Importance of Backyard Habitat in a Comprehensive Biodiversity Conservation Strategy: A Connectivity Analysis of Urban Green Spaces

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Abstract

Connectivity has been an accepted goal in ecological restoration of wilderness areas for some time, but it is a relatively new approach in urban areas. The connectivity analysis presented here explores the numbers and patterns of corridors required to connect urban green spaces as part of an overall biodiversity conservation strategy. Green spaces in this study were weighted based on size and a habitat requirement of 0.5 ha for a hypothetical indicator species. Thirteen potential networks were evaluated using Gamma, Beta, and Cost Ratio indices. The study zone contained 54 green spaces (habitat nodes) with a combined area of 636.5 ha in a total urban area of approximately 2,600 ha. Several models (Travelling Salesman, Paul Revere, and Least Cost to User) were used to evaluate possible connections. These results indicated that at least 325 linkages are necessary to connect half of the nodes. Such large numbers of linkages are only feasible by enhancing the matrix of backyard habitat, planted boulevards, and utility rights-of way found in a city. Strengthening such networks should work well to support the biota protected in urban parks and wildlife refuges and the seasonal migrants that sometimes depend on urban habitats for their survival.

Key words: backyard habitat, connectivity, corridors, Greater Vancouver, green space, habitat matrix, urban ecology.

Introduction

Habitat loss and fragmentation are important factors contributing to a reduction in the planet's biodiversity (Rolstad 1991). Besides resource extraction in mining, fishing, and forestry, most habitat loss and fragmentation is due to urban and agricultural development. The population of Greater Vancouver, British Columbia is expected to increase from its present 2 million to 3.1 million people within 20 years. Globally, the world's population is expected to increase from the present 6 billion people to 10 billion by the year 2050, mostly in urban areas. Many urban regions are in biologically sensitive areas. Increased habitat fragmentation is of particular concern in Greater Vancouver because it is located on the Fraser River estuary. This estuary is home to the world's largest salmon run and is one of three major stops on the Pacific Flyway for migratory birds along the west coast of North America. The region has already suffered substantial habitat loss. One prominent estimate is that about 70% of the wetlands and 80% of the salt marshes found here historically were already lost by the turn of the twentieth century, mainly through diking (Fraser River Estuary Study Steering Committee 1978).

Although habitat loss and isolation result in reductions in smaller natural populations and more local extinctions (Adams & Dove 1989; Rolstad 1991), ecosystem fragments remaining in cities are far more important than their limited size and disturbed state might suggest (Gilbert 1987; Schaefer 1994). In fact, habitat fragments contribute significantly to the viability of the greater ecosystem as part of metapopulations—assemblages of local populations that are connected by migration (Hanski & Gilpin 1991). It is clear from metapopulation theory that the greater the number of patches and the closer they are, the better the colonization (Hanski & Thomas 1994). Seed dispersal and wildlife movements are key processes in determining the survival of metapopulations. Such movements are directly related to the connectivity of the landscape (Schippers et al. 1996). As wildlife moves between nodes or islands, extinction and colonization rates are equalized within fragmented landscapes (Bueno et al. 1995). A concern about urban habitat restoration is that it may lead to habitat sinks, attracting wildlife from good source ecosystems to marginal habi-

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tats (Taylor et al. 1993). Connectivity between large numbers of nodes will lessen this risk.

The connectivity analysis presented here examines the connections between green spaces and analyzes the best potential networks to link them. It is based on concepts outlined by Linehan et al. (1995) in an exercise on using greenway planning to develop an ecological network. The analysis is part of a project begun in 1996 to strengthen biological connections between habitat fragments in Greater Vancouver. Called *Green Links*, the project includes planting native vegetation in utility rights of way and backyard habitat to strengthen natural corridors between green spaces.

The analysis presented here examines one metapopulation zone within Greater Vancouver. A zone is an area bounded by major physical barriers to the migration of flora and fauna. These barriers include major roads and highways and large waterways (Schippers et al. 1996). Zones contain a variety of green spaces. For this study, green spaces include all parks and recreation areas as recognized by the City of Coquitlam and all ravines as determined by an independent study (Fig. 1). These green spaces are referred to as nodes. Two types of nodes are recognized here: mother nodes and satellite nodes. Mother nodes are defined as large green spaces that have a greater influence over satellite nodes than satellite nodes have on each other. There is usually only one mother node within a zone. Satellite nodes are defined as smaller green spaces that act as peripheral habitat.

