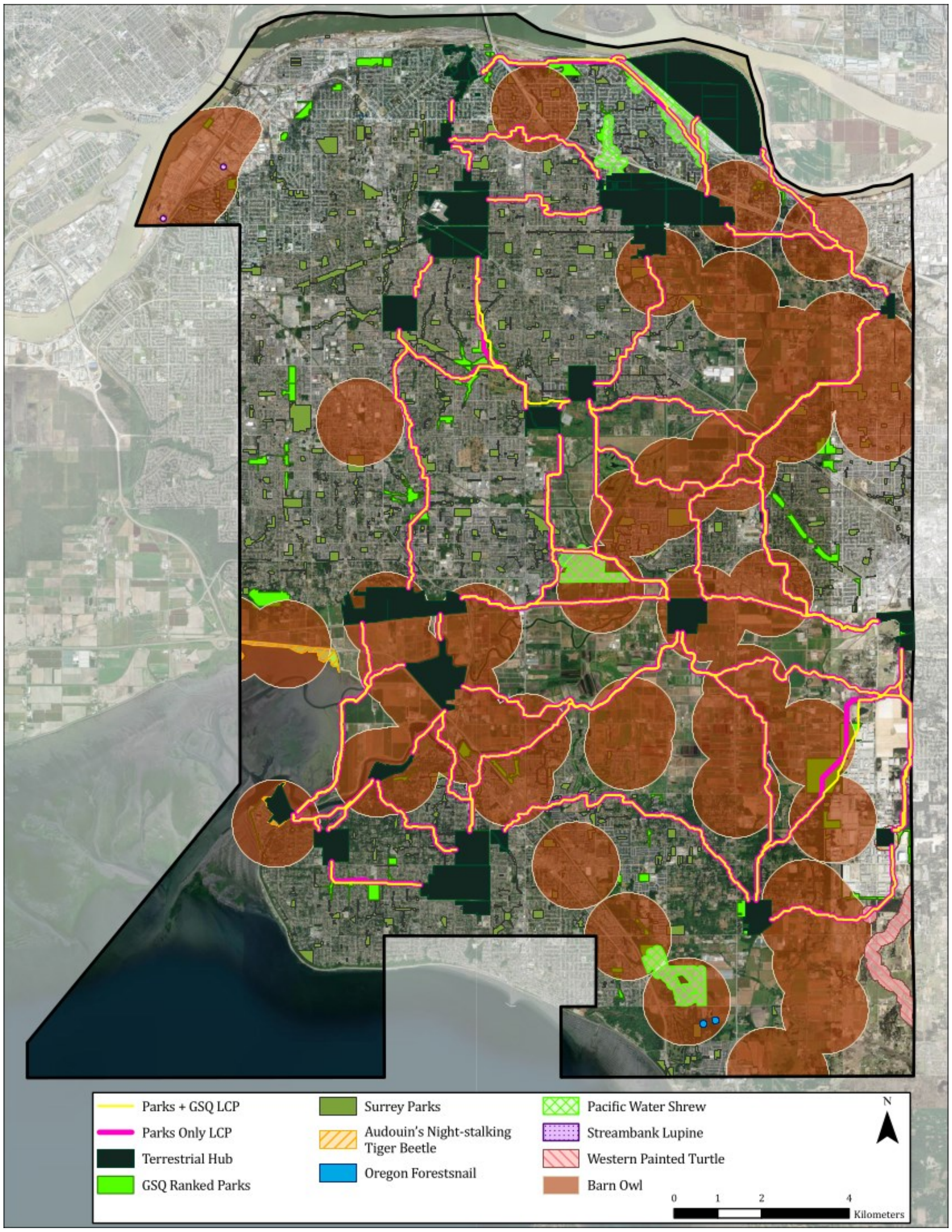

Figure 9. Least Cost Pathway (LCP) overlap with the known critical habitat ranges for federally listed species at risk in Surrey.

