Urban Forestry in a Time of Climate Change:

Can Seattle, Washington become more Resilient through the Effective Management of Urban Forests?

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Abstract

Urban Forestry in a Time Of Climate Change:
Can Seattle, Washington become more Resilient through the Effective Management Of Urban Forests?

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Background: There are hundreds of significant problems that confront cities on a daily basis. This thesis focuses on climate change in particular because it is one of the most important and uncertain problems that our cities face. As scientists and policy makers begin to reach consensus about the possible impacts of climate change, urban resilience has become an increasingly hot topic. Urban resilience is defined as the ability of a city to maintain its functions after disturbances disrupt the normal feedback loops that makes city life possible. There are several possible strategies to enhance urban resilience, although this thesis will focus on urban forests. Urban forests are the trees and associated shrubbery present in city parks, right-of-ways, and private gardens. Seattle is used as a case study within this thesis.

Questions: What is the capacity of urban forests to support urban resilience in the face of climate change impacts in Seattle? And how can Seattle's current Urban Forest Stewardship Plan (UFSP) be improved to achieve resilience when considering climate change?

Methodology: The current literature on the benefits and costs of urban forests is explored to justify how they can work to support urban resilience in general. An adapted scenario planning approach is utilized to identify four plausible futures for Seattle based on the interactions of drivers and variables within two alternative states. The resilience within each future is examined through 14 resilience indicators adapted from the seven qualities of a resilient city from the Rockefeller Foundation. The indicators speak specifically to the resilience of Seattle's urban forest, which in turn speaks to the city's urban resilience.

Results/Conclusion: The management of urban forests plays a significant role in maintaining urban resilience. Yet if it is not coupled with global reductions in greenhouse gases, the urban forest cannot be enough to provide mitigation. The thesis makes five recommendations to Seattle's existing UFSP in order to increase the ability of urban forests to help the city adapt to and mitigate against climate change. The adoption of these recommendations by the city might allow Seattle to achieve resilience in the face of uncertain climate change impacts.

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Chapter 1 – Introduction

1.0 Background

There are hundreds, if not thousands, of significant problems that confront cities on a daily basis. This thesis focuses on climate change in particular because it is one of the most important and uncertain problems that our cities face. Climate change will not only create new issues, but it will also exacerbate others that already exist. As scientists and policy makers begin to agree more about the plausible futures that could result from climate change, urban resilience has become an increasingly hot topic. Urban resilience is defined as the ability of a city to maintain functionality even after disturbances, such as climate change events, work to disrupt the normal feedback loops that make city life possible. The goal is not to keep the city static as it exists today, but to allow for dynamic movements while ensuring that system functionality, such as clean water delivery, remains intact (Alberti et al., 2013a, 49).

The scale for this study of urban resilience and climate change is the city. The city was selected because of its growing dominance in terms of total population, geographic area, and wealth on a global scale. Cities now hold over 50 percent of the world's population (Davies et al., 2011, 1125), and almost 81 percent of those in the United States (U.S.) live in urban areas (Lambert, 2012). To house and employ this growing population, "urban land area is expected to increase by 79 percent between 1997 and 2025" in the U.S. (Berland and Manson, 2013, 750). As the human capital and number of businesses in cities increase, cities have also become economic centers that command international attention. The growing economic power of cities is illustrated by the 2007 statistic that 380 cities generated half of the global GDP that year, and 190 cities in North America generated over 20 percent (Dobbs et al., 2011). These increases in population, landmass, and economic power are important because they imply that what happens in cities will have wide spread ramifications regionally and globally. Cities therefore have a considerable amount of power to create positive or negative change when it comes to climate change based on their individual behaviors. This power is also based partially on the ability of cities to inspire global trends, thereby expanding the impact of their specific actions beyond their borders.

Cities are also large contributors to climate change globally, and are at the same time exposed to a number of climate change risks on a local level. To date, cities are responsible for approximately 80 percent of all greenhouse gas (GHG) emissions worldwide (World Bank, 2010, 1), and this trend does not show any sign of slowing. Somewhat ironically, cities are also at particular risk to the negative effects of climate change due to their often vulnerable locations, vulnerable populations, and because they have so much to loose in terms of people and infrastructure. Cities are both perpetrator and victim to climate change, and thus have an incentive to mitigate and adapt to its impacts. To further muddy the waters, no one city is the primary source of climate change, and no one city has the ability to mitigate climate change on its own. These factors make the study of cities, climate change, and urban resilience especially important and complex.

The above collection of sometimes contradictory characteristics has inspired this thesis to focus on cities in general, and on Seattle, Washington in particular. Seattle is within the Pacific Northwest of the U.S., and is currently one of the fastest growing cities in the country in terms of population, land coverage, and economic power (Balk, 2014). Seattle therefore personifies the attributes of a city explained above, and can serve as a proving ground for resilient strategies to climate change.

There are several possible strategies to enhance urban resilience in Seattle, although this thesis concentrates on urban forests. Urban forests can play a role in addressing climate change through their ability to help cities both mitigate and adapt. For instance, the vegetation within urban forests can sequester carbon, a GHG that contributes to climate change, on a grand scale through reforestation and afforestation projects in and around cities (Phillips, 2014, 8; Donovan and Butry, 2009, 666; Liu and Li, 2012, 121; Akbari, 2002, S119). Although some often look to urban forests as a catchall solution with the ability to help remediate any urban malady. This thesis aims to examine the ability of urban forests to support resilience against one such urban problem, climate change. In doing so, this thesis hopes to begin to test this silver bullet theory of urban forestry.

1.1 Research Questions

More specifically, this thesis examines the effectiveness of an urban forest strategy to support urban resilience within Seattle, Washington. Many scientists and politicians alike sing the praises of urban forests and believe that these spaces can solve almost any urban malady. As a result, there are a plethora of academic studies and articles on the functions and benefits of urban forests. Conversely, and somewhat surprisingly, there are very few scientific articles on the ability of urban forests to support a city’s resilience against possible future threats, such as climate change. The purpose of this project is to begin to fill some of these gaps.

More specifically, the two research questions include:

1. What is the capacity of urban forests to support urban resilience in the face of climate change impacts in Seattle?
2. How can Seattle's current Urban Forest Stewardship Plan (UFSP) be improved to achieve resilience when considering climate change? What actions can be taken today to make the UFSP a more robust plan better able to succeed under alternative plausible future?

Before conducting the research and analyzing the data, this thesis assumed that the abilities of urban forests to help support resilience against climate change had been overhyped. The scale of the urban forest in the City of Seattle in particular did not seem grand enough to be able to play more than a negligible role. Further, as Seattle is often on lists describing the best urban forests in the United States, it was also assumed that the urban forest and the urban forest management plan already in place within the city was sufficient to provide any support that the urban forest had that capacity to deliver (American Forests, 2015b).

1.2 Methodology

To understand how urban forests can affect urban resilience, the current literature on the benefits and costs of urban forests is explored in **Chapter 2**. These theories are applied in Seattle through a scenario planning approach[1] that imagines four plausible futures for the city based on varying driver and variable interactions in **Chapter 3**.

Scenario planning is a form of scientific visioning that identifies plausible futures through the

[1] This thesis utilizes an abbreviated scenario planning approach, not a full scenario planning process, because the public and other stakeholders were not involved in the creation of the scenarios narratives.

use of sound judgment, empirical evidence, and the best available science (Peterson et al., 2003). While climate change is not the only factor that can negatively affect a city's resilience, and an urban forest is not the only potential solution (see **Figure 1-1** on the next page), these two variables are the primary focus of this thesis.

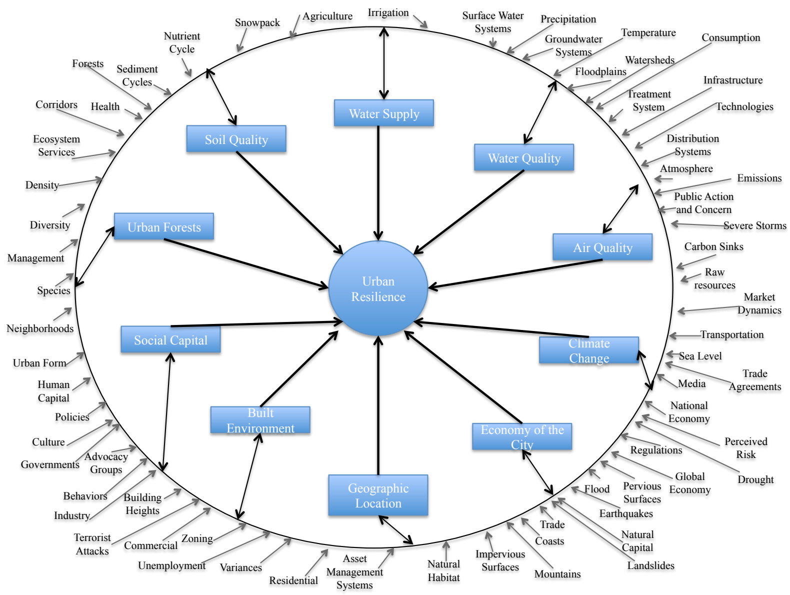

Figure 1-1. A small taste of the various components that help dictate a city's resilience. Climate change and urban forests are just two potential components.

As climate change and urban forests are still complex and broad reaching concepts, these ideas are further narrowed within this thesis. Climate change is primarily discussed in Seattle in terms of two specific Representative Concentration Pathways (RCPs) – RCP 4.5 and RCP 8.5 – as created by the Intergovernmental Panel on Climate Change (IPCC). Urban forests, as a strategy to combat climate change, are examined through the city's institutional framework for conservation planning, as defined by Seattle's existing UFSP and a possible more enduring urban forest management plan. These two change actors are the primary drivers used within this thesis to create the scenario narratives. The two principal internal variables considered within this thesis are Washington State's Growth Management Act (GMA), and the amount of impervious surfaces present in the city. Diverging future scenario narratives are based on different endpoint assumptions for each of the interacting drivers and variables. (See **Chapter 2** for a more in depth discussion on scenario planning, and **Chapter 3** for a discussion of drivers and variables of change.)

Ultimately, the resilience of Seattle's plausible futures is measured through the use of resilience indicators. These indicators allow for a qualitative discussion on how much or little resilience is present in each future, and a comparison of resilience across the four divergent futures of Seattle (see **Chapter 4**). With this analysis, it is then possible to make recommended changes to the existing UFSP in Seattle to create a more robust plan. Ideally, the adoption of these recommendations will create an urban forest management plan that is better able to support resilience against climate change in any of Seattle's plausible futures (see **Chapter 5**). The UFSP is simply the instrument of a greater institutional framework for conservation planning in Seattle that could drastically change in the next 85 years. Although, the UFSP is something that exists in Seattle today, and if the city can take steps to make it more robust now, then perhaps Seattle can enjoy more resilience to climate change over the next 85 years.

1.2.1 Best Available Science

This thesis utilizes scenario planning as an applied science to best answer the research questions. This use of the best available science was selected because it provides more flexibility than modeling, while still allowing for robust policy recommendations. Modeling was not utilized because they can generally only predict one mathematically assumed future. Further, to make such predictions, models must simplify systems to a point where there are no uncertainties. Scenario planning, on the other hand, is a technique to better equip decision-makers to make successful decisions in a world full of uncertainty, where it is not possible to identify the one true future. By incorporating uncertainty, scenario planning discourages decision-makers from getting wed to, or bogged down with, one idea or decision that could be based on a future that may not come to pass. Ideally, strategies that come out of scenario planning will be robust enough to be applicable in any number of plausible futures (Carpenter, 2002, 2081).

The plausible futures created through the scenario planning approach within this thesis, provide narrative snapshots that imagine how Seattle's future could look based on a number of factors. It is not possible to measure these results through strictly quantitative methods, as this approach produces narratives that depend on both sound judgment and empirical evidence. Therefore, to incorporate more measurable metrics into the process, resilience indicators were created based on work done by the Rockefeller Foundation and the World Bank. In **Chapter 4**, the narratives are examined in relation to these indicators in order to quantify how they perform in relation to each other. The result of this analysis is a visual representation of how the divergent futures perform under each resilience indicator.

1.2.2 Limitations

Scenario planning does not follow the process of a normal experiment, and some believe that this is its central limitation. While scenario planning can be repeated using the same assumptions and scientific evidence, the results may shift based on the perspectives of the individual(s) repeating the steps. This is because scenario planning is pre-experimental, and it is not possible to test or prove the validity of the narratives or assumptions in the real world. Due to the level of uncertainty and complexity inherent in examining plausible futures, the author of the scenario narratives must simply wait and see what happens. Additionally, the ability to repeat the process and develop the same results as before is not necessarily the objective of scenario planning. The goal is to aid in the creation of robust strategies able to be successful in any number of plausible futures. Therefore, as long as the narrative futures are thoroughly explained and based in sound judgment and empirical evidence, the goals of scenario planning can be reached.

1.3 Central Audience and Results

The central audience of this thesis are those within Seattle's Department of Planning and Development, Department of Transportation, Urban Forestry Commission, Green Cities Research Alliance, and others responsible for implementing or maintaining Seattle's UFSP. The thesis could also more broadly apply to Seattle government officials and agencies interested in, and charged with, creating urban resilience. The types of Seattle government agencies interested in resilience include, for instance, the City Council and the Office of Sustainability and Environment. Further, there are several non-profit organizations concerned with resilience and urban forests in Seattle that could utilize this thesis as a reference. By the end of **Chapter 5**, the audience will understand four central points:

1. Climate change is a problem in Seattle because it creates uncertainty and increases risks to human and environmental health;
2. Urban resilience is a way to reduce the severity of this risk by maintaining the functionality of the city;
3. Urban forests can support urban resilience; and
4. The management of urban forests will impact the ability of the forests to create benefits that translate to urban resilience.

The scenario planning approach of this thesis has been tailored specifically for Seattle, and as such, the results and discussion mainly pertain to the city. Conducting such a case study approach may restrict the ability of the project to be directly scaled for use in other cities. Although, another city should be able to adapt the assumptions made throughout this process to match their own city's needs, and come to their own rational conclusions.

1.4 Summary

Chapter 1 has described the purpose of the project, as well as the research questions, methodology, central audience, and provided a taste of the expected results. **Chapter 2** provides the necessary definitions of terms such as urban resilience, climate change, and urban forests, to ensure that the reader and author have the same understanding of important concepts. This chapter is primarily composed of a literature review of what benefits an urban forest can provide a city, and how these benefits can translate into urban resilience through effective management. There are several existing academic papers that examine urban forests, climate change, and resilience, and this chapter begins to take the next logical step in connecting the concepts. **Chapter 3** provides the unique scenario planning approach for Seattle that results in four divergent, plausible futures for the city. This chapter provides the assumptions and describes the central actors of change considered in the process, so that it can be as repeatable as possible within other cities, or with different participants. Next, **Chapter 4** analyzes the divergent futures in terms of their urban resilience, and these results form the basis for the UFSP recommendations provided in **Chapter 5**.

Chapter 2 – Review of Existing Literature

2.0 Introduction

Before moving ahead into scenario planning, it is essential to discuss a few of the key concepts and terms that will be continually utilized throughout this paper. These working definitions will help establish common ground between reader and author, allowing for each to share a foundation of understanding that will hopefully prevent any miscommunications. While this thesis does concentrate specifically on the City of Seattle, **Chapter 2** primarily looks beyond this scope because the ideas discussed here are broader than just Seattle. Additionally, while many of the following definitions could apply to metropolitan areas across the world, they are primarily intended for cities in the U.S.

2.1 An Urban Area

It is often hard to create clear geographic boundaries for urban areas, but as this is a political necessity, general rules have been generated. The U.S. Census (2010) defines an urban area as "densely developed territory…[that] encompass[es] residential, commercial, and other non-residential urban land uses." The Census further states that "an urban area…is a densely settled core of census tracts and/or census blocks that meet minimum population density requirements [50,000 or more people], along with adjacent territory containing non-residential urban land uses as well as territory with low population density included to link outlying densely settled territory with the densely settled core" (U.S Census Bureau, 2010). This provides a general definition of an urban area, although, urban and city boundaries are constantly evolving based on population densities, social norms, public opinions, and politics. City A, for instance, can annex neighboring City B, thus changing City A's legal boundaries. Although City A can also grow through the urbanization of surrounding rural towns or virgin forests. (See **Figure 2-1** for the growth of Seattle over time.) Urbanization is the spread of impervious surfaces, populations, and built environments into previously un-urban areas (Merriam-Webster, 2015). As a counterbalance to this type of growth, some cities have created urban growth boundaries in an attempt to confine their cites within stricter borders (Washington State Legislature, 2015a).

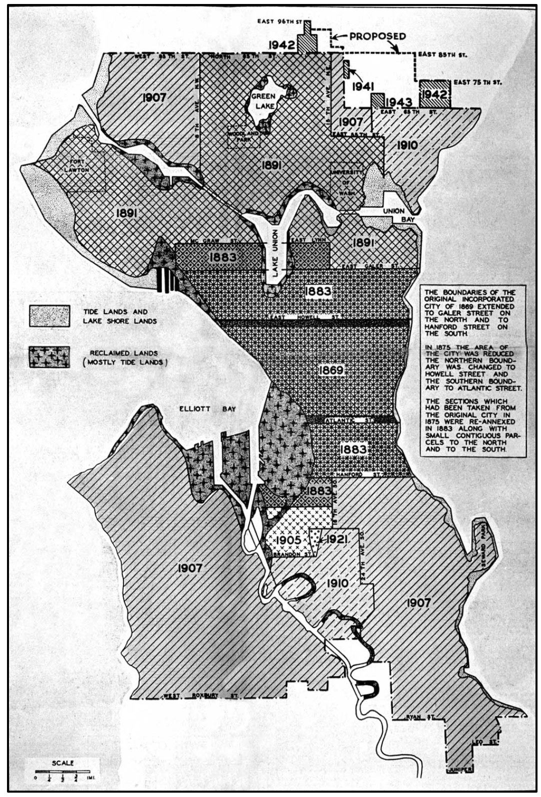

Figure 2-1. Seattle's Boundary growth through time (McDonald, 1944).

2.2 The Urban Problem

Some of the many problems that can plague urban areas, and possibly be addressed by urban forests, are enumerated below. This should not be considered an exhaustive list.

2.2.1 The Urban Heat Island Effect

The urban heat island (UHI) effect is defined as an increase in temperatures within an urban environment when compared to temperatures in the surrounding rural areas (USEPA, 2014a). This phenomenon takes places because a majority of urban areas are made of impervious surfaces, such as roads and buildings, whereas rural areas have a higher percentage of

Seattle's UHI

Despite Seattle's reputation for rain and gray skies, the UHI effect is a very serious issue in the city. Seattle is already one of the U.S.'s top ten cities with the largest temperature differential between its downtown urban core and surrounding rural areas. Further, Seattle is one of the fastest growing cities in America, implying that this temperature differential could get even worse in the future (Climate Central, 2014; Balk, 2014). As it stands now, Seattle's urban core can be up to 17°F hotter than nearby rural areas, and there are on average two more days every year that reach over 90°F in the city than within rural areas (Climate Central 2014).

pervious areas, such as vegetation. As the "hard, dark surfaces…[of impervious areas tend] to be measurably hotter than natural areas…[Their presence] can raise a city's temperature 4 to 10 degrees Fahrenheit on hot summer days" (Chicago Climate Action Plan, 2014). Rising temperatures in cities have been linked to several human health consequences including "elevated rates of illnesses" (Jenerette et al., 2011, 2637), as well as "general discomfort, respiratory difficulties, heat cramps and exhaustion, non-fatal heat stroke, and heat-related mortality" (USEPA, 2013a). These increasing temperatures also negatively affect natural systems by altering water availability and effecting air quality (Jenerette et al., 2011, 2638).

2.2.2 Urban Sprawl/Urbanization

Cities evolve and expand from towns into metropolitan areas as their populations, wealth, and ultimately square footage increase (Davies et al., 2011, 1126). In the U.S., this has historically meant horizontal growth, as opposed to vertical expansion, because of the advent of better transportation technologies over time that has allowed for efficient movement across space. For instance, with increasing access to personal automobiles and their subsequent infrastructure such as roads in the first half of the 20th century, residents no longer had to live in the city center in order to work there. With this reality, and the growing stigma of the city center as a dirty place, those who could afford to do so, moved out to the suburbs. This urban sprawl has continued into present day, and has been the leading cause for the creation of impervious surfaces that now cover most of our urban areas, fragment natural habitats, and destroy native vegetation (Berland and Manson, 2013, 750; Carrara et al., 2014, 13). Urbanization of land is also worrisome due to its ability to undermine many of the ecosystem services we have come to rely upon, such as the hydrological cycle (Berland and Manson, 2013, 750). Impervious surfaces impact the hydrological cycle by preventing rainwater from percolating down into the soil to recharge aquifers. Further, "habitat loss and landscape change are documented to have played a major role in the increased prevalence of vector-born diseases such as Lyme disease, West Nile virus, Chagas disease, and tick borne encephalitis" (Tallis et al., 2008, 9462). Finally, urbanization causes cities to experience UHIs, as well as increased "energy use, carbon dioxide emissions from fossil fuel power plants, municipal water demand, ozone levels, and human discomfort and disease. These problems are accentuated by climate change, which may double the rate of urban warming" (Simpson, 2002, 1067).

2.2.3 Climate Change

One of the central impacts of climate change is the warming of the atmosphere. This warming poses many serious problems directly to cities, such as exacerbating already present UHIs. This warming also presents several new issues that could cascade through natural systems (Liu and Li, 2012, 121). For instance, oceans have a current, very generally speaking, because of thermoaline circulation where cold, dense water from the poles gradually sinks, and warm less dense water from the equator slowly rises. "Anthropogenic climate change is likely to weaken the thermohaline circulation in [the] future" by altering temperatures at the poles, which in turn will change the temperature and salinity of the ocean's waters (Rahmstrof, 2006, 1). Climate change therefore creates a "risk of triggering abrupt and/or irreversible changes" within the oceans of the world (Rahmstrof, 2006, 1). Changes of this magnitude will impact ocean ecosystems, coastal infrastructure, port and fishing industries, and may even push areas of Europe into an ice age (NASA, 2004; NOAA, 2013).

Broadly speaking, climate change is a long term - 10 years or more - “change in the state of the climate,” that can be recognized through persistent changes to “the mean and/or variables of its properties” (IPCC, 2014a, 5). According to the IPCC, our climate is undeniably changing because of the observed warming the system is experiencing beyond the mean. “Since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased” (IPCC, 2013, 4). Our climate is changing and there is high confidence among the scientific community that many if not all of these changes are the result of human actions. Human activities - mainly the burning of fossil fuels for energy, and land cover change - are creating levels of carbon dioxide (CO_2) in the atmosphere that are 40 percent higher than any previously recorded in pre-industrial times (IPCC, 2013, 11). Levels of methane (CH_4) have also increased 150 percent since pre-industrial levels, and nitrous oxide (N_2O) by 20 percent. Ultimately, the concentrations of each of these GHGs in the atmosphere have exceeded their “highest concentrations recorded in ice cores during the past 800,000 years,” and these extreme levels can be attributed to human actions (IPCC, 2013, 11).

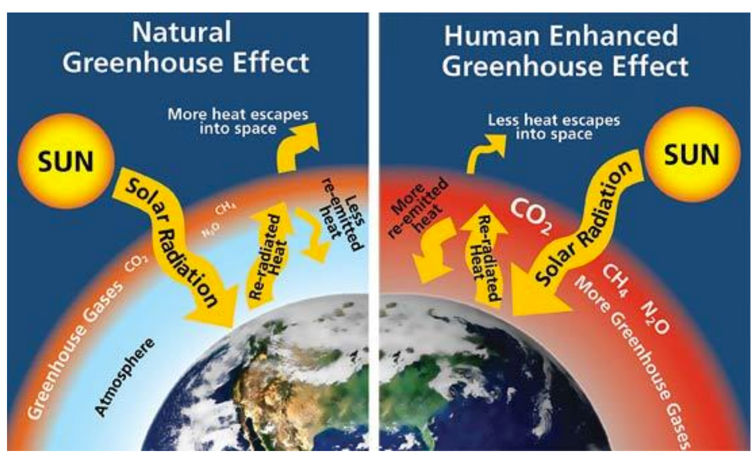

Figure 2-2. Greenhouse Effect (Lallanilla, 2013).

The accumulation of these GHGs in the atmosphere is the root cause behind climate change (see **Figure 2-2**). These gases trap ultraviolet rays from the sun within the earth’s atmosphere by not allowing solar radiation to be reflected back out into space. As more gases accumulate, more radiation is trapped, and the earth's surface and atmosphere becomes hotter (Lallanilla, 2013).

The burning of fossil fuels emits CO_2 because many of our sources of fuel (natural gas, coal, and oil) are made of solid carbon that is released as a gas when burned (USEPA, 2013b). Similarly, deforestation and other land conversions release CO_2 because forests are composed of carbon.[1] Vegetation can also help regulate a city's temperature through its ability to provide evaporative cooling, hold moisture, and provide shade. Therefore its loss through urbanization can be even more harmful because of the resulting need for heightened levels of energy to cool buildings (USEPA, 2013a). The loss of vegetation through urbanization also typically translates to an increase in impervious surfaces. Man-made impervious surfaces are black over 50 percent of the time, and therefore absorb the sun's rays instead of reflect them (Kalkstein et al., 2013, 5). These factors all work together to create a warmer surface of the earth. Outside of the urban context, agricultural activities, such as the management of livestock and soil, are the primary source of CH_4 and N_2O that are released into the atmosphere (USEPA, 2013b).

Climate change is another issue that the world, and especially cities, will have to deal with through mitigation and adaption (Liu and Li, 2012, 121). Cities are singled out in this way because, as described in **Chapter 1**, they hold the majority of the world's population, wealth, and knowledge. Cities have a lot to loose, and yet they are also contributing to climate change at higher rates than rural areas (Younger et al., 2008, 519). Adaption and mitigation are two sides of the same coin, and both strategies are needed if urban resilience is to be achieved. Mitigation is the effort to reduce future changes to the climate through the reduction of emissions and/or

[1] Half the dried weight of a tree is carbon (NYSDEC, 2015).

GHGs in the atmosphere, and adaptation includes the efforts undertaken "to reduce the vulnerability of [the urban] society to climate change impacts" (Bierbaum et al., 2014, 671). Conducting one without the other would be fruitless in the long run.

