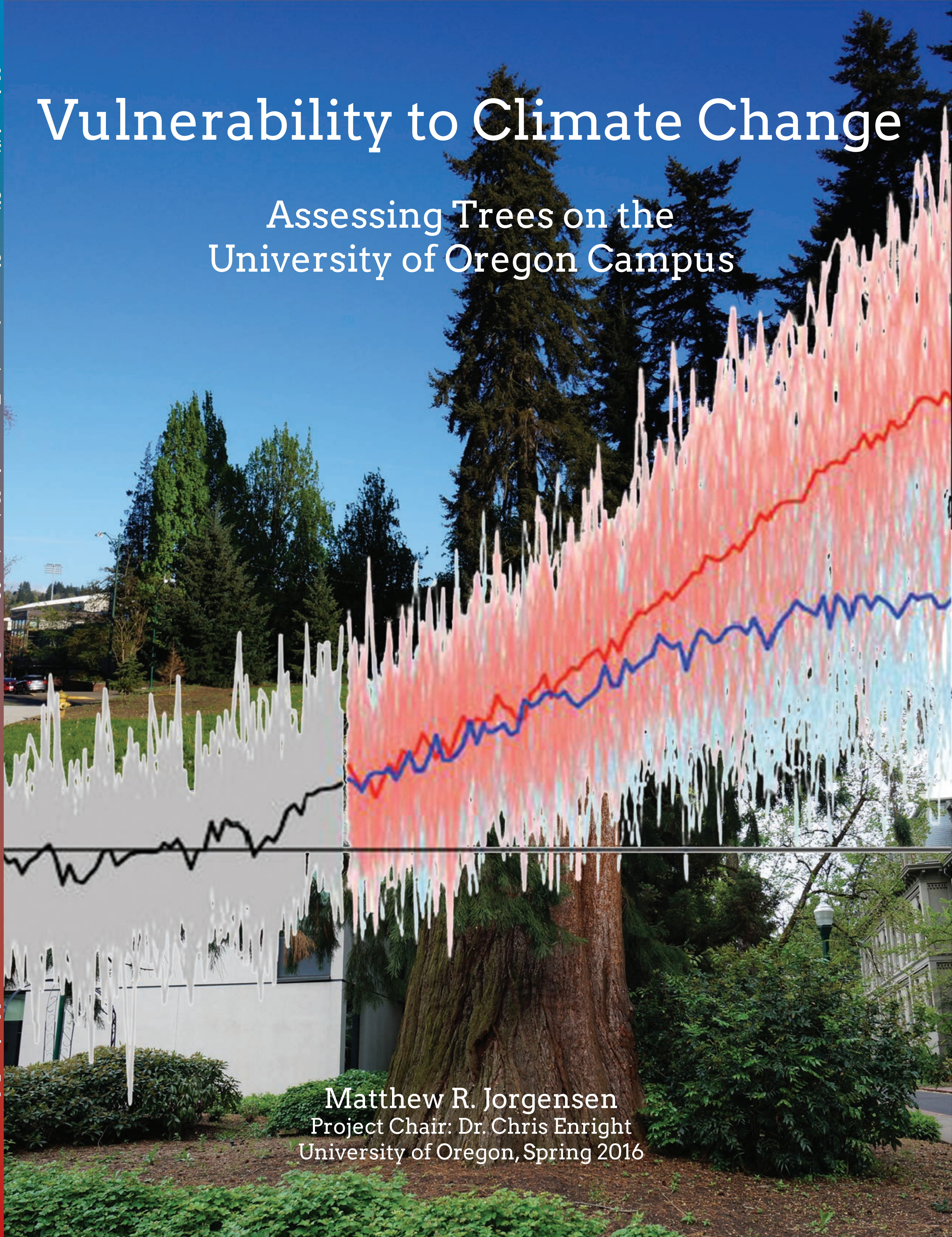

Vulnerability to Climate Change

Assessing Trees on the University of Oregon Campus

Matthew R. Jorgensen
Project Chair: Dr. Chris Enright
University of Oregon, Spring 2016

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Assessing Trees on the University of Oregon Campus

Matthew R. Jorgensen

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APPROVAL PAGE

Student: Matthew R. Jorgensen

Project Title: Vulnerability to Climate Change - Assessing Trees on the University of Oregon Campus

Project Chair: Dr. Chris Enright

Project Committee Member: Dave Hulse

Dr. Chris Enright Date

David Hulse Date

Abstract

Our climate is now changing at an alarming and measurable rate. The next century will bring changes with a speed we have not yet experienced, and it is imperative that we preemptively address projected effects. The focus of this project is on the rising temperature caused by climate change, and the associated impacts that come with it, as they relate to the trees of the University of Oregon campus. At this time, higher education institutions and municipalities are only just beginning to think about and establish plans regarding our long term landscape. Currently, the University of Oregon does not have an established method for identifying tree species which will be vulnerable to climate change. This has the potential to significantly alter the campus landscape, particularly with respect to prominent species. This project develops a matrix that can be used to identify tree species that are vulnerable to climate change, as well as evaluate potential replacement species. Application of the matrix identifies the three most prominent campus species (based on specimen count) that are vulnerable to the impacts of climate change: *Betula papyrifera*, *Acer platanoides*, and *Pseudotsuga menziesii*. *Pseudotsuga menziesii* is used as an example to identify potential replacement species, followed by use of the matrix to select a replacement with reduced vulnerability to climate change. As large landscape plantings such as trees help to create a specific feeling of place, this project also explores the possibility of a changed campus character when transitioned to less vulnerable species. Replacement species selection is directed by finding candidates which have visual qualities similar to the vulnerable species, with the goal of minimizing a change to the current campus character. This is investigated through the use of hand and digital media to compare the qualities of the existing vulnerable species with those of the proposed replacement species. The method and application from this project are readily transferable to institutional and municipal settings in order to aid in: identifying species that are vulnerable to climate change, selecting and confirming suitability of replacement species, and visualizing replacement species in the landscape.

Acknowledgements

I would like to express my deep gratitude to my Project Chair, Dr. Chris Enright, and my Committee Member, David Hulse, for their tireless dedication and assistance with the development and editing of this project. Their guidance and input helped to shape and refine my work into what it has become. I would also like to thank the rest of the faculty within the Department of Landscape Architecture for their contribution to my education at the University of Oregon. I wish to acknowledge the assistance provided by UO Facilities Services and the UO InfoGraphics Lab for taking the time to speak with me, and for providing data that was crucial to the project.

In addition, the completion of graduate school would not have been possible without the undying support of my family. My loving wife, Sarah, has offered nothing but encouragement along the way, and has been very tolerant of my late nights/early mornings working on projects. My late mother-in-law, Judith Silverman, was a key influence in my decision to return to school and pursue a career that would make me happy, and I wish she could be here to see the completion of this milestone. To my parents, brother, and extended family on both sides, thank you for your support and patience while I completed this all-consuming chapter of my life. Lastly, I'd like to thank my cohort and other classmates, who were an incredible group of friends that were always willing to help, always encouraging, always laughing, and always ready for a beer and a late night.

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Chapter 1: Introduction

1.1 Project Scope, Definition and Significance

Our climate is changing. Climate change projections, in regard to trees, have primarily emphasized responses at global or regional scales, highlighting the effects on native forests and/or areas of land (IPCC, 2014; NCA, 2014; CIG, 2013; OCCRI, 2013; Allen, et al., 2010; van Mantgem, 2009). Research has shown the migration of species as a result of shifts in regional hardiness zones (Monleon, 2015). Typically, studies like this address broad landscape processes, and primarily speak to non-urbanized areas. Although the topic of a shift in tree species in the urban environment has begun to be addressed in recent years, the overall suite of plants and the possible shift of genius loci has not. For example, Green (2013) and Ellison (2012) exclusively explored ways to improve the city approved street tree lists for Eugene and Bend, Oregon, respectively, based on climate projections. Similarly, Ordonez and Duinker (2015) offer insight regarding vulnerability assessment of the urban forest in three Canadian cities. However, they neglect to offer insight about replacement species selection or how this shift may alter the character of these cities. Likewise, Barona (2015) suggests urban forest management strategies to combat climate change, but again excludes the specifics of replacements or aspects of changes in landscape character. In the case of the urban forest, species must contend with the challenges of the surrounding built environment, such as poor soils, restricted root zones and soil compaction. Unlike in the wild, the urban landscape setting consists of a large number of domesticated and ornamental plant species, in addition to some native flora.

This project focuses on a particular urban forest: that of an ornamental and institutional setting at the University of Oregon (UO) campus, which is in the Southern Willamette Valley, in the city of Eugene, OR (Figure 1.1). Although trees typically form the backbone of landscape plantings, and often convey the strongest sense of place (or, dictate the overarching character of a place), a possible 'changing of the guard' in the face of climate change has not been a principal focus of investigation to date. For example, an abundance of palm trees brings to mind a tropical or Mediterranean climate, as you would find in Hawaii or California, while many specimens of acacia, mesquite and palo verde exemplify the desert southwest. In the case of the UO campus, however, the typical tree species of the Pacific Northwest (PNW) are not used exclusively, as the campus is an

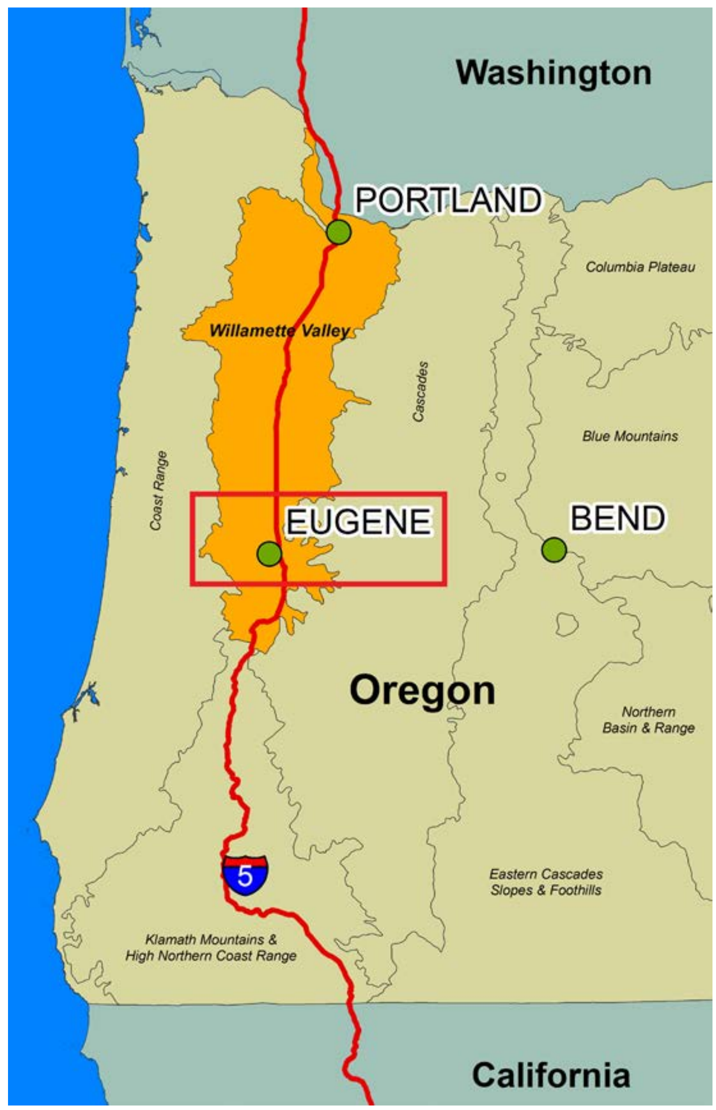


Figure 1.1: Context map locating Eugene, OR. Adapted from http://wvcoop.nativeseednetwork.org/files/2013/01/WVEcoregionInContext.jpg

arboretum (UO Campus Tree Plan, 2008). Many of the species are native to Japan, China, or Europe, since they represent locations with a similar climate.

The domesticated setting of a city is similar to the setting we find on the UO campus, where both native and ornamental species are utilized. However, campus conditions have a reduced number of stressors, and offer a more garden-like setting, as well as a higher level of care (Figure 1.2). The arboretum and educational sensibility found on the UO campus employs both native and ornamental species, and therefore lends itself well to the introduction and transition of different species. Some may argue that a shift toward mimicking the native landscape is in order, however there are reasons to only do so in moderation. For example, as the climate shifts, many natives will be stressed to the edge of tolerance. As temperatures rise and weather extremes occur, there is an increased chance of widespread mortality. If this occurs in the absence of tolerant ornamental and resilient species, a large gap will be left in the landscape, and the number of remaining species will dwindle. As these changes transpire, some native species will struggle to survive, and other species that are better adapted will become more appropriate.

Vulnerability of campus tree species to climate change poses a threat to established planning policies regarding maintenance and creation of the designated open space character (UO Campus Plan, 2014; UO Campus Tree Plan, 2008; UO Campus Physical Framework Vision, 2015), as well as the overall campus aesthetic. The exploration of future tree mortality that may result from climate change will encourage the prospect of identifying replacement

Figure 1.2: The garden-like setting of the UO campus contains thriving specimens of both native and non-native species.

species that will not only survive the current climatic conditions of Eugene and the UO campus, but will continue to flourish with future climate change. A list of existing tree species on campus, campus documents and personal knowledge are used to focus the research.

The project begins with the development of a matrix for assessing currently planted species to determine if they are likely to be vulnerable or hardy in response to climate change. This matrix is developed using the aspect of climate change that maintains the highest confidence level across many projections: an increase in annual average temperatures. Vital characteristics that determine a tree's vulnerability to higher temperatures and the suite of associated impacts are used to determine scores and rank existing campus species. One of the vulnerable species that is found in large numbers on campus is selected, and replacement species candidates are proposed and evaluated for vulnerability. Hand and digital media are used to compare current plant qualities, such as form and foliage type, with potential transitions in these qualities brought about by the introduction of climate resilient species.

This project ultimately aims to illustrate a process of identifying vulnerable species on the UO campus in regard to climate change through the use of a matrix. The project then provides an example of selecting replacement species candidates for a prominent vulnerable species that will not only perform well now, but adapt to future conditions. This is meant to encourage transitional plantings as current species begin to push the limits of zonal tolerance. Finally, graphic representations illustrate the possible effects of a transition to less vulnerable species on the character of the UO campus. The project is approached through the lens of Campus Planning at the University of Oregon, with the intention of being transferable to other institutions and park settings.

1.2 Climate Change

The effects of climate change at all scales have become increasingly apparent over the last three decades. What was once considered a topic for debate is now a reality. No longer are we waiting for the effects, but rather we are looking for ways to adapt to and/or mitigate changes that have already manifested. Adaptation refers to adjusting our behavior to reflect current and projected conditions in a way that ensures survival (for example, plant selection geared toward heat tolerance and drought). Mitigation refers to addressing current problems in order to decrease the severity of the issue both now and in the future (for example, increasing our urban forests to act as a carbon sink to help offset greenhouse gas emissions). This project focuses on adaptation to projected conditions in order to safeguard the future landscape of the UO campus.

The most recent report issued by the Intergovernmental Panel on Climate Change (IPCC) confirms that the last 30 years have not only been the warmest since 1850, but that there has been a record rise in average global surface temperature during this time (IPCC, 2014). Comparison of various datasets around the world indicated an average global warming trend of 1.5° F from 1880 - 2012 (Figure 1.3). Global surface temperatures are predicted to continue to rise; how much depends on the emissions scenario model employed (Figures 1.4, 1.5). In addition, the IPCC concludes that:

It is virtually certain that there will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales, as global mean surface temperature increases. It is very likely that heat waves will occur with a higher frequency and longer duration. Occasional cold winter extremes will continue to occur (IPCC, 2014).

Unlike temperature related projections, worldwide precipitation projections currently

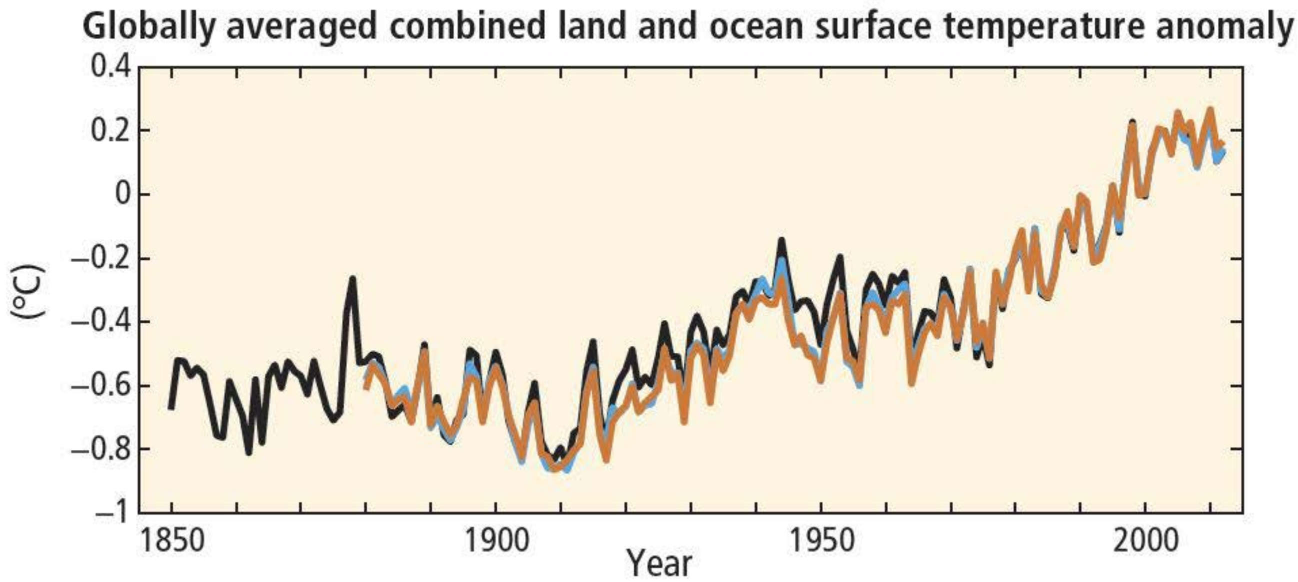
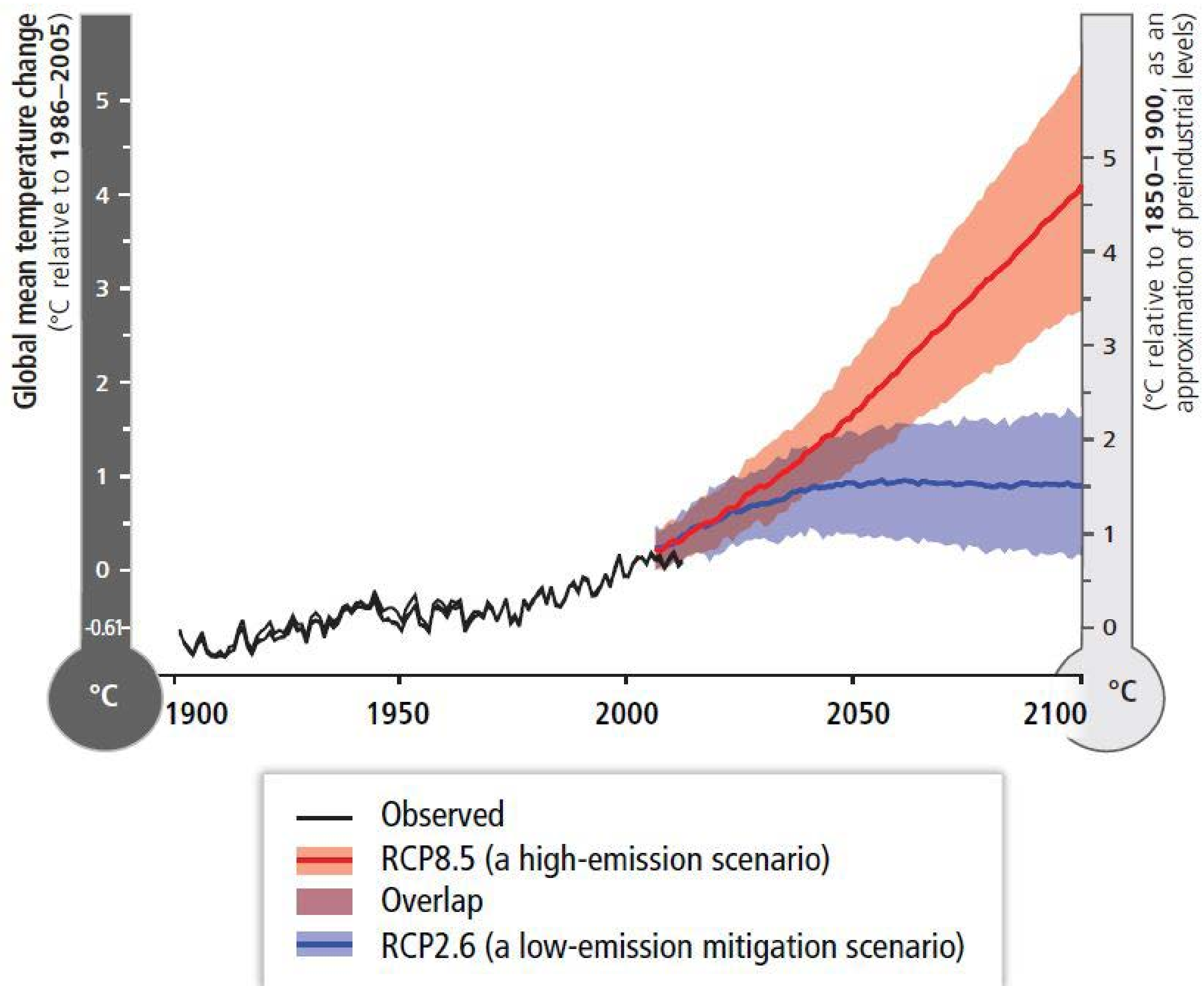


Figure 1.3: Global average surface temperatures have been on the rise since approximately the 1880's. Line colors represent different data sets, and are meant to illustrate the overall agreement between sets. Intergovernmental Panel on Climate Change, 2014.



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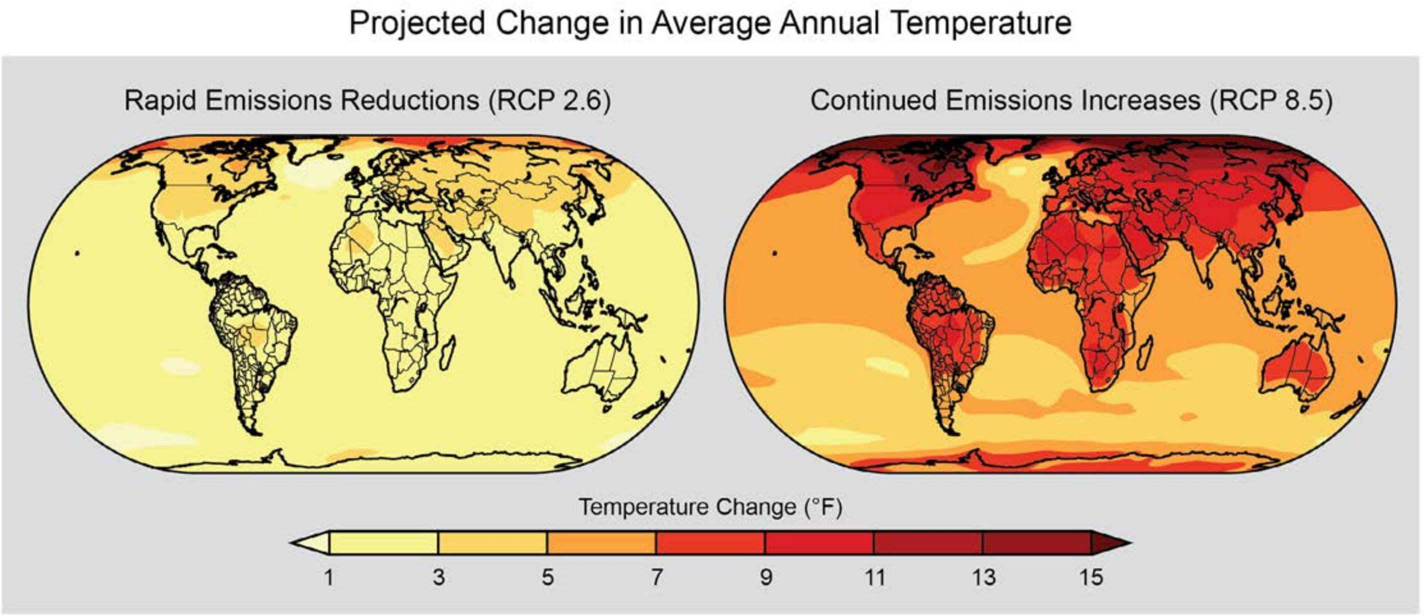

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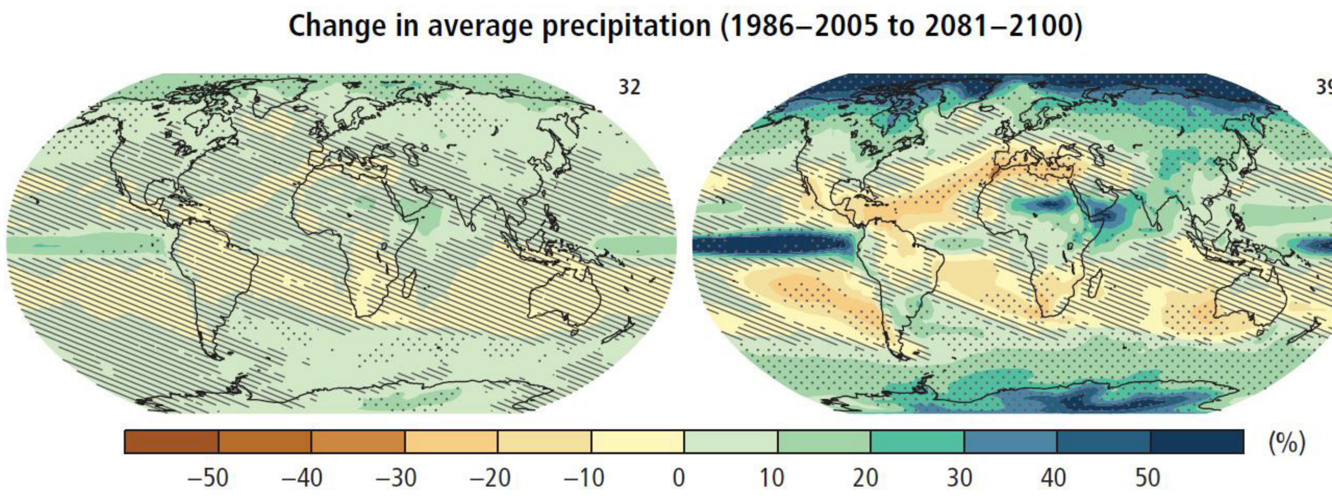


Figure 1.6: Projected changes in precipitation under high and low emissions scenarios. Diagonal hatching indicates low confidence. Intergovernmental Panel on Climate Change, 2014.

do not offer high confidence levels. There have been fluctuations in recorded data, and there are drastic differences between projections based on the emissions scenario employed (Figure 1.6). However, various models and emissions scenarios agree that there will be an increase in precipitation toward the poles (IPCC, 2014; NCA, 2014).