4.3. Summary

The results of the GSQ assessment and connectivity analyses provide valuable information for planners at the City of Surrey on the performance of their GIN, and where future work may best be targeted. First, the GSQ assessment determined that the average GSQ ranking for assessed parks in Surrey is 0.52, with the Tynehead Regional Park ranking the highest at 0.875 and Mound Park Farm the lowest ranking at 0.0. The connectivity analysis for both *Parks Only* and *Parks + GSQ* determined that the highest barriered LCP are most likely to appear in north Surrey, with the majority of LCP connecting Tynehead Regional Park to other hubs being highly barriered. From a GIN perspective, the LCP from both connectivity analyses determined that there was an approximately 52% overlap between identified LCP and the GIN. There was also considerable overlap between LCP and known critical habitat for species at risk in Surrey, with over 46% overlap for both analyses. The LCP were more likely to overlap with habitat ranges for more mobile species like the Barn Owl, but also had moderate overlap with the less mobile species. This data is important for Surrey planners to be able to access and visualize as it can help them make better informed decisions and ensure that biodiversity planning efforts are effective.

Chapter 5.

Discussion

Biodiversity is under threat around the world, especially in urbanized areas (Ives et al., 2016; Nilon et al., 2017; Seto et al., 2012). As the demand for development continues to put pressure on urban ecosystems, it is more important than ever that planners understand how to support wildlife in urban areas (Apfelbeck et al., 2020; Aronson et al., 2017). Access to tools like the GSQ assessment framework and Circuitscape presented in this research are key for helping planners to identify important habitat elements that support wildlife in cities. Green space quality and connectivity cannot be considered independent from one another to effectively plan for biodiversity. This research aimed to answer the following two questions by using the City of Surrey as a case study: First, what elements influence biodiversity in urban areas, and how do we assess overall green space quality (GSQ) for wildlife? Second, how does GSQ assessments influence connectivity analysis for urban green space networks?

This section will first review the results of the GSQ assessment and the two connectivity analyses and discuss the implications for the City of Surrey. It will then delve into the broader significance of conducting GSQ assessments and understanding the importance of green space connectivity for planners in Surrey and beyond.

5.1. GSQ Assessments

5.1.1. The Realities of Quality

Including evaluations of individual patch quality in UGSN design is an important consideration for biodiversity conservation in Canada, especially in the southern portions of the country where urbanization and known habitat for species at risk increasingly coincide with one another (Environment and Climate Change Canada, 2023). National connectivity analyses have shown that regions critical to biodiversity in Canada are also some of the most highly urbanized in the country, including Surrey (Pither et al., 2023). In an ideal scenario, all parks would be larger than a hectare and contain all GSQ elements. However, it is unrealistic to expect that every green space will contain the ‘perfect’ habitat availability, as it cannot be expected that all GSQ elements can be protected during development (Parris et al., 2018), especially for municipalities like Surrey that are rapidly urbanizing to meet population needs and senior agency housing mandates.

5.1.2. GSQ in Surrey

The results of the GSQ assessment determined that 63% of parks visited in Surrey’s GIN were of high quality, supporting on average over 50% of the elements seen to positively influence biodiversity (Beninde et al., 2015). The 78 parks assessed for this project often supported large swaths of natural areas that have remained unmodified for anthropogenic purposes, and turf areas were likely to be intermixed with high quality forest ecosystems. Human disturbance in any capacity is generally not ideal for wildlife (Apfelbeck et al., 2020), however the parks assessed performed well in balancing the needs of human and nature in their design. The application of the GSQ assessment framework in Surrey provides a current snapshot of the quality of many of the parks in Surrey’s GIN and can be used to inform decisions on how to develop in and around these invaluable natural assets.

5.1.3. Wetlands

The results of the GSQ assessment suggests that one of the most commonly missing elements in parks was wetlands and/or waterbodies, however 62% of assessed parks did include these features if creeks and streams were considered. As suggested in the literature review (section 2.2.2), this could have benefits for terrestrial species that require access to water for hydration needs, and 43% of parks may provide habitat for semi-aquatic mammals, waterfowl, pollinators, and amphibians. The importance of aquatic habitat features is a key consideration that needs to be considered, especially with the cumulative loss of wetlands in the lower Fraser area (Wetland Stewardship Partnership, 2010). It is important to note, however, that adding a wetland or waterbody feature can be a costly task and will not be appropriate in every park. As an example, it should not come at the cost of removing an established ecological community (e.g., forest), and should only be done where historical or drained wetlands and waterbodies could be restored. It Consequently it is in the best interest of the City and more effective

– from an ecological and cost perspective – to protect existing aquatic habitat features than to restore or artificially replace them later (Parris et al., 2018).