The Pacific Northwest's Climate Change Quick Facts (Averaged Across Multiple Models)

Estimated Temperature Increase (relative to the 1970-1999 state average of 46.6° F):

- ~2.0° F increase by 2020
- ~3.2° F increase by 2040
- ~5.3° F increase by 2080

Estimated Precipitation Change (relative to the 1970-1999 state average of 43.3 inches):

- ~1% increase by 2020
- ~2% increase by 2040

Estimated Change in Snow Pack (relative to the 1916-2006 average from ***Figure 2-3****):*

- ~28% decrease by the 2020s
- ~40% decrease by 2040
- ~59% decrease by 2080

Energy Effects:

- Declining hydropower production, and
- Increasing winter and summer demands.

Other Events:

- "Potential yield losses reaching 25% for some crops by the end of the century,"
- Reduction in salmon habitat,
- Increased incidence of forest fires, and
- Shifting coastal beaches inland.

(Climate Impacts Group, 2015; Ciecko, 2012)

Cities must begin mitigating their contributions to climate change in order to reduce their negative impacts on the world around them, and to reduce their own exposure to the consequences of climate change locally. At the same time, cities must also begin adapting to climate change because the amount of GHGs in the atmosphere today will continue to cause temperatures to rise into the future. Even if emissions were to drop significantly tomorrow, temperatures would continue to rise for many years into the future because of the lag effect (IPCC, 2013, 27). This lag is present because of the lifespan of CO_2 and other GHGs in

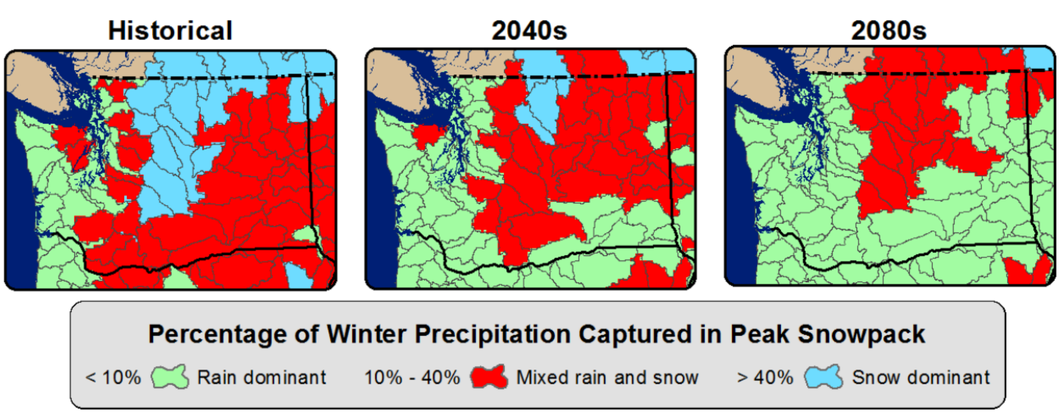

Figure 2-3. Estimated change in snowpack within Washington due to climate change (College of the Environment, 2015, 6-2).

the atmosphere. Further, “A large fraction of anthropogenic climate change resulting from CO_2 emissions is irreversible on a multi-century to millennial time scale, except in the case of a large net removal of CO_2 from the atmosphere over a sustained period” (IPCC, 2013, 28). The only feasible way to have a large net, sustained removal of CO_2 from the atmosphere is through a vast expansion of the world’s forests, including urban forests. (See **Section 2.4.2** to read more about the ability of trees to sequester carbon.)

While the IPCC and others have identified the major causes of climate change and begun to predict how it will affect the world, there is still a lot of uncertainty. Much of this uncertainty is based on trying to guess future human behavior, although it also stems from the large variations in global geography. While scientists have global averages and rough ideas of what will probably happen given a certain number of assumptions, the specifics for cities such as Seattle, Washington in 50 years or Phoenix, Arizona in 100 years are much more difficult to pinpoint with any accuracy.

2.2.4 Obesity and Depression

Citizens of the U.S are becoming more obese than previous generations, and we are now the heaviest nation in the world (Cannuscio and Glanz, 2011, 50). In fact, “two out of every three American adults twenty years or older are overweight or obese” (Jackson, 2011, xvi). This obesity also comes with a number of health risks including diabetes, cancer, stroke, high blood pressure, heart disease, and depression. An indicator of our nation’s growing mental health issue is that since the year 2000, anti-depressants have been “the most prescribed medication” throughout the country (Jackson, 2011, xvi). While the physically and mentally unhealthy do not only reside in urban areas, there are heightened populations within urban centers, and therefore these growing problems have become more obvious in cities. Further, the way we have chosen to design cities – around cars and inactivity – is actually contributing to these obesity and mental health issues (Jackson, 2011, xv and xvii). Our health care system is an important tool to combat this problem, although "health is determined by planning, architecture, transportation, housing, energy, and other disciplines at least as much as it is by medical care" (Jackson, 2011, xvii).

2.2.5 Air, Water, and Soil Quality

Some of the very amenities and services that allow cities to thrive, also work to degrade the quality of the air, water, and soil. The following examples of pollution entering different media within cities discuss only a small fraction of the total number of emitters, and types of pollution present in cities. Personal automobiles as well as commercial trucks, planes, and cargo ships utilize fossil fuels to travel, and in doing so emit CO_2 and other noxious contaminants into the atmosphere that reduce air quality and expose residents to health risks. Smog, for instance, is the visible cloud or fog that forms as "sunlight reacts with hydrocarbon and nitrous oxide emissions" to form ground ozone (Gorman, 2013). Smog has been clearly linked to negative health effects, and also visibly dirties the city. When inhaled, smog can "inflame breathing passages…[to] decreas[e] the lungs' working capacity," sting your eyes, and kill plants (Science Daily, 2014; USEPA, 2009). Further, the infrastructure we put in place to allow for these motorized vehicles to travel across and around cities also works to pollute our water systems. Contaminants from urban life, such as road salts and lead from tires, can accumulate on impervious surfaces and be washed into surface water systems when stormwater runoff from precipitation events travels over the city (USEPA, 2013a). Industries within and around cities can also act as point sources of pollution that can contaminate the air, water, and soil through the dumping – accidental or on purpose – of contaminants into the urban system. An historic example of this is the Cuyahoga River fires that occurred for over 100 years in Cleveland, Ohio because of the accumulation of "debris, oils, sludge, industrial wastes and sewage" in the river from the 22 industrial factories that lined the river's shoes (USEPA, 2014; Adler, 2003, 99-100). While point source pollution has decreased in cities as industries have moved to less expensive real estate outside of the city, non-point sources such as cars and runoff have increased.

2.3 The Urban Forest

Scientists, city planners, and lay people often point to urban forests and trees in general as a silver bullet for the maladies that face cities. Although even with this positive press, there is no consensus on how to best manage urban forests to achieve these goals (Bellassen and Luyssaert, 2014). Widespread agreement has not been attained because of the relative youth of urban forestry as a concept, confusion over what constitutes an urban forest, and the complexity of potential benefits within different contexts.

Urban forestry is still a fairly new idea. The term was coined in 1965 by a University of Toronto professor, and it first received significant funding – $21 million – in the 1990 federal farm bill. The Forest Service appropriated the bill's designated money in order to provide grants to state and city governments to fund the creation of urban forest management plans (Kollin and Schwab, 2009a, 18). As such, the concept of urban forestry is still evolving, and there is no one agreed upon definition of late (Dreistadt et al., 1990, 192). What most definitions have in common is that they tend to be very liberal in their inclusion of what comprises an urban forest.

For example, many would like to include "all vegetation and green spaces" (Sustainable Urban Forest Coalition, 2014) or "all trees and woody shrubs" (Berland and Manson, 2013, 750) in or near an urban area, as part of the urban forest (Dreistadt et al., 1990, 192). Additionally, academics and policy makers do not seem to differentiate between vegetation planted by man, or vegetation that remains from old growth forests in their definitions. The City of Seattle's UFSP defines an urban forest as "the trees and associated understory species that are found on public and private property within the city. This includes forested parks and natural areas, as well as the trees along streets and in yards" (City of Seattle, 2013a, 17). As this thesis focuses primarily on Seattle, the UFSP's definition will form the working definition of an urban forest.

Seattle's Urban Forest Quick Facts

Number of Trees:
- ~130,000 street trees.
- ~ 4.35M trees, and tree like shrubs.
- ~ 80 trees per acre.

Most Common Species:
- Red Alder,
- Big Leaf Maple, and
- Beaked Hazelnut.

Sequestration:
- ~2M metric tons of CO_2 equivalent stored.
- ~140,000 metric tons of CO_2. equivalent sequestered annually.
- ~$10.9M savings from carbon. storage, with an additional $768,000 annually.
- Removes ~725 metric tons of pollution annually, for ~$5.62M in savings.

Energy Savings:
- Residential building energy saving of ~166,000M BTUs of natural gas and 43,000 MW hours of electricity for ~$5.9M in savings.

Estimated Replacement Cost:
- ~$4.9B

Goals:
- 30% of the city will be covered by canopy by 2037.

(City of Seattle, 2013a)

To further understand urban forests it is important to understand the makeup of these vegetated urban spaces. Broadly speaking, an urban "forest is composed of four major types: natural forest stands that somehow survived the expansion of the city, natural corridors along riparian zones, artificial corridors along streets and avenues, and 'green oases' or forests constructed by people…The city also has scattered vegetation and individual trees that, combined with the four forest types, form the city's canopy and vegetation cover" (Lugo, 2010, 576). It is important to study and understand these spaces, because as urbanization spreads and more forested lands are converted to cityscapes, "an increasing proportion of the world's trees will be found in urban areas" (Dreistadt et al., 1990, 192). If nothing else, the idea that a growing percentage of all trees in the world will be located in cities, speaks volumes about the role urban forests could play in mitigating climate change in the future.

Another common attribute of urban forest definitions is their focus on the benefits these spaces can have for humans, or for the ecosystem services that allow humans to survive and thrive. For instance, *The Dictionary of Forestry* defines urban forestry as the "the art, science, and technology of managing trees and forest resources in and around urban community ecosystems for the physiological, sociological, economic, and aesthetic benefits trees provide society" (Society of American Foresters, 2008). It appears that urban forestry has an anthropogenic focus, and this emphasis helps shape management plans and decide long-term goals. This thesis does not stray from this pattern, and examines how urban forests can create a more resilient city, primarily for the benefit of humans.

2.4 Benefits of Urban Forests

"The existence of trees in the immediate vicinity of communities is often critical for maintaining environmental stability" (Arnold, 1987, 122). The following is a list of the most commonly noted benefits of urban forests by scientists and politicians. These benefits speak to the ability of urban forests to help remedy several serious urban issues, and provide urban resilience to climate change (Phillips, 2014, 2).

2.4.1 Microclimate Moderation and Energy Savings

Trees provide shade, and if appropriately placed around buildings, this shade can work to cool structures by reducing the level of radiant energy that can be absorbed by a building (McPherson et al., 2002, 5; Donovan and Butbry, 2009, 663; Arnold, 1987, 122; Berland and Manson, 2013, 750; Simpson, 2002, 1067). Additionally, trees can block or divert winter winds that can work their way into homes as drafts that require homeowners to turn up the heat (Simpson, 2002, 1069; treecaretips.org, 2015). The ability of trees to shade and block wind translates into decreased cooling and heating energy needs for buildings. This can mean declining energy use, and eventually, decreased dependence on fossil fuel energy (Phillips, 2014, 8; Donovan and Butry, 2009, 662; Akbari, 2002, S120; Nowak et al., 2010, 6). Beyond providing shade and blocking wind, trees also work to cool their surrounding microclimates through transpiration that "converts moisture to water vapor and thus cools by using solar energy that would otherwise result in heating of the air" (McPherson et al., 2002, 5). All of these attributes work to moderate microclimates, mitigate UHIs in some cases, and help cities adapt to climate change (Davies et al., 2011, 1126; Jenerette et al., 2011, 2638). This adaptation to climate change also makes economic sense as it has been estimated that "the establishment of 100 million mature trees around residences in the United States…[saves] about $2 billion annually in reduced energy costs" (Nowak et al., 2010, 6).

2.4.2 Carbon Storage and Sequestration

Urban forests also work as carbon stores where CO_2 can be sequestered out of the atmosphere. On average, a tree can sequester 48 pounds of CO_2 a year, and store up to 1 ton over 40 years (Evans, 2015). This can be accomplished for the price of planting and maintaining a tree. In an urban setting this price is estimated to be anywhere between 2 and 500 dollars per tree per year. The wide variability is based on the specific species of tree, the urban context and location, and the level of management (Donovan and Butry, 2009, 666; Akbari, 2002, S119; see **Section 2.5** for more information on costs). Although of course, the specific amount of carbon that can be sequestered within each tree depends on the species, age, and location as well. Despite this diversity, all vegetation works to sequester carbon through photosynthesis (Phillips, 2014, 8; Donovan and Butry, 2009, 666; Liu and Li, 2012, 121; Akbari, 2002, S119). For centuries this ability has created stability within the earth's carbon cycle. As we convert more forested lands into impervious surfaces, and continue to emit carbon from our factories, automobiles, and homes, some believe that the capacity of vegetation to sequester carbon will never be enough to prevent climate change, even with afforestation and reforestation projects.

This has led many scientists to try and invent an alternative technology that could artificially sequester CO_2 from the atmosphere and dispose of it somehow, either by burying it or transforming it into fossil fuels to be reused. These efforts have had some limited success, and those who have invented the technology believe it to be a cost-effective and efficient manner to sequester carbon (Harris, 2013; Kintisch, 2014). Although third party scientists have estimated the cost of this sort of technology to reach at least $600 per metric ton of carbon dioxide stored.

These statistics imply that trees are still the cheapest, most efficient, and easiest method we have at our disposal to sequester carbon (APS, 2011, i).

Urban forests, and reforestation projects in general, must therefore play a large role in any global climate change mitigation effort. It is estimated that the urban forests across the U.S already store approximately "770 million tons of carbon, valued at $14.3 billion" (Nowak et al., 2010, 6). Therefore, the more urban forests present in a city, the more valuable the urban forest becomes for carbon storage. Although, vegetation cannot act as a permanent sink because trees die and can be destroyed. When this occurs, and the vegetation is allowed to burn or decompose, the carbon the tree once held is released back into the atmosphere. This highlights the importance of maintaining urban forests through asset management systems that can ensure timely replacement of dead trees, and improve the health of existing stock. Additionally, it is important to find a use for urban trees after they die that prevent carbon from escaping back into the atmosphere, such as urban wood furniture or art installations (Davies et al., 2011, 1131). Although, due to the small relative size of urban forests when compared to more natural forests, urban forests alone cannot provide sufficient mitigation on a global scale. This highlights the importance of linking urban forests to surrounding natural forests, and encouraging emission reductions where possible.

2.4.3 Improved Air Quality

Not only do urban forests sequester carbon, they can also uptake "ozone, nitrogen dioxide, sulfur dioxide, particulate matter less than 10 microns in size," carbon monoxide, nitrogen oxides, and halogens. By removing these contaminants from the atmosphere, urban forests also work to improve the air quality of cities (Phillips, 2014, 3; Dreistadt et al., 1990, 197; Davies et al., 2011, 1126). When particulates collect on the leaves of vegetation through dry deposition, rainwater can rinse these contaminants into the soil to be filtered out by the root system (Dreistadt et al., 1990, 197; Akbari, 2002, S122). Otherwise, photosynthesis allows a tree to take in and store pollutants in its biomass (Liu and Li, 2012, 121). While trees do emit some volatile organic compounds, this does not outweigh the pollutants that they remove from the atmosphere (Phillips, 2014, 3; Akbari, 2002, S122). Studies suggest that the urban forests throughout the U.S. "remove some 784,000 tons of air pollution annually, with a value of $3.8 billion" (Nowak et al., 2010, 6).

2.4.4 Improved Soil Quality

Pollutants that accumulate in soils within urban forests can be taken up by the root system of trees and other vegetation (Dreistadt et al., 1990, 197; Nowak et al., 2010, 6). Further, tree cover and their root systems reduce soil loss by decreasing the likelihood of erosion (Arnold, 1987, 122). Finally, urban forests also take part in soil formation, nutrient cycling, and pollination (Tallis et al., 2008, 9462).

2.4.5 Improved Water Quality and Stormwater Management

Impervious surfaces in cities encourage stormwater to runoff to surface water systems instead of infiltrating into the ground. Further, the stormwater that runs over the impervious surfaces picks up pollutants that work to contaminant those surface water systems. Urban forests help in two regards on this front. First, "Trees reduce stormwater flow by intercepting rainwater on leaves, branches, and trunks. Some of the intercepted water evaporates back into the atmosphere, and some soaks into the ground reducing the total amount of runoff that must be managed in urban areas" (Kollin and Schwab, 2009a, 4). Therefore, as urban forests increase, so does the amount of stormwater that can be slowed or captured, and allowed to infiltrate into the soil to recharge aquifers (Nowak et al., 2010, 6). This reduction in stormwater reduces the amount of water running down the streets that can cause flooding during heavy rain events. Secondly, urban forests that buffer surface waters work to slow stormwater before it enters the system, and allows the pollutants it has collected to be filtered out within the soil (Berland and Manson, 2013, 750; Phillips, 2014, 2; Davies et al., 2011, 1126).

2.4.6 Health Improvements and Opportunities for Recreation

Urban forests help the natural world as well as the mental and physical well being of the human residents living within urban areas (Goddard et al. 2009, 90; Nowak et al., 2010, 7). This is displayed in studies that illustrate that time spent in urban forests can help reduce stress and increase mental health in individuals. In these respondent driven studies, stress relief reached 87 percent and headache relief was 52 percent among participants who spent time or had views of nature, versus those who did not. The two primary theories that discuss this reported ability of green spaces and urban forests to provide mental health are Ulrich's Stress Reduction Theory (SRT), and Kaplan and Kaplan's Attention Restoration Theory (ART). SRT holds that when individuals are allowed to view natural elements which are unthreatening, they become more relaxed. ART goes further and argues that the natural environment can mentally restore individuals because it can allow one to feel they have escaped the grind of the city. Once the built environment is escaped, they feel that they have entered "a whole other world" and the environment is able to hold their attention because it is different and not demanding (Hansmann et al., 2007, 213). This is because "Places that gently hold our attention…allow individuals to recover from mental fatigue…Natural settings and stimuli such as green landscapes seem to engage our attention effortlessly, allowing us to be in such settings without focusing attention, thus restoring our capacity to pay attention" (Sullivan and Chang, 2011, 110). All of this works together to allow our minds to have a break and feel restored (Hansmann et al., 2007, 213). Even just views of trees from within the built environment has been shown to have a positive effect on the mental well being of individuals. For instance, workers with views of trees from their office call in sick less often than those without a view, drivers with views of urban forests are less stressful than those without a view, and individuals in hospital beds with a view of vegetation tend to need less medication (McPherson et al., 2002, 11).

Other studies have shown that the more opportunities for recreation that individuals have, the more they will recreate (Davies et al., 2011, 1126; Dreistadt et al., 1990, 197). These opportunities can be presented in natural spaces such as urban forests, as several studies have also shown that individuals prefer to recreate and/or exercise in more natural environments (Hansmann et al., 2007, 215; Cornell University, 2009). The U.S has a severe obesity problem, and by providing more opportunities, and more enticing opportunities at that, to walk, bike, or jog, the built environment can help address this issue through the addition of urban forests (Jackson, 2011).

2.4.7 Maintenance of Biodiversity

Urban forests can also provide habitat for species that would otherwise be destroyed if urbanization were allowed to continue unfettered (Berland and Manson, 2013, 750; Davies et al., 2011, 1126; Nowak et al., 2010, 6). Connectivity between urban forests is also very important to allow for larger habitats and migration of non-human species through the city. The more connectivity a habitat has, especially if it connects to surrounding remnant forests or riparian areas, the more species richness the area will contain (Carrara et al. 2014, 13; McPherson et al., 2002, 11). "Trees located within urban forested parcels, along meadow edges and stream banks, and within corridors contribute to the diverse cover, food, and nesting needs for a wide variety of wildlife…Butterflies, songbirds, and other flying species are well adapted to urban areas" (Kollin and Schwab, 2009a, 7). Biodiversity is also key in the continued provision of ecosystem services (Allan et al., 2011, 17034).

2.4.8 Improvement of Aesthetics

Beyond the environmental or economic benefits of urban forests, the presence of urban forests also provides aesthetic benefits for residents and other users of the space (Jenerette et al., 2011, 2638). Urban forests work to soften the hard edges of city skylines and add visual diversity to urban streets and landscapes through additions of "color, texture, line and form" (McPherson et al., 2002, 10). These qualitative benefits can also be quantitatively measured by examining the real estate prices within areas that have high percentages of urban forests, as well as surveys of residents that speak to the importance of having urban forests near their homes (Phillips, 2014, 2; Cornell University, 2009). Such an examination indicates that urban forests in neighborhoods and commercial areas can increase "property values, office occupancy rates, and shopping frequency" (City of Seattle, 2013a, 33; Cornell University, 2009; Kollin and Schwab, 2009a, 9; Nowak et al., 2010, 7). Even one tree can make a difference in a sales price, as studies show that for every large tree in a front yard, there is a 1 percent increase in home sales prices. Shoppers have also reported on surveys that they are willing to shop longer, more frequently, and spend more money when the commercial area has more trees present (McPherson et al., 2002, 10).

2.4.9 Creation of Sense of Place and Social Connections

Those who live in areas with urban forests also tend to feel a greater connection to the land, and have more opportunities to meet and interact with their neighbors (McPherson et al., 2002, 11; Nowak et al., 2010, 7). "The built environment can…promote social interaction by providing recurring opportunities for individuals to have informal social contact with one another. A shared space that is not noisy or crowed…has been shown to promote informal face-to-face contacts. Individuals who have frequent face-to-face contact [in the spaces urban forests can provide] are likely to form and maintain social ties" (Sullivan and Chang, 2011, 109).

There are several other reported benefits of urban forests such as crime reduction and encouraging smart growth. These are not discussed here because they are not as commonly referenced (Sullivan and Chang, 2011, 112; USDA Forest Service, 2014).

2.5 Costs of Urban Forests

In addition to the above-mentioned benefits, there are also costs associated with urban forests. These costs primarily include those associated with planting, pruning - especially for utility line clearance - "management and monitoring operations, leaf removal, and the value of volunteer time" (Phillips, 2008, 15; Donovan and Butry, 2009, 666). There are also costs associated with the need to water trees, use gas powered tools, and the opportunity costs from not converting the land to more economically profitable commercial or residential endeavors (Davies et al., 2011, 1131; Jenerette et al., 2011, 2638). Further costs include sidewalk maintenance from the damage caused by tree roots (Phillips, 2014, 15). Additionally, with a more connected city through urban forests, there is also heightened risk for the quick spread of fires and pests. Considering all of these potential costs, there is no one agreed upon cost per tree because the expense of individual trees, the price of gas and water, minimum wage, and risk of wildfire varies from city to city. Although some studies suggest that the overall cost per tree ranges from 2 to 20 dollars per year (Donovan and Butry, 2009, 666). Others widen this cost differential to 10 to 500 dollars per tree per year depending on type and location (Akbari, 2002, S119). While there are costs, if just one of the above benefits were accurate, such as energy savings from shade and wind protection or improvements to water quality, then the costs of these urban forests would be far less than their benefits. Further, some of the ecosystem services provided by trees, such as carbon sequestration, cannot be replaced with artificial technologies at an efficient rate (APS, 2011, i).

Besides economic costs, there are also unintended carbon costs associated with urban forest management. Carbon costs associated with maintenance activities typically include the carbon emitted from the use of gas powered leaf blowers, vehicles and lawnmowers, chain saws, etc. It is estimated that these carbon expenditures equate to approximately 2 to 8 percent of the "annual CO_2 reductions obtained through sequestration and avoided power plant emissions" (McPherson et al., 2002, 7). Therefore, urban forests are still often economic and carbon net positives.

2.6 Urban Forest Management Plan

How can cities take advantage of the potential opportunities created by urban forests within cities? The answer is the creation and implementation of an urban forest management plan. In several cities, the urban forests are managed through a stewardship or management plan that defines goals, policies, and the methodology to achieve those goals. Some plans even define implementation processes and maintenance schedules. As cities vary in size, geography, and demography, every city's plan will be unique, although there are some qualities that are present in each plan. In general, urban forest management plans concern a specific location, provide some sort of inventory, and prioritize goals and objectives. From these goals, protection and maintenance activities are delineated, and prescriptive actions to achieve goals are recommended (Forest*A*Syst, 2015).

In many cities like Seattle, a majority of the urban forest is located on private lands such as backyard gardens (Berland and Manson, 2013, 750). To be effective, plans must therefore have a strong public outreach and/or regulatory component to reach the entirety of the urban forest (Goddard et al., 2009, 90).

2.7 Cities as Coupled Systems

Successful urban forest management plans must recognize that cities are hybrid systems that are wholly distinct from a strictly natural or human system (Liu et al., 2007; Alberti, 2008). This hybridity is illustrated in the failure of models to predict past events when they only consider human or natural processes on their own. On its most basic level, a city is a synthesis of humans and nature because it is human dominated while still being impacted by nature (Liu et al., 2007; Alberti 2008). We live among and around natural systems, plants, and animals, as well as built structures and paved roadways. Although the natural systems, and even the types of species, located within cities are distinct from those found in more rural or less inhabited areas. This difference stems from the increased amount of humans and infrastructure in cities that together work to alter the "natural" flows experienced within other ecosystems. Humans have disrupted the earth's energy, nutrient, and water cycles, and these actions have created alternate outcomes for cities through changed feedback loops (Alberti, 2008; Levin, 1998). These impacts occur spatially and temporally to create an interconnected, complex, emergent, and innovative system of humans and nature (Alberti, 2013b).

As briefly discussed previously in **Section 2.2.2**, urbanization is especially skilled at diverting flows and changing natural feedback loops because of the subsequent creation of vast quantities of impervious surfaces, the fragmentation of natural systems, and the GHG emissions it necessitates. Similarly, natural systems within cities influence the actions of humans in untold ways through climate, geography, topography, and natural cycles such as floods or El Niños. These drivers impact each other within a reinforcing and adaptive feedback loop that works to create unforeseen results and new paths. In other words, the existence of these drivers in the same space and time within cities is what makes urban areas coupled human natural systems (Liu et al., 2007; Alberti, 2008). The point of bringing this concept up here is to illustrate why urban forests cannot be simply seen as a natural space within a human space. Just like the city on whole, the urban forest is a coupled human natural system that cannot be understood without considering both human and natural interactions and drivers.

