An Investigation of Evaluation Methods of Weighted-Point Landscaping Policy - in Seattle and Malmö

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Abstract

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Urban vegetation plays an important role in influencing ecological function beyond the individual plant scale. City policies set required quantity and quality parameters for urban vegetation that determine the environmental and societal outcomes and ultimately affect urban residents' wellbeing. The way urban vegetation policies are structured varies due to context but one structure that is primed for analysis, due to its clear outcome objectives and transparent structure, is the use of a weighted-point system landscape policy. The objective of this thesis is to test the applicability of a methodological evaluation of weighted-point landscaping policy by inventorying in two locations Seattle, Washington and Malmö, Sweden, the quantity and quality of vegetated outcomes at different points of time. The weighed-point landscaping policy is a structure containing a menu of obligatory landscaping options to fulfill defined requirements organized by point calculations for built environment, applies each intended to produce specific urban vegetation outcomes. Despite the intention, outcomes from urban vegetation policy vary in

implementation and maintenance over time. Evaluation of the required outcomes hold relevant stakeholders accountable by inventorying fulfillment and deviation from policy intentions.

Evaluative methodology and methods are tested to formalize the cyclical relationship between actual policy outcomes and feedback to improve the policy. The feedback from these methods have the potential to inform policy success over time. Two methods, a supervised Object Based Image Analysis (OBIA) and a vertical structure inventory, have the promise to be effective measurement tools given carefully chosen considerations and inputs. Applying these methods has the potential to inform a modified-BAR vegetation indicator useful for comprehensively referencing the quantity and quality of urban vegetation outcomes from weighted-point landscaping policy. In this thesis, the referenced two methods are used to analyze projects across three time periods and two weighted-point landscaping policy contexts. Lessons learned from this analysis provides a preliminary frame work for generating feedback of the policy's outcomes to inform policy makers and relevant stakeholders.

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Introduction

The environmental and societal systems affected by the existence and characteristics of urban vegetation influence urban residents' wellbeing. Variations of urban vegetation influence urban area's storm water runoff conditions, neighborhood perception, biodiversity, urban heat island effects, and local business vibrancy, all points that ultimately affect urban life.[1] Urban planners have a vested interested in implementing policies aiming to improve these systems by regulating various aspects of vegetation in urban areas. How municipalities regulate vegetation depends on the environmental and administrative context. The most pertinent contextual topics range from the global to the city scale and are a part of environmental and administrative themes.

Some of the stated objectives in urban vegetation policies are meant to mitigate human-driven environmental change and potential risk for human health and wellbeing. These include mitigating the consequences of climate change, reducing storm water runoff from storm events, increasing biodiversity in urban spaces, and reducing urban heat island effect. More recently, municipalities are addressing these environmental objectives through an "adaptive design" paradigm focusing on limited projects.[2] The "adaptive design" paradigm stems from three core points, in brief, by

- applying scientific knowledge as the foundational framework for new policy,
- designing experiments guided by transdisciplinary groups of scientists, planners and designers that balances ecological goals with societal and safety considerations,
- design in "a process and approach in which selected urban plans and projects explore innovative practices and methods"[3].

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[1] Sugimura, Diane M. 2011. "Director's Rule 30-2015." Seattle: City of Seattle Department of Planning and
[2] Ibid
[3] Ahern, Jack, Sarel Cilliers, and Jari Niemelä. 2014. "The Concept of Ecosystem Services in Adaptive Urban Planning and Design : A Framework for Supporting Innovation." Landscape and Urban Planning 125: 254–59.

Due to renewed interest in urban agriculture and green infrastructure more attention of this paradigm has become useful for organizing environmentally-sensitive action, encouraging its relevancy.[4]

One urban vegetation policy structure regulating the quantity and quality of urban vegetation is the weighted-point landscaping structure. This policy structure intends to balance user flexibility while delivering specific environmental outcomes. User flexibility as defined by offering a number of options to fulfill the site-specific requirements. This thesis examines and summarizes the applicability of Object Based Imagery Analysis and vertical stratification tools for evaluating vegetation outcomes from weighted-point landscape policy in Seattle, Washington, USA called Seattle Green Factor (SGF) and Malmö, Sweden called Malmö Green Space Factor (MGSF). Both locations use the weighted-point landscape policy structure to administer how urban vegetation and green infrastructure is executed in their respective areas.

The weighted-point landscaping policy is a structure containing a menu of obligatory options to fulfill defined requirements organized by site-specific point calculations intended to produce specific urban vegetation outcomes. Weighted-point landscaping policy is implemented at the municipal administrative level, opening the policy to legal protections and political influences while setting accountability expectations. Weighted-point landscaping policy is formed with input from several stakeholders (real estate developers, municipal planners) while maintaining the responsibility of municipalities to promote the environmental public goods outlined above, rationalizing the policy's existence. Zoning and building codes form the backbone of these policies tying the policy's requirements and accountability standards to the steps in the construction process and legal standards. Especially pertinent to the administration

[4] Haaland, Christine, and Cecil Konijnendijk Van Den Bosch. 2015. "Challenges and Strategies for Urban Green-Space Planning in Cities Undergoing Densification : A Review." Urban Forestry & Urban Greening 14 (4). Elsevier GmbH.: 760–71. doi:10.1016/j.ufug.2015.07.009

of Seattle Green Factor is land use zoning (where Malmö Green Space Factor relies more on the construction process) to dictate site-specific urban vegetation requirements. Both SGF and MGSF are structured using weighted-point landscaping calculations enforced through the zoning and construction process to meet their policy objectives.

SGF and MGSF policies have objectives to secure specific quantity and quality outcomes for urban vegetation. This thesis identifies urban vegetation outcomes from SGF and MGSF weighted-point landscape policy using a land classification method and a vegetation structure method. Using the results from methods that represent quantity and quality of urban vegetation outcomes can inform a comprehensive indicator to evaluate urban vegetation at a broad level, detailed later in this thesis. Quantity is measured through a land classification method using an Object Based Image Analysis (OBIA) using imagery from the National Agriculture Imagery Program. The OBIA process used starts with restructuring the makeup of the image, creating objects within the image, classifying the objects, and interpreting data. To identify urban vegetation quality, a vertical structure inventory is used. Vertical structure was inventoried through on-site visits identifying the most stratified landscape patch at each site. Results from both of these methods are used for this thesis' proposed evaluation framework.

The evaluation of potential discrepancies between the objectives and outcomes starts from initial planting and over time form the rationale for routine evaluation where the reality and ideal outcomes of urban vegetation policy may be disjointed. Municipalities that are accountable for the implementation and enduring maintenance of specific urban vegetation outcomes may be intimidated by the challenge of evaluating vegetation due to its impermanent characteristics and the large spatial scale. Those accountable for program performance at the municipality level may feel discouraged to attempt an evaluation due to limited data and knowledge. Yet, policy evaluation is necessary in order to ensure the continued performance of the policy and by extension the urban vegetation outcomes. This thesis demonstrates the preliminary steps from which municipalities can accurately and reliably evaluate weighted-point landscape policy outcomes with limited resources. The following programmatically detail two evaluation processes described in three time periods in two weighted-point landscaping policy contexts.

Based on the analysis of the current applications, I recognize the modest applicability of the methods. If key qualities of these methods are understood and contextually executed, these methods have promise to evaluate weighted-point landscaping policy outcomes. The methodology and methods used stem from prior studies that attempt to map urban vegetation outside of the weighted-point landscaping policy structure. The following describes workflow for selecting and forming a methodology apt to evaluating weighted-point landscaping policy outcomes over time.

Literature Review

The rationale and structuring logic of weighted-point urban vegetation policy is embedded in thematic contexts. Evaluation of urban vegetation necessitates identifying urban vegetation's existence usually in terms of quantity and quality. The following literature review explores questions of how to identify urban vegetation by their characteristics. Reviewing possible methodologies and methods of past research is meant to inform what is applicable to future identification processes to then be used for evaluation. Similarities, differences, and expressed limitations are reviewed to inform an applicable identification process.

Methods Used to Conduct the Literature Review

Literature Review Sub-Questions

The goal of this section of the literature review is to address four methodological questions: 1) Where and what form of municipal-level evaluation for urban vegetation policy exists? 2) What precedence, if at all, is there for evaluating progress on stated goals for these urban vegetation programs/studies? 3) Are there similar/differing methods for evaluation? 4) What are the limitations and strengths to the reviewed methods? Finding answers to these questions frame how an evaluation of weighted-point landscaping policy outcomes can be conducted ensuring high levels of accuracy and reliability.

The literature search identified three case studies where urban vegetation policies exists but are not explicitly addressed in the description of the study. Despite finding no methodological, peer-reviewed studies that evaluated weighted-point landscaping policy vegetation outcomes specifically, all studies evaluated urban vegetation within differing contexts, and therefore, landscape policy structures. Each of the study's methodological approaches were compared and their similarities and differences reviewed to answer the literature review questions.

One of the three studies summarized the differing methodologies for mapping urban vegetation (selective and comprehensive; discussed below), the two other studies demonstrated a comprehensive methodology through differing methods. This focused review of methodologies and methods framed what to ask and how to measure the quantity and quality of urban vegetation. It is by no means an exhaustive review and more studies and ideas should be considered before attempting a full-scale evaluation. Nevertheless, the input from these studies formed the background research needed to conduct a trial run of this thesis' objective.

This literature review followed a methodology meant to produce "systematic, explicit and reproducible" outcomes.[5] The search began using a variety of search terms (listed in appendix 1) in 14 journals (listed in appendix 2) found through University of Washington Library Databases, Mendeley search suggestions, and Google Scholar. The search terms used at this step are grouped into three and relate to each other in different combinations. Utilizing the first and second columns the "AND" Boolean search logic in the website search boxes for the journals in appendix 2. Notably, the term "evaluation" was subjectively used to limit search findings to the literature review questions. The following points are gathered from three studies stemming from three academic studies outlined in the table below.

Table 1 – Literature Review in Brief

Title/Author	Publication	Year	Summary

[5] Hunt, Vicky. n.d. "Lecture 2 : Research Design Process." Seattle, WA: University of Washington.

A Methodological Study of Biotope Mapping in Nature Conservation/ Bothmer, Roland , et. al.[6]	Urban Forestry and Urban Greening	2010	Reviews vegetation mapping methods and methodologies used for the identification and protection of valuable biotopes with considerations for biodiversity.
The Urban Environmental Indicator "Biotope Area Ratio" – An Enhanced Approach to Assess and Manage the Urban Ecosystem Services using High Resolution Remote-Sensing/ Tobia Lakes and Hyun-Ok Kim[7]	Ecological Indicators	2012	A method for forming Biotope Area Ratio (BAR) is studied to analyze the benefits and limits of BAR as an indicator to assess and manage urban ecosystems services using high resolution remote-sensing. Using Berlin and Seoul as study sites, BAR benefits and deficits are identified along with how BAR serves as an aggregated indicators for vegetation ecosystem services
The Importance of Temporal and Spatial Vegetation Structure Information in Biotope Mapping Schemes: Case Study in Helsingborg, Sweden/ Tian Gao, et. al.[8]	Environmental Management	2012	Evaluate the application of a modified biotope mapping scheme that includes temporal and spatial vegetation structure. The study considers four parameters to biotope mapping including: continuity of forest cover, age of dominant trees, horizontal structure, and vertical structure.

Similarities

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[6] Bothmer, Roland Von, Marten Hammer, Tian Gao, Allan Gunnarsson, and Qiu Ling. 2010. "A Methodological Study of Biotope Mapping in Nature Conservation." *Urban Forestry & Urban Greening* 9: 161–66. doi:10.1016/j.ufug.2010.01.003.

[7] Lakes, Tobia, and Hyun Ok Kim. 2012. "The Urban Environmental indicator 'Biotope Area Ratio' - An Enhanced Approach to Assess and Manage the Urban Ecosystem Services Using High Resolution Remote-Sensing." *Ecological Indicators* 13 (1). Elsevier Ltd: 93–103. doi:10.1016/j.ecolind.2011.05.016.

[8] Gao, Tian, Ling Qiu, Mårten Hammer, and Allan Gunnarsson. 2012. "The Importance of Temporal and Spatial Vegetation Structure Information in Biotope Mapping Schemes: A Case Study in Helsingborg, Sweden." *Environmental Management* 49 (2): 459–72. doi:10.1007/s00267-011-9795-0.

What was common amongst the studies was the need to define terminology and follow similar, but not totally alike, workflows using many inputs to conduct an evaluation. A reminder, analyzing these study's norms for evaluation is useful for attempting the objective this thesis to find and reflect upon applicable evaluating methods for outcomes of weighted-point landscaping policy over time. The similar concepts listed below should be addressed in future attempts of evaluation including the attempt in this thesis. The research begins with defining terms and guiding parameters.

Definition of Terms

Defining terms was a common thread through the studies. To hone and direct vocabulary guiding the reader through the layers of overt and subvert meaning for terms used to evaluate urban vegetation. An example of a term defined by all of the three studies is biotope; biotope is explained definitely in one study as "variable-scale environmental unit of a landscape...an area with uniform environmental conditions providing a habitat for a specific assemblage of plants and animals".[9] As biotopes are important to biological components and functioning "they [are also] significant for human health and well-being through...absorption of air pollution and noise from traffic, creation of shade and ventilation corridors reducing the *heat island effect* of urban areas, and reduction of surface run-offs".[10] Biotope in this thesis is defined by this definition. Defining terms reduces researcher and reader confusion in order to specify and evaluate the relatively nuanced changes of the urban vegetation being evaluated.

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[9] Bothmer, Roland Von, Marten Hammer, Tian Gao, Allan Gunnarsson, and Qiu Ling. 2010. "A Methodological Study of Biotope Mapping in Nature Conservation." Urban Forestry & Urban Greening 9: 161–66. doi:10.1016/j.ufug.2010.01.003.

[10] Lakes, Tobia, and Hyun Ok Kim. 2012. "The Urban Environmental indicator 'Biotope Area Ratio' - An Enhanced Approach to Assess and Manage the Urban Ecosystem Services Using High Resolution Remote-Sensing." Ecological Indicators 13 (1). Elsevier Ltd: 93–103. doi:10.1016/j.ecolind.2011.05.016.

Approach to Evaluation

Put simply, all of the studies follow a set approach to evaluate urban biotope. The six steps include "1) Collection of basic materials 2) Analysis of the collected data 3) Basic classification 4) Field surveys 5) Identification of actual biotopes in the area 6) Contextualization of results in relation to the research question".[11] Where each step differs slightly is dependent on each study's respective research question. Yet, the studies broadly follow each outlined step. To create a workflow these steps serve as reference in forming a workflow to evaluate urban vegetation outcomes of weighted-point landscaping policy in this thesis.

Indicators for Vegetation

The last commonality is the use of indicators, which in these studies use proxies for urban vegetation to analyze the state or condition of biotope as it exists. Indicators useful as they are "standardized…comparable…and comprehensible…for a specific planning or management goal".[12] Where the choice in indicator differs, the similarity holds in the fact indicator are used. Two of the example indicators used to evaluate a site's biotope include the Biotope Area Ratio[13] and vegetative structure.[14] BAR is an indicator that represents the existence of urban biotopes.[15] Calculating Biotope Area Ratio (BAR[16]) stems from the land classification results in step 3 of the workflow. It is defined as the ratio of the amount of ecologically effective surface area (biotope) to the total land area within the study site (by parcel lines).[17]

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11 Ibid
12 Ibid
13 Lakes, Tobia, and Hyun Ok Kim. "The Urban Environmental indicator 'Biotope Area Ratio' - An Enhanced Approach to Assess and Manage the Urban Ecosystem Services Using High Resolution Remote-Sensing." 2012.
14 Gao, et. al. "The Importance of Temporal and Spatial Vegetation Structure Information in Biotope Mapping Schemes: A Case Study in Helsingborg, Sweden." 2012.
15 Ibid
16 Ibid
17 Bothmer, Roland Von, Marten Hammer, Tian Gao, Allan Gunnarsson, and Qiu Ling. 2010. "A Methodological Study of Biotope Mapping in Nature Conservation." Urban Forestry & Urban Greening 9: 161–66. doi:10.1016/j.ufug.2010.01.003.

While BAR is a high-level indicator that broadly represents quantity of biotope, vegetative structure can add more detail to BAR by adding spatial and temporal dimensions to the indicator. Vegetation structures can, and in one of these studies do, incorporate temporal elements such as the continuity of vegetative cover (the presence of vegetation cover over time) and the mean age of dominant trees.[18] Spatial aspects are important to defining the vegetation structure by including horizontal (the distribution of vegetation elements that can be seen in plan view) and vertical elements (vegetation categorized by vertical stratification of canopy layer, understory, shrub layer, and field layer).[19] Vegetation structure tends to be measured within the "boundaries of homogenous biotopes".[20]The inclusion of vegetation structure into BAR is referred to as Modified Biotope Area Ratio, diagramed in figure 1. A Modified Biotope Are Ratio offers insight into the quantity and quality of studied vegetation.

All of these indicators can be used to assess and monitor the state of urban vegetation for strategic purpose. These indicators are benchmarks in which to measure urban vegetation over time accounting for the difficulty in manpower and resources necessary to measure vegetation over large swathes of land or have limited access due to vegetation located on private property.

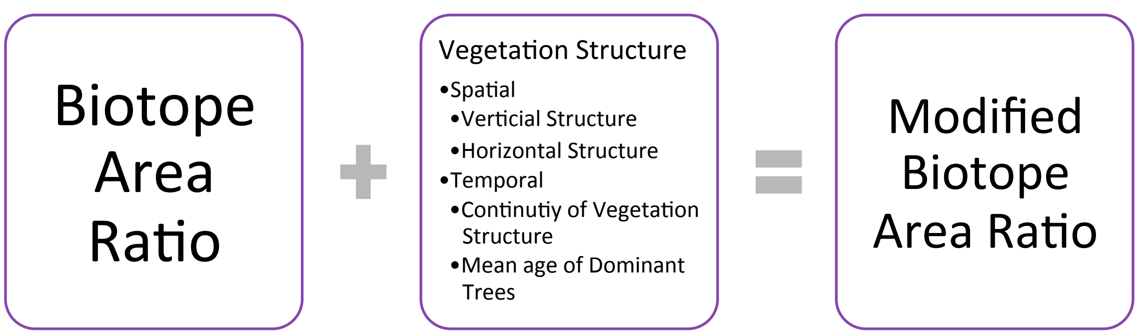

Figure 2 - Graphic of BAR

[18] Ibid
[19] Ibid
[20] Gao, et. al. "The Importance of Temporal and Spatial Vegetation Structure Information in Biotope Mapping Schemes: A Case Study in Helsingborg, Sweden." 2012.

Differences

While there are some similarities among the studies, more telling are the differences due to the differing research questions, methodology, and subsequent accuracy of evaluation. Summarizing the differences details how to appropriately and contextually create new evaluative processes for urban vegetation given different study-site specific considerations.

Differences in Methodology

Depending on the research question, there are multiple methods and, as discussed earlier, indicators for evaluating a site's biotope. Methodological frameworks channel the myriad of options to answer the research questions. While some studies implement a comprehensive methodology layering in more data and setting a large study area, other methodologies are more selective to answer more defined questions at a finer level.[21]

Methodology frames every evaluation choice subsequent to that decision. Comprehensive methodology, as Roland Bothmer, et. al. suggests, due to the its broad nature, meaning all land uses within an area are investigated, means more "preparatory work is needed, compared with selective biotope mapping, including various types of maps and aerial photos…. [while] integrat[ing] field surveys concerning biological, non-biological and historical or cultural aspects".[22] Comprehensive biotope studies account for green and built areas using many layers of secondary data and expert input to identify land uses.[23]

Selective methodology is used for finding the amount and condition of selective urban biotope (excluding built areas). This methodology uses methods that more commonly identify vegetation structure and space and time considerations to explore conclusions specific to

[22] Bothmer, Roland Von, Marten Hammer, Tian Gao, Allan Gunnarsson, and Qiu Ling. 2010. "A Methodological Study of Biotope Mapping in Nature Conservation." Urban Forestry & Urban Greening 9: 161–66. doi:10.1016/j.ufug.2010.01.003.
[23] Lakes, Tobia, and Hyun Ok Kim. "The Urban Environmental indicator 'Biotope Area Ratio' - An Enhanced Approach to Assess and Manage the Urban Ecosystem Services Using High Resolution Remote-Sensing." 2012.

biodiversity questions.[24] These data sources can combine detailed inventories of temporal information such as Ancient Woodland Indicators species, in addition to horizontal and vertical structure data stemming from in-person, field studies and expert surveying, aerial photos, and historic land-use maps.[25] In practice, generally this methodology produces studies with three objectives: to be used as a tool for planning to maintain urban environments, record urban biodiversity opportunities, and also serves as a benchmark indicator for a repeatable process that recognized urban vegetation trends over time.[26] . In order to evaluate places where weighted-point landscaping policy applies, these methodological differences are reviewed to better inform choices for making new, contextually-specific evaluation workflow.

Differences in Land Classification Methods

The land classification processes used to make BAR values are study-specific for both comprehensive and selective urban vegetation evaluations. The methods used are used to define the land classification values (pixel classification or object-based image analysis measurement methods, or expert knowledge) dependent upon the objective of the study that may be used to inform indicators like BAR calculations. Examples demonstrating the complex ties due to the mixing of data and methods is visualized in appendix 3; figures 1 and 2. Each method for classifying land that forms the foundational data for BAR calculation had a classification accuracy of 86.7% in the Berlin study and 79% in the Seoul study using a comprehensive

[24] Bothmer, Roland Von, Marten Hammer, Tian Gao, Allan Gunnarsson, and Qiu Ling. 2010. “A Methodological Study of Biotope Mapping in Nature Conservation.” Urban Forestry & Urban Greening 9: 161–66. doi:10.1016/j.ufug.2010.01.003.
[25] Gao, et. al. “The Importance of Temporal and Spatial Vegetation Structure Information in Biotope Mapping Schemes: A Case Study in Helsingborg, Sweden.” 2012.
[26] Bothmer, Roland Von, Marten Hammer, Tian Gao, Allan Gunnarsson, and Qiu Ling. 2010. “A Methodological Study of Biotope Mapping in Nature Conservation.” Urban Forestry & Urban Greening 9: 161–66. doi:10.1016/j.ufug.2010.01.003.

methodology.[27] This differs from studies that use a selective methodology that may already identify biotope areas from natural resource maps or experts to inventory existing conditions.[28] BAR, each workflow starts with land classification methods that classify at a broad level and then, using more data, narrow to classify to then incorporate details at a finer scale using indicators to create a more accurate, comprehensive evaluation.

