A Framework for Assessing Ecological Health in Vancouver's Naturally Managed Areas

With a Case Study in Renfrew Ravine Park

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Spring 2020

EVSC 400 Environmental Science Capstone
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Executive Summary

Background

Naturally Managed Areas (NMAs) are a valuable part of city infrastructure because they provide ecosystem service and vital connections to nature for Vancouver's citizens. With the inherent value of NMAs comes the need to accurately and efficiently quantify the ecological health of these areas. Through the continual and comparative assessments of NMAs, the Vancouver Park Board can identify areas in good condition that require maintenance and areas in poor condition that require restoration.

In an effort to better understand how Vancouver's NMAs interact with the urban landscape that surrounds them, a methodology needs to be created that is both comprehensive and applicable to a variety of ecosystems. No two NMAs are the same: each NMA has its own unique set of variables that contribute to its health. We created this framework to be specific to the ecosystems of Vancouver, while also remaining applicable to all the unique features of NMAs. Another key issue we have considered when creating our ecological assessment is the urban setting of Vancouver's NMAs.

Our objectives are:

1. Develop a generalized framework that can be used to assess the ecological condition of NMAs in Vancouver, and evaluate which are in Poor, Fair or Healthy condition.

2. Apply the methodology to assess Renfrew Ravine Park as a case study of the framework and recommend potential management actions based on the determined ecological health and condition of the park.

Study Site

Renfrew Ravine Park is a riparian habitat that is unique for being the only park in Vancouver to feature a creek in a natural ravine. The park includes 6 hectares of forest cover and an uninterrupted portion of Still Creek, which is also the longest remaining visible creek in Vancouver. Renfrew Ravine Park is located between the 29th Avenue Skytrain Station and East East 22nd Avenue in the heart of East Vancouver.

The park is divided into two sections by a path running along East 27th Avenue. The Vancouver Park Board started restoration and stewardship efforts in 2013. These plans were implemented mainly in the section North of the path, with little to no work in the South section. As a result, the North section is well-maintained with reinforced slopes, a wooden staircase, boardwalk, and viewing deck. The south section is not maintained, containing only a rugged and eroded trail. Due to time and resource constraints, only the South section of the Renfrew Ravine Park will be the subject of our case study.

Methodology

The following is a framework for the ecological evaluation of NMAs in the City of Vancouver. NMAs will be assessed based on six categories, each category containing its own methodology. These methodologies will each result in a health rating from 1 to 3 (Poor, Fair, or Healthy). These ratings will be combined, taking into account their respective weighting, to give an overall ecological health rating.

Water Quality

This part of the assessment uses physical, chemical, and biological factors to determine the quality of a water body and its contribution to the overall ecological health of an NMA. This methodology is based on the Streamkeepers Handbook (1995) developed by the Department of Fisheries and Oceans. Each water body will be assessed for its dimensions, temperature, pH, turbidity, dissolved oxygen, and macroinvertebrate presence.

The physical and chemical factors are given a value, and used to calculate the Water Quality Index. The biological factors contribute in a similar way in another index. Each index will produce a score of Poor, Fair, or Healthy. The average of these scores will be taken as the final score for water quality in that area.

Soil Quality and Slope Stability

The methodology to assess this category involves surveying the landscape, mapping changes in the slope, and a geochemical study of the contents of the soil. The Core Method is used to obtain soil samples to test for physical and chemical properties of the soil. A soil survey is also conducted to assess soil erosion hazards. A 0.5 m long by 0.5m wide by 1.0m deep excavation is used to obtain soil samples every 10 cm down the excavation. Soil samples are analysed in a lab for bulk density, pH, mineral concentrations, conductivity through sodium, coarse fragments, and organic matter. These qualitative measurements will be put into an index to achieve a rating of Poor, Fair, or Healthy.

Other physical properties of the soil such as permeability, porosity, depth to water-restricting layer, as well as length and uniformity of soil topography are surveyed. Soil stability is measured by mapping slope using aerial photography and comparing to data on previous conditions, if available. If there is no prior available data, slope can also be determined based on the average slope. These physical properties will be weighed in another index to achieve a rating of Poor, Fair, or Healthy. The two ratings will be averaged for the overall health of the soil.

Vegetation

Stratified random quadrat sampling is used to assess Vegetation diversity and presence of invasive species. Quadrats should be 5 by 5 metres, and the number of quadrat samples is based on a goal of assessing 1% of the park, with a minimum of 30 samples in total. At each sampling location, the quadrat is placed on the ground and the surveyor estimates the percent area of the quadrat occupied by each plant species. After sampling is completed, the results from each quadrat are combined to give a rating in two categories: species diversity (number and abundance of species, evaluated using Simpson's diversity index) and invasive species cover (calculated as the total percent cover of the park from all invasive species combined). These are then averaged into an overall Vegetation score of Poor, Fair or Healthy.

Tree Cover

Assessing the health and status of the tree cover in forested NMAs will be accomplished using an adapted version of a forest biodiversity assessment. The original assessment consists of a combination of 60 qualitative and quantitative criteria that are addressed over the course of a walk through the forest. For our purposes we have modified the assessment with the goal of having an efficient, accurate and replicable methodology that assesses tree diversity and health.

Our modified methodology includes 13 quantitative criteria that assess the diversity and age distribution of trees, and 10 qualitative criteria that address the interaction between trees and the environment around them. Users will not need an extensive knowledge of forest ecology to complete this assessment, except the ability to recognize the difference between hardwood and softwood trees. A quadrat sampling method is proposed, with a quadrat size that is based on the relative age and height of the forest: 10m by 10m quadrats for a young forest or 20 by 20m for a mature forest. The number of quadrats sampled is based on a goal of sampling 1% of the NMA.

Animal Habitat

Assessing an NMA based on its potential as animal habitat requires the determination of critical environmental conditions for selected species groups. To begin determining if an NMA is a suitable habitat for a particular animal group, a species list should be created. These lists are constructed by identifying all the animals of that group that may inhabit the area. The list should contain species that currently exist in the area as well as historic species, which will allow for the comparison of species diversity over time. Following the creation of the species list, critical habitat components including biotic factors for each NMA should be identified. Critical habitat components are all the habitat characteristics required by species on the species list. These components are assigned points, and the NMA is given a rating based on how many points out of the total number of components it meets.

In this assessment, we have applied the methodology above to create a table that can be used to assess NMAs for songbird habitat quality. We chose to focus on songbirds because Vancouver has prioritized birds in the Bird Strategy. There are 9 criteria that address the biotic components required for birds to inhabit the NMA. The NMA should be examined for these features and assigned pointes based on the number of features present, which is then divided by the number of features needed. This value is then converted into a rating indicating Poor, Fair or Healthy conditions.

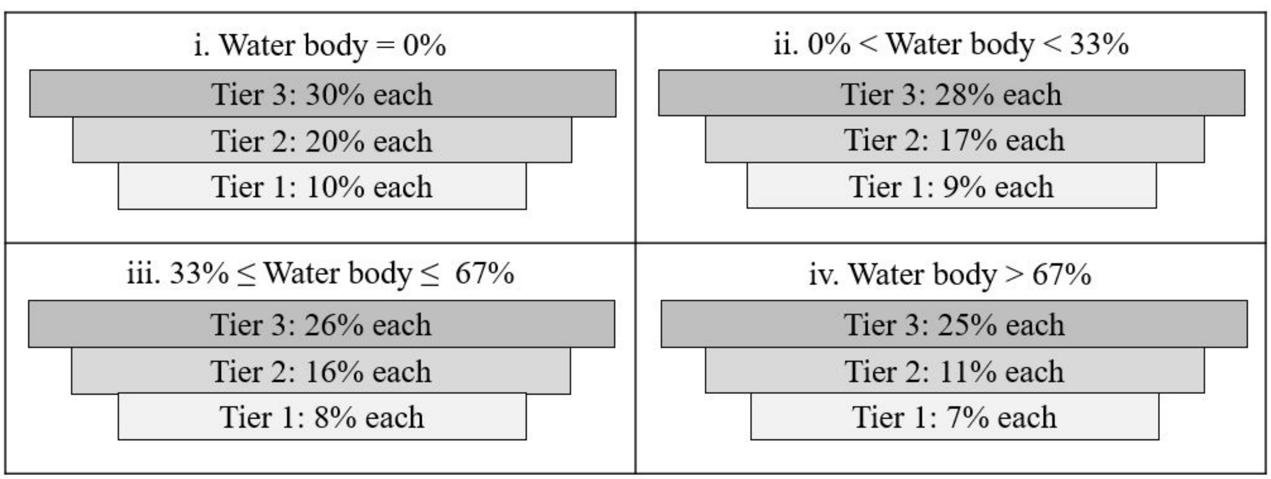
Human Disturbance

The rating system for this category is based on a visual survey of the human presence and disturbance in the NMA. The survey should be conducted simultaneously while completing the other sections of the framework. Two categories are assessed: litter and human presence. A grading scale is used by the surveyor to determine the extent of litter in the area. Human presence is assessed using a similar scale, but looking for signs of human presence and activity (other than litter) that could be disturbing to the ecosystem. The scores for litter and human presence are averaged to give an overall score for human disturbance.

Ecological Health Rating

The Ecological Health rating is based on a three-tier weighing system that weights each health section based on its value, both ecologically and functionally, as identified by Vancouver Parks Board staff. Vegetation and Tree cover have been identified as the top priorities (Tier 3). Animal Habitat is valued as the next highest (Tier 2). Human disturbance along with Soil Quality and Slope Stability have been valued as the lowest (Tier 1). Water Quality may be located in any tier based on the area of the NMA it occupies.

To determine the weighing of the Water Quality Section, the total area of the water body in the park should be determined. A buffer zone is then added around the water body, to account for its associated riparian ecosystem. The width of the buffer zone is based on the size of the water body, according to the BC Forest Range and Practice Act. The area of the water body and buffer zone can then be divided by the area of the NMA and converted to a percent, which determines which weighing scenario (i-iv) is used.



Valued Weighing for final Ecological Health Rating based on different NMA scenarios. i. Water Quality is not used in Ecological Health Rating calculations. ii. Water Quality is in Tier 1. iii. Water Quality is in Tier 2. iv. Water Quality is in Tier 3.

The ecological health rating for a NMA. The weight is the percent each category is worth, depending on the number of categories assessed.

Assessment Category	Score	Weight	Result	Final Rating
Water Quality				
Soil Quality and Slope Stability				
Animal Habitat				
Vegetation				
Tree Cover				
Human Disturbance				
Poor: rating < 2	Fair: 2 ≤ rating < 2.5		Healthy: rating ≥ 2.5	

Case Study Fieldwork and Results

Our assessment of Renfrew Ravine Park serves mainly to test our framework and includes a limited selection of the methodologies. Each section of the framework should be performed to best capture the true ecological status of this NMA. However, due to limited time and resources, we were only able to complete the assessments for the Water Quality, Vegetation, and Human Disturbance. Although we were able to get an Ecological Health rating from these sections, this is not a comprehensive assessment and should not be considered complete.

Water Quality

Wetted and bankfull channel dimensions for the portion of Still Creek that runs through the South section of Renfrew Ravine Park were recorded at five sites. Turbidity, temperature and pH were recorded at each site with a combined electronic meter. With limitations in available equipment, we could not measure dissolved oxygen, so this value was taken from data collected by the Still Creek Streamkeepers on the same day, at a station near our first site. Our survey of benthic macroinvertebrates was conducted at the first four sites. We determined Renfrew Ravine Park's Water Quality Index to be Good and the presence of macroinvertebrates to be Poor. The average of these gives a final rating of Fair for the overall water quality rating in Renfrew Ravine Park.

Vegetation

We stratified the park based on slope risk and planned to assess 1% of the park, which required sampling 135 plots. As this value is extremely high, we created a protocol that determines when enough sample plots have been taken to represent the entire park, using a species vs area curve method. We used a 1m by 1m quadrat for the first four samples and a 2m by 2m quadrat following that.

During our vegetation assessment, we realized we needed more consideration in our framework for the length of the survey. In the field, we realized our small quadrat size, goal of assessing 1% of the park, and species vs area curve protocol would take an unreasonable amount of time to complete and had logistical issues in an urban park. By testing our framework in the Renfrew Ravine Park, we were able to see where the methodology could be improved to make it more applicable for Parks Board staff.

After the fieldwork was completed, the data was analyzed and values were calculated to obtain a health rating for each section. Species diversity, using Simpson's diversity index, was 80% or Healthy. Invasive species cover made up 61% of the park's plant cover, which is a rating of Poor. Taking the average of these two values gave an overall Vegetation score of Fair.

Human Disturbance

During our survey we observed numerous small pieces of litter in all areas of the park. We also observed plenty of large pieces, including a mattress, construction debris, large wooden crates, and more. It was clear that regular dumping is occurring in this park. Because the South section has not been maintained with established trails and boardwalks, there are unofficial trails throughout this entire section with lots of trampled vegetation and human-made clearings, especially next to the stream. We assigned a grade of E to both litter and human presence, which resulted in an overall rating of Poor for Human Disturbance.

Ecological Health Rating

The stream in Renfrew Ravine Park classified for a buffer of 30 metres on each side, resulting in an percent area of 83%. This placed Water Quality in Tier 3 with Vegetation, while Human Disturbance is in Tier 1. Because we only completed three sections, we adjusted the weighing so Water Quality and Vegetation were each worth 40% and Human Disturbance was worth 20%. This resulted in an overall Ecological Health rating of 1.8 or Poor for Renfrew Ravine Park.

