SEATTLE PARKS AND RECREATION / GREEN SEATTLE PARTNERSHIP

FOREST STEWARDSHIP REPORT

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EXECUTIVE SUMMARY

Meeting a Need for Long-Term Stewardship Planning

Seattle Parks and Recreation (SPR) manages 2,747 acres of forested property as part of the Green Seattle Partnership, which is a collaborative effort between the City of Seattle and a network of non-profit organizations, contractors, and volunteers to create a sustainable network of healthy forested parkland[1]. This Forest Stewardship Report (Report) clarifies SPR's stewardship objectives, identifies and classifies current forest conditions, and prescribes forest stewardship actions to address forest health and resilience over a 10- to 50-year time frame.

Defining Forest Stewardship Outcomes

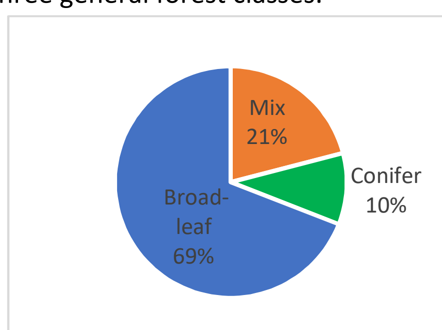
SPR takes an ecological restoration approach to forest stewardship to improve associated functions and benefits, such as water filtration, air quality, and recreation. Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed[2]. The following are priority outcomes of SPR long-term forest stewardship efforts:

- ***Dynamic Multi-Scale Forest Ecosystems*** that respond to and withstand the future range of variability in climate conditions at the level of trees, contiguous forest systems, and the region.
- ***Long-Term Climate Resilience*** that are adapted to the predicted long-term changes in temperature, rainfall amount and patterns, and drought duration.
- ***Long-Term Native Forest Cover*** to ensure biologically diverse, native species moving towards desirable future conditions.
- ***Disease and Pest Resilience*** to withstand native and non-native disease and pest outbreaks by maintaining diverse tree and vegetation species to mitigate losses for hard-to-control outbreaks.
- ***Recreation and Aesthetic Value*** to improve recreational opportunities for all City residents.

Quantifying Forest Current Conditions

Using SPR's extensive datasets, this analysis identifies and categorizes current forest conditions to aid in stewardship planning. Understanding current forest conditions allows park managers to identify areas that do not achieve the stewardship outcomes they desire. Park managers can then develop management actions to set the forest on a trajectory to achieve the target forest ecosystems.

Species composition in SPR's forested parks in three general forest classes.



Broadleaf species dominance (69% of SPR forested parks) presents a long-term challenge for Seattle if

[1] https://www.greenseattle.org/about-us/
[2] https://www.ser.org/page/SERStandards/International-Standards-for-the-Practice-of-Ecological-Restoration.htm

higher conifer cover is a priority. The abundance of bigleaf maple (32% of all tree canopy) is also a concern because it typically plays a minor role in undisturbed forests, and its vulnerable should a maple-specific disease or pathogen be introduced.

We use a detailed dataset called Light Detection and Ranging (LiDAR) to classify and assess forest structure, reducing field work while providing complete coverage of forested parks to show restoration success over time. Up to 43% of SPR forested parks have conditions (species composition and structure) that indicate a high management priority to bring the areas closer to their target conditions.

Forecasting How Climate Change Will Affect Forested Parks

The Report summarizes scientific literature on the effects of climate change on SPR's forests to predict the most vulnerable forest types and areas, allowing Seattle to potentially act preemptively to shift species composition, reduce tree competition in crowded forests, and identify locations that will provide cooler, wetter refugia for the most sensitive species.

- About **10% of SPR forested parks are at high risk** due to high cover of species at risk of drought, insect, and disease mortality that will be higher due to climate change, and **another 20% of acres are at moderate risk**. Common high-risk species include bigleaf maple and western hemlock.
- The Report also **quantifies other vulnerabilities**, such as:
  - Low species diversity,
  - Position on the landscape prone to drought and flooding,
  - Small patches of forest,
  - Under-represented forest ecosystems,
  - Proximity to adjacent properties as weed seed sources,
  - High- and low-density forests
- **49% of SPR forested park have multiple risk factors that impact long-term forest health and resilience.** SPR can potentially alleviate risk through management actions such as shifting species composition.

Prescribing Actions to Improve Long-Term Forest Resilience

The Report presents a decision framework for prioritizing where to conduct stewardship actions, and then gives detailed prescriptions for best management practices designed to move forests towards achieving their target conditions. These include the following categories of management actions:

- ***Alleviating Crowded Forests to Give Big Trees Room to Grow***: Where forests are dense with tree species that are vulnerable to climate change, removing some trees makes light and water available to trees with the best chance of long-term success.
- ***Shifting Tree Composition Towards Long-Lived, Climate-Resilient Species***: Douglas-fir, shore pine, madrone, and Garry oak are among the most drought-tolerant native species. Native seedling stock from warmer climates will also help grow resilient forests.
- ***Creating Habitat with Large Woody Debris***: Standing dead trees and downed dead trees are critical for wildlife habitat, and Seattle lacks these features.
- ***Special Management Considerations for Special Forest Habitats***: Madrone forests, moisture-loving western redcedar and western hemlocks, and other habitats need special management

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I. INTRODUCTION

1. Strategic Forest Stewardship

The underlying management strategy developed in this Forest Stewardship Report (Report) is to identify areas that are climate-vulnerable, and then provide recommendations to adapt these areas to future conditions so that SPR maintains healthy, resilient, diverse native forests. Some sites are more vulnerable to the effects of climate change over the next 50 years while other areas will stay much the same as today. Vulnerable areas must shift towards climate-adapted tree species and forest communities. We identify refugia, or areas that are likely to change little with climate change, to host species and communities that aren't well-adapted to climate change. This Report provides information to identify vulnerable areas and provides prescriptions describing guidelines for how to shift forests towards climate-adapted communities.

2. Seattle Parks and Recreation Forested Parks Overview

Seattle Parks and Recreation (SPR or Parks) manages 2,747 acres of forested property in coordination with the Green Seattle Partnership (GSP). Additional areas in Seattle ownership, such as boulevards and other landscapes, have tree cover but are not included in this Report. GSP formed in 2005 to coordinate ecological restoration across SPR forested parks over a 20-year timeframe, focusing on invasive species removal and planting native species to move SPR properties through four phases of restoration: (1) initial invasive removal, (2) planting, (3) establishment, and lastly, (4) long-term stewardship and maintenance (GSP 2017a). This Forest Stewardship Report (Report) focuses on ecological restoration for the last phase of restoration (Phase 4): forests that have achieved both invasive species removal and have substantial native forest cover. This Report addresses technical aspects of forest stewardship from an ecological restoration approach, to ensure Seattle has healthy and thriving forests far into the future.

SPR relies on the Society for Ecological Restoration (SER) Standards for the Practice of Restoration (McDonald et al. 2016) for an ecological restoration framework. Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged or destroyed (SER 2004 in McDonald et al. 2016). Within that context, ecosystem "resilience" is a key concept in our approach to forest stewardship. Ecosystem resilience is the "capacity of a system to absorb disturbance and reorganize while still retaining similar function, structure, and feedbacks (Suding 2011). In plant and animal communities this property is highly dependent on adaptations by individual species to disturbances or stresses experienced during the species' evolution (Westman 1978)" (in McDonald et al. 2016). Ecological restoration works towards a defined condition, known as a "reference ecosystem." SER defines a reference ecosystem as "a community of organisms and abiotic components able to act as a model or benchmark for restoration. A reference ecosystem usually represents a non-degraded version of the ecosystem complete with its flora, fauna, abiotic elements, functions, processes and successional states that would have existed on the restoration site had degradation, damage or destruction not occurred – but should be adjusted to accommodate changed or predicted environmental conditions" (McDonald et al. 2016).

The Report relies on the best-available-science in forest ecology, restoration, and climate change. The

Report describes the current forest resources managed by SPR, defines the desired future conditions for forest ecosystems, and identifies risks to resilient forest ecosystems over a multi-decade timescale. The Report provides recommendations for SPR forest managers and stewards for maintaining and improving the quality of Seattle's forest systems, considering the urban context and forecasted climate change impacts.

The management recommendations in this Report focus on overstory tree composition, forest density, and forest structure including tree size and diversity in spatial patterns, while also anticipating and mitigating the impacts of climate change. Phase 4 forest stewardship and management actions require a longer time horizon for observing the outcomes of management actions, given changes in overstory trees occur slowly over decades. The Report integrates implementation planning, describing management actions at a sub-park scale over a 20-year planning horizon to help SPR achieve long-term forest ecosystem stewardship outcomes.

In developing this Report, we assessed SPR's strengths and deficiencies in their current data collection and management actions as they relate to long-term forest ecosystem stewardship objectives. Through GSP, SPR has developed a robust system for measuring and reporting changes in small tree regeneration and invasive cover. There are opportunities to improve methods for categorizing current forest conditions, tree overstory and structural characteristics, and forest resilience risks. We provide analyses and methods to fill in these gaps and provide a clear path to successful long-term forest stewardship.

This Report provides recommendations that will be a part of many sources of information that inform SPR management actions. While we approach forest stewardship from a technical and ecological perspective, SPR will consider valuable perspectives including cultural resource use, community involvement with a particular park, volunteers' knowledge and abilities, among others.

3. Data Sources Used in This Report

SPR divides parks into several "zones," or organizational units for management actions. Zones are typically an ecologically distinct area or a geographically distinct area, such as a creek valley or an area bordered by roads and property boundaries. Zones were developed through a public land assessment undertaken in 1999 and 2000 called the Seattle Urban Nature project (Ramsey et al. 2004). As of spring of 2018, SPR manages 2,747 acres of forested parks property in 1529 zones across the city. Zones range in size from less than 1/10th of an acre to more than 20 acres, with a median size of about 1 acre. Some zones span different vegetative communities or geographic features, for example, portions of both a ravine and an adjacent upland flat. GSP maintains an online reference map of zones for public use[3].

Inventory assessments are in-forest survey methods that provide data for species composition, which is

[3] https://www.greenseattle.org/information-for/forest-steward-resources/gsp-restoration-map/

critical to classifying current conditions. SPR has inventory assessment data from 983 out of 1529 zones, and measures or re-measures zones every year. The inventory protocols (GSP 2016) are the primary method of assessing forest conditions. Inventories are conducted by walk-through assessments, including qualitative observations along a transect (called a 'profile') and quantitative assessments of density and regeneration at discrete plots.

Monitoring data are a rigorous set of data from a network of permanent plots established in 2010 (Green City Partnership 2013). The Report uses monitoring data for forest density calculations. Monitoring plots are supported by a collaborative effort among GSP, SPR, EarthCorps, volunteers, and other GSP partner organizations. A rotating sub-set of monitoring plots are measured on a yearly basis. Over the course of the program, more than 275 permanent plots have been established in 71 parks throughout Seattle, and many have already been re-measured. 150 plots have been selected for long-term re-measurement.

LiDAR data, flown in 2015, are used for slope, aspect, ecological structure classes.

GIS data are from the City of Seattle Open Data website.[4]

[4] https://data.seattle.gov

II. FOREST ECOSYSTEM STEWARDSHIP OUTCOMES

Seattle Parks and Recreation and the Green Seattle Partnership take an ecological restoration approach to stewarding public parks in Seattle, while relying on these natural resources' normal functions for human-focused services such as water filtration, air quality, and recreation. These stewardship outcomes align with the benefits of urban forestry described in the GSP Strategic Plan Update (2017a).

Dynamic Multi-Scale Forest Ecosystems

Forests are managed as ecosystems that can respond to and withstand the future range of variability in climate conditions at the level of individual trees, contiguous forest systems, and the Puget Sound ecoregion. Dynamic systems include a range of young to old forest stages. Forests will provide physical and biotic resources to support canopy cover and availability of essential resources.

Climate Resilience

Forests withstand long-term changes in temperature, rainfall amount and patterns, and drought durations that are predicted to occur with climate change.

Long-Term Native Forest Cover

Forest ecosystems will be composed of biologically diverse, primarily native species, with documented reference ecosystems informing target forest ecosystems that guide forest stewardship actions. Target forest ecosystems are considered in the context of species adaptation to changes in climate and the urban landscape.

Disease and Pest Resilience

Withstand native and non-native disease and pest outbreaks by maintaining diverse tree and vegetation species to mitigate losses for hard-to-control outbreaks. Forests will be managed to have communities and densities that are adapted to and supported by site conditions so that individual trees and tree networks have sufficient light, water, and space to decrease the risk of large-scale mortality from disease and pests.

Recreation and Aesthetic Value

Manage forests to maintain recreational opportunities for all City residents. Promote an appealing visual aesthetic of the forest parks.

III. CLIMATE AND CLIMATE CHANGE

Section Highlights

Climate change forecasts indicate substantial change to long-term weather patterns in the Puget Sound region. Seattle can expect longer and more severe summer drought, more rain falling in stronger winter storms, and rising sea levels increasing weathering and erosion along waterfronts.

1. Current Climate

Seattle has a moderate climate mitigated by year-to-year and decadal fluctuations in the Pacific Ocean and Puget Sound with wet, cool winters and dry, moderate summers. Protected by the Olympic Range's rain shadow, Seattle has somewhat less precipitation than other locations in Western Washington. Precipitation averages 36 inches per year (NOAA 2018), falling mostly as rain between October and March; mean January and July temperatures are 40°F and 71°F, respectively. Temperatures infrequently fall below 30°F or above 90°F. Severe weather events include windstorms in the winter with winds reaching 50 miles per hour or more, snow or ice events that can snap tree tops and damage vegetation, and seasonal summer droughts.

2. Forecasted Climate Change Impacts

Climate change is expected to result in drier and longer summers with warmer and wetter winters in the Pacific Northwest (Mauger et al. 2015, SPU 2018, USGCRP 2018). These changes will impact forest health and survival on multiple scales, ranging from region-wide droughts to increased stream flows that disturb riparian vegetation (Mauger et al. 2015). Variables such as tree species composition, soils, and aspect influence where SPR forested parks will be most vulnerable to the effects of climate change.

a. Temperature

By 2050, mean daily temperature is predicted to increase 4.2 to 5.5 degrees Fahrenheit (Mauger et al. 2015). The summers are expected to be hotter and drier, while the winters will be slightly warmer and wetter. The change in the seasonal temperature may cause the growing seasons to start earlier. A longer growing season may promote more annual vegetation growth; however, earlier onset of summer droughts will limit vegetation growth and increase plant stress. Deciduous species require colder winter temperatures to enter dormancy and to reset their budding mechanisms for spring, but warmer winters could delay leaf emergence in the spring (Harrington and Gould 2015). It is difficult to predict how changes in the growing season will affect timing of flowering and reproduction, alter the synchronized life cycles of plants with their insect pollinators, change seed dispersal by animals, and affect other inter-species interactions.

b. Precipitation

Changes in precipitation effect SPR forests in two ways: 1) increased winter stream flow, and 2) prolonged summer drought. By 2080, heavy rainfall events are expected to increase by 22% (Warner et al. 2015). The additional rainfall will mostly be concentrated in winter months. A study from Seattle Public Utilities found that extreme rainstorms in Seattle have grown 30 percent stronger since 2013 (SPU 2017). Increased winter rainfall will shift peak streamflow to earlier in the winter and spring, resulting in more severe flooding in riparian corridors. Low-elevation (rain dominant) watersheds could be more strongly influenced by changes in development and land use than changes in rainfall (Cuo et al. 2011). Many climate change simulations did not include recent projections for an increase in the intensity of heavy rain events, which could alter streamflow for lowland basins (Salathé et al. 2014). The Duwamish River and the Lake Washington-Lake Union-Ballard Canal waterway are fed by mountain snow melt, though the Duwamish has flood control devices upstream and Lake Washington water level is controlled by the Ballard Locks. All other streams receive water supply from rainfall within and adjacent to Seattle. Summer precipitation is expected to decrease, creating longer and more severe summer droughts that will reduce annual growth and survival of many species. Coupled with warming temperatures, we anticipate summer drought to be the most important change affecting SPR forests.