Limitation and Unresolved Questions in the Reviewed Literature

Each reviewed study does address caveats and areas of improvement in answering their respective research questions. One of the limitations is finding an indicator that fully encompasses the findings as they relate to the research questions. If indicators are used, there will always be faults in what the indicator is meant to represent versus what is true on-the-ground. This is also the case in evaluations using indicators like BAR and vegetation structure when studying urban biotopes.

"Biotope Area Ratio" as an indicator has limits, most prominent being its generalizability. Originally, this indicator was developed to address the "ecological value of highly sealed urban areas within the inner core of West Berlin, Germany in the late 1980s".[29] The instrument has evolved over time and used for identification purposes over evaluative purposes, by "reflecting several ecosystem services in one quantitative indicator" providing "a tool for decision-making in environmental planning and management".[30] Using the BAR indicator at other sites, researchers need to be cognizant of its relevance for answering differing research questions within different contexts and adjust accordingly.

[27] Ibid
[28] Ibid
[29] Lakes, Tobia, and Hyun Ok Kim. "The Urban Environmental indicator 'Biotope Area Ratio' - An Enhanced Approach to Assess and Manage the Urban Ecosystem Services Using High Resolution Remote-Sensing." 2012.
[30] Ibid

In acknowledging the site's differences, the BAR indicator must reflect these differences in its creation by calibrating the ratio to determine a contextually representative BAR. For example, land classification in Berlin is different from land classification in Seoul where there are differing amounts of data available with differing defining characteristics. Further, the same process used to determine classified land in Seoul would not work in Berlin where aerial photography and digital elevation model (DEM), data details (resolution, shadow lengths, percentage of cloud cover), and vegetation identification processes differ. Seoul land cover data differ in that it contains more square footage of surface water and diversified greenery found on roofs.[31] This, consequentially, requires altering the process variables used to calculate land classification and BAR by accounting for more surface water and vegetation on roofs in the identification process.

Informing the methodology and methods used in the study is the availability and characteristics of data. There are many types of data specific to urban biotope evaluation needed to perform an accurate analysis. For all studies, the availability of data defines the scope of the research question. One of the studies reflected on the lack of data to adequately address research questions. In order to meaningfully make comparisons, a foundational data environment is essential for assessment in a "reliable, comparable, and affordable" way.[32] More aerial data is not easy to acquire as researchers admit "spectral information content" is a burden to collect (due to logistics and cost), is time-intensive, and requires a skilled hand in order to "clean" and decipher.[33] It is hopeful, however, that through the advancement of "rapidly developing sensor

[31] Ibid
[32] Ibid
[33] Ibid

technology together with advanced image processing methods" this will make the process cheaper and easier to conduct.[34]

The limitations thus far have been focused on qualifying BAR as an indicator and the data used to calculate BAR. Vegetation structure as an indicator also has concerns. Namely, the logistical hardship of visiting sites and accurately measure the stratification. For example, one of the methods used to measure vegetation structure is vertical structure. In order to measure vertical structure, the researcher(s) conducts on-site field visits to record the level of vertical structuring of vegetation. This takes a concerted effort to travel, get permission to access the site, objectively inventory, and analyze the findings.

A point worth reiterating especially for measuring vertical structuring is objective recording. Due to the cyclical nature of vegetation its physical shape and height may change with the season. What may be three feet in the summer may be two feet in the winter as, for instance a stalk that has shrunk or wasted away in accordance to the plant's cycle to its dormant winter phase of life. This change in height may be significant when trying to determine if the vegetation is groundcover or shrubbery. If the vertical structure inventory has not been conducted in the same season, the results may be recorded differently and the findings may be inaccurate. Inconsistent collection of data and analysis are common limitations amongst various spatial and temporal variables that form vegetation structure.

[34] Bothmer, Roland Von, Marten Hammer, Tian Gao, Allan Gunnarsson, and Qiu Ling. 2010. "A Methodological Study of Biotope Mapping in Nature Conservation." Urban Forestry & Urban Greening 9: 161–66. doi:10.1016/j.ufug.2010.01.003.

Summary Points from the Literature Review

The reviewed literature partially answers the questions stated at the beginning of this section. While studies specific to evaluating outcomes from weighted-point landscaping policy do not yet exist; this literature review chose studies evaluating urban vegetation outcomes from other landscape policy structures. These studies serve as reference for how a trial-run evaluation of weighted-point landscaping policy outcomes is attempted by identifying relevant methodologies, methods, variables, and contextualizing information.

A comprehensive methodology (also the methodology addressed in the literature review) was used for evaluation in this thesis. This decision was made because the selective methodologies tend to focus on evaluating strictly on identifying biotope and its connection to biodiversity. As the weighted-point landscaping policies examined in this thesis encourages specific outcomes both in biotope and built space, a comprehensive methodology was chosen to possibly account for and evaluate both land use types. The six steps[35] referred to earlier follow the comprehensive methodology to ensure a systematic, repeatable, and contextualized process can be followed in the future. Two methods were identified as being within the scope of what this researcher could perform given time and knowledge constraints – BAR calculation and vertical structure inventory – to be detailed below. There are a number of limitations learned (availability of resources and relevancy of data parameters), some avoided and others unavoidable yet heeded in order to form an accurate, applicable evaluation process.

[35] 1) Collection of basic materials 2) Analysis of the Collected Data 3) Basic classification 4) Field surveys 5) Identification of actual biotopes in the area 6) Contextualization of results in relation to the research question

Weighted-Point Landscaping Policy Study Groups

Two cities–Seattle and Malmö-where weighted-point landscaping policies apply were chosen for evaluation due to data availability and proximity to the researcher. Although different in context, structure, and objectives, broadly, these two policies and applicable locations share like characteristics in structure and objectives. The two versions of weighted-point landscape policy were chosen and assessed. Starting with the older policy (published in 1999)[36], Malmö Green Space Factor served as one of the inspirations for Seattle Green Factor (enacted in 2007). What follows are the contexts of the two weighted-point landscaping policies addressing their contexts, definition, organization, and, for Malmö, past attempts at evaluation.

Malmö Green Space Factor Summary

Located in southern Sweden, Malmö is adjacent to the Straight of Öresund across the water from Copenhagen, Denmark, mapped in appendix 4. Malmö's weighted-point landscaping policy is titled Green Space Factor (GSF). Its first policy incarnation applies at the Bo01 housing exhibition in Malmö's Western Harbor for the European Homes Fair in 2001.[37] The Western Harbor, has undergone significant changes from its early days as a shipbuilding district to its current resurgence as a destination where the vast majority of Malmo's "10,000-12,000 professional visitors… come to study sustainable urbanism each year".[38] The site has also earned a number of sustainability awards.[39]

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[36] City of Malmö. 1999. "Quality Programme Bo01 1999-03-31." *Bo01 Framtidsstaden*. Malmo, Sweden: City of Malmö.

[37] Gemzoe, Lars. 2017. "Regional Architecture, Human Scale, and Sustainability - Session 8." In *Danish Architecture and Urban Design*. Copenhagen: Gehl Architects.

[38] Jönsson, Erik, and Ståle Holgersen. 2017. "Spectacular, Realisable and 'everyday': Exploring the Particularities of Sustainable Planning in Malmö." *City* 4813 (September): 1–18. doi:10.1080/13604813.2017.1325186.

[39] Ibid

A Brief History of Malmö's Western Harbor

In the 1940s, Malmö looked very different from today due to the heavy influence of the shipbuilding industry. The shipbuilding in Malmö's Western Harbor industry produced the world's first all-welded merchant vessel in 1940 and produced the most tonnage in the world in the years 1952 and 1953.[40] Expansion of factory space and ship manufacturing kept up with demand until the 1970s when demand dramatically changed in 1973 due to the oil crisis and increased competition from East Asian companies.[41] Shipbuilding companies and accessory subcontracting companies shut down in approximately 1986 leaving employment gaps and incentives for Malmö residents to move to the suburbs outside of the Western Harbor to avoid high costs of living.[42] In the 1990s, government intervention started to economically restore the area through ecologically-sensitive planning.

Bo01 Western Harbor Planning Program and Stakeholders

Before going into the details of the Western Harbor redevelopment it is important to note one of the most influential players in the Swedish building process to understand the inception of landscaping policy: the Swedish government. Through multiple levels of governmental planning bodies (national, regional, and municipal), new development is approved and executed with consequential outcomes on land and building uses. All levels of government have their specific roles defined by The Planning and Building Act which requires regional, comprehensive planning, area regulations, and detailed development plans for subsections in urban areas.[43] Beyond making major transportation and maritime planning decisions, the national and regional levels of governance have limited oversight in local municipal land use decisions for

[40] Gemzoe, Lars. 2017. "Regional Architecture, Human Scale, and Sustainability - Session 8." In *Danish Architecture and Urban Design*. Copenhagen: Gehl Architects.
[41] Ibid
[42] Ibid
[43] Ibid

development activity outside of the Stockholm suburban regional area.[44] Nevertheless, local municipalities are obligated to compile a plan to provide an adequate housing supply audited once every 4 years (the length of the average political office tenure) that accounts for growth and changes within the municipality.[45] This review must include implementing housing for "persons that [due to] social and/or socio-economic reasons are not able to arrange housing by his/her own means".[46]

From the policies governing federal bodies to local guidance the Swedish real estate development processes differ from American processes.[47] The differences continue at the first step of development where detailed planning is conducted for the area by the planning department. After planning is conducted, developers are notified and the planning department chooses a few developers from the pool to start "developer's dialogues".[48] The "developer's dialogues" discuss basic financial, urban design, construction, and other logistical issues ensuring financial and market realities are addressed.[49] The output of this dialogue is a "consortium agreement" between the planning department and real estate developer.[50] As part of this agreement there are agreed upon community and environmental-friendly goals and targets to be met in order to approve of the land sale and obtain building permits. In a country where the municipalities are large land owners it is common to have the developer and planning body work together to find a land price that heavily considers the extent developers are willing to advance regional, comprehensive, and neighborhood goals.[51]

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[44] Ibid
[45] Ibid
[46] Ibid
[47] Breslau, K. 2007. "The Green Giant." Newsweek CXLIX (51): 51–59.
[48]Ibid
[49] Ibid
[50] Ibid
[51] Ibid

The above outlined process can be said to be "built on shared interests, shaping the visions and expectations for implementation through dialogue and collaboration, establishing a culture of trust among the various actors, and formalizing expectations in building agreements" as further diagramed in appendix 5.[52] The major themes highlighted through the development process of the Western Harbor are the close relations between developer and government agency and the environmental and livability consequences due to these connections.

[52] Ibid

Bo01 – The Western Harbor

In the late 1990s, these were the contextual development conditions for the redevelopment of the Western Harbor. In 1995 under new mayoral guidance, Malmö gained new interest from regional governance to make the inner city/Western Harbor more appealing to residential and business interests.[53] The city was granted 250 million SEK ($34 million USD) from the Swedish state the Local Investment Program containing 6.2 billion SEK earmarked in the years 1998 – 2002 used primarily to fund sustainability projects and secondly to provide employment.[54] The dramatic redevelopment culminated in the Bo01 project involving the Malmö municipal planning department, 18 housing developers, 22 architecture firms, and 22 project managers.[55] The culmination of these planning processes resulted in the Bo01 plan on 24 hectares of land with 1,200 housing units and 1,700 inhabitants of mixed-use developments.[56]

Figure 2 - Map of Bo0 2
(Gemzoe, Lars., 2017)

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53 Larsson, Ola Segnestam. 2011. "CITY REPORT: MALMÖ, SWEDEN." WILCO 21: 1–35.

54 Jönsson, Erik, and Ståle Holgersen. 2017. "Spectacular, Realisable and 'everyday': Exploring the Particularities of Sustainable Planning in Malmö." *City* 4813 (September): 1–18. doi:10.1080/13604813.2017.1325186.

55 Gemzoe, Lars. 2017. "Regional Architecture, Human Scale, and Sustainability - Session 8." In *Danish Architecture and Urban Design*. Copenhagen: Gehl Architects.

56 Ibid

The Malmö Green Space Factor requirements were enforced by requiring the developer to submit landscape plans to municipal landscape architects at the city planning office.[57] Seattle's and Malmö's weighted-point landscaping policy are similar in structure if not in factor choices. The logic is as follows where the factors are assigned values for each surface type from a menu of options, multiplied by their area, and summed:[58]

$$GSF = \frac{(area\ A\ x\ factor\ A) + (area\ b\ x\ factor\ b) + (area\ C\ x\ factor\ C) + etc.)}{total\ courtyard\ area}$$

Factor multipliers vary by surface type from 1 for vegetation that is in contact with ground water (where there is no underground parking beneath) and open water, to 0 for sealed areas.[59] The higher valued factors are assigned to green roofs, large trees, vegetation in beds over 800 millimeters of soil and wall areas with climbing plants. In addition to the Green Space Factor logic there are also Green Point requirements (both Green Space Factors and Points are listed in appendix 6). Green Points are defined on an additional menu of 35 features for public spaces in close proximity to the private development in which 10 of points are required in the development plans. Malmö's Green Space Factor (MGSF) differs from Seattle Green Factor in consequential ways. Potentially the most influential being higher ratio requirements on the parcel[60] regulating the design of vegetated or MGSF-approved surfaces.[61]

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[57] Ibid
[58] Ibid
[59] Ibid
[60] 0.5 requirement for MGSF compared to 0.3 requirement for SGF

Past Bo01 Evaluations

In 2002, a year after construction, the Bo01 developments were evaluated on how well they accomplished their 0.5 requirement. A year after the housing expo, "most developments had more or less achieved the Green Space Factor".[62] It is unclear how this evaluation was conducted. The developments that did not maintain their score stems from climbing vines not being replaced after installation.[63] Beyond an inventory of the Green Spaces and Points, the intended objectives of the vegetation were evaluated based on their success. In 2002, residents were surveyed as part of a competition to "find the courtyard most suitable for biodiversity while still offering a good environment for the residents".[64] After consultation with representatives from the Swedish National Board of Housing, Building, and Planning, the Swedish Agricultural University, the Swedish Nature Conservation Association awarded one of the smaller courtyards in Bo01.[65] The courtyard (surrounded by residences and businesses) were arranged in biotopes with 40 different species of wild and regional wetland plants.[66] Five other yards were awarded special prizes due to their "interesting and aesthetic biotopes, a very high Green Space Factor, or an intensive green roof".[67]

Finally, one of the goals of the Green Space Factor is to improve biodiversity at the site. Pre-construction of Bo01, there was no baseline survey of biodiversity. From 2002-2005, bird surveys were conducted finding 12 nesting species in addition to one of the bat boxes being

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[61] Kruuse, Annika. 2011. "GRaBS Expert Paper 6: The Green Space Factor and the Green Points System." http://www.grabs-eu.org/downloads/EP6 FINAL.pdf.
[62] Ibid
[63] Ibid
[64] Ibid
[65] Ibid
[66] Ibid
[67] Ibid

occupied.[68] Lastly, the rate of recolonized plant species was high as evidenced in three biotopes in one of the parks in Bo01.[69] The biotopes, however, were of woodland character and the recolonizing plants were weeds – not helping to accomplish the goals of the biotopes.[70]

Seattle Green Factor Defined

The second weighted-point landscaping policy used to test evaluation methods is Seattle Green Factor (SGF). SGF is the product of talks started in 2003 by a Seattle's advisory committee of architects, developers, neighborhood residents, business owners, and planners to review the commercial section of the land use code.[71] Seeing examples from other parts of the world (Berlin and Malmö) helped the committee build the contextual rationale for SGF.[72] In 2007, the SFG superseded the old commercial code for buildings within the relevant zones (mapped in appendix 7).

The Policy and Intent

The Seattle Green Factor is a vegetation policy that requires all new developments in neighborhood business/commercial districts with more than four dwelling units, more than 4,000 sq. ft. of commercial uses, or more than 20 new parking spaces to meet the stipulated regulations.[73] City of Seattle Ordinance 122311 contains the codified language for Seattle Green Factor.[74] It states, developments within commercial and neighborhood commercial zones must reach a score of .30 up to a value of 1 in order to receive their construction permit.[75] Prior to

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[68] Kruuse, Annika. 2011. "GRaBS Expert Paper 6: The Green Space Factor and the Green Points System." http://www.grabs-eu.org/downloads/EP6 FINAL.pdf.
[69] Ibid
[70] Ibid
[71] Elizabeth, Stenning. 2008. "An Assessment of the Seattle Green Factor: Increasing and Improving the Quality of Urban Green Infrastructure." Thesis. University of Washington - Seattle.
[72] Ibid
[73] City of Seattle Department of Planning and Development. 2007. "Seattle/green Factor." Seattle: City of Seattle.
[74] Ibid
[75] Code, S. M. 23.47A.016 Landscaping and screening standards. (2006). Seattle, WA: City of Seattle City Council.

receiving the final Certificate of Occupancy, the developer must submit verification that the approved landscaping has been properly installed per the approved landscape plan.[76]

Developers must choose from a menu of landscaping items both vegetative and non-vegetative (permeable pavement, water features) in order to reach this requirement. The initial 2007 version of SGF is split into five types of designations and given a score based on the amount of area it occupies. Bonuses are supplemented in addition to these required vegetation divisions and used to incentivize the planting of drought-tolerant plants and landscaping that is visible to passers-by.[77]

At a high level, the first five divisions are separated by the soil depth needed for various amounts of vegetation. Vegetation that is horizontal and occupies all stories below the roof is divided and given a different scoring dependent upon their soil depth. Vegetation less than 24" (including ground cover plants and shrubs 3' or shorter at maturity) are given different multipliers than vegetation and non-vegetated materials with soil depth more than 24" (including lawn, shrubs, trees, and permeable pavements).[78] Green roofs, vegetated walls, and water features make up the rest of the five primary divisions developers can be used to earn a score of .30 or higher on their construction permit. The .30 score requirements is a reference from the requirement from the older vegetation code.[79] These divisions and language are further detailed in the SGF worksheet for developers in appendix 8.

Director's Rule 8-2007 a document detailing information about the initial SGF ordinance states the submission of landscape plans for City review are also used for SGF calculations and,

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[76] Sugimura, D. M. (n.d.). City of Seattle Department of Planning and Development Land Use – Technical Standards and Procedural Requirements.

77 Ibid, 2006

[78] City of Seattle Department of Planning and Development. (2007). Seattle/green factor. Seattle: City of Seattle.

[79] Elizabeth, Stenning. 2008. "An Assessment of the Seattle Green Factor: Increasing and Improving the Quality of Urban Green Infrastructure." Thesis. University of Washington - Seattle.

once SGF-approved, are designed to accomplish many goals which align with Seattle Green Factor goals, most pertinently "reduce drainage problems and improve water quality, and to enhance the beauty of the city".[80] Other consequences include "the reduction of headlight and reflective glare, reduction of solid hard surfacing in built environments such as in parking lots, cooling from shade, protection from wind and rain, reduction of dust and pollution, creation of habitat and food for wildlife, protection of and improvement in air quality, and provision of privacy".[81]

SGF differs most notably from the previous open space/vegetation requirement for commercially zoned developments because it is dependent upon the land area versus the gross residential square footage area. Land area was chosen due to the variability of vegetation outcomes from referencing gross residential square footage used in previous vegetation policies.[82] Also, SGF is both more comprehensive and streamlined in communicating the landscape requirement from several governmental agencies to private stakeholders. Whereas before SGF's implementation, a developer would need to get landscaping approvals from five city agencies[83], SGF provides clarity to multiple agencies with a single form for developers to submit to the City for review.

SGF Workflow

Developments receive a score depending on which factors were used on the development. If a development contains a SGF element (sq. ft. of shrubbery or permeable pavers). The unit of the element is then multiplied by the factor attributed to the SGF

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[80] City of Seattle Department of Planning and Development. (2007). Seattle/green factor. Seattle: City of Seattle.
[81] Ibid
[82] Elizabeth, Stenning. 2008. "An Assessment of the Seattle Green Factor: Increasing and Improving the Quality of Urban Green Infrastructure." Thesis. University of Washington - Seattle.
[83] Department of Planning and Development, Seattle Department of Transportation, Seattle Department of Parks and Recreation, Seattle City Light, and Seattle Public Utilities.

element. This logic is followed for each SGF element. Once all the values are calculated for each element, they are added up to form the total sum for all the factors found on the site. With the total sum, the value is divided by the parcel area. This value is the SGF score for the site. In brief, the workflow is as follows:

1. The design includes elements from a menu of 15 landscape elements
2. Multiply the square footage of each element by its given multiplier
3. Add up all other element's product from step 2
4. Divide the summed value of all the elements by the parcel's area
5. Seattle Green Factor Score = .30 of parcel area[84]

In practice, the SGF follows this logic:

Table 2 – SGF Workflow with Example

Steps	Example
Step 1) SGF Element (sq. ft.)	1709 sq. ft.
X	
Step 2) SGF Factor	0.7
=	
Step 3.1) SGF Value	1196.3
Step 3.2) Sum all the SGF Element Values (x_1, x_2, x_3)	1196.3 + x1 + x2 + x3

[84] Elizabeth, Stenning. 2008. "An Assessment of the Seattle Green Factor: Increasing and Improving the Quality of Urban Green Infrastructure." Thesis. University of Washington - Seattle.

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Step 4) Divide the Summed Value of All the Elements by the Parcel Area	$\frac{1196.3 + x1 + x2 + x3}{Parcel\ Area}$
Step 5) Determine Seattle Green Factor Score at least .30 of Parcel Area	$\frac{1196.3 + x1 + x2 + x3}{Parcel\ Area} \geq .30$

Changes over Time

SGF policy has changed in capacity and application over time. Most notable changes are the factor multiplier variables and the zones in which SGF applies (appendix 9 and appendix 10). In 2010, SGF changed the values in its scoring systems for each green factor. In this year there were also changes to how the factors are organized to more clearly define and place more value on factors concerning water in addition to better representing how each type of vegetation falls under which factor (changing tree dimensions, addressing food cultivation, changing parameters for soil depth for rooftop gardens).

Over the years, SGF has expanded outside of solely applying to Neighborhood Commercial (NC) and Commercial (C) zones to now include Mid Rise & High Rise (2009), Low Rise Multifamily & South Downtown Planning Area & Industrial within Urban Centers (2011), Yesler Terrace (2012), and Seattle Mixed Use (2015). Each of these zones has different SGF requirements in order to receive a Certificate of Occupancy.