Recommendations for Renfrew Ravine Park

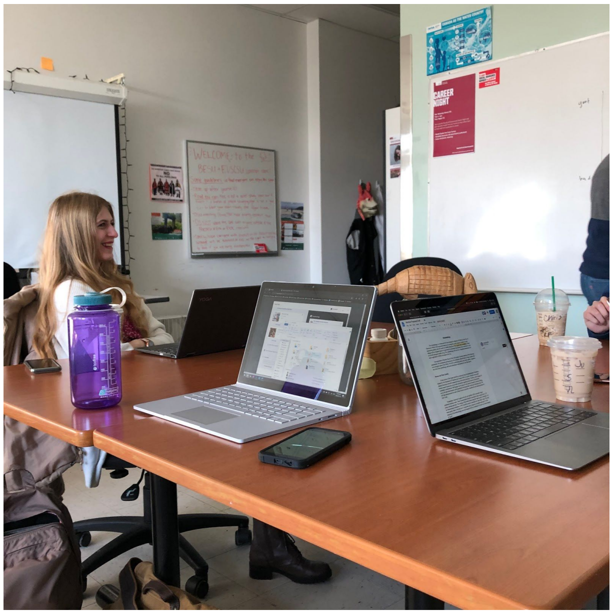
Based on our results and experiences in Renfrew Ravine Park, some recommended actions are as follows: cleaning up litter, installing litter bins, posting warning signs against dumping, invasive species removal, native species planting, upgrading fencing, establishing proper trails, and constructing a boardwalk similar to the one found in the North section of the park. Each of these actions are highly dependent on the others. Cleaning the trash is fruitless if active littering continues. Installing litter bins and warnings against littering both support clean-up actions. Likewise, removing invasive species to plant native species is bound for failure if trails are not established and a high level of trampling continues.

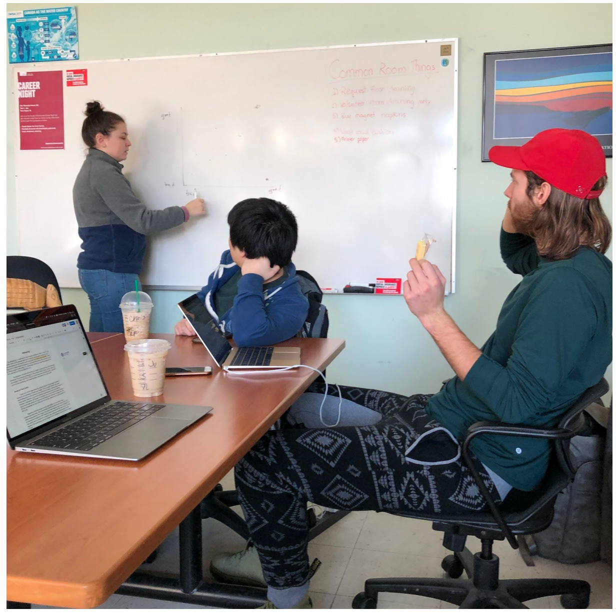
These actions will require regular maintenance to ensure success. If long-term maintenance is not feasible at this time, creating a “no-go” zone of the South section is a possibility following an initial clean-up. Although, creating “no-go” zones is not a preferable action as it reduces the benefit of an NMA to the surrounding community. As an urban park, these NMAs provide considerable benefit to local residents, and all possible action should be taken to preserve that benefit before access is restricted.

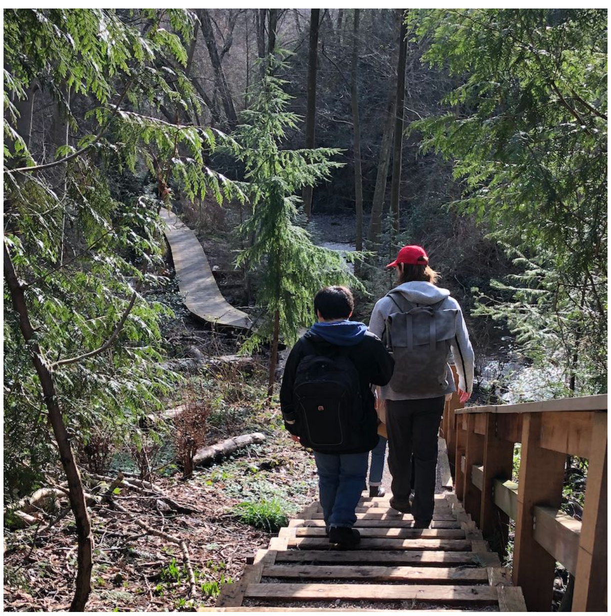
Management Priority Matrix

Assessing the health of NMAs is important for determining management priorities and areas requiring restoration. After the health of each NMA has been evaluated, this section is used to decide in which NMA to begin restoration and management activities. It is a way to compare parks across the City of Vancouver, and move from assessment to actions. Based on the Portland Natural Areas restoration Plan’s Priority Matrix, this matrix evaluates NMA health versus NMA value to demonstrate which parks should receive treatment first. NMAs are rated based on a point system, where they are examined for the presence of valuable ecological features, which are determined by Vancouver Parks Board priorities. Features are worth 1 to 3 points depending on their importance. The points are tallied for each NMA, giving the overall value rating. This value rating is then graphed versus ecological health rating to identify priority management areas. Due to limitations in time, resources, and availability of information, this report describes how the methodology can be created, but does not outline any valuable features or scores.

Authors








We are a team of undergraduate student researchers from the School of Environmental Sciences at Simon Fraser University (SFU), undertaking this project as a part of our EVSC 400 Capstone course. We were challenged to combine our previous years of knowledge with real world experience. Group members include:

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Amanda Wik is a 4th year student at SFU who will be graduating in the Spring of 2021 with a major in Environmental Science - Applied Biology. Besides coursework in scientific writing, fieldwork, biology, ecology, and environmental assessment, Amanda has worked for Environment and Climate Change Canada, the Richmond Nature Park, and will be spending this summer with the Nature Trust of BC.

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Christopher Chang is a 4th year student at SFU who will be graduating in the Spring of 2021 with a major in Environmental Science - Applied Biology. Along with course experience in scientific writing, methodology, field-work, surveying and analysis, he has also received additional training from Bamfield Marine Science Centre.

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Gabi Trainor is a 5th year student at SFU who will be graduating in the Fall of 2020 with a major in Environmental Science and concentration in Applied Biology. Along with coursework in scientific writing, methodology creation, conducting fieldwork, and statistical analysis, she has work experience with the Ministry of Forests, Land, Natural Resource Operations and Rural Development, and the Centre for Wildlife Ecology at SFU.

Grant MacRobbie

Grant MacRobbie is a 5th year student at SFU who will be graduating in the Spring of 2021 with a major in Environmental Science - Applied Biology. Along with course experience in scientific writing, methodology, field-work, surveying and analysis, he has also received additional training from Bamfield Marine Science Centre. He is an avid horticulturist, gardener and landscaper.

Hyeju Lee

Hyeju Lee is a 4th year student at SFU who will be graduating in the Spring of 2021 with a major in Environmental Science - Applied Biology. She has received course experience in scientific writing, methodology, field-work, ecology, surveying and biostatistical analysis. She is an adventurer who loves travelling and exploring new places.

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1.0 Introduction

1.1 Background

The city of Vancouver has identified Naturally Managed Areas (NMAs) as valuable parts of city adaptation strategies because of their ability to provide ecosystem services and to mitigate the effects of a warming climate (Climate Change Adaptation Strategy, 2018). NMAs provide ecosystem services such as reducing the urban heat island effect, decreasing flood risks by reducing stormwater runoff and regulating air quality (Urban Forest Strategy, 2018). In addition to these benefits, NMAs provide Vancouver's citizens and visitors with vital connections to nature (Urban Forest Strategy, 2018). With the inherent value of NMAs comes the need to accurately and efficiently quantify the ecological health of these areas. Through the continual and comparative assessments of NMAs, the Vancouver Parks Board can identify areas in good condition that require maintenance, and areas in poor condition that require restoration.

In an effort to better understand how Vancouver's NMAs interact with the urban landscape that surrounds them, we aim to create a methodology that is both comprehensive and applicable to a variety of ecosystems. No two NMAs are the same; each NMA has its own unique set of variables that contribute to its health. How does one find a balance between specifying a framework to a particular area, at the same time as keeping the framework general enough to apply to other NMAs? Another key issue to keep in consideration when assessing the ecological health of NMAs: how does one account for the fact that most, if not all, NMAs are closely integrated with the urban settings around them?

1.2 Objectives

1. Develop a generalized framework that can be used to assess the ecological condition of NMAs in Vancouver, and evaluate which are in Poor, Fair or Healthy condition.

2. Apply the methodology to assess Renfrew Ravine Park as a case study of the framework and recommend potential management actions based on the determined ecological health and condition of the park.

1.3 Study Site

Renfrew Ravine Park is a riparian habitat unique for being the only park in Vancouver to house a creek in a natural ravine. The park includes 6 hectares of forest cover and an uninterrupted portion of Still Creek, which is also the "longest remaining visible creek in Vancouver" (City of Vancouver, 2019). Renfrew Ravine Park is located between the 29th Avenue Skytrain Station and East 22nd Avenue in the heart of East Vancouver.

The park is divided into two sections by a footbridge running along East 27th Avenue. The Vancouver Park Board started restoration and stewardship efforts in 2013. Figure 1 shows a full map of the park along with the proposed plans. Restoration was mainly completed in the North section, with little to no implementation in the South section. As a result, the North section is well-maintained with reinforced slopes, a recently built staircase, a boardwalk, and a viewing deck. The South section is not maintained, containing only a rugged and eroded trail. Due to time and resource constraints, only the South section of the Renfrew Ravine Park will be the subject of our case study.

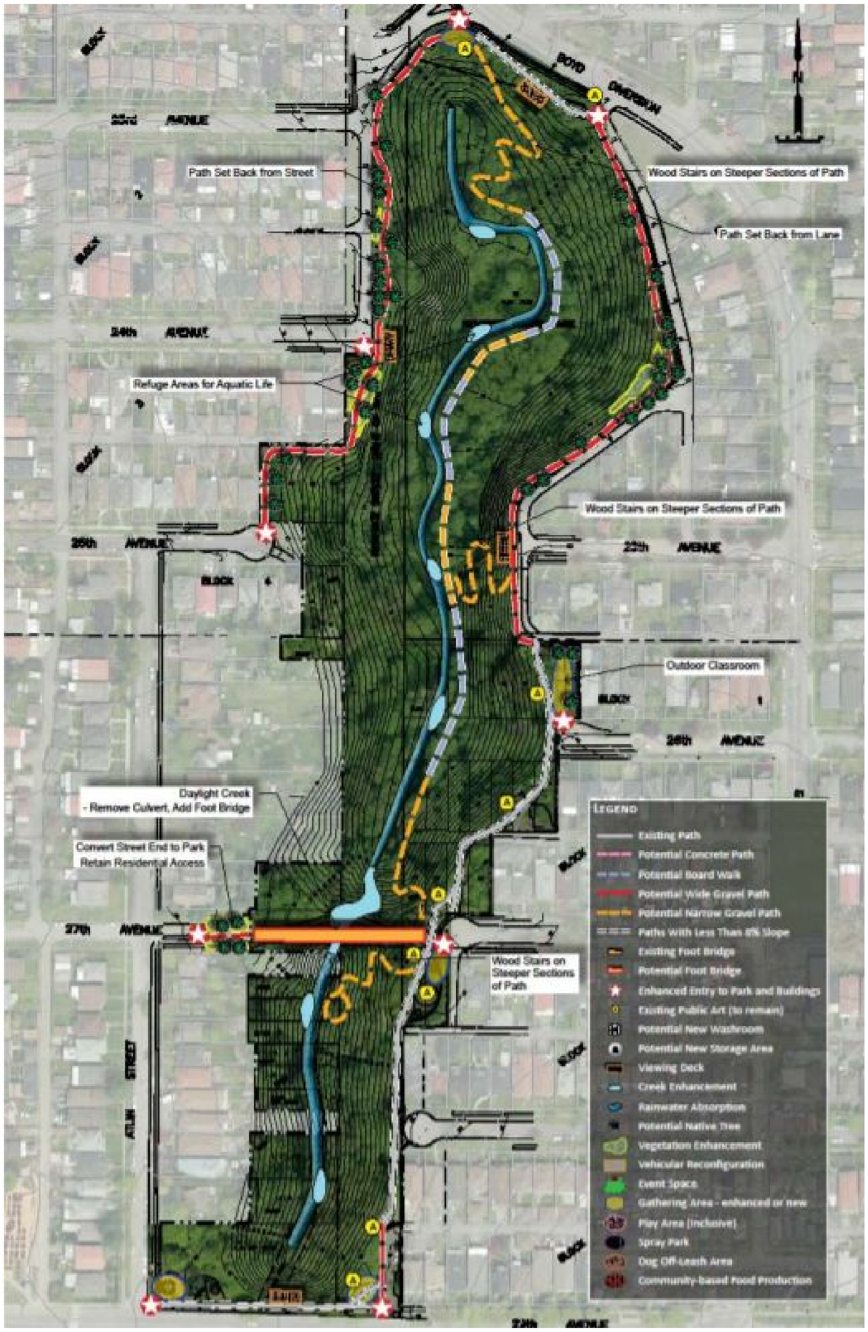

Figure 1. Vancouver Park Board Proposed Layout (Parks and Recreation, 2013)

2.0 Literature Review

2.1 Introduction

To investigate the ecological health of Vancouver NMAs, any methodology created should be both comprehensive and efficient. It should be tailored to fit the NMA in question, but also generalized enough to be applicable across all NMAs. This can be difficult since each NMA is unique, with its own set of parameters contributing to its health. The urban setting that surrounds an NMA is another key consideration in assessment due to its effect on ecological health. These surroundings must be accounted for, and contributors to ecological health should be weighted accordingly.

The literature review will justify the creation of a health assessment for NMAs in Vancouver, as well as discuss some of the research and methodologies relevant to a case study performed in Renfrew Ravine Park. In addition, the depth of knowledge, identification of gaps, and areas of disagreement in the literature will be reviewed, on both the scale of Renfrew Ravine Park as well as to the city of Vancouver in general.

