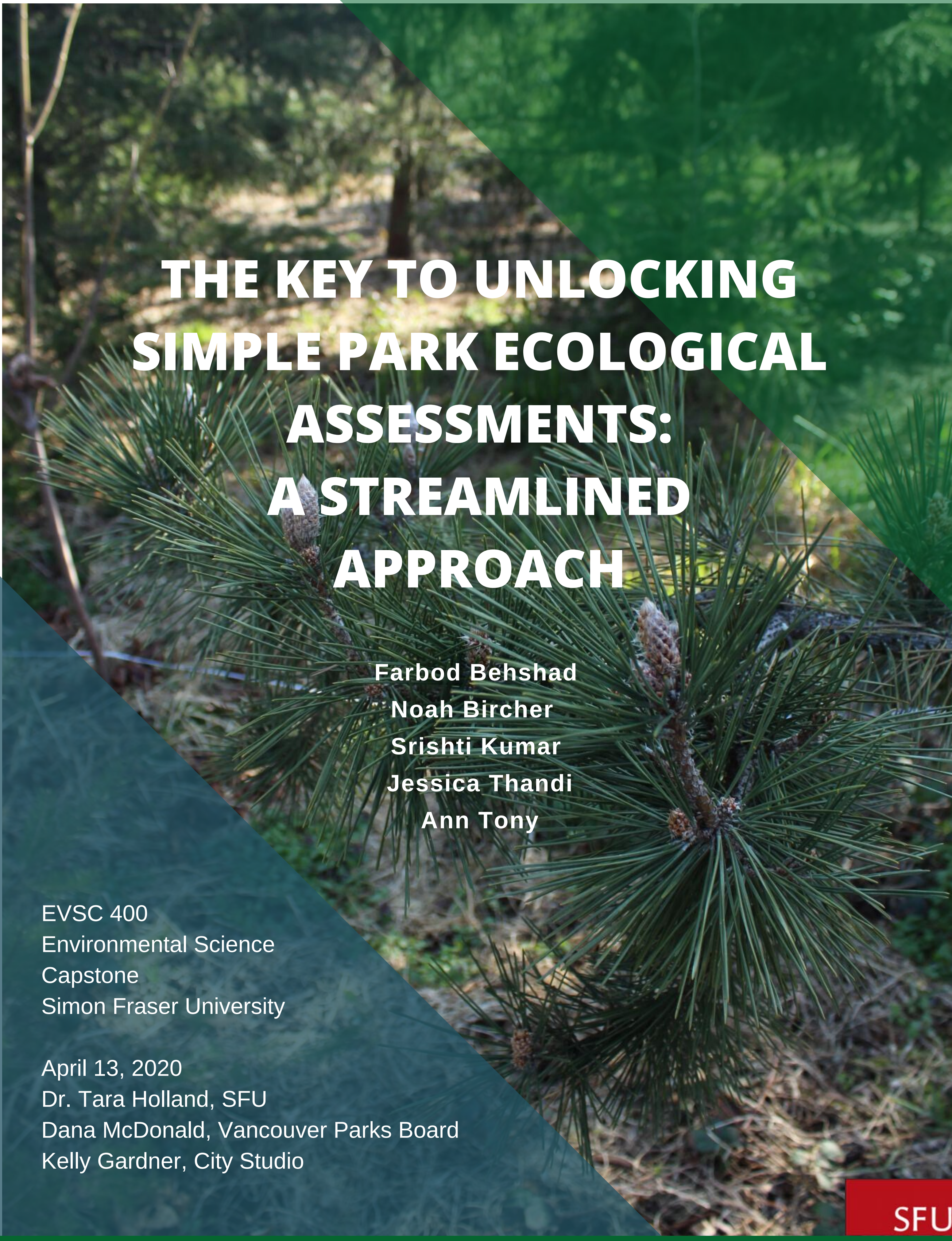


THE KEY TO UNLOCKING SIMPLE PARK ECOLOGICAL ASSESSMENTS: A STREAMLINED APPROACH

Farbod Behshad
Noah Bircher
Srishti Kumar
Jessica Thandi
Ann Tony

EVSC 400
Environmental Science Capstone
Simon Fraser University

April 13, 2020
Dr. Tara Holland, SFU
Dana McDonald, Vancouver Parks Board
Kelly Gardner, City Studio

SFU

EXECUTIVE SUMMARY

Background

Assessing Naturally Managed Areas (NMAs) presents unique opportunities and challenges, particularly because no two ecosystems are alike, but need to be assessed with similar methodologies. Therefore, the main purpose of the work done was to respond to the Vancouver Park Boards request for proposals assessing the condition of NMAs. The scope of the work includes developing a methodology that can be used to assess the ecological condition of NMAs and determine which NMAs are in poor, fair, or healthy condition. The reason why NMAs are the focus of this study is because they are a vital part of the urban parks and green spaces in Vancouver. NMAs have many natural benefits such as being hotspots of biodiversity, providing habitat for plants and wildlife, and being beneficial for human well-being. However, with the shifts in climate and increasing pressure from anthropogenic factors, it is important to ensure Vancouver's NMAs are in good ecological standing. To do this, a comprehensive yet adaptive methodology is required to capture the continual shifts in ecological health within all NMAs in Vancouver.

The case study used to answer the request for proposals was Everett Crowley Park, Vancouver's 5th largest park. Today, Everett Crowley Park is a beloved park for neighborhood residents and dog walkers alike who come out to enjoy its many pathways. Originally, however, Everett Crowley park was a forested area with a salmon bearing creek running through it. In 1944, the park was converted into the Vancouver landfill due to its proximity to factories and wood mills. It wasn't until the late 1960's that the landfill was decommissioned and capped. For 20 years the area was closed; residents petitioned and lobbied the land be reintroduced as a park and, in 1987, Everett Crowley Park opened. Ecologically, the land was slowly colonized by native species, however invasive species thrived as well. This has created a legacy of invasive plants and a need for restoration to allow for native species to thrive. The Vancouver Parks Board recognized this need which means the park has ongoing, intensive restoration work in specific areas contributing to the condition it is in now. Before its redevelopment in the 1870's, the park was a coniferous forest home to Western hemlock (Tsuga heterophylla) and Western Red Cedar trees (Thuja plicata). Now the park is primarily covered with species such as Himalayan Blackberry (Rubus armeniacus), English Ivy (Hedera helix), and planted trees such as Douglas fir (Pseudotsuga menziesii).

EXECUTIVE SUMMARY

Objectives

The objectives of this project are to develop a methodology that can be used to assess the ecological condition of NMAs in Vancouver, and to subsequently assess whether the chosen NMA is in poor, fair, or healthy condition. The objectives of our study were to determine the ecological integrity, an extension of ecological health, of microenvironments within Everett Crowley Park. Ideally, the results of our study would provide insight on which areas in the park need more restoration work, and where to target this restoration work so that it is more effective.

Methodology

The interactions between soil quality and vegetation quality form the backbone of healthy ecosystems. To determine the health of NMAs, a novel framework that functions as a dichotomous key for determining ecological integrity was created. The aim of this methodology is to be both simple and scientifically robust; this reduces time loss and costs associated with obtaining expensive lab equipment and paying specialized individuals to collect data. The main variables in the framework are soil compaction as a proxy for human disturbance, soil quality, the coverage of invasive versus native species, and biodiversity. Factors such as air and water quality have been omitted from the framework as they are expensive and complex; furthermore, based on our research, it is hard to obtain accurate results. If there is a need, however, to include these factors to assess a NMA, then the framework has been designed to allow for easy additions of new factors. Since Everett Crowley Park is one of Vancouver's larger NMAs, sampling was focused on specific site types.

To divide the site into manageable portions and provide a unique way to group different microenvironments around the park, differences in canopy cover were measured. Canopy cover is an ideal parameter to divide a site since it influences micro climates, urban heat islands, shading, and soil temperature. Images from airborne Light Detection and Ranging (LiDAR) were used to determine canopy cover. The following classifications were created: High canopy cover (greater than 80% coverage), medium canopy coverage (between 10% and 80% coverage) and no canopy cover (less than 10% coverage). After site selection, the following factors were assessed:

EXECUTIVE SUMMARY

Human Disturbance (Soil Compaction)

To quantitatively measure human disturbance, measures of soil compaction were taken. Human disturbance is a broad term that can encompass many impacts such as littering, the creation of unofficial trails, and destruction of vegetation. Given the difficulties and uncertainties in measuring these impacts, soil compaction will be considered as a proxy for human disturbance. Soil compaction is important to look at as it can alter soil porosity and permeability at high pressures. Highly compacted soils, therefore, have difficulty exchanging water and nutrients to plants, and the soil structure can become strained. To determine soil compaction, a simple device called a penetrometer can be used. A penetrometer is inserted into the soil and measures the approximate unconfined shear strength, or the ability of materials to resist forces. Distinctions between low compaction and high compaction were created based on a soil classification from the Occupational Safety and Health Administration. A soil is considered to have high human impacts if the penetrometer reading is above 120kPa and low human impact if the reading is below 120kPa.

Soil Quality

Soils in NMAs, specifically Everett Crowley Park, are often imported. This can make it difficult to assess the soil of the park as it may not be native soil. Nevertheless, whether the soil is formed naturally in situ or is deposited from a different source, it still plays a vital role in creating healthy conditions for plant growth. Soil affects the organization, resilience, and biodiversity of NMAs, and therefore the plants that grow in it. A scoring system was used to measure soil quality in a simple, easy, yet robust way. The following soil physical and chemical properties were measured: bulk density, infiltration, texture, percentage of organic matter, and pH. In the scoring system, the suitability thresholds for low soil quality and high soil quality are defined as outlined in O'Neill et al. 2005 and a report by the Environmental Protection Agency (2011). Using the scoring system, if the measured property meets the requirements for either low or high soil quality, it receives a point in each category mentioned above. Whichever quality (high or low) has a higher final score, is the soil quality for that specific sample.