Methodology

Overview

The objective of this thesis is to identify and reflect upon applicable measurement tools to evaluate the performance of weighted-point landscaping policies based on their stated goals. More specifically, the stated goal of SGF to "increas[e] the amount of and improv[e] the quality of landscaping in new development"[85] and of MGSF to create "a certain amount of green cover in every building lot, and to minimize the degree of sealed or paved surfaces in the development"[86] through a comprehensive approach.[87] It follows the framework of a comprehensive methodology to account for encouraged outcomes of both vegetated and non-vegetated (permeable pavement, etc.) surfaces. Yet this evaluation focuses on urban vegetation and not non-permeable surfaces for monitoring over time as changing built area is less likely to occur compared to changes in vegetation.

This objective is meant to answer the question: How, if at all, can applicable evaluation tools be used to assess how required urban vegetation quantity and quality outcomes of weighted-point landscaping policies have endured over time? As this objective does not attempt full mapping of biotope, finding ways to facilitate through demonstrated steps one through four in the reviewed workflow is the focus.[88] These steps focus on measurement methods versus interpretation of results so the other workflow steps were not attempted. Methods for quantity urban vegetation (using OBIA) in the Seattle context and quality (using a stratification inventory) in both the Seattle and Malmö contexts. Finding accurate, applicable methods to

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85 City of Seattle Department of Planning and Development. 2007. "Seattle/green Factor." Seattle: City of Seattle.

86 Kruuse, Annika. 2011. "GRaBS Expert Paper 6: The Green Space Factor and the Green Points System." http://www.grabs-eu.org/downloads/EP6 FINAL.pdf.

87 Ibid

88 1) Collection of basic materials 2) Analysis of the collected data 3) Basic classification 4) Field surveys

accurately and reliably evaluate measuring urban vegetation outcomes and subsequent effects over time.

To attempt to answer this objective, this study details the process of two methods for assessing outcomes (i.e. Object Based Image Analysis, on-site inventory), with the use of publically available resources and data to perform the evaluation. These groups were chosen as they share weighted-point landscaping structures in different levels of development. The methods chosen for measurement-Object Based Image Analysis and vertical structure inventory - were chosen for analysis due to the researcher's available resources and capability at the time of writing. Also due to these limitations, the methods were not used to their fullest extent. Yet the priority of this study is still accomplished by successfully reflecting on methodology and methods applicability for measuring the outcomes of weighted-point urban vegetation policy.

Seattle Green Factor Study Group

The Seattle Green Factor study group is made up of developments that obtained building permits after the first version (out of many future iterations) of SGF was implemented in 2007. In its first incarnation, SGF only applied to Neighborhood Commercial (NC) and Commercial (C) zones and used consistent factor multipliers to form their total SGF score. Notably, these sites (being built right after the regulation was mandated) are most likely to have the most mature, well-defined vegetation. More mature vegetation is significant as it may be denser, larger, and possibly healthier to reflect more clearly within the context of Object Based Image Analysis, a method used in other studies to assess urban vegetation outcomes over time by classifying land. SGF developments within these zones were limited to sites built 2007 - 2010 to then study their vegetated state using 2011 and 2015 aerial imagery and vertical structure in 2017.

The following workflow illustrates how these developments were chosen. Briefly, from 2,753 developments provided in the database from the City of Seattle Department of Construction and Inspection, 16 were selected for studying based on their zone and build year (appendix 11 and appendix 12). By geocoding the points based on their X, Y coordinates, choosing only those within the applicable zones (NC, C), deleting those built outside the years 2007 – 2010, and only using those with available landscape plans online, 16 sites were selected. Narrowing from 2,753 to 16 developments, the majority of them being outside of the pertinent zones or built after the Great Recession (2011). It is noteworthy to state the foundational file may have contained developments where SGF did not apply and where landscape plans were not filed online, making them unfit for studying. In the last steps of the selection process for this group, these considerations were shown to be true as some sites within the list did not need to conform to SGF standards (if they were remodels) or there were not landscape plans found online.

Western Harbor Malmö Study Group

This group is defined by the Bo01 development in the Western Harbor. As mentioned, it stands on 24 hectares of land and holds 1,200 of housing units in addition to commercial space. Defining the boundaries of these housing units are 144 individual parcels (appendix 13) and, from this researcher's point of view, 80 public-private spaces and courtyards (appendix 14). The 144 individual housing parcels hold multiple housing typologies from detached single dwelling units to apartment complexes. The identified public-private courtyards are also diverse in structure ranging from strips of plantings to combinations for planting plots and bioretention facilities to spaces that are fully function as bioretention facilities. As applicable aerial imagery was not found for this area, a vertical structure inventory was performed to review as an applicable method of urban vegetation evaluation.

Measurement Tool – Object Based Image Analysis (OBIA)

As part of the comprehensive methodology steps one through three in the workflow approach instruct an evaluator to collect, analyze, and act upon data pertinent to the study area and research question. Based on the collected data and to meet the "Basic Classification" step in the approach an Object Based Image Analysis is applicable to classify weighed-point policy urban vegetation outcomes. This method is used in 2 studies in the literature review to accurately assess urban vegetation through remote sensing. OBIA builds on older concepts of information extraction and classification that have been used for decades.[89] Comparatively, OBIA is a new classification method also referred to as feature extraction, feature analysis or object-remote sensing.[90] It works best with hyper-spatial satellite and aerial imagery as well as LiDAR (e.i. elevation) data.[91]

OBIA also works well with "highly-variable" topics (like vegetation) that constantly change form and density. This is true because the method considers texture, shape, and its context to measure the amount and type of vegetation and impervious material within an image.[92] This is defined in the OBIA method through defining spectral, spatial, and classifying variables. It is worth noting this differs from earlier versions of classification methods by identifying image-objects versus per-pixel remote-sensed classification methodology. OBIA was chosen over pixel-classification because of its aptitude for identifying vegetative accurately stemming mainly from its avoidance of the 'salt and pepper effect' (the disparate classification

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[89] Blaschke, T. 2010. "Object Based Image Analysis for Remote Sensing." ISPRS Journal of Photogrammetry and Remote Sensing 65 (1). Elsevier B.V.: 2–16. doi:10.1016/j.isprsjprs.2009.06.004.
[90] Moskal, L. Monika, Diane M. Styers, and Meghan Halabisky. 2011. "Monitoring Urban Tree Cover Using Object-Based Image Analysis and Public Domain Remotely Sensed Data." *Remote Sensing* 3 (10): 2243–62. doi:10.3390/rs3102243.
[91] Ibid
[92] Ibid

pattern of like-pixels) and the ease for researchers to incorporate LiDAR information (if available) into this process.[93]

Classification styles have differed over time from methods that classify land use/land cover (LULC) "per-pixel" (meaning each pixel or light gradual that make up the image is given a unique color value stemming from the spectrum band values that form the whole image) versus the image object-based approach performed in this study.[94] There are notable limitations to be discussed but the effectiveness of this approach is compelling. OBIA is conducted in six steps: data selection and pre-processing, image segmentation, creating training samples, classifying the image, calculating classifications to the parcel (BAR), and evaluating the classifications for accuracy. For 2011 and 2015, this process is visualized in appendix 17 and appendix 18. These steps stem from the steps taken in land classification from the literature review.

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[93] Moskal, L. Monika, Diane M. Styers, and Meghan Halabisky. 2011. "Monitoring Urban Tree Cover Using Object-Based Image Analysis and Public Domain Remotely Sensed Data." Remote Sensing 3 (10): 2243–62. doi:10.3390/rs3102243.; Blaschke, T. 2010. "Object Based Image Analysis for Remote Sensing." ISPRS Journal of Photogrammetry and Remote Sensing 65 (1). Elsevier B.V.: 2–16. doi:10.1016/j.isprsjprs.2009.06.004.

[94] USDA. 2017. "NAIP Imagery." Accessed January 1. https://www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-programs/naip-imagery/.

Figure 3 - Original Imagery; 523 Broadway

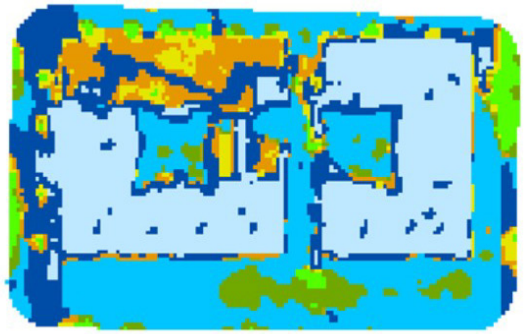


Figure 7 - Pixel Classification; 523 Broadway

Figure 4 - Reconfigured Spectral Bands; 523 Broadway

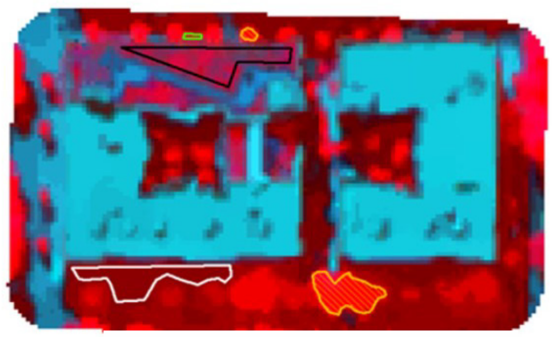
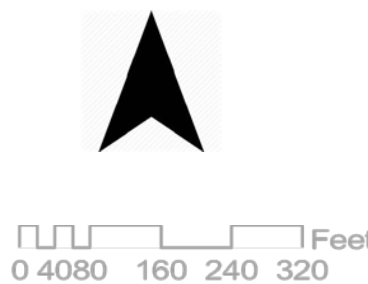


Figure 6 - Training Samples; 523 Broadway

Figure 5 - Segmented Image; 523 Broadway



Data Selection and Pre-processing

Data was selected due to its relevance, price, availability, and resolution. The National Agriculture Imagery Program (NAIP) data is freely available to UW students and on the NAIP website.[95] The mission of the NAIP is to make easily-accessible, high-quality digital ortho-photography available to the public.[96] This imagery has historically been used to monitor croplands but can now be used for multiple topics such as monitoring plant abundancy. The imagery has specifications that make it possible to assess vegetation such as a one-meter ground resolution with a horizontal accuracy that matches within six meters of photo-identifiable ground control points.[97] Resolution is especially important as it has the "greatest impact on the information content of remotely sensed data, particularly for vegetation targets".[98] Additionally, the imagery covers the whole of Seattle (as well as Washington State) over multiple years 2009, 2011, 2013, and 2015. This is shown for experimental group parcel 523 Broadway in Figure 2.

The imagery is made up of several spectral bands in natural colors (Red, Green, and Blue or RGB) with an addition Near Infrared (NIR) band. The imagery has no more than 10% cloud cover and more details as described in appendix 15.[99] The number and type of spectrum bands that composes the imagery is crucial for defining vegetated space. The typical display of these spectral bands is RGB and the NIR is ignored. These bands were reconfigured to better display and measure vegetation. Vegetation reflects light on the green part of the visual spectrum and absorbing blue and red light. That is why humans (who can only view light within the visual spectrum) see vegetation as green.

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[95] https://www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-programs/naip-imagery/.
[96] USDA. 2017. "NAIP Imagery." Accessed January 1. https://www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-programs/naip-imagery/.
[97] Ibid
[98] Ibid
[99] Ibid

For this study, the imagery bands were extracted (using ArcGIS's "Extract Band" tool) and reorganized to better identify the land use/land cover, especially vegetation. In order to measure vegetation better, a Normalized Difference Vegetation Index (NDVI) spectral band was created. NDVI takes advantage of the way vegetation reflects NIR light that is recorded by a satellite to then create a spectral band capable of better identifying vegetation (notably vegetation in shadow). NDVI functions is composed by following this formula: $NDVI = \frac{(NIR-RED)}{(NIR+RED)}$ where NIR is the decimal number value for the Near Infrared Band and decimal number for the RED is the Red Spectral Band. This band along with the green and blue spectral bands made up the studies imagery combination (NIR, Blue, Green) shown in Figure 3.

Using the addresses for the SGF parcels, the study sites were selected. Parcel data made and distributed by the City of Seattle was used to "cut" out the relevant imagery for this study. Made in 2004, this data forms the bases for defining the lines areas within or outside of the study. These parcels were then extended by 40 feet outside of their respective parcel lines to account for the full crown of greenery from street trees (accounted for in SGF) and variance amongst the differing years of imagery layers. This 40' perimeter buffer was chosen to encompass the surrounding sidewalk and the sidewalk's subparts: Landscape/Furniture Zones, Pedestrian Zone, and Frontage Zone.[100] 40 feet was chosen as this additional space follows the perimeter of the parcels (while also erasing areas on or near neighboring parcels). The variance amongst the imaged years (2011, 2013, 2015) for similar parcels stems from the imagery not using the same points of reference amongst the collected years.

[100] City of Seattle. n.d. "Design Criteria 4.1 Introduction." In Citywide Policy Guidance for Right-of-Way Improvements. Seattle, WA.

Segment the Image

This segmentation process uses a process designed by ArcGIS labelled "Mean Shift Approach". In short, the process involves a "moving window" that systematically focuses on each pixel that forms the image.[101] When the "moving window" approaches the pixels that make up the image, it averages the pixel's value to determine which pixel should be included in each segment (a group of like pixels) based on the pre-defined parameters. The pixels are recomputed iteratively to make sure each segment is true to the set pre-defined variables resulting in groupings of image pixels characterized by an average color.[102]

Helping to inform the average color for each pixel are the following variables: spectral, spatial, and minimum segment size. There are not defined parameters for the variable combinations that are transferable across studies. Each study that uses this segmentation process has a different system of trial-and-error to ensure the subject at hand is properly represented. This study conducted 7 iterations of variables to find the finalized version. The spectral variable is defined as the "level of importance given to the spectral differences of features in your imagery".[103] In this study, the spectral variable is 20 on a 1-20 range. This ensures the small differences that make up the objects (vegetation, pavement, roof, etc.) are divided and therefore more accurately identified.

[101] ESRI. 2017. "Understanding Segmentation and Classification." Accessed January 1. http://desktop.arcgis.com/en/arcmap/latest/tools/spatial-analyst-toolbox/understanding-segmentation-and-classification.htm#ESRI_SECTION1_21F2B3D72D2B4401BF39A12D8B54822B.
[102] Ibid
[103] Esri. 2017. "Segment Mean Shift." http://desktop.arcgis.com/en/arcmap/latest/tools/spatial-analyst-toolbox/segment-mean-shift.htm.

The next variable is spatial. Spatial variables "set the level of importance given to the proximity between features in [the] imagery.[104] On a range of 1 – 20, a variable of 10 was used to define the pixel's color combination.[105] A higher value designate segments that are rougher. Smaller value inputs are used to smooth a segment's (object's) classification. Through trial-and-error, 10 was chosen to satisfy how the pixel's related to each other and to what was represented in the imagery. The last variable was Minimum Pixel Size it is defined to serve as the minimum number of pixels allowed to make up a segment. In this study, this value was 1, the lowest value possible. This value was chosen because some of analyzed objects are less than 1 meter large, thus necessitating this value as 1 to classify small objects.

Training Samples

This step involves *training* the computer to classify groups of pixels that are representative of real-world objects. This step is crucial to performing a supervised OBIA. This means human input (drawing training samples) were used in classifying the image. Unsupervised OBIA lets the computer program (ArcGIS) to sort, pick, and classify pixels using a variety of methods. Supervised OBIA was used in this study over unsupervised OBIA as other urban vegetation studies in the literature review used this method.[106]

Each training sample group has its own spectral composition that defines them differently amongst other training sample spectral compositions representing differing real-world objects. In order for training samples to be statistically significant, there must be a representative sample of training sample data in order to classify all the objects in the image. To represent one

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104 Ibid
105 Ibid
106 Lakes, Tobia, and Hyun Ok Kim. 2012. "The Urban Environmental indicator 'Biotope Area Ratio' - An Enhanced Approach to Assess and Manage the Urban Ecosystem Services Using High Resolution Remote-Sensing." Ecological Indicators 13 (1). Elsevier Ltd: 93–103. doi:10.1016/j.ecolind.2011.05.016.

class of ground-verified objects, there must be approximately 20 segments in a training sample that meet the parameters for an object classification. Each of the classifications were chosen by referencing other studies,[107] the quality of the imagery, and the objective of this study (identify vegetation). Altogether, 8 classifications were used each with unique characteristics of spectral band information stemming from the training samples, (see appendix 16 for illustrations).

The 2015 training samples differ from the training samples used in the 2011 imagery. This difference is due to differences in the NAIP imagery that make using the same training sample sets incompatible with one another. The same number of classifications are used for both years but the training sample data that forms these classifications differs. As the foundational imagery does not have the same angle or area of shadows and ortho-rectified differences, one set of training samples is not compatible for both imagery sets. In light of this, the results that are founded upon these training samples cannot be fairly compared and should simply be used as references. The classification band variable are identified and averaged for 2011 and 2015, found in appendix 16.

A generally accepted rule for classifying real-world objects through this method is to find approximately 20 training samples per classification.[108] Each land classification had differing amounts of shadowing and vegetation. Thus some classifications have fewer or a greater number of training samples for identification. This totals to 160 training samples needed for classification. The number of training samples used for the 2015 and 2011 image analysis was

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[107] Hamedianfar, Alireza, and Helmi Zulhaidi Mohd Shafri. 2015. "Detailed Intra-Urban Mapping through Transferable OBIA Rule Sets Using WorldView-2 Very-High-Resolution Satellite Images." International Journal of Remote Sensing. doi:10.1080/01431161.2015.1060645.
Moskal, L. Monika, Diane M. Styers, and Meghan Halabisky. 2011. "Monitoring Urban Tree Cover Using Object-Based Image Analysis and Public Domain Remotely Sensed Data." Remote Sensing 3 (10): 2243–62. doi:10.3390/rs3102243.

[108] ESRI. 2017. "Understanding Segmentation and Classification." Accessed January 1. http://desktop.arcgis.com/en/arcmap/latest/tools/spatial-analyst-toolbox/understanding-segmentation-and-classification.htm#ESRI_SECTION1_21F2B3D72D2B4401BF39A12D8B54822B.

approximately 160. These training samples were made identifying the best representations of real-world objects found in the segmented imagery.

Classification of Land Imagery

Using the training samples, a classification tool is necessary to ensure the accuracy of an interactive supervised classification. This study uses the ArcGIS *Maximum Likelihood Classification* tool using the previously-made imaged segments and training samples. Using "Bayes' theorem" of classification, the training samples in each class are assumed to follow a normal distribution from which segmented pixels are classified based on the segment's likeness to the normalized training samples.[109] This is the first step that designates this study as a *supervisory* OBIA assessment as the user-made training samples are used to classify the image. Supervisory meaning simply because human input was used in the making of the classification.

Calculate the Amount of Land Classification per Parcel

The segments are then spatially tabulated dependent upon classification using the ArcGIS tool "Tabulate Spatial Area". The objective of this step is to find each parcel's composition for each land classification type per SGF parcel. This allows for comparisons to be made between the two groups using the percentage of impervious surface (3 of the 8 classes) to vegetation (5 of the 8 classes) for each parcel when averaged.

Classification Evaluation

Using the "Create Accuracy Assessment Points" tool in ArcGIS, 450 points (50 per class) were created using stratified random sampling (meaning a minimum number of points are

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[109] Ibid

randomly placed in each classification).[110] Each point was then verified by the creator using the original imagery and landscape plans for each development for reference to best estimate what was true to life. With this information, a user's and producer's matrix was created. This matrix is useful for determining the classification's accuracy. The results of a user's and producer's matrix are used to find user's accuracy corresponding to commission (inclusion) and the producer's accuracy as an error of omission (exclusion).

Assessing Accuracy – User's and Producer's Matrix

By selecting 450 equally stratified random points a producer's and user's accuracy matrix was created for each year. [111] These points were placed using an equally stratified random point algorithm to ensure an equal number of points were placed into each classification using the "Create Accuracy Assessment Points". Each point was then assessed by the writer to identify if the assigned point's classification matched with what is seen in the original imagery.

This test measures user's accuracy, meaning a measurement of classified pixels that are incorrectly classified (or type 1 error). In other words, this estimates how many pixels on the map are classified accurately or inaccurately when compared to what is seen on the ground. Conversely, this matrix also assesses producer error. The producer's error value is a measurement assessing the accuracy of the chosen 8 classifications from the role of the map maker. This is meant to measure how well the chosen classes (and subsequently training samples) represent the characteristics of the imaged, segmented pixels. Producer's accuracy measures false negatives. As this concept is a bit more complex, the number is illustrated as:

[110] Lillesand, Thomas M., Ralph W. Kiefer, and Jonathan W. Chipman. 2015. "Chapter 7." In Remote Sensing and Image Interpretation, 7th Ed. USA: Jon Wiley & Sons, Inc.
[111] Sutton, Lynnae. 2012. "Full-Text." In Accuracy Assessment, edited by Portland State University. Portland, OR: Portland State University. http://web.pdx.edu/~nauna/resources/9-accuracyassessment.pdf.

Producer's Accuracy = $\frac{The\ number\ of\ pixels\ correctly\ ground-truthed\ within\ a\ reference\ plot}{The\ number\ of\ pixels\ actually\ in\ that\ reference\ class}$ [112]

This measurement is used to assess the quality of the accuracy of the pixel classification by the number and characteristics of pixels that make up land classifications. The final product gives an estimate of the accuracy for the map data on a whole, adjusting and not adjusting for chance (Kappa). The results are further discussed in the results section below.

Process Limitations

The limitations with the OBIA process begin with the first step, data selection and pre-processing. The data used from this stage sets up the parameters for the final accuracy estimate that follows. The limitations to data selection in this study are many, as the shadow and inconsistent details across the years are especially worth highlighting. One of the most important is the existence of shadows. Shadows are prevalent and contain unique spectral values and shapes. That is why 3 of the 8 land classifications explicitly account for objects in shadow. As these classified pixels tend to have low producer's accuracy (notably tree – shadow, impervious surface – shadow, and shrub – shadow; detailed later) due to the difficulty of establishing representative training samples for those categories for 2011 and 2015. This error may conclude in the underrepresentation of classified objects found within the shadowed areas.

Segmenting the image has its own challenges as the process is iterative without a perfect answer to ensuring all the objects within an image are perfectly defined to what is true on-the-ground. Not perfectly segmenting the image may lead to over-representing or under-representing of an imaged object increasing the likelihood of inaccurate classifications. The same is true for forming training samples. Although an effort was made to ensure no spectral

[112] Ibid

characteristics of a training sample coincided, there are still other, more optimal, ways to creating training samples that better define the land classifications.