5.1.4. Vegetation Structure

The presence of shrubs and herbaceous plants strongly influences higher rates of biodiversity in urban areas – especially for bird and pollinator species (Aronson et al., 2017; Beninde et al., 2015; Plummer et al., 2020; Rogers, 2022). This is also true for the structure of forested areas, where parks with more structurally diverse areas via woody debris, heterogeneity in tree species, and low to mid canopy shrubs and trees also increase biodiversity of birds and mammals alike (Apfelbeck et al., 2020; Beninde et al., 2015; Raymond & St. Clair, 2023; Rogers, 2022). Based on the results of this research, the assessed parks in Surrey's GIN demonstrated strong vegetative structural diversity and quality. The assessment determined that 91% of the 78 parks assessed had shrubs present, suggesting that these parks are likely to provide quality habitat elements for avian species and small mammals (Apfelbeck et al., 2020; Beninde et al., 2015; Rogers, 2022). Similarly, 80% of assessed green spaces contained some sort of grass, however there was a stronger presence of maintained turf than unmaintained or natural meadows. While turf does provide habitat for some insects and birds that predate on them (Aronson et al., 2017; Rogers, 2022), the increased disturbance from maintenance needs reduces habitat quality significantly (Aronson et al., 2017; Beninde et al., 2015). To increase GSQ ratings, Parks operations in Surrey should consider retaining more areas of wet meadows and grasslands in green spaces or maintain green spaces with limited mowing in mind.

It is important for to recognize the significance that shrubs and herbaceous plants play in supporting high quality green space patches for wildlife, and that they are integral for maintaining biodiversity. As discussed, the focus has tended to be on increasing urban tree canopy coverage as a means to increase biodiversity (Parris et al., 2018; Wolch et al., 2014), yet conserving or adding other vegetative elements into green spaces is more effective at increasing species richness and abundance. Employing a GSQ assessment framework can help with the planning and design of planting plans and landscaping that is more effective for supporting wildlife in urban areas.

5.1.5. Limitations in GSQ Assessments

While they provide immense value in understanding the overall quality of an UGSN, there are limitations to using GSQ assessments as a planning tool. First, GSQ assessments are intensive to conduct. This may be achievable in smaller municipalities with less dedicated green space, but for large municipalities with extensive park space like Surrey, a comprehensive GSQ assessment would require a team of dedicated personnel or significant allocations of time to complete. Second, while it is understood that GSQ elements can be generalized across multiple taxa, there are always nuances to how green space planning, design and construction can affect local species, especially species at risk (Ives et al., 2016; Kowarik, 2011). Access to Qualified Environmental Professionals (QEPs) such as professional biologists, or operational staff to validate GSQ assessments is a major limitation to implementation. Finally, the time of year available for conducting a GSQ assessment may influence quality rating. Additionally, many GSQ elements, like wetlands, creeks, and vegetation, may be subject to seasonal variation and coverage. In the Lower Mainland, creeks and some waterbodies may only be present in winter months when rainfall is elevated, or herbaceous coverage cannot be assessed due periods of dormancy. GSQ assessment for UGSN benefits greatly from the input of QEPs, who would be able to give advice on how to evaluate GSQ depending on the season. Finally, information on the presence of Himalayan blackberry – an invasive species that is known to limit movement capacity of many species – was noted during data collection, however it was not included in the final analysis. Future research may want to determine the impact of Himalayan blackberry for ecological connectivity in Surrey.

The limitations of GSQ assessment should not diminish their immense importance for enhancing biodiversity conservation and planning. In an ideal scenario, all planning teams would be comprised of a diverse mix of expertise, including professional biologists, however this is unlikely to be the case in every Canadian city. Canada is not immune to the global biodiversity crisis (Buxton et al., 2024), and tools like the GSQ assessment framework are an essential step in equipping cities with information on what constitutes a ‘good’ green space from a wildlife perspective. In the face of increasing biodiversity loss from urbanization, it is better to do something than nothing at all.