As we look at climate change organizations that are focused on the national level, we see agreement with the trends from global projection models, however now with finer grain detail for the U.S. As with the IPCC, the National Climate Assessment (NCA) reports a total national average temperature increase for the U.S. of 1.3 - 1.9˚ F in the period from 1895 - 2012 (Figure 1.7). However, the NCA notes that the majority of this increase began to occur in 1970 (NCA, 2014; Figures 1.3, 1.7). Also noted is the fact that the observed temperature increase is not uniform across the nation (Figure 1.8). The NCA continues to focus their statistics on specific regions of the country (Figure 1.8), and so we are able to investigate how the Northwest has been

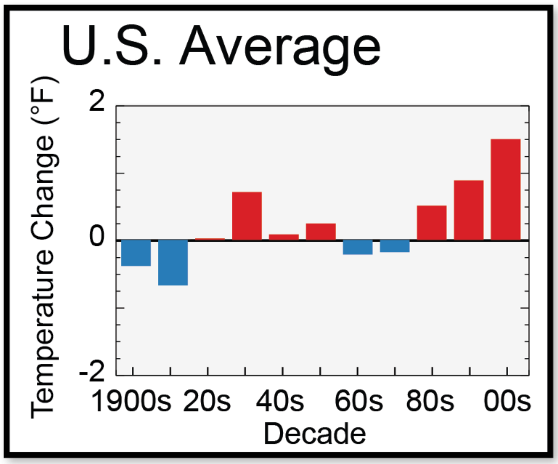
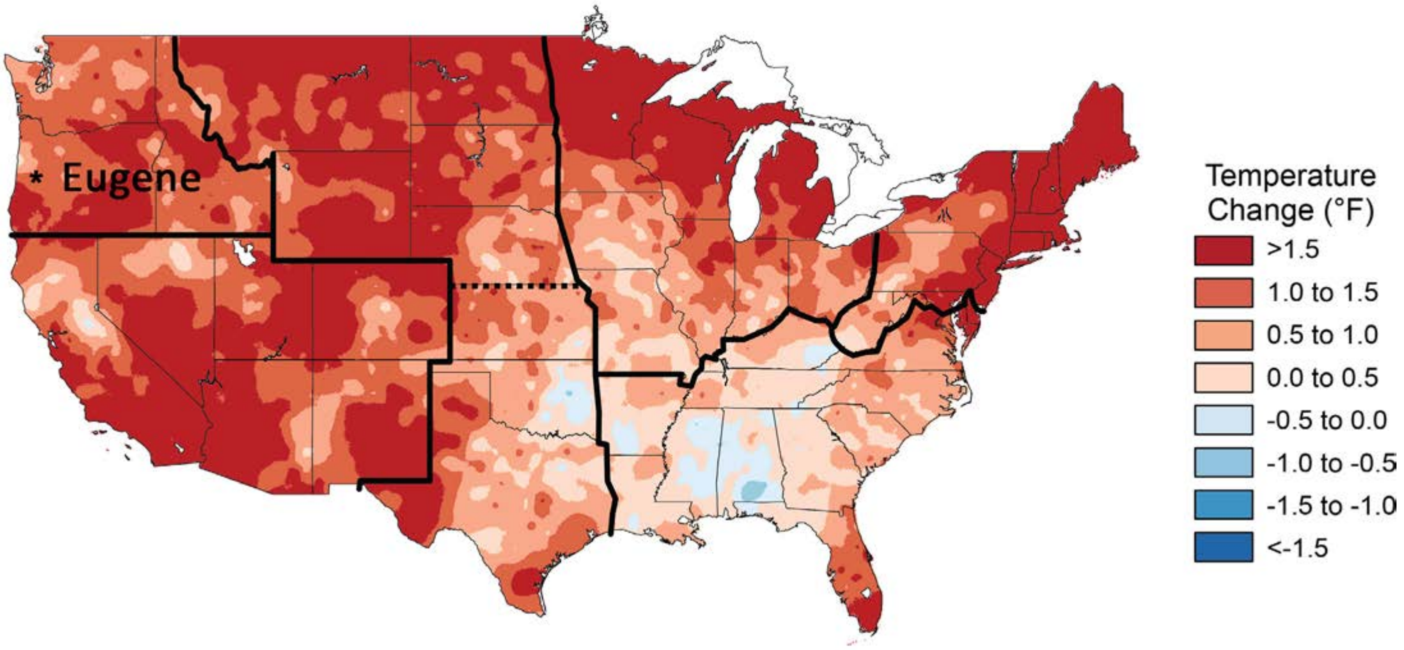


Figure 1.7: Average temperature changes (by decade) for the U.S. since approximately 1900, as compared to the 1901 - 1960 average. National Climate Assessment, 2014.



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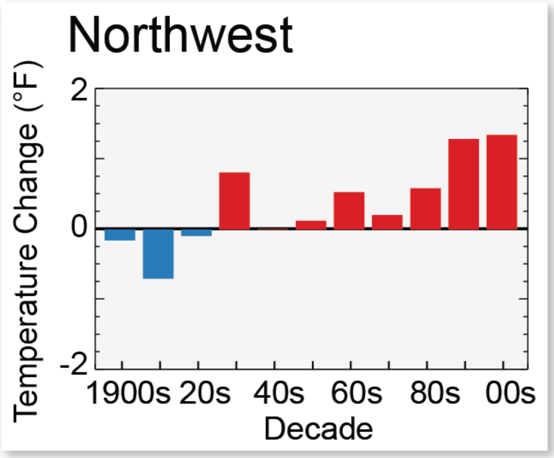

Figure 1.9: Average temperature changes (by decade) for the Northwest U.S. since approximately 1900, as compared to the 1901 - 1960 average. National Climate Assessment, 2014.

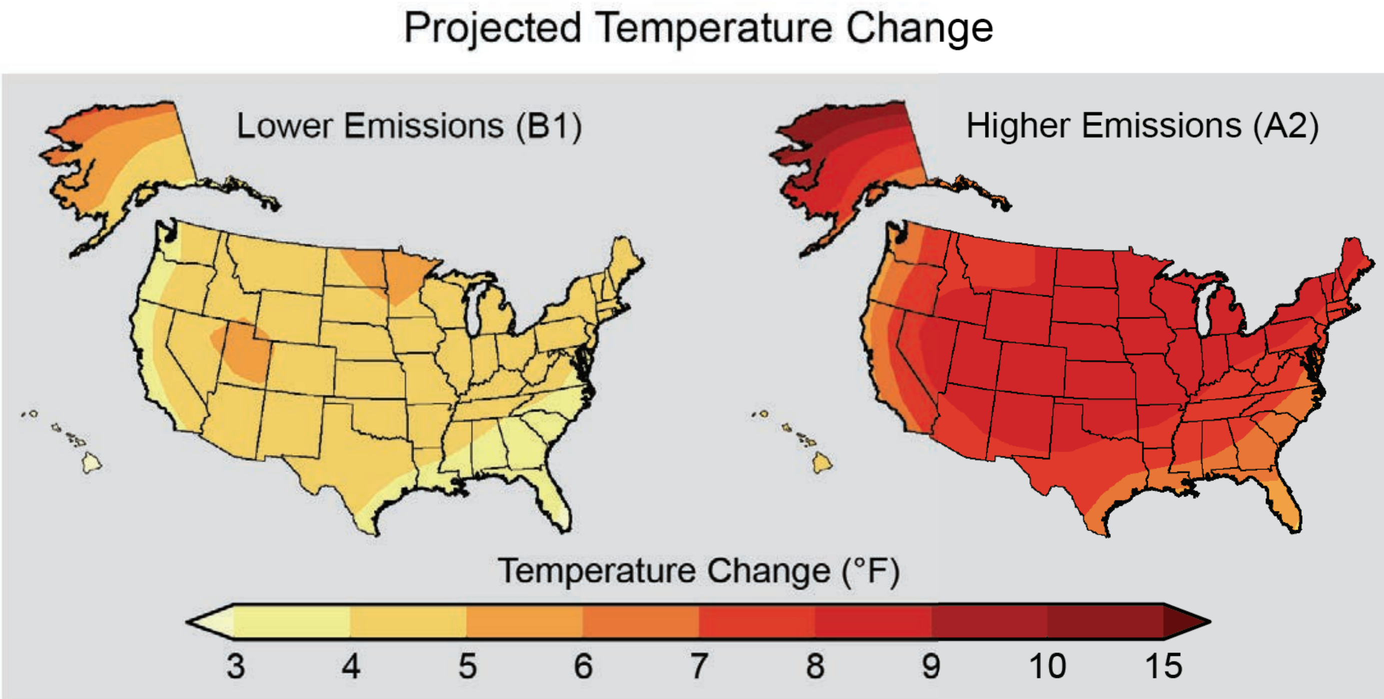

Figure 1.10: Average surface air temperature projections under low and high emissions scenarios for 2071 - 2099, as compared to 1970 - 1999. National Climate Assessment, 2014.

effected (Figure 1.9). As shown in Figure 1.9, the Northwest has maintained a slightly lower temperature increase than the national average shown in Figure 1.7: 1.25˚ F vs 1.5˚ F. When looking at Figure 1.8 more closely, the location of Eugene in the Southern Willamette Valley shows a temperature increase in the 1.0 - 1.5˚ F range, while the Southwest Oregon coast is over 1.5˚ F. The NCA goes on to offer temperature projections under low and high emissions scenarios for the U.S. (Figure 1.10). In the immediate decades to follow, there is a projected increase in annual average temperature of 2 - 4˚ F across the nation. As we approach the turn of the century, those numbers will rise based on the emissions model employed: 3 - 5˚ F for low, and 5 - 10˚ F for high.

Precipitation projections are not conclusive at this time for much of the United States, and they vary widely across the nation. However, in general terms, the higher latitudes in the far north of the U.S. will tend to have an increase in precipitation, while the Southwest will have a decrease, and most areas will experience drier summers (NCA, 2014). Interestingly, this will

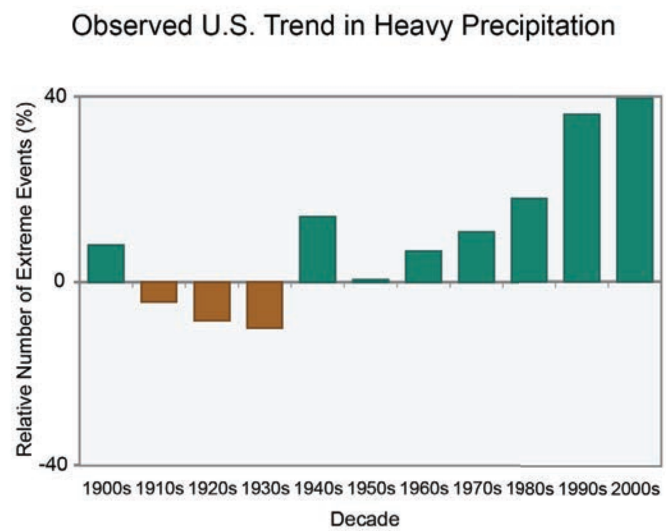

Figure 1.11: Percentage of extreme precipitation events, by decade, as compared to 1901 - 1960. National Climate Assessment, 2014.

coincide with an increase in the number of extreme precipitation events (Figure 1.11).

In order to investigate climate change for the Pacific Northwest at the finest grain possible, I have looked to organizations that call the Northwest home. These organizations have produced their own reports that are more specific to the region. The Oregon Climate Change Research Institute (OCCRI) at Oregon

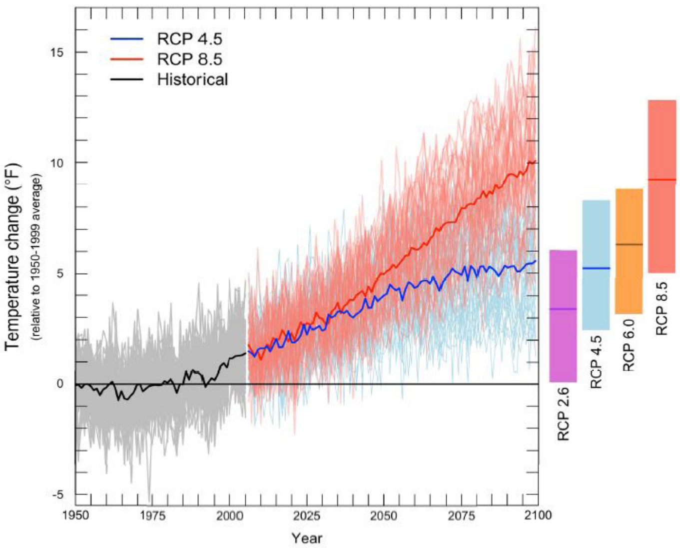

Figure 1.12: Average annual temperature projections as compared to the average from 1950 - 1999 for low and high emissions scenarios. Climate Impacts Group, Washington State, 2013.

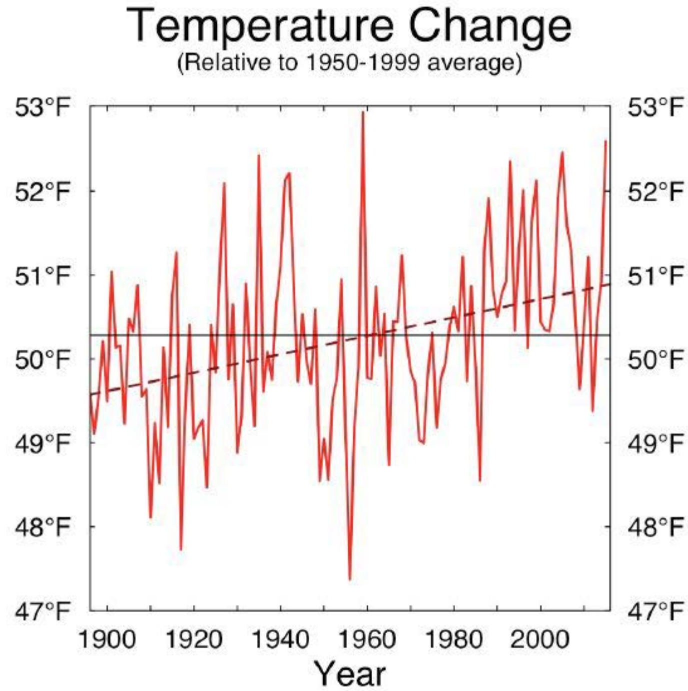

Figure 1.13: Average annual temperature increase from 1895 - 2014, relative to the average from 1950 - 1999. Climate Impacts Group, Puget Sound, 2015.

State University (OSU), and the Climate Impacts Group (CIG) at the University of Washington are two such organizations. OCCRI performed studies of the Northwest in general (OCCRI Northwest Climate Assessment Report, 2013), and Oregon specifically (OCCRI Oregon Climate Assessment Report, 2010). CIG performed studies for WA state as a whole (CIG Climate Change Impacts and Adaptation in Washington State, 2013), as well as the Puget Sound region (CIG Climate Change in Puget Sound, 2015). In short, many of the same conclusions as larger scale investigations were reached (Figure 1.12), however slightly more specific detail was given. For example, OCCRI and CIG concluded that for the Northwest alone, the rise in average annual temperature from 1895 - 2014 was 1.3° F (Figure 1.13), slightly lower than the national average, and there was no discernable consistency regarding precipitation fluctuations (OCCRI, 2013). Similarly, any increase in extreme precipitation events was unclear over the last century.

Along with the confidence of increasing temperatures, OCCRI also determined with high confidence that extremes of heat will increase, while extremes of cold will decrease (OCCRI, 2013). All of the models used by OCCRI were in agreement on these points, and included: the Coupled Model Intercomparison Project phases 3 and 5 (CMIP3/5), the North American Regional Climate Change Assessment Program (NARCCAP), and regional climateprediction.net (regCPDN). One effect of changing temperature extremes is higher overnight low temperatures, which can have a substantial impact on vegetation and agriculture (CIG Puget Sound, 2015). By the end of the century, changes in the Pacific Northwest are predicted for species ranges (Figures 1.14 - 1.19; OCCRI, 2013; CIG Puget Sound, 2015; Allen, et al., 2009), the timing of biological events (CIG Puget Sound, 2015), disturbances such as fire, insects and disease (OCCRI, 2013), and the exacerbation of plant drought conditions due to temperature increase.

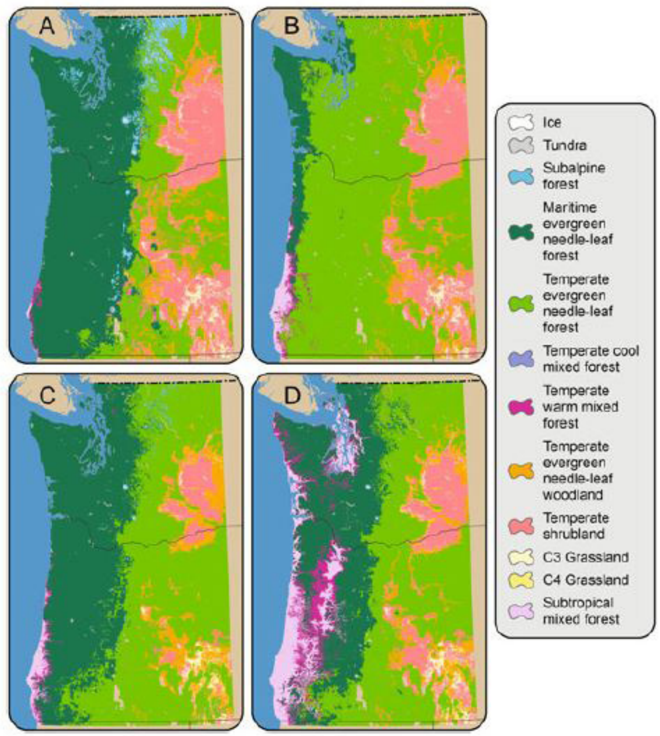

Figure 1.14: Historical and projected vegetation pattern shifts under different climate change scenarios. Oregon Climate Change Research Institute, 2013.

Figure 1.15: Climates currently associated with maritime forests (left) will transition to temperate forest climates (right). This will impact survival of current flora and fauna, and will cause a drastic shift in species range and distribution. Oregon Climate Change Research Institute, 2013.

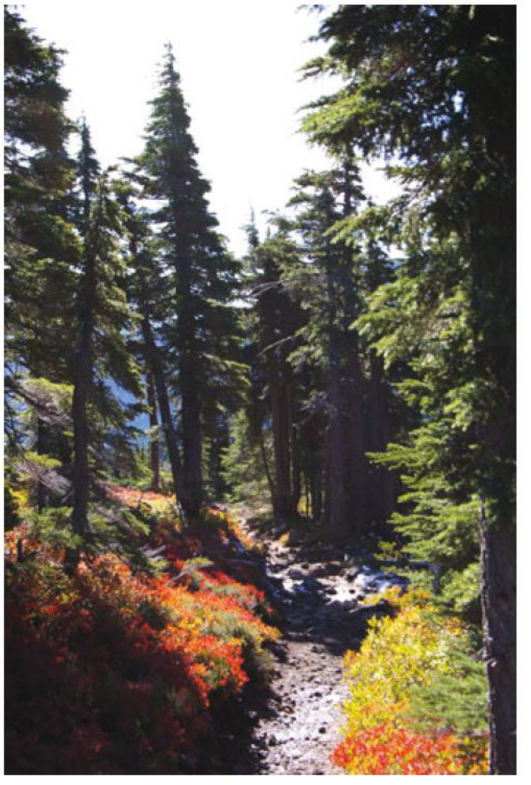

Figure 1.16: Increasing temperatures threaten to radically diminish the range of subalpine forests of both the dry eastern (left) and wet western (right) sides of the Cascade Range. Oregon Climate Change Research Institute, 2013.

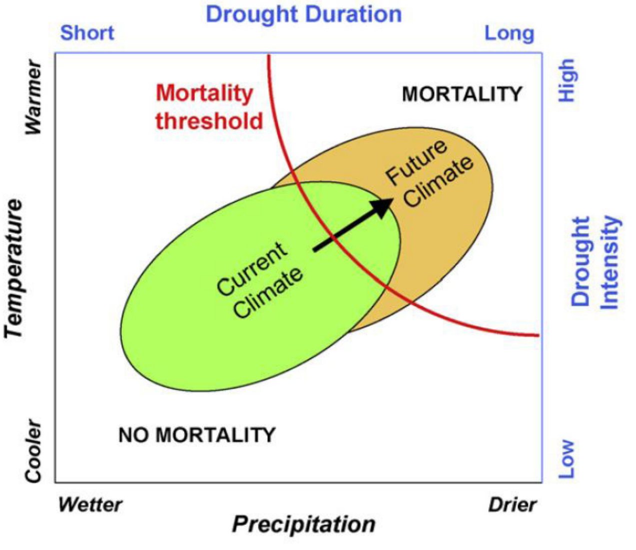

Figure 1.17: A conceptual diagram showing present and future climatic conditions in relation to temperature and precipitation, or drought duration and intensity. This illustrates how the shift will adversely affect tree mortality in the new conditions. Allen, et al., 2009.

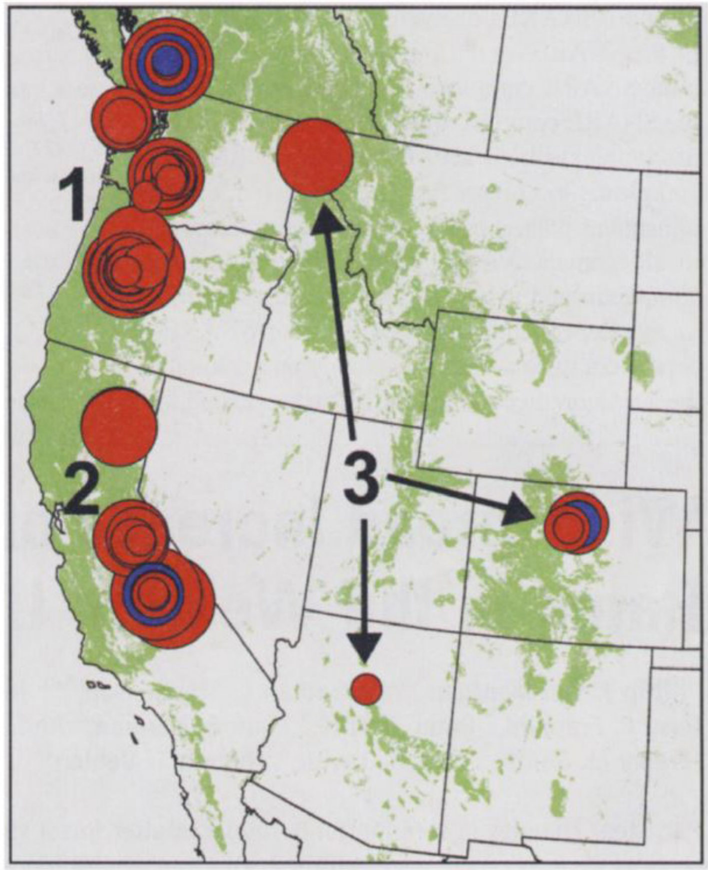

Figure 1.18: Group 1 shows forest plots in the Pacific Northwest in current climatic conditions. Red dots indicate increasing tree mortality rates, while blue dots indicate decreasing. Allen, et al., 2009.

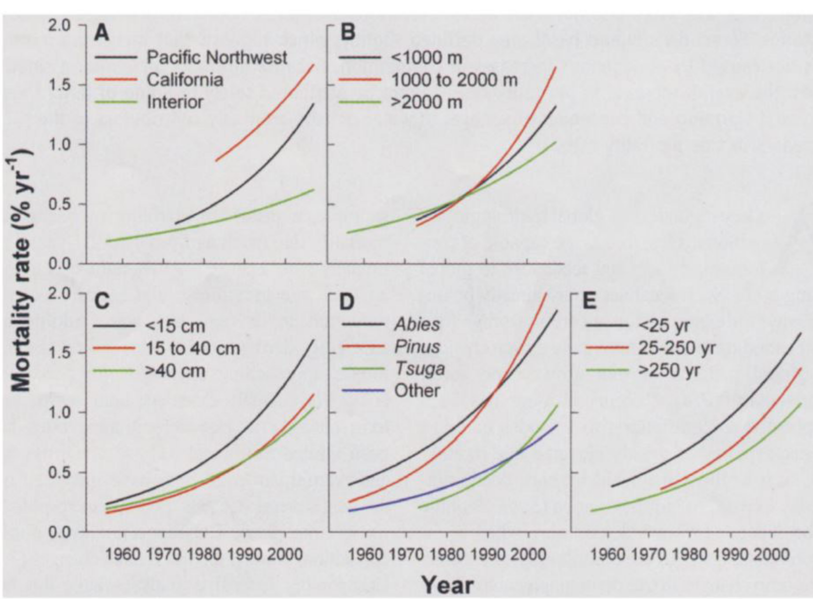

Figure 1.19: Trends of tree mortality in the Pacific Northwest indicate a sharp incline since 1970, especially for small stem diameters and members of the genera Abies or Pinus. Allen, et al., 2009.