The classification step also has qualifying considerations as this specific process uses training samples (that may be lacking) to classify pixels. The classification process used here was the *Maximum Likelihood Classification* (MLC) but there are several others that give different results. Each classification process has its own strengths. For example, this analysis originally used Support Vector Regression (SVR) tool that classifies pixels in a different process. When cursorily comparing the results of SVR to the MLC, it was not as accurate. Lastly, classification evaluation is biased due to human error. This analysis had the maker of the classification also evaluate the accuracy of the classification. This inherently introduces bias to the findings. Ideally, the evaluator should not be the maker of the land classification accuracy points to avoid possible bias in accuracy assessments. Additionally, this thesis uses data from past research questions. Due to the changing research question and gathered data, there is undetermined inaccuracy stemming from over representation of training samples and accuracy points.

Stratification

Measuring vertical structuring, is one type of measurement used for evaluating vegetation structure (others include horizontal structure, the continuity of land cover, or an inventory of the age of noteworthy trees) to inform a modified BAR evaluation within a comprehensive evaluation methodology.[113] SGF and MGSF both specifically encourage the layering of vegetation within the weighted-point landscaping policy structure. Highly stratified vegetation

[113] Ibid

outcomes are encouraged as vegetation structure (especially vertical structuring) relates to increased urban biodiversity, a shared intended outcome of the policies.[114] Stratification is encouraged in SGF as developments that contained higher amounts of layered vegetation earn higher final scores. The choice to conduct a vertical structure inventory as an evaluative tool for Malmö Green Space Factor coincides with its objective of "layer[ing] the different surface cover types (groundcover, shrubs, trees) to achieve a higher Green Space Factor".[115] The Malmö Green Space Factor vegetation was inventoried from public or public-private spaces (visualized in figure 9) but not inventoried were visually inaccessible private viewpoints holding many landscape patches.

Programmatically, SGF divides vegetative forms into three vertical types, groundcover (plants less than 3ft high in length at maturity), shrubs (higher than 3ft), and trees. MGSF encourages vegetation using like, yet different, parameters. These divisions align with other studies of evaluating vertical structures divided by similar divisions.[116] Using these divisions, all developments from Seattle and Malmö were inventoried to

Figure 8 – Map of Bo01 Public Parks
(Gemzoe, Lars., 2017)

[114] Gao, Tian, Ling Qiu, Mårten Hammer, and Allan Gunnarsson. 2012. "The Importance of Temporal and Spatial Vegetation Structure Information in Biotope Mapping Schemes: A Case Study in Helsingborg, Sweden." *Environmental Management* 49 (2): 459–72. doi:10.1007/s00267-011-9795-0.

[115] Ibid

[116] Lehmann, Iris, Juliane Mathey, Stefanie Rößler, Anne Bräuer, and Valeri Goldberg. 2014. "Urban Vegetation Structure Types as a Methodological Approach for Identifying Ecosystem Services - Application to the Analysis of Micro-Climatic Effects." Ecological Indicators 42. Elsevier Ltd: 58–72. doi:10.1016/j.ecolind.2014.02.036.

identify the greatest stratified landscape patch found on-site in September-November, 2017.

Using the approved landscape plans from City of Seattle records, the researcher visited all Seattle study parcels to inventory and photograph the landscape as it existed in 2017 (appendix 21 and 22). Using the landscape plan records, the most stratified landscape patch on each 16 Seattle parcel was catalogued. In Malmö, 148 parcels and 79 public-private spaces/courtyards were inventoried (mapped in appendix 13 and 14). Although the vast majority of the Bo01 space is privately-owned, there are three major public parks not inventoried as this vegetation does not stem from MGSF (identified in figure 8).

As a disclaimer, there were landscape patches that were not audited. Landscape patch in this study meaning vegetation that shares soil without a man-made barrier. These areas include some rooftop gardens and areas not open to the public. Although an effort was made to access these areas, not all were seen. 8 sites in Seattle and the majority of Malmö parcels were not seen in their entirety and therefore not all landscape patches were fully audited as they were inaccessible to the public.

It is worth noting the researcher was limited to inventorying landscape patches in semi-private and public spaces within the 148 private parcels. The private parcels were required to uphold and maintain Malmö Green Space Factor, where the courtyards/public spaces were required to adhere to the Malmö Green Space Factor (MGSF) in addition to containing 10 of the

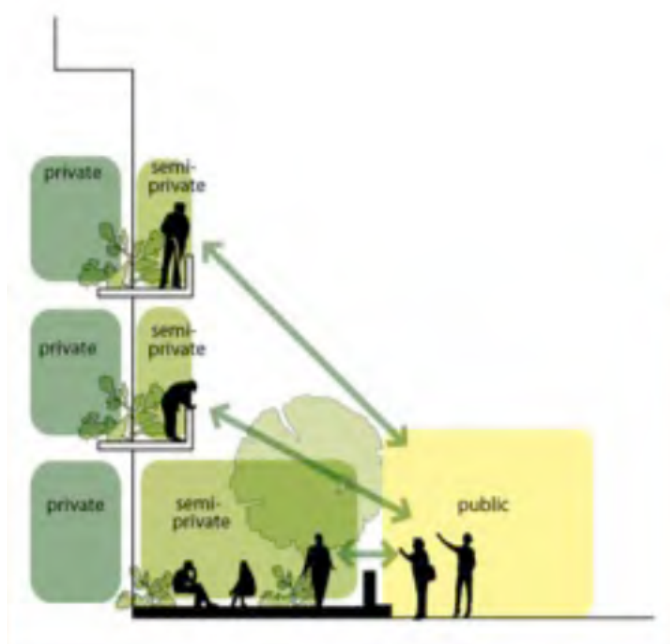

Figure 9- Diagram of Spaces
(Gemzoe, Lars., 2017)

35 items on the Green Point list. The 79 public spaces were identified by aerial imagery (appendix 14). Their most stratified vertical structure was then photographed. Each group, the private parcels and the privately-built, courtyard public-spaces reflect a different inventory of vertical structure. Each development's vertical structure was audited by identifying and capturing a photo of the most vertically stratified vegetation landscape patch visible to the public (does not include inner courtyards, rooftops, and inaccessible areas). The most stratified vegetation patch on each Bo01 parcel mapped in appendix 13.

Process Limitations

Inventorying vegetation in this way has limitations. One of the limitations is the inaccessibility to assess vegetation within private areas. This is consequential as not all the areas were inventoried possibility leaving out examples of multi-layered vegetation. Another limitation is time. Whether adjusting for seasonal changes or changes from maintenance the vegetation may not be the same height at different points of time. This is especially true for groundcover as, anecdotally, comparing the approved landscape plans to what was inventoried, a few areas of potentially well stratified landscape patches did not exist. Planned vegetated groundcover was replaced by stones or mulch eliminating an option to further stratify vegetation. Ideally, the vertical structure inventory is meant to provide data for each landscape patch within the study area and then mapped. Inventorying and mapping each landscape patches necessitates large amounts of time and organization by the researcher. As time and resources were limited in this thesis, examples of the most stratified landscape patch on each site were inventoried qualified by visual access by the researcher. Yet, more comprehensive vertical structure data could then potentially inform a modified BAR by layering mapped land classification data (an indicatory for quantity) with mapped vegetation quality data in this case the vertical structuring.

Results

The objective of this thesis is to review the applicability of evaluation methodology and method processes for vegetation policy. The results from the OBIA and vertical structure inventory are meant to serve as reference indicators for the state of vegetation in their respective years of evaluation and not final results for assessing policy implementation. The results below serve as an intended example for when a more precise process of land classification (OBIA) and a more comprehensive inventory of vertical structure supersedes as evaluation indicators. What follows are the results from the methods organized to inform a modified BAR indicator. By overlapping land classification data with vegetation structuring data, a modified BAR indicator can be formed to give one value to an identified vegetation's quantity and quality.

OBIA Classification - Vegetation Quantity

2011

When averaged, the SGF group had a BAR of 19%. This was calculated by adding all the vegetation (Tree – Light, Tree – Shadow, Shrub – Light, Shrub – Shadow, Groundcover) class segmented pixels within the study parcels, visualized in appendix 19. This was also completed for impervious surface (Roof – Light, Pavement – Light, Pavement – Shadow). The vegetation number was divided by the parcel's area to find the BAR. The BAR from the 16 sites were then averaged. The BAR was the focus of this classification because creating a modified BAR (BAR with additional vegetation structure data) has promise for measuring weighted-point landscaping policy outcomes over time.

Table 3 –Classification of Land Pixels in the SGF Group; 2011

	Vegetation – Avg. Sq. Ft.	Impervious Surface – Avg. Sq. Ft.	Total	Average BAR
SGF Group	1,892	12,004	13,896	
Percentage	*14%*	*86%*		19%

Table 4 – Inventory of Land Classifications by Address; 2011

ADDRESS	TREE LIGHT	TREE SHADOW	SHRUB LIGHT	SHRUB SHRUB	GROUNDCOVER	ROOF LIGHT	IMP. SURFACE LIGHT	IMP. SURFACE SHADOW	VEGETATION SUM	IMP. SURFACE SUM	BAR
13716 LAKE CITY WAY NE	291	280	506	1141	15823	8762	14327	8547	18040	31635	36%
12730 33RD AVE NE	753	194	54	269	549	9483	9924	2530	1819	21937	8%
801 NE 65TH ST	570	355	118	635	1012	118	13713	12217	2691	26049	9%
4422 MERIDIAN AVE N	54	118	65	312	344	172	6824	4295	893	11291	7%
3841 34TH AVE W	86	172	32	22	1195	4898	1270	1044	1507	7212	17%
2946 EASTLAKE AVE E	603	2390	614	2174	3617	9698	8407	10053	9397	28158	25%
523 BROADWAY EAST	4596	3724	2314	3240	14768	44207	18729	25726	28643	88662	24%
222 QUEEN ANNE AVE N	323	0	140	0	140	6997	2712	667	603	10376	5%
1620 BROADWAY	237	215	183	452	1647	26662	11571	10775	2734	49008	5%
1205 E PINE ST	420	484	570	151	1668	10861	6103	4779	3294	21743	13%
1408 14TH AVE	6943	1636	1927	1356	4252	8450	8288	10796	16114	27534	37%
1924 RAINIER AVE S	4499	969	2583	291	10968	15931	31840	13046	19310	60816	24%
2743 CALIFORNIA AVE SW	377	86	560	65	2153	2659	1324	1012	3240	4994	39%
4550 38TH AVE SW	732	183	1141	667	13627	8181	32216	4306	16350	44702	27%
8124 RAINIER AVE S	538	54	1033	32	2842	29784	11420	5565	4499	46769	9%
7300 M L KING JR WAY S	2486	420	2153	958	16221	54982	20053	20279	22238	95314	19%
AVERAGE SGF GROUP	1469	705	875	735	5677	15115	12420	8477	1892	12004	19%

Table 5 – Accuracy Matrix; 2011

CLASS	TREE - LIGHT	TREE - SHADOW	SHRUB - LIGHT	SHRUB - SHADOW	GROUNDCOVER - LIGHT	IMPERVIOUS SURFACE - LIGHT	IMPERVIOUS SURFACE - SHADOW	ROOF - LIGHT	TOTAL	USER ACCURACY	KAPPA
TREE - LIGHT	39	1	2	1	13	0	0	0	56	0.696428571	0
TREE - SHADOW	1	45	0	1	7	0	0	2	56	0.803571429	0
SHRUB - LIGHT	7	3	39	0	5	0	0	2	56	0.696428571	0
SHRUB - SHADOW	0	10	0	37	6	1	0	2	56	0.660714286	0
GROUNDCOVER - LIGHT	3	0	10	4	31	1	4	3	56	0.553571429	0
IMPERVIOUS SURFACE - LIGHT	0	0	0	0	0	1	55	0	56	0.982142857	0
IMPERVIOUS SURFACE - SHADOW	0	1	0	3	0	0	0	52	56	0.928571429	0
ROOF - LIGHT	0	0	0	0	0	48	7	1	56	0.857142857	0
TOTAL	50	60	51	46	62	51	66	62	448	0	0
PRODUCER ACCURACY	0.78	0.75	0.764705882	0.804347826	0.5	0.941176471	0.833333333	0.838709677	0	**0.772321429**	0
KAPPA	0	0	0	0	0	0	0	0	0	0	**0.7398**

Utilizing a user's and producer's matrix, the accuracy of this classification averages at 78% pre-kappa and 74% post-kappa. Used to reflect the difference between actual accuracy and the agreement when adjusted to account for chance (kappa).[117] These values are averages and should be judged accordingly. Note the considerably low accuracy seen in classifying Groundcover – Light (55%) and Shrub – Shadow (66%) to the high accuracy measure for Impervious Surface – Light (96%) and Impervious Surface – Shadow (93%). This could be due to poorly chosen training samples (as evidenced for Groundcover – Light by the low producer's accuracy of 50%) and this method's inability to register Shrub – Shadow possibly due to foundational imagery, spectral bands display, or how the image was segmented.

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[117] Sutton, Lynnae. 2012. "Accuracy Assessment." In , edited by Portland State University. Portland, OR: Portland State University. http://web.pdx.edu/~nauna/resources/9-accuracyassessment.pdf.

2015

The amount of vegetation was averaged and summed similarly to the work in 2011. A reminder that this data is not comparable due to the differences in foundational images and training sample set characteristics. Again, the BARs are found for each parcel and averaged. The parcel's classification are visualized in appendix 20.

Table 6 - Comparison of Classified Land Pixels in Each Group; 2015

	Vegetation – Avg. Sq. Ft.	Impervious Surface – Avg. Sq. Ft.	Total	Average BAR
Experimental Group	3,724	8,958	12,682	
Percentage	*29%*	*71%*		40%

Accuracy assessments show an average of 78% accuracy pre-kappa and post-kappa 74%. Again, there are notable limitations as Groundcover – Light and Shrub – Shadow have comparatively low user's accuracy values at 45% and 66% respectively. High accuracy values are shown for Tree-Shadow 91% and Impervious Surface 93%. This is most likely due to error in the OBIA method perhaps from resolution size, segmentation, classification algorithm, or a combination of these factors.

Table 7 – Inventory of Land Classifications by Address; 2015

ADDRESS	TREE LIGHT	TREE SHADOW	SHRUB LIGHT	SHRUB SHRUB	GROUNDCOVER	ROOF LIGHT	IMP. SURFACE LIGHT	IMP. SURFACE SHADOW	VEGETATION SUM	IMP. SURFACE SUM	BAR
13716 LAKE CITY WAY NE	387	818	2939	355	8934	19676	5264	10882	13433	35822	27%
12730 33RD AVE NE	667	323	495	75	10086	4112	7589	818	11647	12518	48%
801 NE 65TH ST	301	205	764	161	829	16835	8245	1335	2260	26415	8%
4422 MERIDIAN Ave N	11	43	431	54	22	4951	6146	484	560	11582	5%
3841 34TH AVE W	86	280	366	54	3929	2196	1109	700	4715	4004	54%
2946 EASTLAKE AVE E	2045	1884	4133	258	11184	12852	2616	2336	19504	17803	52%
523 BROADWAY EAST	3681	6501	4951	635	35424	22744	34649	8902	51193	66295	44%
222 QUEEN ANNE Ave N	538	0	280	22	5662	3477	495	409	6501	4381	60%
1620 BROADWAY	32	183	635	32	23121	8633	18309	872	24003	27814	46%
1205 E PINE ST	1055	732	1916	215	6286	8966	3692	2293	10204	14951	41%
1408 14TH AVE	3800	2659	2949	484	8137	12432	8536	4564	18029	25532	41%
1924 RAINIER AVE S	5210	1894	5059	431	14165	31840	14359	7255	26759	53453	33%
2743 CALIFORNIA AVE SW	22	1281	700	11	1948	1905	517	1905	3961	4327	48%
4550 38TH AVE SW	1173	215	2196	151	4219	35112	15468	2497	7954	53077	13%
8124 RAINIER AVE S	1066	0	3208	280	26694	16350	2712	1098	31248	20161	61%
7300 M L KING JR WAY S	1959	269	4887	592	58211	24811	19698	7352	65918	51860	56%
AVERAGE SGF GROUP	1377	1080	2244	238	13678	14181	9338	3356	3724	8958	40%

Table 8 - Accuracy Matrix; 2015

CLASS	TREE - LIGHT	TREE - SHADOW	SHRUB - LIGHT	SHRUB - SHADOW	GROUNDCOVER - LIGHT	IMPERVIOUS SURFACE - LIGHT	IMPERVIOUS SURFACE - SHADOW	ROOF - LIGHT	TOTAL	USER ACCURACY	KAPPA
TREE - LIGHT	48	1	2	0	0	1	3	1	56	0.857142857	0
TREE - SHADOW	0	50	0	0	1	1	2	1	55	0.909090909	0
SHRUB - LIGHT	1	6	43	1	0	2	2	1	56	0.767857143	0
SHRUB - SHADOW	2	10	2	37	2	0	3	0	56	0.660714286	0
GROUNDCOVER - LIGHT	2	12	4	7	25	4	1	1	56	0.446428571	0
IMPERVIOUS SURFACE - LIGHT	1	0	0	0	0	50	1	4	56	0.892857143	0
IMPERVIOUS SURFACE - SHADOW	0	1	0	0	1	2	48	4	56	0.857142857	0
ROOF - LIGHT	0	1	1	0	0	5	3	47	57	0.824561404	0
TOTAL	54	81	52	45	29	65	63	59	448	0	0
PRODUCER ACCURACY	0.888888889	0.617283951	0.826923077	0.822222222	0.862068966	0.769230769	0.761904762	0.796610169	0	**0.776785714**	0
KAPPA	0	0	0	0	0	0	0	0	0	0	**0.74493**

Stratification Results

As described in the methods section, each SGF parcel and MGSF parcels and courtyard/public space was inventoried to identify their most stratified landscape patch. The stratified landscaping patches are identified using vertical vegetation divisions set by SGF and past studies. 12 of the 16 SGF parcels had all levels of vegetation (ground cover, shrub, trees) while 4 of the 16 SGF parcels have landscape patches with shrubs and trees.

Table 9 – Summary of SGF Stratification

	SGF Parcels
Ground Cover, Shrubs, Trees	12
Ground Cover	0
Shrub, Tree	4
Shrub, Ground Cover	0
Tree, Ground Cover	0
Shrub	0
Tree	0
None	0

Summarized below are the MGSF private parcels and courtyard/public spaces inventorying the most stratified landscape patches. Fully stratified or strictly ground cover landscape patches were identified at 31 and 35 of the MGSF parcels respectively. For the public spaces, the largest number of spaces had the vertical characteristics in the tree or shrub category followed by courtyards with combination of ground cover, shrubs, and trees and a combination of shrubs and trees

Table 10 – Summary of Vertical Structure Inventory in Bo01

	146 MGSF Parcels	79 Courtyard/Public Spaces
Ground Cover, Shrubs, Trees	31	13
Ground Cover	35	0
Shrub, Tree	15	10
Shrub, Ground Cover	10	7
Tree, Ground Cover	7	7
Shrub	26	22
Tree	1	18
None	21	1

Discussion

Establishing an effective approach to evaluate vegetation outcomes based on weighted-point-based landscaping policy through quantitative methods has yet to be accomplished. Finding accurate, objective methods is meant to improve future policies by providing iterative feedback. This iterative feedback is intended to measure policy performance to inform policymakers and stakeholders to propose improvements to the policy. Supervised, OBIA and stratification inventories have promise, after addressing to the limitations, to be effective measurement tools to inform a modified-BAR indicator given the right inputs and processes for municipal policy analysts implementing evaluations of weighted-point-based landscaping policy. As the technology and understanding of the process becomes more accessible, more municipalities can conduct these processes with limited resources. There are, however, several layers of improvements that needs to be accounted and understood before these processes can be considered applicable, and reliably produce feedback for policy by accurately evaluating vegetation quantity and quality.

Compared to other OBIA processes quantifying vegetation in the literature review, the process used in this thesis produced modest results. The accuracy numbers from the different studies highlighted below are meant to serve as a reference and not as strict comparisons as each of these studies had different inputs, objectives, and level of bias. For example, the accuracy in the 2007 research by Dr. Monika Moskal, et. al. had the goal of "determining existing urban tree cover and potential tree planting sites in the city of Seattle".[118] This study used different land classifications and had a study area at the neighborhood-scale that form the context for the

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[118] Moskal, L. Monika, Diane M. Styers, and Meghan Halabisky. 2011. "Monitoring Urban Tree Cover Using Object-Based Image Analysis and Public Domain Remotely Sensed Data." *Remote Sensing* 3 (10): 2243–62. doi:10.3390/rs3102243.

accuracy percentage. The accuracies are compared as reference to gauge what products possible within the contextual reality of the OBIA process.

<u>*Table 11 – Comparison of Average Accuracy Percentages by Study*</u>

Location of Study/Author	Averaged User's and Producer's Classification Accuracy Percentage w/Kappa
SGF – 2011/ Josh Hoff	74%
SGF – 2015/ Josh Hoff	74%
Seattle, Rainier Valley – 2009/ Moskal[119]	74%
Seattle, Rainier Valley – 2007/ Moskal[120]	75%

One area of improvement is data selection. As touched upon in the Methods – Limitations section, the choice and manipulation of imagery and data dictates the accuracy of the land classification. Images with shadow, cloud cover, and inconsistent ortho-rectification challenges the ability of a study to serve as an accurate measurement over time. This is not acknowledged lightly as the difficulty of attaining perfectly comparable data is high in terms of cost and logistics. To commission aerial flights that capture easily comparable imagery from which to study are costly and logistically a hardship.

Another consideration is the choice to not use elevation data and the use of ArcGIS to classify land uses. Elevation data were not used in this study as the researcher did not find the relevant data nor did the researcher know how to incorporate the information. Other locations or municipalities may have access to elevation data in order to have a more detailed inventory of types of vegetation. Even without elevation data, the processes used to quantify the amount of vegetation at the parcel level necessitates moderate ArcGIS knowledge. Depending on the

[119] Moskal, L. Monika, Diane M. Styers, and Meghan Halabisky. 2011. "Monitoring Urban Tree Cover Using Object-Based Image Analysis and Public Domain Remotely Sensed Data." *Remote Sensing* 3 (10): 2243–62. doi:10.3390/rs3102243.

[120] Ibid

availability of data and expertise of the user, adding depth data to the process of quantifying vegetation produces the greatest improvement to the accuracy compared to the amount of effort needed to incorporate elevation information.

ArcGIS was the computer program used in this study for OBIA. Some studies used eCognition or Definiens computer programs to perform a remote sensing study. Anecdotally, these programs are specifically used for remote sensing and allows the study administer to set up the OBIA process with ease. ArcGIS was what was available to the researcher at the time and the other programs were inaccessible due to funds and time. If the limitations are considered (inconsistent aerial data, incorporation of elevation data, and classifying software) the OBIA is a possible evaluation methods for a comprehensive methodology.