5.2. Planning for Connection

Biodiversity planning cannot rely on quality green space patches alone – connection quality in UGSN is an important aspect that must be considered to develop effective biodiversity plans. Using applications like Circuitscape can be daunting for local government staff that do not come from a background in GIS or ecology, however if time is taken to understand the program, cities can better equip themselves to tackle connectivity assessments within their jurisdictions. For municipalities like Surrey that have an existing GIN, assessing connectivity helps better identify areas outside of the network for future conservation work (B. McRae et al., 2016; Pither et al., 2023). For municipalities that do not have established networks, a connectivity analysis would allow for a better understanding of areas important to wildlife movement and provide insight into where conservation efforts may best be targeted.

5.2.1. Using LCP Information

Circuitscape is a useful tool to help planners quantify the quality of connection within their municipalities. The identification of LCPs between known important habitat patches can help planners understand areas that wildlife are more likely to be using as they move around the urban landscape. This is important for a few reasons – first, LCPs show clear pathways that land use practitioners can use when working on new or existing area plans. If the LCP overlaps with an undeveloped lot or unprotected natural area, planners may use the LCP to set conservation easement locations or acquire new land for protection designation if possible. Second, when LCPs are identified through existing developments that are unlikely to be redeveloped or on private land, public engagement can be tailored to promote awareness of the importance of wildlife movement in urban areas to achieve comprehensive conservation strategies.

In addition to being able to visualize where wildlife movement between habitat patches is likely to occur, Circuitscape provides an idea of the quality of connection within a given area. The CWD to Euclidean and CWD to Path Length ratios give insight on how barriered movement is on an individual LCP. As shown by this research, the ratios for both Euclidean and Path Length distances in Surrey have decent variability. This is an important metric for biodiversity planning as it can help prioritize improving connectivity in LCPs with higher ratio values, meaning that efforts to improve the quality of connection throughout a region can be planned more effectively. For Surrey, this could take the form of/include reviewing LCPs with the highest CWD to Euclidean and/or Path Length ratios. As to be expected, the LCP with the most barriered movement for both the *Parks Only* and *Parks + GSQ* analysis were found in densely urbanized areas, particularly in north Surrey (see Figure 6). Interestingly, some of the highest barriered movement from both analyses is seen around Tynehead Regional Park, the highest GSQ rated park. In understanding this, Surrey should target future biodiversity planning efforts in and around Tynehead to further improve quality and connection.

It is important to note that while this study did not produce statistically significant differences between the *Parks Only* and the *Parks + GSQ* analyses, the variation in CWD ratio values is still important to understand. The results of the *Parks + GSQ* analysis reported a marginally larger range in CWD ratios for both Euclidean and Path Length distances, which may suggest that the inclusion of GSQ rankings in the analysis resulted in a more reflective snapshot of movement barriers for wildlife in Surrey. A complete GSQ assessment of all parks intersecting Surrey's GIN and/or all parks in the city may result in a stronger assessment of quality of movement in Surrey and is worthwhile investigating in future research.

5.2.2. LCP overlaps with Surrey's GIN

Although it was developed a decade before, this study shows that Surrey's GIN has a considerable amount of overlap with LCPs as determined by land cover and current condition data from 2020 to 2024. The GIN performs well as an UGSN designed for wildlife movement given that over 50% of identified LCP segments, particularly along the Nicomekl River and in the northeast corridor adjacent to Surrey Bend (see Figure 8). Due to high land costs in the Lower Mainland, additional GIN acquisition in Surrey is limited by fiscal capacity (personal communication, P. Zevit, 2024). However, there is opportunity to improve alignment of the GIN with LCPs. In Figure 8 a large proportion of LCP can be seen deviating from the GIN in central and southeast Surrey. These same deviations also have considerable overlap with critical habitat ranges for known species at risk in Surrey (see Figure 9). Knowledge of this may provide impetus for more effective protection or stronger mitigation effort for developments even if they occur outside of the GIN.