Recent weather trends forebear the impacts that are forecasted in climate change models: winter months are experiencing a greater proportion of precipitation while summers are drier (though overall precipitation has remained within long-term normal ranges) (NOAA 2018). GSP staff at SPR have already worked diligently to design restoration plans with more comprehensive stormwater and erosion control measures. SPR aligns and adopts best practices (GSP 2017b) with City and State standards and guidelines. Examples from the restoration activities include leaving less bare ground, causing less soil disturbance and planting more densely.

c. Sea Level Rise

Sea level is expected to rise by 6.5 inches by 2050, though could rise as high as 9 inches by 2030, 19 inches by 2050, and 56 inches by 2100 in Washington (National Research Council 2012). A study by Seattle Office of Sustainability and Environment (2015) assessed impacts to Seattle using projections of sea level at high tides and storm surge events ranging from 2 to 5 feet (24 to 60 inches) above current levels, which is a functional approach to predicting the most damaging events that are likely to occur. Seattle also maintains a sea level rise map for public use[5]. The Office of Sustainability and Environment study identifies sea level rise impacts to 16 to 50 acres of Seattle park land, concentrated at Alki Beach, Herrings House, Lincoln Park, Discovery Park, and Golden Gardens, though much of those areas are non-forested beach. SPR forested parks have approximately four miles of shoreline along the Puget Sound Coast. Some of these forested potions of the parks are buffered by railroad tracks (i.e. Carkeek and much of Golden Gardens) or beach (i.e. portions of Golden Gardens and Lincoln Park), but other forested parks have minimal buffers (i.e. much of Discovery and Lincoln parks, Magnolia Boulevard, Arroyos Natural Area, Herring's House).

Rising sea level affects coastal forests in two ways: 1) higher waters will subject coastal forests to additional weathering and erosion, and 2) the one-hundred-year storm surge is expected to increase in frequency to once every eighteen years (Simpson 2012). These changes are likely to increase erosion of coastal feeder bluffs and increase tidal flooding of low-lying areas. Forests on or adjacent to feeder

[5] http://www.seattle.gov/util/EnvironmentConservation/ClimateChangeProgram/ProjectedChanges/Sea-LevelRiseMap/index.htm

bluffs are at risk of eroding onto Puget Sound, while low-lying forests will experience greater tidal flooding and resulting increases in salination. Lake Union and Lake Washington water level is controlled by the Ballard Locks, and is not expected to experience impacts related to sea level rise.

IV. SEATTLE'S FORESTED ECOSYSTEMS

Section Highlights

Seattle's forests will be shaped by changes in climate in coming decades; species including Douglas-fir, Garry oak, and shore pine have drought, insect, and disease tolerances that will allow them to be more viable in the most climate-affected zones. Other species such as western redcedar, western hemlock, and grand fir will need to be carefully managed in refugia where cool and wet conditions will allow their long-term survival.

SPR has opportunities to improve the resilience of SPR's forested parks to maintain forests' desired functions and achieve SPR's objectives. The effects of climate change will come about over several decades, long enough to transition SPR forested parks towards site-specific species composition, structure, and density conditions that give the forests the best chance to withstand climate change. Species that will be better able to survive the impacts of climate change in the Puget Sound Ecoregion are those that can tolerate more drastic seasonal changes: more tolerant of drought and heat stress in the summer, and increased flooding, storm intensity, and rainfall in the winters.

1. Landscape Setting

Seattle and the surrounding Puget Sound region are defined by the Puget Sound of the Pacific Ocean, bounded by the Olympic Mountains to the west of Puget Sound and the Cascade Mountains to the east (Kruckeberg 1991). Seattle lies near the southern extent of multiple glacial advances and was covered by glaciers of the Cordilleran Ice Sheet in the Pleistocene era around 15,000 years ago (Kruckeberg 1991). Seattle's forests are part of the lowland Puget trough mixed conifer forest in the western hemlock zone, where forests were historically mixed conifer forests dominated by Douglas-fir (*Pseudotsuga menzeisii*), western redcedar (*Thuja plicata*), and western hemlock (*Tsuga heterophylla*) (Franklin and Dyrness 1988). These species continue to dominate today, though as second- and third-growth forests that have been influenced by human development and forestry practices. Lesser and variable amounts of bigleaf maple (*Acer macrophyllum*), red alder (*Alnus rubra*), grand fir (*Abies grandis*), Sitka spruce (*Picea sitchensis*), madrone (*Arbutus menziesii*), Pacific dogwood (*Cornus nuttallii*) and Pacific yew (*Taxis brevifolia*) were historically, and continue to be, important species in the region. See Table 1 for a list of species commonly referred to in this Report; species are alternately referred to by their code (based on abbreviations of Latin names), the full Latin names, or common names. A full list of all species recorded in inventory data is included in XI.5 Appendix 5: Species List.

Humans have shaped the forested landscape for generations. The *dxʷdəwʔabš* (Duwamish and Suquamish) Native Americans have lived in Seattle and the surrounding area for millennia, influencing forest composition through occasional burning and low-intensity vegetation removal. Non-Native American settlers took over the land throughout the second half of the 1800s. Seattle and the surrounding landscape was extensively logged in the late 1800s through the 1900s and developed into the urban environment. Consequently, most of the treed portions of Seattle are second-growth forests, with bigleaf maple and other broadleaf species occupying a higher proportion of the landscape than compared with pre-1800s forested conditions and current conditions elsewhere in the region (Franklin and Dyrness 1988).

Elevations range from sea level to just over 500 feet above mean sea level at High Point in West Seattle, with other points above 400 feet throughout the city. Waterbodies define the geography of Seattle, bordered to the west by Puget Sound and to the east by Lake Washington, and punctuated by Lake Union, Lake Washington Cut corridor, and the Duwamish waterway. Inland terrain is characterized by rolling moraines oriented generally north to south.

Table 1: Common species referred to in this Report.

Code	Scientific Name	Common Name	Native	Type
ABGR	*Abies grandis*	grand fir	Yes	Conifer
ACMA3	*Acer macrophyllum*	bigleaf maple	Yes	Broadleaf
ALRU2	*Alnus rubra*	red alder	Yes	Broadleaf
ARME	*Arbutus menziesii*	Pacific madrone	Yes	Broadleaf
FRLA	*Fraxinus latifolia*	Oregon ash	Yes	Broadleaf
ILAQ80	*Ilex aquifolium*	English holly	No	Broadleaf
PISI	*Picea sitchensis*	Sitka spruce	Yes	Conifer
PIMO3	*Pinus monticola*	western white pine	Yes	Conifer
POTR5	*Populus tremuloides*	aspen	Yes	Broadleaf
POTR15	*Populus trichocarpa*	black cottonwood	Yes	Broadleaf
PREM	*Prunus emarginata*	bitter cherry	Yes	Broadleaf
PSME	*Pseudotsuga menziesii*	Douglas-fir	Yes	Conifer
QUGA4	*Quercus garryana*	Garry oak	Yes	Broadleaf
SASC	*Salix scouleriana*	Scouler's willow tree	Yes	Broadleaf
THPL	*Thuja plicata*	western red cedar	Yes	Conifer
TSHE	*Tsuga heterophylla*	western hemlock	Yes	Conifer

2. Native Species Ecology and Climate Impacts

Individual species and their associated environmental settings each have unique light, moisture, and nutrient needs that influence how they became established in SPR forest parks and how they participate in forested ecosystems today and in the future. With changing climate, SPR managers need to use species selection to shift forest compositions towards communities will withstand future conditions. The following 13 common native tree species are fundamental components to forested ecosystems in Seattle. Additional tree species such as bitter cherry and Pacific dogwood are important native species, but they do not typically define overstory conditions, and are not included in this section.

a. Species Descriptions

i. Bigleaf Maple

Ecological Context

Bigleaf maple ecosystems occur in mesic conditions and commonly developed after clearcut logging, thus their prominence in Seattle. Bigleaf maple forests can have substantial red alder, black cottonwood, bitter cherry, and mixed conifer components or may be monocultures. They occur in riparian zones but are also common on upland soils. Bigleaf maple can live up to 250 years and grow to 120 feet tall and 40 inches in diameter as a single stem (Peterson et al. 1999). Bigleaf maple sprout excessively from cut stumps often growing into multi-stem trees. Bigleaf maple produce sprawling expansive crowns, which are able to expand rapidly into adjacent canopy openings when neighboring trees die or are absent. These crown properties cause bigleaf maple ecosystems to have very closed canopies and shady conditions underneath. The large complex crowns can provide extensive habitat for birds and other animals; bigleaf maple host soil ecosystems only found on branches in their canopies (Tejo et al. 2015).

Climate Impacts

Bigleaf maple, the most common tree in Seattle, has been experiencing die-off in recent years for trees ranging from young to old. The causes are not clear, and appear to be a combination of many factors including drought stress, slightly increase prevalence of disease (but not any one particular pathogen), and possibly air pollution (Omdal and Ramsey-Kroll 2011, Ramsey 2016, PNW PMH 2018). The decline is ongoing throughout Washington, though maples in decline seem to be in warmer and drier spots, closer to roads and closer to developed sites (Bentzen 2018). These most recent conclusions indicate the die-off will worsen with climate change.

Bigleaf maple's susceptibility to the Asian longhorned beetle (*Anoplophora glabripennis*, ALB) is alarming. While ALB has not reached Washington yet, it has decimated maples (*Acer* spp.), horse chestnut (*Aesculus hippocastanum*), elms (*Ulmus* spp.), willows (*Salix* spp.), and birches (*Betula* spp.) in the eastern United States and many pathologists believe its arrival locally is inevitable (Cieko et al. 2012).

ii. Red Alder

Ecological Context

Red alder often grow in riparian areas, co-locating with black cottonwood. Red alder also tolerate well-drained nutrient-poor sites, thriving on disturbed soil. As nitrogen fixers, alders rehabilitate low-productivity sites. Red alder live between 80 and 100 years, and often begin to decline at 60 years old, succumbing to heart rots. Mature alder grow to between 70 and 120 feet tall and 10 to 34 inches in diameter (Niemiec et al. 1995). Alder forests rarely regenerate throughout the decline phase due to inadequate regeneration conditions. They generally require disturbances that expose mineral soil such as timber harvesting, fire, or landslide, and regenerate in monoculture or as dominant species. In some cases, shade tolerant species such as western hemlock, western redcedar, and Sitka spruce survive below the alder canopy. As the alder declines and the canopy opens up, these mid-story individuals may grow into the canopy. Absent of these mid and understory trees, declining red alder forests often consumed by dense shrubs and are susceptible to invasive species colonization (Grotta and Zobrist 2009).

Climate Impacts

As nitrogen-fixers, red alder could be a valuable species as climate change alters forest composition in coming decades. As a disturbance-adaptable species (its seeds germinate readily on disturbed soils), as a species it will tolerate flood-prone riparian zones and could colonize areas where less competitive trees die off. Its preference for higher soil moisture indicates it will lose suitable habitat as summer droughts worsen.

iii. <u>Black Cottonwood</u>

Ecological Context

Black cottonwood thrives west of the Cascade Mountains in wetlands and floodplains near streams and rivers. Black cottonwoods are the largest hardwood in western North America, often growing to over 100 feet tall and 6 feet in diameter. Although most individuals live up to 100 years old, some individuals have been found to live up to several hundred years. Black cottonwoods readily sprout new leaders from broken tops and branches, allowing old and damaged trees to survive. Black cottonwood are shade intolerant, requiring full sun in order to regenerate. They grow very fast to outcompete other young trees into the canopy. Black cottonwood can regenerate through seed productions, which require moist soils to germinate, but also successfully reproduce through stump and root sprouting (DeBell 1990).

Black cottonwood-dominated ecosystems are typically defined by flood disturbance, where periodic major flood events kill substantial portions of the overstory and exposing mineral soil, promoting prolific seed germination and rapid growth. Black cottonwood grows well in wet, alluvial soils and is often found with a mix of other species which includes willows, western hemlock, western redcedar, Sitka spruce, and other (Egan et al. 1997).

Climate Impacts

Black cottonwood is a disturbance-adaptable species (its seeds germinate readily on disturbed soils), and as a species it will tolerate flood-prone riparian zones and could colonize areas where less competitive trees die off. Its preference for higher soil moisture indicates it will lose suitable habitat as summer droughts worsen.

iv. <u>Oregon Ash</u>

Ecological Context

Oregon ash inhabits wetlands and floodplains and may reach the age of 250 years, attaining heights of around 80 feet (Owston in Burns and Honkala 1990). It is usually associated with red alder*,* bigleaf maple*,* black cottonwood*,* and willows. They are somewhat shade tolerant (Pfeiffer 1953). Growth is limited by drought, but seedlings survive drought well (Sterrett 1915). They are susceptible to a variety of insects and fugal pathogens (Hepting 1971, Furniss and Carolin 1977).

Climate Impacts
Oregon ash's preference for higher soil moisture indicates it will lose suitable habitat as summer droughts worsen. It is also susceptible to several insects and diseases. Ash's susceptibility to the emerald ash borer (*Agrilus planipennis*, EAB) is concerning. While EAB has not reached Washington yet, it has decimated ashes (*Fraxinus* spp.) in the eastern United States and many pathologists believe its arrival locally is inevitable (Cieko et al. 2012).

v. Garry Oak

Ecological Context
Garry oak is native to the Puget region but is not historically common. It is well adapted to full sun and dry, well-drained soils, but also grows in cool, wet conditions (Stein in Burns and Honkala 1990). Garry oak systems range from low-density woodlands to mixed species forests. While typically a small tree of scrubby growth form, Garry oak can grow to large sizes up to 90 feet tall (Thilenius 1968). Oak sprouts abundantly when damaged or stressed. Garry oak is susceptible to many insects and diseases, though most are of minor consequence (Evans 1985, Shaw 1973).