Further, the qualities of coupled human natural systems create changes within that system that are neither continuous nor gradual, but punctuated. This implies that there are long periods of status quo, or stability, followed by bursts of rapid change. The stability of these systems is followed by rapid change because drivers are constantly interacting, and eventually the adaptive feedback loops change to a point where a regime shift is triggered. When this shift from the norm occurs, the system can drastically change, and innovation will be required to create new structures, functions, and thresholds that follow a new set of rules (Alberti, 2008). Regime shifts are seen as problems in cities because society has come to expect and rely upon a certain modus operandi, or a certain functioning of the city, that regime shifts disturb. Urban resilience is the ability to keep the same functions in place while also allowing for change to occur.

2.8 The Functioning of Cities - Ecosystem Services and Infrastructure

A loss of urban resilience is partially a loss in ecosystem services, as these are some of the main functions society relies upon within urban areas. Beyond ecosystem services, a loss in infrastructure would also signify a reduction in services. Ecosystem services are any service that nature provides free of charge such as soil formation, water purification, pollination, carbon sequestration, and pest control. In general, they can be categorized into four types of services including supporting, regulating, cultural, or provisioning services, and have traditionally been taken for granted as “free social goods” (Kollin and Schwab, 2009a, 4). Ecosystem services are declining for several reasons including human overconsumption, development of impervious surfaces that alter natural cycles and fragment habitats, and the inability to clearly delineate rights and economic markets for these services (Lant et al., 2008, 969, 971; Nowak et al., 2010, 13). “Anytime a human endeavor seeks to derive something of value from our natural world, there is the possibility that overuse or overexploitation could result in failure” (Tallis et al., 2008, 9462). This is a serious problem for urban resilience because most of these free services cannot be recreated or replaced by humans without expending a lot of energy, money, and time. Therefore a loss in ecosystem services can reduce urban functionality.

Cities also depend on man-made services that are collectively referred to as infrastructure. Infrastructure systems include everything from roads, electrical lines, water and sewer mains, and water treatment centers, to power plants and bridges. In many cities across the U.S., including Seattle, these systems are aging without proper maintenance, increasing their risk of breaking down before their expected warranty dates. These essential attributes of city life are also vulnerable to impacts of climate change, such as "rising sea levels, storm surges, heat waves, and extreme weather events" (Cutter and Solecki, 2014, 283). These systems are also highly interconnected and "reliant on each other. For example, electricity is essential to multiple systems, and a failure in the electrical grid can affect water treatment, transportation services, and public health. These infrastructure systems – lifelines to millions – will continue to be affected by various climate-related events and processes" (Cutter and Solecki, 2014, 283). If one sector or service fails and there are no redundancies put in place, this could push a city over a threshold into a regime shift.

2.9 Urban Resilience

Resilience at its most basic level is the capacity of a system to continue to function when presented with a shock (Levin, 2008, 27). Urban resilience is then the ability of a city to retain its functionality after a disturbance or a regime shift (Alberti et al., 2013a, 49). Depending on profession or school of thought, others may think of resilience as the ability to rebound back to business as usual after a disturbance. This idea often evokes the image of a bridge bending or swaying from an earthquake without being destroyed. Bending without breaking is certainly part of resilience, but it is not the whole story. This definition implies that systems are static, uncomplicated, and that we actually have the power to hold things constant. Further, with this engineering definition of resilience, a system cannot evolve and remain resilient. As described in **Section 2.7**, hybrid systems such as cities are, by definition, dynamic and complicated. Therefore, this thesis holds that a system can in fact change and still be resilient if functionality is retained. For instance, a storm can hit a coastal city and change it in irreversible ways; the beachfront could shift or be washed away, roads ruined, and homes demolished. The entire layout of the city could be altered by the storm and still resilience can be retained if the city is able to continue providing essential services. Further, because of this shock the city could be better prepared for the next storm, in terms of new mitigation and adaptation strategies that could work to decrease the severity of the next storm's negative impacts. If we believe that resilience translates to a rigid or unchanging city, and we create policies to attempt to bring this about, we can actually make a city less resilient and more vulnerable. Just as the installation of a levee system along the Mississippi River made New Orleans, Louisiana more vulnerable to the effects of Hurricane Katrina (Maritn-Breen and Anderies, 2011, 6).

Looking at this subject in a slightly different light, stability "is the ability of a system to return to [an] equilibrium state after a temporary disturbance…Resilience is the persistence of relationships within a system and is a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist…Resilience is then a property of the system" (Holling, 1973, 17). Systems can therefore be resilient and dynamic, these systems would just be unstable. In an urban environment for instance, the population can change dramatically, but the city may still be resilient if they have the capacity to absorb shocks and keep functioning as a city (Holling, 1973, 18). Resilience is a factor of the interacting, and constantly changing, drivers and variables that work to alter the depth or width of the basin of attraction that makes up a stable state (Carpenter et al., 2001).

Urban systems are not static because they are coupled systems, but also because there is no one equilibrium or stable state that a system can reside within. There are multiple stable states and multiple equilibria. The problem for humans and cities is that not all of these multiple stable states are desirable or even conducive to urban survival (Holling, 1973, 2). Poverty, for instance, is a very resilient state; highlighting the reality that increasing resilience in general is not always a worthy goal (Martin-Breen and Anderies, 2011, 6). Context is therefore very important when it comes to discussing resilience, as you must define what thing you would like to be resilient, and what you would like it to be resilient against. This thesis examines the ability of urban forests, and therefore the City of Seattle, to be resilient toward climate change.

Collapse of an urban area can come from a regime shift from one resilient state to another. Regime shifts can be extreme, such as the shift from an ice age to a desert where the functions humans rely upon are completely distorted. Regime shifts can also be less extreme and allow for some transfer of functionality between states, such as shifts from forested areas to grasslands, or clear lakes to eutrophic lakes. These regime shifts happen naturally as systems are constantly evolving, although they can also occur because of human intervention changing feedback loops. Shifts from one regime to another are largely unpredictable because the most important drivers and variables, as well as the feedback loops that they create, are uncertain and complex (Liu et al., 2007, 1513). Further, a regime shift can be permanent, potentially reversed through heavy energy and financial inputs by humans, or possibly reversed through long periods of time where human interferences have been removed (Walker et al., 2012, 30).

2.9.1 Seven Qualities of a Resilient System

While the idea of resilience as the ability to retain functionality after a shock may be somewhat logical in theory, it becomes harder to translate this concept in practice. The more we can break down the concept of resilience into smaller, more digestible bites, the less complex this task becomes. With this idea in mind, this thesis has translated the seven essential qualities of a resilient system from the Rockefeller Foundation, into 14 indicators of resilience that revolve around urban forests. These indicators are used within **Chapter 4** to qualitatively measure the level of resilience within each of the four scenario narratives. (See **Chapter 4** for a full discussion of these resilience indicators.)

The adapted seven qualities of resilience are listed below to help explain the framework through which this thesis examines urban forest management plans, climate change impacts, and the level of resilience within Seattle's plausible, divergent futures. The seven qualities are:

- Reflective,
- Robust,
- Redundant,
- Flexible,
- Resourceful,
- Inclusive, and
- Integrated (Ove Arup, 2014, 5).

A **reflective** system is one that accepts that there is uncertainty in the world, and more specifically within the individual system in question. Acknowledging and utilizing uncertainty in design building is an emerging principle within the field of urban resilience, as it is a departure from traditional techniques of policy creation based off static predictions. These one-dimensional policies have been unsuccessful as urban systems will always be somewhat uncertain because of the complexity of the relationships between thousands of drivers and variables (Walker et al., 2012). This uncertainty cannot be ignored or simplified if cities have any chance of becoming resilient (Millennium Ecosystem Assessment, 2014). In a reflective system, the management strategies and citywide plans are constantly evolving based on the best available science. A reflective system is resilient because "people and institutions [within the system] examine and systematically learn from their past experiences, and leverage this learning to inform future decision-making" (Ove Arup, 2014, 5). The system is dynamic, and a reflective city does not have policy makers trying to tie it down to one idealized static state. Policies allow for fluidity and learning from the past, instead of trying to recreate it.

Robust systems have strategies in place for any number of plausible futures. They plan for the unexpected, and do not rely too heavily on one prediction or policy as the silver bullet. Further, robust strategies look at the larger context; they do not just consider the boundaries of the system, they look at what is outside of the system as well. Robust systems are well thought out and include several layers of connectivity, as well as asset management systems[2] to ensure infrastructure systems remain healthy throughout their full expected life (Kollin and Schwab, 2009b, 122). Inventorying urban forests, for instance, is important because the "quantification of carbon storage and sequestration…[for one,] is critical for the assessment of the actual and potential role of urban forests in reducing atmospheric carbon dioxide" (Liu and Li, 2012, 121).

[2] An asset management system is composed of an inventory, conditions assessment, and maintenance schedule.

A **redundant** system is similar to a robust one in that it does not rely on one concept, idea, or species, and can therefore withstand disturbances. Redundancy in relation to urban forests is diversity, which can be defined as “both the number of species (richness) and the relative distribution of individuals among species” (Dreistadt et al., 1990, 192). Redundancy will come from having numerous parks and urban forest areas in a city, and more importantly from ensuring that these areas have more than the same three or four species of trees. Heterogeneity is important so that if one species or tree in a park dies, or one policy fails, there are several others that can fill the functional void. This ensures that one failure cannot lead to a domino effect that destroys the system. Redundancy is therefore why a system can retain functionality after shocks.

A **flexible** system is similar to a reflective one in that it embraces change, but in this case the focus is on adaptation to the changing situation. A further difference is that a flexible system is one that can be broken down into parts of a whole so that if one part decays or fails, it will not negatively impact the whole. The system can adapt around the loss, like a tree growing around a damaged limb. A flexible system also incorporates indigenous and other more traditional methods, as well as the best available science in its day-to-day operations (Ove Arup, 2014, 5).

Resourceful systems are resilient because they are able to incorporate “different ways to achieve their goals or meet their needs during a shock” (Ove Arup, 2014, 5). Similar to being redundant and robust, resourceful systems do not get locked into one solution. They are flexible enough to try several different solutions to see what will work.

An **inclusive** system is one that hears and incorporates a diversity of viewpoints and thoughts in the decision making process. All groups must be included, not just those with the power. The system in question is also not the only thing considered in the conversation; to maximize resilience, neighboring systems are also considered in the planning process (Ove Arup, 2014, 5).

Integration implies that there is consistency in message from all those stakeholders involved. So while the plan and the process are inclusive, the stakeholders and plan speak with one voice in order to create positive outcomes and reduce confusion during implementation or shocks. This is possible through free flowing communication between stakeholders (Ove Arup, 2014, 5).

2.8.2 Resilient Indicators

Even with these seven qualities defined, there is still the question of how to operationalize these qualities into measurable units within the real world. This is not possible as they currently stand, and indicators for each quality have been made in an attempt to be able to better measure the overall urban resilience of an area such as Seattle through urban forests (See **Chapter 4**).

2.10 Scenario Planning

Scenario planning is a systemic method to make robust future plans. As a rule, it embraces uncertainty and uses imagination and science to create plausible futures in a complex and uncertain world (Peterson et al., 2003). Generally speaking, a scenario planning process follows five iterative steps, and includes various stakeholders:

1) Define a focal issue;

2) Identify and rank uncertain drivers;

3) Develop logics and narratives;

4) Use models to assess the impacts of scenarios; and finally,

5) Identify strategies that can be successfully applied in each plausible scenario (Carpenter, 2002, 2081; Peterson et al., 2003, 360).

Scenarios are snapshot narratives imagining how a future could look based on a number of key drivers and variables. The interactions of these drivers and variables are based on empirical evidence in order to bind the narratives to logic, although scenario planning also utilizes imagination to fill in the gaps left by the uncertainties within science (Carpenter, 2002, 360). Scenario planning is therefore a technique to better equip decision-makers to make successful decisions in a world full of uncertainty. By incorporating uncertainty in the scenario planning process, decision-makers can avoid getting bogged down with one idea that could be based on a faulty prediction of the future. Scenario planning allows for resilient decisions, and this by extension allows for the planning of resilient cities. Scenario planning is more than science, while still remaining rational and avoiding normative visioning (Carpenter, 2002, 2081).

City managers often hope to improve the adaptability and resilience of urban environments using predictive models. These models assume that we can know the future if we have the right data (Wollenberg et al., 2000, 65-77). As urban ecosystems are the byproducts of coupled human natural feedback loops that are often beyond our present day understanding, many of these efforts to shore up our cities could be unsuccessful in the long run if they are based on one historical vision of the future. With an increase in ecological issues that are both globally important, and dependent on highly uncertain drivers, scenario planning is becoming more popular as decision-makers realize the restrictions of model predictions. Firms, such as Shell Oil, have successfully used scenario planning to integrate uncertainty in their own decision-making process. In the 1970s Shell Oil was the first private company to adopt scenario planning strategies, and then implement policies based on the resulting narratives. Consequently, Shell was the only oil company to have planned for an OPEC style oil crisis before it happened.[3] This tactic allowed Shell to ride the waves of the economic sector better than the other companies who did not utilize scenario planning (Peterson et al., 2003, 360; Wilkinson and Kupers, 2013).

We cannot embrace uncertainty until we begin to step away from strictly using empirical evidence, and begin to use our imagination. This has been a difficult step for scientists and policy-makers alike, as some feel you cannot prove creativity. Although this is not a new idea in science, and many like Albert Einstein, have understood the power of imagination for some time. Einstein has even been quoted as stating, "Imagination is more important than knowledge. For knowledge is limited to all we now know and understand, while imagination embraces the entire world, and all there ever will be to know and understand" (goodreads, 2015). Additionally, you can falsify imagination and build rational logics, just like with more quantitative theories. Scenario planning narratives rely upon imagination to work through uncertainties, and are grounded in science and common sense. This combination allows for the creation of plausible futures and robust policies (Peterson et al., 2003, 359-360). We cannot rely on what happened historically to identify what will happen in the future because of the complexity of coupled

[3] Peter Schwartz, one of the individuals responsible for implementing the scenario planning process at Shell, later helped start the Global Business Network (GBN). GBN was apart of the team that conducted scenario planning in South Africa, which some believe helped put an end to apartheid (GBN, 1992). As more city managers switch to a scenario planning approach, this could "enable mangers to better understand landscape and larger scale forces for change…and improve adaptiveness not only by responding to changes, but also by anticipating them" (Wollenberg et al., 2000, 65).

systems changing feedback loops. It then follows, that if science alone cannot accurately predict the future, we must utilize it in conjunction with our imagination to make educated guesses (Scheffer et al., 2009, 53-59; U.S. Department of Interior, 2010). We need to use both inductive and deductive reasoning in order to adequately prepare for an unknown future.

2.11 Summary

The urban forest is an evolving concept without one agreed upon definition (Dreistadt et al., 1990, 192). Although, as this thesis focuses on Seattle, the UFSP's definition forms the working definition of urban forests as, "the trees and associated understory species that are found on public and private property within the city" (City of Seattle, 2013a, 17). Further, the diversity of thought surrounding a definition has not prevented many within the academic and political fields from calling upon urban forests as a silver bullet to urban maladies.

It has been argued that urban forests can provide energy savings and moderate microclimates; store and sequester carbon; improve air, water, and soil quality; help manage flooding; have a positive effect on human health; maintain biodiversity; increase urban aesthetics; and increase social capital, among many other things (Phillips, 2014; McPherson et al., 2002; Akbari, 2002; Liu and Li, 2012; Dreistadt et al., 1990; Davies et al., 2011; Nowak et al., 2010).

Resilience, urban or otherwise, is a popular subject for academic discussion. In its most basic form, resilience is the capacity of a system to continue to function when presented with a shock (Levin, 2008, 27). Urban resilience is then the ability of a city to retain its functionality after a disturbance or a regime shift (Alberti et al., 2013a, 49). One must further define what thing you would like to be resilient, and what you would like it to be resilient against. In the case of this thesis, the ability of urban forests, and therefore the city of Seattle, to be resilient toward climate change is being examined. While the idea of resilience may be logical in theory, it is hard to translate into practice. The more we can break down the concept of urban resilience, the less complex this task becomes. This thesis has chosen to accomplish this task through the use of resilience indicators adapted from the Rockefeller Foundation (Ove Arup, 2014).

Ultimately this is a thesis concerned with the concepts of urban forestry, urban resilience, and climate change. While there are several articles that focus on the ability of urban forests to sequester carbon or maintain community ecosystems – thereby helping cities adapt to and mitigate against climate change and support urban resilience – an article that links all of these concepts together could not be found (Phillips, 2014, 8; Donovan and Butry, 2009, 666; Liu and Li, 2012, 121; Akbari, 2002, S119; Society of American Foresters, 2008). There is a gap in the current research concerning how to connect these three important ideas that this thesis hopes to begin to fill. This is a gap because many do not understand how to draw these connections beyond saying that connectivity is important. This thesis argues that management is the missing key because urban forests are the product of human investment in natural systems. How urban forests are managed is the way to connect urban forests with urban resilience to climate change. How cities choose to manage their urban forests directly affects the ability of these forests to provide benefits, and help a city to be resilient in the face of climate change (Nowak et al., 2010, 17). Urban forest management plans have the capacity to effectively manage urban forests for heightened resilience, although creating "Effective urban forest management nationwide has often been hampered by challenges such as inconsistent management approaches, lack of funding, weak linkages with other resource management programs, and inadequate planning that fails to consider the surrounding ecosystem, the community, and the regional context" (Nowak et al., 2010, 13).

By imagining how the concepts explained within this chapter could interact to create future scenarios in Seattle, **Chapter 3** will also explore the effectiveness of different styles of urban forest management plans in the city. **Chapter 4** will then examine the level of resilience within each of the future narratives, and **Chapter 5** will discuss implications for Seattle's existing UFSP.

Chapter 3 – Scenario Planning in Seattle

3.0 Introduction

As stated in **Chapter 1**, the goal of this thesis is to address two central research questions:

1. What is the capacity of urban forests to support urban resilience in the face of climate change impacts in Seattle?
2. How can Seattle's current Urban Forest Stewardship Plan (UFSP) be improved to achieve resilience when considering climate change? What actions can be taken today to make the UFSP a more robust plan able to succeed under alternative plausible futures?

In order to address these research questions and provide possible answers, this thesis applies a scenario planning approach to think critically about Seattle's plausible futures. Different stakeholders or the public were not involved in the specific scenario planning process conducted within this thesis. Instead, the four divergent narratives within this thesis were created by the author considering the possible interactions of uncertain external drivers and internal variables out to the year 2100. The amount of resilience present within these plausible futures is measured through the use of resilience indicators in **Chapter 4**.

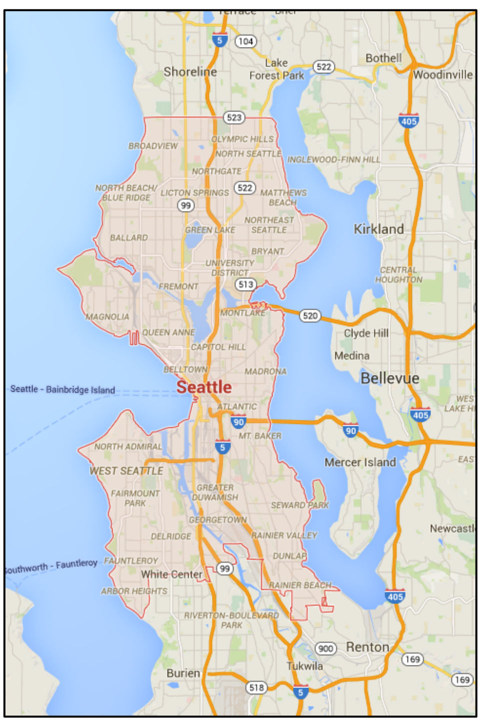

Figure 3-1. Map of Seattle (Google Images).

3.0.1 Defining Seattle's Existing Urban Boundaries

The scale of analysis for this scenario planning approach is the City of Seattle. The boundaries of the city are displayed in **Figure 3-1**. Geographically the city is bound to the east by Lake Washington, and to the west by the Puget Sound. Political boundaries separate Seattle from Shoreline to the north, and from Renton, Tukwila, and Sea-Tac to the South. The bodies of water prevent Seattle from expanding in an east or west direction, although the city could grow north or south through annexation, or more generally through converting the hearts and minds of residents. While the Seattle-Metropolitan Area covers a much wider area, the total existing land area of Seattle proper is almost 84 square miles and the current population is 652,405 individuals. This translates to a density of approximately 7,251 people per square mile (US Census, 2015). The city's population is also considered to be environmentally conscious (MNN, 2015), fairly affluent, racially diverse, liberal (N.L., 2014), physically fit (Cohen, 2014), and intelligent when compared to the rest of the state and the U.S on whole (US Census, 2015).

3.0.2 Defining Seattle's Existing Urban Forest

The urban forest within the City of Seattle is defined by "the trees and associated understory species that are found on public and private property within the city. This includes forested parks and natural areas, as well as the trees along streets and in yards" (City of Seattle, 2013a, 17). The current ratio breakdown of deciduous to evergreen species in Seattle is 69 percent to 31 percent respectively. The majority of all urban forest areas within the city are located on private lands, namely residential units. The broad spectrum of what is considered part of Seattle's urban forest is displayed in **Figure 3-2** on the following page. **Figure 3-3** presents a map of where these areas are present in Seattle.

Figure 3-2. Seattle's Urban Forest Spectrum (Image sources: giant-sequoia.com, 2015; Seattle.gov, 2015a; Savvy Seattle, 2015; Caldbrick, 2013).

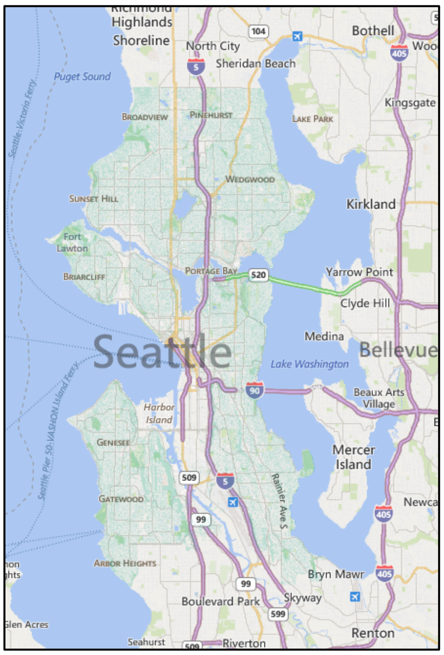

Figure 3-3. Displays the existing urban forest tree canopy in Seattle, where each green dot represents a tree (Seattle.gov, 2015e).

3.1 Imagining the Future

Sections 3.0.1 and **3.0.2** described the current extent of Seattle and its urban forest to set the groundwork for the scenario planning approach utilized within this thesis. The remainder of this chapter discusses plausible futures for the city based on selected drivers of change and internal variables.

3.1.1 Identifying Drivers of Change

Drivers are a mixture of human and natural forces that impact the system. These drivers are not necessarily intrinsic to the internal feedback loops that control the system, although they can most certainly change these internal loops by generating new and uncertain interactions. If the drivers work to change the feedback loops maintaining the system's stability, then the system can be eventually pushed over a threshold into a new regime (Walker et al., 2012, 30). Exactly how the drivers impact the internal variables and feedback loops is not completely understood. This uncertainty underlines the complexity of trying to predict the future. Shifts from one regime to another are therefore largely unpredictable, as many of the most important drivers and variables, as well as the coupled human-natural feedback loops that they create, are uncertain and complex (Liu et al., 2007, 1513-1516).

There are several manmade and natural drivers of change that impact Seattle's urban forest system (Liu et al., 2007; Alberti, 2008). Some of the important manmade drivers within Seattle that impact the state of the urban forest include, the economy, introduced non-native species, invasive species, management plans, political will, the institutional framework for conservation planning, landscape architecture trends, education, consumption demands, urbanization, desire to develop, government objectives, deforestation, amount of undeveloped land and/or open space, zoning, population increase or decrease, technological innovation, construction techniques, and public policy. There are also several important natural drivers that impact Seattle's urban forest such as habitat, weather, temperature, precipitation, carbon cycles, floods, drought, land cover, forest species, chemical balances, and climate change. To identify the most divergent and plausible futures for Seattle's Urban Forest, this scenario planning approach focuses on the two most important and uncertain variables driving potential changes.

3.1.2 Most Important and Uncertain Drivers

The two selected drivers of change for the urban forest within Seattle are: 1) institutional framework for conservation planning in the city, and 2) climate change. The institutional framework for conservation planning in Seattle is made up of several mechanisms and tools that emerge from diverse approaches and perspectives concerning conservation that includes the existing UFSP. Although to be effectively used as a driver of alternative futures, the institutional framework for conservation planning requires a more explicit specification. To make this concept more manageable, this thesis has selected to focus specifically on the urban forest management plan as an indicator of the overall institutional framework for conservation planning. While the urban forest management plan will be a proxy driver within this thesis, it should be understood that a specific plan cannot represent the overall institutional framework as a single element driving the future. A plan is simply the instrument of a greater planning framework. The institutional framework for conservation planning, and the urban forest management plan by extension, is important because it is the roadmap and action plan that a city generates to create, maintain, and enhance their urban forest. Without a framework or plan, activities can be conducted on an ad hoc basis, and the maximum benefits that an urban forest could provide may not be achievable (Tree Pittsburgh, 2015; APWA, 2015, 1). Further, "Without a management plan, the governments and individuals responsible for taking care of an urban forest will not be effective in meeting the true needs of the trees and the community. A management plan… [puts into writing the] priorities and objectives related to the goal of maintaining a productive and beneficial community forest" that exists within an institutional framework for conservation planning (APWA, 2015, 17). This driver is also uncertain because political whims, public opinion, and the power of planners or urban forest advocates can change. If a new city council, with control over budgeting, was voted in during the next election and did not see the rationale behind a strong plan, the ability of the city to follow through on existing urban forest priorities within the institutional framework for conservation planning would decrease. Conversely, if there was a large ground swell for a more enduring plan, or a mayor was elected that believed in the power of urban forests, this could positively impact the urban forest (Seattle.gov, 2015b).