5.2.3. Multispecies Approach

Connectivity analyses typically require the selection of one or two target species to develop the resistance raster. This results in a connectivity analysis that is highly specific to the habitat requirements of the target species. Using a multi-species approach is an effective method for assessing connectivity quality (Pither et al., 2023; S. L. R. Wood et al., 2021). The decision to use the 8 focal species used in previous work in the Metro Vancouver region as a reference point for assigning resistance values was due to the recognition of the importance of using a multi-species approach, also known as "upstream connectivity modeling" (S. L. R. Wood et al., 2021). This is important for land use planning in Canada as important biodiversity areas and connectivity corridors intersect with heavily urbanized areas, including through the entirety of the British Columbia's Lower Mainland (Pither et al., 2023).

5.2.4. Understanding Connectivity Analyses & Limitations

Performing a connectivity analysis can help cities understand the effectiveness of their GIN and make informed decisions on how to plan for biodiversity in urban areas. It is important to note, however, that these analyses should be used in conjunction with other environmental information when available (e.g. natural asset inventories, ecological assessment reports, wildlife camera trapping, etc.). Although circuit theory has been proven to be representative of actual wildlife movement, outputs are prone to human error during data input (B. McRae et al., 2016; B. H. McRae et al., 2008; Pither et al., 2023). Thus, if Surrey and other local governments use connectivity analysis tools like Circuitscape to inform biodiversity planning decisions, they must ensure that they research their ecological landscapes to ensure LCPs are representative of local conditions.

A connectivity analysis is only as good as the data you have access to. For this study, attempts were made to develop a land cover classification raster layer from the latest aerial imagery available for Surrey, which had a 10cm resolution. Unfortunately, due to computational power capacity and time limitations, the raster was not usable due to a high rate of error in the classification. This classification layer would have provided a much higher accuracy in LCP identification due to land cover requiring minimal generalization given the 10cm resolution, as compared to the 5m resolution land cover classification that was used. Additionally, it would have provided an updated reference for land cover, as the higher resolution imagery was captured in 2022, as compared to the 2020 land cover classification raster. Access to high resolution land cover classification datasets is costly and inaccessible to many planners (Wellmann et al., 2020), a limitation that is likely reflective of real-world data access issues for communities. But it does not negate the value in conducting a connectivity analysis.

In addition to being able to access data to run a connectivity analysis, staff must also be able to access and understand how to use the platforms that Circuitscape runs on. GIS access is a known limitation for many planners in Canada (Wellmann et al., 2020), and to use Circuitscape on Esri platforms requires costly advanced licenses. Access limitation is mitigated through Circuitscape being available for use on other multiple platforms, including the standalone platform Julia, however it is significantly less intuitive to operate for those who do not have experience with spatial analysis on other GIS or R platforms.

5.2.5. Transboundary Planning

It is important to understand that nature does not adhere to man-made borders. Biodiversity planning should be considered beyond a single jurisdiction regardless of the scale. Planning for ecological connectivity across multiple jurisdictions – municipal, provincial, and even international – is an important consideration for comprehensive biodiversity strategies(Haaland & van den Bosch, 2015), especially for municipalities like Surrey that are located in heavily populated regions and share multiple municipal and international boundaries. It is also important to understand that LCPs may change if information beyond a municipal border is included, which could result in the identification of additional important movement corridors. For Surrey and the surrounding municipalities, this work is already underway. The Metro Vancouver Regional District – an organization that oversees governance issues that affect the 21 municipalities including Surrey, electoral areas, and Tsawwassen First Nation (Metro Vancouver, 2024) – is currently in the process of developing a Regional Green Infrastructure Network that consists of various types of green space patches and corridors. Conducting a local GSQ assessment and connectivity analysis can help improve the information shared to Metro Vancouver and ultimately contribute to a higher quality regional plan.

Chapter 6.