Climate Impacts
Garry oak is a good candidate for the driest sites in SPR forested parks. *Quercus* spp. are susceptible to Gypsy moth (*Lymantria dispar*) defoliation, and while Gypsy moth is not yet in Washington, many pathologists believe its arrival locally is inevitable (Cieko et al. 2012).

vi. Pacific Madrone

Ecological Context
Although Pacific madrone is often found mixed in with other species as a co-dominant or subordinate species, there are instances of madrone-dominated forests in the Puget Sound Ecoregion. Sites are often located on steep slopes with loose, dry, and cracked rocky soils in areas with mild winters. Madrone forests are located on sites with open sunlight, and will be outcompeted by Douglas-fir in areas more closed to consistent sun exposure. Madrone forest are also found on flat sites with appropriate soil conditions and sun exposure. At a maximum age of 400 years, Madrone forests are long lived relative to other broadleaf forests. Mature madrone trees generally range from 24 to 48 inches in diameter and 80 to 125 feet in height. Madrone can prodigiously regenerate after fire or other disturbances, including stump sprouts after a tree is cut or windthrown where the roots are still in contact with the soil.

Madrone is susceptible to several fungal diseases including *Fusicoccum aesculiI*, *Phytophthora cactorum*, and *Nattrassia mangiferae* (McDonald and Tappeinier 1990, Elliot 1999, Elliot et al. 2002). Madrone decline has been observed in urban areas in recent years (Elliott 1999, Ahrens 2016) and is a primary concern in SPR restoration efforts.

Climate Impacts

While madrone is drought tolerant and is susceptible to few insects, it is susceptible to several fungal diseases that may exacerbate with climate change (Elliot 1999, Elliott et al. 2002). Madrone decline is an ongoing issue and SPR has worked on its restoration for many years (Yadrick, personal communication). Its susceptibility to disease renders it vulnerable to the effects of climate change.

vii. Douglas-Fir

Ecological Context

Douglas-fir grows in a wide range of ecosystems, from hot and dry forest environments to cool and wet coastal and mountain environments. Douglas-fir can live to over 1000 years old, with the largest old growth individuals growing to over 10 feet in diameter and 300 feet tall. Douglas-fir prefers deep well-drained soils and will struggle on poorly drained or compacted soils. Due to Douglas-fir being a prized timber species, there are very few very large old-growth trees left in the Puget Sound region. Douglas-fir is moderately shade intolerant and requires open canopy in order to successfully regenerate. Natural succession of Douglas-fir, which can naturally manifest as large monoculture stands, requires disturbance to create canopy openings and is often a result of wildfire or large patches of windthrow; though it does regenerate in mixed forest environments as well. Shade tolerant species such as western redcedar, western hemlock, and other may grow and thrive beneath a closed Douglas-fir canopy (Burns and Honkala 1990).

Climate Impacts

Douglas-fir is susceptible to several root and stem rots and bark beetles, though usually at moderate to low levels of mortality. It is adapted to dry to mesic soil moisture conditions. In monocultures, laminated root rot (*Coniferiporia sulphurascens*) and other diseases and insects could jeopardize Douglas-fir's survival at a local scale (less than an acre up to a few acres in size), so maintaining high species diversity will be an important goal in Douglas-fir-dominated forests.

viii. Western Redcedar

Ecological Context

Western redcedar grow in a wide range of ecosystems ranging from well-drained soils to cool and wet coastal environments. Redcedar struggles to grow well on coarse and sandy soils. Seedlings prefer disturbed mineral soil. Individuals can grow to over 1000 years old, 200 feet tall, and 10 feet in diameter. Redcedar is a very shade tolerant species that can regenerate and slowly grow in the understory, beneath a closed canopy. Western redcedar will grow into the canopy if an opening should develop due to an overstory tree dying or being cut down. Although redcedar can reach similarly size to Douglas-fir and other conifer species, it grows at a slow pace, and can take much longer to reach similar size. Redcedar are resistant to many common disease agents that affect other species and can survive in areas where disease has killed or is killing other tree species (Minore 1990).

Climate Impacts

Western redcedar is resistant to fungal diseases and tolerates a wide range of soil conditions and is shade tolerant, making it a stalwart species in SPR's planting pallet (Yadrick, personal communication).

However, recent observations of western redcedar mortality in Seattle appear to be related to drought stress, the western cedar borer *Trachykele blondeli Marseul*, and a bark beetle in the *Scolytidae* family (Rippey 2018). These recent observations call in to question western redcedar's role in restoration in SPR (Yadrick, personal communication).

ix. Western Hemlock

Ecological Context

Western hemlock prefer cooler, wet environments with high precipitation, fog, and/or humidity. In drier environments, western hemlock is limited to riparian corridors or seepages. Western hemlock can grow up to 200 feet tall and 8 feet in diameter. Few individuals are found to grow past 300 years old, but can grow older in higher-elevation mountain environments. Western hemlock have prolific seed production and can densely regenerate in soils with high organic content and on nurse logs exceeding 6,000 stems per acre. Western hemlock is also very shade tolerant and is often found growing under mature canopies of hemlock and other species (Packee in Burns and Honkala 1990).

Climate Impacts

Western hemlock does not tolerate drought well and has experienced waves of mortality following drought years in the recent past including in 2002 and 2015 drought seasons (Kohler 2016). Additionally, *Rhizoctonia butinii*, a foliar fungus, worsens needle loss in western hemlock in drought conditions (Ramsey 2018), sometimes accompanied by Annosus root disease (caused by *Heterobasidion occidentale* or *H. annosum*). Western hemlock's drought intolerance and susceptibility to insects and pathogens render it very susceptible to the effects of climate change.

x. Sitka Spruce

Ecological Context

Sitka spruce depends on cool damp air from the Puget Sound and Pacific Ocean and can extend inland along major rivers. Sitka spruce is moderately shade tolerant and most frequently occurs with western hemlock, or with red alder in disturbed sites. It grows best on deep, moist, well-aerated soils but can tolerate occasionally saturated soils and can occupy sandy or coarse-textured soils but requires abundant soil and atmospheric moisture; it tolerates salt (Harris in Burns and Honkala 1990). Sitka spruce it can reach heights greater than 200 feet tall and live more than 500 years (Krajina 1969).

Climate Impacts

Sitka spruce will be limited to cool, protected sites due to its need for damp air and soil moisture. Relatively few insects and diseases are primary morality agents (Harris in Burns and Honkala 1990). *Picea* spp. are vulnerable to Gypsy moth (*Lymantria dispar*) on the east coast, and many pathologists believe its arrival locally is inevitable (Cieko et al. 2012).

xi. Western White Pine

Ecological Context

Western white pine was once common in the region but white pine blister rust (WPBR), a fungus introduced from Europe in the early 1900s, nearly eradicated western white pines in Washington. Western white pine is moderately shade intolerant, growing best in partial to full and it tolerates dry soil moisture and poor, sandy soils sun (Graham in Burns and Honkala 1990). Mineral soils have better seed germination than duff. Aside from WPBR, root and butt rots are common in western white pine (Hepting 1971), and it is susceptible to mountain pine beetle (Furniss and Carolin 1977).

Climate Impacts

Western white pine could be suitable to drier conditions in the future. WPBR-resistant plant stock is becoming common, though generally from seed sources at higher elevations. If seedling stock adapted to low elevations is available, western white pine can play a role in SPRs forests in the future.

xii. Shore Pine

Ecological Context

Shore pine tolerates infertile soils, thus can survive in harsh windy, salty coastal environments (Lotan and Critchfield in Burns and Honkala 1990). Shore pine grows on a range of soil moisture conditions but needs full sunlight to survive. Often found in cool and mesic sites, shore pine tolerates well-drained sites as well. Disturbed mineral soil seedbeds generally produce the best germination and survival, though drought induces mortality in seedlings' first year due to a shallow rooting system (Lotan 1964).

Climate Impacts

Shore pine's ability to tolerate salt and well-drained conditions will be valuable in coastal areas in SPR forested parks.

xiii. Grand Fir

Ecological Context

Grand fir grows on a wide range of sites but grows best on deep, rich alluvial soils along streams and valley bottoms and on moist soils provided with seepage, most commonly above 500 feet elevation but occurs at low elevations (Foiles et al. in Burns and Honkala 1990). It is a shade tolerant species that can reach ages of 250 years (Franklin and Dyrness 1988) and can grow a deep tap root. Grand fir seedlings are relatively resistant to drought on areas exposed to full sun because deep initial root penetration protects them from drying of the surface soil; however, on heavily shaded, cool areas, drought is the most important cause of seedling mortality because initial root penetration is slow; even shallow drying of the surface soil may cause drought mortality despite ample soil moisture at deeper levels (Foiles 1965). *Armillaria* spp. and laminated root rot are the two most important root rot fungi that cause substantial mortality. Western spruce budworm *(Choristoneura occidentalis)* and Douglas-fir tussock moth *(Orgyia pseudotsugata)* have caused widespread defoliation, top kill, and mortality (Hepting 1971).

Climate Impacts

Grand fir's moderate drought tolerance and high susceptibility to common diseases and insects render it vulnerable to the effects of climate change.

b. Species Vulnerability

Species vulnerability relates to a species' ability to withstand changes in precipitation and temperature. Prolonged summer drought is likely to be the most important stressor and factor in tree mortality. Lack of precipitation, increased evaporation or transpiration (loss of water through tree leaves), poor water storage properties of soil, and competing vegetation contribute to drought stress. Trees that are poorly adapted to dry conditions are not likely to survive well in south-facing sites with dry soils and dense vegetation. Many factors, however, affect a species' long-term climate resilience including ability to reproduce, whether the species can grow in a range of conditions, and its competitive abilities. A complete assessment of species vulnerability is in Section VI.2: Proportion of Vulnerable Tree Species at Risk Due to Climate Change.

Suitable species

The common Seattle native species that are better adapted to the drought and disease conditions likely to come about with climatic changes are: Garry (Oregon) oak, Douglas-fir, and shore pine. While these species exhibit better drought, insect, and disease tolerance than other tree species, these species are still likely to experience decreased growth rates (Restaino et al. 2016) and potentially higher mortality rates influenced by drought stress.

Vulnerable species

Common Seattle species that are expected to suffer due to the changing climate are: western hemlock, bigleaf maple, grand fir and Sitka spruce. These species require wetter environments, are drought intolerant, and are susceptible to disease and insects. These drought-vulnerable species will remain viable in more mesic refugia: on northern aspects, poorly drained and wet sites, and in ravines protected from extended sun exposure. Western redcedar and madrone have characteristics that should allow moderate success in the changing climate; however, recent observations of mortality in Seattle indicate these species may also be more vulnerable to climate change than is predicted in the literature referenced in this Report's species vulnerability assessment.

c. Tree Planting Management Implications

Both the landscape-specific and species-specific factors influence how SPR should manage forested parks. Zones that are at a high risk from the effects of climate change (south and west aspect, for example) are a priority for revising target forest types. Where species composition is not well adapted to projected conditions, management actions should be taken to shift species composition towards a more resilient mix. The Stewardship Prescriptions (Section VIII) detail management actions for Seattle's forests.

Tree selection for planting projects must consider the effects of climate change in seedling species and stock. Tree species should be appropriate for the light environment, local soil and moisture conditions, and topographic position of the planting site. Avoid drought-intolerant trees in all but the most mesic sites. Soo-Hyung et al. (2012) recommend selecting a mix of native species seedling stock sourced from the currently-appropriate plant hardiness zone as well as incorporating stock from a half-zone south/less hardy (i.e., Toutle zone). Other organizations in the region, including a partnership among Seattle City Light, Mountains to Sound Greenway trust, and Seattle Public Utilities Watershed[6], are experimenting with seedling stock that is not locally sourced; more information about non-local stock should become available over the next several years.

SPR should track the success of stock selected from other hardiness zones to ensure these trees become well-established. While the climate will be substantially different several decades in the future, seedlings must establish and grow in the current conditions. Using seedling stock from other regions increases the short-term risk of mortality for individuals that are mal-adapted to the current conditions. We do not recommend translocating species that are not native to the Puget Sound ecoregion (known as assisted migration) based on recommendations in Soo-Hyung et al. (2012), though as new data on seedling survival become available, using non-native species may be worthwhile.

3. Natural Disturbances

Natural disturbances have historically shaped the species composition and structure of forests in the region (Franklin et al. 2002), primarily wind and fire. Native insects and disease also play a role in tree survival. Over the last 150 years, non-native invasive plants, animals, and pathogens have also shaped Seattle-area forests.

a. Fire

The fire regime of Western Washington forested areas typically results in infrequent (multiple-century intervals between fires) but large-scale fires that burn tens to hundreds of thousands of acres with devastating severity (Agee 1993, Halofsky et al. 2018). Healthy forests in Western Washington typically have dense vegetation that grows vigorously during the region's wet winters. The same vegetation, when dry due to droughts, offers a substantial fuel load for fire. The landscape-scale fires are thought to occur when three low-probability events occur at the same time: long-term drought, an ignition source (historically lightning or Native American burning), and strong dry winds blowing from the east (Agee 1993). Forests in Western Washington and not well adapted to fire and Seattle's forests would be severely degraded in most fire situations.

Seattle is well protected from landscape-scale wildfires because it is surrounded by waterbodies on most borders and has major road systems that provide space for wildfire fighters to defend against fire's advance. In Seattle, prevalence of ignition sources (sparks, cigarettes, grills, fireworks, etc.) increases the chance of fires getting started during the dry summers compared to less populated areas, though large-scale fires originating in Seattle are unlikely unless windspeeds are high. Preventing and stopping fires before they can burn large areas is the best way to address fire, both ecologically and for human safety.