2.2 Justification of Methodologies

As Vancouver tries to become the "Greenest City," various environmental reports such as the Vancouver Bird Strategy (Vancouver Bird Advisory Committee, 2015), Urban Forest Strategy (City of Vancouver, 2018), Climate Change Adaptation Strategy (City of Vancouver, 2018), and Biodiversity Strategy (Vancouver Board of Parks and Recreation, 2016) justify the implementation of greener management practices. Environmental strategies allow the City of Vancouver to become a greener city, and together, can help guide and improve plans regarding NMAs within the city. By synthesizing the goals and information in these strategies, we can build a framework for assessing the ecological health of NMAs in Vancouver. This framework will allow for informed management decisions and action plans in each NMA that work within the City of Vancouver's long-term sustainability goals.

The City of Vancouver's environmental strategies already work with and reference each other, justifying their integration in our framework. The Urban Forest Strategy introduces a comprehensive network of green infrastructure throughout the city in conjunction with the Biodiversity Strategy, Vancouver Bird Strategy, and Vancouver's Playbook. The Climate Change Adaptation Strategy aims to increase the long-term health of natural spaces, increase canopy cover in the city, and improve the quality of local water bodies. The Greenest City Action Plan (2012) calls for an ecologically healthy park within a five minute walk from every Vancouver resident's home. The goals of the Greenest City Action Plan and the Climate Change Adaptation Strategy support and encourage the aforementioned reports. In addition to the strategies from the City of Vancouver, the Department of Fisheries and Oceans created the Streamkeepers Handbook (1995) to inspire community involvement in local stream and wetland care, integral to the health of many NMAs. The goals of the City of Vancouver as well as the Government of Canada clearly justify the creation of an assessment for the ecological health of Vancouver's NMAs, and can guide decisions on an appropriate and integrated methodology.

2.3 Conceptualization of Ecosystem Health

The priority of our framework is to determine the health of urban ecosystems in the form of NMAs. However, to be able to assess the health of an ecosystem, we must be able to define what ecosystem health is. Examining this topic highlights several areas of disagreement in the literature, particularly when considering ecosystem health in an urban context. The definition of ecosystem health we choose to follow will guide our assessment and standard of health for NMAs in Vancouver.

Ecosystem health, which is often synonymous with ecological integrity, can be broadly described as the state of an ecosystem relative to a management target or reference condition, considering its function and structure (O'Brien et al., 2016). In examining this definition, it is clear that ecosystem health is an intrinsically value-based concept, where the structure and function of a healthy ecosystem are determined by the priorities of the assessor (Ordóñez & Duinker, 2012).

Ordóñez and Duinker (2012) describe two broad interpretations that guide the consideration of ecosystem health in an urban context. The first is a utilitarian approach that defines ecosystem health solely in terms of the maintenance of functions that influence ecological conditions and benefit people. This view enables an approach that uses technology and non-native species to restore ecological functions, where the structure is not an important consideration. The second school of thought is more ecologically focused, where health is considered by the maintenance of function and structure at natural levels relative to a pre-urbanization ecosystem. Examining the literature on ecosystem health assessments clearly demonstrates this divide. For example, assessments that prescribe to the first school of thought tend to focus on measuring ecosystem services that natural areas provide (Su et al., 2009; Mcphearson et al., 2015). For the second, more ecological view, assessments tend to examine the presence of native species and historical fidelity (Page, 2006; Ordóñez & Duinker, 2012). Native species is a major divide between these interpretations of ecosystem health.

Management for native versus non-native plants is a highly debated topic in urban ecosystem assessments and is embedded in the two interpretations of ecosystem health (Ordóñez & Duinker, 2012). From a functional interpretation of ecosystem health, non-native species can be useful because they can be planted to quickly grow and enhance ecosystem service, they can be more resistant to the many stressors of an urban environment, and they can enhance ecosystem adaptation to climate change by facilitating assisted migration (Almas & Conway, 2016). Meanwhile, in the second interpretation of ecosystem health, managers focus on removing non-native species and planting native species to return the ecosystem to its structure before urbanization (Ordóñez & Duinker, 2012). Increased focus on native species is argued because they make the best use of resources available, control invasive species, promote wildlife interactions, regulate the gene pool, and create diverse ecosystem compositions (Ordóñez & Duinker, 2012). Non-native species are argued to create ecosystem disservices like proliferation of new diseases, exacerbation of wildlife problems, homogenization of biotic communities, and the loss of regionally unique native species (Gaertner, 2017). As we determine the definition of ecosystem health used in our assessment, management of native and non-native species will be an important consideration.

To address the controversies in definitions of ecological health, we have decided to use a definition that is midway between the two interpretations outlined by Ordóñez and Duinker (2012). This allows for the prioritization of ecosystem function in the form of services that have been identified as important within the City of Vancouver environmental strategies (Vancouver Board of Parks and Recreation, 2016; City of Vancouver, 2018). However, it also allows us to set a high standard of ecosystem health that is present in pre-urbanization ecosystems, with a precautionary approach. With the management of native and non-native species, this will mean a prioritization of removing invasive species only, while allowing non-native species that are functionally beneficial. However, recommendations will also focus on increasing the amount of native species to attain historical levels of ecosystem health.

2.4 Research & Knowledge Gaps in Urban Ecosystem Health

With many types of ecosystems and expressions of health, creating a generalized ecological health assessment becomes difficult, particularly for urban ecosystems which have unique conditions. Urban ecosystems are inherently subject to more stressors and human interference, preventing certain natural conditions from being met. For example, it is difficult to determine the point where health factors can no longer be achieved to the same high standards as they could in a non-urban ecosystem. This highlights the need for a new definition of ecosystem health that encompasses these distinctive features and alternate considerations, which is a gap in the knowledge and literature.

Many of the methodologies we reviewed in our literature search do not address the complexities of conducting ecological assessments in an urban context. For instance, neither "Invasive Plants in the Still Creek Watershed: Inventory Results and Restoration Prescriptions" (Page, 2006) nor "Conducting a Forest Biodiversity Assessment: A Guide for Forest Owners and Land Stewards" (Northwest Natural Resource Group, 2014), both ecological assessments completed in the Renfrew Ravine watershed, have consideration for non-native plants that are not harmful and are better suited for an urban environment. Similarly, the Streamkeepers Handbook (Taccogna & Munro, 1995) does not address non-natural water features such as creeks fed by storm drain water, like in Still Creek. However, this resource is well-suited for creating a trend of water quality over time, which is especially useful in an urban setting because any improvements can be compared to itself rather than more natural areas. This highlights one way that the literature methodology can be adapted to meet the needs of an urban assessment.

Within the research, it is still unknown what the impacts of urbanization are on the health of an NMA, and this is particularly true when examining soil. For example, USDA Forest Services indicate that the top 12 inches of healthy soils should be 85% organic matter to be healthy. In an urban environment it is unclear if the organic matter present should be higher or lower to indicate a similar level of health as a "natural" soil. Furthermore, the B.C. Ministry of Forests' Hazard Assessment Keys for Evaluating Site Sensitivity to Soil Degrading Processes Guidebook (1999) has no mention of the effect of root cover on the soil nor does it indicate how these soil properties may change given the composition of the soil. The guide is based on soils that are either Temperate Rainforest or Boreal forest, which are historically the primary biomes in British Columbia (BC Parks, 2018). However, the soil in most Vancouver NMAs started as fill and dump from urban activities (J.L.Morel et al., 2005) rather than the natural erosion of rock from primary succession into soil (Harrison & Strahm, 2008). There is no indication of how this changes the rating of soil health.

Research has been done on the health of various ecosystem components, such as water quality (Taccogna & Munro, 1995) or biodiversity (Dobson & Carper, 1993). However, very little research has been done on the relative weight that any one component has on ecosystem health compared to another. Does having a healthy water body nearby more greatly impact the ecological health than quality soil? What is the difference in health if an ecosystem is hospitable to birds but not to a wide variety of plants? It is known that these all contribute to ecological health, but not by how much in relation to each other. Furthermore, much of the literature did not provide a rating system for their ecological methodologies nor had them rated in a way that fit into our Poor, Fair, Healthy framework. For example, while Debinski & Brussard (1994) give a helpful framework for beginning to determine the trends of species diversity and bird and animal habitat overtime, they did not include a rating system regarding bird and animal habitat in an urban setting. In these cases, we have adapted the results to fit into our rating system.

2.5 Conclusion

As the ability to measure the health of NMAs becomes increasingly important, ecological health assessments will be essential to guiding the prioritization of management projects. However, ecological health is a shifting target that is assessed by combining several factors with varying effects and expressions in the environment. Aspects with more impact, or more value to NMAs, should be considered with more weight than others. Comparing the structural and functional components that comprise an NMA is essential in creating a comprehensive assessment. The urban setting of Vancouver's NMAs is another necessary consideration in comparison to other methodologies whose settings are pristine wilderness. Therefore, our assessments and rating scales have been adapted to fit the urban context where Vancouver's NMAs are found.

3.0 Methodology

The following is a framework for the ecological evaluation of NMAs in the City of Vancouver. NMAs will be assessed based on six categories; each category with its own procedure. These sections will each result in a health rating from 1 to 3 (Poor, Fair, or Healthy). All six scores are then combined, accounting for their respective weight, to give an overall Ecological Health rating.

To take a precautionary approach to health that values a high standard of ecosystem function and structure, we adapted the rating scale in all sections so that: below 2, or the bottom 50%, indicates Poor; from 2 to 2.5, or from 50 to 75%, indicates Fair; and above 2.5, or 75%, indicates Healthy. In this way, only NMAs with high ecosystem health, thus requiring very little restoration, will be labelled as Healthy.

We propose that these methodologies be carried out during late Spring to early Summer. This is the peak time of year for biomass, and all trees will have foliage, making them easy to distinguish. Subsequent assessments should be performed at the same time of year to create meaningful comparisons and trends. Future results of this assessment can be compared to determine an NMAs improvement in relation to itself.

A detailed explanation of the field protocols for Water Quality, Soil Quality/Slope Stability, Vegetation and Tree Cover can be found in Appendix 2. Human Disturbance and Animal Habitat do not have field protocols because these sections can be easily completed from their descriptions, which involve filling out the included tables.

3.1 Water Quality

A basic survey of the stream should be conducted using the Streamkeepers Handbook (Department of Fisheries and Oceans, 1995), as a guide. For the purpose of this assessment, Modules 2, 3, and 4 should be completed. Starting downstream, we recommend conducting all procedures every 10 metres. This assessment is only necessary if a water body is present. If that water body is a pond or lake, the procedures in Module 2 may be omitted from the methodology.

Following instructions in Module 2, measure bankfull and wetted channel dimensions along with stream discharge. Although these features are not used when calculating the health rating for Water Quality, tracking yearly changes to stream channel dimensions can provide additional information regarding bank erosion for restoration considerations (Taccogna & Munro, 1995).

Temperature, dissolved oxygen level, pH, and turbidity should also be recorded using an electronic meter, following Module 3 of the Streamkeepers Handbook (1995). Using the average result of each measurement and calculating the index values, the score for this section is determined. This index is divided into 4 categories: Poor, Marginal, Acceptable and Good. For the purposes of this methodology, Poor and Marginal are combined into our framework's lowest category of Poor.

Macroinvertebrate surveys should also be conducted at the same physical intervals. The presence of macroinvertebrates can be used as an indicator of pollution tolerance and overall stream health (Taccogna & Munro, 1995). Specimens are collected by gently disrupting the stream bed and making captures in a net held in the downstream direction. Specimens can then be identified and recorded before being released back into the water. Using the assessment index from Module 4 of the Streamkeepers Handbook (1995), the average assessment rating can be determined for all evaluated sites.

Since this section of the assessment is based on a guide for citizen science and public involvement, data for this section may be collected by local streamkeeper groups who perform similar measurements regularly. In this case, active encouragement and support of such groups in all NMAs should be provided to ensure the consistent and accurate tracking of stream conditions.

3.2 Soil Quality and Slope Stability

Based on the 2008 Renfrew Ravine Report (Still Creek Stewardship Society, 2008) the methodology to assess this category involves surveying the landscape, mapping changes in the slope, and a geochemical study of the contents in the soil. Before starting these processes, archeological considerations need to be taken.

Soil quality methodology includes excavating a 0.5 m long by 0.5 m wide by 1.0 m deep pit to examine soil layers. Samples are taken and analyzed in a lab to determine soil mineral and chemical composition, as well as soil particle size and type. On site, soil layers are tested for waterlogging and oxygen content with a soil oxygen meter. Soil porosity should be at least 90% when found under natural conditions (USDA Forest Service, 2000). The chemical and quantitative physical properties must be measured and examined. Soil samples are obtained through the Core Method as described in the field protocol. Bulk density, pH, and various chemical concentrations are given a corresponding value as shown in Table 1. Not all of the chemicals in Table 1 need to be tested because the overall score is determined as a percent of values tested: the total points can be adjusted by removing the points from sections that were not evaluated. However, the first 6 factors in Table 1 and any factor that could potentially have a maximum score of 2 must be measured. The percentage is then converted into a Poor, Fair, and Healthy rating which can be averaged with the rating from Table 1 to obtain overall soil health.

Soil stability is measured by mapping slope using aerial photography and comparing to data on previous conditions, if available. If there is no prior available data, slope can also be determined by using the average slope. The slope gradient should be entered into Table 2, adapted from B.C. Ministry of Forests (1999). In Table 2 under Climate, the R factor for Vancouver is 50.0 (High) based on the Revised Universal Soil Loss Equation for Application in Canada (Agriculture and Agri-FoodCanada, 2002). Coarse fragment content can be determined by using the Soil Matrix in Figure 2. This defined value is outdated and may have changed due to climate change; if an updated R factor is available, it is recommended that this newer value be used. This table can determine the soil health condition based on its ability to be eroded through contributing factors. In the table's original form, the totalled points were converted to a rating of Low, Moderate, High, or Very High degree of erosion potential, whereas in this framework a Low degree is "Healthy", a Moderate to High degree is "Fair", and a Very High degree is "Poor", with the point totals adjusted to match our cautionary take on health assessment.

3.3 Animal Habitat

Using the instructions provided in subsequent paragraphs, this methodology can be used to create an assessment for the suitability of NMAs as habitat to selected animal groups, based on Forest Bird Habitat Assessment (Audubon Vermont, 2011). We have created an example habitat assessment for songbirds and other small birds (Table 3). We chose to create the assessment for this animal group because the City of Vancouver has prioritized birds through it's Bird Strategy.