Conclusion - Planning with Intention

There is more demand on land use practitioners than ever before to plan cities that will support growing populations, which has resulted in increased pressures and degradation of nature in cities (IPCC, 2023; IUCN, 2015; Kowarik, 2011). Yet, people and wildlife alike depend on access to high quality natural spaces for refuge – from both a wellness and habitat perspective (Apfelbeck et al., 2020; Felappi et al., 2020; Swanwick et al., 2003; E. Wood et al., 2018). It is essential that land use decision makers have access to tools for biodiversity conservation and planning that incorporate this understanding.

The adoption of a GSQ assessment framework is an important step in reducing the barriers around biodiversity planning in Canadian cities. As noted in the literature, generalizations can be made on the design and enhancement of urban green spaces that can benefit species richness and abundance across multiple species (Apfelbeck et al., 2020; Beninde et al., 2015; Kirk et al., 2021; Nilon et al., 2017; Parris et al., 2018). In the absence of subject matter experts or qualified environmental professionals, tools exist for local governments to identify elements in new or existing green spaces to increase habitat quality. A GSQ assessment can be used to evaluate current green spaces in cities, or employed in the development stage to understand where conservation efforts may be most effective.

GSQ assessment frameworks are important tools that can be used to understand how different GSQ elements influence desired biodiversity outcomes, such as the protection of wetlands and/or waterbodies from development. In the absence of bylaws that go above and beyond provincial wetland protection, using a GSQ assessment framework can enable local governments to make more informed decisions on how to work around important existing natural features or GSQ elements while balancing development needs. GSQ assessments may also highlight the elements that can be reintroduced, where appropriate in existing green spaces to improve overall quality. The importance of shrubs, herbaceous density, and structural diversity of vegetation in green spaces in contrast to tree density is a prime example of how a GSQ assessment can communicate element importance.

Developing quality green space patches is not the only component to biodiversity planning. Functional connectivity corridors are equally as important for developing UGSNs that support wildlife in cities. By using the GSQ assessment framework in conjunction with Circuitscape, this research was able to determine that selected parks in Surrey's GIN are likely to contain over 50% of GSQ elements that influence increased biodiversity, and that over 50% of LCP were well aligned with the existing GIN. Improvement to the GIN is possible by addressing movement barriers along LCPs for both connectivity analyses. While there are many limitations to employing GSQ assessments and connectivity analyses in practice, there is still an immense value in using these tools to help identify high quality habitat areas for conservation, as well as areas where improvement is needed.

Exploring the development of tools that can be used to assess UGSNs is crucial in addressing biodiversity loss in Canada and beyond. Developing green space assessment frameworks and demonstrating how connectivity can be measured, helps communicate the value of nature in cities and emphasizes the role that land use decision makers have in protecting natural assets from further impacts caused by urbanization. Being able to effectively assess the state of ecosystems in one's jurisdiction makes for better informed decisions on how to conserve biodiversity and create liveable cities for all.

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Appendix. Supplemental Tables and Figures

Table A1

CWD to Euc. Dis. Ratio	Parks	GSQ
Minimum	4.21	4.21
25% Percentile	8.28	8.41
Median	9.115	9.19
75% Percentile	11.46	11.42
Maximum	29.71	29.88
Mean	10.21	10.31
Std. Deviation	4.18	4.131
Std. Error of Mean	0.645	0.63
Paired t test		
P value	0.891	
P value summary	ns	
Significantly different (P < 0.05)?	No	

Table A2

CWD to Path Length Ratio	Parks	GSQ
Minimum	3.18	3.18
25% Percentile	5.528	5.7
Median	6.8	6.75
75% Percentile	8.36	8.32
Maximum	16.89	16.98
Mean	7.356	7.386
Std. Deviation	2.67	2.626
Std. Error of Mean	0.412	0.4005
Paired t test		
P value	0.983	
P value summary	ns	
Significantly different (P < 0.05)?	No	

Table A1 and A2. **Statistical results for Paired t-tests comparing quality of LCP via CWD to Euclidean Distance and Path length ratios from the Parks Only and Parks + GSQ Circuitscape connectivity analyses. Results determined that there was no statistically significant differences**