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[6] http://durkan.seattle.gov/2018/04/innovative-pilot-project-seeks-to-grow-a-forest-more-resilient-to-climate-change/

i. Climate Impacts on Fire Risk

Forest fire risk is expected to increase as summers become hotter and drier. Increased frequency and severity of fires is likely throughout the region (Raymond and McKenzie 2012). In Seattle, risks to forests are most likely from human-caused ignition starting relatively small fires during summer droughts rather than landscape-scale fires burning into the city (see section IV for more explanation). These fires could be larger in scale than fires that occur in the current climate due to more extensive drought, and more frequent because drought conditions are more receptive to ignition when ignition sources are present.

ii. Stewardship Recommendations

Options for reducing the risk of fire includes enforcing firework restrictions in Seattle parks, banning charcoal grills in parks during droughts or establishing non-vegetated surfaces (concrete, sand, gravel, etc.) around grill sites, and restricting spark-emitting equipment use in parks during dry afternoon hour during summer droughts (chainsaws, gas lawn mowers, heavy equipment, etc.). For SPR forested parks with little recreational use, develop wildfire fighting strategies in coordination with Seattle Fire Department. Rapid detection and suppression are key to protecting Seattle's forested parks from fire.

b. Wind

Wind is a common forest disturbance. Winter storms can bring winds in excess of 50 miles per hour, snapping or uprooting trees ("windthrow"). Wind's impacts depend on patterns of the wind event such as wind direction and speed, landscape variables such as wind-exposed aspect, landforms that may funnel wind (e.g., ravines), tree health and rooting, adjacent trees or structures to block wind, soil composition, or soil moisture (Zielke et. al 2010). Windthrow creates important habitat elements including snags and downed logs, canopy openings to promote understory growth, and tree root mounts expose mineral soil for new seedling germination. In the urban context, windthrow can lead to negative consequences, including damage to structures or utility lines, blocking roads, or human injuries or casualties. Site conditions more strongly influence whether a tree is prone to windthrow more than tree species, though western hemlock and Sitka spruce are more prone, and bigleaf maple are prone to breaking limbs.

i. Climate Impacts

Generally, winter storms are expected in increase in severity and frequency with climate change, with accompanying wind events becoming more common.

ii. Stewardship Recommendations

Where structures, public utilities such as roads and powerlines, or high-use recreation areas are located within a tree height distance of trees, windthrow poses a risk to damage and safety. Mitigating this risk is difficult; wind can topple even healthy trees if located on compacted or wet soils. The only way to eliminate risk is to remove trees within a tree-length of areas where the risk of windthrow is unacceptable. Storms often come from the south or southwest, so trees on exposed south- or southwest-facing ridges are more likely to experience windthrow. Trees infected with root and stem rots are also vulnerable; removal of trees that show signs of these disease near structures, public utilities, or high-use recreation areas will reduce windthrow risk. Away from high-use areas and structures, windthrow is an important ecological event and should be allowed to take place.

c. Insects and Disease

Forest diseases are a common occurrence that often forms pockets of dead and dying trees. Native fungal and insect infections are typically not catastrophic, and in some cases can be beneficial for habitat creation, if the distribution of a single tree species is not too continuous. A forest with a blend of species can create buffers that inhibit the spread of pathogens that affect one single species, while a monoculture has no real barrier to the spread of the disease. Common pathogens in the Seattle area include Swiss needle cast (*Phaeocryptopus geaumannii*), which affects Douglas-fir; root rot (several fungi, including Armillaria, laminated root rot, *Annosus*, *Schweinitzii*, and *Phytophthora*), affecting Douglas-fir, Sitka spruce, red alder, western hemlock, true firs, and pines; Dwarf mistletoe (multiple varieties), which affect Douglas-fir, true firs, and western hemlock; and needle blight (*Dothistroma pini*), which affects pines.

i. Insects and Disease Climate Impacts

Disease and insect outbreaks are an important species-specific risk factor that is affected by climate change. Drought conditions and warm, dry spring weather conditions tend to increase insect abundance, while wet spring weather tends to increase foliage disease (WADNR 2017). Littell et al. (2010) predict that warmer, drier summers are expected to increase the spread of root rots, while bark beetles are expected to decrease in prevalence. Trees that are drought stressed are more susceptible to disease and insects, increasing tree mortality when outbreaks occur. Maintaining high tree species diversity will reduce the risk of wide-spread tree loss in the event of a disease or insect outbreak.

See Section VI.2: Proportion of Vulnerable Tree Species at Risk Due to Climate Change and Appendix 4: Insect and Disease Climate Change Risk Assessment for a complete description of insects and disease that are likely to become more common with climate change.

ii. Insects and Disease Stewardship Recommendations

Insects and disease are natural parts of dynamic forest systems and are difficult to eradicate or reduce. Cutting and removing infected trees is often the only way to eradicate outbreaks of insects or disease. Many common native fungal diseases remain in roots for decades. Invasive insects and diseases can run rampant through affected species and genera, as has recently happened with the emerald ash borer and Asian long-horned beetle in eastern United States. While there is no way to guarantee the prevention of insects and pathogens, or account for the risk of non-native insects or diseases, heterogeneous tree species composition and structure can inhibit the decimation of insect and disease outbreaks. Maintaining and enhancing tree species diversity is essential to mitigate losses if widespread outbreaks occur.

d. Invasive Plants

Invasive species are an ever-present threat to and stressor on urban forests, where desirable native species are a key to healthy ecosystems. Invasive species such as Himalayan or evergreen blackberry, Scotch broom, tansy ragwort, reed canary grass, hawkweeds, knotweeds, and knapweeds thrive in sunny conditions, and can grow so densely that native species are crowded out. Shade-tolerant invasive species such as vinca and English ivy spread easily through closed-canopy forests, out-competing native tree and understory species, and eventually affect the overstory. Seattle Parks' Integrated Pest Management program includes all potential pest suppression and control strategies but focuses on non-pesticide strategies whenever possible. Certain levels of weed populations are accepted within established thresholds and all reasonable non-pesticide pest control options are considered first before resorting to the use of pesticides.

i. Climate Impacts

Limited research is available for the impacts of climate change on invasive plants in the Puget Sound region.

ii. Stewardship Recommendations

SPR's robust and comprehensive approach to invasive plant control will likely need to continue indefinitely as invasives and likely to continue to thrive.

4. Topographic Positions, Susceptibility to Climate Change, and Refugia

a. Climate Impacts

A forest's location in the landscape influences its susceptibility to the effects of climate change. Aspect and topographic position (such as in a ravine, along a shoreline, etc.) have a powerful effect on what tree species are likely to thrive or deteriorate with climate change. Elevation differences in Seattle are not substantial enough to yield different outcomes in climate change, though elevation is an important variable in mountainous terrain.

Vulnerable areas include:

- South and west aspects
- Well-drained soils that do not retain soil moisture
- Site exposed to wind
- Riparian zones adjacent to streams
- Coastal areas adjacent to Puget Sound

South and west aspects, well-drained soils, and sites exposed to wind will experience summer droughts more acutely. Tree species that are adapted to dry conditions will better tolerate droughts. Species that have high soil moisture requirements will not thrive and will experience higher mortality rates.

Trees that are suited to riparian and coastal areas are those that can withstand flooding and periods of inundated roots. Tolerant species include red alder, black cottonwood, willow, Oregon ash, shore pine, Sitka spruce, and Pacific dogwood. Western redcedar and bigleaf maple moderately tolerate flooding. Shore pine and Sitka spruce are salt-tolerant and well suited for coastal forests.

b. Stewardship Recommendations

While SPR can't change a zone's aspect or slope, SPR can work with the topographic settings of its forested parks to identify areas where species composition must shift to accommodate the growing conditions, and other areas that will remain relatively cool and wet that can harbor species and forest communities that are more vulnerable to the effects of climate.

1) Identify climate-vulnerable sites and manage accordingly, primarily shifting species composition and managing density.

Section VI: RISKS TO FOREST HEALTH AND RESILIENCE describes and quantifies where climate-related risks are likely to occur in Seattle. Section VIII: STEWARDSHIP PRESCRIPTIONS AND BEST MANAGEMENT PRACTICES provides management strategies for vulnerable topographic positions.

2) Identify refugia, and prioritize species and forest communities that are more vulnerable to climate change in these refugia

Refugia are "habitats that components of biodiversity retreat to, persist in and can potentially expand from under changing environmental conditions" (Keppel et al. 2011), offer sanctuary for the tree species that are most vulnerable to the effects of climate change. In the context of SPR forested parks, refugia include conditions where the most vulnerable species and populations will be likely to persist in the changing climate. We identify north- and east-facing aspects, particularly in protected ravines, as the most suitable refugia for populations of species with a high soil moisture requirement such as western hemlock, red alder, black cottonwood, bigleaf, maple and western redcedar. While much of this Report focuses on areas negatively impacted by climate change, refugia are essential to maintaining the city's biodiversity and should receive commensurate attention in implementation.

5. Soils

The soils in Seattle are generally glacially derived and were influenced by centuries of conifer forest organic inputs. Multiple ice-sheet glaciations and intervening non-glacial intervals have resulted in complex layered soils. In minimally disturbed areas, soils are often gravelly and/or sandy loams, underlain by gravels and sands or hardpan (Franklin and Dyrness 1988). Organic-rich mucks often developed in anoxic saturated depressions.

Soil interacts with forest growth and health, influencing each other through soil fertility, infiltration and retention of water, filtration of water, slope stability, and changing the microbiomes. Soil also has the ability to store substantial amounts of carbon in organic matter, described in greater detail in the Forest Carbon Storage section of this Report. SPR has collected soil information at many of the parks, but city-wide soil data at a scale relevant to this Report do not exist, and so recommendations in this Report do not take in to account site-specific soil conditions.

Steep slopes are important features in how forests form and how restoration can take place. Sustained slopes greater than 66% can be unsafe and require careful planning and enhanced best management practices to work on. While not all steep slopes are unstable, steep slopes are more prone to erosion and landslides, especially when water saturates soil and/or vegetation cover is inadequate.

6. Water Resources

Seattle contains more than 61 miles of streams and drainages. Many of these are seasonal (only flowing during the wettest months of the year), but all are important for water volume and quality in the waterbodies surrounding Seattle. SPR forested parks encompass 19.8 miles of streams. Management of parks in these riparian corridors can substantially influence water quality and aquatic wildlife locally and in the Lake Washington and Puget Sound watersheds.

Maintaining a coniferous and deciduous canopy cover over these streams provides temperature regulation year-round, which is critical for salmon, trout, and other native fish species. Five salmon-bearing streams flow through SPR parks (Tabor et al. 2010):

- Fauntleroy (Fauntleroy Park, Kilbourne Park, and Fauntleroy Creek Ravine),
- Longfellow (Longfellow Park, West Seattle Golf Course),
- Piper's (Carkeek Park),
- Taylor (Lakeridge Park),
- Thornton (Mathews Beach Park and other parks upstream)

While deciduous trees are very common in wet areas and provide shade in spring, summer, and early fall months, coniferous species guarantee shade during all seasons. Riparian canopy cover is important to maintain at every level, because warm water from unshaded tributaries can negatively affect larger bodies downstream. Maintaining a mix of riparian tree species provides a diverse array of nutritional inputs for aquatic wildlife. Deciduous trees are particularly valuable sources of nutrition as leaves fall and enter waterways. Larger inputs of dead branches and trunks provide essential habitat structure for many aquatic and semi-aquatic species.

Wetland protection and enhancement is another critical element of riparian forest management. Wetlands provide unique habitat for plant and animal species that do not live in running water and play a critical role in pollutant uptake and filtering, storing excess water from rain or flooding events, and hosting migratory birds. They also sequester a great deal of carbon, as the environment is typically anaerobic, preventing the degradation and release of carbon.

Seattle established a Shoreline Master Program that regulates actions within the "shoreline district," which are areas near to water bodies. Within the city shoreline district, vegetation management must follow 23.60A.190 of the Shoreline code. Notably, trees generally must not be removed unless determined to be a threat to health or safety. Restoring or improving vegetation and trees using native vegetation is allowed if the work is performed by or under the direction of a qualified professional. Herbicide and pesticide use is generally prohibited without approval from the city.

a. Climate Impacts

Impacts to steams are described in Section III.2: Forecasted Climate Change Impacts. The main climate impacts are more severe flood events in the winter, and more frequent tidal surges that inundate coastal areas with salt water and powerful erosive forces.

b. Stewardship Recommendations

In flood zones, ensure flood-tolerant species such as red alder, black cottonwood, willow, Oregon ash are dominant. Near coastal areas, salt-tolerant Sitka spruce and shore pine will best survive the increased tidal forces. Salt-tolerant shrubs and forbs will also be important parts of management on coastal zones.

7. Wildlife

Seattle's parks and green spaces provide essential islands of habitat for wildlife in a large matrix of development. These habitats help support the critical web of species that form our ecosystems and sustain our communities. Habitat protection, creation, and restoration can be accomplished through a variety of creative management techniques.

Diversity in forest structure is the key to effective wildlife habitat. A solid, continuous forest canopy may provide a habitat for certain mammals and birds, but a multi-age canopy composed of clusters and canopy openings will host many more species. Birds and small mammals particularly enjoy dead and decaying trees, which provide a rich source of insects and nesting holes. Snags also create openings in the canopy, creating patches of light availability for flowering and fruiting shrubs, which provides another food source for birds, insects, and mammals. These kinds of forested habitats are important for rare or threatened species such as woodpeckers, bats, and shrews.

Continuous forest cover is critical for many species. However, open, recently disturbed areas are rich resources for foraging wildlife. Areas where trees have blown down or otherwise removed are often colonized by sun-dependent plant species that provide habitat for small mammals, reptiles, and amphibians, thereby providing a source of food for raptors and other predators.

V. CURRENT FOREST CONDITIONS

Section Highlights

Broadleaf species dominance (69% of SPR forested parks) presents a long-term challenge for Seattle if higher conifer cover is a priority. The abundance of bigleaf maple (32% of all tree canopy) is also a concern because it typically plays a minor role in undisturbed forests, and its vulnerable should a maple-specific insect or disease be introduced. Up to 43% of SPR forested parks have conditions (species composition and structure) that indicate a high management priority where changes to species composition or density are recommended to bring the areas closer to their target conditions.

Understanding current forest conditions allows park managers to identify areas that do not achieve the stewardship outcomes they desire. Park managers can then develop management actions to set the forest on a trajectory to achieve the target forest ecosystem. We use three main factors in defining forest conditions:

1) **Species composition**. Forest composition includes species of overstory trees, mid- and understory trees, and ground vegetation.
2) **Structure**. Forest structural elements include the range of tree heights and sizes, and spatial distribution of tree density and canopy cover. Structure also include snags and dead logs.
3) **Density**. Density measurements include tree count (trees per acre, “TPA” or synonymous stems per acre, “SPA”), and tree diameter. Density indicates inter-tree competition, where tree growth is limited by competition with adjacent trees for water, light, and/or nutrients.

The Report addresses these conditions at broad scales in order to identify trends in forest resources. SPR has field data from approximately two-thirds of its zones (983 out of 1529), and measures or re-measures zones every year. The Inventory Protocols (2016) are the primary method of assessing forest conditions. Inventories are conducted by walk-through assessments, including qualitative observations along a transect (called a ‘profile’) and quantitative assessments of density and regeneration at discrete plots. We used inventory assessment data to quantify species composition using species percent cover. Inventory data also include density data (number of tree stems and stem diameter), but the non-stratified data collection, small size of density plots, and unexplainable errors in the data result in lower confidence in how well the density data represent zone conditions.

Monitoring data (rigorous data collection in a network of permanent plots) are also used to quantify forest conditions where those data are available. Although the data set is more limited, we used monitoring data for density metrics as these are the most accurate data.

Forest density and structure data are incomplete and difficult to obtain for the large number of SPR-managed areas in Seattle. Remote-sensed LiDAR data (Light Detection And Ranging, which provides detailed height information; see inset “What is LiDAR?” in Section V.2) can provide accurate and extensive information on forest structure in place of field measurements.