With a more detailed inventory of stratification for each landscape patch there could be better integration between inventorying and mapping vegetation both in quantity and quality. If stratified inventories were mapped and overlaid with quantity information (classified maps), there could be better evaluation of the policy. The vertical structure inventory tool is one method that can be conducted within different contexts. Cautiously, the weighted-point landscape policy may not be applicable due to contextual considerations when the policy parameters are not similar.

This paper serves as an evaluative stepping stone to give feedback to policy that is complex within an evaluation context with limited resources. The two methods outlined in this thesis have potential to inform a modified-BAR assessment. This indicator is useful for measuring the quantity and quality of urban vegetation for weighted-point landscaping policy outcomes. The intention of this thesis' objective is met as this information provides inspiration to municipalities or interested private citizens that evaluating and improving policy is possible through objective means.

Conclusion

The challenge remains to develop methods to assess and value the ecosystem services provided by vegetation and integrate them in urban decision-making processes. Weighted-point landscape policies as evidenced in Seattle and Malmö are able to be evaluated. Finding tools that use limited resources, within the technical ability of the evaluator, and have highly accurate outcomes are needed to find an applicable evaluation indicator and methods. Based on the analysis described here, I found modest accuracy using a supervised, OBIA tool to find a broad BAR calculation and an inconclusively accurate, yet applicable process for evaluating vertical structure of vegetation. This work is in early stages of analysis and opportunities are available to combine the tools to create a reliable, accurate evaluation model for weighted-point landscape policy.

Bibliography

Alberti, M., 2005. “The Effects of Urban Patterns on Ecosystem Function”. Int. Reg. Sci. Rev. 28, 168–192.

Ahern, Jack, Sarel Cilliers, and Jari Niemelä. 2014. “The Concept of Ecosystem Services in Adaptive Urban Planning and Design : A Framework for Supporting Innovation.” Landscape and Urban Planning 125: 254–59.

Beatly, Thomas, “Green Urbanism in European Cities,” in The Humane Metropolis, ed. Rutherford H. Platt (Amherst: University of Massachusetts Press, 2006), 311-312.

Blaschke, T. 2010. “Object Based Image Analysis for Remote Sensing.” ISPRS Journal of Photogrammetry and Remote Sensing 65 (1). Elsevier B.V.: 2–16. doi:10.1016/j.isprsjprs.2009.06.004.

Blaschke, Thomas, Geoffrey J. Hay, Maggi Kelly, Stefan Lang, Peter Hofmann, Elisabeth Addink, Raul Queiroz Feitosa, et al. 2014. “Geographic Object-Based Image Analysis - Towards a New Paradigm.” *ISPRS Journal of Photogrammetry and Remote Sensing* 87. International Society for Photogrammetry and Remote Sensing, Inc. (ISPRS): 180–91. doi:10.1016/j.isprsjprs.2013.09.014.

Bothmer, Roland Von, Marten Hammer, Tian Gao, Allan Gunnarsson, and Qiu Ling. 2010. “A Methodological Study of Biotope Mapping in Nature Conservation.” Urban Forestry & Urban Greening 9: 161–66. doi:10.1016/j.ufug.2010.01.003.

Breslau, K. 2007. “The Green Giant.” Newsweek CXLIX (51): 51–59.

City of Seattle Department of Planning and Development. 2007. “Seattle/green Factor.” Seattle: City of Seattle.

City of Seattle. 2004. “Neighborhood Business District Strategy.” Seattle, WA.

City of Seattle. n.d. “Design Criteria 4.1 Introduction.” In Citywide Policy Guidance for Right-of-Way Improvements. Seattle, WA.

Code, S. M. 23.47A.016 Landscaping and screening standards. (2006). Seattle, WA: City of Seattle City Council.

Ellis, E.C., Wang, H., Xiao, H.S., Peng, K., Liu, X.P., Li, S.C., et al., 2006. “Measuring long-term ecological changes in densely populated landscapes using current and historical high resolution imagery”. Remote Sens. Environ. 100, 457–473.

ESRI. 2017. “Segment Mean Shift.” http://desktop.arcgis.com/en/arcmap/latest/tools/spatial-analyst-toolbox/segment-mean-shift.htm.

ESRI. 2017. “Understanding Segmentation and Classification.” Accessed January 1. http://desktop.arcgis.com/en/arcmap/latest/tools/spatial-analyst-toolbox/understanding-segmentation-and-classification.htm#ESRI_SECTION1_21F2B3D72D2B4401BF39A12D8B54822B.

Daniel R. Mandelker et al., *Planning and Control of Land Development: Cases and Materials*, 6th ed. (Newark:Lexis Nexis Press, 2005), 209-211.

DDOE. 2015. "Green Area Ration Guidebook," 123. https://doee.dc.gov/sites/default/files/dc/sites/ddoe/service_content/attachments/GAR Guidebook_errata 03_03_2015.pdf.

Gao, et. al. "The Importance of Temporal and Spatial Vegetation Structure Information in Biotope Mapping Schemes: A Case Study in Helsingborg, Sweden." 2012.

Grimm, N.B., Faeth, S.H., Golubiewski, N.E., Redman, C.L., Wu, J., Bai, X., et al., 2008. Global Change and the Ecology of Cities. Science 319, 756–760.

Gemzoe, Lars. 2017. "Regional Architecture, Human Scale, and Sustainability - Session 8." In Danish Architecture and Urban Design. Copenhagen: Gehl Architects.

Haaland, Christine, and Cecil Konijnendijk Van Den Bosch. 2015. "Challenges and Strategies for Urban Green-Space Planning in Cities Undergoing Densification : A Review." Urban Forestry & Urban Greening 14 (4). Elsevier GmbH.: 760–71. doi:10.1016/j.ufug.2015.07.009

Hamedianfar, Alireza, and Helmi Zulhaidi Mohd Shafri. 2015. “Detailed Intra-Urban Mapping through Transferable OBIA Rule Sets Using WorldView-2 Very-High-Resolution Satellite Images.” International Journal of Remote Sensing. doi:10.1080/01431161.2015.1060645.

Holgersen, Ståle. 2015. “Crisis and the Post-Industrial City: Or Is Malmö Building Yesterday’s City Tomorrow, Again?” Tijdschrift Voor Economische En Sociale Geografie 106 (3): 231–45. doi:10.1111/tesg.12115.

Hunt, Vicky. n.d. “Lecture 2 : Research Design Process.” Seattle, WA: University of Washington.

Jepson, Edward J. 2004. “The Adoption of Sustainable Development Policies and Techniques in U.S. Cities: How Wide, How Deep, and What Role for Planners?” *Journal of Planning Education and Research* 23 (3): 229–41. doi:10.1177/0739456X03258638.

Jönsson, Erik, and Ståle Holgersen. 2017. “Spectacular, Realisable and ‘everyday’: Exploring the Particularities of Sustainable Planning in Malmö.” *City* 4813 (September): 1–18. doi:10.1080/13604813.2017.1325186.

Karr, James. 2002. “What from Ecology Is Relevant to Design and Planning ?” In *Ecology and Design: Frameworks for Learning*, 133–72. Washington, DC: Island Press.

Karlsson, Tobias. 2017. “4 From Boom to Bust,” 1950–86. Accessed May 1. http://portal.research.lu.se/portal/files/23006771/4_Tobias_Karlsson.pdf.

Kruuse, Annika. 2011. “GRaBS Expert Paper 6: The Green Space Factor and the Green Points System.” http://www.grabs-eu.org/downloads/EP6 FINAL.pdf.

Lakes, Tobia, and Hyun Ok Kim. 2012. “The Urban Environmental Indicator ‘Biotope Area Ratio’ - An Enhanced Approach to Assess and Manage the Urban Ecosystem Services Using High Resolution Remote-Sensing.” Ecological Indicators 13 (1). Elsevier Ltd: 93–103. doi:10.1016/j.ecolind.2011.05.016.

Lehmann, Iris, Juliane Mathey, Stefanie Rößler, Anne Bräuer, and Valeri Goldberg. 2014. “Urban Vegetation Structure Types as a Methodological Approach for Identifying Ecosystem Services - Application to the Analysis of Micro-Climatic Effects.” Ecological Indicators 42. Elsevier Ltd: 58–72. doi:10.1016/j.ecolind.2014.02.036.

Lillesand, Thomas M., Ralph W. Kiefer, and Jonathan W. Chipman. 2015. “Chapter 7.” In Remote Sensing and Image Interpretation, 7th Ed. USA: Jon Wiley & Sons, Inc.

McNeill, Desmond., Nesheim, Ingrid, and Brouwer, Floor. Land Use Policies for Sustainable Development : Exploring Integrated Assessment Approaches. Cheltenham [England] ; Northampton, Mass.: Edward Elgar Pub., 2012.

Mok, J.-H., Kim, D.-W., 2005. “A simulation of biotope area ratio BAR for application of district unit plan in Seoul”. J. Korean Plan. Assoc. 40, 87–100 [in Korean: English Abstract].

Moskal, L. Monika, Diane M. Styers, and Meghan Halabisky. 2011. “Monitoring Urban Tree Cover Using Object-Based Image Analysis and Public Domain Remotely Sensed Data.” *Remote Sensing* 3 (10): 2243–62. doi:10.3390/rs3102243.

Poon, Linda. "The Deadline for Cities to Initiate Climate Action Is 2020," CityLab, 2016, , accessed December 12, 2016, http://www.citylab.com/politics/2016/12/immediate-climate-action-falls-on-mayors/509168/.

Stenning, Elizabeth. 2008. “An Assessment of the Seattle Green Factor: Increasing and Improving the Quality of Urban Green Infrastructure.” master’s thesis., University of Washington - Seattle.

Sutton, Lynnae. 2012. “Accuracy Assessment.” In , edited by Portland State University. Portland, OR: Portland State University. http://web.pdx.edu/~nauna/resources/9-accuracyassessment.pdf.

Sugimura, D. M. (n.d.). City of Seattle Department of Planning and Development Land Use – Technical Standards and Procedural Requirements.

UNCED. 1992. “Earth Summit‘92. The UN Conference on Environment and Development.” Reproduction Rio de Jan (June): 351. doi:10.1007/s11671-008-9208-3.

United Nations, 2008. World Urbanization Prospects: The 2007 Revision. Executive Summary.

USDA. 2017. “NAIP Imagery.” Accessed January 1. https://www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-programs/naip-imagery/.

Appendices

Appendix 1 – List of Literature Review Search Terms

Group 1	Group 2	Group 3
	AND	**SUBJECTIVELY USED**
Biotope	Tokyo	Evaluation
Green Infrastructure Regulation	Berlin	
Green Roof	Chicago	
Green Factor	Portland	
Green Space	Seattle	
Storm water Management	Malmö	

Appendix 2 – List of Journals used in the Literature Review

1. *Regional Science and Urban Economics*
2. *Urban Forestry & Urban Greening*
3. *Landscape and Urban Planning*
4. *Journal of Urban health*
5. *International Journal of Urban and Regional Research*
6. *Arboriculture & Urban Forestry*
7. *Cities*
8. *Current World Environment*
9. *Environment and Planning*
10. *International Geoscience and Remote Sensing Symposium*
11. *Journal of Transport Geography*
12. *Science of the Total Environment*
13. *South African Geographical Journal*
14. *Urban Forestry & Urban Greening*

Appendix 3 – Literature Review Urban Vegetation Evaluation

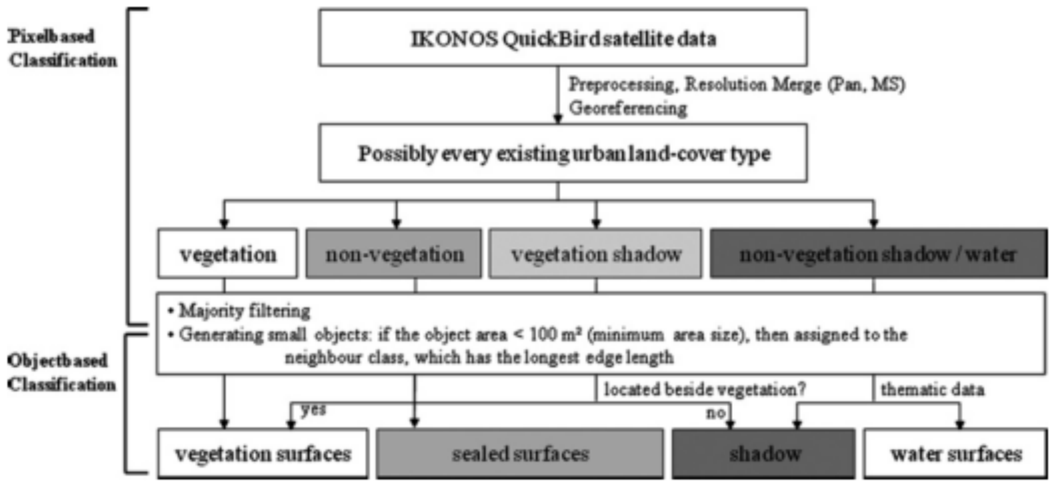


Figure 1 Remote-sensing BAR workflow in Seoul

Lakes, Tobia, and Hyun Ok Kim. 2012. "The Urban Environmental indicator 'Biotope Area Ratio' - An Enhanced Approach to Assess and Manage the Urban Ecosystem Services Using High Resolution Remote-Sensing."

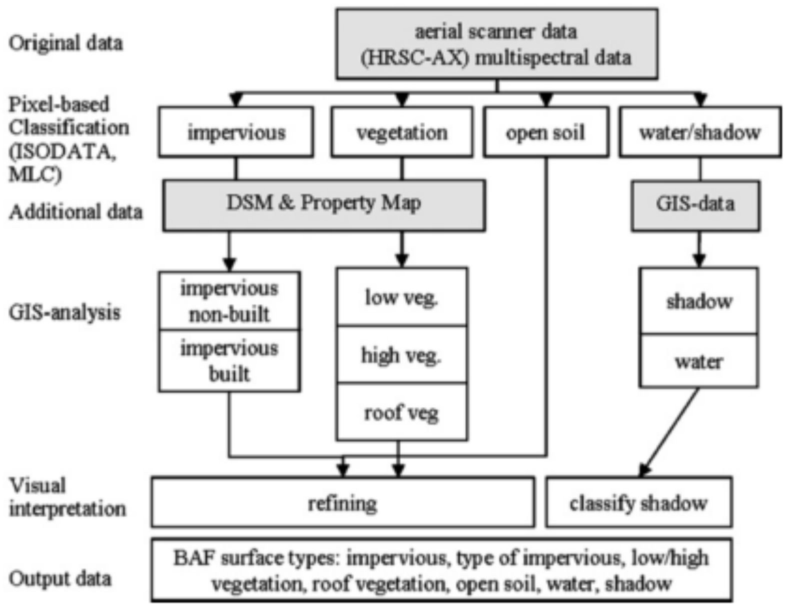
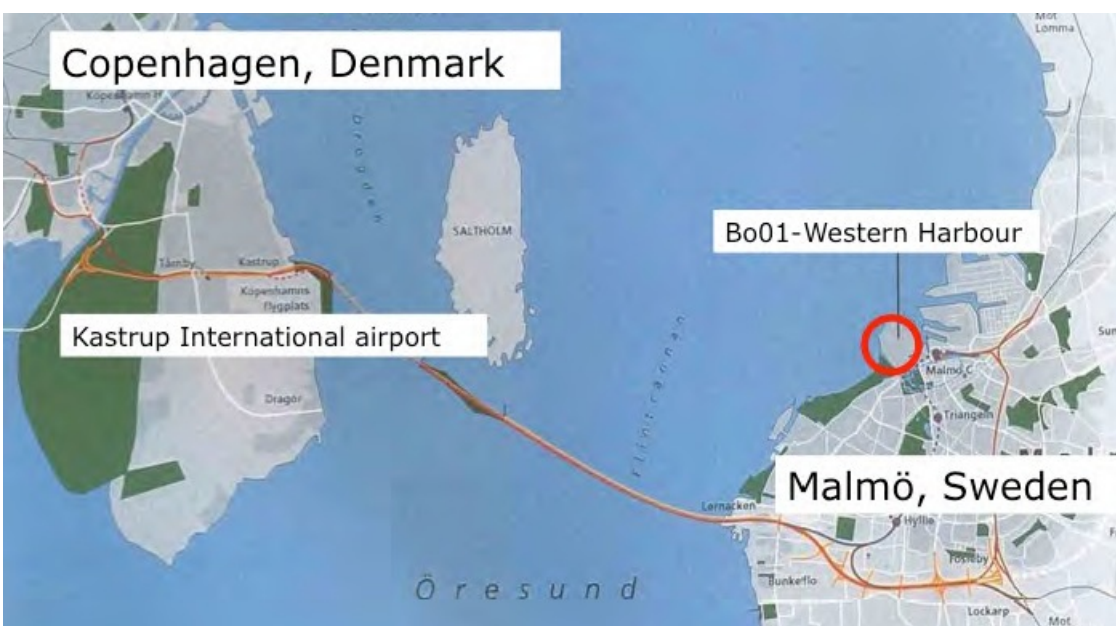


Figure 2. Remote-sensing BAR workflow in Berlin

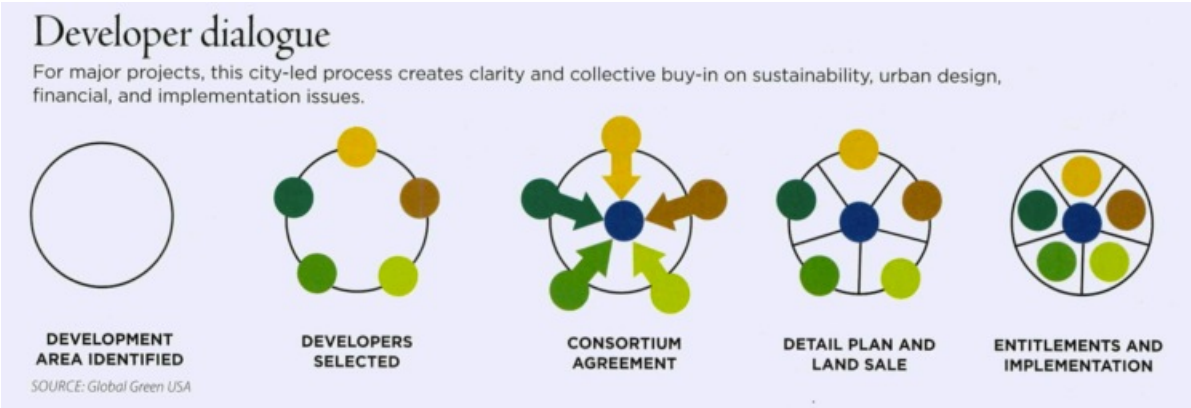
Lakes, Tobia, and Hyun Ok Kim. 2012. "The Urban Environmental indicator 'Biotope Area Ratio' - An Enhanced Approach to Assess and Manage the Urban Ecosystem Services Using High Resolution Remote-Sensing."

<u>Appendix 4 – Malmö Reference Map</u>



Gemzoe, Lars. 2017. "Regional Architecture, Human Scale, and Sustainability - Session 8." In *Danish Architecture and Urban Design*. Copenhagen: Gehl Architects.

Appendix 5 – Swedish Real Estate Development Process



Breslau, K. 2007. "The Green Giant." *Newsweek* CXLIX (51): 51–59.

Appendix 6 – Malmö Green Space Factor + Green Points[121]

Surface Type	Factor
Vegetation on Ground	1
Vegetation on trellis or facade	0.7
Green roofs	0.8
Vegetation in beds, soil depth between 200 millimeters and 800 millimeters	0.6
Vegetation in beds, soil depth more than 800 millimeters	0.8
Water surfaces	1
Trees with Stem Size Greater Than 35cm	0.4
Solitary Bushes, Multistage trees higher than 3 m	0.2
climber and climbing plants higher than 2 m	0.2
Collection and retention of storm water	0.2
Draining of sealed surfaces to surrounding vegetation	0.1
Sealed areas	0
Paved Areas with Joints	0.2
Areas covered with gravel or sand	0.4

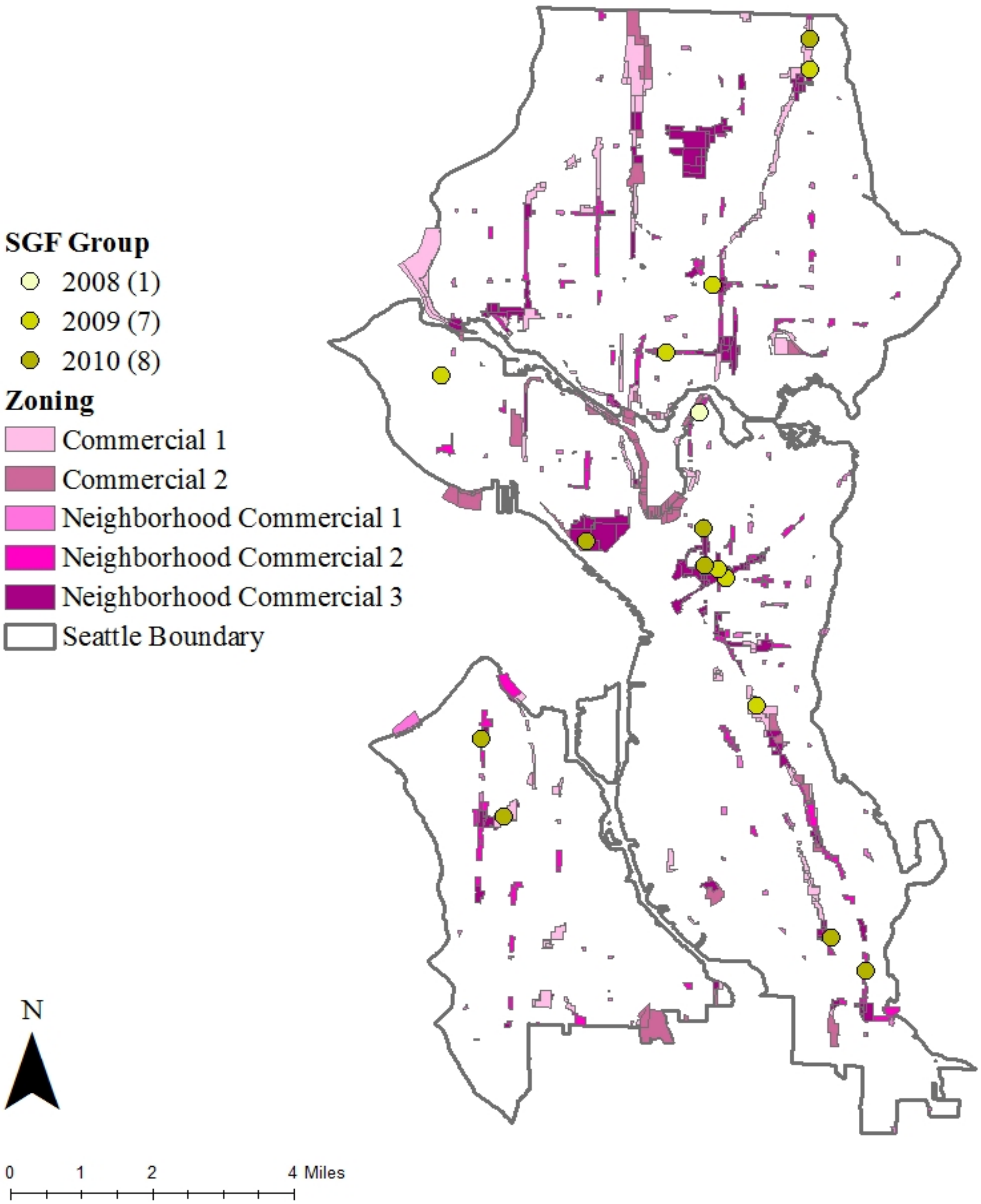
[121] Bo01 Framtidsstaden, and Malmö Stadsbyggnadskontor. 1999. "Grönytefaktor for Bo01." Malmö, Sweden: Bengt Persson.