Climate change was selected as the second driver of change for Seattle's urban forest. If increase, for instance, tree species that are more attuned to moderate temperatures could die. The Northwest region in particular has already experienced an averaged 1.3°F increase in temperatures and variable precipitation increases from the levels experienced in 1895. Overall temperatures are predicted to increase anywhere from 3.3°F to 9.7°F by 2100, and precipitation could increase by 18 percent, decrease by 10 percent, and/or experience as much as a 30 percent decrease during the summer months (Mote and Snover, 2014a, 489). Additionally, as vegetation depends on energy from the sun, CO_2 in the atmosphere, and water in the soil, all of these changes within Washington's weather and climate could influence the health of the urban forest. Inversely, a healthy urban forest could be a key piece of the puzzle that helps the city adapt to, and perhaps mitigate against, climate change. While there is broad agreement that climate change is occurring on a global scale, the specifics on a finer grain are hard to differentiate. Therefore, this driver is not only important, it is also very uncertain on a regional and city scale.

Within this scenario planning exercise, two endpoints for each driver have been selected in order to create divergent plausible futures scenario narratives (as illustrated in **Figure 3-4**). The endpoints for the institutional framework for conservation planning driver are Seattle's existing UFSP and a more enduring urban forest management plan. The endpoints for the climate change driver are minor and major impacts as defined by the IPCC's Representative Concentration Pathways (RCPs): RCP 8.5 and RCP 4.5.

Institutional Framework for Conservation Planning as Driver

The two endpoints for the institutional framework for conservation planning driver are described within this section as they relate to the seven qualities of resilience defined in **Chapter 2**. Utilizing these qualities as a descriptor will help articulate the differences and similarities in the two endpoints. Again, these urban forest management plan endpoints are used as a lens through which to examine the overall driver of Seattle's institutional framework for conservation planning. Although, from this point on, the more general driver will be discussed almost exclusively in terms of the urban forest management plans. The first endpoint is the existing urban forest management plan in Seattle, the UFSP. The second endpoint is a compilation of different attributes from successful urban forest management plans from across the country, the more enduring plan. The parts that make up the whole of the enduring plan were selected based on their stories of success, scientific analysis when available, and judgment. Real policies were selected to highlight the feasibility of adopting at least parts of this more enduring plan in Seattle. The city where each component of the enduring plan was taken is indicated within the reference.

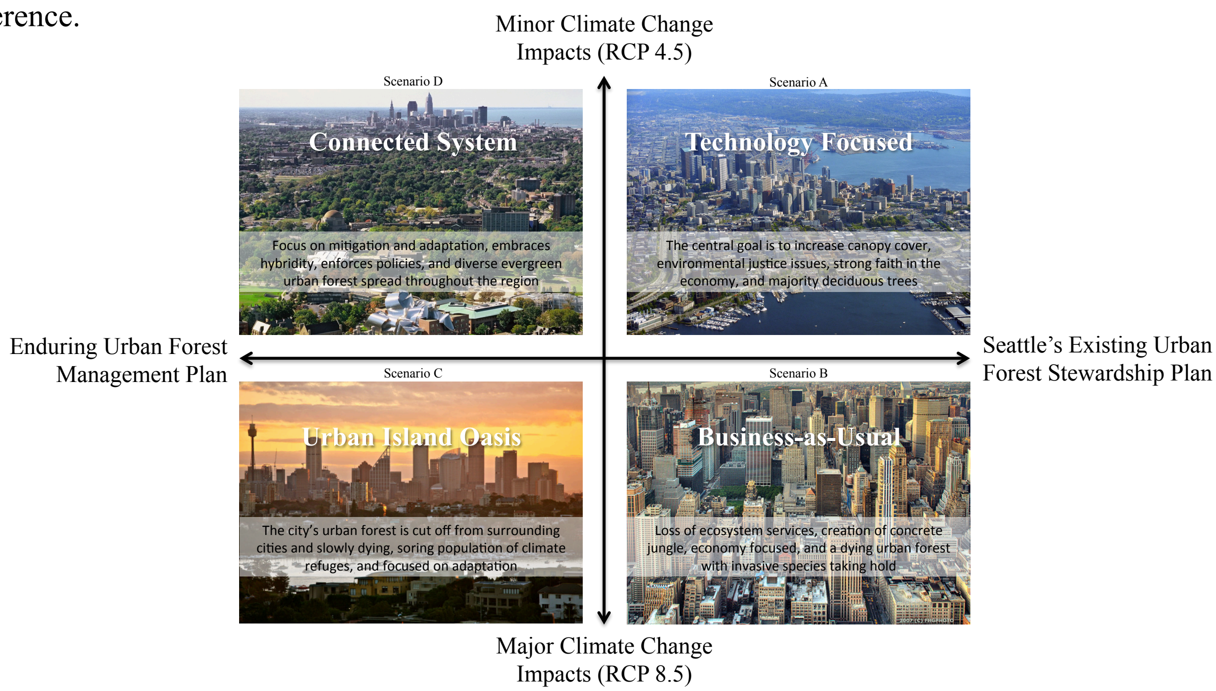

Figure 3-4 Four scenarios based on the important and uncertain drivers of climate change and Seattle's institutional framework for conservation planning (Image sources: Forest City Forever, 2012; SkyscrapperCity.com, 2009; FHG Photo, 2007; CityDesert, 2015).

Seattle's Urban Forest Stewardship Plan (UFSP)

Reflective → Seattle's UFSP is a 24-year plan with comprehensive updates scheduled for every 5 years (City of Seattle, 2013a, 9). The UFSP includes short-term (less than 5 years), mid-term (5 to 10 years), and long-term (over 10 years) goals (City of Seattle, 2013a, 15). The UFSP is reflective in that there are occasional updates, although all of these updates do not seem to be based in science. Further, without specific metrics of success, these updates are not necessarily aimed at trying to improve specific areas of weakness. Further, areas of weakness may not even be identified or understood without specific metrics. Seattle is aware of the need to have a monitoring plan for the UFSP, and this is high on the priority list (City of Seattle, 2013a, 71).

Robust → Seattle has conducted an inventory of the city's urban forest canopy cover utilizing remote aerial sensing and sampling surveys. The canopy was first inventoried in 2007 and has not been updated since 2011 (City of Seattle, 2013a, 35). Without sufficient funds for a wider inventory of parks or private lands, a tree-by-tree inventory has been limited to the street trees within the city, and this has not been updated since 1992 (City of Seattle, 2013a, 37). Even without a full inventory of parks and private lands, the city has assessed the condition of their tree assets, and believes that the majority of trees are in good health (City of Seattle, 2013a, 38). The city has not created a maintenance schedule for the urban forest and therefore lacks a full asset management system. While the focus of the plan is to preserve, maintain, restore, and expand the city's current urban forest assets, management is primarily ad hoc and reactive without a full asset management system (City of Seattle, 2013a, 63).

Redundant → The UFSP recognizes that need for a diverse urban forest and has highlighted the deficiencies that currently exist in terms of a lack of variety in native species and age within the urban forest (City of Seattle, 2013a, 10). The UFSP emphasizes the need for native trees in the city, especially evergreens, and mentions the scientific benefits these species can provide residents (City of Seattle, 2013a, 11). Although, the policies in place to improve redundancy appear to be more like ideas rather than implementable steps. Additionally, locational diversity does not seem to be a priority.

Flexible → The UFSP has three central and broad approaches to manage the urban forest that examines community, ecological, and resource management. The UFSP also highlights a number of different strategies to improve the urban forest and implement these three approaches. The UFSP further breaks up the urban forest canopy cover goals by land uses including single family residential, multi-family residential, commercial/mixed use, downtown, industrial, developed parks, natural area parks, and right-of-way (City of Seattle, 2013a, 11). In this way the UFSP recognizes that to be successful, different goals and strategies must be applied to each land use.

Resourceful → The UFSP utilizes several different strategies to achieve their goals, although the majority of these strategies rely on voluntary compliance instead of being tied to enforceable laws or codes. While the UFSP includes plans to create a more regulated urban forest, it has not progressed past "look[ing] into how to regulate" certain goals or policies. The urban forest codes that do exist in Seattle are often inadequately funded and therefore largely unsuccessful. For instance, the desired policy to replace every lost tree to development with two new trees has not been strictly enforced or followed (City of Seattle, 2013a, 44). Further, there is not a chapter within Seattle's Comprehensive Plan on urban forests, and without a policy framework it is even harder to enforce goals. Although, there are ordinances attached to the urban forest objectives of the UFSP enumerated within the Seattle Department of Transportation's (SDOT's) *Street Tree Manual* that are effectively enforced. These enforced codes primarily include the need for permits to plant, prune, or remove street trees. There are penalties attached to these street tree ordinances for non-compliance. The UFSP primarily relies upon education and outreach during the permitting process to achieve their goals on private lands, and are thinking of further incentives.

Inclusive → There are several government groups involved with the creation and implementation of the UFSP, including the Seattle City Council, Department of Planning and Development, Finance and Administrative Services, Office of Sustainability and Environment, Seattle Center, Seattle City Light, SDOT, Seattle Parks and Recreation, Seattle Public Utilities (City of Seattle, 2013a, iii). The UFSP also emphasizes the need for public involvement, and there are non-profit groups and volunteers who help maintain the urban forest through invasive species removal. There are an estimated 140,000 street trees in Seattle, and SDOT only maintains 40,000, implying that the rest are maintained in some fashion by residents (City of Seattle, 2013a, 45). It is unclear how the city is currently helping and/or educating these residents about proper maintenance, except for during the permitting process. The Seattle reLeaf program provides free trees and training to residents, although this does not seem to be a well utilized program.

Integrated → The UFSP emphasizes the need for cooperation among stakeholders, and there is a clear delineation of power among the involved agencies. There is also an Urban Forest Interdepartmental Team whose job is to coordinate actions and policies among each of the eight governmental agencies with UFSP roles (City of Seattle, 2013a, 25). The UFSP itself speaks with one clear voice.

Enduring Urban Forest Management Plan (Plan)

Reflective → The Plan covers a 20-year period, with updates every 5 years. Annual reports are also required to help policy makers gauge the success of the Plan, and provide transparency to the public (City of Austin, Texas, 2014, 63; City of Portland, Oregon, 2015b). The best available science is utilized to make such updates, as displayed by the various academic references throughout the Plan, as well as the close partnerships with academic institutions such as with the University of Washington (City of Portland, Oregon, 2015b; City of Austin, Texas, 2014, 7; Bassuk [Ithaca, NY], 2009, 75). The Plan has clear ecological and economic metrics by which to measure success (Outen [Baltimore County, MD], 2009, 44). Along with regular Plan updates, the city's codes that relate to the urban forest are also updated regularly to ensure that the policies within the Plan are still enforceable and scientifically defensible (Schwab [Urbana, IL], 2009, 58). What's more, the Plan is constantly looking for ways to improve through the use of pilot programs such as placing structural soil under sidewalks to allow more room for roots to grow without disturbing the pavement above (Bassuk [Ithaca, NY], 2009, 75)

Robust → There is a full inventory of the entire urban forest including street trees, parks, and private areas (City of Portland, Oregon, 2015a). This inventory, along with a conditions assessment of the entire urban forest, has allowed for the creation of a preventative maintenance schedule (Schwab [Urban, IL], 2009, 57). These three attributes provide Seattle with a working asset management system for the urban forest, and proactive management as a result. The schedule also allows the city to follow each tree throughout its entire lifetime, from nursery, to planting, to harvesting for urban wood products or mulching for other trees (City of San Francisco [CA], 2014, 20). This allows the city's inventory to become a dynamic document. The Plan also has clearly stated and implementable goals, sub-goals, and strategies (City of San Francisco [CA], 2014, 47).

Redundant → The Plan will "strive…to achieve a more equitable distribution of greening throughout the city by encouraging planting in areas lacking tree cover and supporting alternate greening methods" (City of San Francisco [CA], 2014, 32). Goals to increase the percentage of different native species, age groups, and locations for the urban forest have been implemented (Bassuk [Ithaca, NY], 2009, 71).

Flexible → The Plan and management strategies are broken down by type of urban forest, such as street tree, park, open space, and those within buildings or on private property (City of San Francisco [CA], 2014, 2). Further, separate management plans (under the umbrella of the one Plan) are encouraged on a neighborhood level to give residents more agency and opportunities to become involved in their surrounding urban forest's maintenance (New York City [NY] Global Partners, 2013). Within the different phases of the Plan based on type, the Plan further differentiates by the physical characteristics, issues, and benefits of the different urban forest areas so that each can be "managed by different bureaus, agencies, or individuals to achieve different results" (City of Portland, Oregon, 2004, 57). The Plan does not take an one size fits all management approach, it is very contextual and place based.

Resourceful → The Plan approaches urban forests from a number of different management strategies and utilizes the skills of a number of different experts including an urban forester on staff (City of Austin, Texas, 2014, 77-78). Additionally, the Plan looks beyond just the traditional urban forest, and encourages alternative ways to green the city such as green roofs and living walls (City of San Francisco [CA], 2014, 32). The Plan is enforceable as a policy framework that has been established by a chapter in the Comprehensive Plan as well as zoning codes, and city ordinances (City of Austin, Texas, 2014, 77-78; Lewis [Olympia, WA], 2009, 64). The city forester also has legal oversight over the actions of private or public individuals when they affect the public urban forest. Notable with this power provided by a city ordinance, "is the discretionary right of the city forester to approve or disapprove the removal of trees and require…tree replacement" (Bassuk [Ithaca, NY], 2009, 72). Finally, the Plan and the urban forest program on whole within the city is very well funded by a diversity of private and public funds such as "tax dollars, donations, parking fees…, capital improvement funds" (Schwab [Urban, IL], 2009, 59), bonds, grants, private donations, volunteers, and the city's operating budget (Outen [Baltimore County, MD], 2009, 48-49).

Inclusive → The Plan and the government stakeholders in charge of implementing it are very active at engaging the public through websites, blogs, event calendars, workshops, economic incentives, and training sessions. The public is also asked to participate in each Plan update, and is continually educated on the importance and value of trees through signs placed on trees that state their economic value, through new technologies such as phone apps, and through partnerships with schools (City of Portland, Oregon, 2015a; City of San Francisco [CA], 2014, 16; City of Austin, Texas, 2014; Monear [Minneapolis, MN], 2009, 53; Lewis, [Olympia, WA] 2009, 65). Additionally, there is an Urban Forest Commission that holds regular meetings with all stakeholders and oversees weekly meetings between the city forester and road crews (Lewis, [Olympia, WA], 2009, 64). The government agencies also participate in active cooperation through interdepartmental reviews of development plans and building permit applications among the Department of Public Works and the Planning Department (City of San Francisco [CA], 2014, 47).

Integrated → The Plan clearly delineates the roles and responsibilities of all stakeholders, and provides clear steps for implementation (City of San Francisco [CA], 2014, 60; City of Portland, Oregon, 2015a; City of Portland, Oregon 2015b, 34; City of Austin, Texas, 2014, 56). Additionally, the urban forest initiatives are well imbedded in other city wide plans such as the Comprehensive Plan and Climate Acton Plan (Lewis [Olympia, WA], 2009, 64; Schwab [Urbana, IL], 2009, 57; City of San Francisco [CA], 2014, 35). Further, city officials look beyond their own borders and engage surrounding cities in active discussions about cross border management (Staszewski [Salem, OR], 2009, 60).

Climate Change as Driver

The two endpoints of the climate change driver are defined by major and minor impacts as based on the IPCC's 2014 Fifth Assessment.[1] The RCPs differ from the previously used emission

[1] The IPCC is composed of several thousand scientists from around the world with the primary goal of providing "the world with a clear scientific view on the current state of knowledge in climate change and its potential

scenarios because they are based on new climate science that became available after the 2007 Fourth Assessment. The transition to RCPs was also a response to the desire of policy makers to identify approaches to achieve climate targets (Bjornaes, 2015, 2). RCPs are based primarily on the amount of radiative forcing predicted to occur. Radiative forcing is "expressed as Watts per square metre, [(W/m^2) and] is the additional energy taken up by the Earth system due to the enhanced greenhouse effect. More precisely, it can be defined as the difference in the balance of energy that enters the atmosphere and the amount that is returned to space compared to the pre-industrial situation. Total radiative forcing is determined by both positive forcing from greenhouse gases and negative forcing from aerosols. The dominant factor by far is the positive forcing from CO_2. As the radiative forcing increases, the global temperature rises. However, the precise relationship between these factors is not fully known" (Bjornaes, 2015, 2).

The two endpoints are based on IPCC scenarios RCP 8.5 and RCP 4.5. RCP 8.5 characterizes a possible climate scenario where the most extreme climate change impacts occur on a global and local scale. This endpoint represents what is expected to occur in Seattle if the city and world remain on the current business-as-usual path. RCP 4.5, on the other hand, represents relatively minor climate change impacts, and is considered aspirational for the City of Seattle to achieve. The least impactful IPCC climate change scenario, RCP 2.6, was not selected as an endpoint because the goal of this thesis is to examine plausible futures. RCP 2.6 is not rationally plausible because it has overly ambitious assumptions for decreases in GHG emissions, such as becoming carbon neutral with zero net emissions by 2050. While the City of Seattle has made a commitment to be carbon neutral by 2050 – this is only a local effort (City of Seattle, 2013b, 3).

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environmental and socio-economic impacts." The group was established in 1988 by the United Nations Environment Program, and the World Meteorological Organization, and is currently on their Fifth Assessment Report (IPCC, 2015).

To successfully hold the world and Seattle's climate to those predicted in RCP 2.6, there must be a global commitment to be carbon neutral by 2050. RCP 2.6 is also predicated on a global population of 9 billion in 2100, when recent predictions estimate that by 2100 the population could be at least 11 billion (The Guardian, 2015; Yamin, 2014; Bjornaes, 2015, 5). RCP 2.6 is further unreasonable because it predicts a 1°F to 5°F increase in temperature in the Pacific Northwest. From 1991 to 2012 temperatures have already increased (when compared to 1901 to 1960 levels) by 0.5 to 2°F (Walsh and Wuebbles, 2014). Therefore, RCP 4.5 is the least climate change impacts that Seattle could reasonably expect to experience with aggressive policy implementation and behavioral changes. RCP 8.5 and RCP 4.5 were also selected based on previous academic work and estimates of the possible climate change impacts within Washington State (Alberti, 2013a; Climate Impacts Group, 2009).

Major Climate Change Impacts – RCP 8.5

Reflective → RCP 8.5 represents business-as-usual in that it assumes that there are no further policy changes made to reduce emissions in Seattle, or the rest of the world, past those in existence in 2015 (Bjornaes, 2015, 4). Large negative climate change impacts are the consequence of this decision because Seattle and the rest of the world have chosen to continue their existing levels of reliance on fossil fuels, rates of urbanization, and enforcement of current climate change mitigation policies (Bjornaes, 2015, 4; NOAA, 2015; van Vuuren, 2011, 12). The world and Seattle have not learned from their mistakes in RCP 8.5, instead they are doubling down on the economy in hopes that the market will resolve any environmental problems. The economy and the environment are considered separate systems and there is faith in technology to discover a silver bullet in the future. Although with less of a focus on technology and more of a focus on fossil fuel extraction and energy intensive industries, the possibility of finding a solution, or even adapting to climate change, declines each year (Bjornaes, 2015, 4).

Robust → There is a heavy reliance on fossil fuels without much consideration for other sources of power, or expansion of the urban forest to sequester and store carbon (Bjornaes, 2015, 4). As a result, radiative forcing has stabilized in the year 2100 at approximately 8.5 W/m^2, or approximately 1,370 parts per million (ppm) in CO_2 equivalent (CO_2e). This level of radiative forcing translates to anywhere between 5 and 10°F of temperature increases, from average 1970 to 1999 levels (Walsh and Wuebbles, 2014, 29). An 8°F increase was selected for this endpoint based on the CMIP5 modeling for the Northwest area (Walsh and Wuebbles, 2014, 30; IPCC, 2014a, 13). In RCP 8.5, annual precipitation has increased by 20 percent in 2100, and this has been coupled with an increase in the consecutive number of dry days to 30 percent (Walsh and Wuebbles, 2014, 33).

Redundant → The population of the world has reached 12 billion without signs of slowing in RCP 8.5. The population of Seattle has mushroomed as an initial location for climate refuges as well. This growth has forced vertical and horizontal expansion of the city, and reductions in the urban forest to make way for new buildings. Additionally, with the growing population in Seattle, more natural forest areas are being converted to croplands outside of the city. This increase in agricultural land also works to reduce species redundancies and increase methane emissions (Bjornaes, 2015, 4). The types of temperature and weather patterns described above are also negatively impacting the "unique and threatened systems" of Seattle and the world.

These changes in the climate have translated to a drastic decrease in the diversity of species, and an increase in the likelihood of long-term drought in Seattle (IPCC, 2014a, 13-14).

Flexible → Seattle has attempted to remain static, stuck in place and time. The city has refused to believe that their behavior or actions can affect the outside world, and this inflexibility has heightened vulnerabilities across the city. Seattle, and every other city, has refused to take action, therefore global GHG emissions have triple by 2100, and the ability to ever revert back to pre-climate change or minor climate change impacts has become unlikely (Bjornaes, 2015, 4).

Resourceful → The city is not attempting to create or pass any new climate change policies, or enforce the ones they already have on the books (Bjornaes, 2015, 4). The city does not invite the opinions of experts or locals concerning climate change or the urban forest because they do not believe there is a problem with relying on fossil fuels. When shocks do occur, Seattle sticks to the plan without adapting to circumstance or new knowledge. There are no incentives or regulations in place to change the current plans, and therefore updates do not occur.

Inclusive → The city is not inclusive. With population on the rise, it is every man for themselves in Seattle. The remaining urban forests in the city are only located in the wealthy enclaves of the city, and the maximum benefits they could provide are being denied to the majority of the citizens. This is also the norm in cities across the world as the gap between rich and poor grows. One of the primary drivers in this endpoint is the goal of "rapid economic growth" at all costs (IPCC, 2014b). As a result, "In this world, people pursue personal wealth rather than environmental quality" (IPCC, 2014b).

Integrated → Bickering among countries has translated to bickering among politicians, residents, and cities in the Puget Sound region and Seattle. This bickering has led to a stalemate without any actions to improve the position of urban forests. This inaction has also allowed for mitigation and adaptation efforts to be largely ignored.

Minor Climate Change Impacts – RCP 4.5

Reflective → RCP 4.5 is an aspirational endpoint for Seattle. This has been possible only by Seattle and other cities around the world leading the charge to drastically cut global emission of GHGs. Within RCP 4.5 the city is learning from mistakes, and is therefore able to recognize the power and necessity of reducing consumption and energy use. As a result, Seattle and the rest of the world have drastically reduced energy consumption, and CO_2 emissions increased only slightly after 2015 before beginning a stead decline in 2040 (Bjornaes, 2015, 5). Seattle in particular has moved away from a material intensive economy and has invested fully in a service and information based economy (IPCC, 2014b). As flood and drought cycles become the norm, the city has learned that denser urban forests can provide flood relief, and help to store water to replenish water systems during periods of drought (Berland and Manson, 2013, 750; Phillips, 2014, 2; Davies et al., 2011, 1126; Arnold, 1987, 122).

Robust → Seattle has begun to focus more on reforestation inside and outside of its borders as a mitigation and adaptation strategy to climate change (Bjornaes, 2015, 4). This reforestation has been able to aid in mitigation efforts because Seattle is one of many cities around the world conducting reforestation and afforestation. The city has also introduced "clean and resource-efficient technologies" to reduce their own GHG emissions, and help create locally specific adaptation measures to minor climate change impacts (IPCC, 2014b). As a result of these ambitious global and local emission reductions through strong reforestation programs, stringent climate change policies, and reductions in energy use, radiative forcing within RCP 4.5 stabilizes in the year 2100 at approximately 4.5 W/m^2, or approximately 650 ppm in CO_2e (Bjornaes, 2015, 4; NOAA, 2015; van Vuuren, 2011, 12). This level of radiative forcing translates to anywhere between 3 and 5°F of temperature increase, from average 1970 to 1999 levels (Walsh and Wuebbles, 2014, 29). A 4°F increase was selected for this endpoint based on the CMIP5 modeling for the Pacific Northwest area (Walsh and Wuebbles, 2014, 30). Annual precipitation in Seattle has increased by 10 percent in 2100, with an increase in the consecutive number of dry days by 10 percent (Walsh and Wuebbles, 2014, 33). Further, Washington's snowpack has decreased even while extreme precipitation events increased (Climate Impacts Group, 2009, 1). This means Seattle is experiencing water availability issues – longer periods and frequency of droughts – as well as the periodic flash floods. This varies drastically by season, with wetter winters and springs and drier summers and falls (Walsh and Wuebbles, 2014, 35).

Redundant → As temperatures still increase within RCP 4.5, the capacity for redundancy decreases as species become stressed and must migrate to survive. As the urban forest is maintained by humans, trees within these spaces cannot easily migrate without the intervention of humans. Even without human involvement though, vegetation has a low capacity to migrate (IPCC, 2014a, 15). Conversely, some species of vegetation, namely deciduous trees, have experienced additional growth with heightened levels of CO_2 in Seattle within RCP 4.5. This additional growth is dependent on an ample supply of other limiting factors such as water and soil nutrients, and works to further reduce species diversity by favoring deciduous over evergreen vegetation (Way and Oren, 2010, 670; EFI, 2015). Further, as temperatures increase, the ability of urban and natural forests to store carbon decreases as tree mortality increases with wildfire, disease, and habitat loss (IPCC, 2014a, 15). Therefore as temperatures increase, the ability of urban forests to help mitigate and adapt to climate change decreases.