To begin determining if an NMA is a suitable habitat, a species list should be created for the animal group of interest. These lists are constructed by identifying all the animals of that group that may inhabit the area. The list should contain species that currently exist in the area as well as historic species, which will allow for the comparison of species diversity over time (Debinski & Brussard, 1994). Following the creation of the species list, critical habitat components, including biotic factors, required for each of these species or the group as a whole, should be identified. This can include presence of grasses, shrubs, ground layer density, tree size or species, and degree of soil cover (Port of Vancouver, 2015).

The assessment will be a qualitative questionnaire; the questions should focus mostly on physical and biotic factors that the group of animals requires to survive. The NMA should be examined for these features and assigned points based on the number of features present, which is then divided by the number of features needed. This value is then converted into a score indicating Poor, Fair or Healthy conditions. This assessment should be completed in the same quadrats used in the tree cover assessment and an overall rating can be assigned by taking the average result of each quadrat.

3.4 Vegetation

A quadrat sampling method is used to assess vegetation for diversity and presence of invasive species, adapted from the Land Degradation and Assessment in Drylands local level assessment methodology, section 3 (FAO, 2016) and the Inventory and Survey Methods for Nonindigenous Plant Species (Rew & Pokorny, 2006). Stratified random sampling will be used to ensure that the NMA is well represented. This is accomplished by dividing the park into sub-areas based on a physically or ecologically relevant factor to the NMSA. Examples include, but are not limited to: slope aspect, proximities to any edges (pathways, park boundaries, buildings), presence of natural water bodies, land-types, and man-made structures.

Quadrat size is recommended to be 5 by 5 metres, based on the tallest vegetation present in most NMAs (Table 4). The number of quadrat samples should be based on the overall size of the park, with a goal of assessing 1% of the park. In the event where the park is too large to sample 1%, it is recommended that at least 30 quadrats be sampled, based on the amount of samples we were able to complete in one day of field work at Renfrew Ravine Park. At each sampling location, the quadrat is placed on the ground and the surveyor estimates the percent area of the quadrat occupied by each plant species. Plant species should be identified using a field guide relevant to the area.

After sampling is completed, the results from each quadrat are combined to get an overall result for the park, in two categories: species diversity (number and abundance of species, evaluated using Simpson's diversity index) and invasive species cover (calculated as the total percent cover of the park from all invasive species combined). These are then combined into an overall vegetation score that is Poor, Fair or Healthy.

3.5 Tree Cover

Assessing the health and status of the tree cover in forested NMAs will be accomplished using an adapted version of a forest biodiversity assessment created by Northwest Natural Resource Group in coordination with the Forest Stewardship Council-US, World Wildlife

Fund-Sweden and Sweden Consulting in 2014. The original assessment consists of a combination of 60 qualitative and quantitative criteria that are addressed over the course of a walk through the forest. For our purposes we have modified the assessment with the goal of having an efficient, accurate and replicable methodology that assesses tree diversity and health.

Our modified methodology includes 13 quantitative criteria that address the diversity of and age distribution of trees within an NMA, and 10 qualitative criteria that address the interaction between trees and the environment around them. Users will not need an extensive knowledge of forest ecology to complete this assessment, except the ability to recognize the difference between hardwood and softwood trees. Questions are answered in quadrats, which are determined through random sampling. Quadrat size is based on the relative height of the tallest trees (see Table 4): either 10x10m quadrats for a young forest or 20x20m for a mature forest. The number of quadrats sampled should be based on sampling 1% of the NMA.

The rating system for quantitative questions is based on Richard's Rule for distribution of softwood trees, where a healthy forest's softwood tree inventory is made up of 40% young, 30% semi-mature, 20% mature and 10% old trees. Any value found within +/- 5% of their optimal percentage gets 3 points. Any value found in successive +/- 5% corresponds to 2 points, 1 points and 0 respectively. The same applies for hardwood trees, except we apply an optimum 60/40 distribution where a healthy forest's hardwood tree inventory is made up of 60% young/semi-mature and 40% mature/old trees. Since NMAs in Vancouver are composed primarily of softwood over hardwood trees, we have more questions and criteria pertaining to softwood trees. This way, softwood tree diversity and distribution counts more towards overall health than hardwood trees. The rating system for the qualitative section is based on a presence or absence of a certain factor. This merits either 1 or 0 points.

For each quadrat, sums for quantitative and qualitative sections are combined and divided by the total points possible to give tree health percentages. The average of all quadrat percentages will give the overall tree health rating.

3.6 Human Disturbance

The rating system for this category is based on a visual survey of the human presence and disturbance in the NMA. Two categories are assessed with similar methodologies: litter and human presence. This section should be carried out simultaneously while completing the methodology of other sections.

Litter is assessed based on the citizen science methodology described by the Keep Scotland Beautiful program (n.d.). The grade scale seen in Figure 3 is used to determine the extent of litter in the area. Small pieces of litter are the average type of litter found and for size can generally rest on one hand, for example cans, bottles, cigarettes, garbage bags, food wrappers, and clothing items. Large pieces of litter are generally uncommon items that are larger in size, for example tires, construction material, large bags of garbage, mattresses and other furniture.

Human presence is assessed using a similar process as the litter section. As before, examine the park for signs of human presence and activity (other than litter). Things to look for include: trampled vegetation (small sign), footprints off the trails (small sign), graffiti (small sign) and carvings (large sign) on natural structures, unofficial human-made trails (large sign), and clearings (large sign). A grade can then be assigned based on Figure 4.

The overall score for human disturbance is calculated by averaging the score for litter and human presence. The grade is then converted to a rating of Poor, Fair or Healthy. A grade of A or B is Healthy, a grade of C is Fair, and a grade of D or E is Poor.

3.7 Case Study of Renfrew Ravine Park

3.7.1 General Information

Our assessment of Renfrew Ravine Park acts as a test of our framework and will include a limited selection of the framework sections. We recommend performing all of the methods outlined in the framework to best capture the true ecological status of each NMA. However, due to limited time and resources, we have performed assessment for Water Quality, Vegetation, and Human Disturbance.

Field work was carried out between 10:30 a.m. and 4:00 p.m on March 14, 2020. Water Quality was assessed by Christopher Chang, Gabi Trainor and Hyeju Lee, while Vegetation was assessed by Amanda Wik and Grant MacRobbie. Human Disturbance was assessed by both groups over the course of the day while performing their respective fieldwork. The weather on this day was clear and sunny, with temperatures between 2 and 6 degrees Celsius.

3.7.2 Water Quality

The downstream end of Still Creek is clearly marked by the opening of a culvert. From this end we measured 10m to find our first field site. The site was marked on either side with stakes on both banks. Temperature, pH, and turbidity were measured first using a combined electronic meter. Next, dimensions were recorded by suspending string at bankfull height across the stream. Wetted and bankfull depths were measured at 1m intervals across the stream. Wetted depth is measured from the stream bed to the surface of the water, and bankfull is measured from the stream bed to the highest to which the water rises. Both wetted and bankfull widths were also recorded. Stream discharge was measured via the some-what unreliable, but simple “tennis ball” method. Lastly, we surveyed for the presence of macroinvertebrates by disrupting the stream bed and capturing specimens using a mesh net held in the downstream direction. Specimens were identified and recorded before being released back into the stream. We repeated these steps at four other sites at 10m intervals moving upstream. Macroinvertebrate sampling was only repeated at three other sites. Measurements for each of the above factors have been recorded to provide a baseline for the selected portion of Still Creek.

3.7.3 Vegetation

To stratify the South Section of Renfrew Ravine Park for Vegetation, we chose to divide the park based on slope, because the park is steeply sloped due to the ravine and this impacts the types of vegetation that can be grown in different sub-areas. We based the sub-areas off a slope risk map obtained from the Renfrew Ravine Hydrology and Geotechnical Study (Still Creek Stewardship Society, 2008). Using this map we identified four distinct sub-areas of varying sizes.

When planning for our Vegetation fieldwork, we decided to use a 1 by 1 metre quadrat to assess 1% of the park, which required sampling 135 plots. As this value is extremely high and we wanted to consider time constraints, we created a protocol that determines when sufficient sample plots have been sampled to represent the entire park, using a species versus area curve method (Scheiner et al., 2000). With this method, sample plots are continually randomly sampled, with the number of species in the quadrat versus the area of the quadrat graphed each time, until this curve flattens out. At this point, enough quadrats have been sampled to represent the entire park; any further samples will have the same distribution of species and therefore will not change the final result.

We overlaid a grid of 1 by 1 metre plots over the map of slope risk (Still Creek Stewardship Society, 2008) (Figure 5). We then used a random generator to generate enough plots to cover 1% of the park, where the number of plots in each sub-area was based on its percent area of the park. This also determined the order we would sample plots, so it was not biased by location. During field work, we used a measuring tape to measure the size of the quadrat, stakes to mark the four corners, and flagging tape between the stakes to mark the boundaries. We used a "Plants of Coastal British Columbia, including Washington, Oregan and Alaska" (Pojar et al., 2004) field guide to identify plant species. We had the same two team members assess all the quadrats together to ensure consistency in percent area estimates. We started with a 1 by 1 metre quadrat, but switched to 2 by 2 metres after four samples. We also abandoned the species area curve protocol and based sampling order on proximity. We sampled 31 quadrats during the full day of fieldwork.

3.7.4 Human Disturbance

The survey for Human disturbance was assessed while completing the Water Quality and Vegetation assessments, and was completed by all team members.

4.0 Ecological Health Rating

The Ecological Health rating is based on a three-tier weighing system that weighs each health section based on its value, both ecologically, functionally and as identified by Vancouver Parks Board staff. Vegetation and Tree cover have been identified as the top priorities (**Tier 3**) for the following reasons: they provide a myriad of benefits within the ecosystem and to other sections (habitat for birds, filtration for water bodies, stabilization for soil); they create ecosystem services that are outlined as goals in the City of Vancouver green strategies (Vancouver Bird Strategy (Vancouver Bird Advisory Committee, 2015), Urban Forest Strategy

(City of Vancouver, 2018), Climate Change Adaptation Strategy (City of Vancouver, 2018), and Biodiversity Strategy (Vancouver Board of Parks and Recreation, 2016)); and they are valued by humans in creating outdoor recreation experiences (Shanahan et al., 2015). Based on the City of Vancouver's value of birds as outlined in the Vancouver Bird Strategy (2015), Animal Habitat is valued as the next highest (**Tier 2**). Human disturbance has been valued as the lowest (**Tier 1**) (based on Vancouver Park Board's stated interests, as well as its evaluation of mainly aesthetic features), along with Soil Quality and Slope Stability (due to the fact that the soil in Vancouver NMAs is unnatural and imported). Water Quality is placed on one of the three tiers based on the area of the NMA it occupies.

To determine the weighing of the Water Quality Section, the area the water body occupies in the park is determined. A buffer zone is then added around the water body, to account for the associated riparian ecosystem (Table 9). The width of the buffer zone is based on the size of the water body along with the presence of fish, according to the BC Forest Range and Practice Act (FLNRORD, 2019). The area of the water body and buffer zone is divided by the area of the NMA and converted to a percent, which determines which weighing scenario (i-iv) is used (Figure 6). As protection of fish habitats is highly valued, fish-bearing streams result in a higher occupied area and thus a higher tier. The overall Ecosystem Health Rating for the NMA can then be calculated by referring to Table 10.

Table 10. The ecological health rating for a NMA. The weight is the percent each category is worth, dependent on how many categories are assessed.

Assessment Category	Score	Weight	Result	Final Rating
Water Quality				
Soil Quality and Slope Stability				
Animal Habitat				
Vegetation				
Tree Cover				
Human Disturbance				
Poor: rating < 2	Fair: 2 ≤ rating < 2.5		Healthy: rating ≥ 2.5	

5.0 Results and Methodological Considerations

5.1 Water Quality

Wetted and bankfull channel dimensions for the portion of Still Creek that runs through the South section of Renfrew Ravine Park were recorded at five sites. Due to the limitations in the methodology in the Streamkeepers Handbook (1995) for shallow water, the value we recorded for stream discharge is not regarded as particularly accurate. The available equipment did not allow us to measure dissolved oxygen, so this value was taken from data collected by the Still Creek Streamkeepers at a station near our first site on the same day.

The equipment we used measured turbidity in ppm. However, the index for turbidity in the Streamkeepers guide uses turbidity values measured in NTU. We were unable to reliably convert our measured values, so we elected to use the visible depth rating, where complete visibility corresponds with a standard value of 160cm regardless of depth. We recorded complete visibility at all sites for a water quality index (WQI) rating of 7.76. The average temperature recorded at all five sites was 8.98^{o}C which corresponded to an index value of 9.3. This was recorded between 10:00am and 3:00pm of the same day and the stream was seen to have warmed from morning to afternoon. The average pH was 7.47, which results in an index value of 10.06. Dissolved oxygen was 6.67mg/L which gives an index value of 13.94. Overall the water quality for this section scored as Good. In our survey of benthic macroinvertebrates, we recorded a total of 51 specimens in Category 1 (pollution intolerant), 105 specimens in Category 2 (somewhat tolerant of pollution), and 105 specimens in Category 3 (pollution tolerant).This section resulted in a rating of Poor.

Appropriate and specialized equipment, such as a staff gauge, is recommended for more accurate stream discharge measurements. Measurements for each of the above factors have been recorded to provide a baseline for the selected portion of Still Creek. The physical and chemical water quality assessment produced an overall rating of Good, while the macroinvertebrate survey produced a rating of Poor. Therefore, the final score for Water Quality in the South section of Renfrew Ravine Park is Fair. Full results along with data and calculations can be found in Appendix 3.