Methods

Study Zone

The study zone is in south Coquitlam and south Port Moody, British Columbia, just east of the city of Vancouver. They are part of the larger urbanized region of

Figure 1. Map of the study area in Coquitlam, British Columbia (Schaefer et al. 1992; City of Coquitlam 1999). The metapopulation zone is an area bounded by Lougheed Highway, North Road, Clark Road, St. John's Street, and Barnet Highway. The total area of the zone is approximately 2,000 ha. The mother node (largest green space) is about 175 ha. Map not to scale.

Greater Vancouver. The area is largely self-contained with significant barriers to the movement of biota, bounded by major roads: Lougheed Highway, North Road, Clark Road, St. John's Street, and Barnet Highway (Fig. 1). This area was chosen because the Institute of Urban Ecology's Green Links project already has one corridor in Coquitlam linking several green spaces (including the large mother node of Mundy Park) and is interested in evaluating other potential links in this area. Table 1 lists the green spaces included in this study and their sizes in hectares.

Assumptions

The nodal analysis requires a minimum area for an indicator species. Choosing a specific indicator species was problematic, so half a hectare was arbitrarily chosen as a hypothetical minimum area requirement. Other studies have determined that most species found in urban areas require at least half a hectare for their minimum habitat requirements. For example, the smallest patch occupied by the Tawny Owl, *Strix aluco,* was 0.3 ha (Redpath 1995); the bank vole, *Clethrionony s glareolus*, is found in areas smaller than 0.3 ha (van Apeldoorn et al. 1992) and Townsends vole, *Microtus townsendii*, is found in areas as small as 0.18 ha (Harris 1984). Robbins et al. (1989) determined that the American Robin, *Turdus migratorius*, the Common Yellowthroat, *Geothlypis trichas*, and the Gray Catbird, *Dumetella carolinesis*, are all found in areas of less than 0.3 ha. Half a hectare was chosen to encompass a wider range of species.

Minimum distances, as the crow flies, between green spaces were measured instead of centroid distances. Centroid distances are measured from the geometric center of one green space to another. This approach simplifies the analysis and gives a more accurate picture of the interactions between nodes. This is especially true for nodes that are close together where minimum distances more accurately reflect distances that must be crossed by biota rather than using centroid distances, which are much further apart.

Nodal Analysis

The gravity model is used to evaluate the level of interaction between the nodes (Linehan et al. 1995). With this model, nodal weight determines the relative significance of the nodes in the study area with reference to the minimum habitat requirement (Linehan et al. 1995).

$$N_a = [x(\text{ha}) / s(\text{ha})] \times 10$$

where N_a is the nodal weight for the green space, x is the area of the green space measured in hectares, and s is the minimum area required for the indicator species. Multiplying by 10 normalizes the data. For example, Mundy Creek has an area of 11.5 ha. Dividing this area by 0.5 ha (the habitat requirement for the hypothetical indicator species chosen for this study) and multiplying by 10 gives the nodal weight of 230. There will be no nodal weights with a value less than 1 (unless the green space is less than 0.05 ha).

Connectivity Analysis

Generally, areas have a greater interaction when they are larger and closer together (Linehan et al. 1995). Connectivity using the gravity model (G_{ab}) is determined as follows:

$$G_{ab} = (N_a \times N_b) / D_{ab}{}^2$$

where G_{ab} is the level of interaction between nodes a and b, N_a is the nodal weight of node a, N_b is the nodal weight of node b, and D_{ab} is the distance between nodes a and b. The gravity model provides an unbiased method to determine different levels of interactions between nodes.

Network Generation

Several potential networks can be generated and evaluated. Figure 2 shows some of the most common types of networks. There are two major groups of network models, branching and circuit. An example of a branching network is the Paul Revere model (Linehan et al. 1995), one of the simplest network models connecting all nodes. It is also the cheapest to create for the group concerned with creating the network.

The other family of networks is circuit networks (Fig. 2). These networks tend to be more complex than branching networks and often represent a lower cost to the user: the flora and fauna using the green spaces as their habitat and benefiting from the networks. Examples include the Travelling Salesman and the Least Cost to User (Linehan et al. 1995). The Travelling Salesman is the simplest, where each node is connected only to two other nodes. The Least Cost to User is the most complex network model because all nodes are directly connected to each other. Networks from both families are evaluated using the Gamma, Beta, and Cost Ratio indices described in the next section.