Green Points

1 A bird box for every apartment
2 A biotope for specified insects in the courtyard (water striders and other aquatic insects in the pond)
3 Bat boxes in the courtyard
4 No surfaces in the courtyard are sealed, and all surfaces are permeable to water
5 All non-paved surfaces within the courtyard have sufficient soil depth and quality for growing vegetables
6 The courtyard includes a rustic garden with different sections
7 All walls, where possible, are covered with climbing plants
8 There is 1 square metre of pond area for every 5 square metres of hard-surface area in the courtyard
9 The vegetation in the courtyard is selected to be nectar rich and provide a variety of food for butterflies (a so-called 'butterfly restaurant')
10 No more than five trees or shrubs of the same species
11 The biotopes within the courtyard are all designed to be moist
12 The biotopes within the courtyard are all designed to be dry
13 The biotopes within the courtyard are all designed to be semi-natural
14 All stormwater flows for at least 10 metres on the surface of the ground before it is diverted into pipes
15 The courtyard is green, but there are no mown lawns
16 All rainwater from buildings and hard surfaces in the courtyard is collected and used for irrigation
17 All plants have some household use
18 There are frog habitats within the courtyard as well as space for frogs to hibernate
19 In the courtyard, there is at least 5 square metres of conservatory or greenhouse for each apartment
20 There is food for birds throughout the year within the courtyard
21 There are at least two different old-crop varieties of fruits and berries for every 100 square metres of courtyard
22 The facades of the buildings have swallow nesting facilities
23 The whole courtyard is used for the cultivation of vegetables, fruit and berries
24 The developers liaise with ecological experts
25 Greywater is treated in the courtyard and re-used
26 All biodegradable household and garden waste is composted
27 Only recycled construction materials are used in the courtyard
28 Each apartment has at least 2 square metres of built-in growing plots or flower boxes on the balcony
29 At least half the courtyard area consists of water
30 The courtyard has a certain colour (and texture) as the theme
31 All the trees and bushes in the courtyard bear fruit and berries
32 The courtyard has trimmed and shaped plants as its theme
33 A section of the courtyard is left for natural succession (that is, to naturally grow and regenerate)
34 There should be at least 50 flowering Swedish wild herbs within the courtyard
35 All the buildings have green roofs

Kruuse, Annika. 2011. "GRaBS Expert Paper 6: The Green Space Factor and the Green Points System." http://www.grabs-eu.org/downloads/EP6 FINAL.pdf.

Appendix 7 – Map of SGF Sites



Seattle Green Factor Group and Zoning

Appendix 8 – Sample of SGF worksheet 2007

SEATTLE green factor

FINAL VERSION 3-9-07

		enter sq ft of parcel			*You need at least 0.300*
	Parcel size *(ENTER THIS VALUE FIRST)**	1		SCORE	-
	Types of Area**		**Square Feet**	**Factor**	**Total**
A	**Vegetation planted with a soil depth of less than 24"**				
1	Lawn or grass pavers or ground covers		*enter sq ft* 0	0.2	-
2	Plants and shrubs 3' and higher at maturity	*enter number of plants* 0	0	0.3	-
B	**Vegetation planted with a soil depth of more than 24"**				
1	Lawn, grass pavers or other plants less than 3' tall at maturity		*enter sq ft* 0	0.7	-
2	Shrubs taller than 3' at maturity - calculated at 16 sq ft per plant (typically planted no closer than 18" on center)	*enter number of plants* 0	0	0.3	-
3	Tree canopy for "small trees" in SDOT's Street Tree Planting Schedule or equivalent canopy spread of 15' - calculated at 50 sq ft per tree	*enter number of plants* 0	0	0.3	-
4	Tree canopy for "small/medium trees" in Street Tree Planting Schedule or equivalent canopy spread of 20' - calculated at 100 sq ft per tree	*enter number of plants* 0	0	0.3	-
5	Tree canopy for "medium/large trees" in Street Tree Planting Schedule or equivalent canopy spread of 25' - calculated at 150 sq ft per tree	*enter number of plants* 0	0	0.4	-
6	Tree canopy for "large trees" in in Street Tree Planting Schedule or equivalent canopy spread of 30' - calculated at 200 sq ft per tree	*enter number of plants* 0	0	0.4	-
7	Tree canopy for preservation of "exceptional trees" or trees with trunk diameter exceeding 24" at four and one half feet above the ground. calculated at 250 sq ft per tree	*enter number of plants* 0	0	0.5	-
8	Permeable paving that drains only itself. It must be at grade. - calculated per square foot		*enter sq ft* 0	0.6	-
C	**Green roofs** - 4" minimum soil depth at time of planting		*enter sq ft* 0	0.7	-
D	**Vegetated walls**		*enter sq ft* 0	0.7	-
E	**Water features (fountains) or rain gardens** (where allowed by SPU)		*enter sq ft* 0	0.7	-
		sub-total of sq ft =	0		
Bonuses					
F	**Landscaping using drought tolerant plants or where at least 50% of annual irrigation needs are met from non-potable sources**		*enter sq ft* 0	0.1	-
G	**Landscaping visible to passers-by from adjacent public right of way or public open spaces**		*enter sq ft* 0	0.1	-
			green factor numerator =		-

** Do not count public rights of way in parcel size calculation.*

*** To calculate your green factor score, you may count the landscape elements that are in public rights of way if they are contiguous with the parcel.*

Elizabeth, Stenning. 2008. "An Assessment of the Seattle Green Factor: Increasing and Improving the Quality of Urban Green Infrastructure." University of Washington - Seattle.

Appendix 9 – Zoning and SGF Changes to Factors

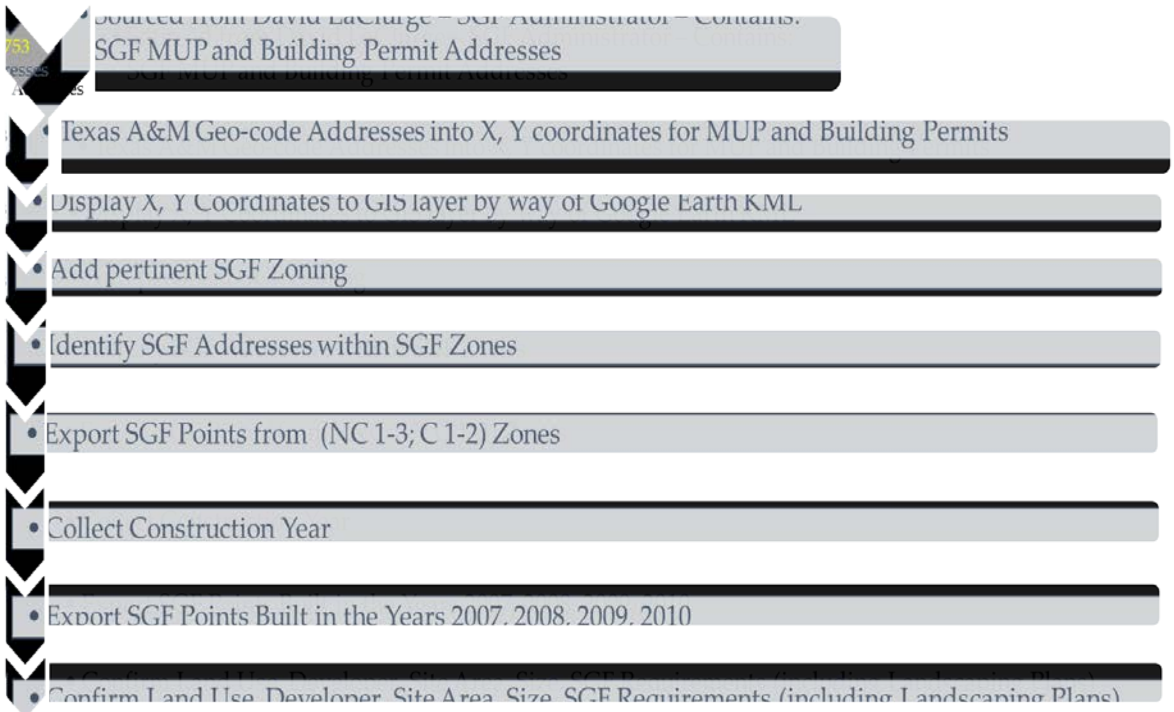
Green Factor	2007 - 2008	2009	2010	2011	2012	2015
SGF Zones	NC, C	+ Mid Rise & High Rise	*Change in SGF Policy*	+ Low Rise Multifamily & South Downtown Planning Area & IC zones within Urban Centers	+ Yesler Terrace	+ Seattle Mixed
A1	Lawn or Grass Pavers or Ground Covers – less than 24”		Landscaped Areas with a Soil Depth of Less than 24”			
A2	Plants and Shrubs 3’ and higher at maturity		Landscaped Areas with a Soil Depth of 24’ or greater			
A3	N/A		Bioretention Facilities			
B1	Lawn, grass pavers or other plants less than 3’ tall at maturity		Mulch, Ground covers, or other Plants Less than 2’ tall at Maturity			
B2	Shrubs taller than 3’ at maturity – calculated at 16 sq ft per plant		Shrubs or Perennial 2’+ at Maturity- Calculated at 12 sq ft per plant (typically planted no closer than 18” center)			
B3	Tree canopy for “small trees” in SDOT’s Street Tree Planting Schedule or equivalent canopy spread of 15’ – calculated at 50 sq ft per tree		Tree Canopy for “small trees” or equivalent (canopy spread 8’ to 15’) – calculated at 75 sq ft per tree			
B4	Tree canopy for “small/medium trees” in SDOT’s Street Tree Planting Schedule or equivalent canopy spread of 20’ – calculated at 100 sq ft per tree		Tree Canopy for “small/medium trees” or equivalent (canopy spread 16’ to 20’) – calculated at 150 sq ft per tree			
B5	Tree canopy for “medium/large trees” in SDOT’s Street Tree Planting Schedule or equivalent canopy spread of 25’ – calculated at 150 sq ft per tree		Tree Canopy for “medium/large trees” or equivalent (canopy spread 21’ to 25’) – calculated at 250 sq ft per tree			
B6	Tree canopy for “large trees” in SDOT’s Street Tree Planting Schedule or equivalent canopy spread of 30’ – calculated at 200 sq ft per tree		Tree Canopy for “large trees” or equivalent (canopy spread 26’ to 30’) – calculated at 350 sq ft per tree			
B7	Tree canopy for preservation of “exceptional trees” or trees with trunk diameter exceeding 24” at four and one half feet above the ground, calculated at 250 sq ft per tree		Tree Canopy for preservation of large existing trees with trunks 6”+ in diameter – calculated at 20 sq ft per inch diameter			
B8	Permeable paving that drains only itself.		N/A			

	It must be at grade – calculated per sq ft	
C1	Green roofs – 4” min. soil depth at time of planting	Over at least 2” and less than 4” of growth medium
C2	N/A	Over at least 4” of growth medium
D1	Vegetated Walls	Vegetated walls
E1	Water Features or Rain Gardens	Approved water features
F1	Landscaping using drought tolerant plants or where at least 50% of annual irrigation needs are met from non-potable sources	Permeable paving over at least 6” and less than 24” of soil or gravel
F2	N/A	Permeable paving over at least 24” of soil or gravel
G1	Landscaping visible to passers-by from adjacent public right of way or public open spaces	Structural soil systems
H1	N/A	Drought-tolerant or native plant species
H2	N/A	Landscaped areas where at least 50% of annual irrigation needs are met through the use of harvested rainwater
H3	N/A	Landscaping visible to passerby from adjacent public right of way or public open spaces
H4	N/A	Landscaping in food cultivation

Appendix 10 – SGF Multiplier Changes Over Time

Factor Change												
2007 - 2009	2010 - 2017	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
A1		0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
A2		0.3	0.3	0.3	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
	A3	N/A	N/A	N/A	1	1	1	1	1	1	1	1
B1		0.7	0.7	0.7	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
B2		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
B3		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
B4		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
B5		0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
B6		0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
B7		0.5	0.5	0.5	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
B8		0.6	0.6	0.6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
C1		0.7	0.7	0.7	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
	C2	N/A	N/A	N/A	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
D1		0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
E1		0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
F1		0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	F2	N/A	N/A	N/A	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
G1		0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	H1	N/A	N/A	N/A	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	H2	N/A	N/A	N/A	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
	H3	N/A	N/A	N/A	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	H4	N/A	N/A	N/A	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Appendix 11 – SGF Parcel Group Workflow



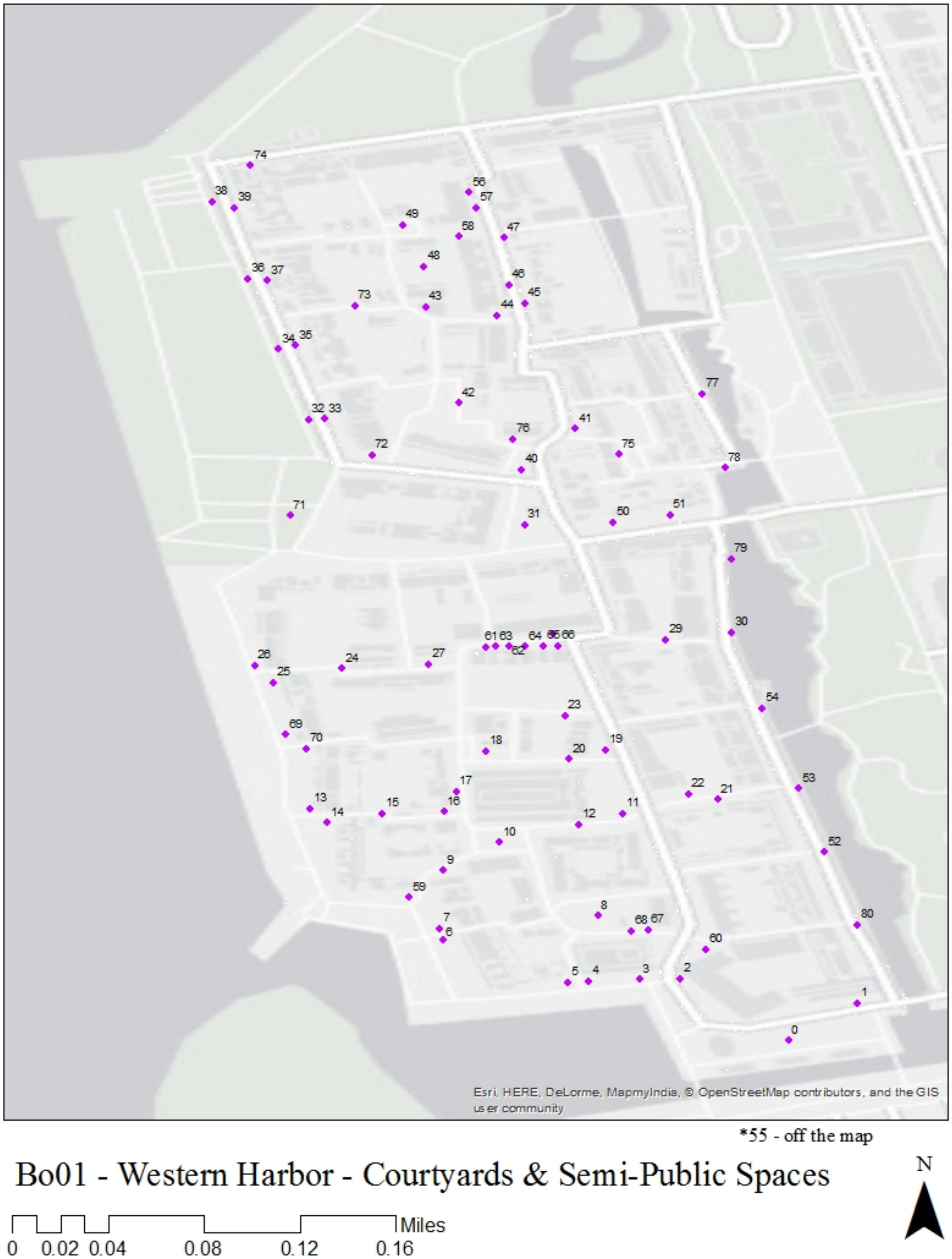
Appendix 12 – Table of SGF Parcels in Detail

ID Number	Address	Zone	Year Built	Lot Area (Sq. Ft.)	Building Gross Area (Sq. Ft.)	# of Units	SGF Value
1	2743 California Ave SW	NC2 - 40	2010	5,650	18,315	All Retail	.306
2	4550 38th Ave SW	NC3 - 65	2010	36,648	213,016	200	.305
3	8124 Rainier Ave S	NC2 - 40	2010	31,879	88,030	71	.351
4	1205 E Pine St	NC3 - 65	2009	11,280	53,679	61	.304
5	12730 33rd Ave NE	NC3 – 65	2009	18,077	56,745	76	.303
6	13716 Lake City Way NE	NC3-65	2010	34,162	165,914	152	0.663
7	1408 14th Ave	NC3-65	2009	29,295	142,586	120	.301
8	1620 Broadway	NC2 - 40	2010	7,680	184,980	122	0.352
9	1924 Rainier Ave S	NC3-65	2009	42,246	38,075	All Retail	0.323
10	222 Queen Anne Ave N	NC3-65	2010	7,434	32,143	29	0.314
11	2946 Eastlake Ave E	NC2 - 40	2008	23,651	7,541	52	0.322
12	3841 34th Ave W	NC2 - 30	2009	6,003	8,244	5	0.305
13	4422 Meridian Ave N	NC2 - 40	2009	9,117	15,212	8	0.315
14	523 Broadway East	NC2 - 40	2010	68,827	436,196	295	0.302
15	7300 M L King Jr Way S	NC3 – 85	2010	81,041	387,971	351	0.305
16	801 NE 65TH ST	NC3 – 65	2009	15,000	4,768	All Retail	0.331

Appendix 13 – Bo01 Parcels[122]

[122] https://kartor.eniro.se/?c=55.612984,12.973373&z=16&l=aerial&som=0

Appendix 14 – Bo01 Courtyards and Semi-Public Space



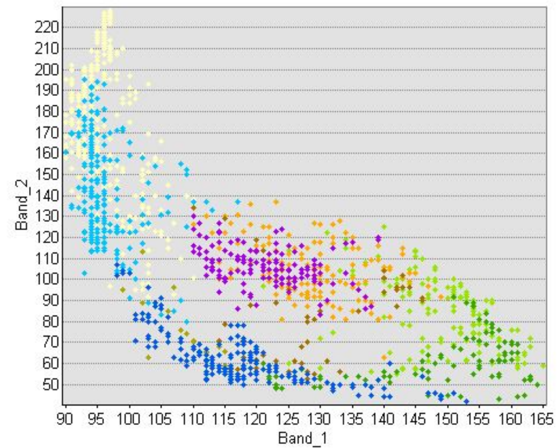
Appendix 15 – Data Library

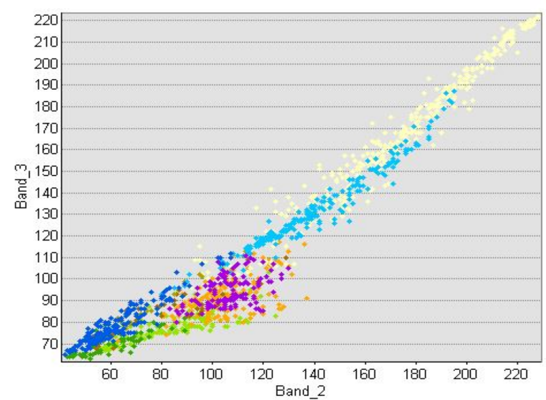
Dataset	Date	Source	Spectral Bands	Description	Used for
NAIP 2009	2009	NAIP	4	Aerial ortho-rectified photography; 1 m per pixel resolution	Vegetation Assessment
NAIP 2011	2011	NAIP	4	Aerial ortho-rectified photography; 1 m per pixel resolution	Vegetation Assessment
NAIP 2013	2013	NAIP	4	Aerial ortho-rectified photography; 1 m per pixel resolution	Vegetation Assessment
NAIP 2015	2015	NAIP	4	Aerial ortho-rectified photography; 1 m per pixel resolution	Vegetation Assessment
Parcel	2004	City of Seattle	NA	Frames all the parcels within the City of Seattle	Estimating the proportion of vegetation within the area of study parcels
ROW	2005	City of Seattle	NA	Outlines Right of Way in the City of Seattle	Used as a reference for impervious surface
Zoning	2004	City of Seattle	NA	Outlines Right of Way in the City of Seattle	Used as a reference to determine applicable groups

Appendix 16 – Training Sample Details

Table: 2015 Training Sample Details

Classification Name	Number of Training Samples	Band 1 (NDVI) - Mean Value	Band 2 (Blue) – Mean Value	Band 3 (Green) – Mean Value	Mean of all Band Values
Tree in Light	21	150.21	84.65	77.56	104.14
Tree in Shadow	20	148.89	60.05	69.46	92.8
Shrub in Light	22	127.61	105.98	92.23	108.61
Shrub in Shadow	16	129.94	80.49	82.76	97.73
Roof - Light	21	93.47	194.45	188.39	158.77
Pavement in Light	21	96.15	132.24	125.91	118.1
Pavement in Shadow	20	117.70	57.98	74.63	83.44
Groundcover	19	121.85	106.23	93.75	107.28