Flexible → Within RCP 4.5 there has been a significant decrease in the amount of croplands utilized to feed the population, as technological advances allow for greater yield efficiencies over smaller areas of land (Bjornaes, 2015, 4). This means that the main sources of food for the world have been condensed into smaller areas, and if disaster were to strike in those specific locations, global food shortages could result. Although, with less croplands there are also significantly less global methane emissions, a factor helping to mitigate climate change. Mitigation in general is a slow, global process without a lot of flexibility because of the lag effect. Without massive removals of GHGs from the atmosphere, the emissions that have accumulated in the past will continue to contribute to climate change in the future. This is true of RCP 4.5, although with strong reforestation programs on a global scale, the world is working to sequester large stores of CO_2 and prevent severe climate change impacts (IPCC, 2013, 27; Bjornaes, 2015, 4). Additionally, in Seattle and abroad, the agriculture and forest knowledge of more indigenous peoples are being incorporated into plans. This helps to create better plans, and plans that have the support of the people. This also has the benefit of creating stronger ties between groups that will help areas recovery more quickly after shocks to the system.

Resourceful → While there is a large emphasis on reforestation globally and locally in order to mitigate the negative impacts of climate change, Seattle is not reliant on the urban forest as the only climate change mitigation and adaptation strategy. The city has looked beyond urban forests and enacted several other stringent climate change policies enumerated within the comprehensive plan, city codes, and updated climate action plans (Bjornaes, 2015, 4). Seattle understands that adaptation to climate change must take place locally, and while urban forests are a part of Seattle's plan to thrive despite minor climate change impacts, it is not the only piece of the puzzle.

Inclusive → In order to address climate change issues and create stringent policies, the Seattle City Council has included several stakeholders to garner enough support for stringent policy adoption. This has included thousands of residents through hundreds of public meetings, neighboring cities, politicians with opposite political leanings, and businesses. This sort of inclusivity has allowed for the local cooperation needed to pass local adaptation strategies. To achieve such levels of global mitigation present in RCP 4.5, Seattle has worked with neighboring states and international cities to agree upon legally binding international emission limits, and share GHG cutting technologies.

Integrated → The findings of the IPCC have been integrated into the climate change policies of Seattle and abroad. These scientific results are also having an impact on the decision making process for urban forest management. Free flowing communication among all local and global stakeholders has been established with a united message of mitigation and adaptation.

Before continuing it is important to explicitly note here, as generally discussed in the descriptions above, that mitigation of climate change must be a global effort, and adaptation to climate change impacts must be accomplished on a local level. This scale is required because first, the sources of climate change are global and massive. Second, there are a diversity of possible impacts from climate change that could effect different localities in various manners. If we, as a global society, are to have success mitigating climate change, efforts to reduce GHG emissions and sequester carbon must be embarked upon together. Conversely, as the impacts of climate change across the world will not be equal, and there will most likely be a lag effect even if we accomplish massive mitigation projects tomorrow, adaptation to climate change must be contextually relevant. Mitigation and adaptation together bring about urban resilience. The scenario narratives below explore the ability of urban forests to help Seattle be resilient to climate change, in other words, to retain urban functionality through mitigation and adaptation to climate change.

To be clear, this thesis does not advocate for Seattle to abandon their own carbon neutral commitments. These local efforts are essential for successful local adaptation to climate change, and can be leveraged to convince other cities to commit to carbon neutrality as well. This thesis does however encourage Seattle to collaborate with other cities and nations in an effort to make global mitigation more feasible, and local adaptation sufficient for survival.

3.1.3 Plausible Scenarios Based on Drivers

The following scenario narratives are based on hypothesized potential interactions between drivers' endpoints out to the year 2100 (as displayed in **Figure 3.4** on page 3-4). The scenarios are grounded in current understanding of these potential interactions and described as if the reader were looking back in time, and was interested in learning the history of Seattle between 2015 and 2100.

Scenario A is entitled "Technology Focused." The scenario is defined by 85 years of interactions between minor climate change impacts (RCP 4.5) and Seattle's existing UFSP in 2015. While the UFSP continued to evolve between 2015 and 2100, these adaptions were often the result of political posturing and "green" image creation more so than because of the best available science (City of Seattle, 2013a, 8). Regardless of the rationale, the central focus of the residents and government bodies was to reforest the city and utilize technology to mitigate climate change impacts (Bjornaes, 2015, 4). This was a goal shared by all cities within the Pacific Northwest, and a majority of cities across the world. As a result, Seattle expanded the canopy cover to 30 percent by 2037 - reaching the goal set in the 2013 UFSP - and significantly lowered their fossil fuel emissions through drastic reductions in energy use. These actions, coupled with successful regional and global mitigation efforts, prevented local temperatures from rising above 4°F by 2100 (Walsh and Wuebbles, 2014, 30; Bjornaes, 2015, 4-5).

Unfortunately for Seattle, while technological advancements continued well after 2037, once the canopy cover objective was achieved, the city focused primarily on maintaining this percentage instead of expanding it further. Funds previously used to purchase trees or additional land for parks to reach the 30 percent objective, were allocated elsewhere after 2037. As a result, the canopy cover oscillated around 30 percent, and did not expand in terms of locational or species diversity. This occurred because the UFSP canopy cover expansion strategy did not include a scientific advancement provision, additional funding past the 30 percent objective, or target specific areas or species of trees for growth in the city (City of Seattle, 2013a, 12). When resources are scarce, decisions must always be made that require tradeoffs (Boundless, 2015). Scarce resources in this case equate to land, funding, and community engagement. Deciding that a parcel must have a certain percentage of trees, for instance, can directly effect how large a building can be constructed which can then impact the building's potential revenues. Officials in Seattle decided that the opportunity costs of pushing for a canopy cover percentage above 30 percent was not efficient when those government funds could instead go to some other worthy or struggling cause. As time went on and only minor climate change impacts were felt, public pressure on city officials to utilize urban forests as an adaptation and mitigation tool also decreased in Seattle and abroad.

Prior to waning public interest, a monitoring plan was adopted during regular UFSP updates in the early 2020s. The monitoring plan and the metrics associated with it allowed for progress towards achieving urban forest goals to be more easily tracked, and maintenance work to become more proactive in nature (City of Seattle, 2013a, 71). While the UFSP was updated every five years, the tree inventory was updated at more irregular intervals based on available funding (City of Seattle, 2013a, 9). Despite the sporadic updates, the coverage of the inventory increased across public and private lands because of the expansion of next generation LIDAR technology (City of Seattle, 2013a, 37). LIDAR became more cost effective around the 2030s as the necessary lasers were installed in all commercial planes.[2] These facts work to highlight a trend during this time period, when tasks were manual in nature, such as updating written plans or

[2] LIDAR (Light Detection and Ranging) is remote sensing technology that utilizes near-infrared lasers flying in planes or helicopters to "generate precise, three-dimensional information about the shape of the Earth and its surface characteristics" (NOAA, 2014). These 3D images helped scientists inventory the urban forests within Seattle, and with the aid of ground truthing, it was also calibrated to identify specific species of vegetation and estimate condition based on size and assumed age parameters.

finding suitable land for urban forest expansion, the funds and pressure to accomplish the task were low. Conversely, when new technologies were involved in more hands off activities, funds were found and excitement levels increased.

Despite the technological advancements that occurred, those in charge of implementing the UFSP never created a full asset management system because a maintenance schedule for the urban forest inventory was never generated. This final component of the asset management plan was never made a priority in the UFSP, and therefore it was never accomplished. This meant that the city was aware of the declining condition of the urban forest from excellent and good/fair to primarily good/fair and critical/dying because of the conditions assessment, but they refused to address the issues in a systematic fashion. There was no political pressure to create a maintenance schedule because to do so would have taken a lot of manual labor and effort, but also because the degradation of the urban forest took place in a patchwork throughout the city over a long period of time. It was therefore easy for residents and politicians to ignore the brewing problem. Further, as the temperatures increased by 4°F, variable precipitation levels became the norm, and this variation as well as the rise in CO_2 affected some species more than others. Without a maintenance schedule, the city was forced to address any issues after they occurred, a strategy that became known as treeage.[3] The problems that were perceived as most extreme were dealt with first, and these perceptions were often swayed by which residents complained the loudest. As this typically occurred in the wealthiest parts of town, those were the urban forests that were best maintained.

This disparity was allowed to grow stronger because locational diversity was never a central

[3] A play on the medical term 'triage.'

concern of the UFSP. Additionally, those in wealthy neighborhoods were able to petition for parks more effectively, and they had more resources to devote to private gardens. This clumping of the urban forest in wealthy neighborhoods was a problem because one or two large disturbances, such as the introduction of a pest or a large fire, could severely degrade Seattle's overall urban forest. Additionally, the imbalance created a social equity issue as the majority of the benefits of urban forests – such as air purification, stormwater and flood slowing, water storage, mental restoration, recreation, and shade (Simpson, 2002, 1067; Solaripedia, 2011; Schlosberg, 2004, 517) – were only enjoyed in wealthy areas.

The locational imbalance of the urban forest was also fueled by the actions of private industries in Seattle. A few of the technology firms in the city began to take an increasing interest in the aesthetic beauty of their campuses around 2050. Driven by this interest, they began to commit substantial amounts of money to improving the urban forests in their vicinity. These funds came with clear locational restrictions that worked to further improve urban forests within wealthy areas and neglected urban forests in poorer areas. This funding also allowed the government to ignore, either subconsciously or consciously, voices beyond the most powerful in business.

The most powerful businesses with the loudest voices in Seattle during this time were those in the technology sector. This industry held massive sway because of their large demand for skilled labor that employed a large portion of the city, and the economic prosperity they brought to the region. In almost direct result of the skilled labor demands from the technological sector and the minor climate change impacts experienced by the city, the population of the area grew exponentially between 2015 and 2100 (Berger, 2014; Seattle.gov, 2015c; Morrill, 2014). This growth brought money to the city, but also put further strain on the aging infrastructure and ecosystem services that helped the city maintain minor climate change impacts in the first place (OECD, 2007, 156; Kelly, 1993). The population growth also caused the city to begin expanding outward from the core, to convert natural landscapes to impervious and pervious pavements that did not include urban forests (Morrill, 2014). Although this urbanization was hemmed in to a certain degree by the urban growth boundary. The urban growth boundary was upheld because of the strict adherence to all climate change oriented policies in Seattle during this time (Bjornaes, 2015, 5). The city may have been technology focused, but they also understood the importance of limiting climate change through both mitigation and adaptation measures. Technologies – such as pervious pavement and green roofs – helped to temper the negative impacts of climate change on the natural systems from the horizontal growth that did occur within the urban growth boundary of Seattle.

Unfortunately for the citywide effort to increase native, evergreen species, deciduous tree species benefited more – in terms of “shoot height, stem diameter and biomass” (Way and Oren, 2010, 669) – from the minor climate change impacts than evergreen species. Additional tree growth from climate change in general depends on several factors, “including water and nutrient availability, the timing of the warming, rising atmospheric CO_2, the ability of species to acclimate to new growing conditions and how close trees already are to their thermal optimum for growth” (Way and Oren, 2010, 669). Subsequently, many evergreen species became stressed because of minor climate change impacts (Way and Oren, 2010, 669). Increased deciduous vegetation growth was possible because “photosynthesis and respiration…are…enhanced at higher temperatures because of quicker enzyme function[ing]” (Way and Oren, 2010, 682).

Further, with the increased availability of CO_2 and energy, other factors became limiting, such as the amount of water or nutrients in the soil. Evergreen species typically flourish in areas with decreased levels of water and nutrients to begin with, so they could not take advantage of the additional CO_2 or energy in the system like the deciduous trees could (Wren and Oren, 2010, 682). However, this increased growth within Seattle's deciduous population was short lived as the increase in atmospheric CO_2 began to slow in 2040 when global GHG emissions were drastically cut (Way and Oren, 2010, 670; EFI, 2015; Bjornaes, 2015, 5). While CO_2 levels began to decrease on a global level in 2040, temperatures still increased past this date due to the lag effect (IPCC, 2013, 27), and this negatively affected the entire urban forest in Seattle as water sources began to evaporate and droughts became more common.

This temperature increase and CO_2 decrease after 2040 was most advantageous to invasive species, such as ivy, that increased despite the eradication efforts of local neighborhoods (Walsh and Wuebbles, 2014, 33; Dukes, 2000; USEPA, 2013a). Invasive species "are generally more tolerant to a wider range of environmental conditions than are native plants" and could handle the shifts better than both deciduous and evergreen species (USEPA, 2013a). As a result of the increased coverage of invasive species and the changing climates in Seattle, habitats for deciduous and evergreen trees shrank. Although, because the urban forest was somewhat diverse, these shrinking habitats did not negatively impact all species in the same way, and the urban forest canopy cover was maintained at 30 percent (USEPA, 2013a; USEPA, 2013b; Dukes, 2000). While the canopy cover may not have significantly shrunk, the percentage of trees that were in a critical/dying condition versus a good/fair condition increased drastically without proactive government sponsored maintenance. Ivy managed to become a community issue thanks to hundreds of public meetings on the topic, and government incentives encouraging neighborhoods to work together to take care of their shared urban forest (Solaripedia, 2011; City of Seattle, 2013a, 66). These efforts were not fully successful because they were not well coordinated, and did not focus on other important issues such as planting native evergreen trees in private yards. While ivy was able to take hold in Seattle's urban forest, there were still several positive consequences of community involvement, such as social bonding that worked to increase community resilience.

While the city was aware that the ratio of deciduous to evergreen trees was not on target all the way back in 2015 (City of Seattle, 2013a, 39), and that evergreen trees were suffering from climate change at higher rates than deciduous trees and invasive species (Way and Oren, 2010, 669), they did not take concrete steps to remedy the situation. Further, while there was a strong focus on reforestation within and surrounding the city (Bjornaes, 2015, 4), this was somewhat stymied by the fact that the majority of the guidelines presented in the UFSP were voluntary (City of Seattle, 2013a, 70). As such, when there was a conflict between the urban forest and the economy, the economy typically won in Seattle despite the environmental leanings of the populous and the goals of the UFSP (de Place, 2015). The UFSP evolved over the years to include more regulated attributes, but these were still few and far between by 2100. Also, without a strong emphasis on science, the UFSP did not take into account the natural reaction of species to climate change, and many residents still took the adaptation benefits that the urban forest provided for granted. With minor climate change impacts, the city was lulled into a sense of complacency about climate change.

Resilience and climate change did not stay hot topics because they had been "solved." What many in Seattle overlooked was the international effort to mitigate climate change that was behind the minimal impacts felt in Seattle. While the urban forest was still flourishing in 2100, and technological advancements as well as minor behavioral changes allowed for reduced energy use in the city, the full range of adaptation benefits of urban forests were not achieved because the city was a patchwork of forests maintained through reactive methodologies rather than a connected network of proactively maintained forests. The urban forest's evergreen species were decreasing faster than deciduous, and the coverage of harmful invasive species was increasing. The attitude of Seattleites was also indicative of those living in other cities and countries that believed the worst of climate change was behind them. As vigilance continued to be lost on a global scale in 2100, climate change impacts began to slowly grow.

Scenario B is the "Business-as-Usual" future, and is explained by major climate change impacts (RCP 8.5) coupled with Seattle's existing UFSP in 2015. From 2015 to 2100 the focus of Seattle was on economic growth at all costs. Therefore when the economy came up against the environment in any capacity, the economy was always given priority. The tradeoff of this decision was an urban forest that was given every opportunity to fail. This attitude was not unique to Seattle, and as a result, climate change mitigation policies were never created on a local, regional, or global scale. Seattle this one step further, and refused to see the relevance of adaptation even as major climate change impacts changed the landscape of the city.

Overall, the Growth Management Act (GMA) and other land use laws were only of note when developers were forced to follow them. The city became one defined by ad hoc variances that allowed for rapid development without a corresponding increase in the urban forest, or technological advances. Developers, for instance, were allowed to ignore the tree replacement ratios in Seattle's code during new construction, decreasing shade and increasing energy consumption throughout the city. Officially, the variance in the tree replacement ratio required developers to put funds into an urban forest trust that could be used to pay for maintenance and growth of existing parks in other parts of town. This urban forest trust functioned similar to wetland mitigation banking, and had many of the same issues (Zedler, 1996, 33). As the more wealthy neighborhoods had the resources to advocate for these funds, the urban forests within those areas benefited most from the trust fund. The fund was also used to plant trees on the outskirts of town where the land was not as economically viable or expensive as within the city core. These activities created an odd, disconnected patchwork of urban forests throughout the Seattle. The UFSP allowed this type of behavior because it never focused on locational diversity or equity (City of Seattle, 2013a, 11, 67, and 73).

With an emphasis on voluntary action in the UFSP, developers were able to disregard urban forest objectives (City of Seattle, 2013a, 70). Further, private landowners were never forced or incentivized to attend educational seminars or trainings that discussed proper species and planting guidelines. Community groups also never organized ivy eradication parties and instead preferred to remain independent of each other. As a result, backyards became increasingly deciduous and monoculture as ivy was allowed to creep in largely unfettered (USEPA, 2013a; City of Seattle, 2013a, 42). Society also became uninterested in the urban forest and, for the most part, each other. As the public became less attentive to the urban forest, most of the stakeholders involved in the implementation of the UFSP began to fight among themselves for dwindling funding and public attention. With this infighting, there was no time to create a monitoring plan to track successes and failures.

With deteriorating funding, the City of Seattle also did not attempt to inventory private lands or parks, although they still committed to conduct inventories of street trees every 10 years as indicated in the UFSP. Consequently, Seattle did not create a full asset management system for their urban forest resources. Maintenance, where done, was completely reactionary, and this had negative impacts on the health and longevity of the vegetation within the urban forest. Without proactive maintenance, the expected life of each species decreased, and each needed replacement at higher rates than expected (Thomson, 2013, 6).

Reactive maintenance and the deteriorating health of the urban forest also negatively affected the adaptive capacity of the urban forest to help the city survive major climate change impacts. As temperature and CO_2 increased, the growth of deciduous species in Seattle as well as harmful invasive species increased while the evergreen population decreased (USEPA, 2013a; City of Seattle, 2013a, 42). Many evergreen trees, such as the Douglas Fir and Ponderosa Pine are water limited, not energy limited. So as temperatures increased, and the moisture in the soil decreased, the ability of evergreens to survive drastically decreased (Albright and Peterson, 2013, 2120). This reduced Seattle's ability to adapt to climate change because deciduous trees lose their leaves in the winter and therefore provide less shade, wind diversion, water storage, and carbon sequestration than their evergreen counterparts. Further, as time progressed and temperatures increased by 8°F above historic levels, consecutive dry days increased by 30 percent, and precipitation levels increased on average by 20 percent, the city became inhospitable for even deciduous species. This was because “Although many trees are resilient to some degree of drought, increases in temperature…make future droughts more damaging than those experienced in the past. In addition, drought increases wildfire risk, since dry trees and shrubs provide fuel to fires. Drought also reduces trees' ability to produce sap, which protects them from destructive insects such as pine beetles” (USEPA, 2013a).

The massive fluctuations in precipitation and increases in temperature and GHGs that Seattle experienced, coupled with the spread of invasive species, wildfire, and pests, reduced the total number of species that survived within the urban forest, as well as the total variety of species in Seattle (USEPA, 2013a; Nowak et al., 2010, 13). Urban forests in the best of situations have little capacity to migrate with changing habitats without the aid of humans. As Seattle, and the surrounding cities, did not consider the health of the urban forest, its condition quickly worsened (Bartlein et al., 1997, 782; IPCC, 2014a, 15). This provided an opening for invasive species like ivy to take control of the urban forest areas that remained. The ivy was able to successfully kill off the remaining deciduous and evergreen trees (IPCC, 2014a, 13; Walsh and Wuebbles, 2014, 33). While deciduous trees may provide less adaptive capacity than evergreen trees, they still provide more than nothing. As the city became more barren, the major impacts of climate change became more evident and serious (American Forests, 2015a; The Forest Foundation, 2015, B4; Albright and Peterson, 2013, 2120; USEPA, 2013a).

Heat was “the No.1 weather-related killer in the U.S.” in 2015, and with an 8°F temperature increase from historic levels in 2100, the death toll in Seattle, especially among those most disadvantaged, rose exponentially (Climate Central, 2014). The UHI effect increased, and warmer days and nights that could not cool down to provide residents any relief resulted. Without respite from the heat, especially when the temperatures reached and stayed above normal tolerance levels of around 90°F, residents became more vulnerable to heat-related health problems (Kalkstein, 2013, 5). Scientists claim that there is a statistically significant relationship between oppressive air masses, which are more humid and hot or dry and hot than average, and an increased incidence of mortality from cardiac arrests and strokes. According to one study that used 2012 NOAA data, the City of Seattle already experienced these types of oppressive air masses 6 percent of the time during the summer months of June through August in 2012. During drier and hotter air masses than average in the same year, Seattle experienced an increase in the mortality rate by 8 percent, or approximately 3.7 deaths. Alternatively, during moister and hotter oppressive air masses in 2012, the mortality rate increased by 10 percent, or 4.7 deaths above the average (Kalkstein, 2013, 8). As summers were much hotter and drier in 2100 than 2012 rates, these oppressive air masses were experienced at higher percentages, and mortality rates increased accordingly (Mote and Snover, 2014, 33 and 21).

Seattle's UFSP attempted to protect the urban forest with policy goals, but without a proactive maintenance approach, it could only put out the most obvious metaphorical and literal fires. The problem was not resources in general, as the economy in Seattle was booming, the problem was simply the priorities of the city. The tradeoff decisions that city officials and the public made did not benefit the urban forest. A secondary, but no less serious problem for the city and the urban forest, was that the economy was not booming for everybody equally. Those able to find work still lived in inhospitable neighborhoods without the benefits of urban forests to keep energy bills low, air quality high, and provide opportunities for mental restoration. This had further ramifications for human health as those most disadvantaged economically were also feeling more of the major effects to climate change.

Despite this divide and the 8°F increase in temperatures the city experienced, there was still a deep faith in technology to save the day. Although with the declining focus on information services in the city and globally, the city's capacity to deliver on such dreams was waning. Without a strong focus on technology or curbing growth, the industries that did exist in Seattle emitted millions of tons of GHGs into the atmosphere, and worked to further increase the microclimate of the city (Bjornaes, 2015, 4). The increased air pollution and temperatures that led to the decreased urban forest canopy coverage, resulted in enormous energy use in the city to both cool and heat buildings to bearable levels (Bjornaes, 2015, 4; Nowak et al., 2010, 13). With the increased demand for energy, more fossil fuels were mined globally and emitted both locally and worldwide. These activities created an adaptive feedback loop of increasing reliance on fossil fuels that tripled CO_2 emissions by 2100 (Bjornaes, 2015, 4). There were also rapid increases in other GHGs such as methane as more land surrounding Seattle was razed as agricultural lands in an attempt to feed Seattle's growing population.

On a global scale, several important ecosystem services were lost due to this adaptive feedback loop, such as water filtration from trees, which forced the cost of water treatment, and thus water, to rise steeply. As flood and drought cycles continued to rise in Seattle, the residents believed that more structural controls without corresponding infrastructure upkeep could help keep functionality in place. Not only were these beliefs scientifically unfounded, they were also too little, too late. The global society ignored mitigation opportunities for 85 years, and Seattle lost the ability to adapt to climate change somewhere along the way due to its focus on the economy. The local system was on the brink of collapse in 2100.

Scenario C is the "Urban Island Oasis" defined by major climate change impacts (RCP 8.5) interacting with an enduring urban forest plan (Plan). The residents and City Council of Seattle saw the writing on the wall when temperatures reached 2°F above historic levels in the 2020s (Climate Impacts Group, 2015), and implemented an enduring Plan in result. Unfortunately, this foresight did not translate into the creation of overall stringent climate change policies (Bjornaes, 2015, 5). Consequently, the urban forest was given every opportunity to flourish within the city borders, while climate change impacts continued to rage within and around the city with a lack of local or global mitigation efforts. Without the urban forest and Seattle's proactive management of it, life in Seattle would have been much worse. For instance, even with major climate change impacts hitting the region and the city, Seattle avoided heightened heat related mortality rates because of the increased percentage of shade and microclimate moderating attributes of the dense urban forest (McPherson et al., 2002, 5; Donovan and Butbry, 2009, 663; Arnold, 122; Berland and Manson, 2013, 750; Simpson, 2002, 1067).

The primary focus of the enduring Plan and the city in general was not to mitigate climate change. The emphasis was to adapt to the major climate change impacts that many felt were inevitable. This tradeoff was practical in the city's opinion, as the rest of the state, country, and world had not taken such an enduring stance on their urban forests or climate change. The majority of the world had chosen not to curb their GHG emissions throughout the 85 year period. Instead, they focused on growing the economy at the cost of the environment and society

(Bjornaes, 2014, 5). Many in Seattle therefore believed that the actions of their one city could not make a positive dent on their regional climate. Instead of fighting for reductions in GHG emissions, the city chose to follow the lead of the rest of the world, and the use of fossil fuels in the city actually increased during this time. As a result the economy grew dependent on energy intensive activities. With this growing dependence, the emphasis on technological advancements and innovation, for anything but the development of the fossil fuel industry, slipped (Bjornaes, 2015, 5). Energy intensive industries were both accepted and encouraged as Seattle tried to poach major employers from other cities. In doing so, the city forced the technology sector to switch gears in order to survive. Coal and natural gas were the primary sources of energy, and not a lot of stock was placed in renewable technologies.

Regardless of the declining emphasis on green technologies, the urban forest was still able to reduce the brunt of the major climate change impacts felt in Seattle. The impacts were reduced thanks to the ability of urban forests to shade buildings, sequester and store carbon, reduce surface temperatures, and slow and store stormwater (McPherson et al., 2002, 5; Donovan and Butbry, 2009, 663; Arnold, 122; Berland and Manson, 2013, 750; Simpson, 2002, 1067). Although as temperatures rose from the global burning of fossil fuels, the ability of the urban forest to withstand the strong impacts of climate change and allow for the functional survival of the city, began to decline (American Forests, 2015a; The Forest Foundation, 2015, B4; Albright and Peterson, 2013, 2120; USEPA, 2013a; Nowak et al., 2010, 13). Even with the declining capacity of the urban forest to provide benefits, the emphasis on maintaining the urban forest's diversity and density from the enduring Plan and asset management system, ensured some longevity. Seattle was therefore like an urban island oasis within a sea of struggling cities. As a result Seattle became a destination city, and the population sored.