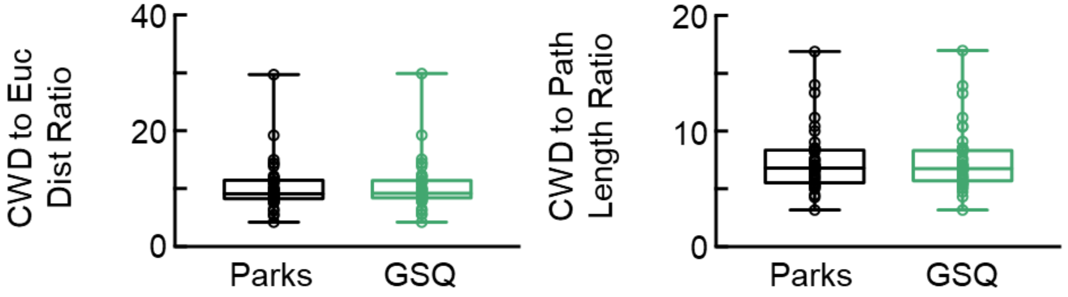

Figure A1. **Box and whiskers plot for the Paired t-test comparing quality of LCP via CWD to Euclidean Distance (left) and Path Length (right) ratios from the Parks Only and Parks + GSQ Circuitscape connectivity analyses. Circles represent recorded ratios per LCP per analysis. No statistical significance was reported for either analysis.**