Although OCCRI and CIG modeled climate change in the Pacific Northwest region, they relied on generalized models developed for very large areas. Given the vast topographic variance found throughout the PNW, the accuracy of such generalized models begins to break down at finer scales. For this reason, Rupp, et al. (2013) focused on 41 global climate models (GCMs) from the CMIP5 group, and determined projection reliability in relation to the Pacific Northwest, specifically. In the end, Rupp, et al. concluded that "...models closely reproduced observations for a wide variety of temperature-based metrics...[but] performed less well as judged by the precipitation-based metrics...". This conclusion is demonstrated in Rupp, et al.'s contribution to the Willamette Water 2100 project (2014; Figure 1.20), which shows agreement of an increase in temperature for all models, but a fairly even split of models predicting increased or decreased precipitation. All of the GCMs in CMIP5 were run to project climate for the years 2041 - 2070, in relation to the observed climate from 1970 - 1999. Using the high confidence models identified in their research, Rupp, et al. (2014) selected representative models for a high, reference (middle), and low climate change scenario to characterize the projected increase in temperature range for the Pacific Northwest (Figure 1.20). Based on the specificity and reliability of the selected models, the defined range of 1.44 - 5.85° F (0.8 - 3.25° C) annual average temperature increase is what will be considered for this project.

The changes and effects previously discussed all become factors to contemplate when considering the health and welfare of current and future plant specimens. Although the above projections are considered at a large scale for broad landscape processes, this same information is transferable to the urban forest and ornamental plants. Climate zones can be used to consider which plants will survive rising temperatures; current pest and disease risk can be assessed for the future based on projected shifts in growing conditions; water

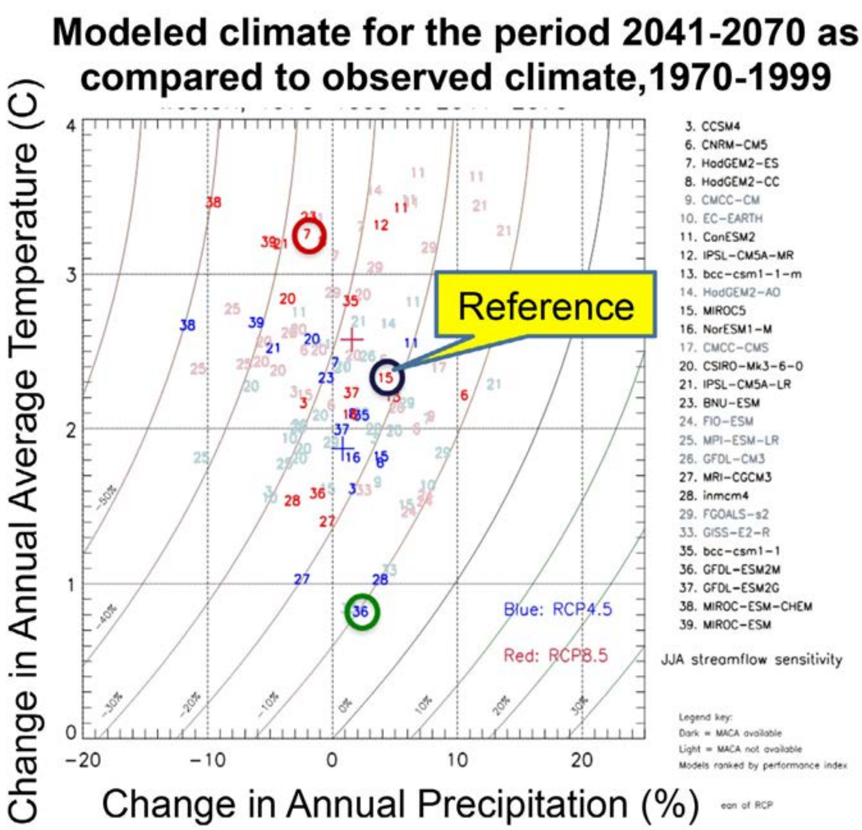

Figure 1.20: Selected high confidence climate models specific to the Pacific Northwest. Rupp, et. al., 2014.

needs and soil moisture level tolerance can be evaluated based on the likelihood of future drought. When considered together, these factors can be used to enhance the evaluation and selection of both native and ornamental plants in domesticated settings. In the case of this project, they are considered on the University of Oregon campus.

1.3 Campus Planning

There are currently several University of Oregon documents pertaining to management of landscape elements in the present, as well as into the future. The primary document regarding campus policies for items such as landscape, growth, maintenance, transportation, and open space, is the UO Campus Plan (2014). A strong emphasis is placed on open space, corridors, pathways, promenades, greens, quadrangles, axes, and edges, especially in relation to trees and other vegetation that play a vital role in defining these spaces. The plan suggests a framework for how to address changes, and the preservation and maintenance of these landscapes. However, nearly all of the framework elements are exceedingly vague, and do not contain an actual process for carrying out the action. For example, when addressing the Open-Space Framework policy regarding landscape, the plan states:

Landscape materials are assets to the campus and are to be carefully selected and properly maintained...

Appropriate Campus Operations personnel shall be consulted before planting any new plant materials on the campus.

Use native or well-adapted species for landscaping when appropriate while recognizing the importance of a variety of plant materials necessary for instructional use.

Maintain an Integrated Pest Management [IPM] approach, which carefully considers plant selection and design and minimizes use of herbicides, pesticides, fertilizers, and irrigation.

Unfortunately, all of these items lack the defining guidelines necessary to come to a conclusion and take action. How should plants be carefully selected? Which personnel should be consulted regarding planting, and what is their knowledge and process of plant selection based on? In what ways should species be well-adapted (USDA climate zone, future climatic conditions, water needs, urban conditions...)? Is there a maximum allowable use of herbicides, pesticides, fertilizers, and irrigation when considering IPM?

When possible, protection is afforded to significant trees when considering and carrying out new construction on campus (UO Campus Plan, 2014; UO Campus Tree Plan, 2008). Unless otherwise noted in this document, the term "significant" comes from the UO Campus Plan and UO Campus Tree Plan. The UO Campus Plan (2014) defines significant trees as meeting one or more of the following criteria: "Trees that help form or reinforce the identity of Designated Open Spaces and Pathways...", or "...those that have historical association, have educational value, are an excellent species example, or are designated in memory or in honor of an individual." When more detail regarding trees is necessary, the Campus Plan refers to the UO Campus Tree Plan (2008). This notion of significant campus trees is certainly something that needs to be taken into account throughout this project. If a significant tree is identified as a highly vulnerable species, this does not mean that it should be immediately removed. However, over time, these specimens should be closely monitored and replaced when conditions cause the tree to decline and become unhealthy. In these instances, one approach would be to select a replacement species with similar qualities, such as form, color and texture.

The Campus Tree Plan states that its goals include "...to have policies in place that define how to replace lost trees..." due to new campus development, and to establish "...patterns addressing tree siting and selection...". The plan contains more detail regarding the existing character, existing condition, existing canopy coverage, and the desired character for designated open spaces throughout campus. It goes on to describe the values and benefits of trees, which include "...aesthetic, environmental, educational, historical, and psychological." The Campus Tree Plan's use of the word "aesthetic" when referring to trees is described as:

Aesthetic: Trees are a primary character-defining element of the campus landscape. They enhance the aesthetics of any campus experience by defining open spaces and views, shielding unwanted noise, and providing shady areas to sit. Seasonal changes provide an ever-changing landscape, which accents the campus infrastructure and the architectural design of each building.

Of particular interest to this project is the "aesthetic" value/benefit. However, once again, the plan does not define what the specific campus aesthetic is...and this is rightfully so. The perceived aesthetic is a very subjective concept. In Chapter 3: Application, Section 3.3, this project applies what is learned from tree vulnerability ranking (Ch.2) and plant selection (Ch. 3.2) to inform a visual representation of the resulting character, should a vulnerable species be replaced with a more climate resilient alternative.

When older, large canopy trees have been removed for various reasons in the past, as well as with most newer project plantings, there has been a tendency toward replacing them with smaller species. If one of the goals of the Campus Tree Plan is to maintain and sustain the existing campus aesthetic, as defined by the UO Campus Tree Plan, this practice is clearly counterintuitive. This tendency causes concern with respect to maintaining scale, which in turn will lead to an altered future character of the campus overstory. In Chapter 3: Application, Section 3.2, this project identifies a replacement for the selected vulnerable species in question, and takes qualities such as size into consideration.

The Campus Tree Plan contains a decision tree for project responsibilities affecting trees (Figure 1.21). Again, this resource only points toward established patterns to follow, such as: tree siting and selection, long-lived tree sites, and tree replacement strategies. Although the plan offers many good suggestions for maintaining patterns and suggesting ideal placement, most policies and patterns only refer to things like tree arrangement and canopy cover, and do not address tree selection itself, much less tree selection in light of future climate. In the end, the plan recommends initiation of a tree replacement program:

Trees that are removed due to poor health have generally been replaced, and some initial work has been completed to assess the health of campus trees. A more proactive approach is necessary to replace trees in decline and maintain the character of the campus...

I contend that an additional condition of this should be to select climate resilient species to add to and replace vulnerable species.

The most current campus document that has the potential to affect change is the UO Campus Physical Framework Vision (2015), prepared by an advisory group for the Campus Planning, Design and Construction (CPDC) Office. In this document, proposed items include open space expansion, building placement, and circulation changes. Among the open space expansion suggestions is a vast "garden walk", which winds through campus. The many admirable

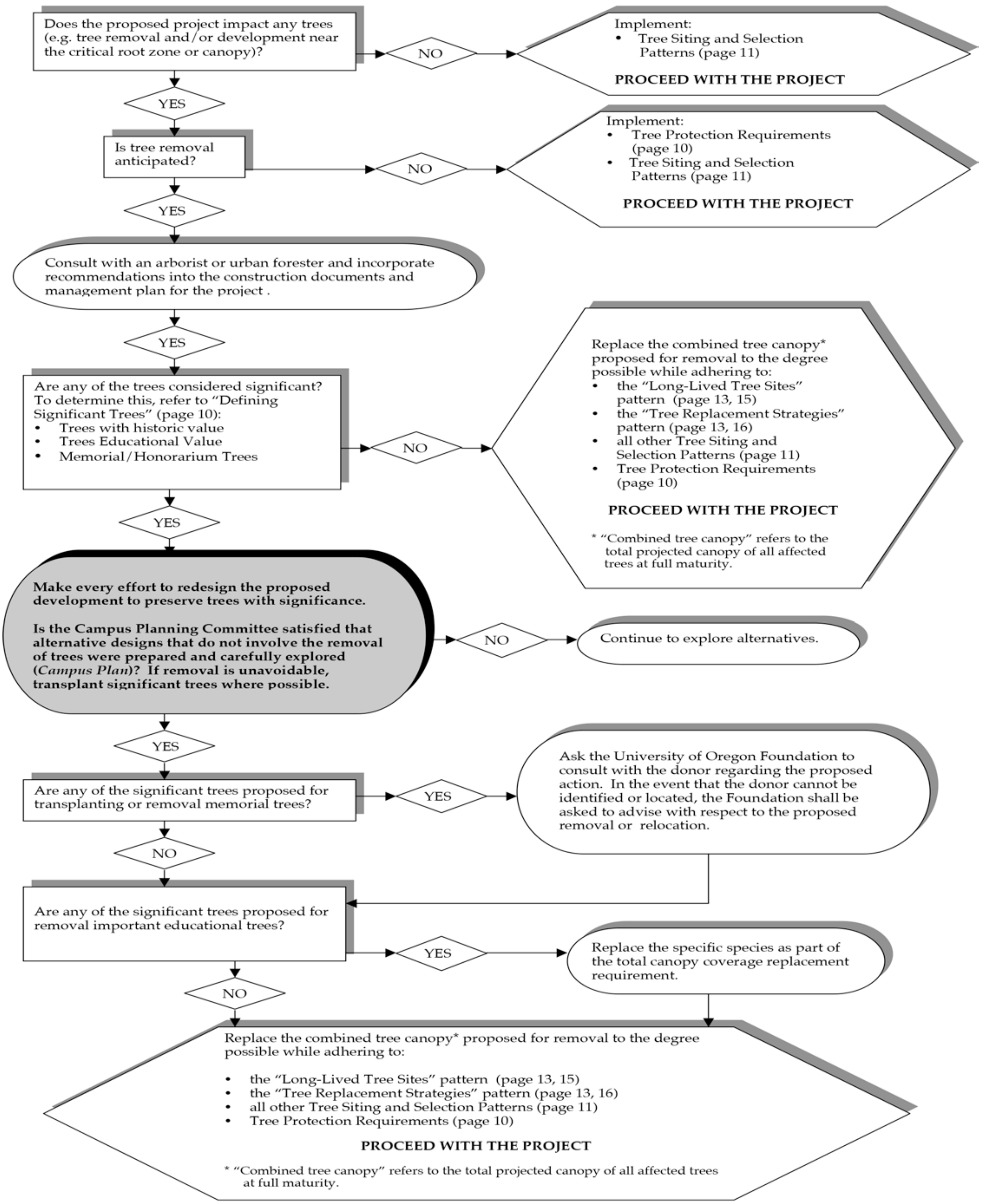

Figure 1.21: University of Oregon decision tree for project responsibilities affecting trees. Campus Tree Plan, 2008.

recommendations contain desired outcomes such as: extending "campus character", defining spaces with trees, blending old and new, and developing a vocabulary of plants. According to CPDC, the factors comprising "campus character" are: "sustainable design, outdoor rooms, engaged with the community, human-scaled growth, inclusive and transparent environments, walkable campus, informal learning spaces, and excellence in design" (University of Oregon CPDC, 2015). Many of these factors contain elements contributed or created by the landscape, such as: scale, places to gather, connection to the outdoors, sunny/shady places, positive outdoor spaces, native/well adapted species, connection to history, and outdoor classrooms. However, as with the other campus plans, no specifics are given regarding plant selection in general, nor does the Framework Vision project discuss desired long term conditions which will be influenced by climate change as the project matures. This offers an opportunity to preemptively address plant selection and envision how such decisions may affect the perception of campus.

Surprisingly, the number of campus plans that specifically acknowledge response to climate change as part of the planning process is quite small. Cornell, Dalhousie University, MIT, Harvard, and the University of British Columbia are some of the universities currently working to establish protocols to address these needs. However, only Harvard specifically calls out landscape intentions with regard to climate change:

Design landscapes and choose plant species that are likely to be robust to future environmental change...
-Harvard University Sustainability Plan, 2015

Even though this assertion is made, they too currently lack the framework and methodology to evaluate vulnerable species. Developing a resource such as this for the University of Oregon will be beneficial and transferable to other institutions as they aim to enhance landscape choices for a changing climate.

1.4 Plant Information

Many resources exist containing plant characteristics and growing requirements. However, as demonstrated above, such resources are rarely compiled and distilled into a targeted form, which can then be included as an integral part of the decision making process. In the case of this project, climate change projections, specifically in relation to temperature increase, are an added element to consider. Both national and regional resources are utilized to glean and cross reference plant information for trees found on the UO campus.

Several previous Master's Projects at UO have addressed climate change in regard to tree resiliency and benefit potential (Green, 2013; Ellison, 2012; Voelckers, 2015). In all instances, a matrix was developed based on the goals of the project, and trees were scored and ranked. In the case of Green, the matrix was focused on climate and urban adaptability in the City of Eugene, OR. Ellison used Bend, OR as a case study for resiliency of existing tree species. Her matrix took into account resilience to climate change, pests and disease, and city conditions, which was then followed by a benefits analysis for each species. Voelkers had a different emphasis, as he was looking at the benefits of trees in an agricultural landscape in the Okanogan Valley of Washington state. He, too, developed a matrix including climate resiliency, but also included economic and ecological benefits to farmers.

This type of method (a ranking system based on development of a matrix) offers the advantage of tailoring the matrix to address the specific areas of concern, in the specific environment under study. My focus is on climate resiliency specifically in relation to temperature increase and the associated ills that follow, such as decreased soil moisture, drought conditions, and an increase in pest and disease risk. The development of a matrix enables a tailored exploration of UO campus conditions, and is useful for identification of existing vulnerable species, as well as for ranking candidates for replacement species.

1.5 Goal, Objectives and Process

Key Project Goal:
Create a matrix for evaluating climate vulnerability of tree species on the University of Oregon campus.

Objectives:
1) Identify prominent species that are vulnerable by using the matrix
2) Develop a set of replacement species candidates
3) Evaluate potential replacement species using the matrix
4) Propose a less vulnerable species that minimizes changes to campus character
5) Compare visual qualities of a current vulnerable species with the proposed replacement species

Figure 1.22 denotes the process and tasks necessary to complete the project.

The matrix is intended to address the needs of campus planning and to aid in the decision making process for the University. In the coming chapters, I: describe the development and rationale for my method (an evaluation matrix), including its use to assess prominent campus tree species (Chapter 2); demonstrate application of the matrix to evaluate candidates and select a replacement species, and to visualize the replacement species in the landscape (Chapter 3). Chapter 4 goes on to discuss the project, including limitations, recommendations, and a summary.

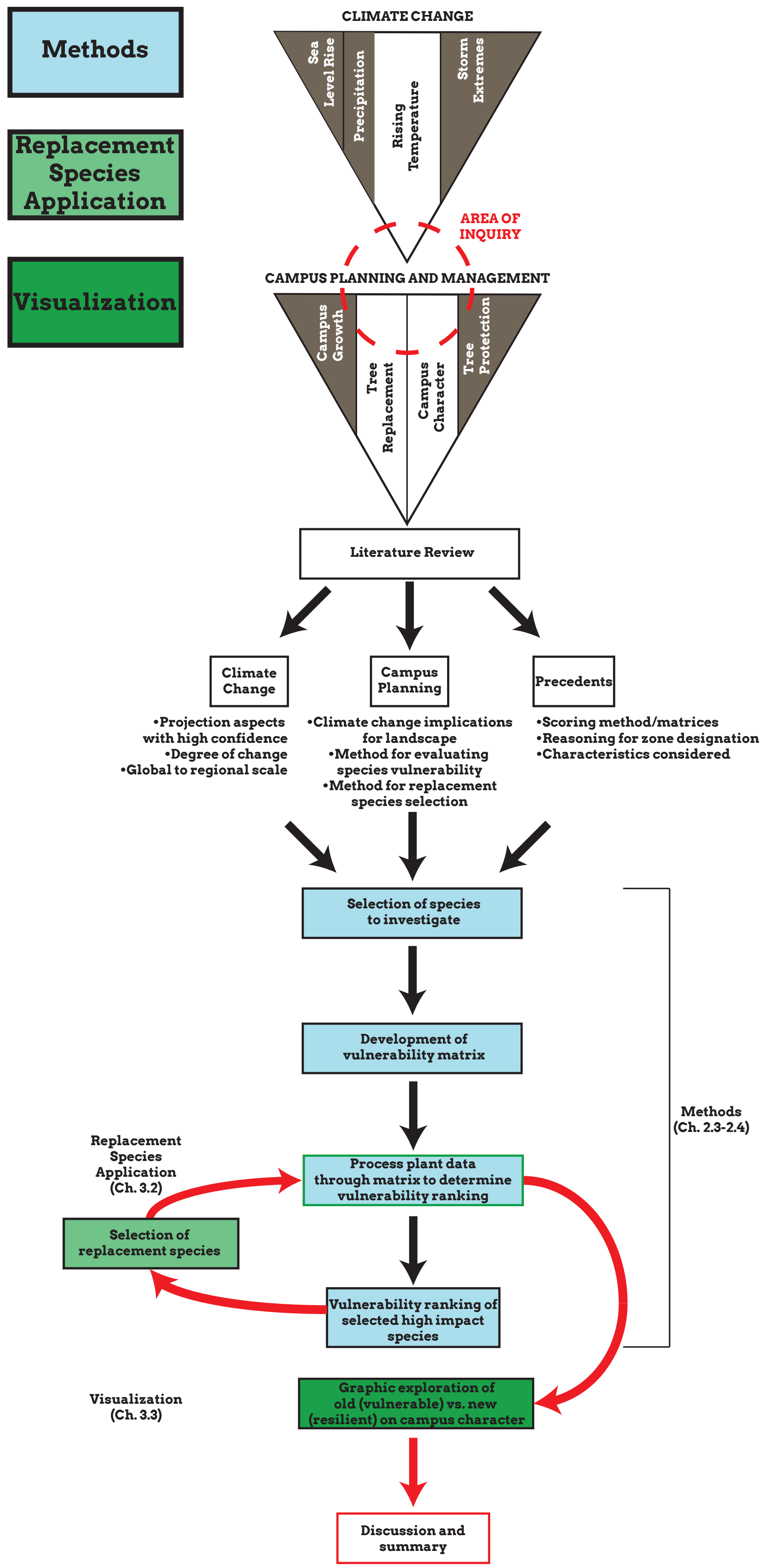

Figure 1.22: Process diagram. Author, 2016.

Chapter 2: Methods

2.1 Introduction and Overview

In the previous chapter we looked at climate change projections ranging from a global to regional scale. The set of models described by Rupp, et al. (2013) were chosen as the focus set of projections, as they offer the highest confidence levels for the Pacific Northwest. For the purposes of this project, the rising average annual temperature was selected as the focus within this set of models. This temperature increase is projected to have several corresponding effects, including hardiness zone shifts, soil moisture content, and pest/disease risk (Monleon, 2015). It was also established that the UO campus does not have a defined evaluation process for vulnerability, replacement, or effects on campus character for the campus tree resources (replacement and character are addressed in Chapter 3: Application).

This chapter introduces the development of a matrix for the purpose of identifying campus tree species that are vulnerable to rising temperatures resulting from climate change. The progression leading to the formation of the matrix includes the selection of species to be evaluated, the identification of plant information resources, and the definition of "vulnerability" for this project (Figure 2.1 diagrams this sequence). Scoring of species takes the institutional context into consideration. For example, the level of care is higher than a typical urban forest or street trees. Matrix categories were selected based on anticipated effects of temperature increase caused by climate change: zonal tolerance, soil moisture tolerance, water needs, and pest and disease risk. The matrix logic and scoring are discussed in the following sections.

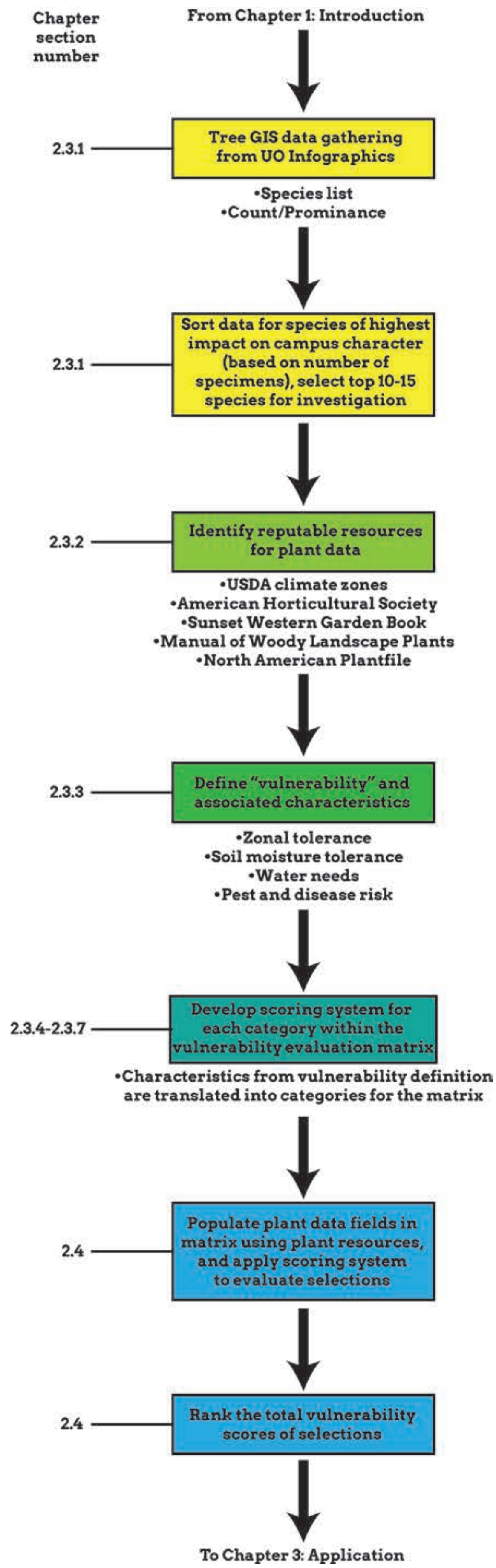

Figure 2.1: Methods process diagram.

2.2 Research Strategy

The strategy of inquiry used in this project, as defined by Deming and Swaffield (2011), lies firmly in the Constructionist row of the nine possibilities (Figure 2.2). This category of strategies straddles the line between objectivism and subjectivism. Further, the specific type of strategy used within the Constructionist category is Classification, which falls in the Inductive column of the chart. In description of these terms, Deming and Swaffield go on to say:

Classification strategies produce new knowledge by sorting and structuring data into a system of organization, using typical properties, patterns, behaviors, or themes.

and:

Inductive research…is the generation of descriptions and explanations of relationships in the world through strategies of inquiry grounded in the world of experience and empirical evidence.