5.2 Vegetation

During our case study of the Vegetation section, we realized we needed more consideration in the framework for the length of the survey. Our original plan of small quadrats and covering 1% of the park would take an unreasonable amount of time to complete. Even switching to 2 by 2 metre quadrats still required too many plots to cover 1% of the park in one day. Although the species-area curve method may have reduced the number of plots needed, it was not applicable in an urban ecosystem. Firstly because the park is so disturbed that we would reach a plateau very quickly. Secondly because it required a random order of sampling plots which meant we were walking back and forth across the park and couldn't create an efficient sampling plan in advance of fieldwork. By testing our framework in the Renfrew Ravine Park, we were able to see where we needed to improve the methodology so that it is more applicable to parks staff. We decided to increase the size of quadrats again, and preferentially sample 1% of the park area, but where this is not feasible due to park size, allow for a smaller number of samples to be taken. Another consideration is that we completed this assessment in winter. Season is particularly important for vegetation, as much of the vegetation cover is not visible, or species are unidentifiable, in Winter. This is important for invasive species like blackberry, which most likely has a much higher cover in Summer.

With fieldwork complete, the data was analyzed and values were calculated to obtain a health rating for diversity, invasive species cover, and overall Vegetation health. Calculations and data can be found in Appendix 3. Species diversity, using Simpson's diversity index, was 80% or Healthy. Invasive species cover (Himalayan Blackberry, English Holly and English Ivy) made up 61% of the park's plant cover, which is a rating of Poor. Taking the average of these two values gave an overall Vegetation score of Fair.

5.3 Human Disturbance

We observed numerous small pieces of litter in all areas of the park. We also observed plenty of large pieces, including a mattress, construction debris, large wooden crates, pipes, bags of clothing and garbage, an entire plastic garbage bin and multiple furniture items. It was clear that regular dumping is occuring in the park. Because the South section has not been maintained with established trails and boardwalks, there are unofficial trails throughout this entire section with lots of trampled vegetation and human-made clearings, especially next to the stream. We assigned a grade of E to both litter and human presence, which corresponds to a rating of Poor.

5.4 Ecological Health Rating

The stream running through Renfrew Ravine park qualified for Riparian class S5 based on Table 9, requiring a 30 metre buffer added to each bank. This resulted in a water body comprising 83% of the park, which fits into weighing scenario **iv** from Figure 6, where Water Quality falls into Tier 3 with Vegetation. Because Tree Cover, Animal Habitat and Soil Quality/Slope Stability were not completed, we adjusted the weighings so that Tier 3 are each worth 40%, and Tier 1 is worth 20%. With a final result of 1.8, the Ecological Health rating of the South Section of Renfrew Ravine park, based on Vegetation, Water Quality and Human Disturbance, is Poor. Full results along with data and calculations can be found in Appendix 3.

Table 10. The Ecological Health Rating for the South section of Renfrew Ravine Park

Assessment Category	Score	Weight	Result	Final Rating
Water Quality	2	0.40	0.8	1.8
Soil Quality and Slope Stability	—	—	—	
Animal Habitat	—	—	—	
Vegetation	2	0.40	0.8	
Tree Cover	—	—	—	
Human Disturbance	1	0.20	0.2	
Poor: rating < 2	Fair: 2 ≤ rating < 2.5		Healthy: rating ≥ 2.5	

6.0 Recommendations for Renfrew Ravine Park

This methodology and grading system are designed in such a way that the factors which contribute to the failure to achieve a Healthy rating for a section can be identified by the result. This allows for easily identifiable management. For example, if the vegetation section scores a Poo or Fair, and the percentage of invasive species is high, invasive species removal as a part of the restoration actions for that area is clearly needed. Some familiarity with the evaluated NMA will be required to create a precise action plan, but tracing the cause of a depressed rating to its source is simple.

Based on our results and experiences in Renfrew Ravine Park, the recommended actions are as follows: cleaning up litter, installing litter bins, posting warning signs against dumping, invasive species removal, native species planting, upgrading fencing, establishing easily-walkable trails, and constructing a boardwalk similar to the one found in the North section of the park. Each of these actions are highly dependent on the others. Cleaning the area of trash is fruitless if active littering continues. Installing bins and warning signs support this action, and vice versa. Likewise, removing invasive species to plant native species is bound for failure if trails are not established and a high level of trampling continues.

These actions will require regular maintenance to ensure success. If long-term maintenance is not feasible at this time, creating a “no-go” zone of the South section is a possibility following an initial clean-up. Although, creating “no-go” zones is not a preferable action as it reduces the benefit of an NMA to the surrounding community. As an urban park, these NMAs provide considerable benefit to local residents, and all possible action should be taken to preserve that benefit before access is restricted.

7.0 Management Priority Matrix

Assessing the health of NMAs is important for determining management priorities in areas requiring restoration. After the health of each NMA has been evaluated, this section is used to decide where to begin restoration and management activities. This is a way to compare parks across the City of Vancouver and move from assessment to action. Based on the Portland Natural Areas restoration Plan's Priority Matrix (Portland Parks & Recreation, 2015), this matrix evaluates ecological health against both ecological and social values to demonstrate which parks should receive treatment first. The methodology outlined in this section is a recommendation for further action by the Vancouver Parks Board. NMA values will need to be determined by the Vancouver Parks Board. Due to limitations in time, resources, and availability of information, this report describes how the methodology can be created, but does not outline valuable features and associated grades.

The idea for this section is to evaluate each NMA for its ecological value, using specific criteria that can be adapted from the Portland Natural Areas Restoration Plan (Portland Parks & Recreation, 2015) and based on Vancouver Parks Board goals. NMAs are rated based on a point system, where they are examined for the presence of valuable ecological features. Features are worth 1 to 3 points depending on their importance. As listed in Appendix A of the Portland Natural Areas Restoration Plan (Portland Parks & Recreation, 2015), examples of valuable features include presence of a salmon-bearing stream (3 points), presence of valuable tree species (2 points) and active stewardship group or school (1 point). The features should be adapted to be more specific to the City of Vancouver priorities and unique ecosystems. The points are tallied for each NMA, giving the overall value rating.

A graph is created with "Value" on the y-axis and "Health" on the x-axis. Each NMA is then placed on the graph, giving an overview of the intersection of value and health across the City of Vancouver NMAs. NMAs with high value and low health should be prioritized for management and restoration. See Figure 7 for an example.

Acknowledgements

We respectfully acknowledge this project took place on unceded Coast Salish Territory - the traditional territories of the xʷməθkʷəy̓əm (Musqueam), Sḵwx̱wú7mesh Úxwumixw (Squamish), səl̓ilw̓ətaʔɬ (Tsleil-Waututh), kʷikʷəƛ̓əm (Kwikwetlem) and Katzie Nation.

We would like to thank Dr. Tara Holland for hours of feedback and support, Dana McDonald for bringing the project to life, Kelly Gardner for facilitating the project, Rebecca Ho for providing access to equipment, and the Stillcreek Streamkeepers for their cooperation.

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Appendix 1: Additional Figures and Tables

SOIL MATRIX

TEXTURE	COARSE FRAGMENT CONTENT		
	<30%	30–70%	>70%
S, LS, SL	Coarse	Very Coarse	Very Coarse
fSL, Si	Medium	Coarse	Very Coarse
SiL, Loam	Medium	Medium	Coarse
SC, SiC, SCL, SiCL, CL, C	Fine	Medium	Medium

Soil texture abbreviations:

S - sand
SL - sandy loam
L - loam
SiL - silt loam
SCL - sandy clay loam
SiCL - silty clay loam
LS - loamy sand
fSL - fine sandy loam
Si - silt
SC - sandy clay
SiC - silty clay
C - clay
CL - clay loam

Figure 2. Soil Matrix Determining Soil Texture from Coarse Fragment Content from BC Ministry of Forest (1999).

Tick (✓) to show your answer	Grade	Description
	A	No litter can be seen
	B	A couple of small pieces
	C	More small pieces and some larger pieces
	D	Lots of small pieces and some large pieces
	E	Lots of large and small pieces

Figure 3. Litter grade scale from the Keep Scotland Beautiful Upstream Battle Litter Survey (n.d.)

Tick (✓) to show your answer	Grade	Description
	A	No signs can be seen
	B	A couple of small signs
	C	More small signs and some larger signs
	D	Lots of small signs and some large signs
	E	Lots of large and small signs

Figure 4. Human presence grade scale based on the Keep Scotland Beautiful Upstream Battle Litter Survey (n.d.)

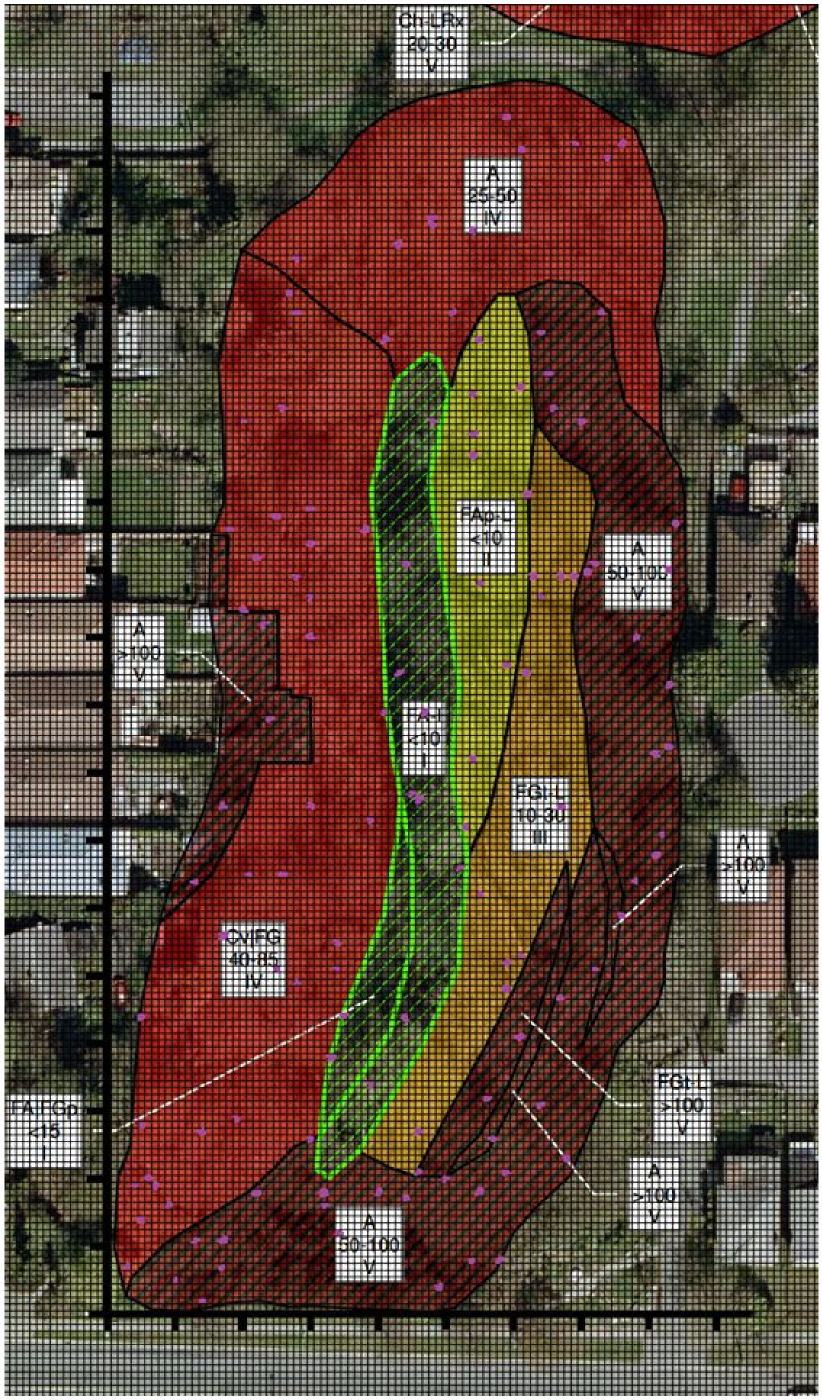


Figure 5. Map of Renfrew Ravine park divided into sub-areas based on a slope stratification. A 1 by 1 metre grid has been overlayed and pink points show the predetermined sampling plots, based on sampling 1% of the area of the park.

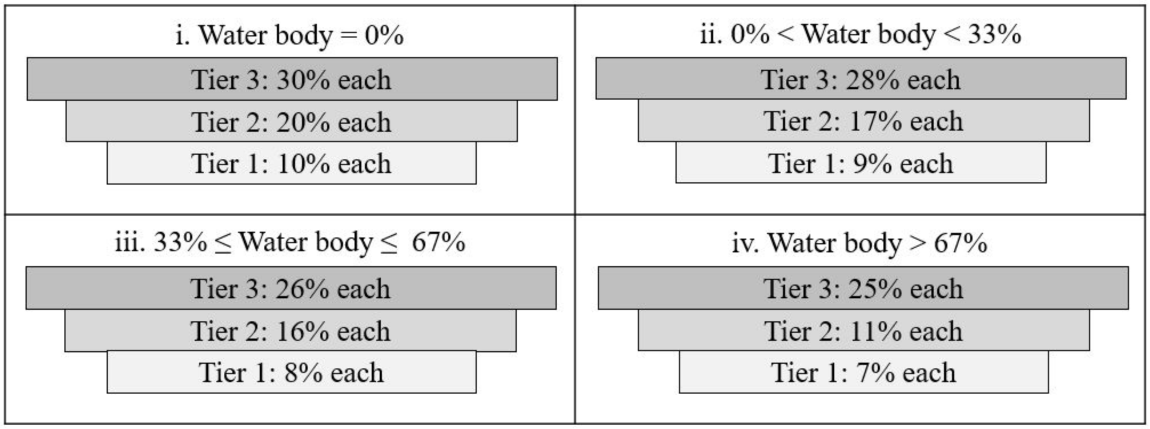


Figure 6. Valued Weighing for final Ecological Health Rating based on different NMA scenarios. Tier 3 is sections Vegetation, and Trees. Tier 2 is section Animal Habitat. Tier 1 is sections Soil Quality and Slope Stability, and Human Disturbance. i. Water Quality is not used in Ecological Health Rating calculations. ii. Water Quality is in Tier 1. iii. Water Quality is in Tier 2. iv. Water Quality is in Tier 3.