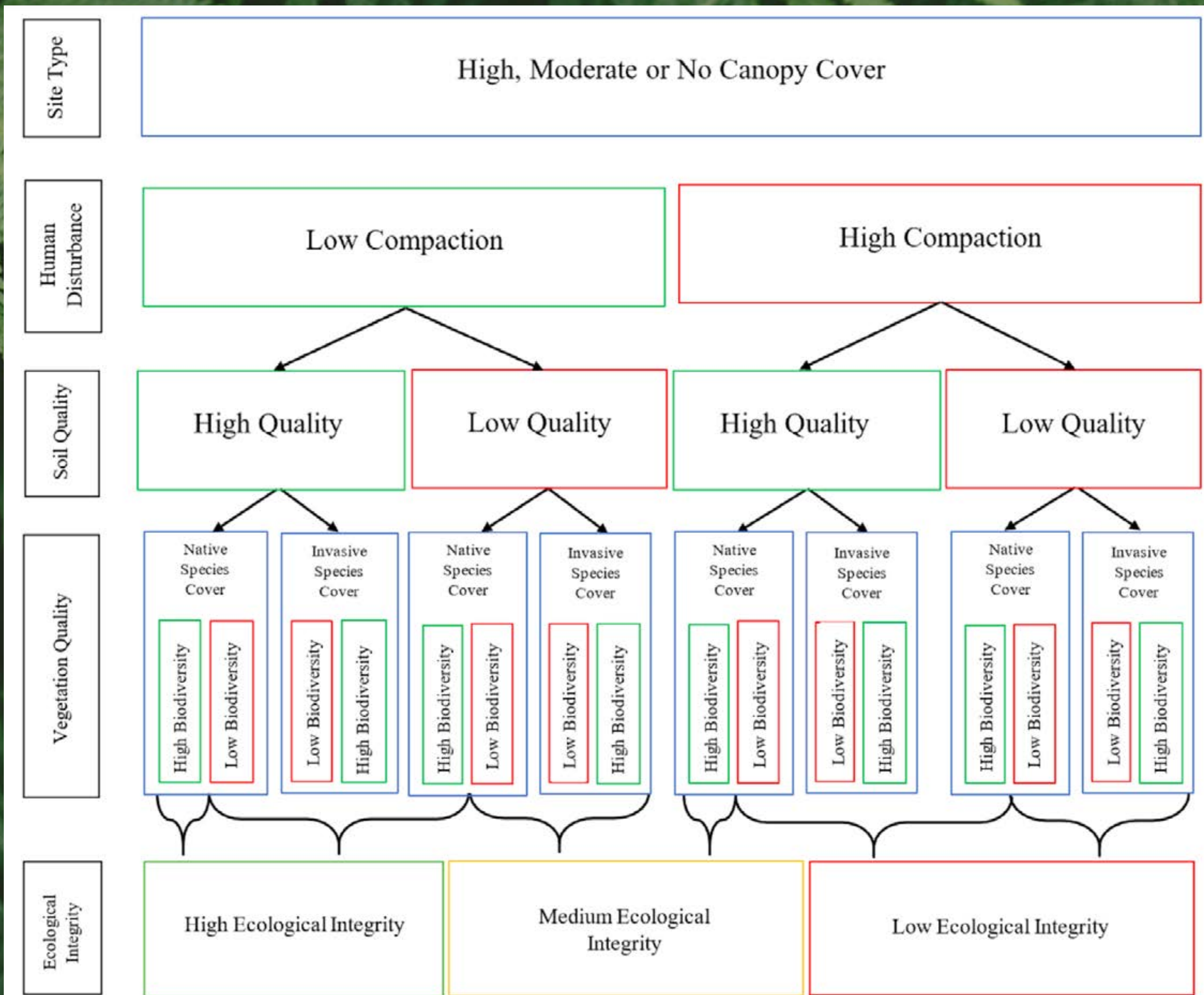
EXECUTIVE SUMMARY

Presence of Native and Invasive Plant Species

Everett Crowley Park, and other NMAs in Vancouver, all have been colonized to some degree by invasive species. Invasive species are often aggressive species that out-compete native plants by either redirecting below ground nutrients or occupying large above ground land cover. Measuring the percentage cover that invasive species occupied was the main priority due to the many difficulties of measuring below ground competition between native and invasive species. The logic follows that if an area has a high percentage of invasive species coverage, then there is less resources for native species, ultimately reducing biodiversity and robbing the park of the natural benefits from native plants. To determine the status of the coverage of invasive species, a simple observational system was used. If a plot was more than 50% covered by invasive species, then it was categorized as invasive dominant, and if it was dominated by more than 50% of native species then it was native dominant.

Biodiversity

Biodiversity relates to both soil health and function; therefore, it is an important part of this framework. Without enough biodiversity, an ecosystem risks reduced ecosystem services, soil loss and erosion. One of the most common ways to measure biodiversity is to use a biodiversity index. Simpson’s Diversity Index (D), was chosen as it calculates both species richness and evenness. Richness is a measure of how many species there are in a plot, whereas evenness is a measure of the relative abundance of the different species in a plot. To use the Simpson's formula, a species and individual's count has to be done in the field. The results of a Simpsons diversity computation yield answers between 0 and 1. Where 1 represents complete biodiversity and 0 represents complete uniformity or poor biodiversity. In this framework, only native species are included in the biodiversity calculation. If the result of the calculation is less than 0.5, it is classified as low biodiversity and if the result is higher than 0.5 it is classified as high biodiversity.



A framework that appears to be simple, but is backed by concrete evidence and tests that determine the ecological integrity of NMAs. The process begins by identifying if the sites have no, medium, or high canopy cover then analyses: soil compaction as a human disturbance, soil quality, invasive versus native species cover, and biodiversity. This key was adapted from Gibbons and Freudenberger (2006) but altered significantly to work in NMAs.

EXECUTIVE SUMMARY

Results

The results of the case study in Everett Crowley Park showed that four sites had high ecological integrity, one had medium ecological integrity, and three had low ecological integrity. A closer look at each variable shows patterns within the factors of this framework. It was found that all the sampled areas with no canopy cover had high compaction rates, indicating that there was higher human disturbance in these areas, most likely due to easier access compared to high canopy areas. Based on the soil analyses, the park's soil rating was generally suitable for plant growth. As an example, the average bulk density of all sites was found to be suitable to host both short shrubs and tall trees. Five of the eight sampled sites were dominated by native plants such as Vine maple, Douglas fir, Western red cedar, Spruce and Black hawthorn. Lastly, in 6 out of 8 plots, and in each of the three canopy cover areas, the biodiversity indices were higher than 0.5. (it is important to note that the number of sites that are invasive dominant are underrepresented here as access to areas covered in blackberry was not possible). The park's overall biodiversity score generally indicates high biodiversity meaning that the vegetation is in a good state. All this considered, the overall health of the park is moderate according to both the sample plots and the presence of invasive species in many plots that could not be sampled.

Recommendations

The proposed framework is versatile in its execution and scope. To tailor it to specific park ecologies, we make the following recommendations. Firstly, variables such as water and air pollution can be added if they are of importance to other NMAs. We also recommend that further in-depth research be done in defining the microenvironment of the selected NMA to include more factors such as temperature, vegetation type, and land use. This would result in a more accurate alignment between canopy cover maps and canopy cover reality in the field. Further, we suggest vegetation sampling occur in the spring when the majority of species are in bloom. We recommend that plots be charted and evaluated each year due to the rapid growth of invasive species and that large areas of invasive species are mapped for future research.

Based on the findings of this project, there are a few ways to improve the ecological functionality of Everett Crowley Park. Large amounts of blackberry in the study area are creating areas of inaccessibility, therefore, we recommend that there is continued removal of invasive species and replanting of native species by trained locals, volunteers, and the Vancouver Board of Parks and Recreation. This will aid in future sampling efforts, increase biodiversity where at the moment there is barely any, and prevent the fast spread of invasive species. To reduce human disturbance and protect all the restored areas, we recommend that efforts be taken to reduce off-trail human and dog compaction. Areas which are easily accessible and do not have many invasive species should be prioritized before areas where natural barriers such as trees prevent entrance.

Authors

Farbod Behshad: Farbod is a 4th year student in the Environmental Science (Water Science concentration) program interested in water management in both the aquacultural and agricultural industries. He currently works as a grain inspector at SGS company.

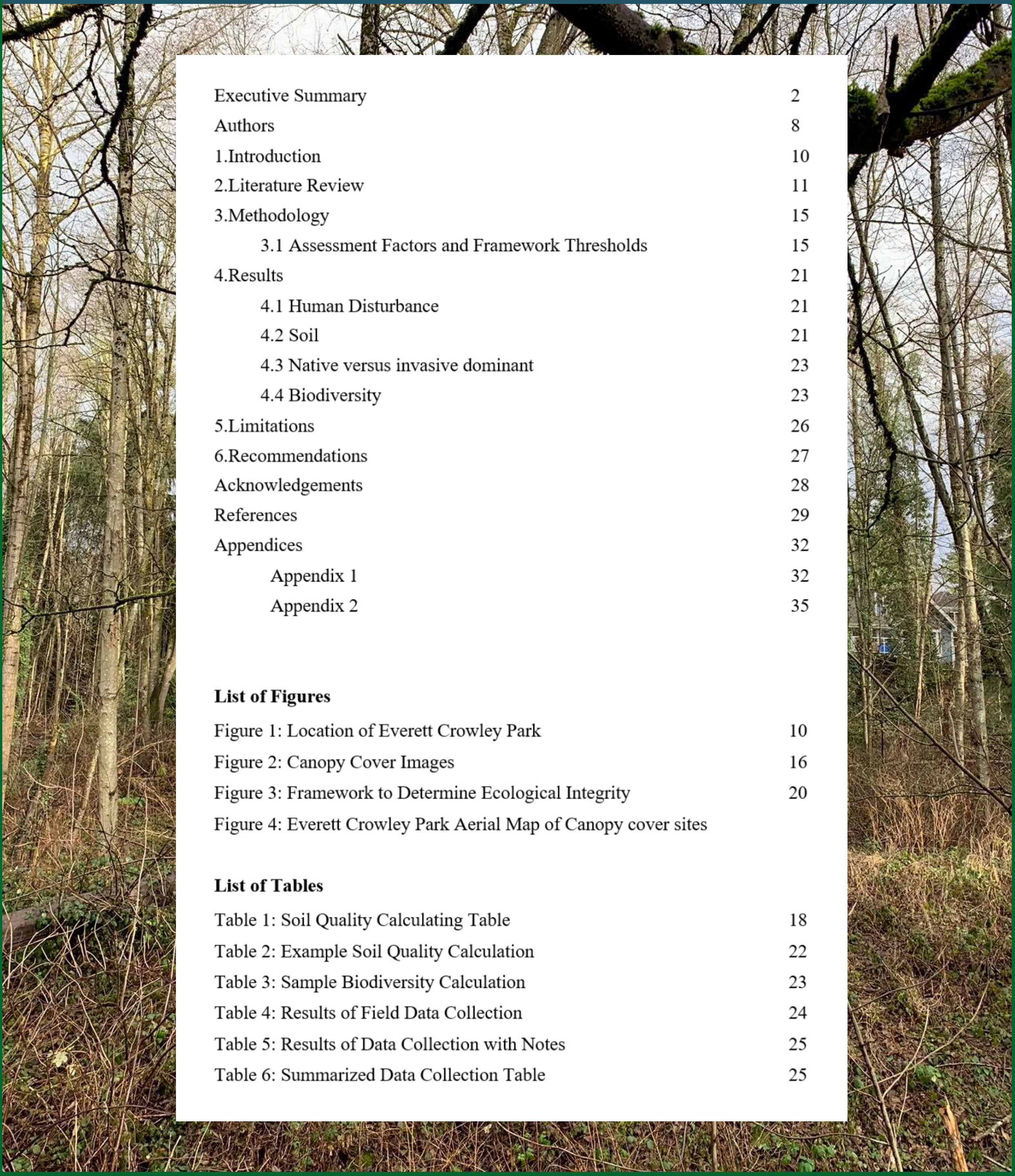
Noah Bircher: Noah is a 4th year student in the Environmental Science (Environmental Earth Systems concentration) program and is completing a certificate in GIS. He has experience working, implementing and organizing projects in the field while working at a salmon habitat restoration program and for Parks Canada in Jasper.