In this work, the term "experience" found in the Inductive Research definition is not referring to the experience of professionals obtained through a process such as interviews. Rather, it refers primarily to gleaning information from professional publications and personal experience.

	Inductive (theory building)	Reflexive (theory/practice interactions)	Deductive (theory testing)
Objectivist strategies	Description	Modeling and correlation	Experimentation
Constructionist strategies	Classification	Interpretation	Evaluation and diagnosis
Subjectivist strategies	Engaged action	Projective design	Logical systems

Figure 2.2: Strategies of Inquiry chart, from Deming and Swaffield (2011). The inquiry strategy for this project uses Deming and Swaffield's category of Classification.

Assumptions about Knowledge & the World	The Purpose of Knowing	Examples of Theoretical Perspective	Examples within Landscape Architecture	Typical Research Strategies	Typical Research Methods	Predominant Modes of Representation
Objectivism	**Instrumental/ Predictive** *What, where & how?*	[Post]positivist natural sciences	Landscape perception studies Landscape ecology.	Descriptive survey Modeling Experimentation & Quasi-experiments	Measurement and mapping Questionnaire surveys Statistical analysis Alternative futures	Mathematical symbols, with written interpretation
[Social] Construction	**Interpretive** *Who, when and why?*	Pragmatism Hermeneutics Symbolic Interaction Phenomenology	Design process Place studies Community studies Historical studies Project evaluations	Classification Ethnography Discourse Analysis Iconography Historiography Evaluation and Diagnosis	Close observation Interviews and focus groups Documentary analysis Life histories Post Occupancy Evaluation	Written narrative, with illustrative diagrams and photographs
Subjectivism	**Critical** *What are the consequences?* *How might things be done differently?*	Critical Inquiry Post-structuralism Feminist	'Expressivist' Theory 'Critical Visual Studies' Design scenarios	Action Research Projective Design Logical systems & argumentation	Deconstruction Reflection Creative Intervention	Diverse media -written -graphic -aural -performance

Figure 2.3: Foundations for Knowledge Claims chart, from Deming and Swaffield (2011). Construction is an interpretive approach to inquiry, and contains a range of possible research strategies. This project utilizes the Classification research strategy, coupled with Documentary analysis as a research method.

For classification, "purposive" sampling was used, as it "…seeks out data expected to be most helpful in addressing the research question" (Deming and Swaffield, 2011). This was helpful in narrowing the range of species selected, as well as information pertaining to the evaluation categories. Also, the specific method of classification used "…employs the techniques of an inventory of stores-that is, collecting, sorting, and (re)grouping-in order to identify belonging…" (Deming and Swaffield, 2011). The primary research method employed as a "foundation for knowledge claims" (Deming and Swaffield, 2011) is documentary analysis (Figure 2.3).

2.3 Matrix Development for Vulnerability Evaluation

Figure 2.4 illustrates the starting point for thinking about a vulnerability evaluation matrix. What follows is the process used to identify and populate the table with species, categories and data.

Species to be evaluated	Categories/characteristics to be evaluated

Figure 2.4: Beginning template for thinking about matrix development.

2.3.1 Species Selection

How should tree species be selected for examination?

I began by speaking with University of Oregon (UO) Campus Operations and the UO InfoGraphics Lab to determine the availability of campus tree data. A GIS database is maintained which contains a list of all individual trees, including data for each specimen's species and location (UO InfoGraphics Lab, 2015). As this list contains upwards of 4200 trees representing upwards of 460 species and varieties, it is necessary to focus the area of inquiry. These data are sorted by species and a count is performed in order to determine the most numerous, and by extension prominent, tree species on the UO campus. Although Vine Maple (*Acer circinatum*) is the species with the highest number, it is excluded from this study due to the tree's small size. This study focuses on larger tree species which have a greater impact as viewed and experienced both near and far. This study makes the assumption that the large tree species that occur in the greatest numbers both: a) provide characteristics that greatly influence the feeling and character of campus, and b) have the highest probability of altering the campus character should there be a drastic change in numbers due to climate change. Therefore, the top 10 - 15 species (based on number of specimens on campus) are chosen for further investigation of vulnerability to climate change (Figure 2.5).

2.3.2 Data source selection

Which data sources should be utilized to gather plant information?

The first resource to be established is the United States Department of Agriculture (USDA) Plant Hardiness Zone Map (Figure 2.6). This is a government sanctioned system based on minimum winter temperatures that is the most widely used national standard for defining plant hardiness zones. Because of this, the majority of resources containing information about specific species use the USDA zone designation when describing temperature thresholds for plants. One such resource is the *American Horticultural Society A-Z Encyclopedia of Garden Plants* (Brickell, 2004). The American Horticultural Society (AHS) was established in 1922, and is one of the oldest gardening organizations in America. The large following and member group speaks to the quality of information that they provide. Another resource is the *Manual of Woody Landscape Plants* (Dirr, 2009). The author is a professor of horticulture, and has written books and articles prolifically, for which he has received many prestigious

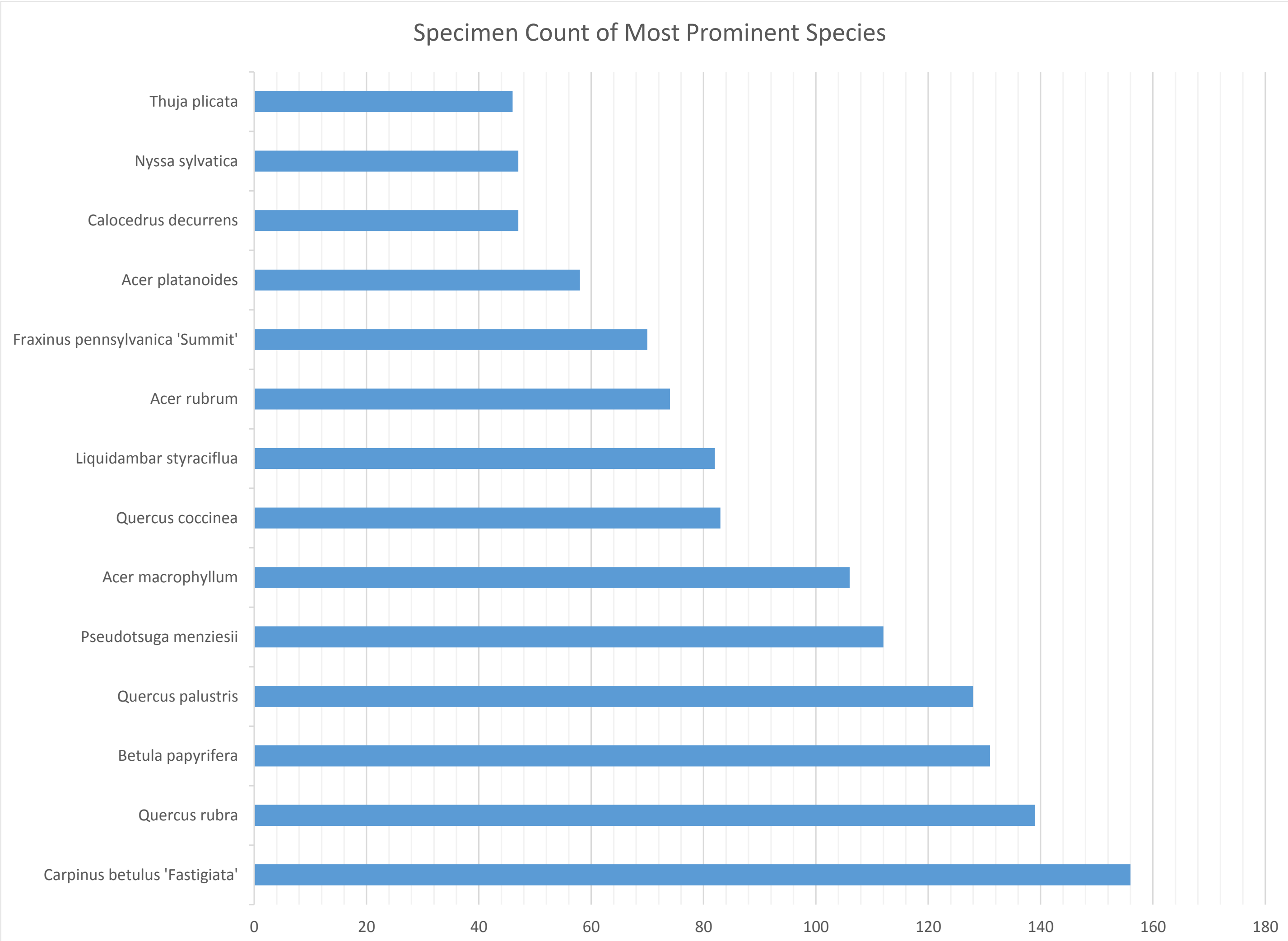

Figure 2.5: Selected species for evaluation, based on prominence on the UO campus.

awards. Since the AHS and *Manual of Woody Landscape Plants* have a vast national emphasis, I want to include a resource that is more specific to the Pacific Northwest in order to obtain regionally informed data. For this reason, I use *The New Sunset Western Garden Book* (Brenzel, 2012). In the west, this is a well-respected resource, although it does not use the USDA national standard for plant hardiness zones. This is an issue that will be addressed in the corresponding section below. Lastly, although these three sources contain scattered information regarding pests and disease, none of them are consistent and comprehensive enough to develop a scoring system for these aspects of vulnerability. The resource which does provide comprehensive pest and disease information is the *North American Plantfile* (Hightshoe and Groe, 1998). Obtaining all necessary information regarding pests and disease from one source is the best way to have consistent data across all species in question. Gary Hightshoe is a Professor of Landscape Architecture, and has published books and articles regarding plant material, solidifying his expertise with various awards.

2.3.3 Defining Vulnerability

How is vulnerability defined?

In the Introduction (Chapter 1), I discussed climate change and narrowed my focus to the aspect of an increased annual average temperature. With rising temperature comes a suite of associated complications to plant survival and success, such as: zonal tolerance, soil moisture requirements, plant water needs, and pest and disease risk. The previous chapter demonstrated that literature supports the likely exacerbation of pests and disease due to temperature increase and drought conditions (OCCRI 2013, Allen, et al. 2009).

The *Merriam Webster Dictionary* defines "vulnerable" as:

1: capable of being physically or emotionally wounded
2: open to attack or damage

As plants are susceptible to damage due to their lack of mobility and defense, they certainly qualify as "capable of being wounded," whether it is caused by direct or indirect factors. This project is first concerned with the direct factor of temperature, which in turn effects water availability. Stressors such as increased temperatures and low water availability can lead to increased risk of other indirect factors, such as pests and disease, which would exacerbate any weaknesses and further contribute to decline. Therefore, for the purposes of this project and due to the projective nature of climate change, vulnerability takes into account future conditions caused either directly or indirectly by increased temperatures:

Vulnerable:

Ability to survive is:

- *directly threatened* due to increased temperatures resulting from climate change;

- *indirectly threatened* due to the associated factors of limited soil moisture, plant water needs, and pest/disease risk which are further exacerbated by changes in climate.

The categories of Zonal Tolerance, Soil Moisture Tolerance, Water Needs, and Pest and Disease Risk are chosen as the best descriptors of vulnerability for the purpose of the matrix. This is based on the most severe effects caused by an average annual temperature increase as predicted by high confidence models for the PNW (Rupp, et al., 2014), coupled with the lowest cost and effort required by the university to keep trees healthy. It should be noted that certain assumptions are made as to the high level of care provided to plants in the University setting. Among these are soil improvements (including amendments and drainage), irrigation (within reason), and maintenance (including integrated pest management and pruning).

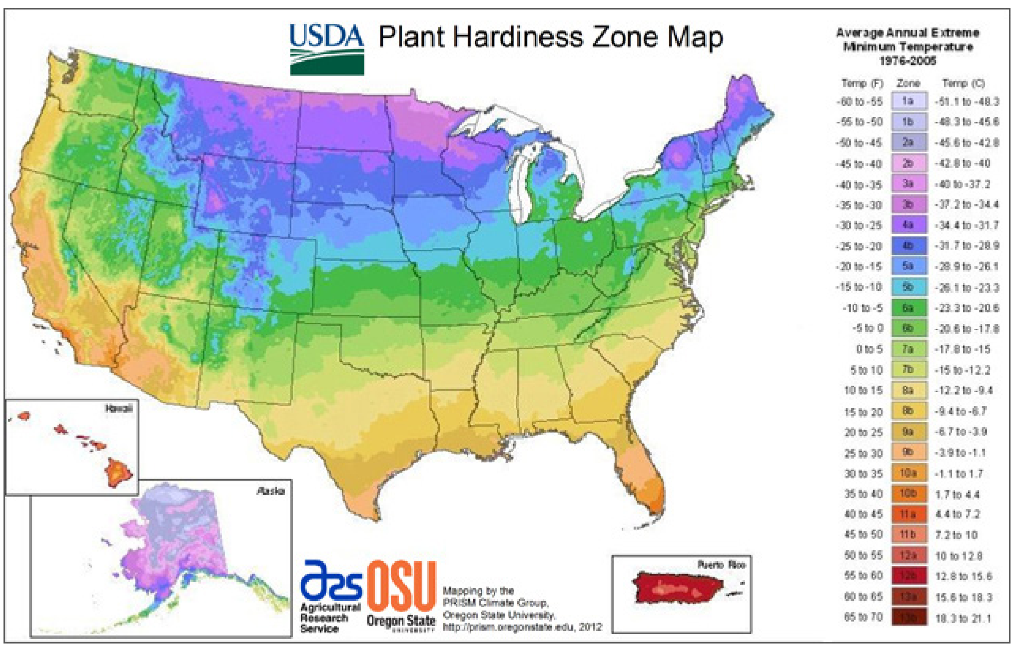

Figure 2.6: USDA Plant Hardiness Zone Map. http://planthardiness.ars.usda.gov/PHZMWeb/Maps.aspx

2.3.4 Defining and Scoring Zonal Tolerance

How should a zonal tolerance range be established and scored as a category in the matrix?

The current USDA zone for Eugene, Oregon is 8b, which is based on average annual minimum winter temperatures of 15 - 20˚ F. Zone 8a indicates winter lows in the range of 10 - 15˚ F, while Zone 8 as a whole indicates winter lows in the range of 10 - 20˚ F. (See Figure 2.6 for the complete USDA zone map.) Using the climate change models described by Rupp, et al. (2013 and 2014) that are most reliable for the Pacific Northwest, the models project an increase in annual average temperature of 1.4 - 5.9˚ F. To be cautious regarding heat/drought tolerance, the upper limit of the range is applied to the range of tolerance that is necessary in order to minimize vulnerability.

Currently there is no widely accepted zone system that also takes average annual maximum temperatures into consideration. The AHS has developed a Heat Zone Map (Brickell, 2004) which is used in conjunction with the USDA hardiness zones that has begun to address the issue, however it is not widely used. The Sunset zones take high and low temperatures, humidity, and precipitation into account. However, their system is limited to the western U.S., the methods used for determination of zones are not transparent, and it does not reference or work in conjunction with the USDA hardiness zones. Because of this, it is necessary in this project to make assumptions in order to use the USDA hardiness zones as guides for an increase in average annual maximum temperatures.

The Oregon Climate Service at Oregon State University wrote a report concerning the climate of the Willamette Valley (Taylor, 1993), stating:

The climate of the Valley is relatively mild throughout the year, characterized by cool, wet winters and warm, dry summers. The climatic conditions closely resemble the Mediterranean climates which occur in California, although Oregon's winters are somewhat wetter and cooler.

Monleon (2015) concluded that species range shift of trees in the western states of California, Oregon and Washington is significant toward colder climates, indicating a northern shift. Generally, an increasing USDA climate zone number does not necessarily correspond to overall higher maximum temperatures. For example, northern Texas has a USDA zone of 6, but the AHS Heat Zone Map indicates that it receives 90 - 120 days per year over 86˚ F. In comparison, Eugene has a higher USDA zone of 8, but corresponds to only 14 - 30 days per year over 86˚ F. However, the California/ Mediterranean climate zones that are present and migrating north to Oregon do appear to have this characteristic. The western side of northern California contains USDA zones 8 and 9, which correspond to heat zones 6, 7 and 8. These heat zones have a range of 45 - 120 days per year over 86˚ F. Therefore, the assumption is made in this project that as USDA climate zones are projected to increase, higher temperatures will follow due to the Mediterranean nature of the region.

Although annual average temperature is projected to increase, this does not remove the current threat and fluctuation of winter minimum temperatures, on which the USDA zones are based (Figure 2.7). For this reason, it is sensible to include Zone 7 (one below the current Zone 8) in the ideal tolerance range, as it is not uncommon for temperatures to fall below the range of USDA Zone 8. Outside of extreme temperature/weather events, temperatures are still projected to rise in all seasons (OCCRI, 2013). In addition, Monleon's findings (2015) of a northern range shift of tree species in the western states suggests that those zones that are currently higher than

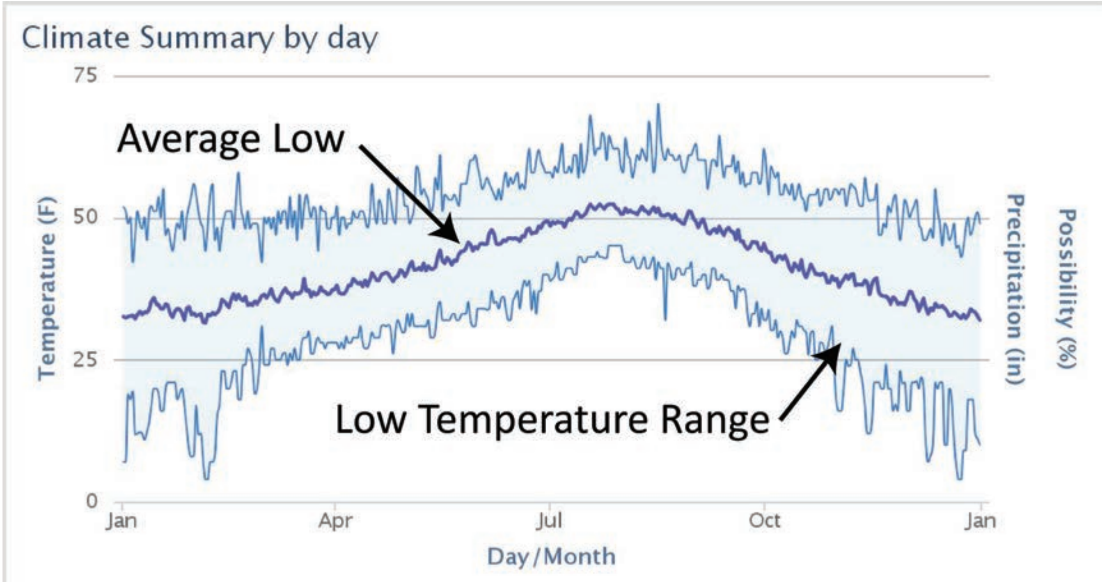

Figure 2.7: Average and low temperature extremes throughout the year for Eugene, OR. Temperature extremes below the given USDA zone 8b (15 - 20° F) for Eugene still need to be taken into consideration for zonal tolerance. These are not regular events, but occur often enough to be of concern, and tolerance of low extremes bolsters a plant's ability to survive. http://www.climatespy.com/climate/summary/united-states/oregon/mahlon-sweet-fld

Eugene may contain suitable species for future conditions. The effects of higher temperatures are further addressed in other categories of the matrix. Plant zone data are rarely given in half zone increments, so a full zone is utilized on either side of the current climate zone (8), to encompass a broad range of possible future temperatures. Therefore, the ideal plant hardiness zone range selected for climate change adaptability on the UO campus includes USDA zones 7 - 9.

Zonal tolerance to both current and future conditions is crucial to tree survival and success. It is the most basic aspect exerting influence on a tree's environment, and the least controllable with management practices. To reflect the importance of this category to plant survival and success on the UO campus in the face of climate change, it is weighted relative to the other categories.

Trees that contain USDA zones 7, 8 and 9 in their accepted range are scored 2 points. Trees that contain the current zone (8), as well as either zone 7 or 9, are assigned a score of 1 point. Trees that do not include zone 8 are given a score of 0 points. Since not all sources agree on hardiness zone ranges, several references are used. To counteract the variation in hardiness, the zonal ranges from two sources (Dirr and AHS) are scored separately and then averaged. Sunset is not included in this because it does not use USDA hardiness zones.

As previously noted, the *AHS A-Z Encyclopedia of Garden Plants* and Dirr's *Manual of Woody Landscape Plants* share the use of USDA climate zones. The third source for zonal tolerance, *The New Sunset Western Garden Book*, provides their own zone system (Figure 2.8), which differs from USDA. This zone system is meant to take into account factors such as precipitation, humidity, and high temperatures/heat. Eugene has a Sunset climate zone of 6. However, due to the nature of Sunset's zone assignments, it is not as simple as applying a temperature shift number to find the range of zones on either side of zone 6. Therefore, the Sunset zone range was used to confirm that a species is acceptable in the current zone of 6, and if so, it is considered in agreement with the other two sources, and scores 0 (no effect). However, if the given species is on the edge/fringe of the Sunset range, for example if the upper or lower extreme of the plant's range is zone 6, then

Figure 2.8: The New Sunset Western Garden Book zone map for Western Oregon. http://www.sunset.com/garden/climate-zones/sunset-climate-zone-oregon

this information is used to deduct points. In a situation such as this, the deduction taken is a half point, because it suggests that there is disagreement with other sources regarding zonal tolerance.

The above scoring system yields a maximum score of 8 points. Two points are awarded if USDA zones 7 - 9 are in the accepted range given by Dirr. Two points are awarded if USDA zones 7 - 9 are in the accepted range given by AHS. These two scores are then averaged, yielding a maximum score of 2 points. Zero points are then deducted from this average if Sunset zone 6 is contained within the larger accepted zone range given by *The New Sunset Western Garden Book* (i.e. zone 6 is not the starting point or ending point of the accepted range given). As previously stated, to reflect the importance of this category to plant survival and success on the UO campus in the face of climate change, it is given the highest weight over other categories by multiplying the final point total by four, thus yielding a total maximum score of 8 points (see Figure 2.9 for an example of the scoring system).

2.3.5 Defining and Scoring Soil Moisture Tolerance

How should a soil moisture tolerance be established and scored as a category in the matrix?

Soil moisture content is an important factor when considering climate change. In the case of increased annual average temperature, this will cause increased evapotranspiration from plants, and greater evaporation in general, thus causing soils to dry out faster than at lower temperatures. In addition to higher temperatures, it is projected that warm season rain events will be fewer and farther between, causing an increase in drought conditions. On the other side of the spectrum, the PNW is known for long wet seasons. Although

Scientific Name	Common Name	Dirr	AHS	Sunset	Score	Multiplier	Final score
Fraxinus pennsylvanica 'Summit'	Green Ash	3-9	4-9	A2, A3, 1-6	1.5	4	6

Figure 2.9: Scoring zonal tolerance. An example of scoring based on the resources utilized and designated importance of the category. Zones 7, 8 and 9 are all included in the ranges provided by Dirr and AHS, therefore 2 points are awarded for each. The average of these scores is 2. However, the Sunset zone of 6 is at the very fringe of accepted values of tolerance, therefore ½ point is deducted. This yields a score of 1.5, which is multiplied by 4 given the assigned importance of the category, resulting in a final score of 6.

precipitation projections are not at a high confidence level, the PNW is not predicted to undergo a drastic change, meaning that it remains important for trees to be tolerant of high soil water content for much of the year. For these reasons, the soil moisture tolerance range selected includes wet, average and dry conditions. Plants that can tolerate "wet feet" as well as drought receive the highest scores.

Similar to hardiness zones, different sources vary slightly when referring to soil moisture tolerance. In the case of the *American Horticultural Society A-Z Encyclopedia of Garden Plants*, this range is only given per genus, without further detail at the species level. In the case of *The New Sunset Western Garden Book*, information is incomplete regarding soil moisture, in favor of water needs. Because of this, Dirr's *Manual of Woody Landscape Plants* is used as the sole source for species specific information. Species that are able to tolerate wet, average and dry soil moisture conditions are given a score of two points. Those that can tolerate either wet or dry conditions in addition to average conditions receive a score of one point. Lastly, plants that can only tolerate one of the three conditions receive a score of zero (Figure 2.10).

2.3.6 Defining and Scoring Water Needs

How should water needs be established and scored as a category in the matrix?

Scientific Name	Common Name	Dirr	Score
Fraxinus pennsylvanica 'Summit'	Green Ash	wet, avg, dry	2

Figure 2.10: Scoring soil moisture tolerance. An example of scoring based on the number of moisture levels tolerated (3 levels=2 points).

In the institutional setting of the University of Oregon campus, it is very important to consider the water needs of trees. Large scale and long term irrigation can be quite costly, and as temperatures rise and water supplies decrease, this will only get worse. Therefore, minimizing the inputs required to keep trees alive and healthy is preferable, so those needing the least amount of applied water are favored.

As is the case with previous characteristics, sources do not always agree or have complete information about water needs. Many sources only spoke of soil moisture tolerance, without giving specifics about the actual water needs of the species. However, *The New Sunset Western Garden Book* provides specific water needs information at the species level, making it an ideal source for this category. The scoring system is set so that more points are awarded for lower water needs. Sunset specifies water needs as: ample (very high), regular (high), moderate, or low. The lowest water need/ tolerance in the range of a species is used to assign a score. Species with low water needs score two points; moderate water needs score one point; high and very high water needs score zero points.

The above scoring system for water needs yields a maximum score of 2 points. Due to the costs and difficulties associated with large scale irrigation and maintenance by UO, as well as a reduced water supply and increased drought conditions in a climate with rising temperatures, this category is considered the second most important to plant survival and success on the UO campus in the face of climate change. Because of this, the final point total is multiplied by two, thus yielding a total maximum score of 4 points (Figure 2.11).