Figure 7. Example graph of NMA health as a function of ecological value.

Table 1. Soil Quality Index, adapted from Amacher et al. (2007).

Soil Quality Index			
Parameter	Level	Interpretation	Points
Bulk Density (g/cm^3)	1.5 or greater	Adverse effects unlikely	1
	>1.5	Possible adverse effects	0
Coarse Fragments (%)	50 or greater	Adverse effects unlikely	1
	>50	Possible adverse effects	0
Soil pH	< 3.0	Severely acidic – almost no plants can grow in this environment	-1
	3.01 - 4.0	Strongly acidic – only the most acid tolerant plants can grow in this pH range and then only if organic matter levels are high enough 0 to mitigate high levels of extractable Al and other metals	0
	4.01 - 5.5	Moderately acidic – growth of acid intolerant plants is affected 1 depending on levels of extractable Al, Mn, and other metals	1
	5.51 - 6.8	Slightly acidic – optimum for many plant species, particularly more 2 acid tolerant species	2
	6.81 - 7.2	Near neutral – optimum for many plant species except those that 2 prefer acid soils	2
	7.21 - 7.5	Slightly alkaline – optimum for many plant species except those that prefer acid soils, possible deficiencies of available P and 1 some metals (for example, Zn)	1
	7.51 - 8.5	Moderately alkaline – preferred by plants adapted to this pH 1 range, possible P and metal deficiencies	1
	> 8.5	Strongly alkaline – preferred by plants adapted to this pH range, 0 possible B and other oxyanion toxicities	0
Total Organic Carbon in Mineral Soils (%)	> 5	High - Excellent Buildup of Organic C with all Associated Benefits	2
	1 - 5	Moderate - Adequate Levels	1
	< 1	Low - Could Indicate Possible Loss of Organic C from Erosion or Other Processes, Particularly in Temperate or Colder Areas	0
Total Nitrogen in	> 0.5	High - Excellent Reserve of Nitrogen	2
	0.1 - 0.5	Moderate - Adequate Levels	1

Mineral Soils	< 0.1	Low - Could Indicate Loss of Organic N	0
Exchangeable Na Percentage	> 15	High - Sodic Soil with Associated Problems	0
	15 or less	Adverse Effects Unlikely	1
K (mg/kg)	> 500	High - Excellent Reserve	2
	100 - 500	Moderate - Adequate Levels for Most Plants	1
	< 100	Low - Possibile Deficiencies	0
Mg (mg/kg)	> 500	High - Excellent Reserve	2
	50 - 500	Moderate - Adequate Levels for Most Plants	1
	< 50	Low - Possibile Deficiencies	0
Ca (mg/kg)	> 1000	High - Excellent Reserve, Probably Calcareous Soil	2
	101 - 1000	Moderate - Adequate Levels for Most Plants	1
	10 - 100	Low - Possibile Deficiencies	0
	< 10	Very Low - Severe Ca Depletion, Adverse Effects More Likely	-1
Al (mg/kg)	> 100	High - Adverse Effects More Likely	-1
	11 - 100	Moderate - Only Al Sensitive Plants Likely to be Affected	0
	1 - 10	Low - Adverse Effects Unlikely	1
	< 1	Very Low - Probably an Alkaline Soil	2
Mn (mg/kg)	> 100	High - Possible Adverse Effects to Mn Sensitive Plants	0
	11 - 100	Moderate - Adverse Effects or Deficiencies Less Likely	1
	1 - 10	Low - Adverse Effects Unlikely, Possible Deficiencies	1
	< 1	Very Low - Deficiencies More Likely	0
Fe (mg/kg)	> 10	High - Effects Unknown	1
	0.1 - 10	Moderate - Effects Unknown	1
	< 0.1	Low - Possible Deficiencies, Possibly Calcareous Soil	0

Ni (mg/kg)	> 5	High - Possibile Toxicity to Ni Sensitive Plants, May Indicate Serpentine Soils, Mining Areas, or Industrial Sources of Ni	0
	0.1 - 5	Moderate - Effects Unknown	1
	< 0.1	Low - Adverse Effects Highly Unlikely	1
Cu (mg/kg)	> 1	High - Possible Toxicity to Cu Sensitive Plants, May Indicate Mining Areas, or Industrial Sources of Cu	0
	0.1 - 1	Moderate - Effects Unknown, but Adverse Effects Unlikely	1
	< 0.1	Low - Possibile Deficiencies in Organic, Calcareous, or Sandy Soils	0
Zn (mg/kg)	> 10	High - Possible Toxicity to Zn Sensitive Plants, May Indicate Mining Areas, or Industrial Sources of Zn	0
	1 - 10	Moderate - Effects Unknown, but Adverse Effects Unlikely	1
	< 1	Low - Possibile Deficiencies in Organic, Calcareous, or Sandy Soils	0
Cd (mg/kg)	> 0.5	High - Possible Adverse Effects	0
	0.1 - 0.5	Moderate - Effects Unknown, but Adverse Effects Less Likely	1
	< 0.1	Low- Adverse Effects Unlikely	1
Pb (mg/kg)	> 1	High - Adverse Effects More Likely, May Indicate Mining Areas, or Industrial Sources of Pb	0
	0.1 - 1	Moderate - Effects Unknown, but Adverse Effects Less Likely	1
	< 0.1	Low- Adverse Effects Unlikely	1
S (mg/kg)	> 100	High - May Indicate Gypsum Soils, Atmospheric Deposition, Mining Areas, or Industrial Sources	0
	1 - 100	Moderate - Adverse Effects Unlikely	1
	< 1	Low - Possible Deficiencies in Some Soils	0

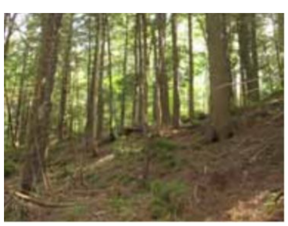
Total (%)		
Poor **< 50%**	**Fair** **50-80%**	**Good** **> 80%**

Table 2. Soil Erosion Hazard Point Allocation, adapted from BC Ministry of Forests (1999).

Site Factors	**Degree of Contribution from Erosion Factors**			
	Low	**Moderate**	**High**	**Very High**
Climate	<25 **3**	25-49 **6**	50-100 **9**	>100 **12**
Description: The R factor, or the amount of rainfall that contributes to soil erosion.				
Topography (Slope Gradient %)	1-15 **1**	16-30 **2**	31-60 **3**	>60 **4**
Description: The higher the slope gradient, the more erosive power water has as it runs downhill.				
Length and Uniformity of Topography	<1.5m, broken **1**	<1.5 m, uniform **2**	>1.5 m, broken **3**	>1.5 m, uniform **4**
Description: Slope structure in its shape: variable, complex, or benchy slopes.				
Surface Soil Detachability	Sandy Clay Clay Silty Clay **1**	Silty Clay Loam Clay Loam Sandy Clay Loam **2**	Sandy Loam Loam **4**	Silt Silt Loam Fine Sandy Loam Loamy Sand Sand **6**
Description: The type of soil textures found in the active layer of the soil.				
Depth to Water-Restricting Layer (cm)	>90 **1**	61-90 **2**	30-60 **3**	<30 **4**
Description: Depth which restricts downward flow of water, but not necessarily to root growth. Includes impermeable, dense, compact or cemented layers; bedrock; or permanent water table				
Subsoil Permeability	Sand Loam Sandy Loam Fine Sandy Loam	Loam Silt Loam Silt	Clay Loam Sandy Loam Clay Silty Clay Loam	Clay Sandy Clay Silty Clay

	1	**2**	**3**	**4**
Description: Rate of water penetration as inferred from soil texture and volume of coarse fragments.				
Total Erodibility Score	**Healthy** < 9	**Fair** 9-17		**Poor** > 17

Table 3. Bird Habitat Point Allocation, adapted from Audubon Vermont (2011).

Bird Habitat				**Points**
Habitat Quality	**Low Function 1 point**	**Mid Function 2 point**	**High Function 3 point**	
Understory Vegetation				
Description: Live vegetation in the 1-5 ft. height range, including tree seedlings and saplings, shrubs, and herbaceous vegetation.				
Midstory vegetation				
Description: Live, woody vegetation in the 6-30 ft. height range including trees and shrubs.				
Coarse material			N/A	
Fine woody material			N/A	
Description: Coarse woody material (CWM) is downed logs and branches >4 in. diameter. Fine woody material (FWM) is limbs and branches <4 in diameter including slash.				
Snags and cavity trees	Overall low abundance of any snags or cavity trees	Snags and cavity trees present, but of small diameter(s) or minimal abundance	Abundance of target diameter snags and cavity trees	

		of snags and cavity trees of target diameters		
Description: Snags are standing dead or partially dead trees that are relatively stable. Cavity trees may be alive or dead. *See questions 8 to 12 in Tree Cover Assessment. Result for this section should be informed by overall results from these questions.				
Leaf litter	Covers very little of the ground and is very thin.	Covers around half of the ground surface, and is only a couple cm deep.	Covers almost all of the ground, and is several cm deep.	
Description: Leaves, twigs and pieces of bark that have fallen to the ground. *When determining the points for this section, use the quality that gives you the lowest point value				
Canopy height	Trees of only one height	Some trees of different heights, but many trees of the same height	Variety of tree heights	
Description: A distribution of canopy, mid canopy and sub canopy trees give habitat areas suitable for multiple birds species				
Berry shrubs	Yes	N/A	N/A	
Description: Presence of berry shrubs like salal, blackberry, salmonberry				
Canopy Closure	Closed (>80%)	Intermediate (30-80%)	Open (<30%)	
Description: Percent of area blocked by tree canopy looking up from the central point of your quadrat.				

Total out 23	**Poor** < 12	**Fair** 12 - 18	**Healthy** 19 - 23

Table 4. Optimal size of quadrats in vegetation surveys (FAO, 2016).

Type of Vegetation	**Vegetation height (m)**	**Size (m)**
Moss / Lichens	< 0.05	0.1 x 0.1
Short grassland (annual grassland)	< 1	1 x 1
Tall grassland (perennial grassland)	< 2	2 x 2
Shrub	< 4	5 x 5
Young forest (sub-forest)	< 8	10 x 10
Mature forest	> 8	20 x 20

Table 5. Tree (Quantitative) Survey, adapted from Conducting A Forest Biodiversity Assessment: A Guide for Forest Owners and Land Stewards Forest Stewardship Council-US, World Wildlife Fund-Sweden, and Sweden Consulting (2014).

Trees (Quantitative)					**Points**
1) **# Species that compose the canopy**					
# Species	> 5	4 - 5	2 - 3	0 - 1	
Points	**3**	**2**	**1**	**0**	
2) **% Hardwood Trees < 50 cm dbh (optimal value is set within a +/- 5% of 60%)**					
%	55 - 65	50 - 55, 65 - 70	45 - 50, 70 - 75	Other	
Points	**3**	**2**	**1**	**0**	
3) **% Hardwood Trees > 50 cm dbh (optimal value is set within a +/- 5% of 40%)**					
%	35 - 45	30 - 35, 45 - 50	25 - 30, 50 - 55	Other	
Points	**3**	**2**	**1**	**0**	
4) **% “Young” softwood trees 25 - 50 cm dbh (optimal value is set within a +/- 5% of 40%)**					
%	35 - 45	30 - 35, 45 - 50	25 - 30, 50 - 55	Other	
Points	**3**	**2**	**1**	**0**	
5) **% “Semi-mature” softwood trees 50 - 75 cm dbh (optimal value is set within a +/- 5% of 30%)**					
%	25 - 35	20 - 25, 35 - 40	15 - 20, 40 - 45	Other	
Points	**3**	**2**	**1**	**0**	
6) **% “Mature” softwood trees 75 - 100 cm dbh (optimal value is set within a +/- 5% of 20%)**					

%	15 - 25	10 - 15, 25 - 30	5 - 10, 30 - 35	Other	
Points	**3**	**2**	**1**	**0**	
7) **% "Old" softwood trees > 100 cm dbh (3 point lies within +/- 2% from 10%)**					
%	8 - 12	6 - 8, 12 - 14	4 - 6, 14 - 16	Other	
Points	**3**	**2**	**1**	**0**	
8) **% Standing dead or dying "young" trees 25 - 50 cm dbh (optimal value is set within a +/- 5% of 40%)**					
%	35 - 45	30 - 35, 45 - 50	25 - 30, 50 - 55	Other	
Points	**3**	**2**	**1**	**0**	
9) **% Standing dead or dying trees or snags 50 - 75 cm dbh (optimal value is set within a +/- 5% of 30%)**					
%	25 - 35	20 - 25, 35 - 40	15 - 20, 40 - 45	Other	
Points	**3**	**2**	**1**	**0**	
10) **% Standing dead or dying trees or snags > 75 cm (optimal value is set within a +/- 5% of 30%)**					
%	25 - 35	20 - 25, 35 - 40	15 - 20, 40 - 45	Other	
Points	**3**	**2**	**1**	**0**	
11) **% Down logs < 75 cm diameter at mid-log (optimal value is set within a +/- 5% of 60%)**					
%	55 - 65	50 - 55, 65 - 70	45 - 50, 70 - 75	Other	
Points	**3**	**2**	**1**	**0**	
12) **% Down logs > 75 cm diameter at mid-log (optimal value is set within a +/- 5% of 40%)**					

%	35 - 45	30 - 35, 45 - 50	25 - 30, 50 - 55	Other	
Points	**3**	**2**	**1**	**0**	
13) **% of trees affected by invasive plant species**					
%	0 - 5	5 - 10	10 - 20	> 20	
Points	**3**	**2**	**1**	**0**	
Total (Quantitative) out of 39					

Table 6. Tree (Qualitative) Survey, adapted from Forest Stewardship Council-US, World Wildlife Fund-Sweden, and Sweden Consulting (2014).