Srishti Kumar: Srishti is a 4th year student in Environmental Science (Water Science concentration) interested in water science and the relationship between water and geology.

Jessica Thandi: Jessica is a 4th year Environmental Science Student (Environmental Earth Systems concentration) interested in soil science and the interplay between soil and plant health.

Ann Tony: Ann is a 4th year Environmental Science Student (Environmental Earth Systems concentration). She is interested in public education on environmental issues concerning waste management . She has experience in both working in the field and analysing data with different softwares.

TABLE OF CONTENTS



List of Figures

List of Tables

1.Introduction

Parks allow people to be close to nature and provide ways to connect, relax and recreate. One such park is Vancouver's Everett Crowley Park, a 38-hectare forested park with trails, located in the southeast corner of Vancouver at the intersection of SW Marine drive and Kerr Street (see Figure 1) (Greenest City Scholar, 2017). Compared to other Vancouver parks, Everett Crowley Park is unique because of its status as a landfill until 1967, only becoming a recreational area in 1987 (Greenest City Scholar, 2017). The park is now primarily used for walking, jogging, biking, and dog-walking.

The goal of the EVSC 400 Capstone course was to respond to the request for proposals from the Vancouver Board of Parks and Recreation to develop a methodology to assess the condition of the Naturally Managed Areas (NMAs). NMAs consist of forest, wetland, shoreline, and other ecosystems which are beneficial to creating urban habitats for birds, mammals, and marine species. Everett Crowley Park is one such NMA and has undergone intensive restoration work resulting in the ecological condition that it currently is in. Park accessibility has also improved by adding washrooms, parking, and benches (Greenest City Scholar, 2017). The objective of this proposal is to present a methodology that can be used to assess the ecological condition of NMAs in Vancouver using Everett Crowley Park as a case study. Therefore, a simple, robust and easy to follow framework was designed to measure the ecological integrity of Everett Crowley Park and other NMAs in Vancouver.

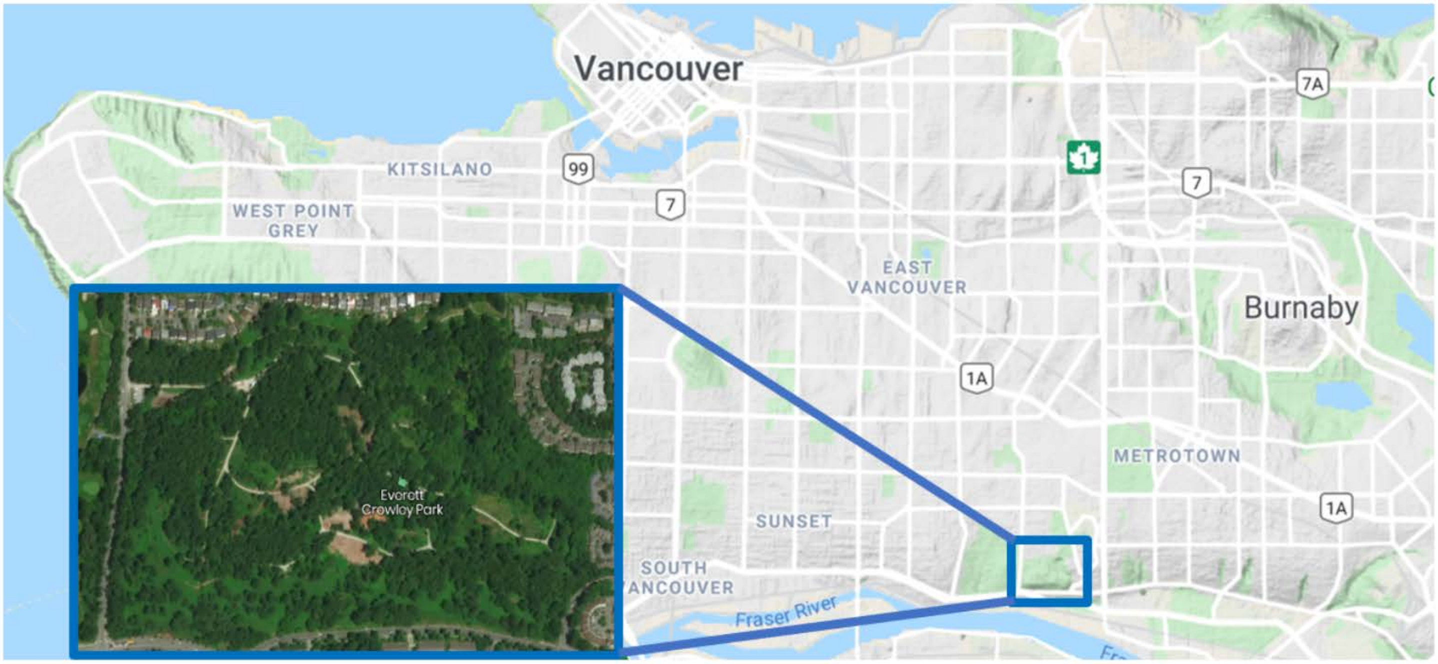


Figure 1: The location of Everett Crowley Park within the city of Vancouver

2. Literature Review

Naturally Managed Areas (NMAs) are a vital part of the City of Vancouver. The Vancouver Park Board aims to protect these NMAs using strategic moves to increase their biodiversity, connectivity, and community access (Vancouver Board of Parks and Recreation, 2019). Since these areas are undergoing shifts due to climate change and facing constant pressure from humans, it is important to manage urban forests and green areas (City of Vancouver [CoV], 2012; CoV, 2018). Some of the main goals of NMAs are to improve access for the community, design landscapes inclusive to bird habitat, and protect existing canopy cover and increase it (CoV, 2012; CoV, 2015; CoV, 2018). Biodiversity hotspots, small areas that contain higher than normal biodiversity of an area, are also vital areas that support biodiversity in parks. Many parks in Vancouver have a mutual relationship between biodiversity, and the health of the park (Vancouver Board of Parks and Recreation, 2016). However, as is true in many urban parks, invasive species tend to threaten this biodiversity; therefore, restoration is a common practice (Portland Parks & Recreation, 2015). Since it is hard to quantify the negative and positive aspects of factors that affect NMAs health, a methodology was developed to see the quality of parks within the City of Vancouver. The metrics of an NMA assessment methodology discussed below are based on the percentage of canopy cover, soil compaction as an indicator of human disturbance, soil quality, biodiversity, and invasives/non-invasives. These metrics all have both pros and cons associated with their inclusion in the methodology, however, they will all be assessed on a scale of ecological integrity in the setting of Everett Crowley Park.

Ecological Integrity

The concept of ecological integrity is quite complex, as it interacts with various physical and biological components. The fascinating thing with ecological integrity is its capacity of an ecosystem that supports and preserves the components and functions of a community even after a disturbance (Silva et al., 2009). It is concerned with ecological services for humans as well as the condition of biodiversity in ecosystems. It helps with managing natural and cultural goals and understanding the impacts of management techniques and environmental stressors like air pollution or climate change (Tierney et al., 2009). It mainly consists of three elements: physical, chemical and biological integrity, but how each of these elements weighs together has the topic of debate. However, ecological integrity incorporates concepts like sustainability, naturalness, resilience, and biodiversity (Andreasen et al., 2001). The framework for the terrestrial ecosystem should be formed in a way that leads to habitat fragmentation, succession, productivity, and species richness (Fraser et al., 2009). Many studies have used indicator species to restore ecological integrity, but it has many problems associated, such as, a species can be a good indicator of one characteristic but no other characteristics (Carignan and Villard, 2002). For example, butterflies are a good indicator of vegetation heterogeneity but not of plant species richness (Carignan and Villard, 2002). Some of the other characteristics of the terrestrial index of ecological integrity are multi-scaled, based on natural history, relevant, flexible, measurable, and comprehensive (Andreasen et al., 2001).

The biggest challenge with ecological integrity is how to measure changes, describe the results to various audiences, and solve an identified problem depending on the conditions of an ecosystem. The issue with the terrestrial index is what approach to take to integrate these characteristics, like arithmetic means, weighted average, ecosystem model, and more (Andreasen et al., 2001). Our methodology focuses on canopy cover, soil compaction, soil quality, and biodiversity to try and solve these challenges

Percentage of Canopy Cover

At the starting point of the methodology, the NMA must be divided into smaller sites representing microenvironments. This is because microenvironments have an influence on the soil quality and temperature gradient across the park (Sarah & Zhevelev, 2007; Parmehr et al., 2016; Hasselquist et al., 2018) An efficient way of doing this without going to the field is by using the percentage of canopy cover (Liu et al., 2017). Canopy cover is defined as the area or fraction of the tree crown that is covering the ground (Rutledge and Popescu, 2006; Jacob et al., 2014; Parmehr et al., 2016). Importantly, it can be determined by visually interpreting air photos from remote sensing data. Since canopy cover can influence microclimates, urban heat islands, insolation, shading, and soil temperature, it is an ideal parameter to divide the park into microenvironments (Sarah & Zhevelev, 2007; Parmehr et al., 2016). The main aspects to take into consideration while measuring canopy cover are forest structure and the radius of the crown (Parmehr et al., 2016). Images from airborne Light Detection and Ranging (LiDAR) are an excellent data source to determine the percent of canopy cover, as it is both accurate and can measure the areas covered with trees or shrubs (Liu et al., 2017).