Scientific Name	Common Name	Sunset	Score	Multiplier	Final score
Fraxinus pennsylvanica 'Summit'	Green Ash	high, med	1	2	2

Figure 2.11: Scoring water needs. An example of scoring based on the lowest given water need in the range and designated importance of the category. A moderate water need yields a score of 1, which is multiplied by 2 given the assigned importance of the category, resulting in a final score of 2.

2.3.7 Defining and Scoring Pest and Disease Risk

How should pest and disease risks be established and scored as categories in the matrix?

It was established in the introduction chapter that rising temperatures and drought stress conditions are projected to aggravate and intensify both pest and disease threats/occurrence (OCCRI 2013, Allen, et al. 2009). Although both can have the end result of jeopardizing tree survival, they are separate issues, and are addressed individually in two separately scored categories. Species that are currently prone to pests or disease will likely have an even greater risk as temperatures rise and conditions for some pest and disease life cycles become more favorable. In addition, there is an unknown factor of the arrival of additional pests/diseases.

Consistent and complete information is again very difficult to acquire from sources, and most sources are at the national level or in regions other than the PNW. However, one source contains consistent information for all of the species being evaluated: *North American Plantfile* (Hightshoe and Groe, 1998). Species are listed as having frequent, occasional, or no known problems for pests and disease (separately). Those with frequent problems that threaten survival, health and/or appearance receive a score of zero. Those species with occasional problems that do not threaten survival, health and/or appearance receive a score of one. Any species with no known/documented problems due to pests and disease receive a score of two. A maximum score of two is possible for each category of pests and disease, totaling four points (Figure 2.12).

Scientific Name	Common Name	NA Plantfile	NA Plantfile	Score
		Pests	Disease	Total
Fraxinus pennsylvanica 'Summit'	Green Ash	1	1	2

Figure 2.12: Scoring pest and disease risk. An example of scoring based on severity of risk associated with pests and disease. Both categories indicate occasional problems, therefore they both receive a score of 1.

2.4 Completed Vulnerability Matrix and Scores

After applying the above scoring system to the selected species of interest (Figure 2.5), the complete and populated matrix is shown in Figure 2.13. These scores indicate 3 species as the most vulnerable: Paper Birch, Douglas-fir, and Norway Maple. According to the UO campus tree GIS data, these trees are widely represented on campus, with specimen numbers totaling 131, 112, and 58, respectively. These numbers correspond to the 3rd, 5th, and 11th most abundant species on campus. Many specimens of these species are found in prominent places on campus, as well. For example, there is an established allee' of Douglas-fir trees along the Deady Hall Walk Axis, as well as many noteworthy specimens in the Old Campus Quadrangle.

In the next chapter, characteristics of the most vulnerable species indicated above, such as size, foliage type and form, are utilized to help inform the selection of replacement species. Zonal requirements play a large role in creating an initial pool of candidates. The matrix developed in this chapter is then be applied to a selection of candidates to determine those less vulnerable to increased temperatures resulting from climate change.

Scientific Name	Common Name	Zone	Soil Moisture	Water Needs	Pest	Disease	TOTAL
Acer macrophyllum	Bigleaf Maple	8	2	2	2	2	16
Nyssa sylvatica	Black Tupelo	8	2	2	2	2	16
Liquidambar styraciflua	American Sweetgum	8	1	2	2	2	15
Acer rubrum	Red Maple	8	1	2	1	1	13
Calocedrus decurrens	California Incense Cedar	4	2	4	2	1	13
Quercus coccinea	Scarlet Oak	8	1	2	1	1	13
Fraxinus pennsylvanica 'Summit'	Green Ash	6	2	2	1	1	12
Quercus palustris	Pin Oak	4	1	2	2	2	11
Thuja plicata	Western Red Cedar	2	2	2	2	2	10
Carpinus betulus 'Fastigiata'	Pyramidal European Hornbeam	4	0	0	2	2	8
Quercus rubra	Northern Red Oak	6	0	0	1	1	8
Pseudotsuga menziesii	Douglas-fir	0	1	4	1	1	7
Acer platanoides	Norway Maple	0	1	2	1	2	6
Betula papyrifera	Paper Birch	-2	1	0	0	1	0

Figure 2.13: Summary of score totals. The lowest three point totals are highlighted, and indicate the most vulnerable species.

Chapter 3: Application

3.1 Introduction and Overview

The previous chapter established a research strategy and applied it to developing a vulnerability evaluation matrix for campus tree species. Tree species were selected for investigation based on those that were most numerous, and by extension prominent, on the UO campus. Reputable resources were identified for gathering significant plant data, and "vulnerability" was defined for this project. Categories meriting inclusion in the matrix were based on projected temperature increase due to climate change, and the associated complications to plant survival and success. The selected categories were: Zonal Tolerance, Soil Moisture Tolerance, Water Needs, and Pest and Disease Risk. These were weighted so that Zonal Tolerance exerted the most influence, followed by Water Needs, with Soil Moisture Tolerance and Pest and Disease Risk having equal weight and less influence. When scores were tallied for the selected species, those with the lowest scores were deemed most vulnerable to projected rising temperatures due to climate change. The three most vulnerable species, beginning with the most vulnerable, were: *Betula papyrifera*, *Acer platanoides*, and *Pseudotsuga menziesii*.

This chapter presents an additional application relating to the output of the matrix developed in Chapter 2. After determining a pool of replacement candidates, the matrix is used to rank the species for vulnerability as part of the selection process (this sequence is diagrammed in Figure 3.1, and discussed in Section 3.2). After a replacement species is selected for one of the identified vulnerable species, Section 3.3 addresses the visualization of the replacement species in the campus landscape. *Pseudotsuga menziesii* is used as an example to demonstrate how the matrix can be used to evaluate potential replacement species. For this example, the objective is to select a species that resembles the qualities of

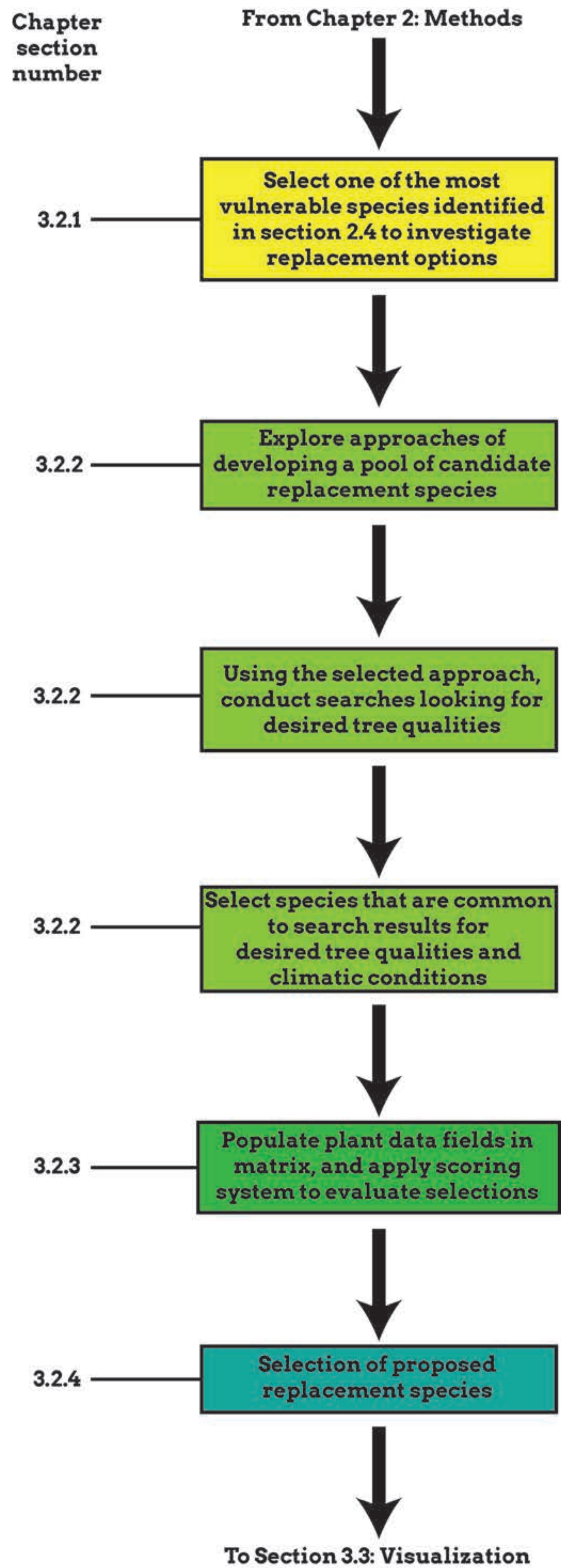

Figure 3.1: Application process diagram.

P. menziesii (for example, height, foliage type, and form) as closely as possible to maintain campus character, and that is less vulnerable to the effects of climate change.

3.2 Replacement Species Application

This section discusses the selection of one species identified in Chapter 2 as highly vulnerable as an example of selecting and evaluating a replacement species. The selection method for replacement species candidates is then outlined, searches for specific qualities are carried out, and a list of candidates is compiled. This time the matrix is used to find species with the highest score, indicating low levels of vulnerability. The processes, reasoning and selection of a replacement species are discussed in the following subsections.

3.2.1 Selection of Vulnerable Species to Investigate

Of the three species identified as most vulnerable in Section 2, which species should be selected as an example?

The three prominent species on the UO campus identified as most vulnerable to the effects of climate change are (starting with the most vulnerable): *Betula papyrifera*, *Acer platanoides*, and *Pseudotsuga menziesii* (Figure 3.2). Since the objective is to choose a prominent species based on the specimen count found on campus, the Norway Maple (11th most prominent species) was removed from consideration, as both of the other species are substantially greater in number (Figure 3.2). Part of the objective is to select a vulnerable species that largely contributes to current campus character. For this project, the contribution to campus character is partly based on how widespread the species is distributed on campus, i.e. how commonly visible it is. The specimen counts for Paper Birch and Douglas-fir are quite close (3rd and 5th most abundant, respectively), and for this reason the merits of choosing one or the other are discussed.

Paper Birch is not a native species to the Willamette Valley (Oregon Forest Resources Institute, 2016), preferring colder, more northern latitudes for optimal growth (Dirr, 2009). It has the potential of reaching 50-70' in height, however it is very rarely found to exceed 40' in cultivation (Dirr, 2009). In 2015, the City of Eugene officially removed the species from the Approved Street Tree list for reasons outlined in the "City of Eugene Approved Street Tree Species List: Selection Process, Definitions, and Evaluation Criteria" (2014). Besides being intolerant of heat and having poor growth in Eugene's zone designation, the Paper Birch is susceptible to the Bronze Birch Borer, which has already been impacting the Eugene area (Thoumsin, 2012). In regard to the contribution to campus character (based on distribution), approximately 90% of the specimens are densely concentrated around the Jaqua Center rather than being widely distributed around campus (see Appendix A for GIS maps locating specimens on campus). Lastly, according to the UO Campus Plan (2014) and UO Campus Tree Plan (2008), there are no Paper Birch trees mentioned as significant specimens (historic, memorial, or defined edges of designated open spaces).

Scientific Name	Common Name	Total Score	Count on UO Campus
Pseudotsuga menziesii	Douglas-fir	7	112
Acer platanoides	Norway Maple	6	58
Betula papyrifera	Paper Birch	0	131

Figure 3.2: Score totals derived from the matrix, and total count of specimens on the UO campus.

The Douglas-fir is a native species to the Willamette Valley (Oregon Forest Resources Institute, 2016), is the most common tree found in the state of Oregon, and is designated as the state tree of Oregon (Oregon Department of Forestry, 2009). Douglas-fir trees have the potential to reach a height of more than 200', and have reached up to 160' in cultivation (Dirr, 2009; Brenzel, 2012). The species is listed as an approved street tree for the City of Eugene (Eugene Approved Street Tree Species List, 2015). As shown on the map in Appendix A, Douglas-firs are widely distributed around campus. This translates to high visibility of the species and contribution to campus character. According to the UO Campus Plan (2014) and UO Campus Tree Plan (2008), there are multiple specimens designated as significant due to defined edges of open spaces, axes or historical importance. Examples include the Deady Hall Walk Axis, the Gerlinger Field Green, and a particular specimen found in the "13th Avenue Axis: Between University Street and Moss Street". In addition, there are many large, older specimens within the Old Campus Quadrangle. Although the Douglas-firs in the Old Campus Quadrangle are not specifically called out as significant specimens, I contend that they are noteworthy, particularly because the UO Campus Tree Plan (2008) states that the "Existing character… [of] this quadrangle is an informal arrangement primarily of conifers with shrub plantings interspersed in a lawn setting… The existing character of the area should be preserved and enhanced." Also, it states that "Many of the conifers are in a state of decline due to old age…" In order to preserve the character of the quad long-term, it is essential to select other coniferous replacement species that will fare well in future conditions. Based on the UO Campus Plans and the University's own statements regarding the preservation of the existing character of the Old Campus Quadrangle, these large, old specimens should be reconsidered under an expanded significant designation. However, for this project only the areas/specimens that the University has already designated as significant will be considered.

Although the Paper Birch receives the lowest score in the matrix (most vulnerable), and has a slightly greater number of specimens present on campus, the lack of significant status of specimens in the UO Campus Tree Plan (2008) is a mark against selecting this species as an example. Coupled with the relatively diminutive size as compared to Douglas-fir, lack of widespread distribution, and the fact that it is not native to the Willamette Valley, Paper Birch loses more ground. Even though Douglas-fir may not have the greatest numbers, it is widely distributed and very visible throughout campus, and it is quintessentially an Oregon tree that is ubiquitous west of the Cascades. The hills and ridgelines surrounding the UO campus and Eugene are covered with a blanket of the species, and this borrowed landscape can conspicuously be seen from much of the campus, adding to the apparent number and influence to the campus character. The dramatic height and evergreen foliage further contribute to the year round impact the species exerts. In addition to these merits, the multiple significant designations throughout campus, as well as other noteworthy specimens, lead to the selection of the Douglas-fir as the example species, as the potential reduction in prominence due to climate change would be substantial.

3.2.2 Identifying Replacement Candidates

How should the pool of candidate replacement species be developed? What tree qualities should be used to yield species of similar character which are also resilient to the projected effects of climate change?

There are a variety of alternatives that one could pursue in order to develop a pool of candidate replacement species. In the case of a university, faculty experts or the grounds and maintenance crew could be consulted for recommendations. Similarly, city personnel within departments such as urban forestry, parks, landscape architecture and maintenance could be asked to weigh in. Private entities such as local arborists, horticulturists, landscape architects and non-profit organizations (for example, Friends of Trees in Eugene, OR) are another cache of information that could be consulted. However, much of this information would be locally specific, and would not necessarily take projected climatic conditions into account. It may be necessary to supplement the information by considering knowledge of experts outside the region. If this is the case, looking to other cities in the projected climate zones is an option. Like Eugene, many other cities (for example, Santa Rosa, CA, which is in USDA zone 9) have an approved tree list which could offer insight for possible replacement species. Likewise, experts such as the types mentioned above could be contacted in these cities.

One of the aims of this project is to simplify and streamline the process of identifying candidates for replacement of species vulnerable to climate change. One way of doing so is to utilize a freely available online tool to aid in plant selection. Many online tools exist to assist in identifying plants for use in specific situations, but which tool should be used? Some of the tools I encountered include: Monrovia Plant Catalog (http://www.monrovia.com/plant-catalog/); University of Illinois Extension Tree Selector (http://extension.illinois.edu/treeselector/); Great Plant Picks (http://www.greatplantpicks.org/); SelecTree: A Tree Selection Guide (https://selectree.calpoly.edu/). All of these tools allow options for the user to modify the search to suit their needs in many categories, for example: Hardiness Zone. However, not all are suited to the needs of this project. The Monrovia Plant Catalog is limited to species grown and sold by the Monrovia company. The University of Illinois Extension Tree Selector is regional in nature, and lacks a comprehensive list of trees that extends to the western U.S. Great Plant Picks is a valuable regional source for the maritime Pacific Northwest, however it exclusively contains a list of species that are proven to perform well currently. Therefore, species from warmer zones that may be good choices based on projected climatic conditions are excluded. However, SelecTree (Urban Forest Ecosystems Institute, 2016) is a tool that fulfills the necessary requirements for this project. SelecTree is administered by the Urban Forest Ecosystems Institute (UFEI) at Cal Poly State University, San Luis Obispo. San Luis Obispo is located in California's Central Coast, and has a USDA Hardiness Zone of 9, which is the upper range designated as appropriate for this project's replacement species. Its west coast location and inclusion of zones higher than those found in Oregon ensures greater coverage of potential species common to the western U.S., and the fact that it is maintained by a university lends it credibility. For these reasons, SelecTree is utilized as the tool of choice for this project.

An objective of this project is to minimize changes to campus character, while at the same time providing a replacement candidate that exhibits the least vulnerability to projected climate change. To do so, it is necessary to first describe the essential visual qualities of the example species: *Pseudotsuga menziesii*.

Throughout this document, the terms "visual qualities" and "character" are used extensively. Unless otherwise noted, for this project these terms are defined as:

Visual qualities:

Physical descriptors of a species, such as shape and height. These are the building blocks that, when combined, yield the character of a species.

Character:

The comprehensive combination of visual qualities that determine the overall appearance of a species.

Establishing a set of essential visual qualities for the selected vulnerable species aids in the search for candidate species of similar visual appearance. In section 3.2.1 I touched on several of the qualities of Douglas-fir which are immediately apparent when encountered: the imposing size/height, and the evergreen foliage. On campus, the Douglas-firs are readily seen, as the mature specimens dwarf most other species, reinforcing that their height is a defining quality that cannot be overlooked. The evergreen foliage of this conifer is another defining visual feature. The abundance of Douglas-fir specimens on campus dictates that their evergreen foliage plays a large role in the year round visual impact, particularly in the winter months when deciduous trees are bare. Other important qualities defining the visual appearance include the erect habit and conical shape. Again, these are readily identifiable qualities that stand out against the various shapes and habits of deciduous counterparts. The foliage type of needles also has value, as not all evergreens share this quality. In addition, the color and texture of the foliage is important. Due to the exposed trunk of mature specimens, and the fact that mature specimens exhibit an exposed trunk at all, bark pattern and color become contributing factors to Douglas-fir's visual impact. These qualities collectively make up the visual character of the species. But among these descriptors, are some more important than others in influencing the experience of campus? I contend that the most basic, obvious qualities contribute the most to the campus experience: size, evergreen foliage, habit and shape.

In the search for replacement species candidates, I begin with the aforementioned basic contributing qualities when employing the use of the SelecTree tool: evergreen, size, habit and shape. These four qualities provide a good starting point, as it is not possible to perform a search that satisfies all of the previously mentioned qualities while still casting a wide enough net to yield a reasonably sized pool of candidates. Should search results yield a prohibitively large number of species to investigate, then other qualities mentioned above can be added to the criteria one at a time to narrow results. One must work with the tool to produce what the user deems a reasonable output pool of candidates. In addition to these visual tree qualities, those features which have been previously deemed important in the matrix for resilience to climate change are included. However, only two of the five matrix categories can be used with this tool: USDA Hardiness Zone and Soil Moisture. Water Needs are not available as a selectable criterion. As with searching for plant data to populate the matrix, sources typically specify either soil moisture OR water needs, but not both. Pest and disease resistance and susceptibility are selectable criteria in the tool. However, only individual pests/diseases are presented, disallowing the selection of multiple known threats. For example, aphids and borers are listed individually, thus requiring selection one at a time. This means that if several pests and diseases need to be selected, one must perform many individual searches and cross reference the results of all searches to discover species commonly identified in each search. Nevertheless, the pest and disease criteria are addressed and scored when the candidate species are processed through the matrix, so they will not be overlooked. Figure 3.3 shows a portion of the SelecTree online form.

The qualities identified to describe *P. menziesii* must be translated to the terms used by the SelecTree tool. In order to do so, a search is performed for *P. menziesii*, and the key terms are identified (Figure 3.4). The Habit of Erect, the Tree Shape of Conical, the Max Height range, and the Foliage Type of Evergreen are the terms to be used in the search for replacement candidates. In the SelecTree form, the top two Max Height categories are 50' and 65', with an adjustable qualifier ranging from "less than" (<) to "greater than" (>). Even though *P. menziesii* can be much taller than 65', I do not want to exclude any species out of hand that are just under 65', as

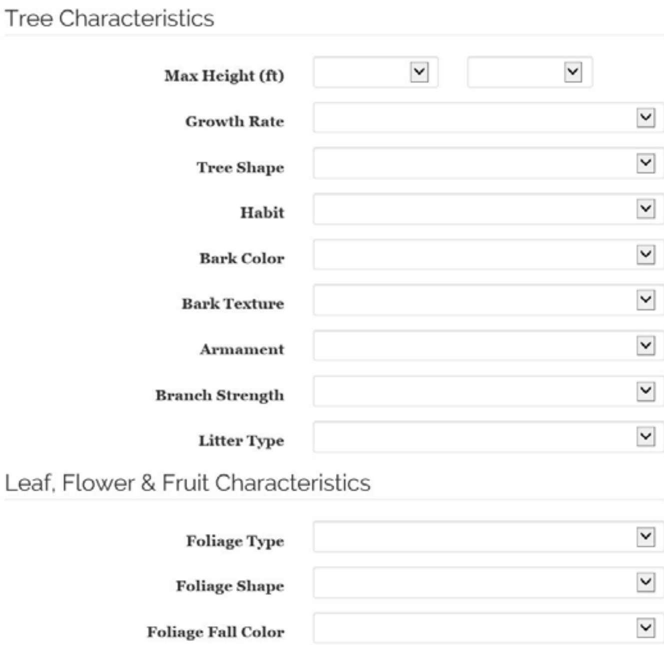

Figure 3.3: Example of a portion of the SelecTree search form, illustrating the pull-down menu format for characteristic selection. https://selectree.calpoly.edu/search-trees-by-characteristics

they could still represent some of the tallest available candidates. (As there are relatively few species that reach heights comparable to Douglas-fir, this is a preemptive action to include all of the tallest species.) Therefore, in order to increase the pool of search results in the tallest two ranges, I selected a Max Height of ≥50'. The form drop down menu for the USDA Hardiness Zone category allows selection of only one zone: the lower tolerance of the species. Because of this, searches must be performed multiple times to cover the desired range of Zones 7 - 9. Similarly, Soil Moisture only allows the selection of one type, therefore searches must again be performed multiple times for Wet, Moist, and Dry soils. Those species identified which match across all searches represent plants with qualities most similar to *P. menziesii*, and have qualities with reduced vulnerability to climate change. Many additional categories are present as options within the SelecTree tool which can be utilized to enhance the search. For example, the form section titled "Health, Safety & Environmental Concerns" includes an option regarding California Invasive status. Although this was not a consideration incorporated into the matrix, it is relevant and appropriate to exclude California invasives when looking for suitable replacement species. There can be many unknowns when bringing a species to a new environment, so this allows the user to exclude plants based on known characteristics in another area.

Tree Characteristics

Erect and requires ample growing space.

Conical Shape.

Has Evergreen foliage.

Height: 80 - 160 feet.

Width: 20 - 30 feet.

Growth Rate: 24 Inches per Season.

Longevity Greater than 150 years.

Leaves Needle, Blue Green or Dark Green, No Change, Evergreen.

Flowers Inconspicuous. Flowers in Spring. Has separate male and female flowers on the same tree (monoecious).

Brown Cone, Very Large (Over 3.00 inches), fruiting in Winter or Summer.

Bark Red Brown, Furrowed.

Shading Capacity Rated as Moderate to Dense in Leaf.

Litter Issue is Dry Fruit.

Figure 3.4: Terminology used by the SelecTree tool to describe Pseudotsuga menziesii. Red boxes indicate important visual qualities of the species. Adapted from https://selectree.calpoly.edu/tree-detail/pseudotsuga-menziesii

To play the devil's advocate: Why should "invasive" species be excluded if the goal is to find a species that will grow well now, and in future climatic conditions? The answer lies in the definition of an invasive species, which is stated well by the City of Eugene in their document "City of Eugene Approved Street Tree Species List: Selection Process, Definitions, and Evaluation Criteria" (2014): "Invasive: Non-native plants whose introduction causes harm to local ecosystems or human health, or has negative economic

Max Height	Tree Shape	Habit	Foliage Type	USDA Hardiness Zone	Soil Moisture	CA Invasive	# of Results Returned
>=50	conical	erect	evergreen	7	dry	no	44
>=50	conical	erect	evergreen	9	dry	no	40
>=50	conical	erect	evergreen	7	moist	no	71
>=50	conical	erect	evergreen	9	moist	no	57
>=50	conical	erect	evergreen	7	wet	no	1
>=50	conical	erect	evergreen	9	wet	no	3

Figure 3.5: Selected qualities for SelecTree search criteria, including number of results obtained.

impacts." The document goes on to say that: "Invasive tree species may establish at high densities in natural areas, displacing native plant species and contributing significantly to increased fire risk and loss of habitat quality for native wildlife. Some species may also have negative effects on human health." Although specimens planted in the institutional, garden setting of the UO campus will be maintained and controlled, there is no guarantee that an invasive would not escape due to dispersal mechanisms such as wildlife or wind. Once out in the wild, the possibility exists that native plant species which are able to survive the conditions of climate change may not be able to survive the increased competition of invasive species. The loss of these species and reduction in plant biodiversity could have a cascading detrimental influence on ecosystem stability and wildlife biodiversity.