SPR has substantial field data on forest conditions and uses a two-tiered method for classifying zones' forest ecological communities. The classification systems were developed for defining desired future conditions, rather than for accurately describing current conditions. At the broad scale, seven "Forest Systems" delineate zones into similar forest composition and site condition groups. At a fine scale, SPR uses a comprehensive system for classifying "Target Forest Types" or TFTs for forested zones based on the Chappell (2006) system of plant associations, developed for upland ecosystems in the Puget Trough ecoregion and on Kunze (1994) for riparian and wetland systems, with other sources for less-common plant associations. SPR staff synthesized this historical information as a starting point for identifying restoration targets in the early years of GSP. Considering natural variation in the urban ecosystem and anticipated environmental change, particularly with climate, restoration and management actions should allow for native plant communities to recover, and healthy forests to reassemble and evolve over time. Target forest types and forest systems are described on the Green Seattle Partnership website[7].

Quantifying current conditions is essential for developing forest stewardship recommendations. Forest Systems and Target Forest Types are forward-looking, defining the most suitable management outcome for a site. Stewardship recommendations are the pathway to bring the current conditions to the desired future conditions.

[7] https://www.greenseattle.org/information-for/forest-steward-resources/restoration-resources/reference-ecosystems/

1. Current Conditions: Species Composition

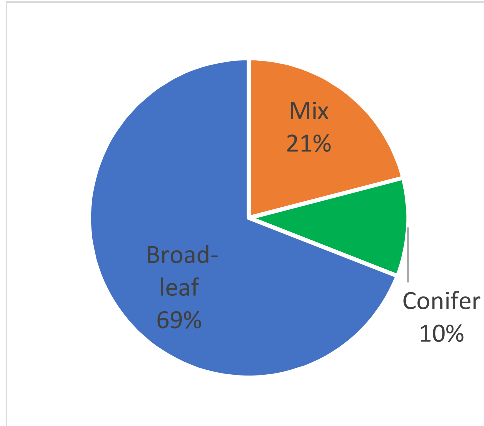
The current forest conditions are determined using inventory assessment data collected by SPR at the zone level. Inventory assessments include a walk-through method of data collection that provides an efficient qualitative and quantitative overview of the forest composition and general conditions of the zone. Data recorders walk through each zone recording percent canopy of each tree species, in addition to using plots to assess overstory density and tree regeneration (GSP 2016). Tree species canopy cover data are available for all zones where inventory assessments have taken place and are used to inform the current conditions of the species compositions for this analysis.

Forest species composition is traditionally derived from trees-per-acre (TPA) or basal area-per-acre (BA) measurements. We found that the density plot measurements from the inventory assessments that could develop TPA and BA metrics did not cover all zones where assessments took place. The methods for these density measurements were not designed for scaling to the zone level, and the results we do have from the density measurements include densities that are outside the range of theoretical biological maximums, indicating errors for which we cannot account.

Inventory assessments have percent cover data for overstory trees in 974 out of 1529 zones (1,835 acres out of 2,747 acres; 67% of SPR acres). Where zones have been sampled multiple times, we used data from the most recent visit. Zone data were analyzed to determine canopy classes, calculated as the relative tree percent canopy dominance of broadleaf tree species, conifer tree species or a mix of conifer and broadleaf (Table 2). Percent cover of 65% was used as the threshold for conifer or broadleaf classes. Zones that have neither broadleaf nor conifer more than 65% are categorized as mixed class.

Species Composition Classifications

Canopy classes are the three general forest types. Data are from inventories representing 1,835 acres (67%) of parks.



Cover types are 15 sub-categories of the canopy classes. The letter-number code indicates species based on Latin name.

Cover Type	Common name
Broadleaf	
Broadleaf-ACMA3	*Bigleaf maple*
Broadleaf-ALRU2	*Red alder*
Broadleaf-POTR15	*Black cottonwood*
Broadleaf-ARME	*Madrone*
Broadleaf-Other	*Other*
Mix	
Mix-PSME	*Douglas-fir*
Mix-ACMA3	*Bigleaf maple*
Mix-THPL	*Western redcedar*
Mix-TSHE	*Western hemlock*
Mix-Other	*Other*
Conifer	
Conifer-PSME	*Douglas-fir*
Conifer-THPL	*Western redcedar*
Conifer-PICOC	*Shore pine*
Conifer-TSHE	*Western hemlock*
Conifer-Other	*Other*

Table 2: Inventory assessment data coverage for canopy classes.

Canopy Class	Zones	Acres	% of Measured Acres	% of Total Acres
Mix	164	384	21%	14%
Conifer	97	183	10%	7%
Broadleaf	713	1,267	69%	46%
Subtotal	**974**	**1,835**	**100%**	**67%**
No Data	555	912	0%	33%
Total	**1,529**	**2,747**	**100%**	**100%**

Canopy cover is further specified by the dominant species occupying the greatest percent canopy cover (Table 3), even if that species does not occupy a majority of the canopy cover. Uncommon or non-native species were not eligible to indicate the dominant species; instead, these were grouped into an "other" category. These data allow us to develop management approaches based on species composition and canopy species dominance. We can also identify zones that have low species diversity (Table 4) and zones that have a high proportion of species that may be vulnerable to disturbances, such as disease outbreaks or drought.

We investigated other data sources to attempt to designate canopy classes for the 555 zones (covering 912 acres) where no inventory data are available (33% of SPR acres). Most promising was the 2014 Graduate Nearest Neighbor (GNN) data set (Ohmann and Gregory 2002 using data updated in 2014), which is developed from satellite imagery and classifies land cover, including forested land cover, at regional scales. GNN stands for Gradient Nearest Neighbor, derived from statistical "imputation methods that have proven to be an effective tool for characterizing vegetation structure and species composition in forested landscapes."[8] While GNN is available at the tree species level, the data are not calibrated for urban forests with non-native species and are not typically used at this fine of scale. We tested using GNN at the coarse vegetative cover classes (broadleaf, mix, or conifer) but found substantial discrepancies in canopy classes for zones that have both GNN and inventory assessment coverage, such that we determined GNN data are not suitable for this application (Appendix 1: Comparison of GNN to Measured Data).

[8] https://lemma.forestry.oregonstate.edu/data

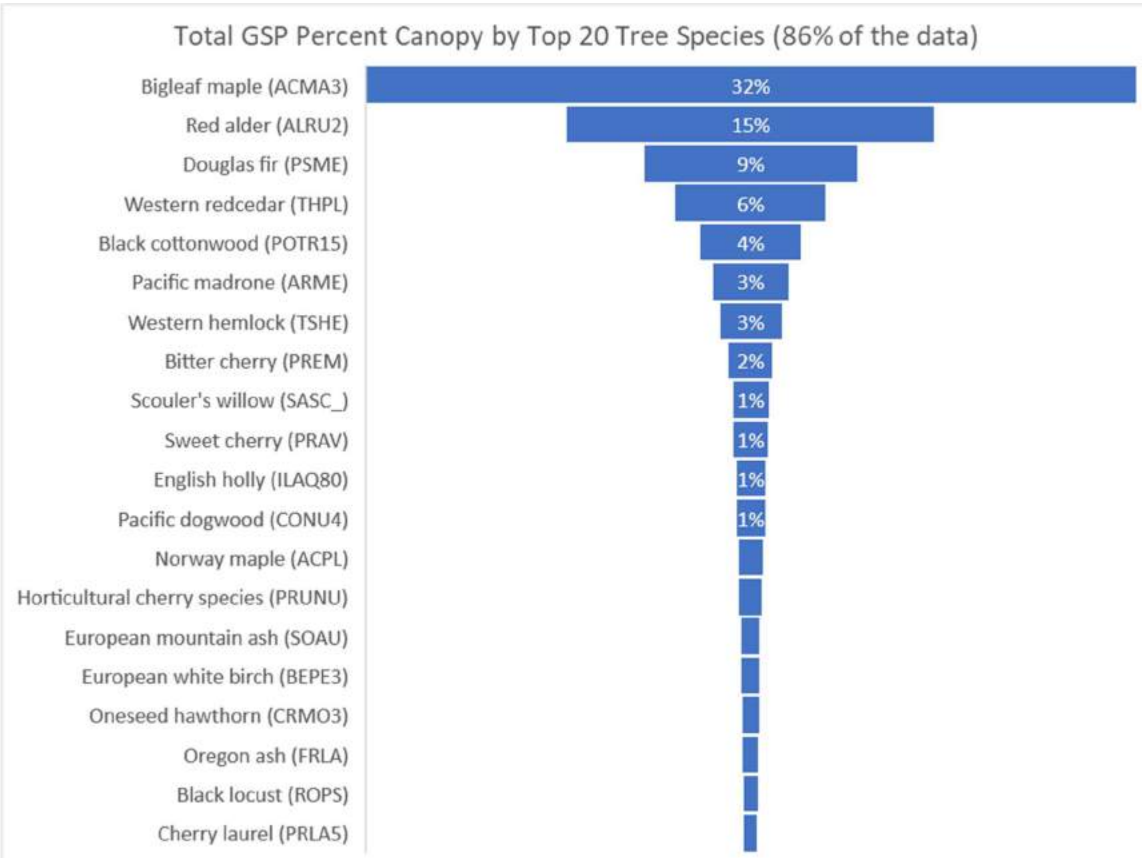
Table 3: Canopy cover types. Broadleaf are zones with >65% canopy cover of broadleaf species, Mix are zones with 35-65% canopy cover broadleaf tree species (i.e., a mix of conifer and broadleaf species), and Conifer are zones with >65% canopy cover conifer tree species. The breakdown of the four most common species indicates the single species that occupies the most percent canopy – this species often is not a majority of the canopy cover. The “Other” category includes non-native and uncommon species.

Canopy Cover	Common name	Zones	Acres	% of Acres
Broadleaf		**713**	**1,267**	**69%**
Broadleaf-ACMA3	*Bigleaf maple*	*346*	*599*	*33%*
Broadleaf-ALRU2	*Red alder*	*124*	*182*	*10%*
Broadleaf-POTR15	*Black cottonwood*	*33*	*51*	*3%*
Broadleaf-ARME	*Madrone*	*13*	*28*	*2%*
Broadleaf-Other	*Other*	*197*	*409*	*22%*
Mix		**164**	**384**	**21%**
Mix-PSME	*Douglas-fir*	*41*	*92*	*5%*
Mix-ACMA3	*Bigleaf maple*	*36*	*87*	*5%*
Mix-THPL	*Western redcedar*	*17*	*33*	*2%*
Mix-TSHE	*Western hemlock*	*7*	*27*	*1%*
Mix-Other	*Other*	*63*	*146*	*8%*
Conifer		**97**	**183**	**10%**
Conifer-PSME	*Douglas-fir*	*49*	*75*	*4%*
Conifer-THPL	*Western redcedar*	*12*	*41*	*2%*
Conifer-PICOC	*Shore pine*	*6*	*15*	*1%*
Conifer-TSHE	*Western hemlock*	*2*	*4*	*0%*
Conifer-Other	*Other*	*28*	*49*	*3%*
Total		**974**	**1,835**	**100%**

Table 4: One species occupying 50% or more of the canopy cover within measured zones.

Majority Species (by % Cover)	Common Name	Zones	Acres	% of Acres
ACMA3	Bigleaf maple	*253*	*510*	*28%*
ALRU2	Red alder	*73*	*130*	*7%*
PSME	Douglas-fir	*40*	*77*	*4%*
THPL	Western redcedar	*8*	*34*	*2%*
TSHE	Western hemlock	*9*	*31*	*2%*
POTR15	Black cottonwood	*13*	*19*	*1%*
ARME	Madrone	*4*	*10*	*1%*
PICOC	Shore pine	*2*	*1*	*0%*
No single species >50% canopy	Other	*572*	*1,023*	*56%*
Total		**974**	**1,835**	**100%**

Figure 1: Percent canopy cover of the top 20 tree species across SPR parks. These values show how much of SPR's tree canopy is represented by each of these species. For example, 32% of all of SPR's tree canopy is bigleaf maple. Species with around 1% or less canopy cover should be interpreted as present at low levels rather than a relative abundance; data are not detailed enough to state with confidence the relative amounts of low-coverage species.

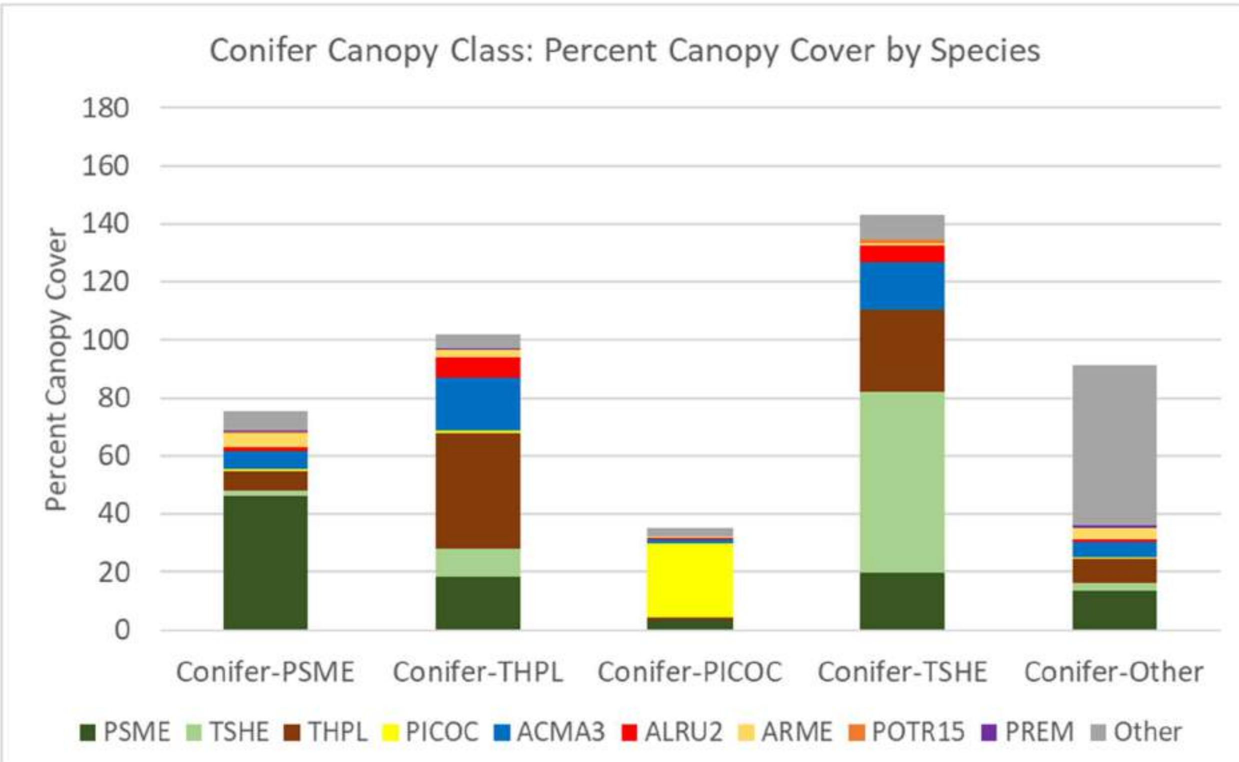


Seattle has a high proportion of broadleaf-dominated forest (Table 3), with bigleaf maple representing one-third of all tree canopy in SPR management (Figure 1). Species composition differs substantially from the conifer-dominated forests that historically covered the area (Franklin and Dyrness 1988). The tree canopy is approximately 85% native tree species, with most of the remainder composed of non-invasive trees. About 4% of the tree canopy are invasive species: English holly (1.2%, *Ilex aquifolium*), European mountain ash (0.8%, *Sorbus aucuparia*), oneseed hawthorn (0.7%, *Crataegus monogyna*), cherry laurel (0.6%, *Prunus laurocerasus*), horse chestnut (0.3%, *Aesculus hippocastanum*), and Portugal laurel (0.2%, *Prunus lusitanica*).