However, results depend on the availability of LiDAR data and certain air photos might not be up to date, or not taken when canopy cover is high. Urban parks are constantly changing with anthropogenic activities like deforestation, afforestation, and natural changes like seasonality or natural disasters. In addition to the lack of data, human error while interpreting the images can also be a misleading factor (Richardson and Moskal, 2014). There might be sites that are labeled as low canopy cover, but in the field may not be; therefore, site division solely based on remote sensing data will have to be checked in the field.

Soil Compaction as a Measurement for Human Disturbance

Soil compaction is an important variable used to understand the human impacts in NMAs. Park visitors can have other direct impacts on the park, such as littering and mechanical destruction of vegetation (Sarah & Zhevelev, 2007). Given issues with measuring litter and the mechanical destruction of vegetation, soil compaction will be considered as the main direct human impact in NMAs. Soil compaction is the alteration of soil porosity and permeability due to external pressure on the soil, which is detrimental to plant growth (Millward et al., 2011). An increase in human interference within an area would increase soil compaction, resulting in a decrease in soil porosity and permeability (Supuka et al., 2009).

When the soil gets highly compacted the exchange of water and nutrients within the soil structure becomes strained (Patterson, 1976; Millward et al., 2011). There are different methods to measure soil compaction, but the literature points to assessing the bulk density of the soil to calculate soil compaction (Patterson, 1976). Bulk density is defined as the mass per unit volume (Patterson, 1976). Research and studies across the world have been conducted to understand the changes in soil compaction in different land-use areas. The ideal soil compaction rate depends on the soil types, moisture level, land use, and land cover. Data based on O'Neill et al. (2005), Hanks and Lewandowski (2003) and a document by the Environmental Protection Agency (2011) will be used to determine the soil compaction in the park.

Soil compaction is not only caused by park visitors, but the land cover and land use also influence the soil compaction and bulk density rates. Especially in Everett Crowley Park, where there are a lot of restoration efforts, there are non-human factors that are altering soil compaction: for example, the mulch which is used to prevent invasive species regrowth. This means that there is likely to be an overlap of factors. However, due to time constraints, the study will assume that human influences are the only factor affecting soil compaction.

Soil Quality

Continuous soil assessment allows the organizations responsible for revitalization, conservation and creation of urban forests and parks to make sure the soil and other related elements remain healthy and functional (Evaluation of Urban Soils, 2011; Millward et al., 2011; Pariente et al., 2015). The variability of soil within parks and essential functionality of it in any ecosystem have made it an important determinant of park health (Pariente et al., 2015). As Morgan and Connolly (2013) state, healthy soil is the cornerstone of a healthy ecosystem. Since NMAs are subject to some changes in soil layers, it is important to include soil quality in any park health assessment methodology. The soil suitability framework, using the scoring system of O’Neill et al. (2005), Hanks and Lewandowski (2003) and a document from the Environmental Protection Agency (EPA, 2011), integrates physical and chemical variables of soil and uses a scoring system to determine the suitability and health of the sampled soil. Some of the variables are bulk density, infiltration capacity, pH, and soluble salts. Monitoring chemical properties can prevent soil contamination which can lead to contamination or death of plants and animals. The physical properties such as bulk density and texture also play important roles in plant growth and soil erosion capacity. Most of the literature points out that both groups of properties can be treated to improve ecosystem resilience and reduce human disturbance effects (Millward et al., 2011; Pariente et al., 2015).

Some issues with approaches in the literature, such as the Soil Quality Index developed by O’Neill et al. (2005), are that they require multiple and repeated measurements of nineteen variables of soil. Due to the limitation of resources, only the variables that are in common with the EPA document are considered here (2011). Neither of the studies included the measurement and effect of soil contaminants, but due to the flexibility of this methodology it is possible to add them to the scoring system later. It should also be mentioned that errors in measuring parameters or ignoring very specific soil variables may lead to less accurate assessment.

Biodiversity and Invasive/Non-invasives

Biodiversity and the presence of invasive species provides many insights into ecological health. Our methodology proposes an investigation of whether the ecosystem is primarily dominated by native or non-native species. This helps to determine overall ecosystem health as non-native species can have negative effects on native species and ecosystems (Portland Parks & Recreation, 2015). For example, non-native species can out-compete native species for resources and if non-native species hybridize with native species,he resulting genetic constitution is considered a loss of biodiversity (Manchester & Bullock, 2001). This can create poor conditions for ecosystems since biodiversity has been shown to maintain ecosystem services (Isbell et al., 2011). Biodiversity is also important to measure as it provides an indicator of overall ecosystem health. Plant biodiversity provides ecosystem services such as carbon sequestration, resilience, resistance to perturbation, and nutrient cycling (Grime, 1998). Simpson's Index (D) will be used to determine the biodiversity of a habitat or site type. Simpson's Index measures both the number of species per sample (richness) and the relative abundance of different species in the sample (evenness) (Mooney, 2011).

The problems with this approach are that Simpson's Index of biodiversity is an estimate and is very limited. Simpson's index was chosen over the Shannon index since the Simpson index gives more weight to dominant or common species. This means that any rare or uncommon species will not affect biodiversity (Protect U.S., n.d). This can be a problem as there may be some rare species that are uncommon but are the pillars of the ecosystem. There is also the issue that the distinction between native and non-native species is often not as straightforward as it seems (Manchester & Bullock, 2001). In our case, we are not performing any experiments to see if traditionally invasive species such as Himalayan Blackberry are truly competing with native species, or whether they provide ecosystem services, instead we are making a generalization that such species are detrimental to the health of the ecosystem.

Conclusion

The variables involved in this method all point to ecological integrity as a metric for the health of NMA. Furthermore, even though ecological integrity is a complex metric, we have broken it down into parts and implemented it in urban forest related methodology that can be applied to any natural area in the City of Vancouver. Importantly, ecological integrity includes not only all the measures in the methodology but also assesses how healthy a system is to support humans who use and live around this. As an important first step in site choice, canopy cover is a favorable indicator of microenvironments, which are ideally where the methodology could be further developed in the future. Soil compaction mainly influences bulk density and is shown to be an indicator of the level of human disturbances in parks, and importantly is a quantitative and not qualitative measure of human disturbance. Soil compaction ties in directly to soil quality, which is an indicator of biodiversity and ecosystem health even though many of the NMAs have been disturbed and filled with soil.

Furthermore, measures of biodiversity and invasive and native species play an important role in maintaining or degrading park ecological integrity. The best measure based on the literature is Simpson's index and is relatively simple to calculate adding value to the number of individuals and number of species in an area. All the research points to these factors being important parts of urban parks and although they have downsides, the use of them in a methodology is well-founded and appropriate.

3. Methodology

Our proposed methodology focuses on the interplay between soil quality and vegetation quality, as healthy soil is the cornerstone of a healthy ecosystem (Morgan & Connolly, 2013). The aim was to develop a methodology as a simple tool that can be used to get accurate and meaningful results without needing access to a specialized lab, lots of funding, or an extensive scientific background. This is how our methodology will allow us to evaluate the health of urban parks in an innovative, efficient, but still highly scientific way. To streamline our methodology, factors such as air quality, water quality, and certain human disturbances were excluded. The rationale is that not all sites may have similar water bodies to measure, and air quality is a measure that is hard to differentiate around Vancouver and requires specialized equipment. Human disturbances such as garbage dumping and mechanical destruction across parks are hard to quantify in urban areas.

This methodology is also meant to be easy to implement for the Vancouver Park Board. To do this, a framework based on five different steps was created. The components and the framework itself are flexible and can be applied across different parks and naturally managed areas, resulting in a level of ecological integrity. The steps involved in this framework are outlined in Figure 3 and include: whether the site has high, moderate, or low canopy cover (Figure 2), compaction due to human disturbance, soil quality, native and invasive species coverage, and plant biodiversity. This framework works similarly to a dichotomous key, and goes through the 5 steps above in the order they are presented. Details on equipment and data collection methods are listed in Appendix 1.

3.1 Assessment Factors and Framework

Canopy Cover:

Understanding canopy cover percentage is essential in dividing up the park into smaller sampling sites, as it influences the microenvironments. Microenvironments are small areas within an ecosystem that is distinct due to its temperature, solar radiation and moisture level. of the selected site (Sarah & Zhevelev, 2007; Parmehr et al., 2016; Hasselquist et al., 2018). Areas with higher percentage of canopy cover can block more solar radiation and increase rate of transpiration from the trees, keeping the microclimate of the area cooler . These sites are likely to have a higher soil quality as moisture is locked in which enables better vegetation quality. As the canopy cover fraction decreases, the temperatures of the microenvironment increases(Sarah & Zhevelev, 2007). This is because the ground is more exposed to wind and solar insolation so the soil and the ground above will be warmer.

For the purpose of this study, canopy cover percentage is incorporated as follows: site 1 with high canopy cover greater than 80%, site 2 with moderate to low canopy cover between 80% to 10%, and site 3 with less than 10% canopy cover (Figure 2). Images from airborne Light Detection and Ranging (LiDAR) are an excellent data source to determine the percent of canopy cover of the park, as it is both accurate and can measure the areas covered with trees or shrubs (Liu et al., 2017).

Figure 2: (Top left) plot with no canopy cover, (Top right) plot with medium to low canopy cover, (Bottom) high canopy cover. Photos taken in Everett Crowley Park on March 21st, 2020

Human disturbance or soil compaction:

Urban parks are constantly impacted by park visitors, so their disturbance can be evaluated in different ways (Sarah & Zhevelev, 2007; Environmental Protection Agency 2011). Quantifying litter or surveying park visitors can be time consuming and subjective (Sarah & Zhevelev, 2007), so one of the direct impacts of human disturbance can be measured using the level of soil compaction (Supuka et al., 2009). By measuring the shear strength of the soil, the rate of compaction can be determined. Increased soil compaction in an area will increase human disturbances in the site. Higher compaction levels affect the vegetation by affecting soil pores size, disturbing moisture, air, and nutrient movement (Patterson, 1976; Millward et al., 2011).