The various criteria employed for the SelecTree searches are displayed in Figure 3.5. Searches were performed for USDA Hardiness

Scientific Name	Common Name
Cedrus atlantica	Atlas Cedar
Cedrus atlantica 'Glauca'	Blue Atlas Cedar
Cedrus libani	Cedar of Lebanon
Chamaecyparis lawsoniana	Port Orford Cedar
Chamaecyparis thyoides	Atlantic White Cedar
Cupressocyparis × leylandii 'Naylor's Blue'	Naylor's Blue Leyland Cypress
Hesperocyparis abramsiana	Santa Cruz Cypress
Hesperocyparis guadalupensis	Guadalupe Cypress
Hesperocyparis macrocarpa	Monterey Cypress
Hesperocyparis pygmaea	Pygmy Cypress
Juniperus virginiana	Eastern Red Cedar
Pinus jeffreyi	Jeffrey Pine
Pinus muricata	Bishop Pine
Pinus palustris	Longleaf Pine
Pinus parviflora	Japanese White Pine
Pinus peuce	Macedonian Pine
Pinus pinaster	Cluster Pine
Pinus ponderosa	Ponderosa Pine
Pinus ponderosa var. washoensis	Washoe Pine
Pinus strobus	White Pine
Pinus sylvestris	Scots Pine
Pinus wallichiana	Himalayan White Pine
Sequoiadendron giganteum	Giant Sequoia
Torreya californica	California Nutmeg

Figure 3.6: Replacement candidates identified across all SelecTree searches regarding tree qualities and climate change. Highlighted species are already present on the UO campus. Note: the Genus name of Hesperocyparis is more commonly acknowledged as Cupressus.

Zones 7 and 9. For USDA Hardiness Zone ratings, the designated range listed for plants is sequential. Therefore, any plant which appears in both a zone 7 and a zone 9 search is also hardy in zone 8. As discussed in section 2.3.5: Defining and Scoring Soil Moisture Tolerance, plants that can tolerate "wet feet" as well as drought receive the highest scores. In other words, species that are able to tolerate wet, average and dry soil moisture conditions are considered most suitable. Therefore, any species appearing across searches for all three soil conditions would receive the best scores. However, as Figure 3.5 indicates, searches for wet soil moisture in Zones 7 and 9 only yield 1 and 3 candidates, respectively. For this reason, the "wet" Soil Moisture category was excluded, as it is too limiting when comparing searches. All results from the other four searches are cross referenced. Those species which meet the criteria of Zone 7 and 9, as well as soil moisture conditions of dry and moist, constitute the pool of replacement candidates. According to the SelecTree tool, these species have the highest number of qualities similar to *P. menziesii*, as well as the lowest vulnerability to climate change as defined for this project (Figure 3.6). There are a total of 24 candidate species, 14 of which are currently present on the UO campus (highlighted in Figure 3.6).

3.2.3 Processing of Candidate Species Through Matrix

Which candidate species yield the highest scores, indicating low levels of vulnerability?

The procedure outlined in Chapter 2 is employed to populate the matrix with the plant data for species listed in Figure 3.6. Once populated, these data are scored and ranked to determine the species least vulnerable to climate change (Figure 3.7).

There are 10 candidates which receive a score of NA for at least one of the five categories. These candidates have one or more categories with incomplete information available in the established sources utilized for populating the matrix. This most commonly occurs with the *Manual of Woody Landscape Plants* (Dirr, 2009) and *The New Sunset Western Garden Book* (Brenzel, 2012). Several species are not included in one or the other of these sources

Scientific Name	Common Name	Zone	Soil Moisture	Water Needs	Pest	Disease	TOTAL
Juniperus virginiana	Eastern Red Cedar	8	1	4	2	1	16
Cedrus atlantica	Atlas Cedar	8	1	2	2	2	15
Cedrus atlantica 'Glauca'	Blue Atlas Cedar	8	1	2	2	2	15
Cupressocyparis × leylandii 'Naylor's Blue'	Naylor's Blue Leyland Cypress	8	1	2	2	2	15
Sequoiadendron giganteum	Giant Sequoia	6	1	2	2	2	13
Pinus jeffreyi	Jeffrey Pine	2	1	4	2	2	11
Cedrus libani	Cedar of Lebanon	4	0	2	2	2	10
Chamaecyparis thyoides	Atlantic White Cedar	4	2	0	2	2	10
Pinus ponderosa	Ponderosa Pine	2	1	4	1	1	9
Pinus ponderosa var. washoensis	Washoe Pine	2	1	4	1	1	9
Chamaecyparis lawsoniana	Port Orford Cedar	4	0	0	2	2	8
Pinus parviflora	Japanese White Pine	4	0	0	2	2	8
Pinus strobus	White Pine	2	2	0	1	2	7
Pinus sylvestris	Scots Pine	0	1	2	1	0	4
Hesperocyparis abramsiana	Santa Cruz Cypress	NA	NA	NA	0	0	NA
Hesperocyparis guadalupensis	Guadalupe Cypress	NA	NA	NA	0	0	NA
Hesperocyparis macrocarpa	Monterey Cypress	6	NA	4	2	0	NA
Hesperocyparis pygmaea	Pygmy Cypress	NA	NA	NA	NA	NA	NA
Pinus muricata	Bishop Pine	6	NA	4	2	2	NA
Pinus palustris	Longleaf Pine	6	NA	NA	1	1	NA
Pinus peuce	Macedonian Pine	4	0	NA	2	2	NA
Pinus pinaster	Cluster Pine	NA	NA	NA	2	2	NA
Pinus wallichiana	Himalayan White Pine	2	1	4	NA	NA	NA
Torreya californica	California Nutmeg	8	NA	2	2	2	NA

Figure 3.7: Scored and ranked replacement candidate species for P. menziesii.

due to regional specificity. For example, *The Sunset Western Garden Book* does not contain some species currently found in the southeastern U.S. that are uncommon in the west. Similarly, the Dirr book, which is at a national scale but based in the Midwest, does not contain some species which are exclusive to the west.

3.2.4 Selection of Proposed Replacement Species

Which high scoring candidate should be selected as the replacement species?

As discussed in Section 3.2.1, the dramatic and impressive height of the Douglas-fir is a defining quality that, along with evergreen foliage, habit and shape, constitutes the essential character that the species provides to the campus. These four qualities play a vital role in selecting one of the top candidates as a replacement, because the score derived from the matrix focuses on climate vulnerability alone.

The species receiving the highest point total from the climate vulnerability matrix was *Juniperus virginiana*, or Eastern Red Cedar. *J. virginiana* received 16 out of a possible 18 points, having 1 point reductions in the categories of Soil Moisture and Disease Risk. However, although the species ranks least vulnerable to climate change, and is similar to *P. menziesii* in shape, habit and foliage, its size is significantly less. *J. virginiana* has a maximum mature height of 50', versus 160' (in cultivation) for *P. menziesii*. Similarly, the next highest scoring candidate species of *Cedrus atlantica*, *Cedrus atlantica 'Glauca'*, and *Cupressocyparus x leylandii 'Naylor's Blue'* (all received 15 points) also have considerably shorter maximum mature heights than Douglas-fir (65', 60', and 50', respectively). All three of these species received deductions of 1 point for Soil Moisture tolerance, and 2 points for Water Needs, while scoring the maximum in the other categories. However, once again the mature height is brought to bear as an overriding quality due to the magnitude of difference and the fact that several larger species are identified. Therefore, these candidates are passed over for replacement of Douglas-fir. These species are certainly suitable replacement candidates if species more closely resembling Douglas-fir for all four of the defining visual qualities were not available, or if the visual qualities were not important. As stated in Section 3.2.2, for this project the visual qualities of height, shape, habit and foliage collectively make up the character of the species. Therefore, the replacement candidate which shares the greatest number of these visual qualities with *P. menziesii* (and thus, character), in addition to scoring well in the climate vulnerability matrix, is selected as the replacement species.

The next species on the list, *Sequoiadendron giganteum*, or Giant Sequoia, is a promising candidate. The Giant Sequoia scored a total of 13 points when processed through the matrix. Due to a disagreement between sources regarding the upper zonal range (Dirr listed the range as 6 - 8, while AHS listed it as 6 - 9), there was a deduction in the Zonal Tolerance score of 2 points. However, *The Sunset Western Garden Book* included a wide range for the species, in which Eugene is firmly planted. A deduction of 1 point was made for Soil Moisture tolerance, as the species was not listed as tolerant of exceedingly wet soils. However, the institutional, garden setting of the UO campus allows for proper placement and accommodations to be made for sufficient drainage to counteract such a condition. Lastly, a deduction of 2 points was taken regarding the Water Needs category, since Sunset attributed moderate needs for the species. Again, the campus setting allows irrigation practices to be utilized until the tree is well established, at which time water may only need to be applied in extreme conditions. Full marks were received for Pest Risk and Disease Risk. A direct comparison of matrix derived scores can be found in Figure 3.8.

Scientific Name	Common Name	Zone	Soil Moisture	Water Needs	Pest	Disease	TOTAL
Pseudotsuga menziesii	Douglas-fir	0	1	4	1	1	7
Sequoiadendron giganteum	Giant Sequoia	6	1	2	2	2	13

Figure 3.8: Comparison of matrix derived scores for Douglas-fir and Giant Sequoia.

Like the previous candidates, *S. giganteum* fulfills the qualities of shape (conical), habit (erect), and foliage type (evergreen). Unlike the previous candidates, the Giant Sequoia offers a towering mature height that can match that of Douglas-fir. Many of the significant Douglas-firs on campus are quite mature and are currently in a state of decline, including specimens within the Deady Hall Walk Axis (UO Campus Tree Plan, 2008). Some of this decline is due to age (UO Campus Tree Plan, 2008). Douglas-firs are known to live up to approximately 150 years in ideal conditions (SelecTree, 2016), however according to the plant data collected in this study, Eugene does not offer the conditions necessary to maximize its lifespan. In addition, the UO Campus Tree Plan (2008) classifies 49% of the Douglas-fir specimens on campus to be "Mature" or "Very Mature." Since UO was established in 1876, any Douglas-firs planted in the first 40 years of existence would now be 100 - 140 years old. Giant Sequoia has a possible lifespan exceeding 3,000 years (SelecTree, 2016; Brenzel, 2012). The high percentage of Douglas-firs that are nearing the end of their lifespan reiterates the necessity to select a replacement species with similar qualities that can be substituted as necessary, giving the replacement species as much time as possible to mature before

Pseudotsuga menziesii

Erect and requires ample growing space.

Conical Shape.

Has Evergreen foliage.

Height: 80 - 160 feet.

Width: 20 - 30 feet.

Growth Rate: 24 Inches per Season.

Longevity Greater than 150 years.

Leaves Needle, Blue Green or Dark Green No Change, Evergreen.

Flowers Inconspicuous. Flowers in Spring. Has separate male and female flowers on the same tree (monoecious).

Brown Cone, Very Large (Over 3.00 inches), fruiting in Winter or Summer.

Bark Red Brown, Furrowed.

Shading Capacity Rated as Moderate to Dense in Leaf.

Litter Issue is Dry Fruit.

Sequoiadendron giganteum

Erect and requires ample growing space.

Conical Shape.

Has Evergreen foliage.

Height: 60 - 100. May reach 260 feet.

Width: 30 - 50 feet.

Growth Rate: 36 Inches per Season.

Longevity Greater than 150 years.

Leaves Scalelike, Gray Green No Change, Evergreen.

Flowers Inconspicuous. Flowers in Spring. Has separate male and female flowers on the same tree (monoecious).

Brown or Red Cone, Large (1.50 - 3.00 inches), fruiting in Fall or Winter.

Bark Red Brown, Fissured.

Shading Capacity Rated as Dense in Leaf.

Litter Issue is Dry Fruit.

Figure 3.9: The qualities of P. menziesii and S. giganteum, as given by SelecTree. Red boxes indicate important visual qualities that are considered/compared when selecting a replacement species. Adapted from https://selectree.calpoly.edu/tree-detail/pseudotsuga-menziesii and https://selectree.calpoly.edu/tree-detail/sequoiadendron-giganteum.

A

B

Figure 3.10: Comparison of habit, shape and height, from immature to mature, of A) P. menziesii and B) S. giganteum.

A

B

Figure 3.11: Comparison of foliage texture and color of A) P. menziesii and B) S. giganteum. Images by author (2016) and Oregon State University (2015). http://oregonstate.edu/dept/ldplants/psme4.htm, http://oregonstate.edu/dept/ldplants/segi9.htm

A

B

Figure 3.12: Comparison of trunk shape, bark pattern and color of A) P. menziesii and B) S. giganteum.

the Douglas-firs are gone. *P. menziesii* and *S. giganteum* qualities specified by SelecTree are compared side by side in Figure 3.9. Although not identical, many similarities are shared between these species. Figures 3.10 - 3.12 display a visual side by side comparison of these important qualities.

Currently, the UO Campus GIS data indicates that only 8 specimens of *S. giganteum* are present on campus. But the question remains: What would the campus look like, particularly in the areas containing significant specimens of Douglas-fir, if Giant Sequoias were to replace Douglas-firs? In the following section, photography and hand drawing are used to visualize just such a scenario in an area of campus where *P. menziesii* is designated as significant.

3.3 Visualization to Inform Design Decisions

This section uses photography and hand drawn visualization techniques to depict the replacement of *Pseudotsuga menziesii* with *Sequoiadendron giganteum*, as it would appear in a distinct location on the UO campus. This serves as an exploration of the possible effect of a substituted species on the character of the selected location.

3.3.1 Deady Hall Walk Axis

The University of Oregon Campus Tree Plan (2008) indicates several areas with what it deems as significant Douglas-fir specimens. Among these areas, the Deady Hall Walk Axis is the area that will be considered for visualization for the following reasons: it contains the highest density of mature Douglas-firs among the areas containing significant specimens, it is partially contained within the Deady Hall National Landmark boundary, and it is highly visible due to its intersection with the Dads' Gates Axis, which is a major pedestrian entrance to UO. Figure 3.13 locates the area containing the Deady Hall Walk Axis on a campus map of Designated Open Spaces, which includes quadrangles, malls, axes, view corridors and greens (UO Campus Tree Plan, 2008). Figure 3.14 shows an aerial image enlargement of the vicinity, while Figure 3.15 zooms in to the Deady Hall Walk Axis, specifically.

Interestingly, there is a Giant Sequoia tree that is designated as significant (the class tree of 1880) near the intersection of the Deady Hall Walk and Dads' Gates Axes. This is labeled in Figure 3.15, and can also be seen in the background, left of the Douglas-fir allee' in Figure 3.16.1. The following images depict the series of views as one approaches and passes through the Deady Hall Walk, moving from Kincaid St. on the West to Deady Hall on the East (collectively grouped as Figure 3.16). Image locations and direction can be referenced in Figure 3.15.

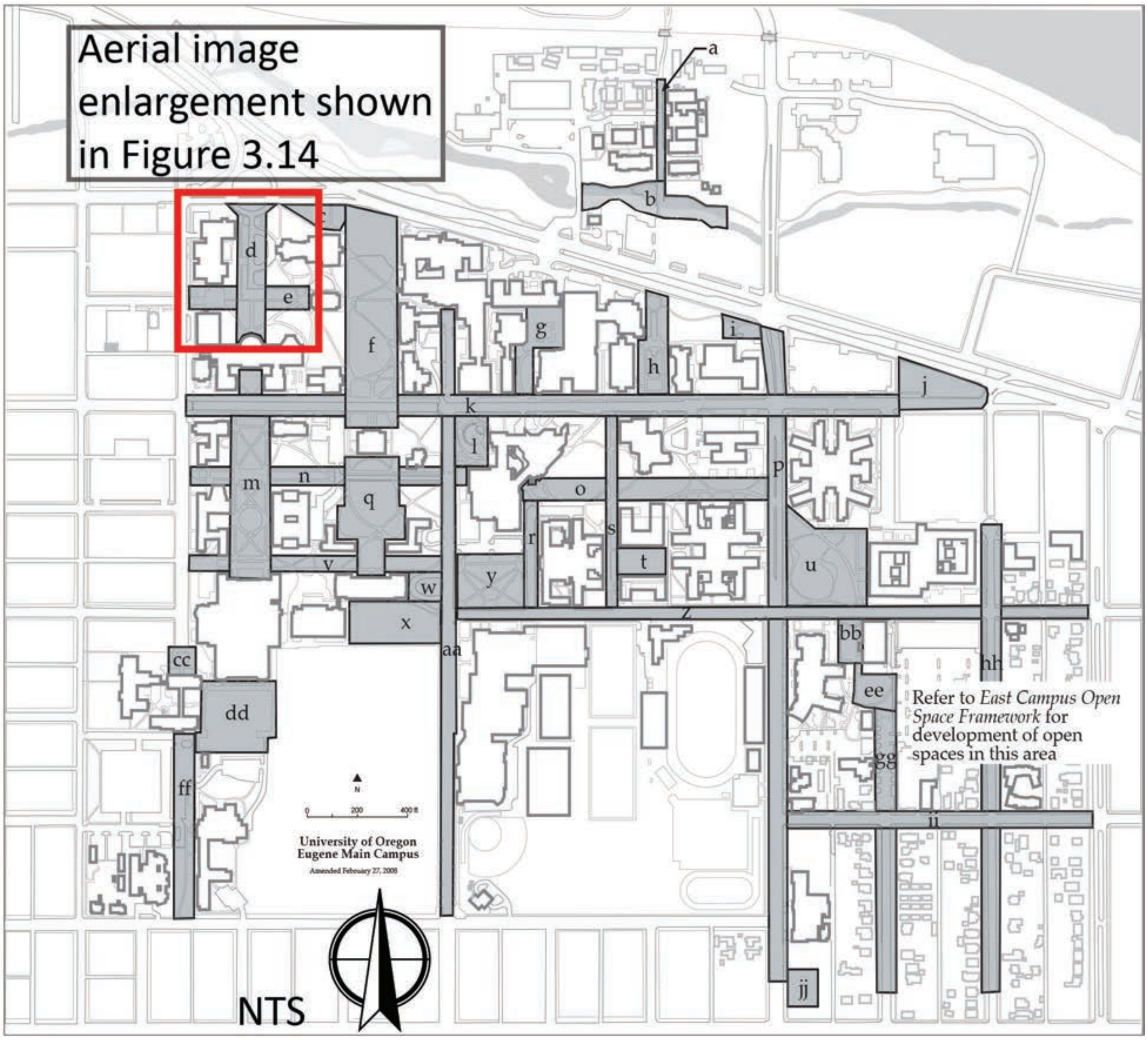

Figure 3.13: UO campus map locating Deady Hall Walk Axis vicinity. Map indicates Designated Open Spaces, including quadrangles, malls, axes, view corridors and greens, per the UO Campus Tree Plan (2008).

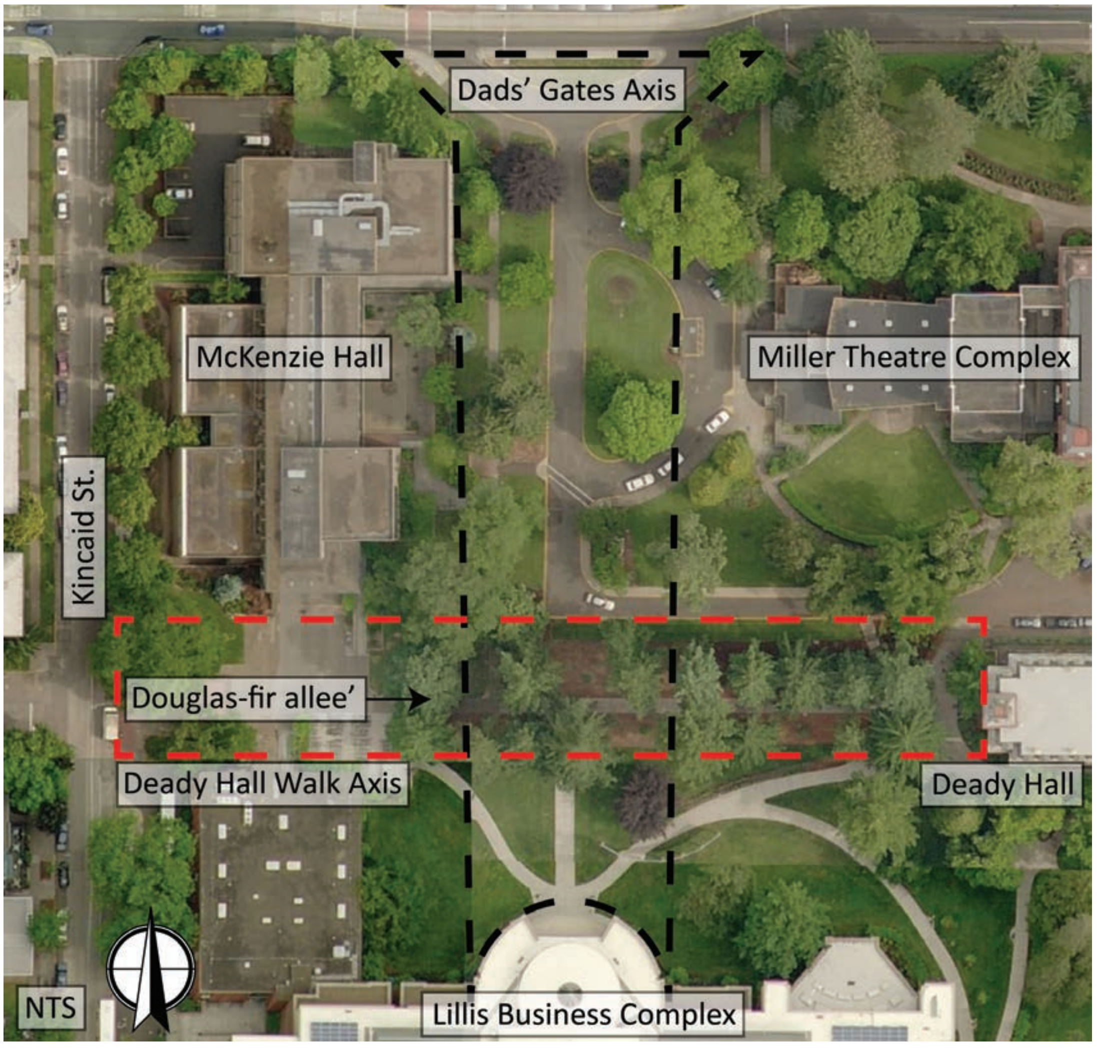

Figure 3.14: Aerial image enlargement of the Deady Hall Walk Axis vicinity. Adapted from the Oregon Imagery Explorer, 2009. http://imagery.oregonexplorer.info/

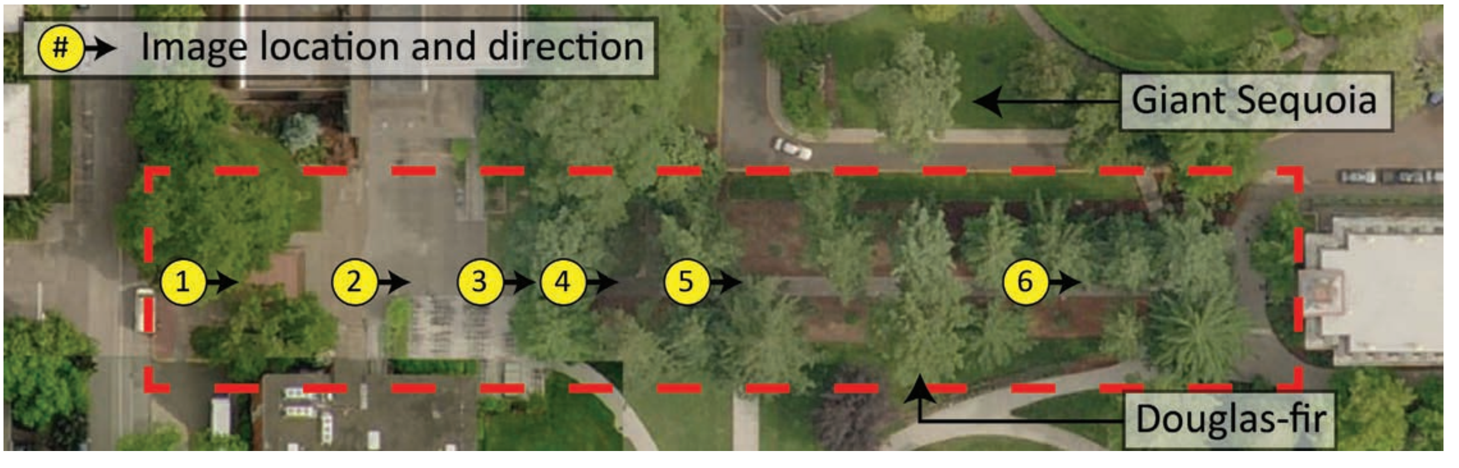

Figure 3.15: Aerial image enlargement of the Deady Hall Walk Axis. Numbers indicate the location and direction of photographs depicting current conditions in the Figure 3.16 series (image 1 refers to Figure 3.16.1, and so on). This image allows easy comparison of the spread of a Giant Sequoia to that of a mature Douglas-fir. Adapted from the Oregon Imagery Explorer, 2009. http://imagery.oregonexplorer.info/

Figure 3.16.1: West to East movement through the Deady Hall Walk Axis.

Figure 3.16.2: West to East movement through the Deady Hall Walk Axis.

Figure 3.16.3: West to East movement through the Deady Hall Walk Axis.

Figure 3.16.4: West to East movement through the Deady Hall Walk Axis.