With the burgeoning population, the city's services were stretched thin despite active asset management programs for green and man-made infrastructure (City of San Francisco [CA], 2014, 20; Tubilewicz, 2006, 10; Cromwell, 2007; Bougheas et al., 2000, 516). The city still believed in the power of the urban forest, although as temperatures rose, and the economic wealth of the city decreased as the growth in population outstripped jobs, the ability of the city to maintain and/or replant the forest slowly decreased. The actual land available to the urban forest also decreased with the expansion of impervious surfaces. This horizontal expansion was both official, through high-rise development at the urban fringe, and unofficial, as residents cut down trees into order to make space for new dwelling units. With land quickly becoming a scare resource, Seattleites and city officials did not choose to prioritize the urban forest.

Less land was also available to the urban forest at the periphery of Seattle because of the increased emphasis on agriculture. The local government attempted to encourage and incentivize more intensive use of existing agricultural lands outside of the city. This was done so that as little conversion of forested land to agricultural land could take place as possible (Bjornaes, 2015, 4). Monetary incentives for this took priority over funding for other services that were not seen as essential, such as mental health facilities and welfare programs like food stamps. The agricultural incentive program backfired as it effectively put more people out on the streets. Further, the efforts did not produce the necessary amount of food to feed the burgeoning population. As farmers began more intensive use of their agricultural lands, they no longer let fields stay fallow, therefore the quality of the soil and the crop yields decreased. Nutrients were sapped from the soil, soils eroded, and sedimentation increased the turbidity of the rivers (Tubilewicz, 2006 9). As food shortages became the norm, residents converted their own backyards and other public spaces - that previously housed large diameter, old trees - into pea patches. This sort of vegetation still benefited the city and the urban forest, although as the crops were harvested and took nutrients from the soil, these types of activities ultimately worked to reduce the carbon storage potential of the city (FAO, 2015).

The enduring Plan included a monitoring plan and every annual update of the Plan utilized the best available science. Seattle was therefore aware of their urban forest related weaknesses, and where to focus the greatest effort (Outen [Baltimore County, MD], 2009, 44). Accordingly, they took steps to address the issues with more concerted efforts to plant evergreen trees within private and public lands. They also provided natural fertilizers to residents to help replenish the subsequent loss of nutrients that came with heightened levels of CO_2 in the atmosphere (City of Portland, Oregon, 2015b; City of Austin, Texas, 2014, 7; Bassuk [Ithaca, NY], 2009, 75). Although as temperatures increased further, it became more difficult to colonize land in the core and outskirts of the city for urban forest afforestation. The city's urban forest was actually slowly dying from the outside in. Seattle was aware of this fact and attempted to form deals with neighboring cities and towns to no avail. Many did not understand how connectivity of the urban forest, as well as social connectivity, could help on this regional scale when the global system was in such shambles. The city increased pilot programs in an attempt to increase the adaptive capacity of the urban forest that remained, but without the support of surrounding cities and regions, the price efficiencies of such actions did not increase with wider adoption.

While those outside of the city did not see the benefits of the urban forest, residents in Seattle understood its need for the most part. Each neighborhood unit had been given agency over the urban forest within their area. There were also different public agencies that had domain over the different types of urban forests in each area. This put a lot of cooks in the kitchen, but there was still one guiding voice and policy objectives coming from the enduring Plan that the government agencies and residents rallied behind. As a result, the urban forest helped to stave off the worst of the major climate change impacts in Seattle. Although as temperatures continued to increase despite these local efforts, and many evergreen species began to die, the ability of the urban forest to achieve these benefits diminished. As the population of Seattle mushroomed, the need to expand and feed this rising total increased to near unbearable levels. Residents began to see the urban forest as in direct odds with needed expansion, and began to protest the strict adherence to the enduring Plan and the GMA. As a result, many within the City Council and Governor's Office began to rethink the strictness of the Plan and the GMA. As the city began to lose more of its ability to adapt to, and mitigate against, climate change, a regime shift became more imminent.

Finally, within **Scenario D**, Seattle is an internally and externally "Connected System," composed of minor climate change impacts (RCP 4.5) intermingling with an enduring Plan. Seattle's urban forest became a connected, integrated piece of the urban puzzle. The evolving Plan continually made use of the best available science to become more scientifically relevant with each iteration. With every year that passed, the city identified more locations and policies within the urban forest or enduring Plan that could use improvements and carefully weighed the tradeoffs of each decision (City of Portland, Oregon, 2015b; City of Austin, Texas, 2014, 7; Bassuk [Ithaca, NY], 2009, 75).

Also with each year that passed the city gained more scientific understanding, and the technologies to better address identified issues. More specifically, the urban forest monitoring system created awareness of the weak spots where the city should focus the greatest effort to receive the greatest benefit (Outen [Baltimore County, MD], 2009, 44). Annual reports on the state of the urban forest were also created and shared with the public and surrounding towns through social media, mass media, and public meetings to allow for greater understanding among policy makers and residents (City of Austin, Texas, 2014, 63; City of Portland, Oregon, 2015b). This dispersion of information also encouraged private-public partnerships to rectify any deficiencies in the urban forest on private land. These annual reports were also able to show surrounding cities the benefits of urban forests and advertise Seattle's successes. This empirical evidence worked to convince many surrounding cities to create their own enduring plans. With each newly converted city, the mitigative multiplier of Seattle's actions grew.

Further, a complete asset management system allowed for proactive maintenance that successfully allowed the age of the urban forest to expand by allowing trees to live for their entire expected lifespans (City of San Francisco [CA], 2014, 20; City of Portland, Oregon, 2015a). This variety of age was coupled with policies to encourage species and locational diversity that created an urban forest that was primarily evergreen and ubiquitous throughout the city. There were a lot of moving parts working to maintain the healthy urban forest within Seattle because maintenance plans were created for each type of urban forest, as well as the

different land uses the urban forests occupied (City of Portland, Oregon, 2015a). The ability to take into account different contexts allowed Seattle to achieve heightened success, because a one size fits all plan can only work to a point. To ensure the best strategies were applied to each unique situation, there were finer grain plans under the umbrella of the enduring Plan.
Seattle also took a proactive approach to climate change in general, and chose to implement, fund, and enforce a number of stringent policies to allow for maximum success (City of Austin, Texas, 2014, 77-78; Lewis [Olympia, WA], 2009, 64; Bjornaes, 2015, 4). The goal was to both locally adapt to climate change, and contribute to global mitigation efforts. As a result more than just the canopy cover of the urban forest was considered. The emphasis on lifecycle tree care also allowed dying trees to be repurposed as furniture or art. In this way the community was able to stay involved in the urban forest, jobs were created, and the vegetation's carbon stores were not released into the atmosphere. The community took a leading role in both sponsoring homegrown artists, and creating installation space for the pieces. Seattle also constructed and opened city run lumber mills for this reclaimed wood that brought historically significant jobs back to the region (City of San Francisco [CA], 2014, 20). Seattle's first industry was timber, and through technological improvements, these new, small-scale mills were run on renewable energy sources and no longer emitted harmful pollutants (Taylor, 1994, 15).

Along with a mix of species in the urban forest, there was also a mixture of industries in Seattle that did not rely upon fossil fuels. In fact, the city government called upon Seattle's technology firms in 2020 to create carbon neutral technologies and energy sources ahead of the original 2050 goal within the 2015 Climate Action Plan (Bjornaes, 2015, 5; City of Seattle, 2013b, 3). To achieve minimal climate change impacts Seattle became climate negative in 2025 and this was achieved in equal parts through the use of urban and natural forest carbon sequestration, technological advancements, and regional cooperation (Bjornaes, 2015, 4).

Despite these advancements, Seattle was not able to escape the impacts of climate change. Urban forests were still called upon to help adapt to rising temperatures and changes in precipitation through the provision of shade, flood reduction capacity, water storage, and contaminant filtration. As a result, the residents truly considered themselves a part of a hybrid system where the natural and the urban system were connected (City of Portland, Oregon, 2015a; City of San Francisco [CA], 2014, 16; City of Austin, Texas, 2014; Monear [Minneapolis, MN], 2009; Lewis, [Olympia, WA] 2009, 65). Despite the benefits provided by this connectivity, there were also some negative tradeoffs brought on by this decision. As the urban forest became more integrated and dense, the likelihood that an urban forest fire would catch surrounding built infrastructure increased. Further, the possibility of a single disturbance – such as a wildfire or a pest infestation – affecting the entire system also increased. One massive fire in 2040 raged through the city and displayed this fact plainly to policy makers and residents. The city learned from its mistakes, and in the aftermath of the fire, they rebuilt smarter and stronger. Good management was also called upon to counteract the potential risks by breaking the urban forest into different parts, with different maintenance schedules that could put up obstacles from fires spreading throughout the city again (City of San Francisco [CA], 2014, 20; City of Portland, Oregon, 2015a).

Populations increased due to the opportunity for jobs and the comparatively mild impacts of climate change in Seattle. Although with strong urban planning and the use of technology, this growth mostly occurred vertically, with minimal need for horizontal expansion. In this technological era, agricultural techniques also grew more efficient and sustainable, and as a result agricultural lands were not forced to expand to accommodate the growing populations. There was a large emphasis placed on connectivity in the city that stemmed from an urban forest chapter in the Comprehensive Plan of Seattle and surrounding cities. The city also understood that connectivity alone was not enough to prevent major climate change impacts, and focused on technological advances to help mitigate and further adapt to climate change.

3.2 Regime Shifts

The scenario logics described above are the first step in identifying plausible futures for Seattle, and understanding the role that urban forests can play in supporting resilience in the face of climate change. These narratives are significant because of what they could mean in terms of regime shifts within Seattle's urban forest, and the city in general. Regime shifts occur when the resilience of a system degrades to a point where functionality is lost (see **Chapter 2**). This loss can be gradual and caused by an internal process such as soils gradually losing nutrients, or be the result of an abrupt and powerful shock to the system from the outside, such as a flash flood or wildfire. Whatever the cause, regime shifts tend to be abrupt, large, and long-lasting changes that have an impact on human society, and bring about different rules and feedback loops (Biggs et al., 2009). Similar to other systems that provide functionality for the City of Seattle, the urban forest maintains its existing state through natural feedback loops. The internal variables that play a role in maintaining or shifting these feedback loops, and alternative states that could result from any alterations to the system, are discussed below.

3.2.1 Defining Regime Shifts in Accordance with Slow and Fast Variables

Drivers are able to alter the feedback loops of a system by changing the internal relationships of the system that are made up of slow and fast variables. As these feedback loops change, so too can the resilience of a system, increasing the chance that a system is led over some threshold that indicates a regime shift (Walker et al., 2012, 30). As the name implies, slow variables respond gradually to the long-term changes in a system. Without the aid of fast variables, slow variables can eventually bring about a regime shift by slowly eroding resilience until a breaking point is reached. Just like a meandering river can eventually carve a new path through the landscape, so too can slow variables work to alter the overall system. In combination with a fast variable or an external shock, however, the system can more abruptly and quickly experience a regime shift (Holling, 1973, 9). For instance, if a flash flood were to strike the meandering river, the new system could be carved out at a much faster pace with the influx of water and energy (Scheffer, 2001, 591). A fast variable can have a more direct and visible impact on a system than a slow variable (Walker et al., 2012, 30). In this example, the fast variable may be the flash flood, or the parameters that made the flash flood possible, such as deforestation, the increase in impervious surfaces, or the altering precipitation patterns.

There are hundreds of internal variables that could lead the urban forest within Seattle toward a regime shift. This thesis has chosen to focus on Washington State's GMA as a slow variable, and the development of impervious surfaces as a fast variable. Further, there is no one stable state that the urban forest within Seattle could reside within based on these variables, because the system is composed of multiple-equilibria. This thesis has selected two of the many plausible alternative states. It is argued here that the selected internal variables and external drivers could interact in such a way within the four divergent futures to result in a primarily evergreen, native, dense, and diverse urban forest, or a primarily deciduous, non-native, sparse, and mono-crop urban forest. Regime shifts from evergreen to deciduous states can also take place on a much longer, more geologic time scale influenced primarily by succession and other natural variables. Although within this thesis the decision has been made to focus on the human scale of development, as evidenced by the two selected variables.

3.2.2 Important and Uncertain Slow and Fast Variables

The GMA is a Washington State law that was originally passed in 1990 as a result of public outcry and frustration that began in 1964 over King County's rapid growth (Oldham, 2006). While its level of enforcement can oscillate depending on regional governance, these changes represent small movements that do not necessarily affect the overall law. Further, amendments can and do happen on a near yearly basis, but these focus on small portions of the law (Oldham, 2006). The GMA is important because it can have a large impact on how a county or urban area can develop over time. It has been called "the single most important legislation in terms of land use and planning for local governments" (CTED, 2015). The law itself requires the most populated, or fastest growing, counties within the State to concentrate growth within certain boundaries – urban growth areas – based on future population and economic predictions. Each county must also adopt comprehensive plans that are the blueprints for future growth. Ultimately, the law hopes to protect natural resources by preventing "Uncoordinated and unplanned growth, [that] together with a lack of common goals expressing the public's interest in the conservation and the wise use of our lands, pose a threat to the environment, sustainable economic development, and the health, safety, and high quality of life enjoyed by residents of this state" (Washington State Legislature, 2015b).

The GMA is also important because of its ability to bring down serious sanctions on cities or counties that are not in compliance. Namely, the governor can "withhold the portion of revenues to which the county or city is entitled under one or more of the following: The motor vehicle fuel tax…the transportation improvement account…the rural arterial trust account…the sales and use tax…the liquor profit tax…and the liquor excise tax…or...temporarily rescind the county or city's authority to collect the real…until the governor files a notice rescinding the notice of noncompliance" (Washington State Legislature, 2015c). Cities and counties therefore have a strong incentive to comply with the GMA.

The GMA is also uncertain because as written, it gives local officials leeway to interpret the law and implement it based on those interpretations (Pivo, 1993, 1155). Therefore, if public opinion was to shift and there was enough pressure from powerful economic agencies, the local government could acquiesce and reduce their enforcement of the law or amend the law's wording. This is still considered a slow variable because while change is possible, the GMA is still a political document, and as with all political ventures, nothing happens overnight. Public opinion can swing like a pendulum, but to go through the political process that would be necessary for real and lasting change could take several years, if not decades (Porter, 2005, 3). Seattle is currently the fastest growing city of the "50 most-populous U.S cities" (Balk, 2014). This translates to a rapidly expanding population and job market, as well as rampant construction in the urban core and periphery. Development of impervious surfaces is the selected fast variable because of the speed at which this growth is occurring,[4] and the direct impact the expansion of impervious surfaces can have on Seattle's urban forest. As the city expands, impervious surfaces, such as roads, sidewalks, and buildings can stand where urban forests used to exist, or could exist in the future (Barnes et al., 2002, 5; Nowak et al., 2010, 13).

While much of Seattle's recent growth has taken place in the urban core because of the demands of a few successful businesses such as Amazon, the majority of Seattle's growth between 2000 and 2010 occurred in the outer suburbs, and through natural lands (Cox, 2011). This urban sprawl increased the amount of impervious surfaces in the region, and reduced opportunity spaces for urban forests (Nowak et al., 2010, 13). The Tree Protection Code in Seattle currently protects some trees during development – namely, those within environmentally critical areas, those larger than six inches in diameter in undeveloped land, or exceptional trees on developed land. Although if the protection of trees prevents an individual or developer from effectively using their property, then the rules can be relaxed by decision makers (Seattle.gov, 2015d). The UFSP also has a goal of replacing every cut tree with two new trees, but this is not currently written into code, legally enforceable, or provided sufficient funding to be successful (City of Seattle, 2013a, 44). There is a tension between impervious surfaces and the urban forest as opportunity areas for each land cover often overlap. This tension makes the development of impervious surfaces an important fast variable.

The development of impervious surfaces is also uncertain because a lot of Seattle's current growth is highly dependent on a few successful businesses, and the whims of the public. With the success of these businesses, "the city added nearly 15,000 new jobs between 2012 and 2013"

[4] From 2012 to 2013 "Seattle grew by 2.8 percent" (Balk, 2014).

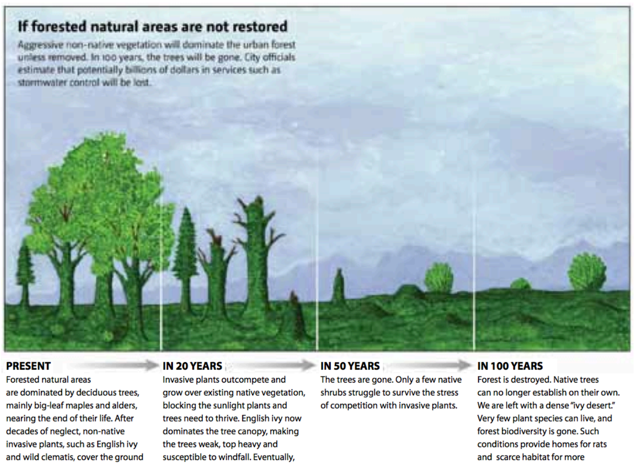
(Balk, 2014). These new jobs pull individuals and families to the city, and also bring wealth and economic power to an increasingly dense Seattle. Although this also means that if some or all of the businesses that are generating this growth, such as Amazon, Costco, Microsoft, or Nordstrom decide to leave Seattle, the city could be in financial trouble. If this were to happen, the demand for expansion could stall and the need for more impervious surfaces could decrease. This may be a positive outcome for the urban forest, or perhaps without these major corporations in the city the amount of money available to invest in climate change adaptation or mitigation efforts could also decrease. Growth is also dependent on public policy and preferences that are notoriously fickle. In years past, young families and retirees have moved to the suburbs within low-density, single family homes. This required the creation of more roads out to previously forested or agricultural lands. Recently the tides of public preference have begun to change, and many young families and individuals are choosing to live in denser neighborhoods and multi-family residential units (Florida, 2015). If this trend were to continue, the need for horizontal expansion could slow. The uncertainty around this fast variable is also dependent on public policy in Seattle, of which the GMA plays a large role.

The selected slow and fast variables have independent as well as integrated feedback loops. The development of impervious surfaces could create a feedback loop with itself as the construction of more impervious surfaces necessitates the construction of more impervious surfaces to supply appropriate infrastructure services to those newly developed areas. This continued expansion could cause the city's borders to expand further in all directions (Cox, 2010). The GMA is also a self adaptive variable; if, for instance, the GMA is not strictly enforced, more variances that allow for more growth outside of the urban growth boundaries could occur, pushing the need for more variances in the future. This could result in policy makers believing that the GMA is not effective, and enforcing the law even less. A strong enforcement of the GMA could also limit the boundary of Seattle's urban area, and by association limit the amount of impervious surfaces. On the other hand, if there is pressure to reduce the strictness of the urban growth area boundaries in King County, the Seattle City Council and the state could lax their enforcement of the GMA, and urbanization as well as impervious surfaces could spread.

3.2.3 Alternative States

Seattle's urban forest is approximately 31 percent evergreen and 69 percent deciduous, although this ratio varies by land use. In parks, for instance, there are 82 percent deciduous plantings, and downtown there are 100 percent deciduous plantings. The three most commonly found trees in Seattle's urban forest – red alder, the bigleaf maple, and the beaked hazelnut – are deciduous (Ciecko et al., 2012, 1). Before human intervention in the region, the northwest forest had closer to the opposite ratio, with a majority of evergreen species including cedars, pines, spruces, hemlock, and fir present throughout Seattle, and deciduous species primarily relegated to disturbed areas or those with steep slopes (City of Seattle, 2013a, 39). To experience this type of transition, the city must have undergone a regime shift of some sort during development. Several in the scientific and policy-making community would like to return to a more evergreen dense area. The rationale behind this desire is that evergreen species can provide more benefits than their deciduous relatives because of their ability to, for instance, retain their canopy year round and provide more shade year round (City of Seattle, 2013a, 13).

The shift from primarily evergreen to majority deciduous was most likely caused by several factors such as private homeowners' personal preferences, and short-term urban forest management decisions like planting deciduous trees along streets for aesthetic beauty. The evergreen population is also threatened by invasive species threats such as English ivy, English laurel, English holly, and Himalayan blackberry. Without active management to keep these invasive species at bay, many predict they could overtake both evergreen and deciduous tree populations to a point where the urban forest is made up primarily of ivy (City of Seattle, 2013a, 41). (See **Figures 3-5** and **3-6**.) The alternative states discussed in this thesis include a primarily evergreen, native, dense, and diverse urban forest (evergreen), similar to a pre-urbanized Seattle, and a primarily deciduous, non-native, sparse, mono-crop urban forest (deciduous).



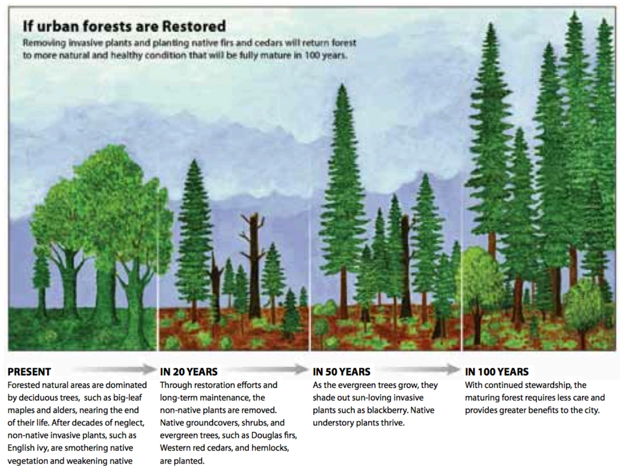


Figure 3-5 (Left) and Figure 3-6 (Right). Provides artist visualizations of what could happen without and with active urban forest management in Seattle (City of Seattle, 2013a, 42).

The two alternative states described here do not necessarily signify resilience or lack thereof, and they do not represent end states on opposite ends of some spectrum. They are simply two feasible future states for Seattle in 2100 based on how the variables and drivers within this scenario planning process could interact. Both states can be resilient, and depending on a normative understanding of what is desirable, this can be seen as a positive or negative. It is assumed that Seattle would prefer to reside within an evergreen state, based on the preferences within the UFSP.

3.3 Scenario Hypotheses

3.3.1 How Scenarios Influence Slow and Fast Variables

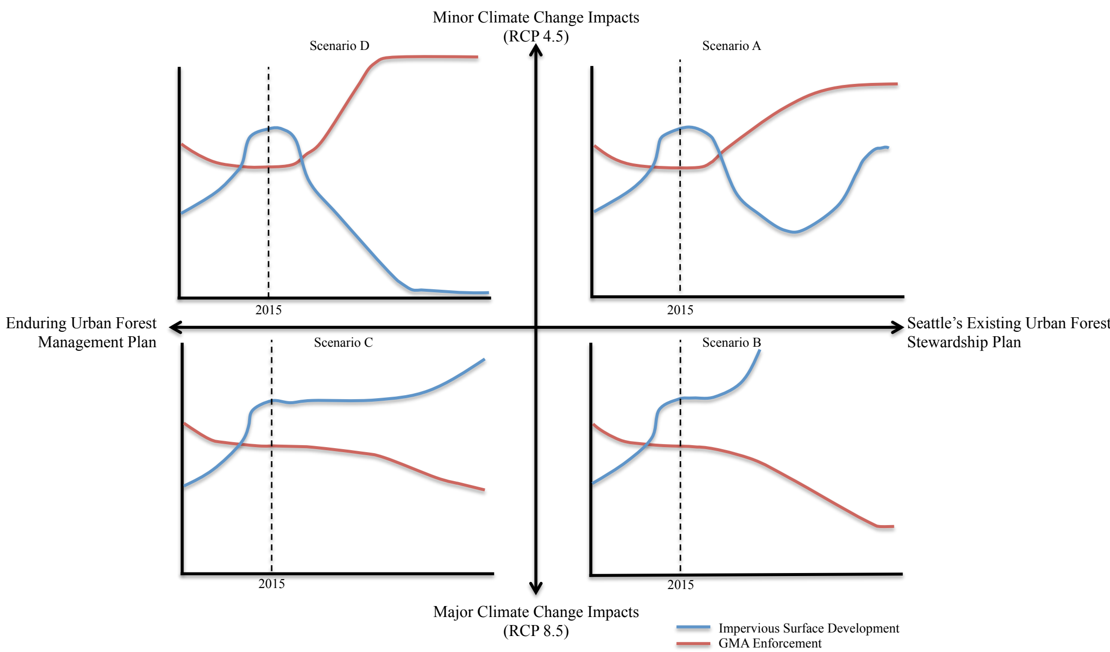


Figure 3-7. Slow and fast variable movements within each scenario.

The above **Figure 3-7** provides a visual representation of how the selected important and uncertain internal variables could progress through time in each scenario. The following text provides a narrative description of this visual representation.

Scenario A - Impervious surfaces within the city decreased as the canopy cover of the urban forest increased, and the use and efficiency of technologies such as pervious pavement, green roofs, and Low Impact Development (LID) increased. The success of the technology sector and the minor climate change impacts felt in the city together pulled millions of people to the city

(Berger, 2014). While most of this population and infrastructure growth was accommodated by vertical expansion of the city and higher skyscrapers, a lot of the growth spilled out horizontally and began to look like urban sprawl. Horizontal growth worked to spread impervious surfaces at the periphery of the city, although pervious technologies were effectively utilized and the GMA was strictly enforced, so the growth of impervious surfaces was limited. To hold climate change impacts to a minimum, Seattle created and maintained stringent climate change policies (Bjornaes, 2015, 4). As the GMA was one of the most important land use policies in the state (CTED, 2015), its border was strictly enforced (**Figure 3-7**).

While there was plenty of space for the urban forest to flourish in the city, the mixture of species was still primarily deciduous in 2100. The UFSP did not provide implementable steps to increase the percentage of evergreen trees with varying ages and in a diversity of locations that would have brought about greater redundancy. Although the UFSP did focus on invasive species removal, and increased the canopy cover to 30 percent. As a result of these push and pull factors, the system oscillated within the deciduous alternative state, at times almost reaching a threshold into an evergreen state, and at other times becoming further entrenched within the deciduous state (**Figure 3-8**).

Scenario B - With business-as-usual, the enforcement of the GMA fell throughout the 85 years between 2015 and 2100. The strength and enforcement of the GMA decreased due to the belief of many in business – and therefore politics – that the GMA unfairly hindered the ability of the city to grow and become more economically successful. Nearly unfettered growth was allowed and almost encouraged in Seattle, therefore the development of impervious surfaces exponentially increased. Without the technology to replace impervious surfaces with pervious surfaces, or any strict limits placed on the urban growth boundary, the city sprawled and the need for roads expanded (**Figure 3-7**).