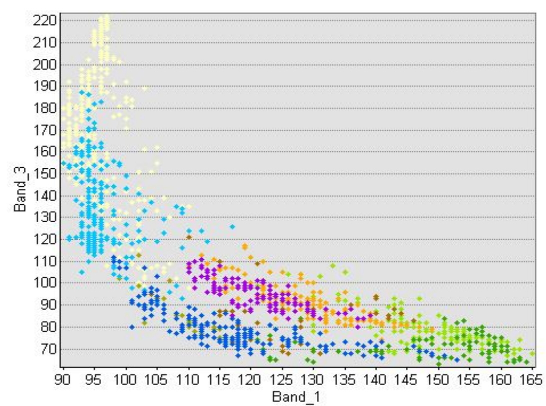
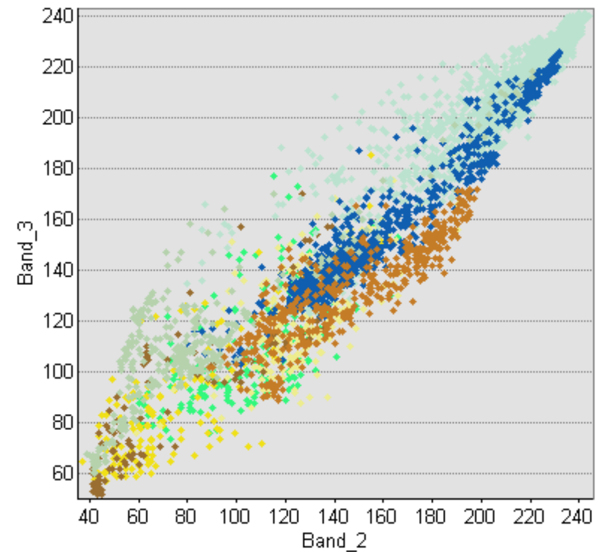
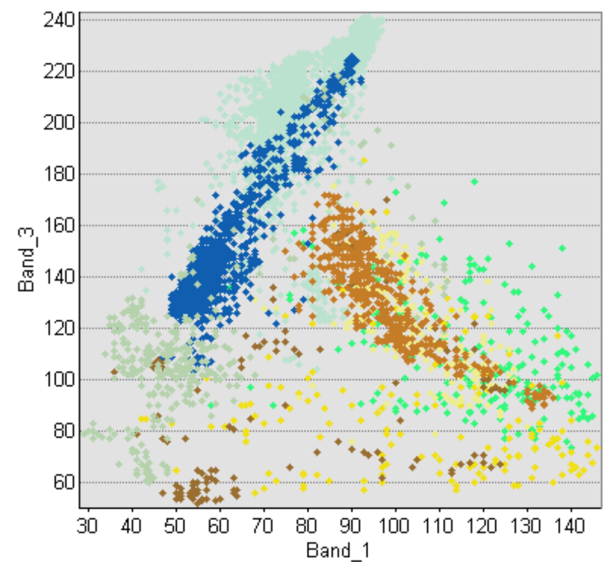
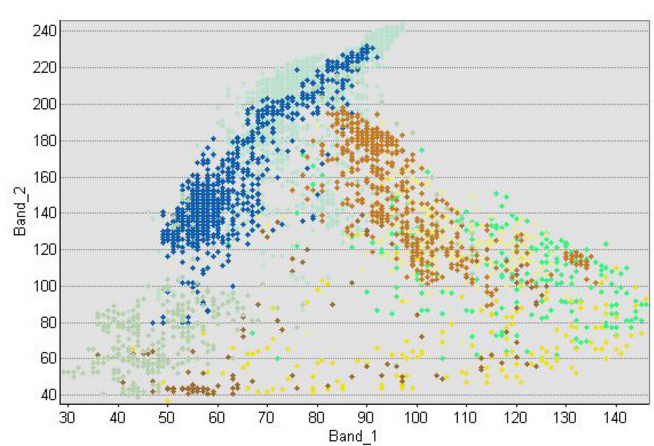


Table: 2011 Training Sample Details

Classification Name	Number of Training Samples	Band 1 (NDVI) - Mean Value	Band 2 (Blue) – Mean Value	Band 3 (Green) – Mean Value	Mean of all Band Values
Tree in Light	21	119.98	107.72	109.23	112.31
Tree in Shadow	20	24.81	70.03	84.09	59.64
Shrub in Light	22	105.38	128.07	121.52	118.32
Shrub in Shadow	16	75.59	68.32	82.87	75.59
Roof - Light	21	84.61	223.40	221.58	176.53
Pavement in Light	21	60.61	152	150.26	120.9
Pavement in Shadow	20	52.23	79.96	109.27	80.49
Groundcover	19	97.76	149.30	132.80	126.62