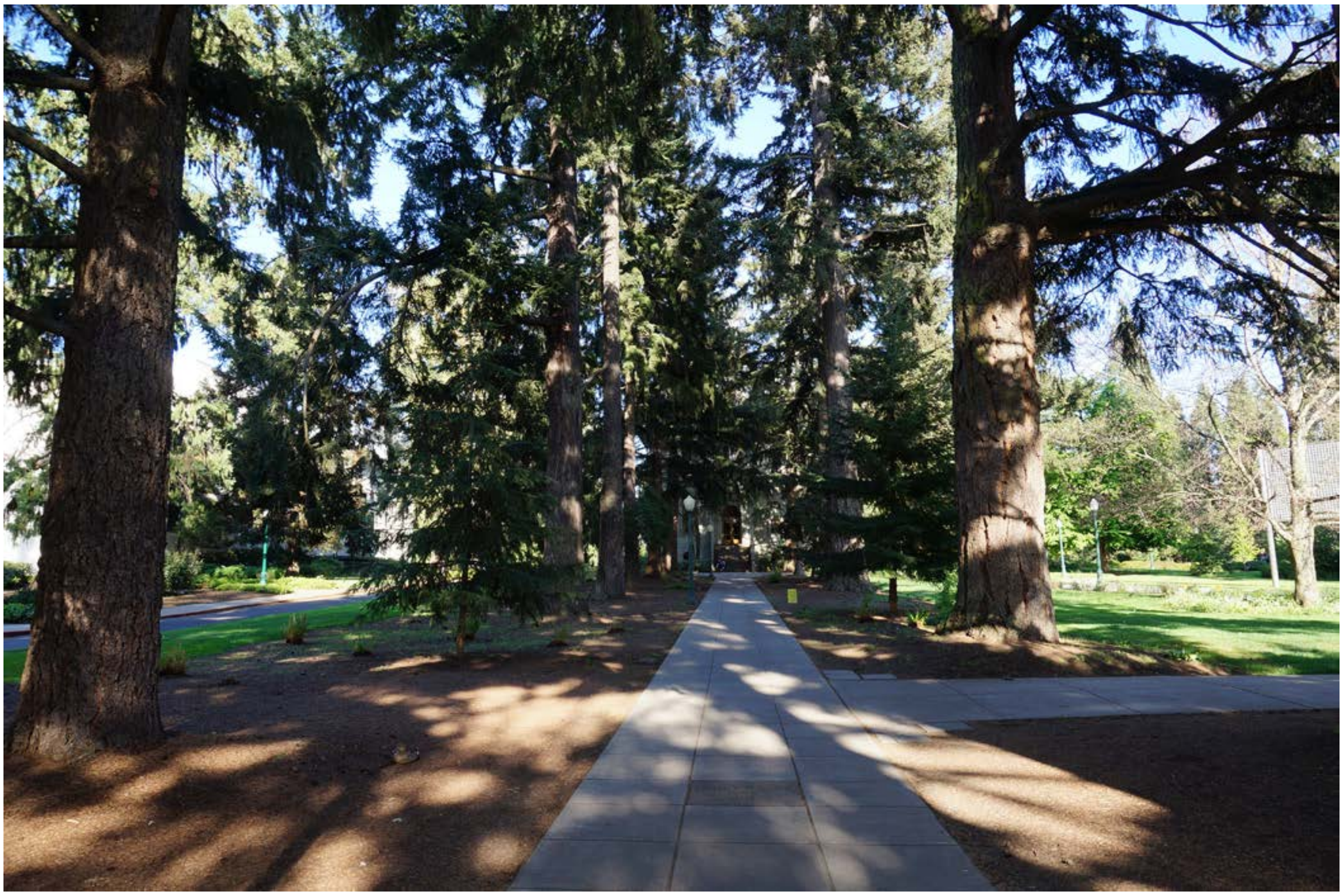

Figure 3.16.5: West to East movement through the Deady Hall Walk Axis.

Figure 3.16.6: West to East movement through the Deady Hall Walk Axis.

As shown in the images, the Douglas-firs have rather dense foliage and many overlapping branches across the width of the allee'. Although at this mature stage there are few branches very low on the trunks, there are some that droop down, particularly at the west end of the allee', where more sunlight is available. Deep shade is cast beneath the canopies, but the overall high branching allows the space to open up overhead, creating a vast tunnel to walk through. Interior limbs are sparse down low, as *P. menziesii* tends to shed deeply shaded limbs (it is possible, however, that these trees were limbed up by the grounds staff in the past to open the walkway more).

As discussed in Section 3.2, the Giant Sequoia shares qualities with the Douglas-fir that make it a good choice as a replacement, while minimizing the possible change in campus character. Figures 3.17 and 3.18 illustrate the approach to the Deady Hall Walk Axis from the west with the current Douglas-firs (Figure 3.17), and with mature Giant Sequoias (Figure 3.18) in their place. Likewise, Figures 3.19 and 3.20 illustrate a view toward Deady Hall from within the allee' with Douglas-firs and Giant Sequoias, respectively.

Figure 3.17: Current view approaching the Deady Hall Walk from the west, with Douglas-firs in place.

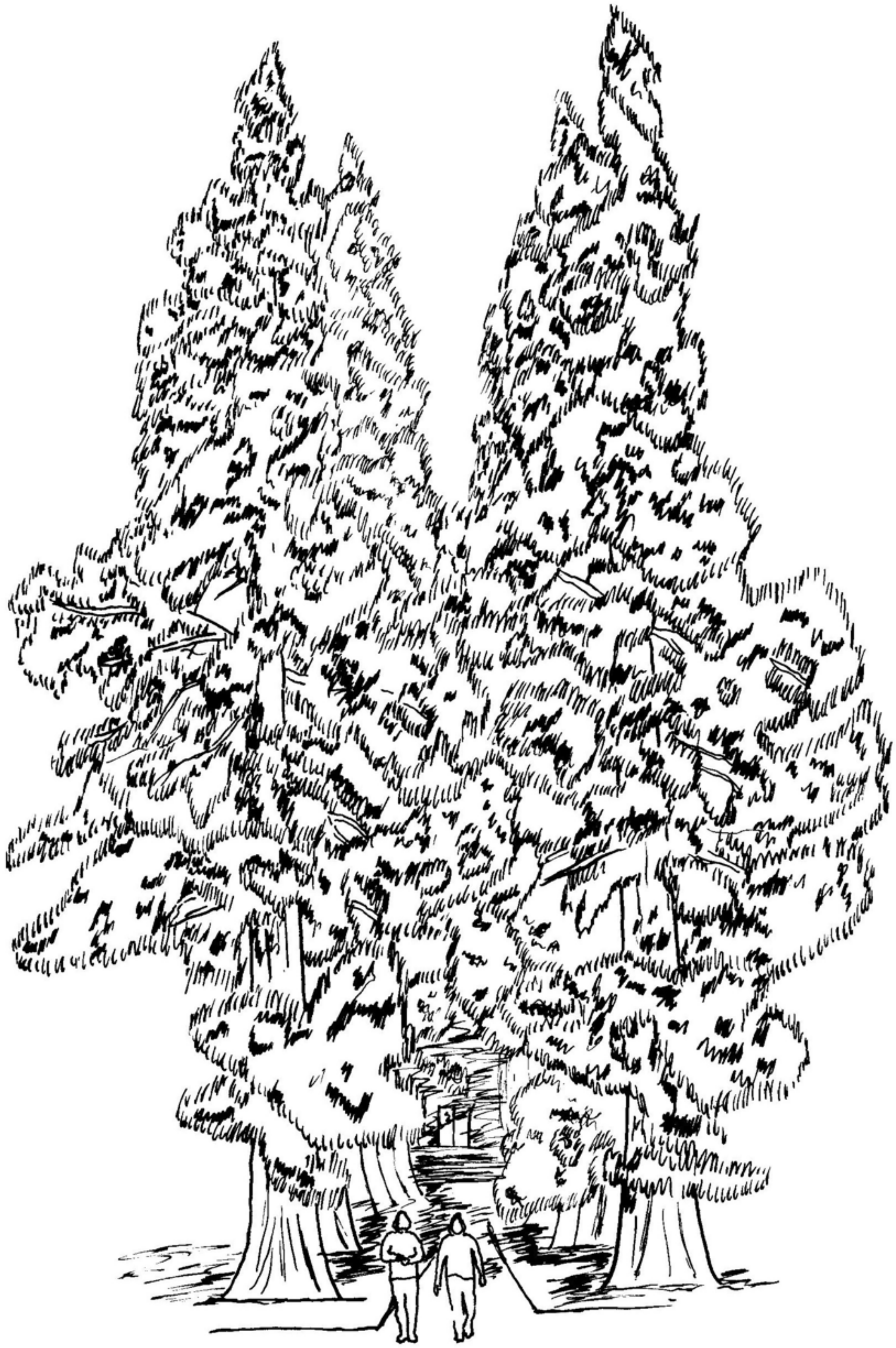

Figure 3.18: Future view approaching the Deady Hall Walk from the west, with Giant Sequoias substituted for the Douglas-firs. The qualities of height, form and shape are reminiscent of Douglas-fir.

Figure 3.19: Current view approaching Deady Hall from within the allee', with Douglas-firs in place.

Figure 3.20: Future view approaching Deady Hall from within the allee', with Giant Sequoias substituted for the Douglas-firs. The qualities of an exposed trunk, high branching and foliage density/shading are reminiscent of Douglas-fir.

The towering height, evergreen foliage, erect conical shape, and exposed trunks of the Giant Sequoias simulates that of the Douglas-firs. In early growth stages, both species have quite dense foliage. Giant Sequoias maintain this density for longer, as their branching is more plentiful than Douglas-fir, and often extends to ground level. Like *P. menziesii*, the Giant Sequoia tends to have higher branching with age. However, this can take some time, so as trees mature and threaten to impede the path, some lower drooping limbs may need to be removed. In maturity, the Giant Sequoia's dense foliage is held rather high, and therefore allows light to penetrate the interior of the allee', while still providing shade. The form also allows a slightly less obstructed view of Deady Hall at the east end of the walk. The Giant Sequoia's presence is punctuated with its immense trunk, which is significantly wider than the Douglas-fir.

There are some differences from Douglas-fir, to be sure, however the overall character of the Deady Hall Walk Axis remains fairly intact. *Sequoiadendron giganteum* fulfills the requirements set forth by this project of visual quality (and therefore, character), as well as a reduced vulnerability to climate change.

Chapter 4: Discussion and Summary

4.1 Discussion

The current conditions and continued looming threat of climate change prompts the need for planned action in our landscapes. Although this action is necessary at many scales, this project focuses on the institutional setting of the University of Oregon (UO). The University values its botanical resources and designated open spaces of the past, present and future, as well as the contributions they make to the character of campus. These are demonstrated by the UO Campus Plan, the UO Campus Tree Plan, the UO Campus Heritage Landscape Plan, and the UO Campus Physical Framework Vision Project. However, among these documents there remains a gap in relation to landscape planning and climate change. Currently, UO is lacking in two areas: 1) an evaluation method to identify species vulnerable to climate change; 2) an established protocol for selecting replacement tree species that are less vulnerable to climate change and maintain campus character as much as possible.

The method and application presented in this document provide an approach to addressing the gap and aiding in the decision making process of the University of Oregon. This work has several facets which can be used to identify species vulnerable to climate change that merit replacement over time, and to select replacement species which are less vulnerable to climate change and help to maintain campus character. In other words, suitable plant selections are crucial for developing a resilient landscape for the future. In addition, plant selections can considerably affect the campus character. Modifications can be made by University staff to determine, for example, the importance of qualities such as foliage color, texture, height, or shape, to customize the process of compiling a pool of replacement species candidates. The climate vulnerability matrix can then be used to process these candidates, and the highest scoring (least vulnerable) options can be compared to the vulnerable species. The user must prioritize the candidate pool considering climate vulnerability and other visual qualities to select a replacement species. One way to aid in this decision is the use of hand drawing to depict how the replacement species would look in place of the original. Another possibility is a photorealistic rendering/photo simulation. This method and application aids in the decision making process of the University regarding the long-term management of the campus landscape.

Section 1.3 discussed campus planning intentions regarding the landscape. The description of the word "aesthetic" when referring to trees by the UO Campus Tree Plan (2008) includes benefits such as defining views, providing shade, and "...accent[ing] the campus infrastructure and the architectural design of each building." In the Deady Hall Walk Axis example, all of these concerns are addressed. The view corridor created by the existing allee' of Douglas-fir would be preserved and maintained when replaced by Giant Sequoia, as the height, foliage, shape and habit are comparable. Similarly, these visual qualities would continue to fulfill the roles of providing shade, maintaining the relationship of the allee' to Deady Hall, and accenting the walkway. The pattern and spacing of tree specimens would also be maintained.

The UO Campus Plan (2014) and UO Campus Tree Plan (2008) also refer to campus character and that "Trees are a primary character-defining element of the campus landscape" (UO Campus Tree Plan, 2008). I operationalized the term "character" by breaking it down into a suite of visual qualities. These visual qualities are the building blocks which, when combined, yield the character of a species. The character of species then combine to yield the character of a campus area. The important visual qualities selected are physical descriptors which allowed comparison and judgement calls to be made. However, in a tangential way they describe the feeling of being in the presence of the species referenced. The feeling that a tree imparts is difficult to convey with data tables or to describe with scores. Because of this, the visualization portion of the project was very important to explore how the visual qualities/character of the species came together, especially when grouped into an allee'. Section 1.3 also touched on the detail that smaller tree species have been used at times to replace older, larger trees. This goes against the UO Campus Tree Plan (2008), which aims to maintain and sustain the existing campus character and aesthetic. The replacement of Douglas-firs with Giant Sequoias in the Deady Hall Walk Axis addresses this aim by maintaining the scale of species and the future character of the campus overstory.

4.2 Limitations

The matrix was developed with the garden-like and high-care institutional setting in mind. In other words, assumptions were made regarding the attention and maintenance that the university landscape receives. As discussed in Chapter 2, factors such as soil quality are disregarded due to the assumption that soils on campus are being amended and improved to maintain plant health. Similarly, irrigation is assumed to be available, within reason, as well as plant maintenance such as Integrated Pest Management and pruning. There are areas of campus, such as the north end of campus near the Willamette River, that are minimally maintained, if at all. Areas such as this may not be tended as intensely as the campus core, meaning that the aforementioned factors could play an important role in plant consideration. Other factors could have been included as categories related to climate change in the matrix, for example: maintenance or timing of biological events in relation to temperature change. However, in an effort to streamline and simplify the method of identifying vulnerable species for general use, I chose to utilize categories with data that were relevant and readily available.

The majority of the UO campus is not open to vehicular traffic, thus prompting the overall designation as a "garden-like" setting, since circulation is primarily geared toward pedestrians and bicycles. This designation infers that there is little concern regarding stress factors associated with urban street trees, such as impermeable surfaces, poor soils (including compaction, pH level, and fertility), constricted root zones, water supply, and poor drainage. However, there are several prominent roads which traverse the campus. Even if some roads are only open to authorized university or emergency vehicles, and therefore contribute little in the way of traffic, the compacted, impermeable and paved surfaces can impact trees along the route. Aside from vehicles, it should be noted that excessive foot traffic alone is capable of compacting soil enough to impact the roots of even large tree specimens. The matrix does not take these potential factors into account.

Zonal tolerance scores were calculated using USDA climate zones as the primary source. However, the question remains as to whether USDA zones, which rely exclusively on average annual minimum winter temperatures, are the best choice to gauge this metric. It is certainly the most widely used and recognized plant zone tolerance system, but other systems exist that account for a greater diversity of factors such as heat, humidity and precipitation (for example, Sunset Garden Zones). However, until classification systems like Sunset become more widely used, have wider coverage than the west, and are transparent in their calculations, the USDA climate zones are the best option. I combined Sunset with USDA in an attempt to account for some of the discrepancy, however doing so is inherently subjective, and would not work if employing my method outside of Sunset's covered region.

Pest and disease risk data were obtained from a national source. Using a source such as *North American Plantfile* takes generalized pest and disease data from vast areas, considering all of the potential problems. It also runs the risk of being/becoming outdated (published in 1998). Not all regions will have the same problems to the same degree. A localized data source would be the best option to account for pest and disease concerns. Even so, localized data would still only take into account the current conditions. When considering the effects of climate change, additional "local" sources from areas with similar climatic conditions to projected conditions could be incorporated. As climate shifts occur, new pest and disease risks have the potential of moving in quickly and without warning, so they are difficult to account for. I began to seek localized data from local experts for this project, however incomplete and/or conflicting information, coupled with a lack of time resources, precluded pursuing this method to completion.

4.3 Transferability

Although designed with the University of Oregon in mind, the method and application described here are widely transferable at various scales. With the update of climate projections for the given area, this method could be utilized for any institutional setting that manages considerable land and plantings, has limited vehicular traffic, and actively maintain their grounds, for example: educational institutions or museum estates. Similarly, cities could use the method to help manage and inform their decisions regarding tree replacement in public open space and park land. Even the homeowner could apply the method to their plot of land, should they be inclined to forward thinking and the long term benefits that even small properties can contribute to the character of their neighborhood/region and mitigation of climate change.

4.4 Recommendations

At first glance, this project may come across as recommending the removal and replacement of highly vulnerable species found on the UO campus. This is not the intention. Particularly in the case of significant specimens, this project does not suggest removal until absolutely necessary. This project aims to identify species vulnerable to climate change and assist in determining (eventual) replacement species that will adapt to climate change. This is proposed in a way that simulates as many qualities of the vulnerable species as possible, thus preserving as much of the character contributed to campus as possible. As vulnerable species decline and must be removed due to health or age concerns, this work recommends that rather than replacing a specimen with the same species (for example, a young Douglas-fir among an allee' of very mature Douglas-firs), that a climate resilient species with similar qualities should be used as a replacement. This would allow for a slow transition to the new species selections, and would minimize the future risk of a large scale die-out of older vulnerable species that would leave a noticeable hole in the landscape.

In addition, this project recommends maintaining a high diversity of trees on campus. It is not suggested that vulnerable species be removed or omitted from campus planting, particularly due to the educational value, habitat and arboretum qualities that they provide. It is only recommended that known vulnerable species be limited in order to minimize loss when their tolerance is exceeded. Any potential decrease in current species diversity due to vulnerability can be addressed by utilizing new species identified as less vulnerable that are not present on campus. For the example used in this project, 10 out of 24 identified replacement candidate species are not currently present. However, in doing so, restrictions based on visual qualities may need to be loosened for the replacement species.

4.5 Future Research

Data Needs

During the course of this project, there arose instances where data were insufficient or lacking altogether. Compilation/Creation of the following data could benefit this and other research going forward.

1) A compilation of local pest and disease information. Even if this were to include only prominent species on campus, or species from Eugene's Approved Street Tree list, it would be beneficial.

2) A Climate Zone system that takes multiple factors into account in addition to hardiness, such as humidity, precipitation, and even climate change projections.

Monitoring

With the limited resource of time being a factor in this project, the luxury of verifying findings long term is not an option. It would be beneficial to establish a monitoring system for the University and City of Eugene to develop a local cache of data for those species identified as highly vulnerable. Since climate change is occurring at an increasingly rapid rate, responses to climatic conditions over time should be (relatively) much faster to detect than in the past. In addition to monitoring the health of vulnerable species over time, those existing (or newly introduced) species identified as less vulnerable can also be monitored to confirm their resiliency to climate change.

Additional Application of the Method

In regard to this project, time only allowed the processing and evaluation of the most prominent species on campus for vulnerability to climate change. Ideally, all campus species could be evaluated using this method (or at least those with numbers greater than one or two arboretum specimens). Doing so would not only reveal which species are vulnerable, but also which species are resilient, coupled with the number of specimens currently present. Those found to be resilient but low in numbers could be prioritized to be used more often in new plantings. Also, species identified as replacement candidates that are not currently found on campus could be incorporated as the number of vulnerable species specimens are reduced over time, therefore maintaining current species diversity numbers when vulnerable species are finally no longer able to survive.

4.6 Summary

This project helps to bridge a gap currently existing at the University of Oregon. The University lacks an evaluation method to identify species vulnerable to climate change, and an established protocol for selecting replacement tree species that are least vulnerable to climate change. The selection of replacement species that maintain campus character is also not addressed.

The climate vulnerability evaluation matrix, and the application of identifying replacement species and visualizing their presence in the landscape, assists the University in managing their tree resources. The use of the method described here helps to inform decisions regarding current species' vulnerability to projected climate change, and to identify and select replacement species that are both less vulnerable to climate change, and share visual qualities that help to maintain campus character.

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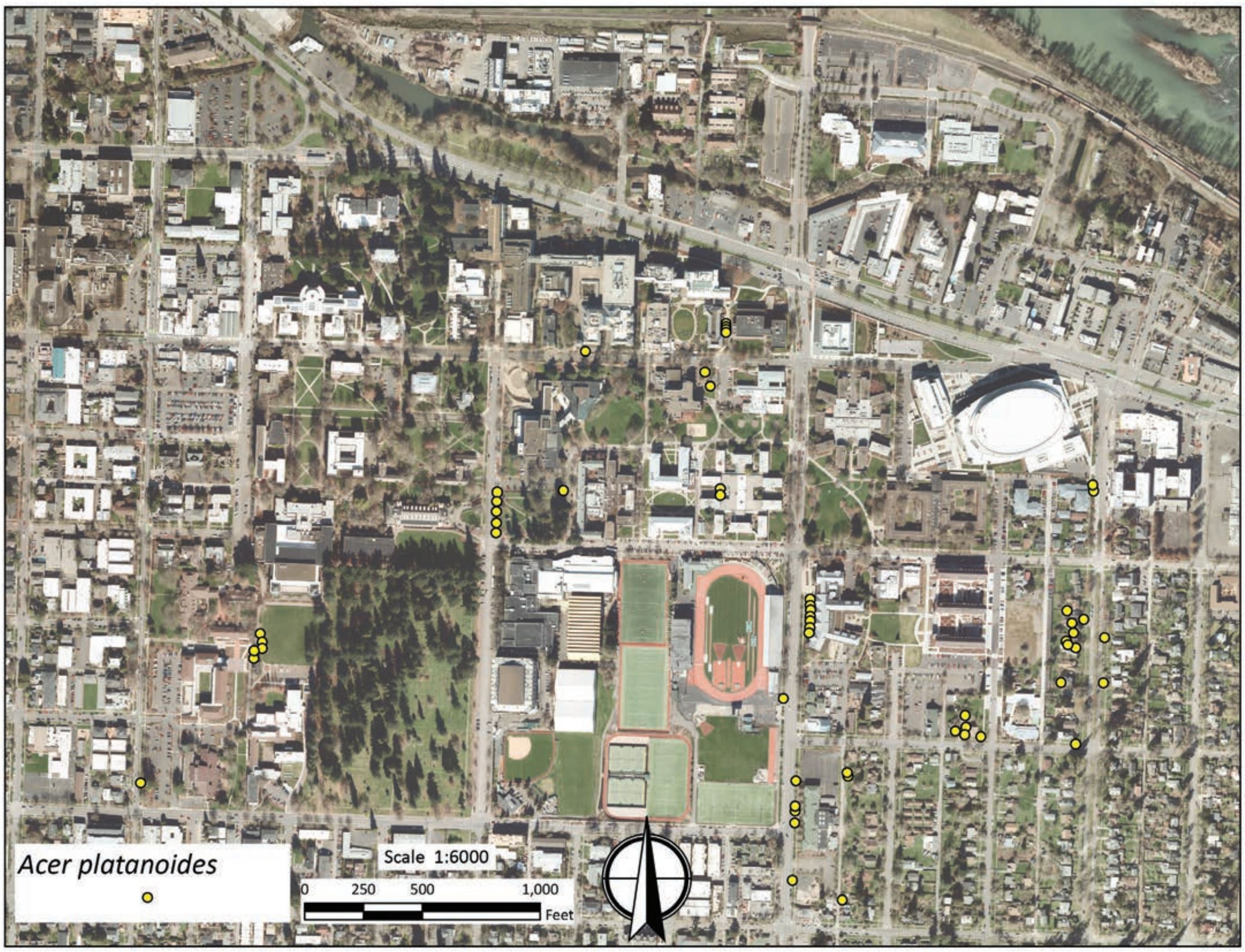
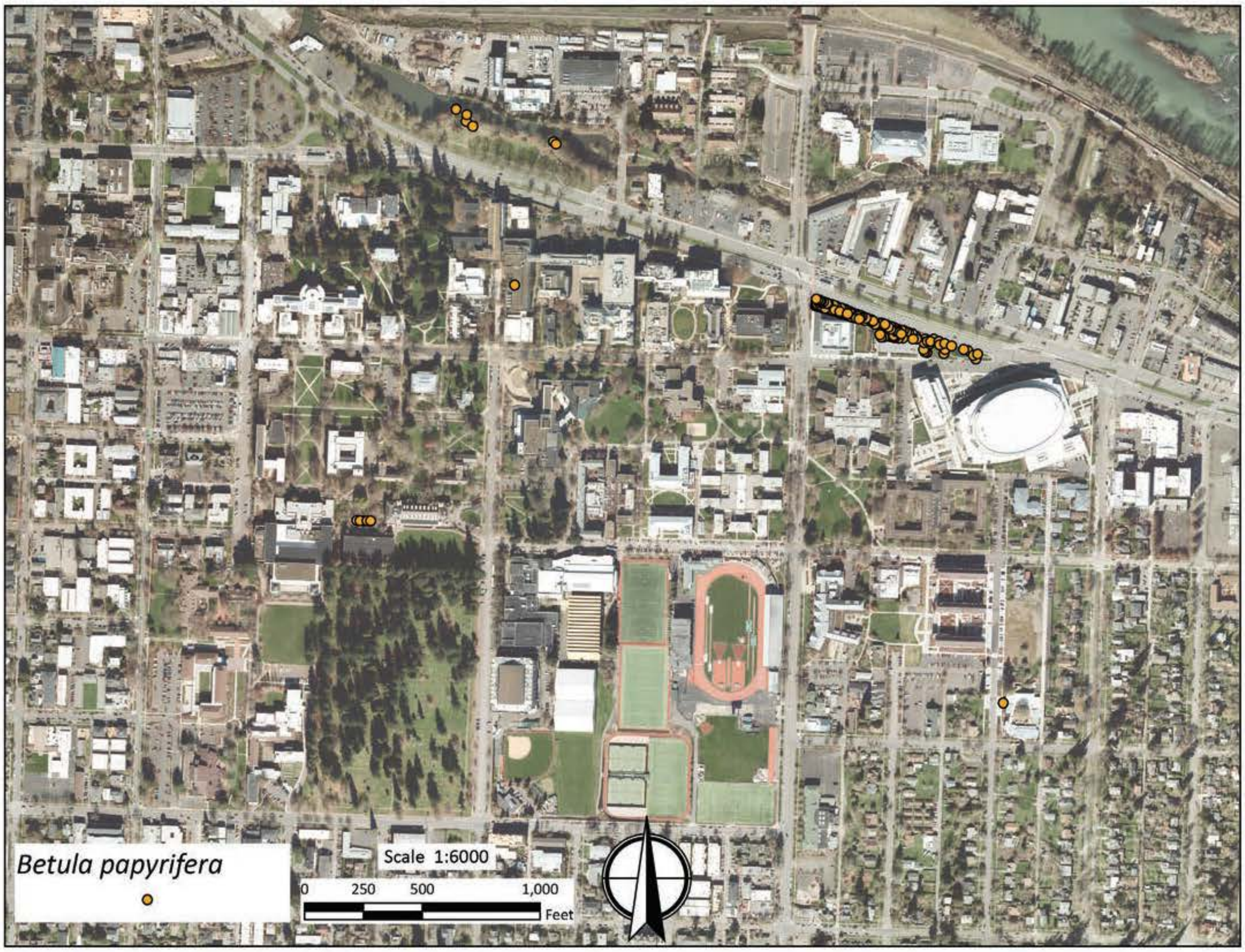
Appendix A