To quantify human disturbance, a penetrometer is used to determine an approximate unconfined shear strength. Unconfined shear strength is the ability of the material to resist imposed forces. The Occupational Safety and Health Administration (OSHA) classifies soils into three categories; type A, B, or C (United States Department of Labour, n.d.). Type A soils are the most stable, cohesive and have high unconfined compressive strengths, 144kPa or greater. Type B soils are cohesive, but may have been disturbed or have cracks, they have a compressive strength between 144kPa and 48kPa. Lastly, type C coils are the least cohesive, with particles that do not stick together and have low compressive strength, 48kPa or less. To classify the sites into areas of either high human disturbance or low human disturbance, the OSHA distinctions were reclassified into type A (high human disturbance) as being greater than 120kPa and type B (high human disturbance) as being less than 120kPa.

Soil quality:

Soil health has a distinct role in the functionality of naturally managed areas through its components like organic matter, nutrients, minerals, air and water (Schoenholtz et al., 2000; Andrews et al., 2004). In an ecosystem, soil is an important factor which impacts vegetation, various habitats, animals, plants, birds, and water quality, in turn affecting the ecological health of a park (Millward et al., 2011). Soil ultimately affects the organization, resilience, biodiversity, physical and chemical characteristics, and other aspects of the naturally managed areas (Millward et al., 2011). Without soil there wouldn’t be any parks, whether the soil is formed naturally or brought in, to promote health.

For the purpose of this study two soil samples at each plot are taken. Soil sampling involves measures of the physical properties of soil including bulk density, infiltration, texture, percentage of organic matter, and the chemical property of pH. The suitable ranges of these variables are extracted from articles by O’Neill et al. (2005), Hanks and Lewandowski (2003) and a document by the Environmental Protection Agency (2011).

Table 1 demonstrates the scoring methods adapted from these three documents; use this table for each soil sample taken. For each sample: after measuring each variable, and if the criteria is met, place a score of 1 in the appropriate high or low quality column. In addition, place a 0 in the quality column which did not receive the 1 (For an example calculation, see the results section). In the plots where the two soil sample final scores show clearly a high (or low) quality that is the designation it receives. In the plots where the two soil sample final score show both high and low soil qualities, add the two final scores for low soil quality together and add the two final scores for high soil quality scores together. Whichever combined score is higher determines the ultimate designation of high or low quality soil in that plot.

Table 1: Soil Quality calculation table

Variable	Low Quality		High Quality	
infiltration (in/hr)	<0.25		>0.25	
Sand %	>75		<75	
Clay %	>65		<65	
Coarse Fragment %	>50		<50	
Bulk Density (g/cm3)	>1.5		<1.5	
pH	4 - 8.5		<4 and 8<	
organic matter %	<1		1<	
FINAL SCORE		0		0

Plant Species cover:

Soil and plant species are interlinked as they both affect ecosystem services and biotic components of any NMA (Grime, 1998). Plant species inform scientists about the compositions of flora and fauna, primary production, quantity and quality of habitats (Byrnes et al., 2014). Plant species can be divided into native and invasive species. Native species are adapted to harsh conditions, and provide value for food and shelter for wildlife. They are cost-effective as they require less watering and mulching, and eventually less usage of pesticides (City of Superior). Invasive species are aggressive and can out-compete local native species. This results in a loss of native species, disrupting the natural balance and community, hence affecting the health and productivity of an area (Vila & Weiner, 2004). Furthermore, species cover of either invasive or native species is an important measure particularly in urban parks (Portland Parks & Recreation, 2015; City of Vancouver and Vancouver Park Board, 2018). In this study, the invasive versus native species coverage is determined based on whether native or invasive species within the whole plot are dominant, or cover more than 50% of the site. Species that cover others, generally in the case of English Ivy, are dominant if they grow on top of native species.

Biodiversity:

Plant species diversity is important to consider as it relates to soil health and function. It has been shown that plant species diversity reduces soil erosion resistance on slopes, and that soil loss increases when diversity declines (Berendse et al., 2015). Therefore, diverse plant communities are essential in minimizing soil erosion and keeping ecosystems functional and healthy. In more general terms, biodiversity is important as it is needed to maintain ecosystem services (Isbell et al., 2011). Different species are needed to promote varying ecosystem functions, and the species needed for ecosystem functioning can vary year by year (Isbell et al., 2011). This means it is important to ensure there is an adequate biodiversity in NMAs, since it is an important indicator of general ecosystem health.

In this study, the biodiversity of the plots is determined by the Simpson's Diversity Index (D). This is an index used to calculate diversity which considers both species richness and evenness (Royal Geographical Society). Richness is the number of species per sample area, and evenness is a measure of the relative abundance of the different species in an area. The Simpson's Diversity Index is a method used to compare and contrast the biodiversity of sites amongst each other (Royal Geographical Society).

$$D=1-(n(n-1)/N(N-1))$$

n = the total number of organisms of a particular species

N = the total number of organisms of all species

The output of the Simpson Diversity Index yields results between 0 and 1, with 1 representing complete biodiversity and 0 representing complete uniformity. Therefore, the threshold boundaries are as follows: if $D>0.5$ = high biodiversity, if $D<0.5$ = low biodiversity

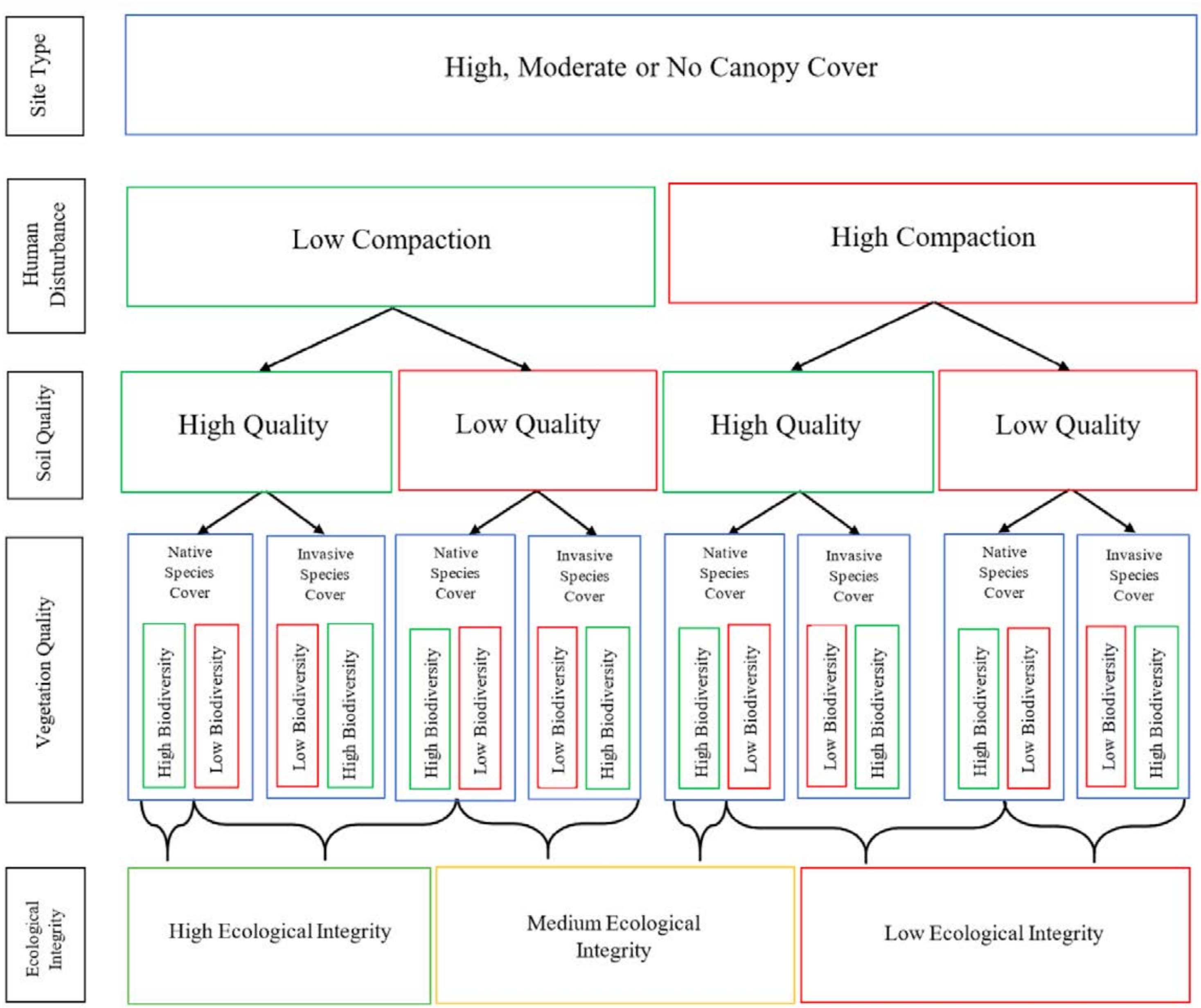


Figure 3: Framework that determines the ecological integrity of a naturally managed area. The process begins by identifying if the sites have no, medium, or high canopy cover then analyses soil compaction as a human disturbance, soil quality, invasive versus native species cover, and biodiversity. This key was adapted from Gibbons and Freudenberger (2006) but altered significantly to work in NMAs.

4. Results

The results of this report focus both on the ecological integrity of Everett Crowley Park, and how the methodology that was created for addressing the health of NMAs was successfully implemented. Figure 4 below shows points of no, medium, and high canopy cover, but this did not translate accurately to the field where upon assessment we changed the canopy designation of some areas. This ultimately meant that four no canopy cover, one moderate canopy cover, and three high canopy cover areas were sampled (Table 4). Photos of each sampling site are given in Appendix 2.