The networks were generated using MATLAB (version 5.2.0.3084, Math Works Inc.), a high level programming language. A Monte Carlo random search technique was used to determine an estimate of the most effective networks. The program searches for the best linkages, but depending on the random starting point and the path chosen it produces different results. The program ran hundreds of times to produce the best possible results. The models presented below represent the results after the program ran for 5 hr. At this point the results had stabilized, and it is likely that no better result would be found.

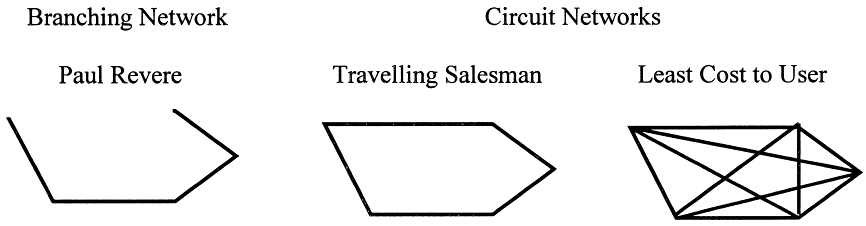

Figure 2. Examples of branching and circuit networks (after Linehan et al. 1995).

Evaluation

The importance and significance of these networks were evaluated using the Gamma, Beta, and Cost Ratio indices. The Gamma ratio represents the percent of connectiveness within each network. It can be determined by dividing the number of links in the network by the maximum number of possible links. The Gamma index ranges from 0 to 1, and the closer to 1, the greater the degree of connectiveness within the network (Bueno et al. 1995). This index can also be adjusted to analyze how different degrees of network development correspond to the theoretical maximum or the project maximum (Linehan et al. 1995). The Beta index indicates the complexity of the network. It is calculated by dividing the number of links by the number of nodes. When the results are less than 1 the network is open or branching. If the result is 1, the network is a single circuit, and if Beta is greater than 1, there is greater complexity within the network (Linehan et al. 1995). The Cost Ratio index indicates the relative cost to both the user and the builder. It is calculated by subtracting 1 from the product of the number of links in the network by the total distance of those links. The closer to 1 the Cost Ratio is, the greater cost to the builder and the lower cost to the user (Linehan et al. 1995).

Results

There were 54 green spaces with a combined area of 636.5 ha (Table 1), in a zone that itself was about 2,600 ha in area. The largest, or mother, node was Mundy Park, 174 ha in area and 2.5 times larger than the next largest green space. The smaller satellite nodes in the metapopulation zone ranged from 0.1 to 6.3 ha. There

Table 1. Sizes and nodal weights of green spaces.

Node	*Park Name*	*Size (ha)*	*Nodal Weight*	*Node*	*Park Name*	*Size (ha)*	*Nodal Weight*
AP2	Alouette Park	0.15	3.04	C15	Kyle Creek	5.92	118.40
C16	Axford Creek	13.70	274.00	PP18	Lost Creek	0.32	6.46
AP4	Blue Mountain Park	8.03	160.52	C4	Lost Creek	3.22	64.40
C1	Booth Creek	16.68	333.60	C13	Machley Creek	12.48	249.60
AP6	Brookmere Park	2.18	43.56	AP29	Mackin Park	7.05	140.94
AP7	Burns Park	0.41	8.14	PP21	Mariner at Dewdney Trunk	0.10	2.00
AP8	Burquitlam Park	1.56	31.24	AP31	Mariner Park	2.01	40.24
AP9	Cape Horn Playground	0.15	3.00	AP33	Miller Park	4.97	99.42
PP2	Como Creek	4.02	80.30	PP23	Mundy Creek	11.54	230.74
AP11	Como Lake Park	11.32	226.42	AP34	Mundy Park	174.17	3483.36
C9	Correll Creek	12.16	243.20	PP24	Nelson Creek	10.64	212.80
AP12	Cottonwood Park	0.56	11.26	C17	Ottley Creek	19.80	396.00
AP13	Crane Park	0.46	9.14	PP29	Pinnacle Creek Ravine	54.37	1087.48
AP14	Crestwood Park	0.45	9.08	AP41	Place des Arts	0.99	19.84
AP16	Dacre Park	1.09	21.74	AP42	Poirier Community Centre	8.06	161.22
C8	Dallas Creek	11.40	228.00	AP43	Poirier Library	3.13	62.60
AP17	Dawes Hill Park	2.99	59.82	AP44	Poirier Sports Centre	6.26	125.20
PP6	Dewdney Wetland	10.08	201.60	AP45	Ranch Park	0.60	11.90
AP20	Ebert Park	0.18	3.64	PP31	Riverview Forest	25.13	502.52
C10	Elginhouse Creek	17.04	340.80	AP46	Riverview Park	2.80	56.00
AP23	Good Neighbor Park	1.10	21.98	AP47	Robinson Memorial Park	3.07	61.32
C11	Goulet Creek	22.04	440.80	AP49	Rochester Park	7.33	146.58
AP24	Guilby Park	0.19	3.74	C18	Schoolhouse Creek	17.24	344.80
PP11	Harbour View Ravine	2.50	49.98	AP51	Selkirk Park	0.12	2.40
PP12	Hickey Street Park	4.31	86.12	C12	Sundial Creek	12.20	244.00
AP26	Hickey Street Park	5.39	107.86	C7	Suter Creek	28.84	576.80
AP28	Keets Park	0.46	9.16	PO9	Vancouver Golf Club	63.56	1271.20