Trees (Qualitative)			**Points**
1) **Presence of (native) nut-, berry- or fleshy fruit trees or shrubs**			
Answer	Yes	No	
Point	**1**	**0**	
2) **Presence of (significant) understory trees**			
Answer	Yes	No	
Point	**1**	**0**	
3) **Canopy and subcanopy trees of different diameters**			
Answer	Yes	No	
Point	**1**	**0**	
4) **Presence of trees with thick branches or stem forks**			
Answer	Yes	No	
Point	**1**	**0**	
5) **Presence of tree trunks and branches covered by mosses and lichens**			
Answer	Yes	No	
Point	**1**	**0**	
6) **Presence of standing sun-exposed dead or dying trees or snags**			
Answer	Yes	No	
Point	**1**	**0**	
7) **Presence of down logs in various stages of decay**			
Answer	Yes	No	
Point	**1**	**0**	
8) **Presence of down logs covered by mosses**			

Answer	Yes	No	
Point	**1**	**0**	
9) **Presence of trees, snags or logs with shelf fungi**			
Answer	Yes	No	
Point	**1**	**0**	
10) **Signs of woodpecker foraging on trees, snags or logs**			
Answer	Yes	No	
Point	**1**	**0**	
Total (Qualitative) out of 10			

Table 7. Tree Survey Total Point and Rating.

Total (Quantitative)	
Total (Qualitative)	
Total (Quantitative + Qualitative)	
[Total (Quantitative + Qualitative) / 39] x 100	

Table 8. Total Tree Survey Health Assessment Rating.

Rating		
< 50%	**51 - 75 %**	**> 75 %**
Poor = 1	**Fair = 2**	**Healthy = 3**

*Table 9. Buffer zones added to water bodies based on size and presence of fish (*FLNRORD, 2019*).*

Riparian Class	**Defining Stream Characteristics**	**Buffer Width in metres (added to each side of the water body)**
S1-A	Fish streams or streams where: 100 m < stream width/active floodplain width Active floodplain: level area that is periodically flooded by stream water and shows evidence of: i. Food channels free of vegetation ii. Rafted debris or fluvial sediments iii. Recent scarring of trees by flood water transported debris	100
S1-B	Fish streams where: 20 m <stream width	70
S2	Fish streams where: 5 m ≤ stream width ≤ 20 m	50
S3	Fish streams where: 1.5 m ≤ stream width < 5 m	40
S4	Fish steams where: stream width < 1.5 m	30
S5	Non-fish streams where: 3m < stream width	30
S6	Non-fish streams where: Stream width ≤ 3m	20
Lake/pond	N/A	30

Appendix 2: Field Protocol

Water Quality

Pre-Fieldwork

1) Prepare all equipment listed in Modules 2, 3 and 4 of the Streamkeepers Handbook (1995).

Field Work

1) Determine the location of survey sites by starting at the farthest point downstream that is still contained within the NMA, moving 10m upstream for every new site. If the water body is a lake or pond, survey sites can be located every 20m around the perimeter.
2) Mark each site with a temporary visual aid, and record the coordinates.
3) Record temperature, pH, turbidity, and dissolved oxygen.
4) Suspend a string so that it is taught from each side of the stream bank, and measure wetted and bankfull depths at 1m intervals starting from one end. Omit this step if the water body is a lake or pond.
5) Measure wetted and bankfull widths. Omit this step if the water body is a lake or pond.
6) Begin the macroinvertebrate survey by placing a mesh net against the bed of the stream with the opening facing upstream. Scrub the rocks and stones immediately upstream of the net with a brush, allowing any specimens to flow into the net. The stream bed can also be gently disturbed by hand or foot to allow further collection.
7) Using water from the stream, rinse the net into a bucket or container.
8) Carefully identify each specimen and record its occurrence (Table 23).
9) Move on to the next site and repeat steps 2 through 8.

Post Fieldwork

1) Convert all physical and chemical values to the appropriate Q-value found in the conversion tables (Figures 15 and 16).
2) Average the Q-values for each variable, as seen in Tables 18, 19, 20 and 21.
3) Find the final index value and rating for the physical and chemical Water Quality Index (Table 22).
4) Calculate all ratios and indices found in Figures 18 and 19 for the macroinvertebrate data.
5) Find the final index value and rating for the biological Water Quality Index (WQI) (Table 24).
6) Average the results of the two WQI ratings to determine the overall water quality rating for the NMA.

Soil Quality and Slope Stability

Pre-Fieldwork

1) Determine the slopes and contours of your NMA by comparing satellite imaging and GIS data.
2) Take appropriate archaeological considerations to consider which areas of the NMA you will excavate in the field. Considerations include:
    a) Getting permission from the appropriate parties to begin digging
    b) Choosing spots in the NMA that are open enough to not have root cover impede your digging or ability to extract samples while also being close enough to the vegetation to be usable in the future.
    c) For weather conditions, avoid excavating during rainy periods or immediately after rainy periods.
3) Determine the number of excavations your plan on doing. Based on the stratification sub-sectioning done for vegetation, 1 excavation should be done per sub-section determined.
    a) For sufficiently large areas such as Stanley Park, you may want to break down the park into several subsections.
    b) Considering financial and temporal constraints, at least 1 representative excavation of the park should be done.

Field Work

1) Survey the slopes and note down lengths of uniformity and differing topography displayed by the NMA.
2) Analyse the soil composition of the top layer of soil based on fragmentation and coarse material contents based on figure 2, and record the soil texture.
3) At each sampling location, mark 0.5 m x 0.5 m square in order to begin excavating.
4) Aim to excavate down to approximately 1.0 m, or until the water table is reached
    a) Consider starting an excavation in another area if water begins flooding into the excavation too high.
    b) Record the depth at which there is a restrictive downward flow of water. This may be impermeable, dense, compact or cemented layers, bedrock; or permanent water table, but not root cover.
5) Samples will be collected using the Core Method.
    a) Every 10 cm down from the top of the soil take a sample.
    b) Cut the soil with your soil corer with the centre point being the 10 cm marks

c) Insert the soil corer into the soil horizontally, hammering it in if you need to.
   i) If the corer does not go in smoothly or stops abruptly, you may have hit a large rock or roots. Pick an alternate sampling location along your mark.
d) In order to remove your soil corers dig around the rim of your soil corer to gently pull out the soil sample.
e) Secure the soil sample into tightly shut containers in order to send the samples to a lab after your field work is completed.
f) Repeat this every 10 cm down into your excavation.

Post Fieldwork

1) Send samples of your soil to a lab in order to determine:
   a) Bulk density
   b) pH
   c) Coarse fragment percentage
   d) Soil texture
   e) Total organic carbon and nitrogen in mineral soils
   f) Exchangeable sodium percentage
   g) Various mineral concentrations as seen in Table 1.
2) Total points as in Table 2 based on the Site Factors to obtain the Soil Erosion Hazard and a rating of Poor, Fair, or Healthy.

Poor	**Fair**	**Healthy**
> 17	9 - 17	< 9

3) After receiving the results back from the soil samples sent to the lab, assign values in Table 1 to obtain a rating of Poor, Fair, or Healthy.

Poor	**Fair**	**Healthy**
< 30%	30% - 70%	> 70%

4) Average the two scores obtained in steps 2 and 3 for the overall soil health factor. Where Poor = 1, Fair = 2, and Healthy = 3.

Poor	Fair	Healthy
< 50%	50% - 75%	> 75%

Vegetation

Pre-Fieldwork

1) Determine the stratification: choose a topographic feature that is the most influential to your NMA, and use that feature to divide the NMA into sub-areas. Determine the percent area each sub-area occupies within this NMA.
2) Determine the number of quadrats to sample:
   a) The area sampled through quadrats should be equal to 1% of the park area to gain a full representation of the vegetation cover in your NMA. For example, if your park is 10,000 m^2 then you should sample 100 m^2 through quadrats.
   b) Divide the area of 1% of the NMA by the area of the quadrats used in sampling, to get the number of quadrats. We recommend using 5 by 5 metre quadrats (25 m^2), based on the height of the tallest vegetation found in most NMAs (Table 4). If it is unrealistic to sample 1% of the NMA, we recommend sampling at least 30 quadrats, as this is the amount of samples we were able to complete in one day of field work at Renfrew Ravine Park.
3) Determine how many quadrats to do in each sub-area: distribute the quadrats into each sub-area based on its percent area of the NMA.
4) Determine sample locations: divide the entire park into 5 by 5 metre quadrats, then randomly generator your sampling locations.

Fieldwork

1) At each sampling location, lay your 5 by 5 metre quadrat on the ground.
2) Within the quadrat, record each species present and its estimated percent cover. Include trees only if they occur directly in the quadrat. As vegetation occurs in multiple layers, it's possible to have over 100%. For example, two species may overlap over the entire quadrat and thus receive 100% cover each. For consistency, all quadrats should be sampled by the same people. The figure below gives an example of sampling a quadrat.

Example quadrat assessment. This quadrat was identified as: 8% english ivy, 18% blackberry, 20% mahonia, 5% english holy and 20% unknown plant.

Post-Fieldwork

1) For each species, add together the percent cover throughout the entire area of the NMA that was sampled.
2) Calculate Simpson's diversity index (D) using the following equation, and multiply by 100%, then determine the rating:

$$D = 1 - \frac{\Sigma n(n-1)}{N(N-1)}$$

n = the percent cover of an individual species
N = the total percent cover of all species

Poor	Fair	Healthy
D < 50%	50% ≤ D < 75%	D ≥ 75%

3) Using the invasive species guide from the Invasive Species Council of BC (2020) designate which species are invasive and add together all their percent areas. Divide this number by the percent area of all plants together and multiply by 100% to get the percent of the NMA that is invasive (I). Determine the rating:

Poor	Fair	Healthy
I ≥ 50%	50% > I > 25%	I ≤ 25%

4) Find the average of the total from step 2 and 3, then assign a rating (R):

Poor	Fair	Healthy
R < 2	2 ≤ R < 2.5	R ≥ 2.5

Tree Cover

Pre-Fieldwork

1) Determine the stratification: choose a topographic feature that is the most influential to the NMA, and use that feature to divide the NMA into sub-areas. Do not include non-forested areas. Determine the percent area each sub-area occupies within this NMA.
2) Determine the number of quadrats to sample: the area sampled through quadrats should be equal to 1% of the park area to gain a full representation of tree cover in the NMA. We recommend using 10 by 10 metre quadrats for young forests or 20 by 20 metre for mature forests, based on the height of the tallest trees found in most NMAs (see Table 4).
3) Determine how many quadrats to do in each sub-area: distribute the quadrats into each sub-area based on its percent area of the NMA.
4) Determine sample locations: divide the entire park into 10x10m or 20x20m quadrats, then randomly generate sampling locations.

Fieldwork

1) For quantitative questions, record the following for each tree in the quadrat:
    a) Species
    b) If it is in the canopy or sub-canopy
    c) DBH (diameter at breast height), measured as the length around the tree at ~4.5ft
    d) Maturity of the tree based on it's DBH
    e) Classification of hardwood or softwood
2) Answer and record answers to qualitative questions in Table 6.
3) Repeat steps 1) and 2) in each quadrat.

Post Fieldwork

1) Calculate out percentages based on questions 1) through 13) and add values into Table 6.
2) Take total values from Table 5 (Quantitative) and Table 6 (Qualitative) and enter into Table 7 giving a tree health rating (Table 8) for the quadrat in question.
3) The average of each quadrat's result will give your overall tree health score.

Appendix 3: Data and Calculations

Water Quality

Data

Table 11. Stream dimension data from site 1 of Renfrew Ravine Park.

Stream Dimensions: Site 1		
Location: 49.245758, -123.044614		
Time: 10: 23 a.m.	**Air Temperature**: 2ºC	**Water Temperature:** 8.5ºC
pH: 7.5	**Turbidity (ppm):** 171	**Dissolved Oxygen:** N/A
Point Along Channel	**Wetted Channel Depth (cm)**	**Bankfull Channel Depth (cm)**
Left Bank: 0 m	0	0
1 m	3	50
2 m	8	53
3 m	0	41
4 m	0	41
5 m	0	41
6 m	1	51
7 m	0	58
Right Bank: 7.0 m	0	58

Table 12. Stream dimension data from site 2 of Renfrew Ravine Park.

Stream Dimensions: Site 2		
Location: 49.245643, -123.044615		
Time: 11: 48 a.m.	**Air Temperature:** 3ºC	**Water Temperature:** 8.6ºC
pH: 7.62	**Turbidity (ppm):** 171	**Dissolved Oxygen:** N/A
Point Along Channel	**Wetted Channel Depth (cm)**	**Bankfull Channel Depth (cm)**
Left Bank: 0 m	0	53
1 m	13	53
2 m	10	50
3 m	9	49
4 m	6	50
5 m	1	51
6 m	0	46
7 m	0	27
Right Bank: 7.0 m	0	27

Table 13. Stream dimension data from site 3 of Renfrew Ravine Park.

Stream Dimensions: Site 3		
Location: 49.245380,-123.044654		
Time: 12: 46 p.m.	**Air Temperature:** 3ºC	**Water Temperature:** 9.1ºC
pH: 7.45	**Turbidity (ppm):** 161	**Dissolved Oxygen:** N/A
Point Along Channel	**Wetted Channel Depth (cm)**	**Bankfull Channel Depth (cm)**
Left Bank: 0 m	0	13
1 m	13	26
2 m	10	27
3 m	9	25
4 m	10	30
5 m	0	21
6 m	0	20
7 m	N/A	N/A
Right Bank: 6.8 m	0	15

Table 14. Stream dimension data from site 4 of Renfrew Ravine Park.

Stream Dimensions: Site 4		
Location: 49.245259,-123.044809		
Time: 2:07 p.m.	**Air Temperature:** 3ºC	**Water Temperature**: 9.3ºC
pH: 7.41	**Turbidity (ppm):** 180	**Dissolved Oxygen:** N/A
Point Along Channel	**Wetted Channel Depth (cm)**	**Bankfull Channel Depth (cm)**
Left Bank: 0 m	19	44
1 m	10	31
2 m	12	30
3 m	9	31
4 m	1	28
5 m	11	38
6 m	0	9
7 m	N/A	N/A
Right Bank: 6.0 m	0	9

Table 15. Stream dimension data from site 5 of Renfrew Ravine Park.