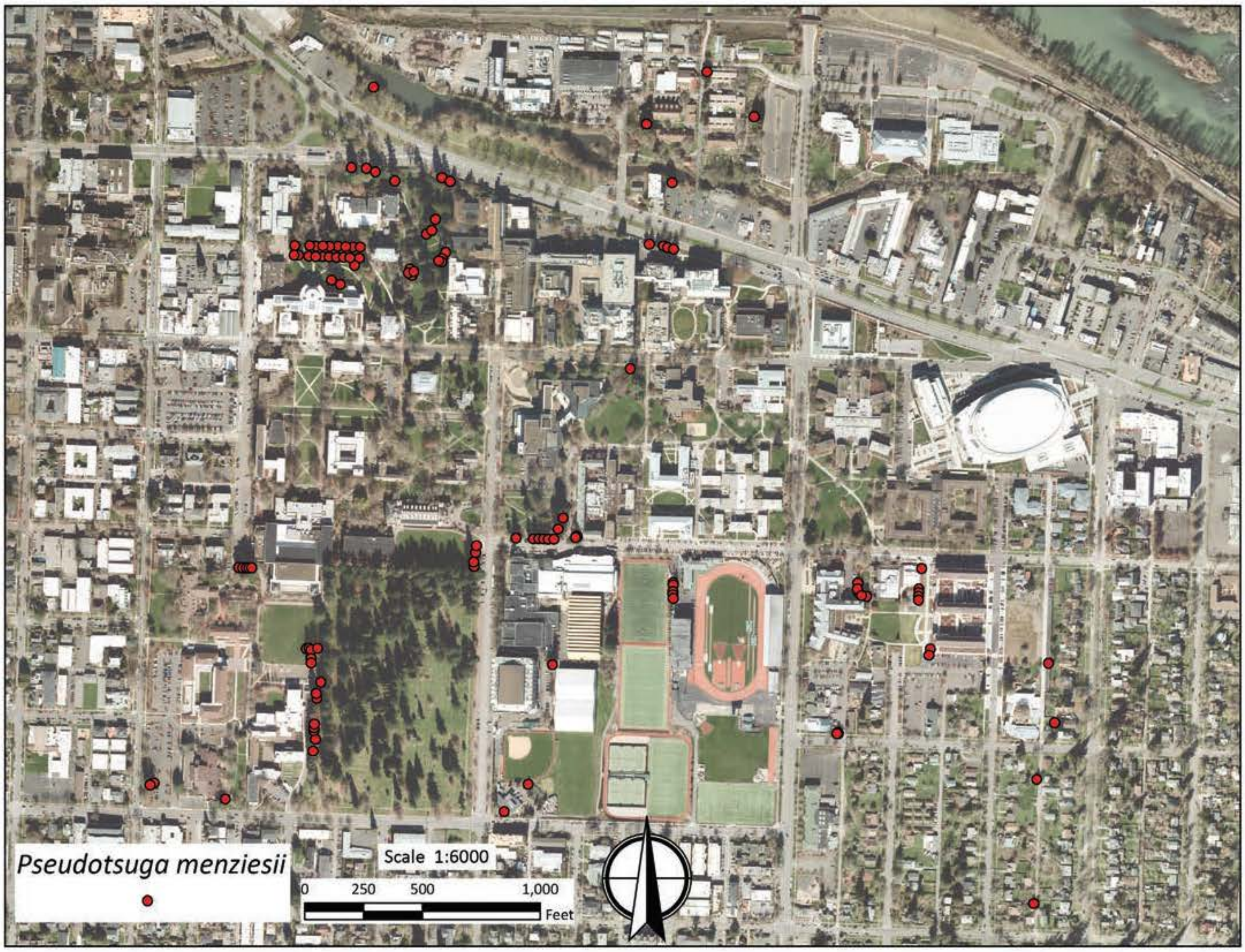
GIS maps of the three most vulnerable species on campus

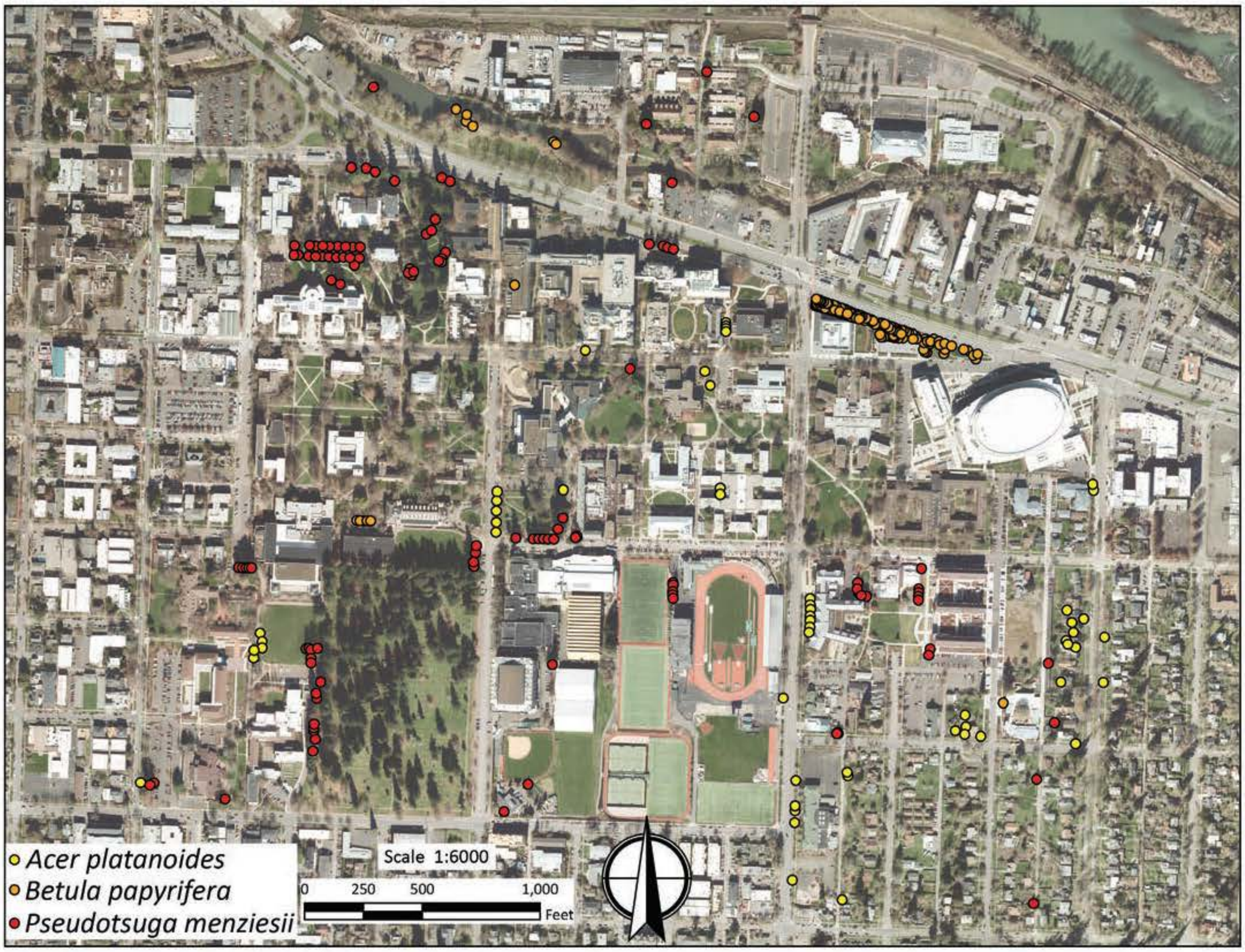
The following aerial imagery maps spatially locate all specimens of *Acer platanoides*, *Betula papyrifera*, and *Pseudotsuga menziesii* on the University of Oregon campus. First, each species is displayed individually, and then combined on the same map. This process aided in determining high densities of individual species, as well as an area of focus deemed "significant" by the various UO Campus Plans.





Betula papyrifera
Scale 1:6000
0 250 500 1,000
Feet


Pseudotsuga menziesii
Scale 1:6000
0
250
500
1,000
Feet



Acer platanoides
Betula papyrifera
Pseudotsuga menziesii
Scale 1:6000
0
250
500
1,000
Feet

Appendix B

Matrix Tables

The following tables are populated with the data necessary to score all categories within the matrix. The first set pertains to the top 14 most prominent species present on the UO campus. The second set pertains to the 24 species identified as replacement candidates for *Pseudotsuga menziesii*.

Set 1: Prominent Campus Species

Climate Zone

Scientific Name	Common Name	Dirr	AHS	Sunset	Score	Multiplier	Total Score
Acer macrophyllum	Bigleaf Maple	5-9	5-9	2-9, 14-24	2	4	8
Acer platanoides	Norway Maple	4-7	3-7	A2, A3, 1-9, 14-17	0	4	0
Acer rubrum	Red Maple	3-9	3-9	A2, A3, 1-9, 14-17	2	4	8
Betula papyrifera	Paper Birch	2-7	2-7	A1-A3, 1-6	-0.5	4	-2
Calocedrus decurrens	California Incense Cedar	5-8	5-8	2-12, 14-24	1	4	4
Carpinus betulus 'Fastigiata'	Pyramidal European Hornbeam	4-8	4-8	2-9, 14-17	1	4	4
Fraxinus pennsylvanica 'Summit'	Green Ash	3-9	4-9	A2, A3, 1-6	1.5	4	6
Liquidambar styraciflua	American Sweetgum	5-9	7-9	3-9, 14-24	2	4	8
Nyssa sylvatica	Black Tupelo	4-9	5-9	2-10, 14-21	2	4	8
Pseudotsuga menziesii	Douglas-fir	3-7	5-7	A2-3, 1-10, 14-17	0	4	0
Quercus coccinea	Scarlet Oak	4-9	5-9	2-10, 14-24	2	4	8
Quercus palustris	Pin Oak	4-8	5-8	2-10, 14-24	1	4	4
Quercus rubra	Northern Red Oak	3-8	5-9	1-10, 14-21	1.5	4	6
Thuja plicata	Western Red Cedar	4-7	6-8	A3, 1-9, 14-24	0.5	4	2

Soil Moisture

Scientific Name	Common Name	Dirr	Score
Acer macrophyllum	Bigleaf Maple	dry, avg, wet	2
Acer platanoides	Norway Maple	dry, avg	1
Acer rubrum	Red Maple	avg, wet	1
Betula papyrifera	Paper Birch	avg, wet	1
Calocedrus decurrens	California Incense Cedar	dry, avg, wet	2
Carpinus betulus 'Fastigiata'	Pyramidal European Hornbeam	avg	0
Fraxinus pennsylvanica 'Summit'	Green Ash	dry, avg, wet	2
Liquidambar styraciflua	American Sweetgum	avg, wet	1
Nyssa sylvatica	Black Tupelo	dry, avg, wet	2
Pseudotsuga menziesii	Douglas-fir	avg, wet	1
Quercus coccinea	Scarlet Oak	dry, avg	1
Quercus palustris	Pin Oak	avg, wet	1
Quercus rubra	Northern Red Oak	avg	0
Thuja plicata	Western Red Cedar	dry, avg, wet	2

Water Needs

Scientific Name	Common Name	Sunset	Score	Multiplier	Total Score
Acer macrophyllum	Bigleaf Maple	high med	1	2	2
Acer platanoides	Norway Maple	high med	1	2	2
Acer rubrum	Red Maple	high med	1	2	2
Betula papyrifera	Paper Birch	high	0	2	0
Calocedrus decurrens	California Incense Cedar	med low	2	2	4
Carpinus betulus 'Fastigiata'	Pyramidal European Hornbeam	high	0	2	0
Fraxinus pennsylvanica 'Summit'	Green Ash	high med	1	2	2
Liquidambar styraciflua	American Sweetgum	high med	1	2	2
Nyssa sylvatica	Black Tupelo	high med	1	2	2
Pseudotsuga menziesii	Douglas-fir	high med low	2	2	4
Quercus coccinea	Scarlet Oak	med	1	2	2
Quercus palustris	Pin Oak	high med	1	2	2
Quercus rubra	Northern Red Oak	high	0	2	0
Thuja plicata	Western Red Cedar	high med	1	2	2

Pest and Disease Risk

Scientific Name	Common Name	NA Plantfile	NA Plantfile
		Pest	Disease
Acer macrophyllum	Bigleaf Maple	2	2
Acer platanoides	Norway Maple	1	2
Acer rubrum	Red Maple	1	1
Betula papyrifera	Paper Birch	0	1
Calocedrus decurrens	California Incense Cedar	2	1
Carpinus betulus 'Fastigiata'	Pyramidal European Hornbeam	2	2
Fraxinus pennsylvanica 'Summit'	Green Ash	1	1
Liquidambar styraciflua	American Sweetgum	2	2
Nyssa sylvatica	Black Tupelo	2	2
Pseudotsuga menziesii	Douglas-fir	1	1
Quercus coccinea	Scarlet Oak	1	1
Quercus palustris	Pin Oak	2	2
Quercus rubra	Northern Red Oak	1	1
Thuja plicata	Western Red Cedar	2	2

Total Scores

Scientific Name	Common Name	Zone	Soil Moisture	Water Needs	Pest	Disease	Total Score
Acer macrophyllum	Bigleaf Maple	8	2	2	2	2	16
Acer platanoides	Norway Maple	0	1	2	1	2	6
Acer rubrum	Red Maple	8	1	2	1	1	13
Betula papyrifera	Paper Birch	-2	1	0	0	1	0
Calocedrus decurrens	California Incense Cedar	4	2	4	2	1	13
Carpinus betulus 'Fastigiata'	Pyramidal European Hornbeam	4	0	0	2	2	8
Fraxinus pennsylvanica 'Summit'	Green Ash	6	2	2	1	1	12
Liquidambar styraciflua	American Sweetgum	8	1	2	2	2	15
Nyssa sylvatica	Black Tupelo	8	2	2	2	2	16
Pseudotsuga menziesii	Douglas-fir	0	1	4	1	1	7
Quercus coccinea	Scarlet Oak	8	1	2	1	1	13
Quercus palustris	Pin Oak	4	1	2	2	2	11
Quercus rubra	Northern Red Oak	6	0	0	1	1	8
Thuja plicata	Western Red Cedar	2	2	2	2	2	10

Set 2: Candidate Species to Replace Pseudotsuga menziesii

Climate Zone

Scientific Name	Common Name	Dirr	AHS	Sunset	Score	Multiplier	Total Score
Cedrus atlantica	Atlas Cedar	6-9	6-9	3b-10, 14-24	2	4	8
Cedrus atlantica 'Glauca'	Blue Atlas Cedar	6-9	6-9	3b-10, 14-24	2	4	8
Cedrus libani	Cedar of Lebanon	5-7	6-9	3-10, 14-24	1	4	4
Chamaecyparis lawsoniana	Port Orford Cedar	5-8	5-9	A3, 3-6, 15-17	1	4	4
Chamaecyparis thyoides	Atlantic White Cedar	4-9	3-8	1-6, 15-17	1	4	4
Cupressocyparis × leylandii 'Naylor's Blue'	Naylor's Blue Leyland Cypress	6-10	6-9	3b-24	2	4	8
Hesperocyparis abramsiana	Santa Cruz Cypress	NA	6-9	NA	NA	4	NA
Hesperocyparis guadalupensis	Guadalupe Cypress	NA	7-9	NA	NA	4	NA
Hesperocyparis macrocarpa	Monterey Cypress	7-9	7-11	17	1.5	4	6
Hesperocyparis pygmaea	Pygmy Cypress	NA	NA	NA	NA	4	NA
Juniperus virginiana	Eastern Red Cedar	3-9	3-9	A3, 1-24	2	4	8
Pinus jeffreyi	Jeffrey Pine	5	6-8	2-9, 14-19, H1	0.5	4	2
Pinus muricata	Bishop Pine	NA	7-9	5, 14-17, 22-24	1.5	4	6
Pinus palustris	Longleaf Pine	7-10	8-11	NA	1.5	4	6
Pinus parviflora	Japanese White Pine	4-7	6-9	2-9, 14-24	1	4	4
Pinus peuce	Macedonian Pine	4-7	5-9	NA	1	4	4
Pinus pinaster	Cluster Pine	NA	NA	NA	NA	4	NA
Pinus ponderosa	Ponderosa Pine	3-7	5-8	1-10, 14-21, H1	0.5	4	2
Pinus ponderosa var. washoensis	Washoe Pine	3-7	5-8	1-10, 14-21, H1	0.5	4	2
Pinus strobus	White Pine	3-7	4-9	1-6	0.5	4	2
Pinus sylvestris	Scots Pine	3-7	3-7	A1-A3, 1-9, 14-21	0	4	0
Pinus wallichiana	Himalayan White Pine	5-7	6-9	A2, A3, 4-6, 15-17	0.5	4	2
Sequoiadendron giganteum	Giant Sequoia	6-8	6-9	1-9, 14-23	1.5	4	6
Torreya californica	California Nutmeg	NA	7-11	4-9, 14-24	2	4	8

Scientific Name	Common Name	Dirr	Score
Cedrus atlantica	Atlas Cedar	dry, avg	1
Cedrus atlantica 'Glauca'	Blue Atlas Cedar	dry, avg	1
Cedrus libani	Cedar of Lebanon	avg	0
Chamaecyparis lawsoniana	Port Orford Cedar	avg	0
Chamaecyparis thyoides	Atlantic White Cedar	dry, avg, wet	2
Cupressocyparis × leylandii 'Naylor's Blue'	Naylor's Blue Leyland Cypress	dry, avg	1
Hesperocyparis abramsiana	Santa Cruz Cypress	NA	NA
Hesperocyparis guadalupensis	Guadalupe Cypress	NA	NA
Hesperocyparis macrocarpa	Monterey Cypress	NA	NA
Hesperocyparis pygmaea	Pygmy Cypress	NA	NA
Juniperus virginiana	Eastern Red Cedar	dry, avg	1
Pinus jeffreyi	Jeffrey Pine	dry, avg	1
Pinus muricata	Bishop Pine	NA	NA
Pinus palustris	Longleaf Pine	NA	NA
Pinus parviflora	Japanese White Pine	avg	0
Pinus peuce	Macedonian Pine	avg	0
Pinus pinaster	Cluster Pine	NA	NA
Pinus ponderosa	Ponderosa Pine	dry, avg	1
Pinus ponderosa var. washoensis	Washoe Pine	dry, avg	1
Pinus strobus	White Pine	dry, avg, wet	2
Pinus sylvestris	Scots Pine	dry, avg	1
Pinus wallichiana	Himalayan White Pine	dry, avg	1
Sequoiadendron giganteum	Giant Sequoia	dry, avg	1
Torreya californica	California Nutmeg	NA	NA

Water Needs

Scientific Name	Common Name	Sunset	Score	Multiplier	Final score
Cedrus atlantica	Atlas Cedar	med	1	2	2
Cedrus atlantica 'Glauca'	Blue Atlas Cedar	med	1	2	2
Cedrus libani	Cedar of Lebanon	med	1	2	2
Chamaecyparis lawsoniana	Port Orford Cedar	high	0	2	0
Chamaecyparis thyoides	Atlantic White Cedar	high	0	2	0
Cupressocyparis × leylandii 'Naylor's Blue'	Naylor's Blue Leyland Cypress	med, high	1	2	2
Hesperocyparis abramsiana	Santa Cruz Cypress	NA	NA	2	NA
Hesperocyparis guadalupensis	Guadalupe Cypress	NA	NA	2	NA
Hesperocyparis macrocarpa	Monterey Cypress	low, med	2	2	4
Hesperocyparis pygmaea	Pygmy Cypress	NA	NA	2	NA
Juniperus virginiana	Eastern Red Cedar	low, med, high	2	2	4
Pinus jeffreyi	Jeffrey Pine	low	2	2	4
Pinus muricata	Bishop Pine	low	2	2	4
Pinus palustris	Longleaf Pine	NA	NA	2	NA
Pinus parviflora	Japanese White Pine	high	0	2	0
Pinus peuce	Macedonian Pine	NA	NA	2	NA
Pinus pinaster	Cluster Pine	NA	NA	2	NA
Pinus ponderosa	Ponderosa Pine	low	2	2	4
Pinus ponderosa var. washoensis	Washoe Pine	low	2	2	4
Pinus strobus	White Pine	high	0	2	0
Pinus sylvestris	Scots Pine	med	1	2	2
Pinus wallichiana	Himalayan White Pine	low	2	2	4
Sequoiadendron giganteum	Giant Sequoia	med	1	2	2
Torreya californica	California Nutmeg	med	1	2	2

Scientific Name	Common Name	NA Plantfile Pests	NA Plantfile Disease
Cedrus atlantica	Atlas Cedar	2	2
Cedrus atlantica 'Glauca'	Blue Atlas Cedar	2	2
Cedrus libani	Cedar of Lebanon	2	2
Chamaecyparis lawsoniana	Port Orford Cedar	2	2
Chamaecyparis thyoides	Atlantic White Cedar	2	2
Cupressocyparis × leylandii 'Naylor's Blue'	Naylor's Blue Leyland Cypress	2	2
Hesperocyparis abramsiana	Santa Cruz Cypress	0	0
Hesperocyparis guadalupensis	Guadalupe Cypress	0	0
Hesperocyparis macrocarpa	Monterey Cypress	2	0
Hesperocyparis pygmaea	Pygmy Cypress	NA	NA
Juniperus virginiana	Eastern Red Cedar	2	1
Pinus jeffreyi	Jeffrey Pine	2	2
Pinus muricata	Bishop Pine	2	2
Pinus palustris	Longleaf Pine	1	1
Pinus parviflora	Japanese White Pine	2	2
Pinus peuce	Macedonian Pine	2	2
Pinus pinaster	Cluster Pine	2	2
Pinus ponderosa	Ponderosa Pine	1	1
Pinus ponderosa var. washoensis	Washoe Pine	1	1
Pinus strobus	White Pine	1	2
Pinus sylvestris	Scots Pine	1	0
Pinus wallichiana	Himalayan White Pine	NA	NA
Sequoiadendron giganteum	Giant Sequoia	2	2
Torreya californica	California Nutmeg	2	2

Total Scores

Scientific Name	Common Name	Zone	Soil Moisture	Water Needs	Pest	Disease	Total Score
Cedrus atlantica	Atlas Cedar	8	1	2	2	2	15
Cedrus atlantica 'Glauca'	Blue Atlas Cedar	8	1	2	2	2	15
Cedrus libani	Cedar of Lebanon	4	0	2	2	2	10
Chamaecyparis lawsoniana	Port Orford Cedar	4	0	0	2	2	8
Chamaecyparis thyoides	Atlantic White Cedar	4	2	0	2	2	10
Cupressocyparis × leylandii 'Naylor's Blue'	Naylor's Blue Leyland Cypress	8	1	2	2	2	15
Hesperocyparis abramsiana	Santa Cruz Cypress	NA	NA	NA	0	0	NA
Hesperocyparis guadalupensis	Guadalupe Cypress	NA	NA	NA	0	0	NA
Hesperocyparis macrocarpa	Monterey Cypress	6	NA	4	2	0	NA
Hesperocyparis pygmaea	Pygmy Cypress	NA	NA	NA	NA	NA	NA
Juniperus virginiana	Eastern Red Cedar	8	1	4	2	1	16
Pinus jeffreyi	Jeffrey Pine	2	1	4	2	2	11
Pinus muricata	Bishop Pine	6	NA	4	2	2	NA
Pinus palustris	Longleaf Pine	6	NA	NA	1	1	NA
Pinus parviflora	Japanese White Pine	4	0	0	2	2	8
Pinus peuce	Macedonian Pine	4	0	NA	2	2	NA
Pinus pinaster	Cluster Pine	NA	NA	NA	2	2	NA
Pinus ponderosa	Ponderosa Pine	2	1	4	1	1	9
Pinus ponderosa var. washoensis	Washoe Pine	2	1	4	1	1	9
Pinus strobus	White Pine	2	2	0	1	2	7
Pinus sylvestris	Scots Pine	0	1	2	1	0	4
Pinus wallichiana	Himalayan White Pine	2	1	4	NA	NA	NA
Sequoiadendron giganteum	Giant Sequoia	6	1	2	2	2	13
Torreya californica	California Nutmeg	8	NA	2	2	2	NA