Nodal weights determine the relative significance of the nodes with reference to the minimum habitat requirements. The larger the number, the more significant the node.

were 26 green spaces with nodal weights greater than 100, 11 greater than 250, and 5 greater than 500 (Table 1).

Nodal weights ranged from 2.00 to 3483.36 (Table 1). These weights reflect the different sizes of the green spaces and indicate their importance in the study area relative to the minimum habitat requirement of 0.5 ha. The average nodal weight for this project is 235.74 (Table 2). The nodal weight of 250 was chosen as a criterion for evaluation because it is close to the average and it represents half of the green spaces studied. Nodal weights of 100 and 500 were chosen to evaluate significantly more and less green space without including or excluding all of them. Table 2 summarizes the mean and standard deviation of the sizes and nodal weights of the green spaces in the study area.

The connectivity analysis shows the level of interaction between each of the green spaces in the study area. These results were used in the network analysis. The values range in magnitude from 10^{-1} to 10^{9}.

The analysis tested the Paul Revere, Travelling Salesman, and the Least Cost to User network models. Four different node configurations were examined for each of the above models: the maximum number of nodes (54) and nodes with a weight greater than 100, 250, and 500, respectively. A total of 13 different network scenarios were possible (Networks A-M). The Gamma, Beta, and Cost Ratio indices were then used to evaluate each of the scenarios (Table 3).

Network A connects all green spaces in the study area, including those less than 0.02 km apart from each other. Network B excludes those green spaces that are 0.02 km apart but connects the rest of them. The green spaces that are 0.02 km apart are structurally connected. These areas are close enough together that there is already a corridor and movement can easily occur (Fahrig & Merriam 1985). However, this depends on the species using the corridor and its specific requirements (Bennett et al. 1994) and whether the discontinuity is an impenetrable barrier (e.g., a busy freeway).

Network A is the best network model as the Gamma is 1, the Beta is 26.5, and the Cost Ratio is 0.62 (Table 3). This indicates the highest possible complexity and the greatest degree of connectivity. Network B is the second best model with similar index values. However, Networks A and B, with 1,431 and 1,403 links, respectively, may in fact require continuous habitat joining nodes.

Table 2. Summary of statistics for green space size and nodal weight.

Statistic	*Size (ha)*	*Nodal Weight*
Mean	11.79	235.74
SD	25.60	512.09

There are three networks that represent the most optimistic and realistic choices for the study area. These networks have an unadjusted Gamma of 0.04 or larger, a Beta greater than 1, and a Cost Ratio greater than 0.45. Network D joins 54 nodes with 54 links. It is one complete circuit and is moderately complex. Of all the networks, D represents the network with the greatest ease of use for the user.

Networks E, F, and G include only nodes with weights greater than 100. Network E joins 26 nodes with 325 links. With a Beta of 12.5, and the cost to both the builder (e.g., people) and the user (e.g., wildlife) being equalized, it is a complex network.

Networks H, I, and J include only nodes with a nodal weight greater than 250. Network H joins 11 nodes with 55 links. It has a Beta of 5 and a Cost Ratio of 0.46. The cost to the builder and user is almost equal and represents more than one circuit. In Networks E and H, the user has more than one option for dispersal between the green spaces.