Stream Dimensions: Site 5		
Location: 49.245082,-123.044637		
Time: 2:54 p.m.	**Air Temperature:** 6ºC	**Water Temperature:** 9.4ºC
pH: 7.35	**Turbidity (ppm):** 166	**Dissolved Oxygen:** N/A
Point Along Channel	**Wetted Channel Depth (cm)**	**Bankfull Channel Depth (cm)**
Left Bank: 0 m	1	25
1 m	12	30
2 m	21	40
3 m	17	42
4 m	17	47
5 m	N/A	N/A
6 m	N/A	N/A
7 m	N/A	N/A
Right Bank: 4.7 m	0	36

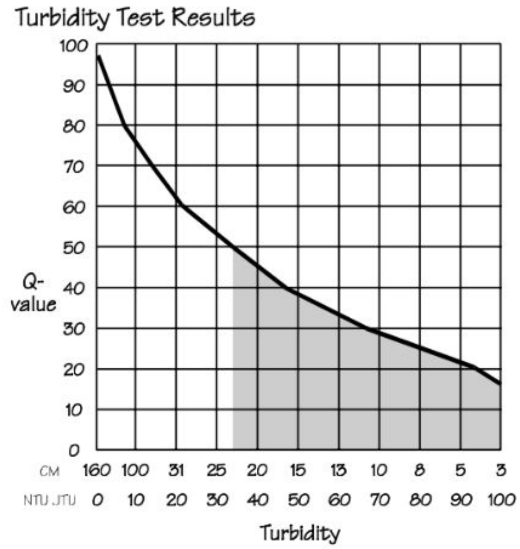


Figure 8. Turbidity to Q-value conversion table from the Streamkeepers Handbook (1995).

Table 16. Turbidity values converted to Q-values and the corresponding index value for each survey site in Renfrew Ravine Park.

Average Turbidity WQI			
Location	**Q-Value**	**Weighting Factor**	**Index Value**
49.245758,-123.044614	97	0.08	7.76
49.245643,-123.044615	97	0.08	7.76
49.245380,-123.044654	97	0.08	7.76
49.245259,-123.044809	97	0.08	7.76
49.245082,-123.044637	97	0.08	7.76
Average Index Value			**7.76**

The meter used gave ppm values for turbidity, which are recorded in the tables above. However, the table provided by the Streamkeeper's handbook does not have a conversion for ppm into their Q-Value index, and so we elected to use the cm (visible depth) rating, where if you could see all the way to the bottom, that also counted as "160 cm" of sight.

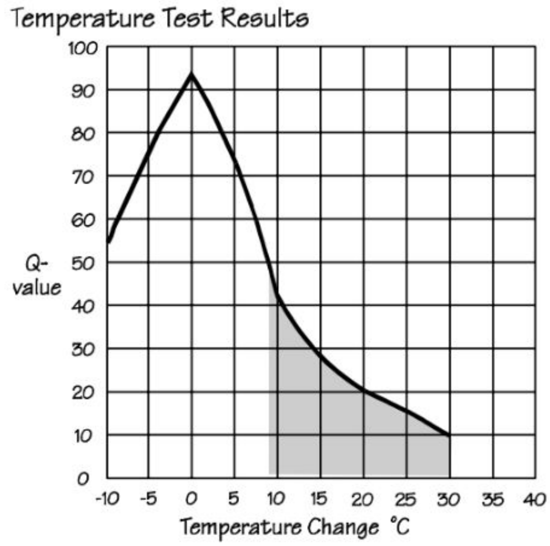


Figure 9. Temperature to Q-value conversion table from the Streamkeepers Handbook (1995).

Table 17. Temperature values converted to Q-values and the corresponding index value for each survey site in Renfrew Ravine Park.

Average Temperature WQI			
Location	**Q-Value**	**Weighting Factor**	**Index Value**
49.245758,-123.044614	-	-	-
49.245643,-123.044615	94	0.1	9.4
49.245380,-123.044654	92	0.1	9.2
49.245259,-123.044809	93	0.1	9.3
49.245082,-123.044637	93	0.1	9.3
Average Index Value			**9.3**

Table 18. pH values converted to Q-values and the corresponding index value for each survey site in Renfrew Ravine Park.

Average pH WQI			
Location	**Q-Value**	**Weighting Factor**	**Index Value**
49.245758,-123.044614	92.6	0.11	10.186
49.245643,-123.044615	92	0.11	10.12
49.245380,-123.044654	91.8	0.11	10.098
49.245259,-123.044809	91	0.11	10.01
49.245082,-123.044637	90	0.11	9.9
Average Index Value			**10.063**

Table 19. Dissolved oxygen values converted to Q-values and the corresponding index value for each survey site in Renfrew Ravine Park.

Average Dissolved Oxygen WQI			
Location	**Q-Value**	**Weighting Factor**	**Index Value**
-	82	0.17	13.94
Average Index Value			**13.94**

The meter we used was unable to give a dissolved oxygen reading. Earlier in the semester we had contacted the Streamkeeper's group and asked if they could provide us with the data they collect monthly, which included dissolved oxygen readings at a station near where we did our field work. When we reviewed the data they had given, they had updated with data collected on the same day we had done our fieldwork, and just hours earlier than we had arrived. We decided to use station 5's reading as a representation of the stream section we sampled, as it is close to where we began sampling.

Chemical Test	Result	Q-value	Weighting Factor	Index Value
temperature change			x 0.10 =	
oxygen saturation			x 0.17 =	
pH (units)			x 0.11 =	
Turbidity (JTU, NTU, or cm ✪)				
Total = Water Quality Index				

✪ amount above background, if available

Water Quality Chart	
Good	0-45
Acceptable	30-40
Marginal	20-30
Poor	<20

Figure 10. Water Quality Index from the Streamkeepers Handbook (1995).

Table 20. WQI table adapted from the Streamkeepers Handbook (1995) displaying recorded values and final index values for Renfrew Ravine Park.

Chemical Test	Q-Value	Weighting Factor	Index Value
Temperature Change	93	0.10	9.3
Dissolved Oxygen (%)	82	0.17	13.97
pH	91.48	0.11	10.0628
Turbidity (cm)	97	0.08	7.76
Total			**41.0628 / Good**

From the QWI given by the Streamkeeper's guide, Renfrew Ravine scores **Good** based on its total of 41.06.

Table 21. Benthic macroinvertebrate survey findings.

Macroinvertebrate Survey						
Column A	Column B					Column C
	Location: 49.245758,-123.044614	**Location:** 49.245643,-123.044615	**Location:** 49.245380,-123.044654	**Location:** 49.245259,-123.044809	**Total**	
Category 1: Pollution Intolerant	0	0	0	0	**0**	Caddisfly Larva
	0	0	0	0	**0**	Dobsonfly
	0	0	0	0	**0**	Gilled Snail
	25	4	15	7	**51**	Mayfly Nymph
	0	0	0	0	**0**	Riffle Beetle
	0	0	0	0	**0**	Stonefly Nymph
	0	0	0	0	**0**	Water Penny
Subtotal	25	4	15	7	**51**	1
Category 2: Somewhat Tolerant of Pollution	0	0	0	0	**0**	Alderfly Larva
	0	0	0	0	**0**	Aquatic Beetle
	0	0	0	0	**0**	Aquatic Sowbug
	0	0	0	0	**0**	Clam, Mussel
	0	0	0	0	**0**	Cranefly Larva
	0	0	0	0	**0**	Damselfly

						Larva
	0	0	0	0	**0**	Dragonfly Larva
	0	0	0	0	**0**	Fishfly Larva
	9	63	10	2	**84**	Scud
	7	4	6	4	**21**	Watersnipe Larva
Subtotal	16	67	16	6	**105**	2
Category 3: Pollution Tolerant	3	4	3	4	**14**	Aquatic Worm
	0	0	0	0	**0**	Blackfly Larva
	0	0	0	0	**0**	Leech
	0	0	3	0	**3**	Midge Larva (chironomid)
	0	1	0	0	**1**	Planarian
	0	0	0	0	**0**	Pouch and Pong Snails
	91	2	10	2	**105**	True Bug Adult
	0	0	0	0	**0**	Water Mite
Subtotal	94	7	16	6	**123**	4

Calculations

C) WATER QUALITY ASSESSMENTS

POLLUTION TOLERANCE INDEX: use the **total number of broad** taxonomic groups found in each tolerance category, from Field Data Sheet (**Column D**)

POLLUTION TOLERANT INDEX			
Good	**Acceptable**	**Marginal**	**Poor**
>22	22-17	16-11	<11

3 x (# of category 1)
\+ 2 x (# of category 2)
\+ (# of category 3) = ☐

EPT INDEX: total number of **EPT** taxa from **Column C**, Field Data Sheet

EPT INDEX			
Good	**Acceptable**	**Marginal**	**Poor**
>8	5-8	2-5	0-1

EPT are stonefly, caddisfly and mayfly = ☐

EPT TO TOTAL RATIO: total number of **EPT** organisms from **Column B**, Field Data Sheet divided by the total number of organisms

EPT TO TOTAL RATIO			
Good	**Acceptable**	**Marginal**	**Poor**
0.75 - 1.00	0.5 - 0.75	0.25 - 0.50	0 - 0.25

\# of **EPT** _______ ÷ total = ☐

Figure 11. Pollution tolerance index from the Streamkeepers Handbook (1995).

Pollution Tolerant Index = [3 x (1)] + [2 x (2)] + [1 x (4)] = 11 = **Poor**
EPT Index = 1 = **Poor**
EPT to Total Ratio = (1) / (11) = 0.0909 = **Poor**

D) DIVERSITY ASSESSMENT

TOTAL NUMBER OF TAXA: from **Column C**, Field Data Sheet ☐

PREDOMINANT TAXON RATIO: divide the **number** of invertebrate in the **predominant taxon** by the **total number of invertebrates** counted:

__________ ÷ ________ = ______
predominant total

PREDOMINANT TAXON RATIO			
Good	**Acceptable**	**Marginal**	**Poor**
0 - 0.40	0.40 - 0.60	0.60 - 0.80	0.80 - 1.0

☐

Figure 12. Predominant taxon ratio guide from the Streamkeepers Handbook (1995).

E) SITE ASSESSMENT RATING:

Assign a rating between 1 and 4 to each index or ratio, then average the results to produce a general site assessment.

SITE ASSESSMENT RATING			
Good	**Acceptable**	**Marginal**	**Poor**
4	3	2	1

General Comments -
Unknown Bugs

see page 13 and 14 of Module 4 for further information

SITE ASSESSMENT RATING	
Index or Ratio	**Rating**
Pollution Tolerance Index	
EPT Index	
EPT to Total Ratio	
Predominant Taxon Ratio	
Total	
Average	

Figure 13. Site Assessment Rating from Module 4 of the Streamkeepers Handbook (1995).

Predominant Taxon Ratio = Invertebrate with Highest Count / Total Invertebrates Counted = 105 / 279 = 0.376 = **Good**

Table 22. Site assessment rating table from Renfrew Ravine Park adapted from the Streamkeepers Handbook (1995).

Site Assessment Rating	
Pollution Tolerance Index	Poor (1)
EPT Index	Poor (1)
EPT to Total Ratio	Poor (1)
Predominant Taxon Ratio	Good (4)
Total	7
Average	**1.75 / Marginal**

According to the site assessment done by us, Renfrew Ravine scores 1.75, or **marginal**, based on our study of the benthic macroinvertebrates, meaning it scores **Poor** health in our framework,

Total Rating:
Good (3) + Poor (1) / 2 =
2 = **Fair**

Averaging both the **Good** and **Poor** score from each section of this assessment, Renfrew Ravine is in **Fair** health for water quality.

Vegetation

Data

Table 23. Total percent cover by plant species found in Renfrew Ravine Park.

Plant Species	Total Percent Cover	Invasive	n(n-1)
Allium	10		90
Begonia	17		272
Blackberry	433	Yes	187056
Bluebell	15		210
Daffodil	25		600
English Holy	294	Yes	86142
English Ivy	1407	Yes	1978242
Grass	13		156
Horsetail	7		42
Iris	34		1122
Mahonia	188		35156
Moss	244		59292
Skunk cabbage	30		870
Snowdrop	4		12
Spring Bud	95		8930

Sword Fern	394		154842
Unknown bush 1	30		870
Unknown tree 1	158		24806
Unknown tree 2	90		8010
Western Hemlock	12		132
Western Red Cedar	5		20
Total (N)	3505	2134	2546872

Calculations

Simpson's diversity index (*D*):

$$D = 1 - \left(\frac{\Sigma n(n-1)}{N(N-1)}\right)$$

n = the percent cover of an individual species
N = the total percent cover of all species
D = 1 - (2546872 / (3505(3504)) = 0.80 x 100% = 80%
Healthy (3)

Invasive species cover (I):

I = (percent invasive species) / (total percent plant species) x 100%
I = 2134/3503x100% = 61%
Poor (1)

Vegetation Rating (V):

V = (D + I)/2
V = (1 + 3)/2 = 2
Fair

Ecological Health Rating

Calculations

Length of the stream: approximately 750 m
Average width of the stream: 6.3 m
Riparian class based on Table 8: S5 (30 m buffer)
Width of stream and buffer: 6.3 m +2(30 m) = 66.3 m

Area of stream and buffer: 49,725 m
Area of NMA (South section): 60,000 m
Percent area of stream: 49,725/60,000 x 100% = 82.875%

This classifies as scenario iv) under Figure 6, where Water Quality falls in Tier 3.

Because Tree Cover, Bird Habitat and Soil Quality/Slope Stability were not completed, we adjusted the weighings so that Tier 3 are each worth 40%, and Tier one is worth 20%.

Final Ecological Health Rating:
0.40(Vegetation) + 0.40(Water Quality) + 0.20(Human Disturbance) = 0.40(2) + 0.40(2) + 0.20(1) = 1.8 = **Poor**