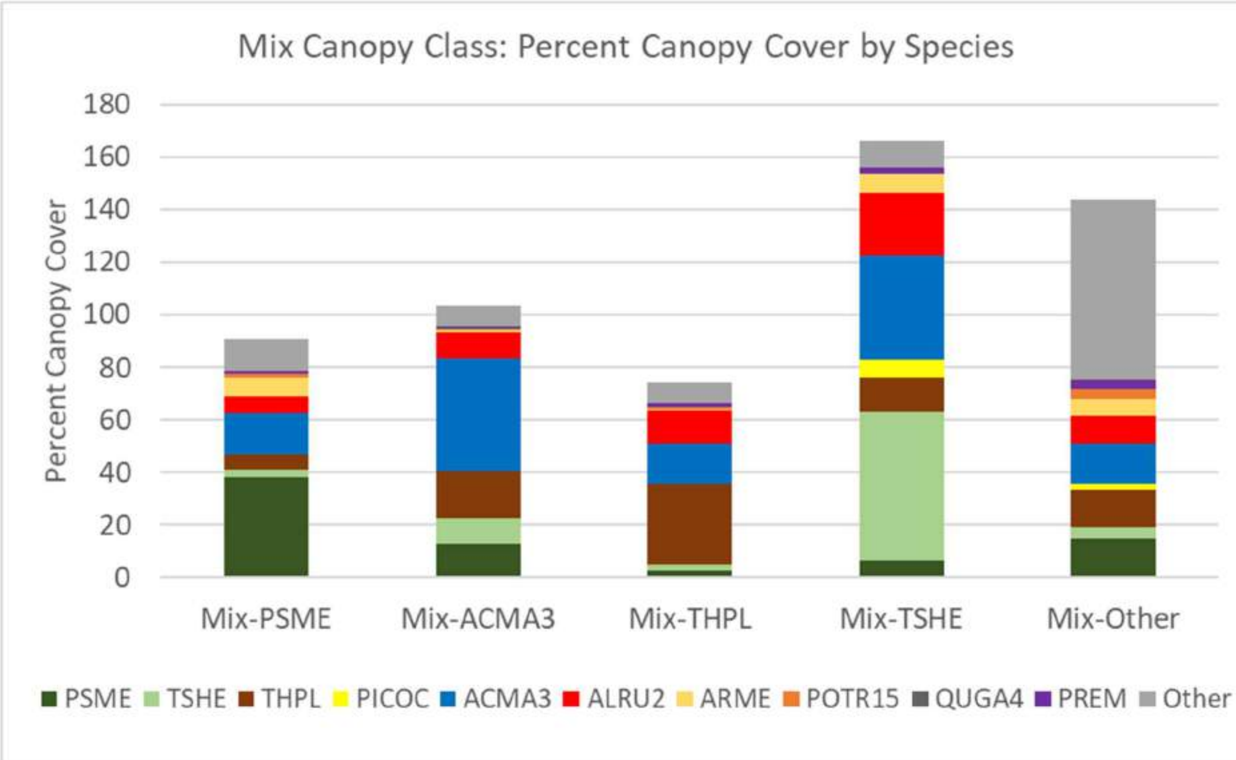
Species distribution curves for each canopy class are shown in Appendix B (XI.2). The Conifer cover types all have Douglas-fir, western hemlock, western redcedar, and bigleaf maple as the top four species, except for the Conifer-PSME (Douglas-fir) cover type, which includes madrone in the top four and generally includes species that are better acclimated to drier conditions. Conifer-THPL (western redcedar) has a higher proportion of non-native trees, including incense cedar (*Calocedrus decurrens*) and coastal redwood (*Sequoia sempervirens*). Conifer-PICOC (shore pine) is associated with bog habitats and has a very low total canopy cover of 35% (meaning 65% of the area has no trees; Figure 2). Conifer-Other is the most diverse Conifer cover type with 60 species, though Conifer canopy types are generally less diverse than Mix and Broadleaf cover types, perhaps because they have a higher proportion of native species.

Figure 2: Percent cover for canopy types, broken out by common species. Inventory data collection procedures allow total percent cover to exceed 100% where multiple canopy layers overlap.

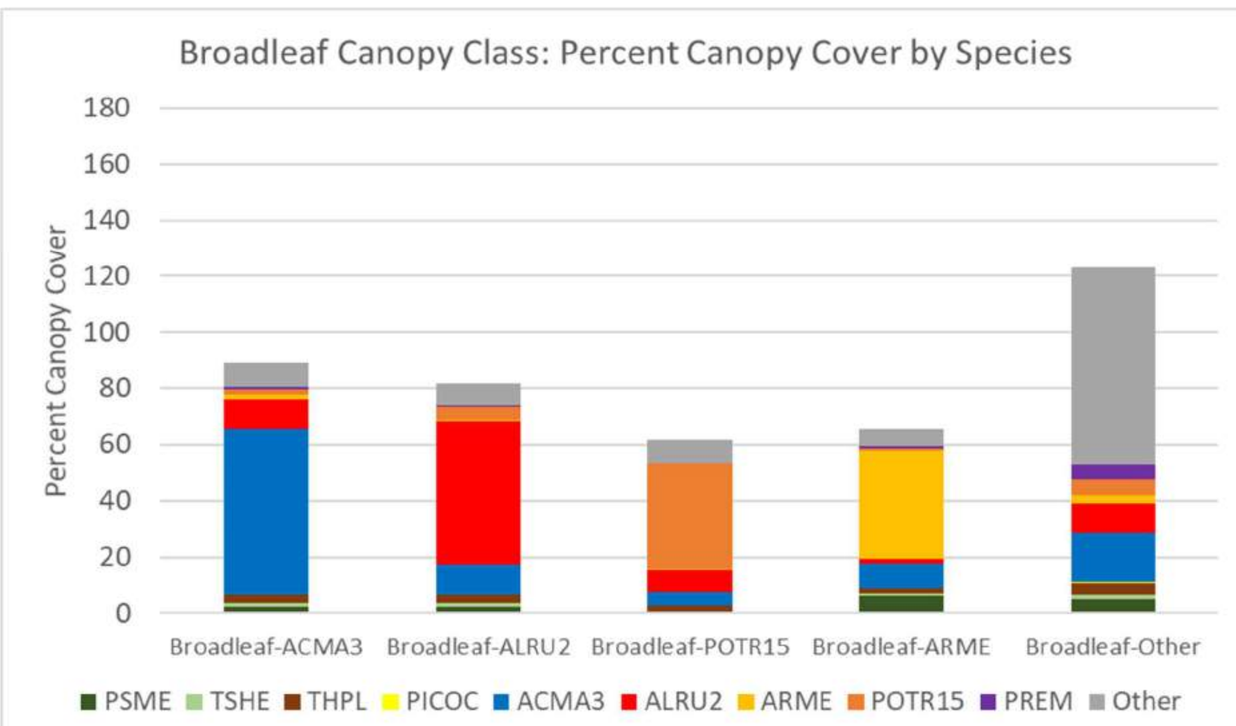
a) Conifer cover types



b) Mix cover types



c) Broadleaf cover types



For Mix cover types, bigleaf maple is the most common broadleaf species, followed by red alder. Mix-

PSME (Douglas-fir), like its corollary Conifer cover type, hosts a higher proportion of species acclimated to dry conditions. Mix-Other is a species-rich cover type, with 109 different species recorded. Mix cover types have the highest total canopy coverage, indicating dense foliage and potentially multiple canopy layers. Mix-TSHE (western hemlock) has a total canopy coverage of over 160% (Figure 2), meaning that the cover type has multiple trees overlaying one another throughout the area.

Broadleaf canopies tend to be diverse, with Broadleaf-ARME (madrone) as an exception. Broadleaf-Other has 140 different species. This is related to the expansive coverage of the Broadleaf class across the city; surveys are more likely to detect infrequent species within a bigger sample size. Broadleaf cover types have more invasive and non-native cover than Mix or Conifer, though the strength of this correlation is unclear because of the smaller sample size in Mix and Conifer classes.

Broadleaf species dominance presents a long-term challenge for Seattle if higher conifer cover is a priority. The abundance of bigleaf maple is also a concern because it typically plays a minor role in undisturbed forests, and its expansive coverage renders the city vulnerable should a maple-specific disease or pathogen be introduced. The recommendations in Section VIII: Stewardship Prescriptions and Best Management Practices address these concerns and provide a pathway for species compositions that achieve the desired future conditions.

2. Current Conditions: Structure

Forest structure refers to the spatial distribution of trees as well as the size and height patterns of the trees. Structure is important for identifying wildlife habitat niches, tree regeneration opportunities, and forest development stages. Forest structure includes the variability in tree heights and diameters (often referred to as “vertical” structure) and the variability or patchiness of tree density and canopy closure (“horizontal” structure) (Franklin et al. 2002). Structure can also include the number and size of standing dead trees (“snags”) and dead logs on the ground (together referred to as large woody debris, LWD).

Existing SPR data partially address structure but there are significant issues with using it. In the inventory dataset, tree height data are lacking, and assessments of vertical structure and patterns in density and canopy openness are absent. In addition, forest structure data can vary substantially across zones, even when grouping zones of similar forest species composition. With the variable forest conditions found in SPR forested parks, field data sufficient to capture the variability is an onerous and costly task.

To better support SPR’s understanding of forest structure, we have utilized publicly available LiDAR data (see inset: “What is LiDAR?”). While LiDAR is limited in its ability to reveal mid- and understory trees, it provides sufficient information to provide ecologically useful assessments of structure without any field data collection. As the city collects new LiDAR data over time, SPR can track changes in forest structure at a fine scale. LiDAR data is available for Seattle from 2016 offering a detailed and complete set of data to assess aspects of forest structure. Therefore, we rely on LiDAR data for the structure analysis.

Two systems were developed using LiDAR to classify forest structure into ecologically useful categories: (1) direct height and canopy closure measurements, and (2) structure classes to group zones with similar structure.

WHAT IS LIDAR?

LiDAR is a set of data collected by laser sensors mounted on an airplane that measures the height of objects. The sensor measures the amount of time it takes a narrow laser beam to travel from the plane, to the earth’s surface, and bounce back to the sensor. Paired with a highly accurate GPS, LiDAR data are a cloud of points (see image below), showing the height at which the laser hit an object.

From the LiDAR data, we can extract the data points that took the longest to return to the sensor, showing the “bare” ground. We can also extract the data points that were the first to return to the sensor, showing the tops of trees and building. For our analysis of each zone we also extracted the 25th percentile of data points to indicate understory vegetation, the average of the data points to indicate mid-story vegetation, and the 95th percentile of data points to show the heights of the dominant cohort of trees.

Direct measurements allow comparing changes in a zone from one LiDAR flight to another. This provides accurate measurements of canopy cover and height of the dominant tree cohort (the top 95% of the data in the LIDAR data set, called P95), and approximations of mid-canopy height (Average Height, and the height at the 25% of the data in the LIDAR data set, called P25) at fine scales such that SPR can track management actions that took place between LiDAR flights. The direct measurements from the 2016 LiDAR data have been appended to a shapefile for every zone where data are available.

The second system of "ecological structure classes" (ESC) uses four LiDAR data variables: three measures of tree height and one measure of canopy closure (Table 5). Seven ESCs were created using nearest-neighbor statistical analysis, where LiDAR data within a zone were analyzed for the four LiDAR variables. The analysis grouped zones into similar classes (the statistically most similar "neighbor" based on the four variables, not geographic proximity). We then interpreted the ESC into ecological descriptions that are useful for SPR managers and stewards to help identify structural conditions and recommend management actions. In future LiDAR flights, these ESC can be re-calculated to measure changes in forest structure. We can also observe the directly-measured canopy closure and heights to see changes from one measurement year to another.

Table 5: LiDAR variables used in the ecological structure class analysis.

Variable	Definition	Utility
P95	Tree height at the 95th percentile of LiDAR data	Reports the heights of the tallest cohort of trees.
Average Height	Average of all height measurements in the LiDAR data	Indicates the range of heights; a low Average Height indicates there are many smaller trees in the data, or many open areas. A high average height indicates a relatively uniform forest canopy.
P25	Tree height at the 25th percentile of LiDAR data	Indicates the presence of small trees in the understory - a P25 value between 10 and 30 feet may show substantial understory tree component.
Canopy Closure	Percent of LiDAR data that has tree canopy occupying the pixel	Reports canopy closure. Indicates overstory tree cover, shrub habitat, and planting opportunities.

The seven ECSs represent a gradient of conditions based on canopy cover, height of the dominant tree cohort, and heights of intermediate layers of the forest (**Error! Not a valid bookmark self-reference.**).

Figure 5 through Figure 11 show top-down views of LiDAR data, color-coded to represent tree heights and open patches that lack tree cover. Healthy forest landscapes include a wide range of structural conditions, ranging from old-forest conditions to post-disturbance regeneration conditions. The images are paired with photographs from the same structure class, usually the exact same zone, to provide visual examples of on-the-ground conditions associated with the ESC.

Table 6: Average ecological structure class values and descriptions. Height measurements are in feet.