Appendix 17 – 2011 SGF Group Images

SGF Group – Original Images

523 Broadway

8124 Rainier Ave S

1924 Rainier Ave S

4422 Meridian Ave N

1620 Broadway E

1205 E Pine St

222 Queen Anne Ave N

7300 MLK Jr Way S

2743 California Ave SW

12730 33rd Ave NE

2946 Eastlake Ave E

801 NE 65th St

4550 38th Ave SW

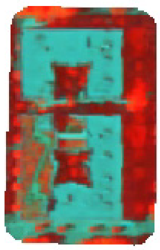
1408 14th Ave

3841 34th Ave W

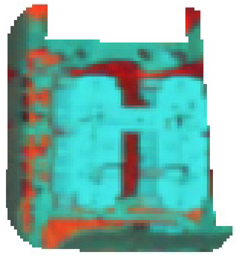
13716 Lake City Way NE

SGF Group – Extract Bands

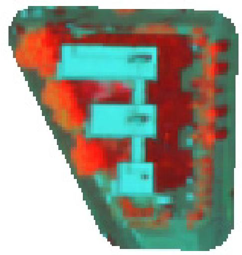
523 Broadway



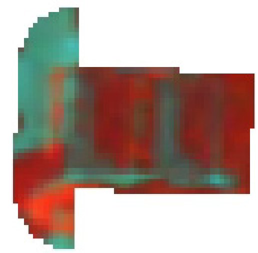
8124 Rainier Ave S



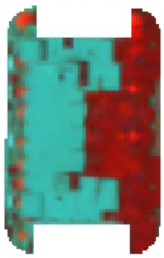
1924 Rainier Ave S



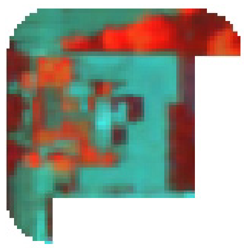
4422 Meridian Ave N



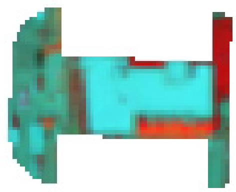
1620 Broadway E



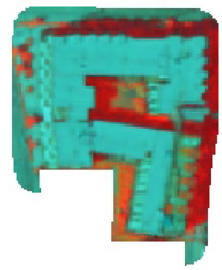
1205 E Pine St



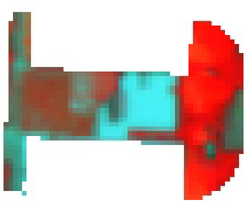
222 Queen Anne Ave N



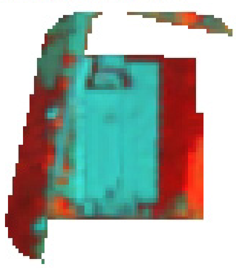
7300 MLK Jr Way S



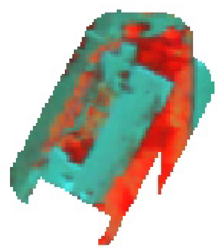
2743 California Ave SW



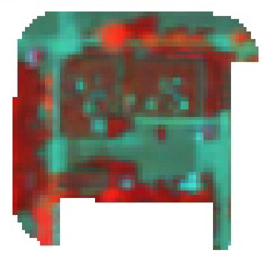
12730 33rd Ave NE



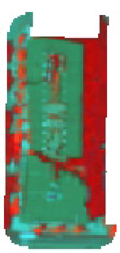
2946 Eastlake Ave E



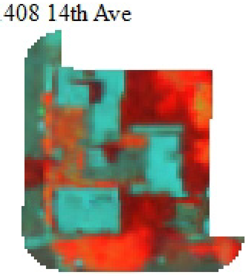
801 NE 65th St



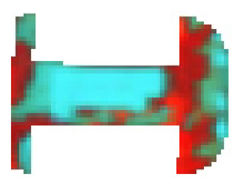
4550 38th Ave SW



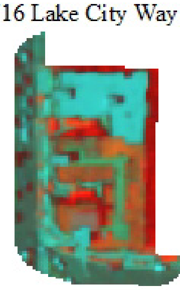
1408 14th Ave



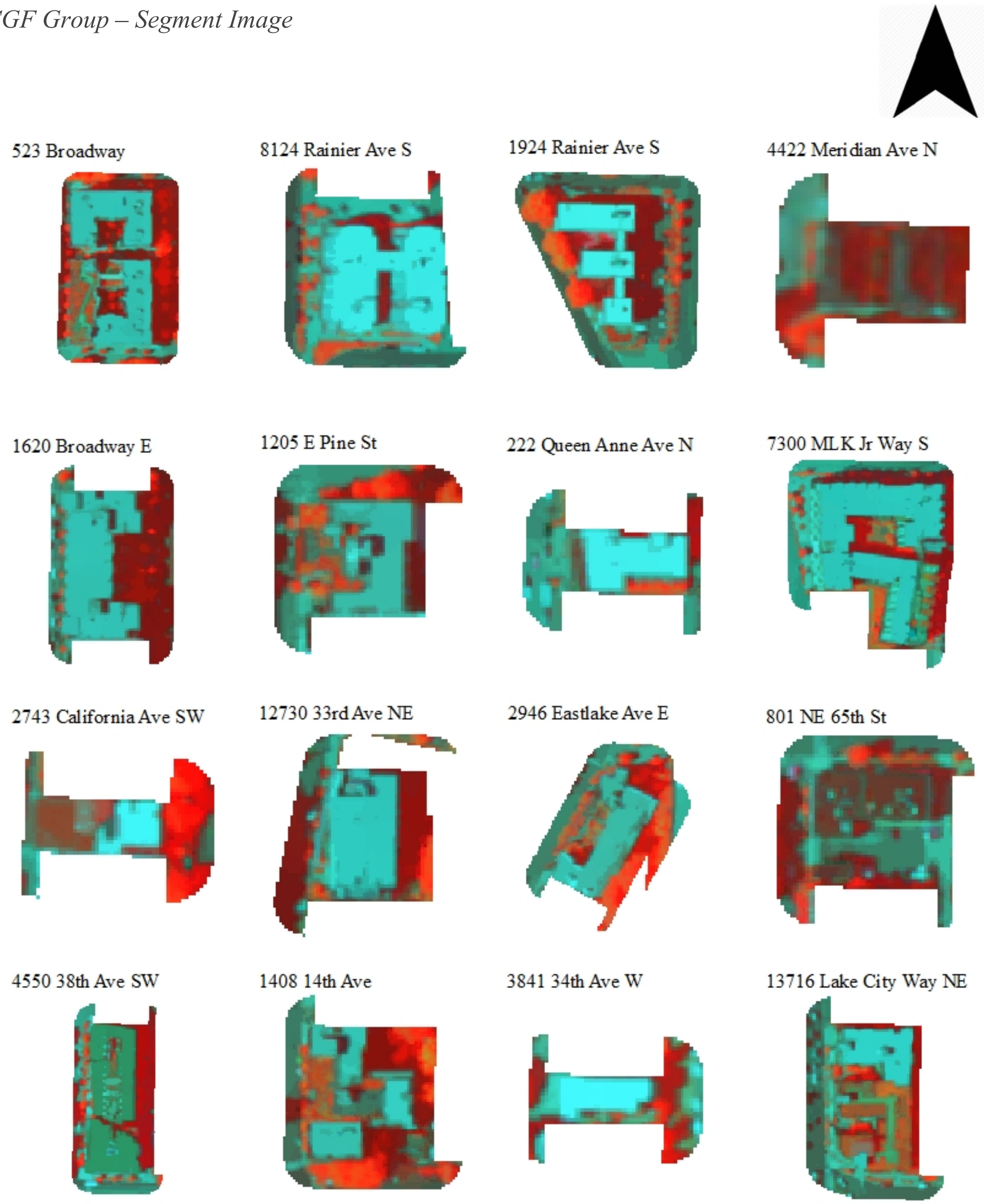
3841 34th Ave W



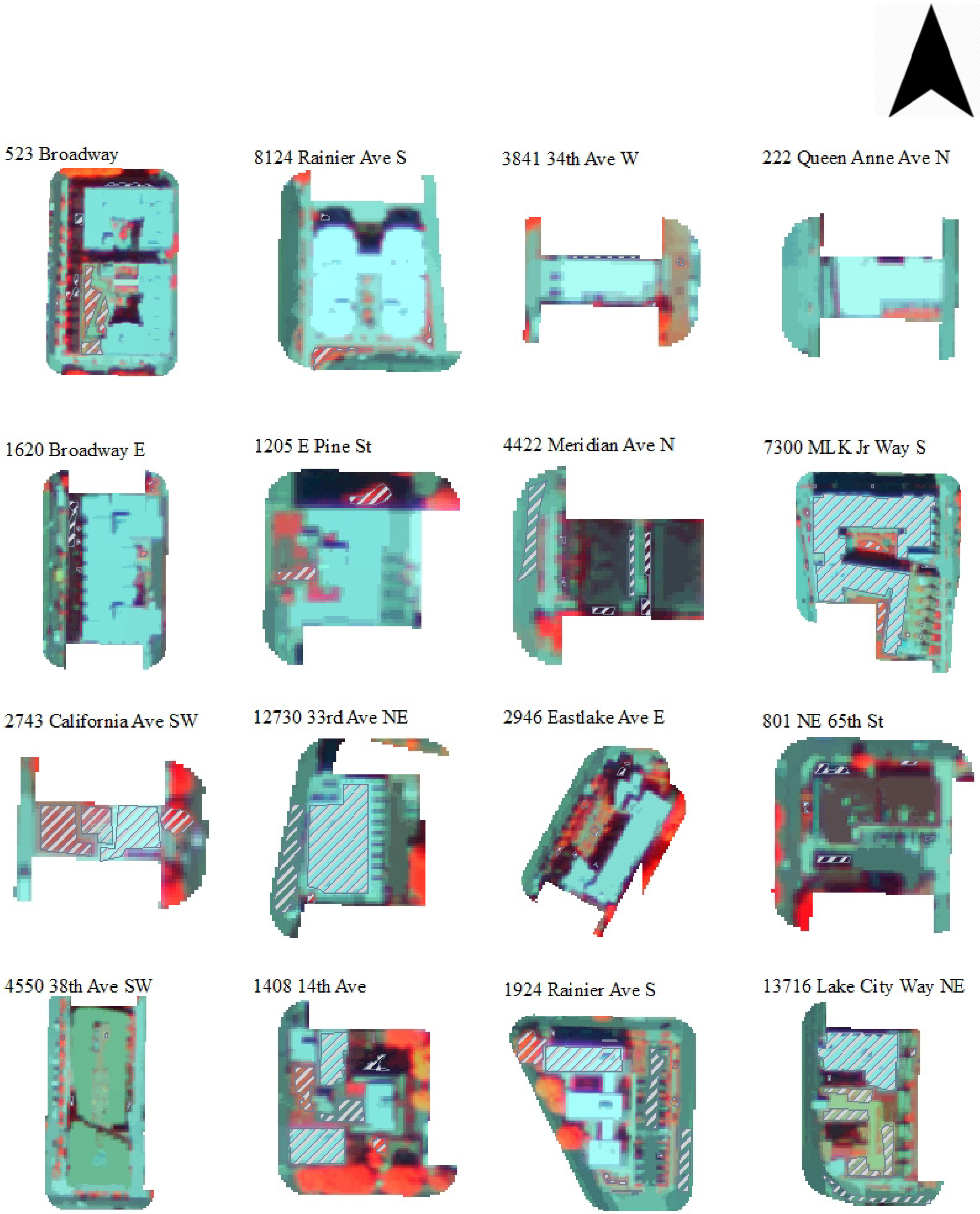
13716 Lake City Way NE



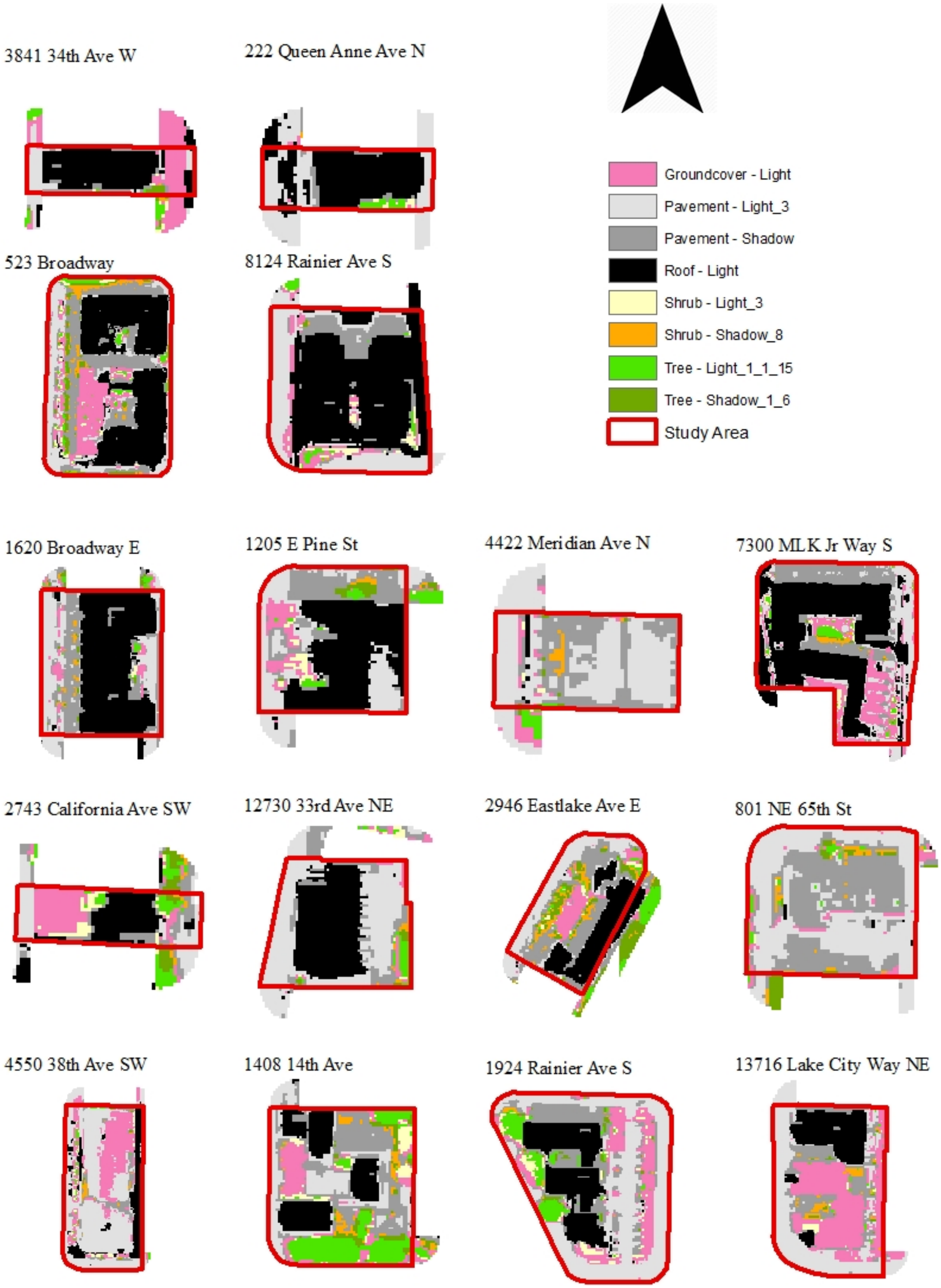
SGF Group – Segment Image



SGF Group - Segment + Training Samples



SGF Group – Classification



Appendix 18 – 2015 SGF Group Images

SGF Group – Original Images

523 Broadway

8124 Rainier Ave S

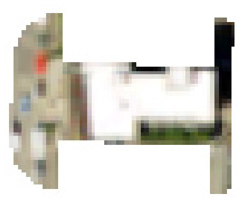
1924 Rainier Ave S

4422 Meridian Ave N

1620 Broadway E

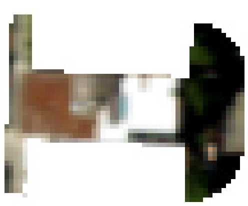
1205 E Pine St

222 Queen Anne Ave N



7300 MLK Jr Way S

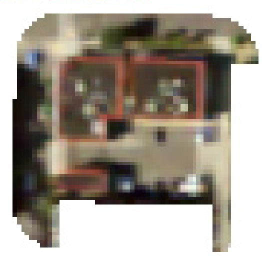
2743 California Ave SW



12730 33rd Ave NE

2946 Eastlake Ave E

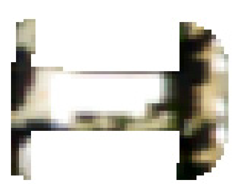
801 NE 65th St



4550 38th Ave SW

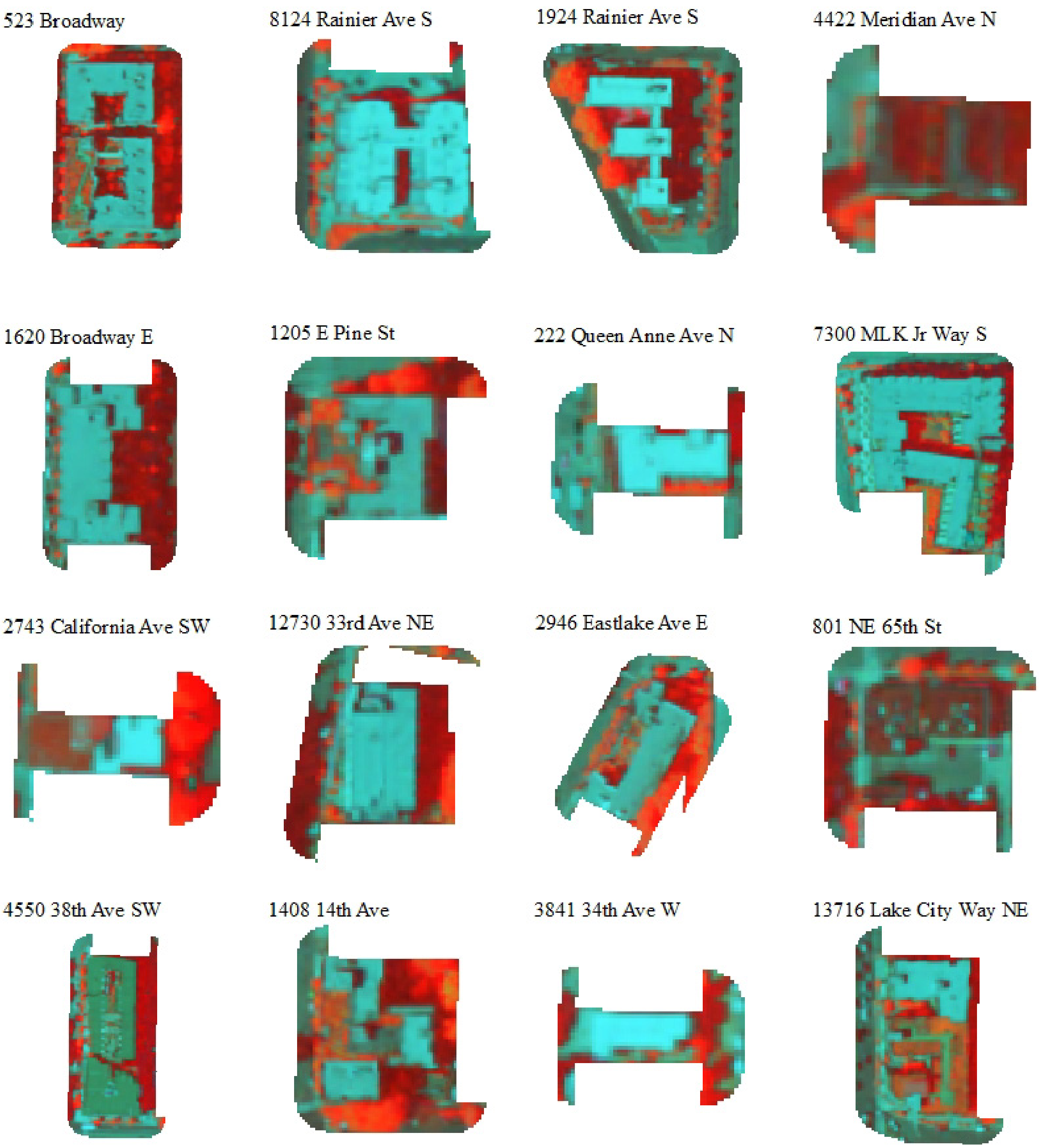
1408 14th Ave

3841 34th Ave W

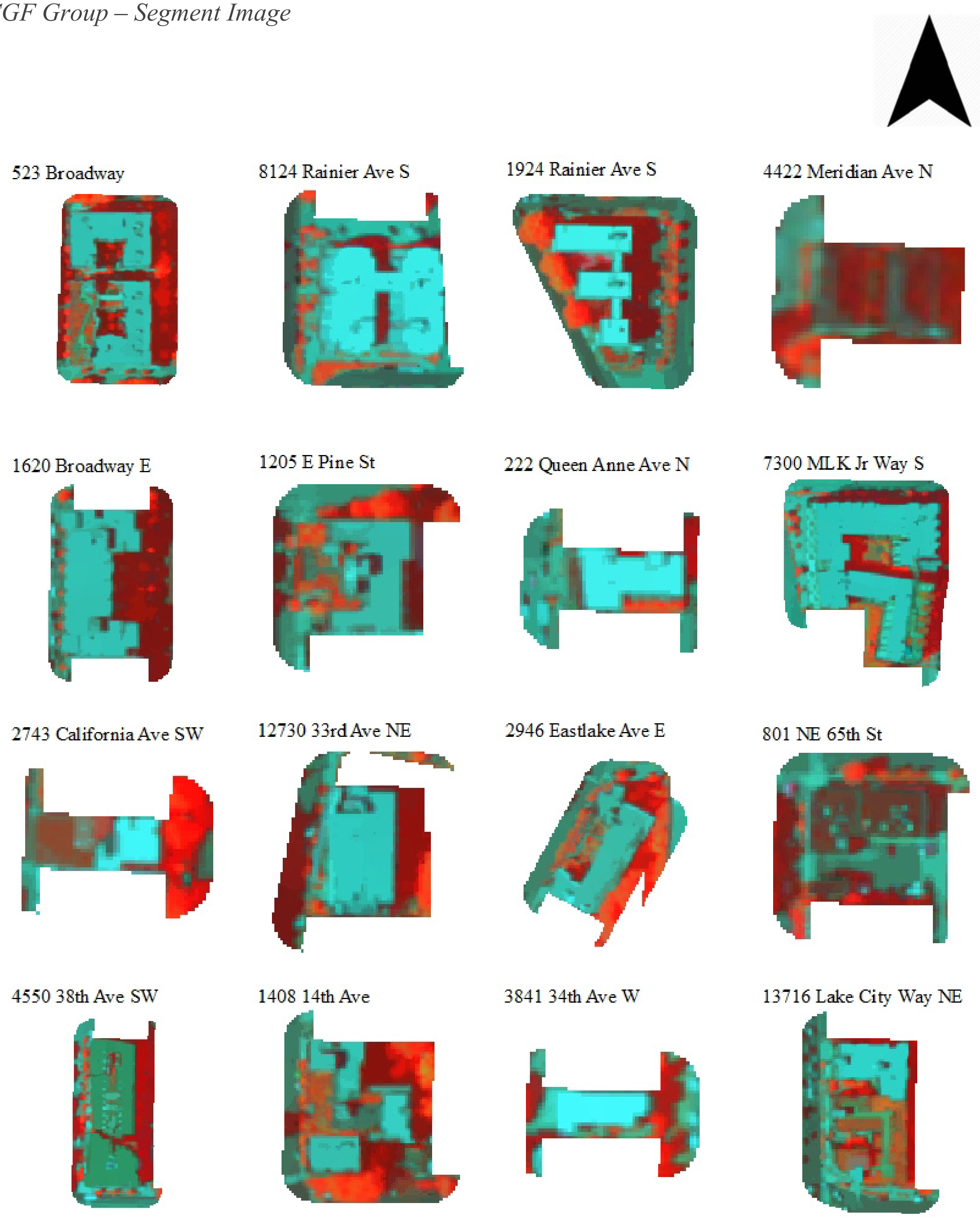


13716 Lake City Way NE

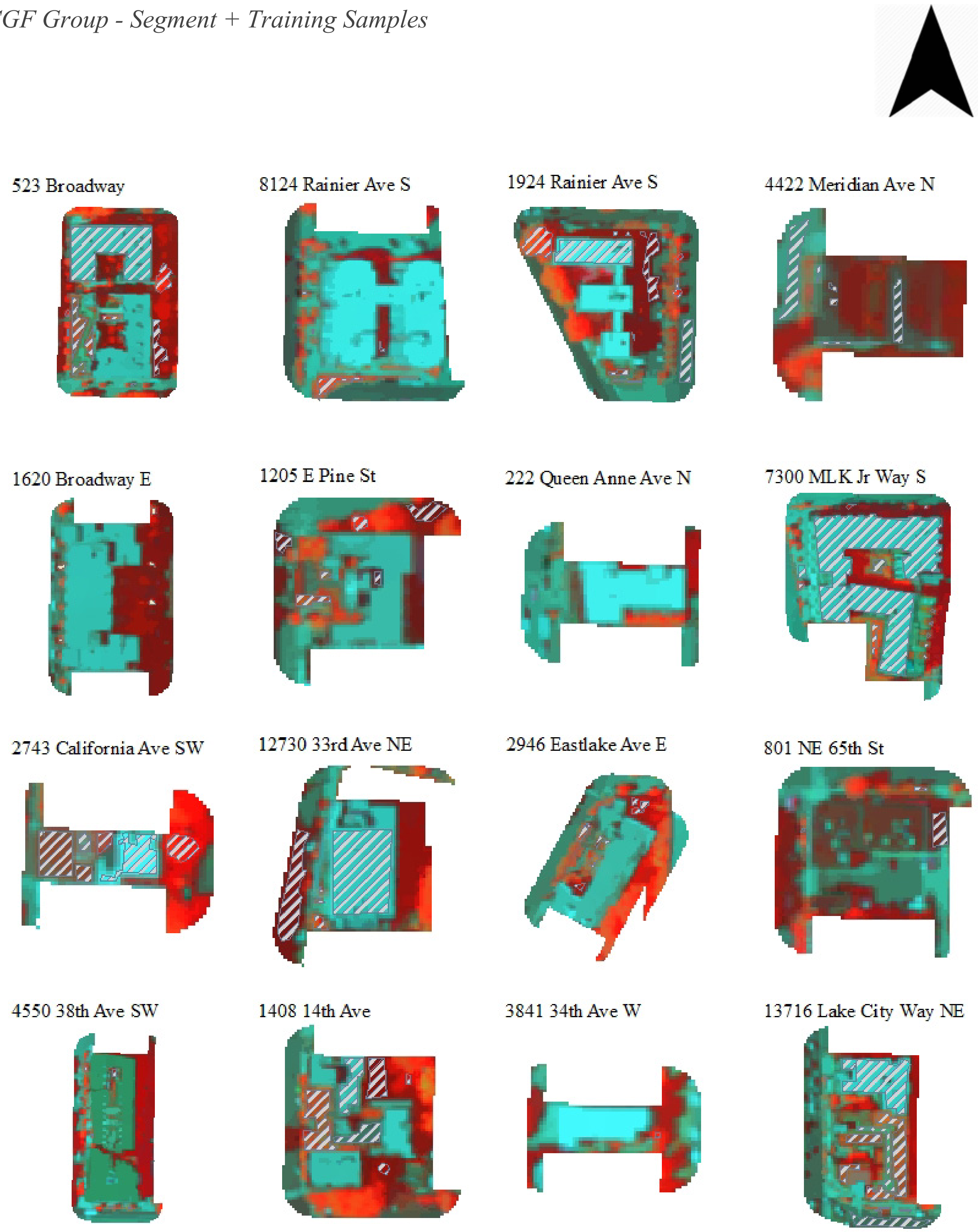
SGF Group – Extract Bands



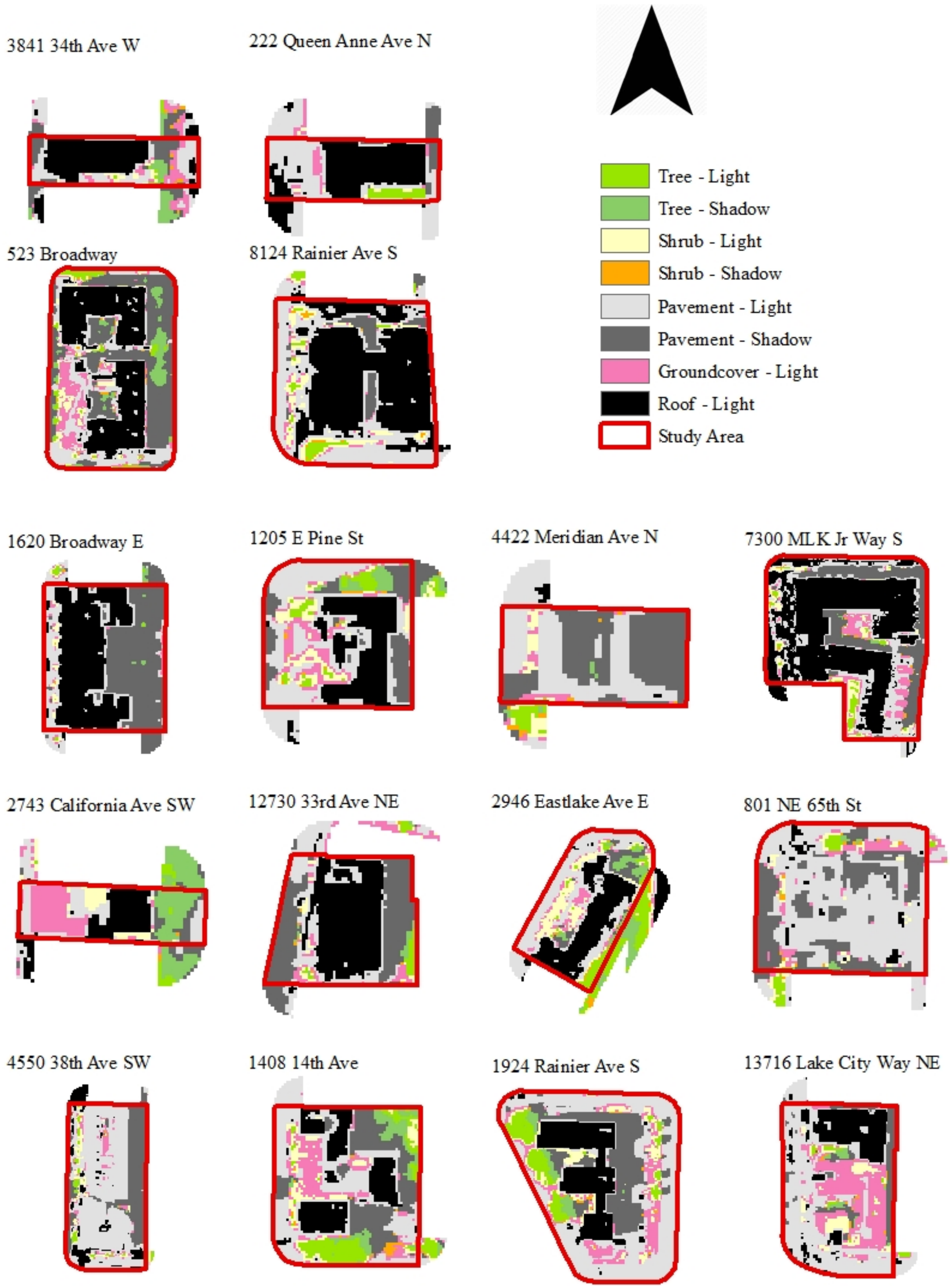
SGF Group – Segment Image



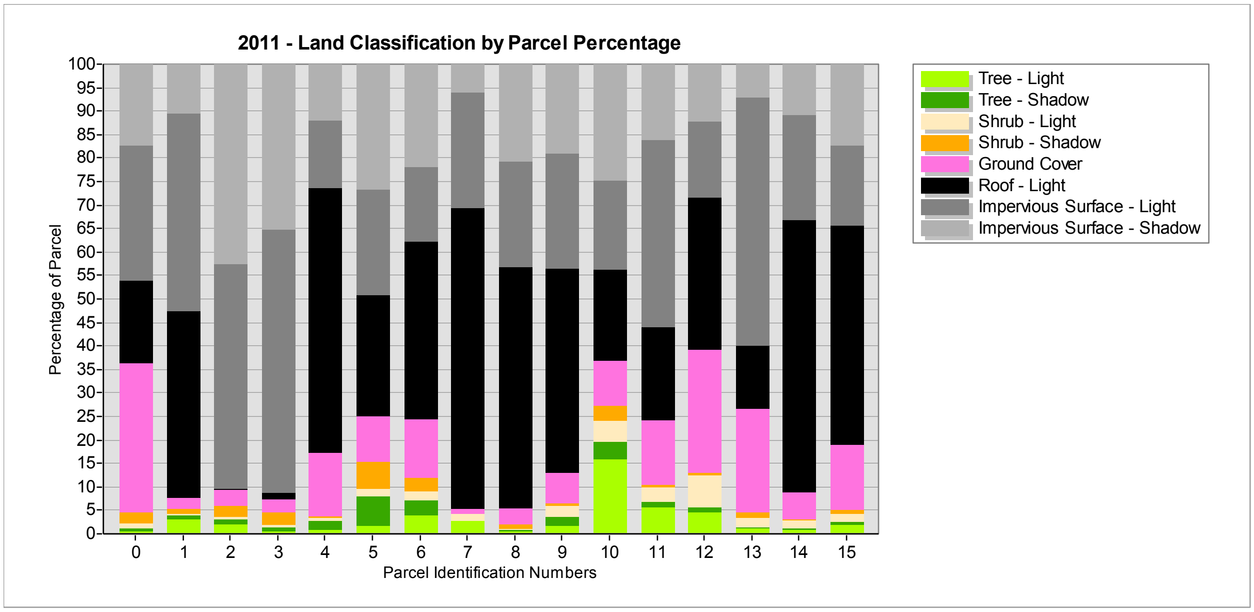
SGF Group - Segment + Training Samples



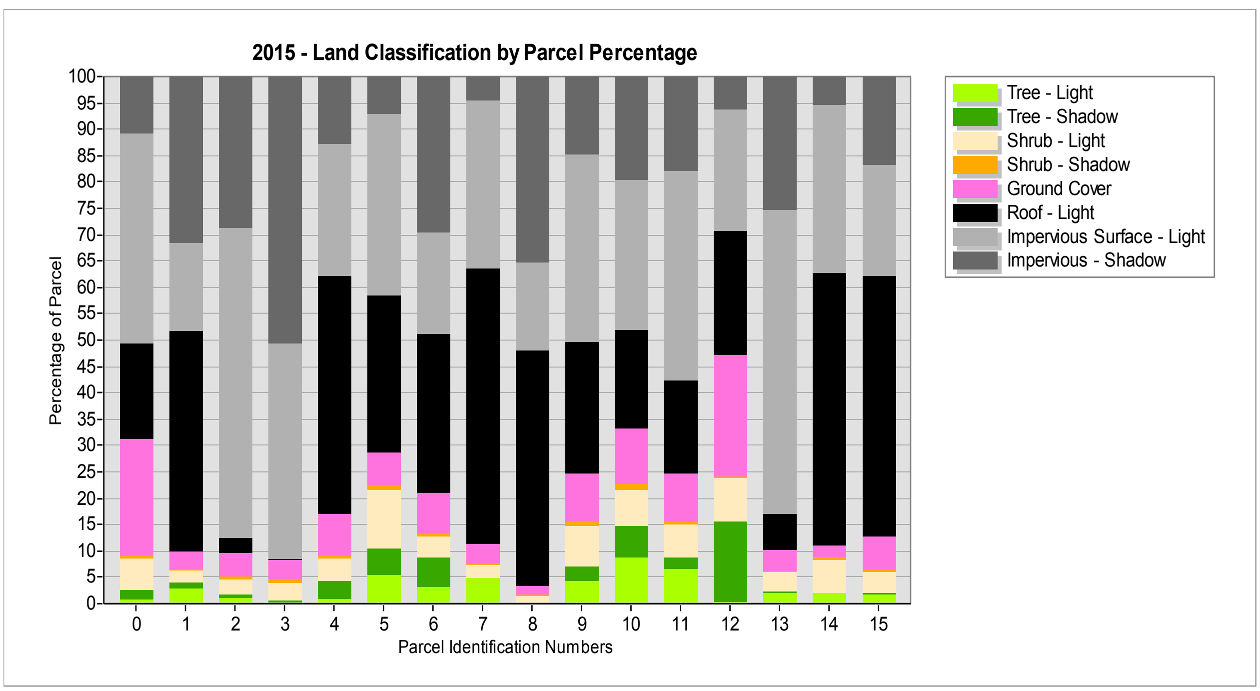
SGF Group – Classification



Appendix 19 – 2011 BAR Table



Appendix 20 – 2015 BAR Table



Appendix 21 – Most Complex Stratification per SGF Site

1620 Broadway	1408 14th Ave	13716 Lake City Way NE	12730 33rd Ave NE	1205 E Pine St	8124 Rainier Ave S	4550 38th Ave SW	2743 California Ave SW	Address
								Groundcover – less than 3’
								Shrub – 3’
								Trees – canopy of 15’
								Groundcover + Shrubs
		x	x				x	**Shrubs + Trees**
								Groundcover + Trees
x	x			x	x	x		**All**
x	x	x	x	x		x	x	**Green Roof**
x				x				**Green Wall**

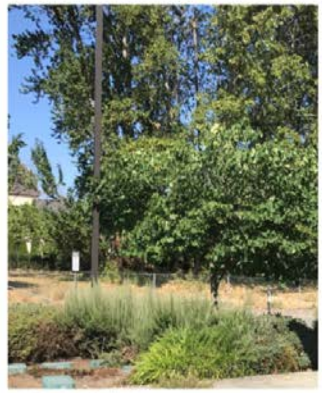
SGF Group Totals	801 NE 65TH ST	7300 M L King Jr Way S	523 Broadway East	4422 Meridian Ave N	3841 34th Ave W	2946 Eastlake Ave E	222 Queen Anne Ave N	1924 Rainier Ave S
							x	
	x	x	x	x	x	x		x
10		x	x			x		
5		x					x	x

Appendix 22 – SGF Group Pictured Stratification

801 NE 65th St

4550 38th Ave SW

8124 Rainier Ave

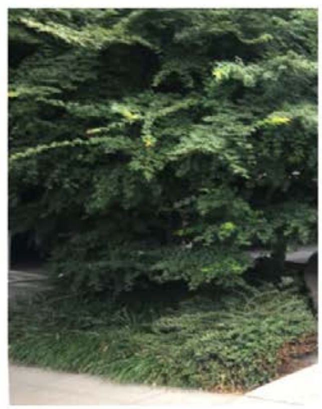


1205 E Pine St

12730 33rd Ave NE

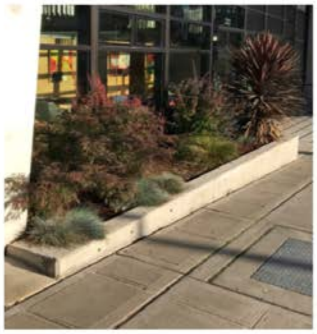
13716 Lake City Way NE

1408 14th Ave



1620 Broadway

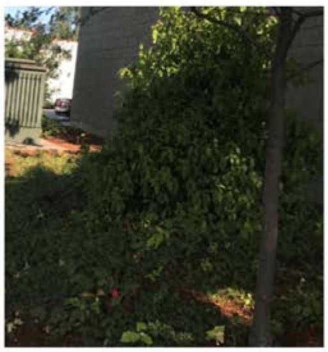
222 Queen Anne Ave N



2946 Eastlake Ave E

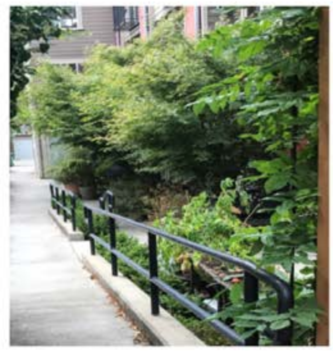
523 Broadway East

1924 Rainier Ave S



7300 MLK Jr Way S

3841 34th Ave W



4422 Meridian Ave N

2743 California Ave SW