Networks K, L, and M use the criterion of a nodal weight greater than 500, resulting in only five nodes and a maximum of 10 links. This is unsuitable to gain significant connectivity between green spaces. Other unsuitable networks are those that have a Gamma index of less than 0.04, a Beta index of less than 1, and a Cost Ratio that bears a significant cost to the user (under 0.4).

Discussion

Network E represents the best option. It uses half of the nodes and has a high degree of connectivity. Although Network E's 325 links seems unattainable in an urban environment, the distance between many of the nodes is small and is realistic for this area. The small distances between nodes enables the large number of links to be created through backyard habitat enhancement, forming a matrix of pathways through the zone.

Network E also encompasses the entire study area, whereas some of the networks only include portions of the study area. Backyard habitat creation is the best approach to creating the largest ecosystem areas within a zone. Green spaces with nodal weights of less than 100 may also be included in Network E, because these smaller nodes will become part of the corridors between the major nodes of the network.

Well-connected networks such as Network E have a lower probability of extinction; populations can recolonize with greater ease if they are highly connected (Schippers et al. 1996). Network E has 325 links connecting half the nodes in the study area. This high degree of connectivity is just as important to maintain regional biodiversity as are the sizes and or number of nodes (Noss 1983). Dispersal between nodes, which is simpler

Table 3. The connectivity indices for the 13 networks using the Paul Revere (PR), the Travelling Salesman (TS), and the Least Cost to User (Project Max) models.

	Network	*Nodes*	*Links*	*Gamma*	*Adjusted Gamma*	*Beta*	*Cost Ratio*
A	Theory Max	54	1431	1.00	n/a	26.5	0.62
B	Project Max	54	1403	0.98	1	25.98	0.63
C	PR Project	54	53	0.04	0.04	0.98	0.62
D**	TS Project	54	54	0.04	0.04	1	0.62
E*	$N_a > 100$ Max	26	325	0.23	1	12.5	0.5
F	PR $N_a > 100$	26	25	0.0175	0.08	0.96	0.4
G	TS $N_a > 100$	26	26	0.0182	0.08	1	0.42
H	$N_a > 250$ Max	11	55	0.04	1	5	0.46
I	PR $N_a > 250$	11	10	0.0070	0.18	0.91	0.16
J	TS $N_a > 250$	11	11	0.0077	0.2	1	0.08
K	$N_a > 500$ Max	5	10	0.01	1	2	0.41
L	PR $N_a > 500$	5	4	0.0028	0.4	0.8	−0.08
M	TS $N_a > 500$	5	5	0.0035	0.5	1	0.34

The adjusted Gamma, how the Gamma index corresponds to the project maximum, e.g., the number of links in D, are divided by the number of links in B to obtain the adjusted Gamma.
*Best option.
**Alternative option.

in a well-connected network, is essential to prevent inbreeding depression and the disease and extinction that follow (Noss 1983). Generating 325 discrete corridors is unrealistic. However, increasing biodiversity in backyard habitat, boulevards, and utility rights-of-way can produce a matrix functional as 325 corridors for plants and animals in the zone.

An alternative network is D. This network uses all 54 nodes identified in the study area and has two links to and from each one. Because the number of links is reduced it seems more attainable. However, as the number of links decreases the ease of dispersal also decreases. This increases the probability of extinction, whereas connected networks have a lower rate of extinction (Schippers et al. 1996). The major goal of preservation is to protect the integrity, structure, and function of the ecosystem (Noss 1983). Although Network D is good because it connects all of the nodes, it is not as complex as Network E and may lead to higher rates of extinction and loss of ecosystem integrity.

The Gamma, Beta, and Cost Ratio indices were chosen for this analysis because together they produce a clear picture of the network (Linehan et al. 1995). If used alone they can be misleading. For example, Network C has a very low Gamma, a Beta under 1, and a high Cost Ratio. A low Gamma index represents a diminished degree of connectiveness. A Beta under 1 indicates that the network is not a complete circuit and all nodes are not linked together, therefore reducing ease of dispersal between nodes. A high Cost Ratio is good because it indicates lower cost to user and promotes ease of dispersal. If the Cost Ratio were the only index used to evaluate Network C, the network would appear to be ideal. However, when using all three indices, it is evident that much better networks satisfy all the criteria.