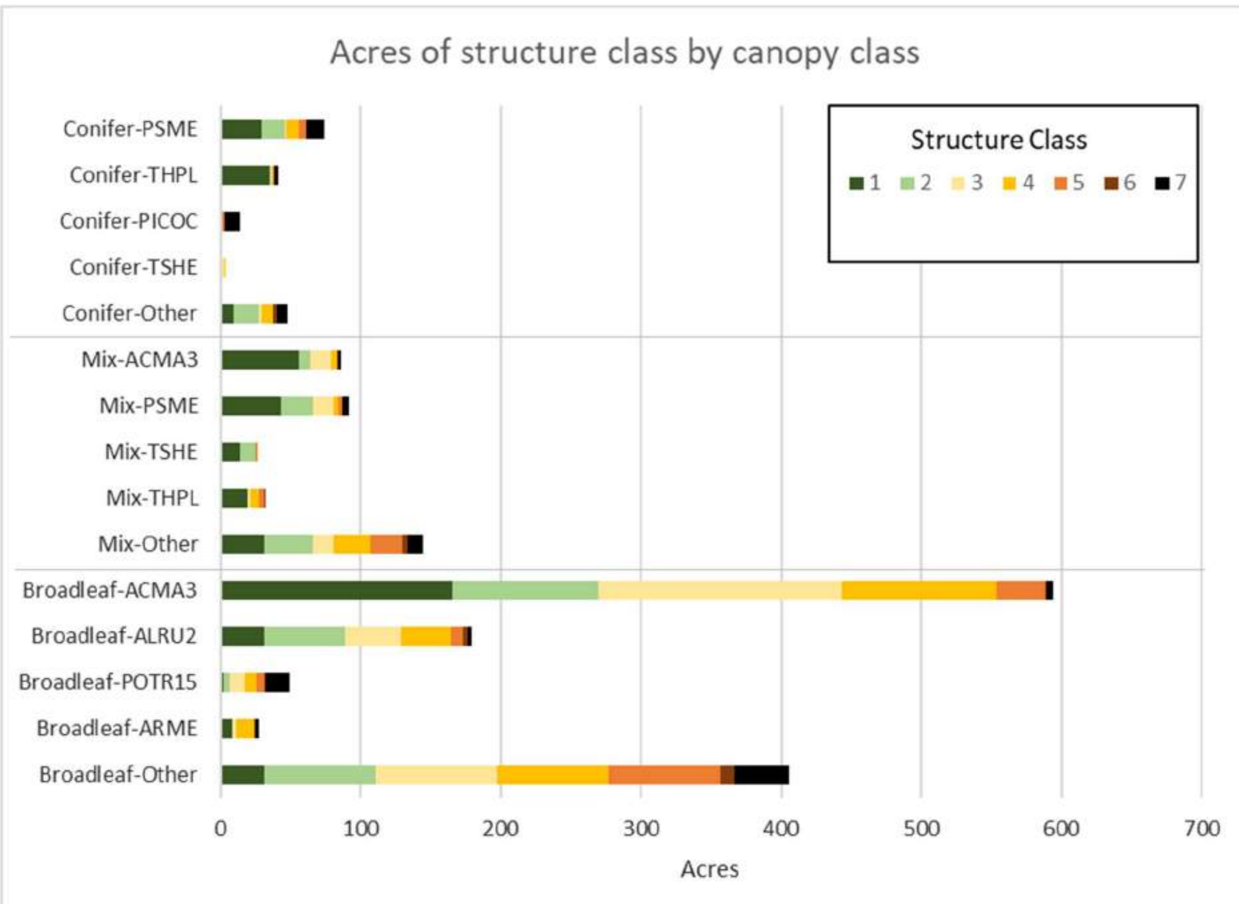
Structure Class	95th % Hgt	Avg Hgt	25th % Hgt	Canopy Closure %	Acres	Ecological Description
ESC 1	111	85	50	79	561	Tall, uniform, single cohort, closed canopy
ESC 2	99	72	38	77	504	Tall, moderate mid-story, closed canopy
ESC 3	87	60	30	76	646	Medium tall, mixed-story, mostly closed canopy
ESC 4	74	42	24	69	506	Medium tall, mixed-story, somewhat patchy
ESC 5	60	25	18	53	244	Medium-short, mixed-story, patchy canopy
ESC 6	46	13	14	37	35	Short, patchy canopy
ESC 7	39	11	14	25	236	Open woodland / tall shrubs; highly variable

Since LiDAR only measures heights and canopy closure, we must interpret the data in ecologically useful ways. Average height and 25th percentile height represent mid- and under-story vegetation. Taller average height and 25th percentile height relative to the 95th percentile height indicates a more uniform forest canopy; greater divergence indicates more robust mid- and understories. Canopy cover is a direct measurement of how uniform or patchy the canopy is. Canopies that are more open allow more light to reach lower levels of the forest, allowing robust mid- and understory vegetation. Closed canopies prevent light from reaching lower levels and are more likely to be single-cohort forests. Height of the 95th percentile indicates forest maturity, with taller trees correlating with older, more advanced forests.

ESC 1 and ESC 2 represent mature forest conditions, or even old forest conditions in the case of Seward Park, portions of Lincoln Park, portions of Llandover Woods, and other old-growth relics. ESC 1 is the most frequent class in SPR forested parks. Conifer canopy class represents a higher proportion of ESC 1 relative to conifer canopy class in other ESCs, though broadleaf forest commonly reaches ESC 1 and 2.

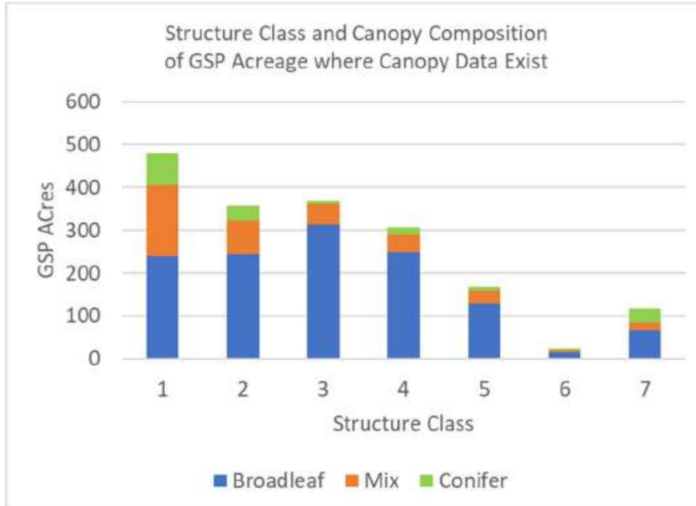
Mix canopy class are also relatively abundant in ESC 1 and 2. ESC 2 allows for a more open canopy and more developed mid- and understory vegetation, but the overall height is not as tall as ESC 1.

Figure 3: Acreage break-down of ecological structure classes for each canopy class.



Broadleaf forests represent a larger proportion of ESC 2. ESC 3 and ESC 4 are shorter, broadleaf-dominated forests with closed canopies (ESC 3) or somewhat patchy canopies (ESC 4) that are more likely to have developed mid- and understory vegetation. Broadleaf canopy classes are most abundant in ESC 3 followed by ESC 4; broadleaf trees typically aren't as tall as conifers, limiting their entry into the taller ESCs. ESC 5 generally has shorter trees at low density with substantial canopy openings. ESC 6 is rare, with consistent cover of very short trees. ESC 7 is highly variable, but generally has very few large trees and robust tall shrub or small tree components.

Figure 4: Distribution of ecological structure classes and canopy classes.



Given the lack of old forest conditions on the landscape, working towards forest structures that include taller, larger, longer-lived conifers will achieve SPR's stewardship goals. ESC 1 and 2 represent the typically desired forest with tall trees, but each ESC provides unique forest services that should persist on the landscape.

Figure 5: Ecological structure class 1. Tall, closed canopy, single cohort. Carkeek Park, Zones 1B1, 1B2, 1B3, & 1B4.

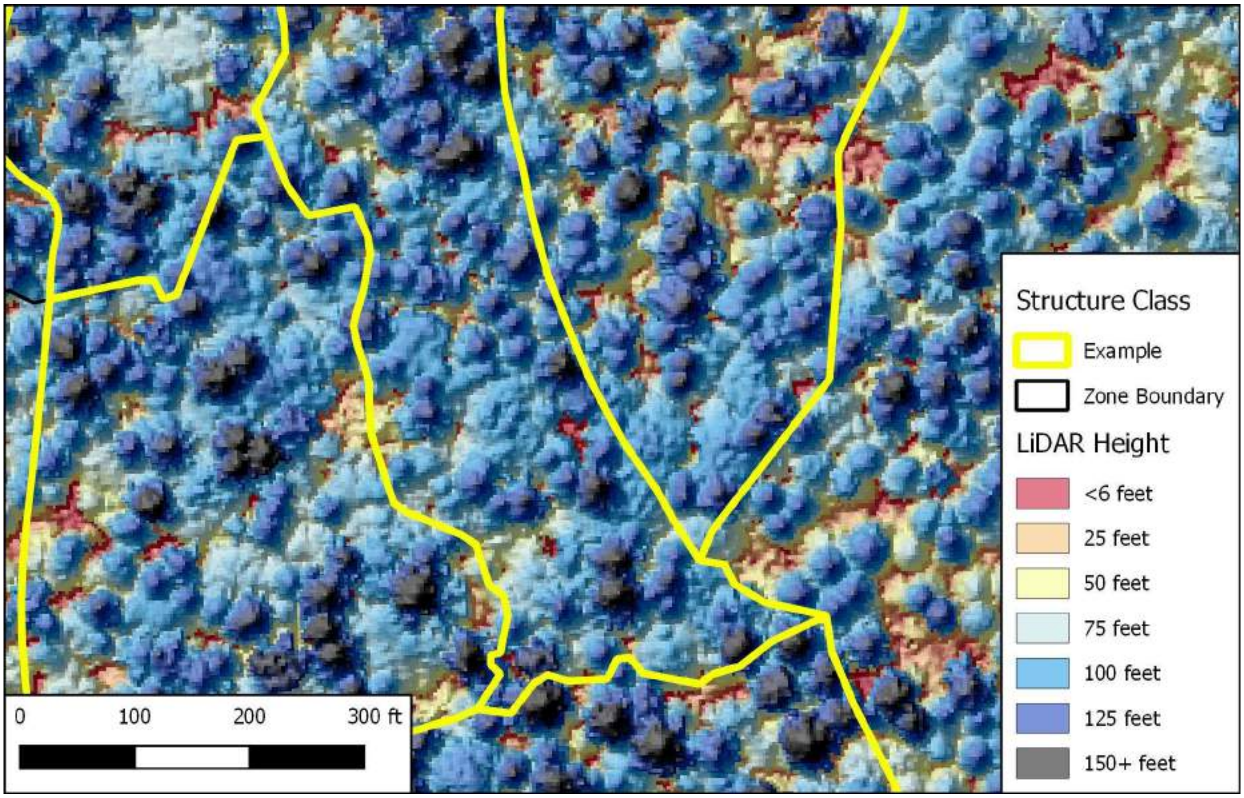


Photo: Ecological structure class 1. Seward Park, Zone.

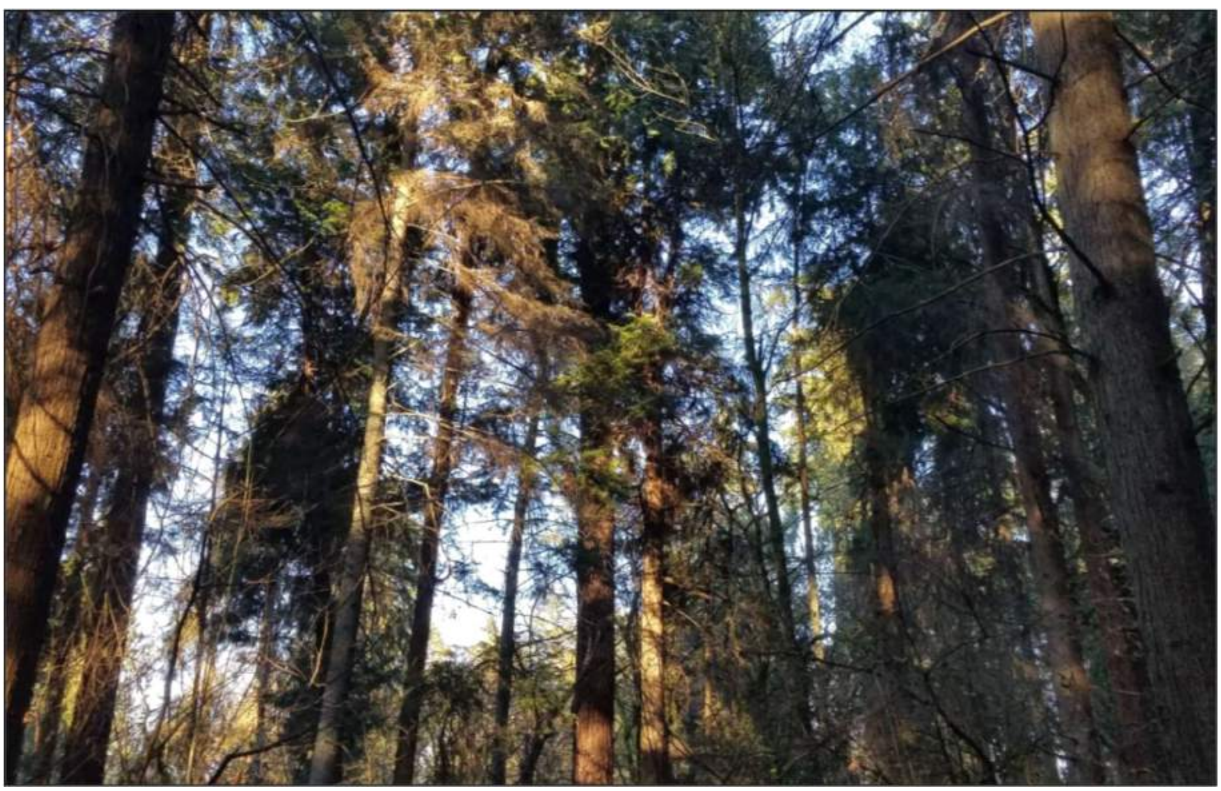


Figure 6: Ecological structure class 2. Tall, moderate mid-story, closed canopy. Carkeek Park, Zone 4B.

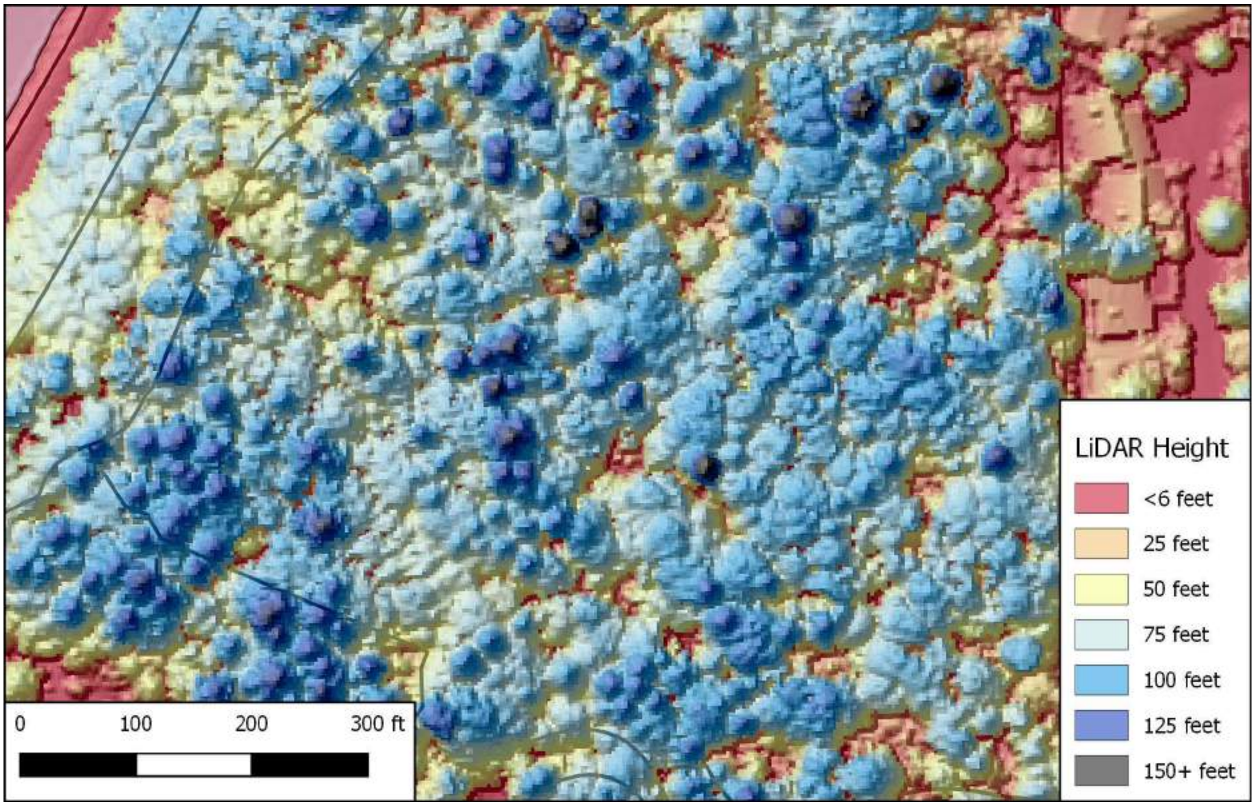


Photo: Ecological structure class 2. Discovery Park, Zone Tom Palm Site.