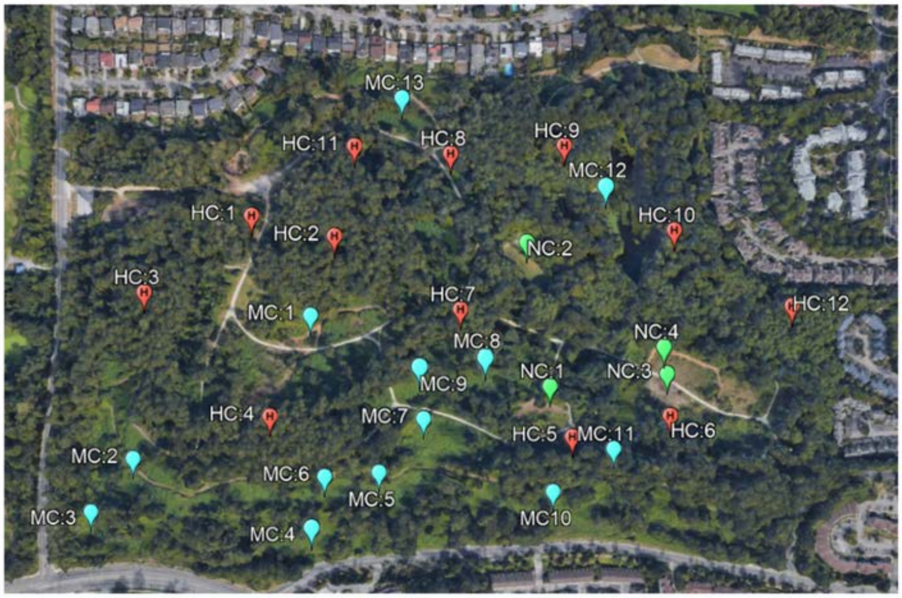


Figure 4: Aerial map of Everett Crowley park showing potential sites. High Canopy cover is indicated by HC, Moderate to low canopy cover indicated by MC, and No canopy cover indicated by NC.

4.1 Human Disturbance

The compaction rates at each site were measured and averaged between two soil sample locations. Results showed an average range of soil compaction between 25 to 172kPa. All the areas with no canopy cover had high compaction rates in the soil, highlighting the fact that areas which have high or moderate canopy cover are harder to access and less likely to be compacted by humans or dogs. The compaction of moderate and high canopy areas were all within the suitable range of 25 to 37kPa, therefore were considered low compaction as seen in Table 4 and 6.

4.2 Soil

The soil within the rooting root zone, which is about the first 7.5 cm of the top layer is mostly silty loam and in a few cases silty clay. This texture was determined using the texture by feel method, but using precise equipment such as sieves and a shaker would have achieved a better result. The pH could not be obtained due to equipment access limitations but because of the amount of mulch and organic matter we believe that the soil is acidic and more suitable for coniferous trees. The bulk density of all the plots ranged between 0.118 to 1.20 g.cm-3.

The average bulk density of the park’s soil, considering the amount of coarse fragments in it, is suitable for plants ranging from short shrubs to large trees. Limited access to equipment meant that the organic matter of soil wasn’t measured, but our rough overall estimate showed that organic matter made up about 20% of the total material in the samples. Although there were areas of high compaction, the infiltration capacity of the plots ranged between 20 to 180 second to infiltrate 1 inch of water. This range also puts the soil samples of this park in a suitable soil group according to the research (Table 6). A sample calculation for waypoint HC10 (Table 2) is shown below:

Table 2: An example of soil calculation is shown above for high canopy cover 10 (Waypoint HC10; Figure 4)

Variable	Low Quality		High Quality	
Infiltration (in/hr)	<0.25	0	>0.25	1
Sand %	>75	0	<75	1
Clay %	>65	0	<65	1
Coarse Fragment%	>50	0	<50	1
Bulk Density(g/cm3)	>1.5	0	<1.5	1
pH	<4 and <8	-	4-8.5	-
Organic Matter %	<1	0	>1	1
Final Score		0		6

4.3 Native versus invasive dominant

More than half (five out of eight) of the randomly sampled plots are dominated by native plant species, however, invasive species such as Himalayan blackberry (Rubus armeniacus) was present in 6 out 8 sampled areas. Dominant native trees included Douglas fir (Pseudotsuga menziesii), Western red cedar (Thuja plicata), Spruce (Picea engelmannii), Black hawthorn (Cratoegus douglasii) and Black cottonwood (Populus trichocarpa). Native shrubs included Vine maple (Acer circinatum), Red-osier dogwood (Cornus sericea), Osoberry (Oemleria cerasiformis), Salmonberry (Rubus spectabilis) and fern species. In two of the plots, located on the east side of the park, English ivy (Hedera helix) cover was 25% in one case and 50% in the other (see Tables 4 and 5 for species counts).

4.4 Biodiversity

In 6 out of 8 plots, and in each of the three canopy cover areas, the biodiversity indices were higher than 0.5. The overall scores and the number of native species indicate that the park's vegetation is representative of high biodiversity. It should be mentioned though that one site with high canopy cover had a low biodiversity indices of 0.16, which pointed to how it is necessary not only to have a high number of individuals on a site, but also that those individuals are divided relatively evenly among species, which was not the case in this site. A sample biodiversity calculation for waypoint HC 10 (Table 3) is included below:

$$D= 1-(n(n-1)/N(N-1))$$

n = the total number of organisms of a particular species

N = the total number of organisms of all species

Table 3: Sample Biodiversity Calculation for Waypoint HC10

Species name	n(n-1)
Cottonwood	2(2-1)= 2
Vine Maple	1(1-1)= 0
Osso berry	25(25-1)= 600
Salmonberry	12(12-1)= 132
Ferns	4(4-1)= 12
Unidentified tree species	1(1-1)= 0
Sum of n(n-1)	746

$$N(N-1)= 45(45-1)= 1980$$

$$D=1-(n(n-1)/N(N-1))= 1-(746/1980)= 0.62$$

As can be seen above, there are a couple of characteristics of Simpson's diversity index that affect the results. First of all it does not give a lot of weight to rarer species such as the vine maple for example in this case plays a little role in the overall score. One big benefit that this index has though is that as long as you can differentiate between plants within the plot, you do not have to identify each species. For example in this site there was one tree which we could not identify but was not a cottonwood tree, this species was still used to get an accurate score.

To tie this all together, through the framework and thresholds for each factor measured, four of the sites had high ecological integrity, three had low ecological integrity, and one had moderate ecological integrity. Although there were not as many samples taken to get a representative look at the park, these results do hold valuable information for determining whether Everett Crowley Park is in poor, moderate, or good health. Also, it should be mentioned here that access to nearly half of the randomly selected sites was limited as they were in full Himalayan blackberry berms. This was taken into account when determining the final health of Everett Crowley Park. Therefore, the results of this study suggest that the health of the parks is moderate and the final overall rating we are giving.

Table 4: Results of data collection, as collected in the field

Field Data Sheet

Plot type	Canopy Cover	Date	Data collectors	GPS Coordinates of plot (SW corner)	Waypoint name	Compaction	Soil Quality 1	Soil Quality 2	Native/Invasive Dominant	Invasive Species (# of plants)				
										H.Black berry	English Holly	English Ivy	English Laurel	Other
Low Canopy Cover	NC	3/21/2020	Noah, Jessica, Farbod	49°12'36.49"N, 123°2'7.79"W	MC8	High	MS-HS	HS	Native	50				
	NC	3/21/2020	Noah, Jessica, Farbod	49°12'35.90"N, 123°1'58.12"W	NC3	High	HS	HS	Invasive	11			1	
	NC	3/21/2020	Noah, Jessica, Farbod	49°12'36.82"N, 123°1'58.27"W	NC4	High	HS	HS	Invasive	10				40 Dune Tansy
	NC	3/21/2020	Noah, Jessica	49°12'34.46"N, 123°2'11.12"W	MC7	High	MS-HS	MS-HS	Invasive	8				
Moderate Canopy Cover	MC	3/21/2020	Noah, Jessica, Farbod	49°12'38.10"N, 123°2'17.01"W	MC1	Low	HS	HS	Native	29				
High Canopy Cover	HC	3/21/2020	Noah, Jessica, Farbod	49°12'38.16"N, 123°1'51.50"W	HC12	Low	HS	HS	Native	4	18			Lamium cover 25%
	HC	3/21/2020	Noah, Jessica, Farbod	49°12'40.85"N, 123°1'57.71"W	HC10	Low	MS-HS	HS	Native			50%	6	
	HC	3/21/2020	Noah, Jessica	49°12'34.64"N, 123°2'19.27"W	HC4	Low	HS	HS	Native			25%		

Table 5: Further results of data collection along with important notes about each site.

Native Species (# of plants)													Biodiversity Indices	Photo # (From SW corner)	Ecological Integrity	Notes
Coniferous Trees			Deciduous Trees				Shrubs					Other				
D. Fir	Cedar	Pine	Spruce	Cotton wood	Alder	Hawt horn	V. Maple	Dogw ood	Osso berry	Salmon berry	Ferns					
1							3	3			2	1 Rose species	0.84	2	Medium	Lots of logs in this area, well worn section
2	1		2			9	7					2 uniden	0.81	3	Medium	The NE corner of this plot is near the trail, big hawthorn but we still consider it to be NC
													0.00	6	Medium	Site about 10 meters from trail with part of it in grassy area
3						2	6		1				0.71	7	Medium	Site is part of a dog track area and appears to have been covered in morning glory (hence invasive dominated)
8		1					5					2 uniden	0.69	1	Medium	Couple of relatively worn paths in the site
				3					30	22		trailing blackb	0.57	4	Medium	Trailing blackberry in this site, hard to count # of individuals
				2			1		25	12	4	1 uniden	0.62	5	Medium	
				4	1				75		1	trailing blackb	0.16	6	High	Lots of coarse woody debris at this site

Table 6: A summarized table, after applying measures such as the soil quality table and Simpson's index calculation.