Creating corridors using the connectivity analysis is much more effective than randomly selecting links. The results of the analysis indicate the value of a network of backyard habitat, boulevards, and utility rights-of-way to provide a matrix of corridors. This analytical technique allows a realistic approach in using scientific data to support qualitative ideas of greenways (Linehan et al. 1995). Randomly selected networks may not be as effective at protecting and enhancing biodiversity. Both the theory of island biogeography and metapopulation dynamics assume that suitable patches of habitat are interspersed with uninhabitable areas (Andren 1994). This creates a divided landscape. Therefore, it is important to remember that preserving parks is only part of the solution. Without connections between them, isolation and loss of genetic diversity is imminent (Hobbs & Saunders 1990). Green corridors, utility rights-of-way, and backyard habitat are important parts of urban planning, because they increase biodiversity in cities and improve the quality of life for all residents. For example, they increase opportunities for wildlife viewing, human relaxation and education, and controlling pollution, temperature and climate, erosion, and noise (Adams & Dove 1989).

In urban environments there is usually one large green space or mother node in a metapopulation zone that has significant influence on the surrounding area. As the demand for land to develop grows with the population, cities can usually only afford to preserve a few large green spaces. These green spaces tend to have high biodiversity and provide important breeding and seeding habitat for interior species, as well as edge species and transients. In this study, smaller green spaces or satellite nodes range in size from 0.1 to over 100 ha. The satellite nodes may not be able to support large numbers of species on their own but are able to provide important peripheral habitat to species in the mother node (Hansson 1991). Satellite nodes are partly or entirely dependent on individuals immigrating from the mother node (Hansson 1991). They have a higher rate of extinction than the mother nodes and therefore need to be repopulated constantly (van Apeldoorn et al. 1992). This requires proximity to the mother node. As the urban environment becomes increasingly more fragmented, satellite nodes are getting smaller and farther away from the mother node, making dispersal even more difficult. As a way of preserving the biological integrity of a landscape, corridors and habitat matrices must be in place to allow dispersal between green spaces.

Mundy Park is the mother node for this study area. It is the largest park in the area and has the largest nodal weight and therefore the greatest influence over the surrounding green spaces. Mundy Park has a variety of different habitat types: wetland, coniferous forests, deciduous forests, and fields. Because the satellite nodes also vary in their habitat types, the variety of flora and fauna in each of Mundy Park's habitat types is also able to use the different satellite nodes to the fullest extent. The corridors could allow for dispersal between Mundy Park and the other nodes. Although no studies have been done on dispersal from Mundy Park to its satellite nodes, it is well documented that mother nodes provide a base for dispersal, and corridors aid in this dispersal (Hobbs & Saunders 1990; Taylor et al. 1993; Bennett et al. 1994; Beier & Noss 1998). This is why it is important to have a complex network. More links equal more routes to suitable habitat, creating more opportunities for dispersal. This is important because suitable habitat often remain unused if isolated (Hanski & Thomas 1994).

Another very important component of network planning is the consideration of private and unprotected areas. Backyard habitat can be an invaluable food and habitat source for a wide range of urban species and is essential in developing the matrix that supports the large numbers of corridors required for connectivity. Public education on gardening with native plants and providing proper habitat is another tool to enhance the connectivity of the region and improve the viability of the corridors. This is crucial in urban areas because of existing development and lack of green space.

This study is a general analysis that examines the structural connectivity of the landscape. The literature is not consistent in the definition of connectivity. Taylor et al. (1993) defines landscape connectivity "as the degree to which the landscape facilitates or impedes movement among resource patches," whereas connectedness refers to structural or physical connections between patches or nodes. Where resources are available future studies should concentrate on connectivity rather than connectedness. However, this poses another problem because examining connectivity is usually conducted on a single species (e.g., Bennett et al. 1994) and the results may not be transferable to all species in an area. Analyzing structural connectivity may present more general results. Future work in this area should use a species–area curve to determine a more accurate minimum habitat size requirement for urban species. Species lists from a variety of urban parks of varying sizes can be obtained and plotted to develop a species–area curve that is appropriate for urban habitats. Once all green spaces in the area have been identified, it would be useful to evaluate the quality of the nodes when resources are available. There is a possibility that some municipal parks may not provide suitable habitat for flora and fauna.

The analysis presented here gives a solid foundation for developing a greenway network in urban areas. This can be applied to other areas throughout Greater Vancouver and cities around the world.

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