With diminished space available for the urban forest, and increasingly inhospitable temperatures from climate change, the system's state was firmly entrenched within the deciduous domain of attraction. To undergo a regime shift to an evergreen state would have required a lot of energy, money, and time that the city was not willing to put forward. With little to no focus on creating implementable steps to increase the redundancy of evergreen species, coupled with a shrinking urban forest due to ivy encroachment and major climate change impacts, there was little hope that the city would ever shift into an evergreen state (**Figure 3-8**).

Scenario C - As an island oasis with plenty of jobs (initially, and as compared to other cities in the U.S) in the technology and fossil fuel focused industries, Seattle became a magnet for population growth. Most of the initial growth was accommodated by vertical expansion, and did not require much development of impervious surfaces. The city incentivized and regulated vertical growth so that residents and infrastructure could stay within the beneficial influence of the island oasis's urban forest. Over time, vertical growth was not enough to accommodate the growing population, and some horizontal expansion took place (USGS, 2014). The city also rapidly lost purchasing power as more and more people flooded its borders without a sufficient number of jobs to keep everyone working with a steady income. As a result, shantytowns popped up around the periphery of the city, and unofficial cutting of the urban forest occurred to make room for these communities. Additionally, with less money collected in the form of taxes, the city had fewer funds to put towards welfare programs or the enforcement of government regulations. The enforcement of the GMA decreased over time, plateauing only briefly when vertical growth was still an option, and jobs were keeping pace with population (**Figure 3-7**).

There was a heavy focus on evergreen species, diversity, and the density of the urban forest for the right scientific reasons in Seattle. Therefore the system was within the evergreen state, although with increasing climate change impacts and more unofficial management of the system, the stability of the urban forest decreased over time. A regime shift into a deciduous state was imminent (**Figure 3-8**).

Scenario D - In this connected system, many technologies that were too expensive in 2015 became ubiquitous and cost effective by 2100 through mass adoption. Such technologies increased the amount of pervious surfaces within the city, and increased opportunity spaces for the urban forest to flourish. The need for impervious surfaces all but evaporated, even as the city expanded to fit the growing population and business sector. Within this connected future there was also a strong emphasis placed on the enforcement of climate change policies that included the GMA, in order to keep climate change impacts to a minimum (**Figure 3-7**).

With an enduring Plan that was fully endorsed and enforced, the city emphasized and implemented steps to create a more diverse and evergreen heavy urban forest. Further, the density of the forest increased along with connectivity. While stability within the evergreen alternative state could shift with a major disturbance such as a wildfire or pest outbreak, the system was within a deep domain of attraction (**Figure 3-8**).

3.3.2 Resilience Hypotheses

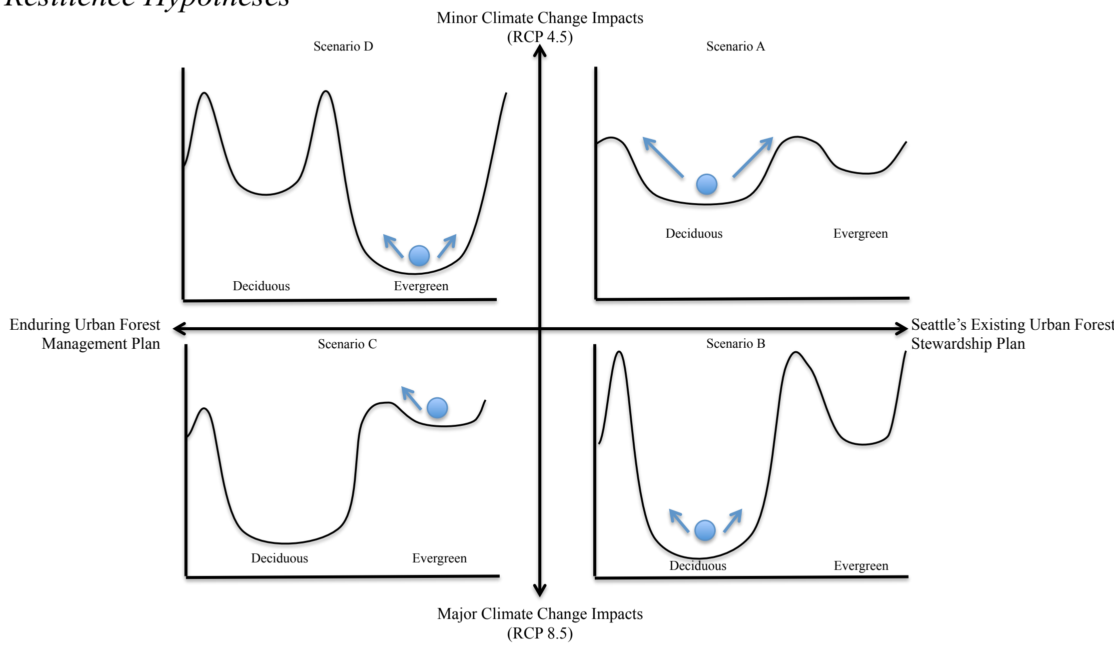


Figure 3-8. Potential resilience of each alternative state.

Figure 3-8 above illustrates the resilience hypotheses of the alternative states within each scenario based on scientific understanding, the scenario narratives, and variable hypotheses. The figure demonstrates the stability of each plausible future's system by indicating the amount and direction of movement, as well as the depth and width of each domain of attraction. Arrows in either direction indicate movement within the basin towards or away from a possible regime shift. The depth of each basin, and the height of each potential threshold, demonstrates the ease at which a regime shift could take place within each scenario.

It is hypothesized that Scenario A underwent a regime shift into a deciduous state at some point between 2015 and 2100. Also during this time, Scenario A experienced movements both towards and away from an evergreen state. Scenario B experienced a regime shift into a stable deciduous state. Scenario C resided within an evergreen state that was oscillating towards an imminent regime shift to a deciduous state. Finally, it is hypothesized that Scenario D was firmly entrenched in the evergreen state for the duration of the 85 years between 2015 and 2100. Although, with such uncertainty concerning the future of Seattle, these are simply educated hypotheses that could begin to be tested through mathematical models, or time.

3.3.3 Testing Hypotheses

The resilience hypotheses stated above can be tested by expanding the boundary conditions of land cover and climate change models using the four scenario narratives. Alberti et al. (2013a, 54) propose that "Scenarios are extremely powerful when combined with predictive modeling. An integrated model can help in three ways: 1) test hypothesized trajectories and interactions; 2) refine potential relationships and feedback among variables; and 3) assess potential impacts of hypothesized futures on ecosystem services and human wellbeing." Although this step is beyond the scope of this thesis, future work on this subject could utilize model predictions to further justify the presented ideas with quantitative mathematics. The goal of this thesis is not to predict the future, but to better prepare Seattle for plausible futures with the creation of a robust UFSP.

Chapter 4 – Resilience Assessment

4.0 Introduction

Chapter 3 generated plausible futures for the City of Seattle and its urban forest by imagining the interactions of the selected drivers and variables to rational end points in 2100. **Chapter 4** will examine the resilience of each scenario through the use of resilience indicators adapted from the Rockefeller Foundations' seven qualities of resilience. The indicators will shed light on the resilience of Seattle's urban forest within each scenario. As explained below, and in **Chapter 2**, this thesis considers the resilience of the urban forest to be an overall indicator of resilience against climate change within the City of Seattle. If the urban forest is resilient, it can better provide mitigation and adaptation to climate change, thereby helping the city retain functionality of essential infrastructure and services. The below indicators primarily focus on measuring attributes of local adaptation, although many also help measure the contribution that Seattle makes on a regional and global scale to mitigation.

4.1 Resilience Indicators

There are several key qualities that indicators of resilience should have in order to be effective. First, multiple indicators must be utilized because the use of just one will not have enough predictive power. Some are better than one in this instance because the concept of resilience is more complex than one indicator can represent. Using a variety of indicators in combination, that each speak to different aspects of urban resilience, will provide a more rounded measure. Next, to successfully use multiple indicators, each must be linked to the others and be relevant to the system in question. Currently, all the indicators used within this thesis describe attributes of a healthy and functional urban forest. Further, successful indicators should be sensitive to changes in the system, and most importantly, indictors must be measurable. As even the best indicators are useless if we cannot understand or measure their signs. The indicators used within this thesis are primarily qualitative to allow for a discussion to take place and uncertainty to be embraced. Their results, while not quantifiable, can none-the-less guide decision-makers in the creation of more robust management plans (Alberti, 2014).

The indicators utilized within this thesis are based upon the seven qualities of resilience defined in **Chapter 2** and tailored for the urban forest. Descriptions of what a resilient urban forest in Seattle could look like in 2100 according to each quality, form the basis for the specific indicators. Each of the seven qualities have two indicators; one is more spatial in nature, and measures increases or decreases in canopy cover for instance, and the other is more social, and attempts to measure concepts such as popular opinion or policy decisions. The indicators will be used to hypothesize the level of resilience within each of the four divergent futures.

- **Reflective** – An urban forest that is reflective has fluctuated in terms of canopy cover over time, although the total canopy cover has increased since 2015. It is important that the canopy cover increase in order for the city to receive more resilience generating benefits such as carbon sequestration to aid in regional efforts at mitigation, and shade production to support local adaptation strategies. Additionally, measuring canopy cover is the easiest way to identify the extent of the urban forest (Kenney et al., 2011, 109; Kollin and Schwab, 2009b, 120). While canopy cover is easier to measure than other urban forest parameters, it cannot be the only one considered when determining resilience as it cannot shed light on other important qualities such as redundancy or flexibility (Kenney et al., 2011, 109; Nowak et al., 2010, 7). In a reflective system, residents living near and within the urban forest also accept that change is inevitable and have not tied themselves to one image of urban forests with hard lines between the built and the natural. Based on this understanding, residents have also begun to plant trees in their yards to shade their homes and reduce their energy needs.

- *Spatial Indicator:* Examines the canopy cover percentage in the city. Has canopy cover decreased, fluctuated but generally stayed the same, or increased to at least 30 percent (the original goal of Seattle's UFSP) by 2100?
- *Social Indicator*: Examines residents' attitude towards the urban forest. Do residents try and keep the system static, make some attempts to increase the urban forest, or accept that the city is dynamic?

- **Robust** – A robust urban forest is highly connected to itself and the city with corridors leading from one patch to another. These connections include links between more natural areas and landscaped private gardens. The condition (health) of the urban forest is good or better, and has consistently increased in a robust system due to proactive management. This proactive management stems from a complete, and up to date asset management system. As mortality rates decrease, the longevity of the resource is ensured and the urban forest is allowed to sequester carbon, filter contaminants, and provide shade to its full potential (Kenny et al., 2011, 110). Connectivity is also crucial for animal and vegetative populations to flourish within less fragmented habitats. It also allows for the creation of longer recreational paths that increase opportunities to advance the mental and physical health of humans (Goddard et al. 2009, 90; Hansmann et al., 2007, 213; McPherson et al., 2002, 11). Finally, more green corridors running through the city also provide more opportunities for the urban forest to absorb stormwater (Dreistadt et al., 1990, 197; Akbari, 2002, S122; Phillips, 2014, 3). Urban forests in a robust system are just one of the many strategies contributing to regional mitigation and local adaptations to climate change. If urban forests were the only strategy, and failed, resilience would be even harder to achieve.

- *Spatial Indicator:* Examines connectivity of the urban forest and the presence of an asset management system. Has connectivity failed to increase and/or maintenance is only conducted on a reactive basis (Kenney et al., 2011, 114)? Connectivity has increased on a primarily ad hoc basis without a full maintenance schedule (Kenney et al., 2011, 114)? Or connectivity has increased and new trees are planted based on a scientifically established asset management system (Kenney et al., 2011, 115)?
- *Social Indicator*: Examines the number of climate change strategies in the city. Are urban forests the only strategy; are there several plans, but none have regulatory teeth; or is the urban forest one of many strategies to fight climate change, each with enough regulatory strength to impact the city?

- **Redundant** – The redundant urban forest has species, age, and locational diversity (Kenny et al., 2011, 110). Studies have shown that vegetated communities with high levels of diversity can "maintain [a] consistently high function…over time" (Allan et al., 2011, 17034). A redundant population also allows for "turnover between functionally complementary species, with different species needed for function in different years" (Allan et al., 2011, 17034). Additionally, diversity is essential for urban resilience as different species, ages, and locations of urban forests provide different benefits to different residents. Older trees may have a larger diameter and a denser canopy to provide more shade for a home, but a young tree planted in a neighborhood park may have the ability to create more social capital. Within a redundant system, residents and urban forest staff have also begun an invasive species removal program to allow more native species to flourish. It is important to remove invasive species, such as ivy, so that diversity can be maintained (Kenny et al., 2011, 111; Nowak et al., 2010, 13).

- *Spatial Indicator:* Examines the species, age, and locational diversity of the urban forest. Is the majority of the urban forest composed of a few (1 to 5) species of trees in primarily wealthy neighborhoods, most of which are non-native and young (Kenney et al., 2011, 114)? Does the urban forest have no one species that represents more than 20 percent of the entire urban forest in a mixture of locations throughout the city (Kenney et al., 2011, 114)? Or does no one species represent more than 10 percent of the urban forest with at least 60 percent evergreen, a wide variety of ages, and an equal percentage of urban forest areas present in wealthy and poorer regions (Kenney et al., 2011, 114)?
- *Social Indicator:* Examines residents' response to the problem of invasive species. Are there resident groups that have made attempts to combat the invasive problem; is there is a voluntary invasive removal plan in place, but action has primarily occurred on public lands (Kenney et al., 2011, 114); or are there several work parties to remove invasive species that occur frequently through the year, and maintenance crews devote some of their time to invasive removal? Are native plantings required, as applicable, per new project (Kenney et al., 2011, 114)?

- **Flexible** – If certain urban forest areas within the city have been disturbed by fire or another shock, a flexible urban forest resists a domino like wave of destruction through surrounding urban forest and built environment areas. Policy makers have broken down the urban forest into different zones in terms of priority, but also in terms of type, such as street trees versus parks, because each zone and layer requires a slightly different management strategy to be successful. An one-size fits all approach will not be successful as context is very important when it comes to resilience (Ove Arup, 2014, 5).

- *Spatial Indicator:* Examines how the system responds to a disturbance. If an area has been disturbed, does it start a domino effect of failures; can shocks be contained; or can shocks be contained without loosing the connectivity and functionality of the urban forest?
- *Social Indicator:* Examines how the urban forest is broken down for management purposes. Are all urban forest types treated the same; is the urban forest broken down into geographic zones; or is the urban forest zoned by type and priority, and each type is maintained differently?

- **Resourceful** – A resourceful urban forest program in Seattle has created pilot programs around the city experimenting with different management strategies, including lifecycle management. The program is well funded with stable financing sources, is included within citywide plans, and has regulatory teeth (Kenny et al., 2011, 111; Kollin and Schwab, 2009b, 121). Inclusion within other citywide plans creates a policy framework for urban forests, and helps ensure that necessary activities will occur (Kollin and Schwab, 2009b, 121). Efforts to include urban forest language and policies in the plans of neighboring cities have also been made in order to make regional mitigation of climate change possible.

- *Spatial Indicator:* Examines pilot programs and new management techniques. Are there any pilot programs or new management techniques being implemented around the city; are pilot programs occurring on a small scale; or are there several different strategies in use throughout the urban forest?
- *Social Indicator*: Examines funding. Does the urban forest program receive any funding; is funding only received from within the government; or is the program funded from private and public sources (Kenney et al., 2011, 115)?

- **Inclusive** – An inclusive urban forest has users and policy makers as diverse as the species within the forest (Kenny et al., 2011, 111). Just as diversity of species, age, and location are crucial for the resilience of the urban forest, multiple parties must be involved in the management and implementation of this shared responsibility. Increasing numbers of stakeholders also creates redundancy by allowing for more individuals to be involved, and more tasks to be accomplish at a faster pace. This inclusivity further translates to urban resilience because as more people feel invested and participate, they will also form social bonds with each other and the land. This social cohesion can help prepare them to survive future shocks. A truly inclusive program must also reach past the borders of Seattle into other regions and states. Finally, an inclusive system is also easily accessible, with urban forests open to the public at all hours of the day and within a variety of locations.
  - *Spatial Indicator:* Examines access to the urban forest. Are the urban forests only accessible to wealthy areas; are natural areas closed off to residents; or are urban forests open to all residents of the city during most of the day?
  - *Social Indicator:* Examines public and regional involvement. Are residents

involved in the urban forest; are there multiple stakeholders, although only one with power (Kenney et al., 2011, 115); are a number of governmental agencies involved, or are a number of governmental, non-profit, and residential groups involved including small businesses, large private and institutional landholders, neighborhoods, and neighboring regions (Kenny et al., 2011, 111)?

- **Integration** – The urban forest is clearly being maintained with one overarching goal in mind within an integrated system. The central goal is to increase resilience, and the sub-goals do not distract from this central mission. Urban forests and the built environment are not separate entities but integrated in look, feel, and practice. There is a clear delineation of roles and responsibilities among those charged with tasks in the UFSP, and stakeholders are in constant communication.
    - *Spatial Indicator*: Examines dispersion of the urban forest. Does the urban forest have clear boundaries, or does it seem to bleed out through the city and beyond; is the city one indiscernible mix of pervious and impervious surfaces?
    - *Social Indicator:* Examines the urban forest message. Are there conflicting messages among agencies; are there one or two powerful agencies that have produced strong messages that are sometimes at odds with one another and cooperation is still low (Kenney et al., 2011, 115); or is there one message and harmony among agencies? Further, have the urban forest policies been translated into enforceable laws and/or ordinances (Kollin and Schwab, 2009b, 121)?

4.2 Achieving Resilience

Context is very important when it comes to discussing resilience. This thesis examines the ability of urban forests, and therefore the City of Seattle, to be resilient towards the uncertain impacts of climate change over the next 85 years. Having resilience against a range of climate change impacts is important for Seattle because the true future effects of climate change in the region are uncertain. If the city is prepared for a variety of futures, the variety of possible external shocks to the system that do occur may not result in a loss of functionality. Resilience allows cities to deal with uncertainty by retaining functionality in the wake of disturbances and the changing environment of adaptive feedback loops (Welsh, 2014, 20). If the city were to lose functionality of its necessary systems, such as the electrical grid because of, for instance, rising temperatures that melt unprotected fuses, the city may become less hospitable to humans. If Seattle prepares for these shifts by planting street trees around electrical boxes to provide shade, and then conducts proactive maintenance of these trees, they will be better prepared for if and when temperatures do rise. The goal is to make the UFSP a more robust document. This will in turn allow the urban forest to support resilience against future climate change impacts.

The language within the UFSP, as well as the local nicknames for Seattle and Washington State - the Emerald City and the Evergreen State, respectively - speak volumes about the regional culture. From this information, it is assumed that Seattle considers resilience within an evergreen state normatively better than resilience in a deciduous state. Beyond normative preferences, a resilient urban forest within an evergreen state would have positive benefits. For instance, resilience within an evergreen state would provide more adaptive and mitigative capabilities than a deciduous state to climate change (City of Seattle, 2013a, 13).

Further, a regime shift to a fully deciduous state could spell environmental, economic, and social ruin for the City of Seattle (City of Seattle, 2013a, 13). As the impacts of climate change became more severe in the city, the health of all Seattle's inhabitants (human or otherwise) would begin to degrade (American Forests, 2015a; The Forest Foundation, 2015, B4; Albright and Peterson, 2013, 2120; USEPA, 2013a; Climate Central, 2014). At the extreme end of the spectrum, parks and backyards as we know them could cease to exist. The ecosystem functions that we rely upon to survive in urban environments could slow or stop, causing mortality rates and costs for necessary goods to skyrocket (Berland and Manson, 2013, 750; Allan et al., 2011, 17034; Davies et al., 2011, 1126). If the city were to instead experience a regime shift into an evergreen state, any impacts felt by climate change could be tempered through the adaptive capacities of the urban forest. The health and wellbeing of all residents could also increase as regional mitigation efforts reduce the total amount of GHGs in the atmosphere. With these assumption and arguments in place, the evergreen state is put forth as the objective, and updating the UFSP is put forth as the method to achieve these objectives.

4.3 Measuring Resilience

The resilience of the four plausible future scenarios generated in **Chapter 3** is gauged utilizing the indicators of resilience below. Each indicator is measured for each narrative based on hypotheses of whether the urban forest is experiencing an increase, decrease, no change, or an unknown change in relation to that particular factor. These judgments are visually displayed in **Figure 4-1**, and shed light on the ability of urban forests to support urban resilience in Seattle in the face of climate change and the resilience of different urban forest management strategies. Overall, the figure represents hypothesized trajectories for the resilience indicators under the different scenarios driven by climate change and alternative urban forest management strategies. Examining **Figure 4-1** allows for a qualitative discussion concerning the resilience within each future, and the potential rationales for, and implications of, the variations among the futures. With this analysis, it is possible to recommend changes to the existing UFSP in Seattle because such an exercise is an assessment of the resilience of different urban forest management strategies under alternative climate change settings. The adoption of these recommendations by the City of Seattle could create a more robust UFSP that is able to bring about resilience to climate change within a variety of plausible futures.

Resilience Qualities	**Resilience Indicator**	**Scenario A - Technology Focused**	**Scenario B - Business as Usual**	**Scenario C - Island Oasis**	**Scenario D - Connected System**
Reflective	*Spatial* - canopy cover	↗→	↘	↗	↗
	Social - resident attitude	↗	↘	↘	↗
Robust	*Spatial* - connectivity and asset management system	↗→	↘	↘	↗
	Social - climate change strategies	↗→	↘	↘	↗
Redundant	*Spatial* - diversity	→↘	↘	→↘	↗
	Social - response to invasive species	↗→	↘	→	↗
Flexible	*Spatial* - disturbance response	↘	↘→	↘	→
	Social - decentralized plan	↗	↗	↗	↗
Resourceful	*Spatial* - pilot programs	→	↘	↗	↗
	Social - funding	→	↘	→↘	↗
Inclusive	*Spatial* - access	↘	↘	↘	↗
	Social - public involvement	↗	→↘	↗	↗
Integrated	*Spatial* - dispersion	↘	↘	↘	↗
	Social - message	↗	↗	↗→	↗

Figure 4-1. Visually presents the hypothesized trajectories of the resilience indicators across scenarios. The arrows indicate how the urban forest within each scenario is performing in relation to each indicator. For example, the canopy cover within Scenario A is hypothesized to increase initially, although over time the canopy cover becomes relatively stable and is thought to no longer increase or decrease. It is not possible to assign a numeric score to each scenario because these indicators are qualitative in nature.

The results from **Figure 4-1** are discussed on the following page. The examination also describes the rationale behind the hypothesized trajectories of the resilience indicators (i.e. the logic for each arrow's direction) depicted in **Figure 4-1.**

Scenario A →

- **Reflective** –
  - *Spatial Indicator:* Seattle's urban forest canopy cover increased to 30 percent in 2037. After 2037, the canopy cover held constant without significant change.
  - *Social Indicator*: Residents were focused on the capacity of technological advances to solve climate change issues. They were also increasingly aware of the benefits of urban forests, and worked to plant vegetation in their own backyards and support local parks. They tried to allow the system to be dynamic.
- **Robust** –
  - *Spatial Indicator:* The city made strides towards completing an asset management system, but lacked a maintenance schedule. Connectivity of the urban forest within the city did not increase because there was not a focus on locational diversity or social equity. Ultimately, the system was managed in a reactive fashion.
  - *Social Indicator*: The city had very strict climate change policies that went beyond the urban forest, although many lacked regulatory teeth.
- **Redundant** –
  - *Spatial Indicator:* There was a focus on increasing the age and species diversity of the urban forest, and this paid some dividends. Although due to rising temperatures and a UFSP that did not consider locational diversity, evergreen trees did not increase in percentage compared to deciduous trees.
  - *Social Indicator:* Residents took a very active role in invasive species removal, although with the complacency that resulted from minor climate change impacts, the urgency with which the invasives were initially removed slacked.

- **Flexible** –
    - *Spatial Indicator:* As diversity levels declined and invasive species crept in, the ability of Seattle to rebound from disturbances. However, as connectivity also decreased during this time, disturbances could only spread so far.
    - *Social Indicator:* The urban forest was broken down into different management plans based on land use.
- **Resourceful** –
    - *Spatial Indicator:* The city had more new technologies at their disposal, but they did not necessarily conduct any more or less pilot programs.
    - *Social Indicator*: Funding for the urban forest did not fluctuate.
- **Inclusive** –
    - *Spatial Indicator:* As locational diversity decreased, access to urban forest areas also decreased as a smaller percentage of residents lived within proximity to urban forests. Poor communities also had less capacity to plant trees near their homes.
    - *Social Indicator:* The city successfully involved more and more groups within the urban forest planning process, and maintenance of the urban forest. Neighborhoods had agency to take care of their urban forests – assuming there was one.
- **Integration** –
    - *Spatial Indicator*: The urban forest had clear boundaries within the city.
    - *Social Indicator:* There was one clear message coming from the leadership group.

Scenario B →

- **Reflective** –
    - *Spatial Indicator:* With the lack of emphasis on the urban forest and the decreasing health of the forest due to major climate change impacts, the canopy cover decreased. The city did not reach its goal of 30 percent coverage by 2037.
    - *Social Indicator:* Residents did not see the purpose of the urban forest, nor did they make any attempts to plant vegetation, much less diverse or native vegetation, in their personal spaces.
- **Robust** –
    - *Spatial Indicator:* The city did not make any strides towards completing their asset management system or connecting urban forest areas through corridors.
    - *Social Indicator*: There were no other climate change reduction strategies in the city, and the urban forest was not even primarily seen as a mitigation or adaptation strategy so much as an aesthetic luxury. The urban forest policies lost much of their regulatory power as the influence of business and commerce increased.
- **Redundant** –
    - *Spatial Indicator:* The urban forest was composed of primarily five deciduous species of trees, and they seemed to never age as the city was forced to replace trees as they died at much faster rates due to climate change impacts and development desires. Further, surviving urban forest areas were concentrated in wealthy neighborhoods that could afford to water their yards and fund parks.
    - *Social Indicator:* The city did not have any active groups fighting invasive species despite initial attempts to drum up excitement and participation.