Plot type	Canopy Cover	Waypoint name	Compaction	Soil Quality 1	Soil Quality 2	Native/Invasive Dominant	Biodiversity Indices	Ecological Integrity
Low Canopy Cover	NC	MC8	High	High	High	Native	0.84	Moderate
	NC	NC3	High	High	High	Invasive	0.81	Low
	NC	NC4	High	High	High	Invasive	0.00	Low
	NC	MC7	High	High	High	Invasive	0.71	Low
Moderate Canopy Cover	MC	MC1	Low	High	High	Native	0.69	High
High Canopy Cover	HC	HC12	Low	High	High	Native	0.57	High
	HC	HC10	Low	High	High	Native	0.62	High
	HC	HC4	Low	High	High	Native	0.16	High

LIMITATIONS

This research was conducted during a school semester for the Environmental Science capstone project so there was a time limit of 13 weeks. We chose the most essential variables as parameters, but with more time and resources, the research would include variables like water quality, air quality and other human disturbance factors. This also means we had limited time to sample and would have preferred to have at least 4 plots done from each canopy cover and 3 soil samples taken per plot. Lastly, we also had issues getting and using equipment due to the closure of SFU near the end of the semester. This meant that data collection and data analysis relating to soil had to be improvised.

RECOMMENDATIONS

The framework methodology can be easily applied to parks across Vancouver as it is or can be tailored to suit the ecology of each park. However, there are some recommendations that can be made for future use of this methodology. First of all if there are other variables that are important to the ecology of the park, for example a water body, a water/stream quality layer can be added into the framework. The framework is flexible in this sense as more or less variables can be added. Also, the site selection of this methodology was based on microenvironments so we recommend doing further research in defining microenvironments to encompass a broader range of factors such as temperature, vegetation type, and land use type. Secondly, it is important to consider the fact that many of the canopy covers that we found using GIS data did not always match what was true in the field, this means it is a good idea to have plenty of extra sites in each canopy cover. Furthermore, we recommend that sampling occur in the spring when most plants are in full bloom and that three or more soil samples be taken at each plot. Lastly, setting up plots that can be evaluated on a yearly basis is our recommendation to ensure that variation in plot and park characteristics is charted, particularly due to the rapid growth of invasive species and the human disturbances across the park.

Everett Crowley Park has come a long way from being a forest, landfill, and now an urban park. The park is still under restoration in terms of establishing more native species and we encourage the continuation of that approach. This will improve accessibility to different areas of the park to collect data, as well as increase the overall biodiversity and ecological integrity of the NMA. Furthermore, the restored areas need to be closed off to human interference to reduce the effects of soil compaction through unofficial trail formation. Areas which are easily accessible and do not have many invasive species should be prioritized before areas where natural barriers such as trees prevent entrance. Overall, this park is popular in the community and has the potential to become an area of great ecological significance.This useful tool that we developed to determine the health of NMAs showed that Everett Crowley Park had a variety of ecological health ratings, but that there is room for improvement. Our methodology showed that efficiency, simplicity, solid scientific evidence, and flexibility were the backbone of this framework of assessment.

Acknowledgements

We would like to thank the following people, without them this project would not have been possible. Vancouver Park Board member Dana Mcdonald for her feedback and insight into Everett Crowley Park, CityStudio Partner Kelly Gardner, Rebecca Ho from the School of Environmental Science for helping us get equipment, and above all our teacher Tara Holland who supported throughout the project. We would also like to acknowledge that at Simon Fraser University we live and work on the unceded traditional territories of the Coast Salish peoples–Sḵwx̱wú7mesh (Squamish), Stó:lō and Səl̓ílwətaʔ/Selilwitulh (Tsleil-Waututh) and xʷməθkʷəy̓əm (Musqueam) Nations

References

A Guide to Simpson's Diversity Index. (n.d.). Royal Geographical Society with IBG. Retrieved from https://www.rgs.org/CMSPages/GetFile.aspx?nodeguid=018f17c3-a1af-4c72-abf2-4cb0614da9f8&lang=en-GB

Andreasen, J., O'Neill, R., Noss, R., & Slosser, N. (2001). Considerations for the development of a terrestrial index of ecological integrity. *Ecological Indicators*, 1(1), 21-35.

Andrews, S., Karlen, D., & Cambardella, C. (2004). The Soil Management Assessment Framework. *Soil Science Society of America Journal, 68*(6), 1945-1962.

Berendse, F., Van Ruijven, J., Jongejans, E., & Keesstra, S. (2015). Loss of Plant Species Diversity Reduces Soil Erosion Resistance. *Ecosystems, 18*(5), 881-888.https://doi.org/10.1007/s10021-015-9869-6

Byrnes, J., Gamfeldt, L., Isbell, F., Lefcheck, J., Griffin, J., Hector, A.,Cardinale, B., Hooper, D.,Dee, L., Duffy, J., & Freckleton, Robert. (2014). Investigating the relationship between biodiversity and ecosystem multifunctionality: Challenges and solutions. *Methods in Ecology and Evolution, 5*(2), 111-124.

Carignan, V., & Villard, M. (2002). Selecting Indicator species to monitor ecological integrity: a review. Environmental Monitoring and Assessment, 78, 45–61.

City of Vancouver. (2012). *Climate Change Adaptation Strategy*. Retrieved from https://vancouver.ca/files/cov/Vancouver-Climate-Change-Adaptation-Strategy-2012-11-07.pdf

City of Vancouver. (2012). Greenest City 2020 Action Plan. (Publication No. 11-125). Retrieved from https://vancouver.ca/files/cov/Greenest-city-action-plan.pdf

City of Vancouver. (2015) Vancouver Bird Strategy. Retrieved from https://vancouver.ca/files/cov/vancouver-bird-strategy.pdf

City of Vancouver and Vancouver Park Board. (2018). Urban Forest Strategy: 2018 Update. Retrieved from https://vancouver.ca/files/cov/urban-forest-strategy.pdf

United States Environmental Protection Agency (2011). Evaluation of urban soils: Suitability for green infrastructure or urban agriculture. EPA Publication No. 905R1103

Superior Wisconsin (2020). Benefits of Native Species. Retrieved from https://www.ci.superior.wi.us/630/Benefits-of-Native-Species

Fraser, R., Olthof, I., & Pouliot, D. (2009). Monitoring land cover change and ecological integrity in Canada's national parks. *Remote Sensing of Environment*, 113(7), 1397-1409

Gibbons, P., & Freudenberger, D. (2006). An overview of methods used to assess vegetation condition at the scale of the site. *Ecological Management & Restoration*, *7*(s1), S10–S17. https://doi.org/10.1111/j.1442-8903.2006.00286.x

Greenest City Scholar and Vancouver Park Board. (2017). Everett Crowley Park: An assessment of current and future restoration efforts. Retrieved from https://sustain.ubc.ca/sites/sustain.ubc.ca/files/GCS/2017_GCS/Final_Reports/Everett%20Crowley%20Park%20-%20An%20assessment%20of%20current%20and%20future%20restoration%20efforts_Campbell_2017%20GCS.pdf

Grime, J. (1998). Benefits of Plant Diversity to Ecosystems: Immediate, Filter and Founder Effects. *Journal of Ecology, 86*(6), 902-910.

Hanks, D., & Lewandowski, A. (2003). Protecting Urban Soil Quality: Examples for Landscapes Codes and Specifications. US Department of Agriculture, Natural Resources Conservation Service.

Hasselquist, N., Benegas, L., Roupsard, O., Malmer, A., & Ilstedt, U. (2018). Canopy cover effects on local soil water dynamics in a tropical agroforestry system: Evaporation drives soil water isotopic enrichment. *Hydrological Processes, 32*(8), 994-1004.

How to Calculate Biodiversity. Protect U.S. Community Invasive Species Network. Retrieved from http://entnemdept.ufl.edu/hodges/ProtectUs/lp_webfolder/9_12_grade/Student_Handout_1A.pdf

Isbell, F., Calcagno, V., Hector, A., Connolly, J., Harpole, WS., Reich PB., Scherer-Lorenzen, M., Schmid, B., Tilman, D., van Ruijven, J., Weigelt, A., Wilsey, BJ., Zavaleta, ES., & Loreau, M. (2011). High plant diversity is needed to maintain ecosystem services. *Nature*, 477, 199–202.

Jacobs, B., Mikhailovich, N., & Delaney, C. (2014). Benchmarking Australia's Urban Tree Canopy: An i-Tree Assessment, Final Report.Prepared for Horticulture Australia Limited. Sydney

Liu, L., Coops, N., Aven, N., & Pang, Y. (2017). Mapping urban tree species using integrated airborne hyperspectral and LiDAR remote sensing data. *Remote Sensing of Environment, 200*, 170-182.

Manchester, S., & Bullock, J. (2001). The impacts of non-native species on UK biodiversity and the effectiveness of control. *Journal of Applied Ecology,* 37(5), 845-864. https://doi.org/10.1046/j.1365-2664.2000.00538.x

Millward, A. A., Paudel, K., & Briggs, S. E. (2011). Naturalization as a strategy for improving soil physical characteristics in a forested urban park. *Urban Ecosystems*, *14*(2), 261–278. doi: 10.1007/s11252-010-0153-4

Mooney, P. (2011). The effect of human disturbance on site habitat diversity and avifauna community composition in suburban conservation areas. *Ecosystems and Sustainable Development,* 144(8), 13-25. doi:10.2495/ECO110021

Morgan, J. B., & Conolly, E. L. (2013). Plant-Soil Interactions: Nutrient Uptake. *Nature Education Knowledge* , 4(8):2.

Nature Conservancy. (1994). Field Methods for Vegetation Mapping: USGS/NPS Vegetation Mapping Program-Final Draft. Retrieved from https://www1.usgs.gov/vip/standards/fieldmethodsrpt.pdf

O'Neill, K., Perry, Charles Hobart, Amacher, Michael C, & United States. (2005). *Soils as an indicator of forest health: A guide to the collection, analysis, and interpretation of soil indicator data in the Forest Inventory and Analysis Program*. USDA Forest Service, North Central Research Station.

Patterson, J. C. (1976). Soil compaction and its effects upon urban vegetation. *FS Santamour, HD Gerhold e S. Little ed., Better trees for metropolitan landscapes, USDA Forest Service (Upper Darby)*, 91-101.

Pariente, S., Zhevelev, H. M., & Oz, A. (2015). Urban Park Soil and Vegetation: Effects of Natural and Anthropogenic Factors. *Pedosphere*, *25*(3), 392–404. doi: 10.1016/s1002-0160(15)30007-2

Parmehr, E., Amati, M., Taylor, E., & Livesley, S. (2016). Estimation of urban tree canopy cover using random point sampling and remote sensing methods. *Urban Forestry & Urban Greening, 20*, 160-171.