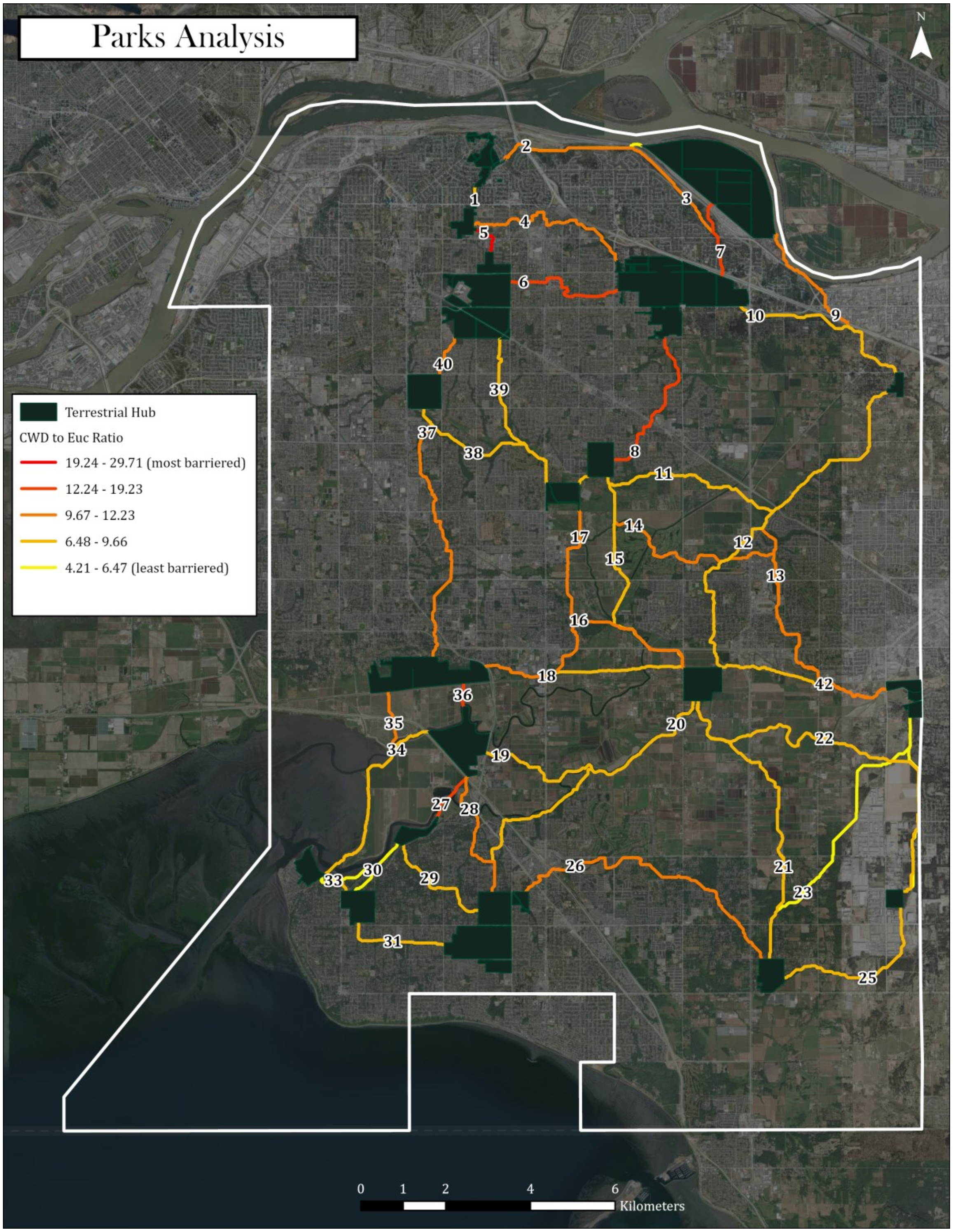

Figure A2. Matching LCP for the Parks and Parks + GSQ connectivity analyses. Numbers on LCPs correspond with the CWD to Euclidean Distance and Path Length ratios in Table A3.

Table A3 **Raw pathway barrier values for matching Least Cost Pathways (LCPs) for the Parks Only and Parks + GSQ connectivity analyses. Pathways barrier values are represented by the Cost Weighted Distance to Euclidean Distance Ratios and the Cost Weighted Distance to Path Lenth (PL) Ratios. The higher the ratio value the more barriered the LCP.**

Parks LCP ID	CWD to Euc. Dist. Ratio	CWD to PL Ratio	GSQ LCP ID	CWD to Euc. Dist. Ratio	CWD to PL Ratio
1	7.76	7.56	1	7.84	7.64
2	6.47	5.71	2	6.49	5.7
3	11.33	5.08	3	11.42	5.08
4	11.95	8.54	4	11.95	8.55
5	29.71	16.89	5	29.88	16.98
6	14.39	10.43	6	14.4	10.43
7	19.23	11.17	7	19.24	11.17
8	13.88	8.49	8	13.89	8.49
9	9.83	8.19	9	9.85	8.21
10	8.37	6.61	10	8.38	6.62
11	8.55	5.94	11	8.55	5.95
12	9.17	7.01	12	9.18	7.01
13	11.95	6.71	13	12	6.73
14	9.88	6.62	14	9.93	6.65
15	9.06	6.94	15	9.09	6.96
16	9.94	7.03	16	9.97	7.05
17	12.23	7.35	17	12.24	7.35
18	9.45	8.48	18	9.48	8.5
19	8.72	5.95	19	8.72	5.95
20	8.95	6.29	20	8.95	6.3
21	8.63	6.75	21	8.63	6.75
22	9.66	5.52	22	9.66	5.52
23	5.38	4.48	23	5.62	4.74
24	6.17	5.53	24	6.17	5.53
25	8.87	5.38	25	8.91	5.4
26	9.9	6.85	26	9.87	6.83
27	14.35	13.33	27	14.4	13.27
28	11.04	8.32	28	11.08	8.32
29	8.32	5.04	29	8.41	5.09
30	5.51	4.27	30	5.56	4.32
31	7.73	5.28	31	8.79	6.03
32	9.06	5.27	32	9.19	5.33
33	4.21	3.18	33	4.21	3.18

Parks LCP ID	CWD to Euc. Dist. Ratio	CWD to PL Ratio	GSQ LCP ID	CWD to Euc. Dist. Ratio	CWD to PL Ratio
34	8.16	6.18	34	8.16	6.18
35	10.26	7.13	35	10.26	7.12
36	15.03	14.01	36	15.08	13.93
37	11	9.04	37	11.07	9.1
38	7.58	5.27	38	7.8	5.38
39	7.86	6.55	39	8.05	6.66
40	11.84	10.01	40	12.39	10.37
41	8.4	7.01	41	8.48	7.08
42	8.97	7.56	42	8.97	7.57