- **Flexible** –
  - *Spatial Indicator:* The urban forest was in such a state that one disturbance, such as a pest targeting one species, could destroy the entire forest. Although because the urban forest was reduced to small pockets, the city was able to contain disturbances.
  - *Social Indicator:* The urban forest was broken down into different management units based on land uses.
- **Resourceful** –
  - *Spatial Indicator:* The city made very few attempts to pilot new programs partially because of a lack of interest, and partially because of a lack of cheap and effective technologies.
  - *Social Indicator*: There was little to no funding available for agencies maintaining or planting new trees. Most government funds went to incentivize businesses to locate in Seattle, and private funds went towards commerce focused organizations.
- **Inclusive** –
  - *Spatial Indicator:* Access to urban forests greatly diminished, as the small pockets of urban forests were primarily in wealthy neighborhoods.
  - *Social Indicator:* There were not any more or less groups involved in the urban forest. Although, interest in the urban forest was generally low.
- **Integration** –
  - *Spatial Indicator*: There were clear boundaries for the urban forest in the city as impervious surfaces increased, and the canopy cover decreased.
  - *Social Indicator:* There was one clear message, although this message was one of indifference towards the urban forest.

Scenario C →

- **Reflective –**
    - *Spatial Indicator:* The canopy cover increased over time, surpassing 30 percent before 2037 as the desire to utilize the benefits of a denser urban forest increased.
    - *Social Indicator:* Residents would have liked to keep the system static with the same benefits received without the need for additional work. Although as populations increased, so did tensions, and many felt that the urban forest received too much land and too much funding when so many individuals were suffering from homelessness and hunger.
- **Robust –**
    - *Spatial Indicator:* As the city's urban forest was increasingly cut off from surrounding cities and other urban forests, the overall connectivity of the urban forest decreased over time. Further, there was an asset management system and a proactive approach to maintenance, although keeping the system up to date was not high on the priority list.
    - *Social Indicator*: The city felt strongly about the urban forest as a strategy to reduce the impacts of climate change through adaptation, although there were no other policies that addressed climate change.
- **Redundant –**
    - *Spatial Indicator:* Non-native species decreased and evergreen species increased because of the enduring Plan, although as connectivity and space for the urban forest decreased, locational diversity steadily decreased as well. The age of the

trees on the perimeter also got uniformly younger as they were replaced more often. Further, as temperatures continued to rise, the habitat for evergreen species shrunk.

- *Social Indicator:* There were groups that participated in invasive species removal, although numbers did not significantly increase after 2015.

- **Flexible** –
    - *Spatial Indicator:* With a denser forest concentrated in a small area, it was easier for a disturbance to quickly spread throughout the urban forest. Although the decentralization of the management plan attempted to prevent a large catastrophe.
    - *Social Indicator:* The urban forest was broken up into different management systems by geographic location, and type of urban forest.
- **Resourceful** –
    - *Spatial Indicator:* There was a large emphasis on pilot programs in order to hopefully discover new and improved ways to manage the forest.
    - *Social Indicator*: Funding went from steady to declining as other welfare issues begin to take precedence.
- **Inclusive** –
    - *Spatial Indicator:* As the urban forest increased in density in the city center and decreased around the perimeter, those on the outside were afforded little access.
    - *Social Indicator:* The public was very involved with the urban forest as they knew the stakes and believed that the urban forest would save them. They had faith - at least initially - in the abilities of local adaptation and ignored regional mitigation out of necessity.

- **Integration** –
  - *Spatial Indicator*: There was a very clear line between forested area and non-forested area, but within the forested area, the lines blurred.
  - *Social Indicator:* There was one message concerning the urban forest, although as tensions increased over available space, this message began to erode.

Scenario D **→**

- **Reflective** –
  - *Spatial Indicator:* The canopy cover increased as the urban forest spread and became denser. The 30 percent canopy cover goal was achieved and expanded upon using science to select where and why to grow.
  - *Social Indicator*: The residents credited the urban forest with helping the city to adapt to, and mitigate against, climate change. They accepted the need for urban forests, and further understood the need for it and the city to remain dynamic.
- **Robust** –
  - *Spatial Indicator:* The city had a full asset management system and was very connected both internally and externally to other cities.
  - *Social Indicator*: The city had several stringent climate change policies in place that were heavily enforced.
- **Redundant** –
  - *Spatial Indicator:* Evergreen and other native vegetation species increased, and with the city's proactive management approach, trees begin to live longer, resulting in a greater diversity of age. Further, locational diversity was highly encouraged.

    - *Social Indicator:* Residents and city staff understood the rationale for a strong response to invasive species such as ivy, and very aggressively fought it.
- **Flexible** –
    - *Spatial Indicator:* With high levels of connectivity, there was high potential for an event like a wildfire to spread quickly through the city. With a decentralized management approach, there were as many safety nets as possible.
    - *Social Indicator:* The management of the urban forest was broken down by the different phases in the lifecycle of a tree, with each age group managed by a different agency with slightly different strategies.
- **Resourceful** –
    - *Spatial Indicator:* The city was constantly testing new technologies and piloting new management approaches for the urban forest.
    - *Social Indicator*: Heavy funding from public and private sources kept the program afloat and up to date with the most recent science.
- **Inclusive** –
    - *Spatial Indicator:* With locational diversity as a central tenant of the Plan, access improved throughout much of the city.
    - *Social Indicator:* The government provided several incentives for resident participation, and this paid off with large attendance at planning meetings and volunteer maintenance.
- **Integration** –
    - *Spatial Indicator*: The urban forest and the non-urban forested areas appeared as

one from an aerial view of the city. With the increase of pervious pavement and upturn in connectivity of the urban forest, it was hard to differentiate where the "urban" began and the forest ended.

- *Social Indicator:* There was one strong message that all agencies worked under.

4.4 Summary

Based on the number of increasing arrows in the indicator rows within **Figure 4-1**, it appears that Scenario D has the most resilience of the four scenarios. Scenario A has the second most increasing arrows and least number of decreasing arrows, implying that Scenarios D and A could have the most resilience of the divergent futures. Both of these scenarios are within the minor climate change impacts end of the driver spectrum, further suggesting that while the urban forest management plan and overall institutional framework for conservation planning is important – as seen in the difference between Scenarios A and D, as well as Scenarios B and C – the ultimate decider may be the amount of climate change impacts that the region is experiencing.

This chapter has assessed the hypothesized trajectories of the resilience indicators within each scenario driven by climate change and the institutional framework for conservation planning. As such it has opened the door for a discussion on the resilience of the different urban forest management strategies against different climate change regimes. **Chapter 5** will focus more on what these results could mean, and how Seattle can benefit from this study through the creation of a more robust UFSP.

Chapter 5 – Strategies and Conclusions

5.0 Introduction

Scenario planning aims to help decision-makers in local governments and business to identify robust strategies that can be effective under several plausible future scenarios. This thesis developed a stylized version of the scenario planning approach, as discussed in **Chapter 3,** to identify plausible futures for Seattle. **Chapter 4** discussed the resilience of these plausible futures focusing on the urban forest, and **Chapter 5** discusses the implications of the gauged resilience for each future narrative. This discussion aims to provide decision makers in Seattle a road map to create a more robust UFSP that could support resilience to climate change.

5.1 Discussion of Results

As stated in **Chapter 4**, the "connected system" Scenario D is the most resilient of the four divergent scenario narratives. The "technology focused" Scenario A has the second highest level of resilience, followed by the "urban island oasis" Scenario C, and finally, the "business-as-usual" Scenario B. It is interesting to note that the two most resilient scenarios occur within futures under minor climate change impacts, and the two least resilient scenarios are expected under futures of major climate change impacts. Holding climate change impacts constant, the most resilient scenarios had an enduring urban forest management plan. This implies that the urban forest management plan is an important factor in deciding resilience, although the ultimate decider may by the severity of climate change impacts that the city is experiencing. A factor that Seattleites cannot fully control. The local climate in Seattle is driven by energy and land use decisions at the regional, national and global scales, and while the urban forest can help the city adapt to a changing climate, its mitigative capacity might not be large enough to maintain resilience over the long term.

Alternatively, what the City of Seattle has complete control over is how they choose to manage their urban forests through their institutional framework for conservation planning. The scenario narratives within **Chapter 4** imply that even if major climate change impacts do occur in Seattle, a more enduring plan could provide heightened protection over the capabilities of the existing UFSP. While the city will still suffer the consequences of climate change, a healthy urban forest and strong management plan should be able to mitigate its effects. The caveat is necessary because the ability of the urban forest to provide benefits decreases as temperatures and droughts increase, and precipitation levels fluctuate (as discussed in **Chapter 4**). This means that first, the City of Seattle, along with other cities, must simultaneously implement policies to prevent major climate change impacts from occurring. A healthy urban forest can help in this respect, but it cannot be the only action taken because of the scale of cities and urban forests. In order for Seattle to become a resilient city, surrounding cities, regions, and the global community must be on board with GHG reductions and stringent climate change policies. Regional cooperation coupled with a more enduring UFSP could increase Seattle's chances of being resilient to climate change impacts.

The dominoes of change must start somewhere. If Seattle can show the world the benefits of urban forests, the necessity of enduring plans, and the importance of stringent climate change policies before climate change impacts get too extreme, they can perhaps begin to shift societal tides and help make global mitigation efforts possible.

5.2 Recommended Strategies

The results discussed above are in almost complete opposition to the initial hypotheses of the thesis before the scenario planning process was completed. The thesis originally assumed that the abilities of urban forests to help support resilience against climate change had been overhyped in Seattle because of the small scale of the urban forest. Further, as Seattle always seems to make it onto lists that advertise the top ten best urban forests in America, it was also assumed that the urban forest and the UFSP already in place was sufficient (American Forests, 2015b).

This thesis has found that the UFSP effectively manages Seattle's urban forest in many respects, although it is sometimes hampered by inadequate planning (Nowak et al., 2010, 13). Seattle should adopt a more enduring UFSP and engage in regional cooperation to inspire mitigation efforts if it hopes to create a more resilient future. There is a lot of overlap between the UFSP and the enduring Plan described in **Chapter 3**, although there are five holes in Seattle's UFSP that if filled, could help create a more resilient future. These gaps could be filled if:

1. Seattle adopted a complete asset management system for its urban forest;
2. Seattle adopted a lifecycle management approach for its urban forest;
3. Seattle emphasized diversity of species, age, and location, and created enforceable regulations to implement such goals in other citywide plans;
4. Seattle adopted more ordinances that relate to, and help implement, goals written in the UFSP; and
5. Seattle coordinated these UFSP polices and objectives with neighboring cities and states.

Further advances could also be made if more diverse and plentiful funding sources were identified for urban forest management. Although, this recommendation overlays all of the others, and is not strictly necessary if a more favorable budget from within the city and state could be created. The five updates identified above are feasible in the short, mid, or long term, and would provide the most effective and cost efficient outcomes in Seattle. Further information about these recommendations, and possible implementation strategies are listed below.

1. Seattle adopts a complete asset management system for the urban forest.

Completing this recommendation would first and foremost allow for a proactive management approach that could help prevent problems and increase the health of the urban forest (Schwab [Urbana, IL], 2009, 57; City of San Francisco [CA], 2014, 20). The urban forest is a part of Seattle's green infrastructure system, and as such, it must be properly taken care of like any other man-made infrastructure system (Nowak et al., 2010, 3). Seattle has taken steps toward the creation of a full asset management system by inventorying street trees and assessing the condition of the city's urban forest, although more must be done (City of Seattle, 2013a, 37-38). First, the inventory must extend to park areas and private lands, and the conditions assessment must be ground-truthed. Additionally, these attributes of the asset management system must be more regularly updated. These initial tasks will be difficult, although can be accomplished through the creation of a full time urban forester position within the city, and increasing outreach to the public. A specific job in local government dedicated to urban forestry could increase funding to the program, and help the inventorying process. This would be a benefit because there would be a knowledgeable person dedicated full time to inventorying, who would also be better situated to more efficiently delegate tasks to volunteers or interns (Bassuk [Ithaca, NY], 2009, 72; Lewis [Olympia, WA], 2009, 64). Further, by increasing outreach and education to the public, residents could become more involved in the process and choose to help with the inventory (Outen [Baltimore County, MD], 2009, 48-49; City of San Francisco [CA], 2014, 16, 59; City of Portland, Oregon, 2015a; Monear [Minneapolis, MN], 2009, 53). This increased outreach could be achieved through hands off measures, such as attaching signs to public trees that list the economic and environmental benefits (City of San Francisco [CA], 2014, 16); or more labor intensive methods, such as providing free trees and classes to the public (Lewis [Olympia, WA], 2009, 65; Outen [Baltimore County, MD], 2009, 48-49). Whatever the specific strategy, this increased outreach could work to involve more citizens and increase feelings of connectivity to the urban forest (Monear [Minneapolis, MN], 2009). This heightened level of involvement from the residents of Seattle could then be leveraged to increase the accuracy and coverage of the city's tree inventory and conditions assessment. Residents could inventory and assess their backyards and these data points, combined with those from street trees and parks, could be used to extrapolate a more complete inventory and conditions assessment for the city.

Next, a maintenance schedule must be created to support and protect the urban forest assets in the city. This can be accomplished after a full inventory and conditions assessment has been created and are annually updated to ensure accuracy. With this information in hand, the urban forester of the city – or whomever is in charge of the urban forest – will understand what areas need the most help, and can therefore create an effective schedule that addresses problem areas before they become real issues (Thomson et al., 2013, 20). A complete asset management system – inventory, conditions assessment, and maintenance schedule – will ensure a healthier urban forest that is better able to serve the city through provision of maximum benefits.

2. Seattle adopts a lifecycle management approach for the urban forest.

Emulating the lifecycle management system utilized in San Francisco, CA (see **Figure 5-1**) could increase the longevity and health of the urban forest stock, while also creating jobs and opportunities for art installations within the City of Seattle (City of San Francisco [CA], 2014, 21). This is not possible in the short term, as city run facilities such as nurseries and lumber mills will ultimately be necessary, but the process can begin now by contracting with existing facilities and changing the way city staff maintain the street trees and parks. Further, educational programs for the public can be created and performed in neighborhood settings to garner support, and possible funding sources, for this management approach. These workshops and public meetings can also inform the public about their possible role in the urban forest lifecycle. The workshops can also help educated the public on how they can take advantage of the many benefits of urban forests. Long-term steps include constructing, or converting current buildings into artist studios/galleries, lumber milling facilities, and nurseries.

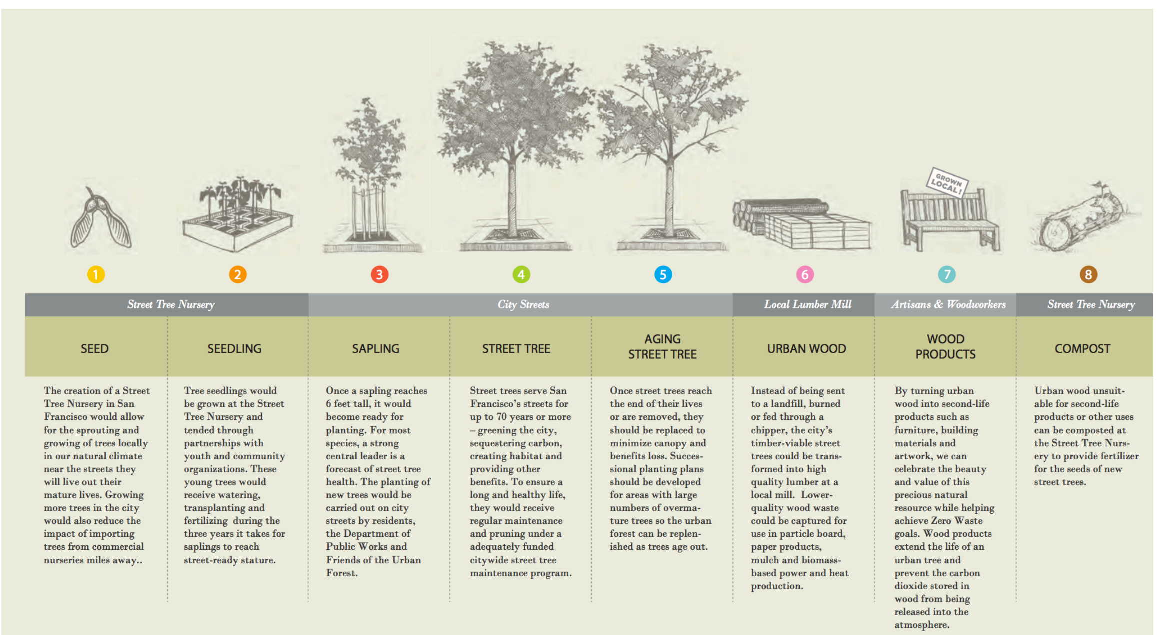


Figure 5-1. A visualization of the lifecycle approach that the City of San Francisco utilizes within it urban forest management plan (City of San Francisco [CA], 2014, 21).

3. Seattle emphasizes diversity of species, age, and location with enforceable regulations.

Without enforceable regulations or even an implementation plan, we cannot ensure and monitor success in maintaining the diversity of Seattle's urban forest. In addition to adopting ordinances that regulate and incentivize diversity goals within the UFSP, Seattle should also add language to the UFSP that elevates locational diversity to the importance of species and age. The first step to accomplish this recommendation is to add this type of language to the UFSP during the next update, the second is to create an implementation plan within the UFSP that lays out how heightened levels of diversity can be achieved in Seattle. Part of this process could be to encourage neighborhood plans as well as Seattle's Comprehensive Plan to include urban forest redundancy goals. Once again, public education plays a crucial role in the implementation process. The final step involves adopting regulations in city codes that emulate these UFSP objectives. This is a longer-term action item that requires convincing the city council to enact ordinances that incentive redundancy and place stricter fines on noncompliance with tree ordinances already on the books. Incentives could include discounted evergreen species at nurseries, and creating property tax incentives attached to the percent canopy coverage, for instance, of private property with older, evergreen, or native species. A disincentive, on the other hand, could be adopting heftier fees for not following a one to two replacement ratio during the development process.

Locational diversity is crucial because as urban forests spread throughout the city, a broader swath of the population has access to the benefits that urban forests can provide. Further, maintenance of locational diversity is a social equity as well as an environmental objective. As distributional equity increases – in terms of the benefits and risks associated with urban forests –

so too can public participation in the UFSP, and the political process involved with the implementation of the goals of the UFSP (Schlosberg, 2004, 517). Locational diversity is also important for the environmental health of the urban forest because as the urban forest grows, a single shock within one area of the city cannot wipe out the entire urban forest population of a redundant system. Further, as more space is allotted to the urban forest, a wider range of species are able to survive and thrive within the city. As Seattle's green infrastructure (Nowak et al., 2010, 3), the urban forest must be properly spread throughout the city like any other infrastructure system.

4. Seattle adopts more ordinances that relate to, and help implement, goals of the UFSP.

Many of the goals within the UFSP are only backed by voluntary guidelines presented in one document. While some individuals, businesses, and industries will choose to voluntarily abide by the guidelines presented in the UFSP, studies show that many corporations will not choose to willingly regulate themselves without government intervention when it comes to environmental issues (Markowitz and Rosner, 2009, 165). Societal norms and corporate shaming can affect behavior without regulations, although until regulations force action, many can also try and circumvent social pressure by not disclosing their activities and/or trying to spin the conversation. The story of the chemical and lead industries in the U.S can serve as examples. Historically, when the chemical industry was asked to perform their moral obligation and disclose scientific findings concerning public risk, "The chemical industry decided to act in its own, rather than the public's, interests and not tell the National Institute for Occupational Safety and Health what it knew about the carcinogenic potential of vinyl chloride for humans" (Markowitz and Rosner, 2009, 197). Further, in response to reports on how dangerous lead was to human health, "the lead industry…[embarked on] a three-decade advertising campaign to convince people that lead was safe…From 1906 through the 1940s, for example, [the] industry engaged in a massive effort to portray lead as a benign substance, essential to the economic, social, and cultural development of the country and of no threat to children" (Markowitz and Rosner, 2009, 170). While these are extreme examples of corporate maleficence, and undoubtedly do not always hold true today especially when effective economic arguments can be made for environmental decisions, it cannot be assumed that educational workshops alone can help the city achieve UFSP objectives. Regulations must be enacted on the city and state level, and variances or exceptions to these laws must be severely limited. Enforcement is a key element of regulations as well, as this leaves less up to chance or interpretation. This recommendation can be achieved by backing more of the objectives of the UFSP with language in codes or other ordinances.

5. Coordination of policies and objectives within neighboring cities and states.

The four previous policy recommendations will primarily help the city adapt to climate change impacts. They will not necessarily help in the regional or global effort to mitigate climate change on any substantial level due to the small relative contribution of Seattle's urban forest. To mitigate climate change through mass amounts of carbon sequestration, the city must become an active participant within an effective global whole. This integration must start on a regional level, and then spread. Like within the "connected system" future Scenario D, to truly have an impact on mitigation, the City of Seattle's urban forest must connect through reforestation and afforestation projects to the city's surrounding natural forested lands areas - such as within the Olympic and Cascade Mountain ranges. This connectivity must then spread further into surrounding cities such as Pasco, Moses Lake, and eventually reach surrounding states such as Idaho and Oregon. In such a situation, the positive impacts of this amount of carbon sequestration will be real and lasting. The carbon stocks held in this potentially vast canopy cover would be able to significantly reduce the amount of CO_2 in circulation within the atmosphere. This massive reduction could then help prevent Seattle and the rest of the world from slipping into an RCP 8.5 business-as-usual climate situation that will most likely have devastating results (as seen in Scenarios B and C). This connectivity is possible only through a type of regional, national, and international integration and cooperation so far unseen in 2015. The only way to feasibly reach this aspirational goal is to start small – leverage Seattle's 2050 carbon neutrality pledge to neighboring cities (City of Seattle, 2013b, 3), and recommend a heightened emphasis on increasing connectivity and canopy cover. These actions, and Seattle's regional economic power, can encourage surrounding cities to join in the effort. The first, short-term step is to explicitly state in the UFSP, Comprehensive Plan, and Climate Action Plan the goal of international cooperation on this front.

Without this type of regional, then national, and finally international cooperation, Seattle's urban forest cannot mitigate climate change in any realistic fashion. Without this cooperation, Seattle's urban forest can only help the city adapt to climate change impacts that will be largely decided by the whims of a global collective of cities, each acting in their own best interest. The first four recommendations are essential in case cooperation fails, and Seattle must learn to survive within a world of major climate change impacts, as with the "urban island oasis" future Scenario C. Even if this final recommendation were to be accepted and acted upon in Seattle, the first four adaptation recommendations would still be essential because of the lag effect, and the reality that minor climate change impacts, at least as described in RCP 4.5, are inevitable. The final recommendation of this thesis is aspirational for Seattle and the world, but it is no less essential because adaptation to climate change will ultimately not be enough. Global mitigation efforts will need to take place to prevent massive economic, social, and environmental causalities. Climate change is a global issue that needs a global solution as no one city's actions can truly make it, or the world, resilient to climate change. Seattle should therefore become a leader in pushing this agenda of international cooperation if they hope to be relevant, or alive by 2100.

5.3 Concluding Remarks

This thesis has primarily focused on a discussion of the resilience of Seattle's urban forest; whether the system can remain within one domain of attraction or another as an indicator of the City of Seattle's ability to do the same in a grander domain of attraction. Here, in the concluding chapter of the paper, the veil has been removed, and the discussion focuses around the resilience of the city itself. The discussion around the resilience of urban forests has provided a necessary example to identify a road map and practical steps that must be taken today, with the UFSP and city policy, in order to create urban resilience tomorrow. It is also now possible to answer the original research questions of this thesis concerning the ability of the urban forest to support urban resilience within the City of Seattle.

Urban resilience to climate change is achieved through mitigation and adaptation to climate change. Urban resilience is both adaptation and mitigation because adaptation alone can only allow a city to retain its functionality to a certain point. For instance, planting more trees around mechanical equipment to provide shade is an effective adaptation strategy for the short term.

Although without mitigation efforts, the impacts of climate change will eventually become too severe and too prolonged for the urban forest to survive or provide adaptive capacity. Without mitigation, functionality can be reduced in the long term. In other words, eventually those trees will no longer be able to shade the equipment. This reduction will cause the urban system to move closer to, and eventually over a threshold into a new regime. As urban resilience must include both mitigation and adaptation, Seattle's current UFSP does not adequately provide resilience. With the adoption of the five recommendations in this thesis, Seattle's urban forest could better help the city contribute to global mitigation and local adaptation to climate change.

5.4 Summary

Can Seattle be resilient? Probably. Can urban forests help in this quest to support resilience in the face of climate change? Yes. Is the city currently on track to achieve this end? Not yet. As the scenario planning approach of this thesis has displayed, there are a lot of factors that play a role in resilience. To complicate the subject further, most of these factors are very important, very uncertain, and not completely in control of humans in general, or Seattle in particular. What is in our control, and how we can link the ideas of urban forests, climate change, and resilience together, is management. How we manage the urban forest plays a big part in its ability to adapt to and mitigate against climate change for the city. The ability of urban forests to support functionality of infrastructure and ecosystems services in the city (i.e. support urban resilience) is impacted by how the city chooses to manage the resource. Simply having an urban forest is not a silver bullet. The urban forest must be managed in a way so that the necessary benefits can be achieved, and even then, urban forests are just one piece of the urban resilience puzzle that must all fall into place.

Poorly managed urban forests still provide benefits, although without proper management the full potential suite of benefits may not always be considered, maximized, or maintained as other city concerns could take priority and funding. Even with a well managed urban forest, its ability to help the city mitigate and adapt to climate change will be tempered by the impacts that are already being experienced. Strategies to update Seattle's UFSP to better fit a management plan that creates these opportunities has been the focus of **Chapter 5**.

There are hundreds of significant problems that confront cities on a daily basis, and even more possible solutions proposed by planners, scientists, residents, and politicians. This thesis has selected to focus on climate change in particular as a problem, and urban forests as a possible solution. To this end, a scenario planning approach was conducted to begin to test the ability of urban forests to support resilience in the City of Seattle in the face of climate change. Through analysis and discussion, this thesis has ultimately concluded that urban forests can support the city's efforts to be more resilient to climate change. Although to truly become resilient, Seattle must work to minimize climate change impacts through the creation of a more enduring UFSP, and encouraging the rest of the U.S and world to follow suit.

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