Portland Parks & Recreation. (2015). Natural Areas Restoration Plan. Retrieved from https://www.portlandoregon.gov/parks/article/323540

Richardson, J., & Moskal, L. (2014). Uncertainty in urban forest canopy assessment: Lessons from Seattle, WA, USA. *Urban Forestry & Urban Greening, 13*(1), 152-157.

Rutledge, A.M., & Popescu, S.C. (2006). Using LiDAR in determining forest canopy parameters. In: ASPRS Annual Conference, Reno, Nevada, May, 1–5.

Sarah, P., & Zhevelev, H. M. (2007). Effect of visitors' pressure on soil and vegetation in several different micro-environments in urban parks in Tel Aviv. *Landscape & Urban Planning*, *83*(4), 284–293.

Schoenholtz, S., Miegroet, H., & Burger, J. (2000). A review of chemical and physical properties as indicators of forest soil quality: Challenges and opportunities. *Forest Ecology and Management, 138*(1-3), 335-356.

Silva, D., De Marco, P., & Resende, D. (2010). Adult odonate abundance and community assemblage measures as indicators of stream ecological integrity: A case study. *Ecological Indicators*, 10(3), 744-752.

Supuka, J., Bajla, J., & Szombathová, N. (2009). Soil compaction in urban parks and green spaces of the Nitra city as a favourable growth criterion for woody plants.

Tierney, G., Faber-Langendoen, D., Mitchell, B., Shriver, W., & Gibbs, J. (2009). Monitoring and evaluating the ecological integrity of forest ecosystems. *Frontiers in Ecology and the Environment*, 7(6), 308-316.

United States Department of Labour (n.d.). Occupational Safety and Health Administration. Soil Classification. https://www.osha.gov/dts/vtools/construction/soil_testing_fnl_eng_web_transcript.html

Vancouver Board of Parks and Recreation. (2016). Biodiversity Strategy. 53 pp. Retrieved from https://vancouver.ca/files/cov/biodiversity-strategy.pdf

Vancouver Board of Parks and Recreation. (2019). Vancouver's Parks and Recreation: Strategic Bold Moves (Appendix A). Retrieved from https://parkboardmeetings.vancouver.ca/2019/20191009/REPORT-VanPlay-Report3-StrategicBoldMoves-AppendixA-20191009.pdf

Vilà, M., & Weiner, J., (2004). Are invasive plant species better competitors than native plant species? evidence from pair-wise experiments. *Oikos*, 105(2), pp.229-238.

Appendices

Appendix 1: Materials and Sampling Methods

Materials:

-Measuring tape, minimum 40 meters long (2)
-GPS
-Compass
-pH meter
-Stakes (8-10)
-Penetrometer
-Sharpie
-Ziplock Bags (~30)
-Gloves (leather ones to move Blackberry)
-Datasheet (2) and clipboard
-Plant ID book
-Camera
-Maps of canopy cover and associated plot GPS points
-Notebook, pencil
-Machete
-Shears
-Scale

Data Collection Methods and Framework:
To perform the methodology in the field, the following steps must be taken:

-Use GIS to look at LiDAR and aerial orthophotos and find three categories of NMA forest canopy cover: >80% cover, 80 to 10% cover, and <10% cover. Use time periods when deciduous trees have leaves.

-Within ArcMap, generate about 10 points in each of the three areas randomly, discard any points that are 10 meters or less to adjacent polygons and roads and ensure that there is at least one point per polygon (Nature Conservancy, 1994).

-If edge effect occurs while in the field, twist the compass dial multiple times, take a random bearing, and walk in the direction of that bearing until edge effect is mitigated, or walk opposite the bearing if it points back towards the edge. Do this only if there are no randomly selected points remaining. Remember to set a new waypoint for this plot.

-Find your waypoint location in the field (based on the coordinates in ArcMap) and assess whether the canopy cover is true to what it is in ArcGIS. If it is not, then rename the waypoint and change canopy cover based on visual observation.

-Have your partner hold the end of the measuring tape. Take a bearing North and walk 10 meters in that direction ensuring the tape measure is straight and low to the ground.

-Stake the tape measure at 10 meters to hold it in place and repeat this process taking bearings to the East, South, and West until a square plot is formed (See Appendix 2). The 10 square meter plot size is based on guidelines in the Nature Conservancy field methods for vegetation mapping and covers a variety of vegetation types and differing areas (1994, page 56).

-At the center of the plot, take a soil sample using a metal cylinder core of known volume driven into the ground with a hammer. The surficial material of grass, rocks, and debris should be cleared to obtain a sample of just soil. The core should be submerged into the soil fully up to the top and then removed carefully with a shovel. Empty the contents into a labeled plastic bag. In case of encountering hard barriers like gravel or tree roots an area as close as 10 cm to the assigned area will be sampled.

-At the center of the plot take a soil compaction measurement using a penetrometer. We used the Humboldt MFG. Co H-4200. With this penetrometer, the scale indicator was lifted until only the “0.0” was showing. The piston is then inserted into the soil until the soil level reaches the engraved line. This value on the scale indicator is recorded.

-Repeat these two steps above to take a second soil sample, a maximum distance of one meter from the first one, still in the center of the plot.

-Count all vegetation species and determine visually whether the plot is invasive or native dominated. Take notes if there is any homogeneity within the plot and keep notes on rare species and identifiable species names.

-If necessary, use the second tape measure and split the plot into two or three smaller quadrants, this can make counting easier when there are many individuals.

-If you estimate a plot to have more than 100 individuals then take a five by the five-meter plot from the South-East corner (Appendix 2) as a representative sample of the larger plot.

-Take one photo from the starting point of the plot (South-West corner) looking towards the north-east corner and take any other relevant notes.

-Once all the data has been collected, it should be analyzed according to standard procedures for each type of test. The test results should be compiled and results should be categorized into either suitable nor not suitable, healthy or not healthy.

-Once suitability has been determined for each variable, the framework flowchart can be used to determine the ecological integrity of the selected site.

Notes:

-According to the Nature Conservancy guidelines, many parks in Vancouver are classified as medium-sized, this means that at least ten plots per vegetation type, which in our case can be thought of as canopy cover, should be sampled.

-For vegetation types that occur in fewer than 10 polygons, all polygons need to be sampled (Nature Conservancy, 1994).

-In general, one plot per polygon is enough although the following exceptions should be considered: multiple vegetation types within a polygon, where polygons are very large, and where polygons have complex and heterogeneous vegetation cover (Nature Conservancy, 1994).

-Take a bearing and find a natural marker in the distance to move towards, then ensure you walk a straight line keeping the tape measure low down by your side. Do not deviate around trees, invasive species, or any other obstacles.

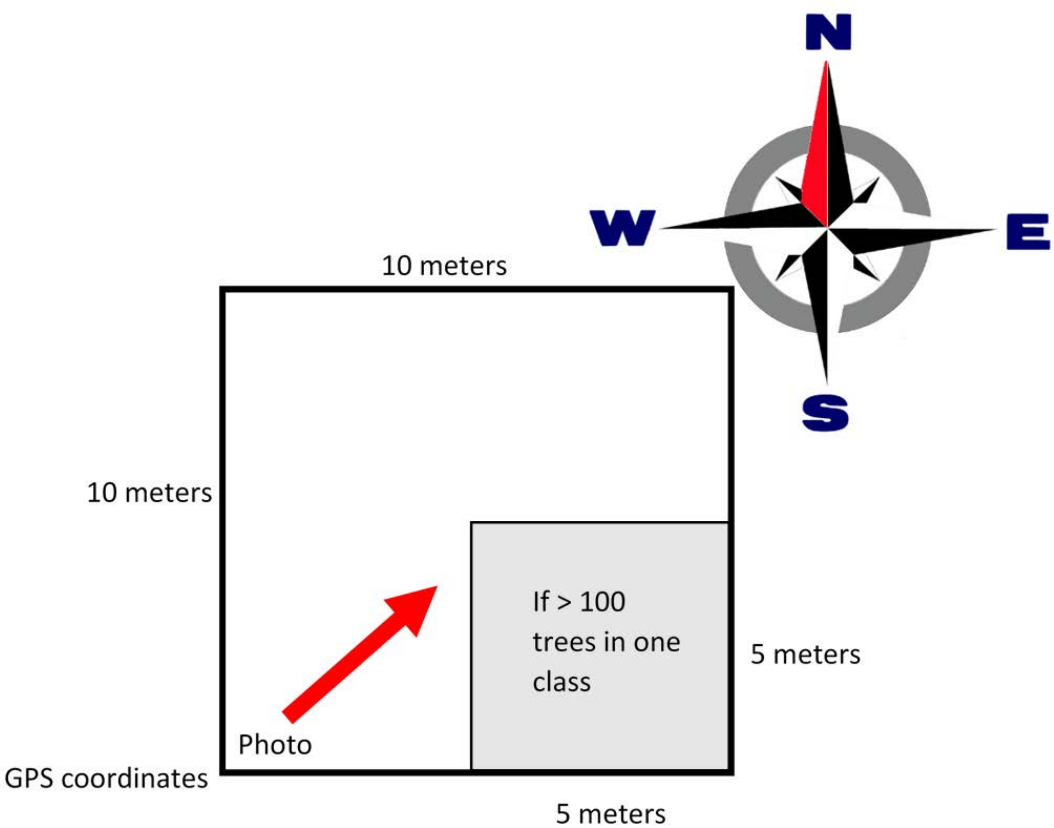
-Ensure that plots are well described in the notes section. According to the Nature Conservancy, this involves taking note of certain abiotic factors: Slope, slope aspect, a soil profile description, soil texture, and soil drainage (1994).

Appendix 2

Site Identification

	
Waypoint MC1 with a moderate canopy cover (March 21, 2020)	Waypoint NC5 with a low canopy cover (March 21, 2020)
	
Waypoint NC3 with a low canopy cover (March 21, 2020)	Waypoint HC12 with a high canopy cover (March 21, 2020)
	
Waypoint HC10 with a high canopy cover (March 21, 2020)	Waypoint NC4 with a low canopy cover (March 21, 2020)

	
Waypoint MC7 with a low canopy cover (March 21, 2020)	Waypoint HC4 with a high canopy cover (March 21, 2020)



A standard 10 by 10-meter plot is illustrated above along with where the GPS coordinates are to be taken and in which direction the photo is to be taken. Note the addition of a five by five-meter plot in the South-East corner if there are over 100 individuals in the large plot.