Figure 7: Ecological structure class 3. Medium tall, mixed-story, mostly closed canopy. Discovery Park, Zones 03A-02, 03A-05, 03A-07, 13-02, and Top of Texas.

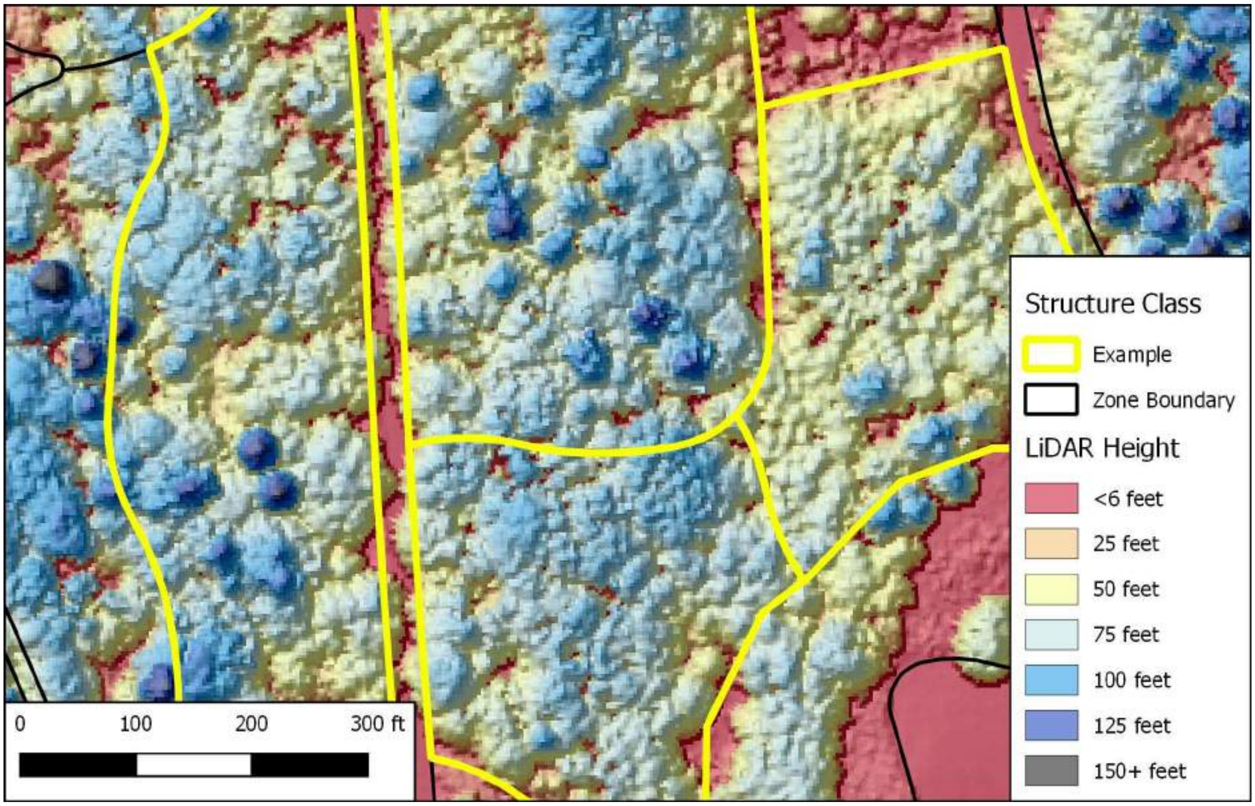


Photo: Ecological structure class 3. Discovery Park, Zone 03A-05.

Figure 8: Ecological structure class 4. Medium height, mixed-story, partly patchy canopy. Coleman Park, Zone C11_C12_C13.

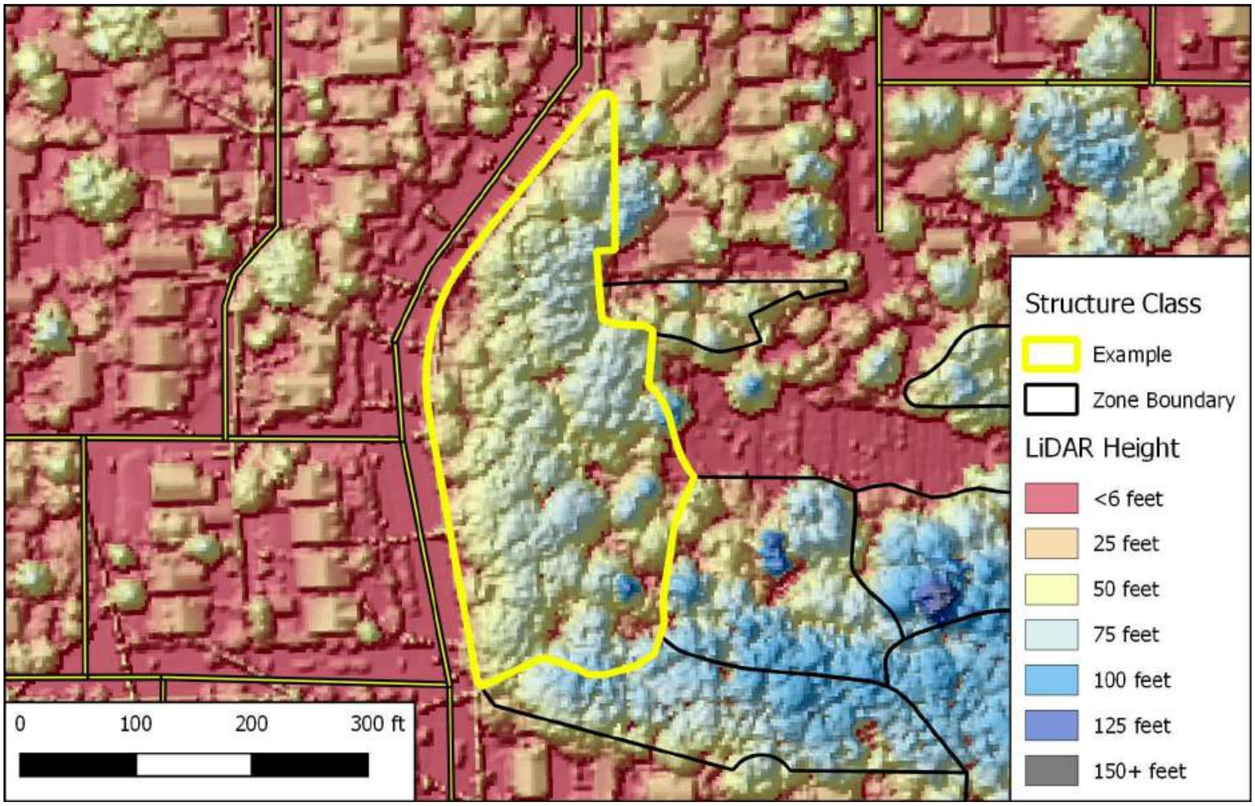


Photo: Ecological structure class 4. Coleman Park, Zone C11_C12_C13

Figure 9: Ecological structure class 5. Medium-short height, mixed story, patchy canopy. Discovery, Zone 16-09.

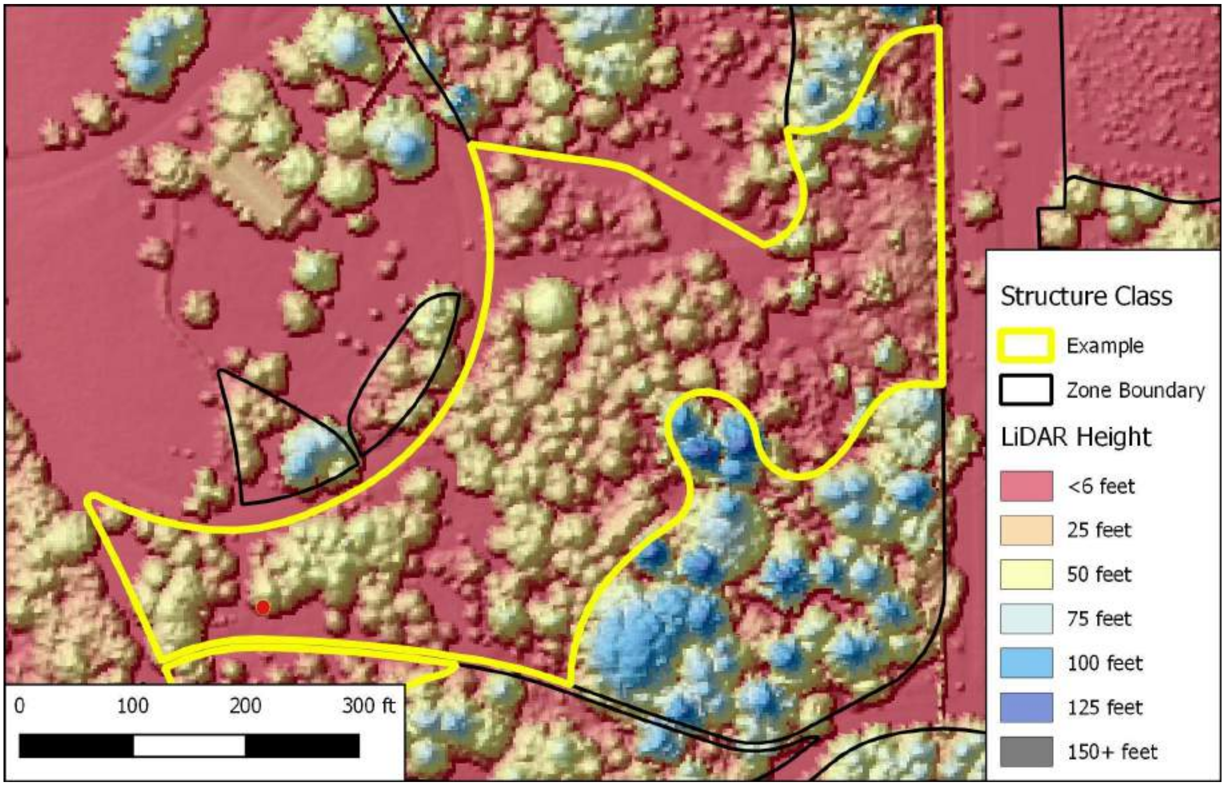


Photo: Ecological structure class 5. Discover Park, Zone 16-09.

Figure 10: Ecological structure class 6. Short, patchy canopy. Sam Smith Park, Zone Sam Smith 11.

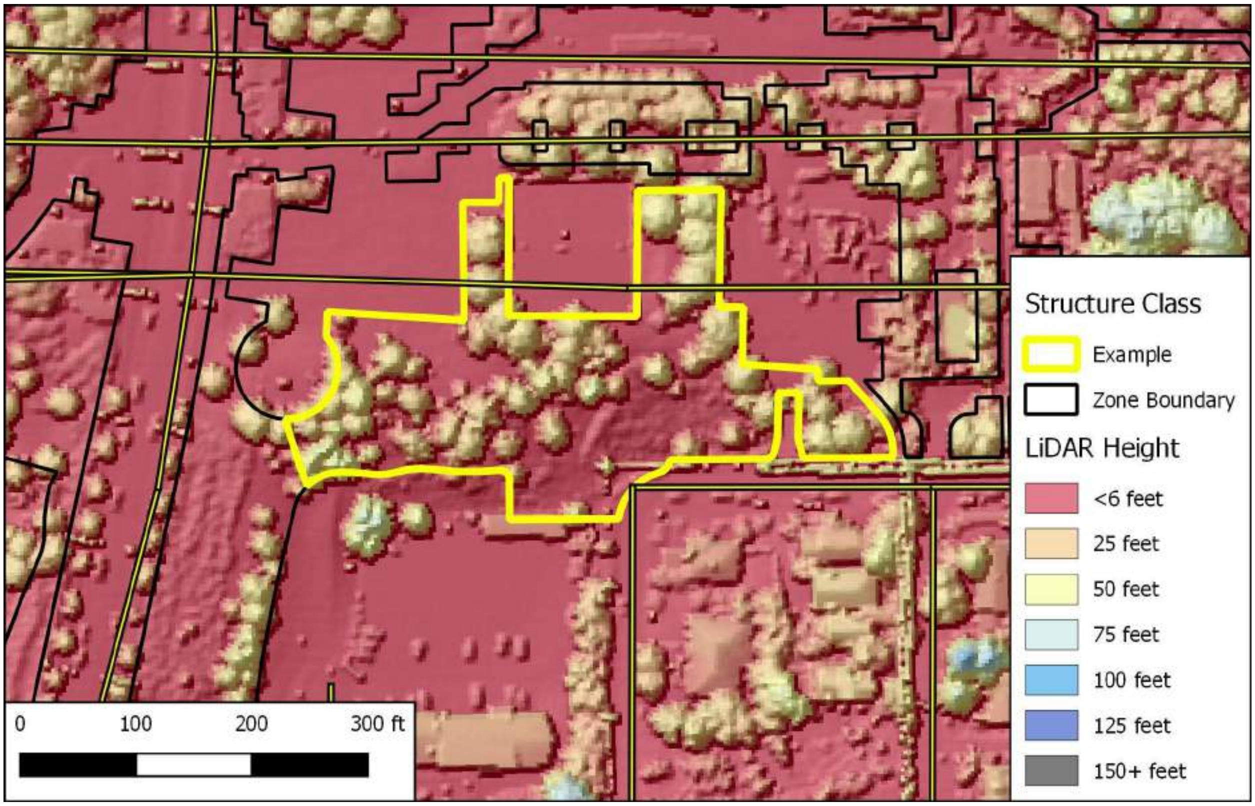


Photo: Ecological structure class 6. Sam Smith Park, Zone Sam Smith 11.

Figure 11: Ecological structure class 7. Open woodland / tall shrubs; highly variable. Discovery, Zone Capehart 1A.

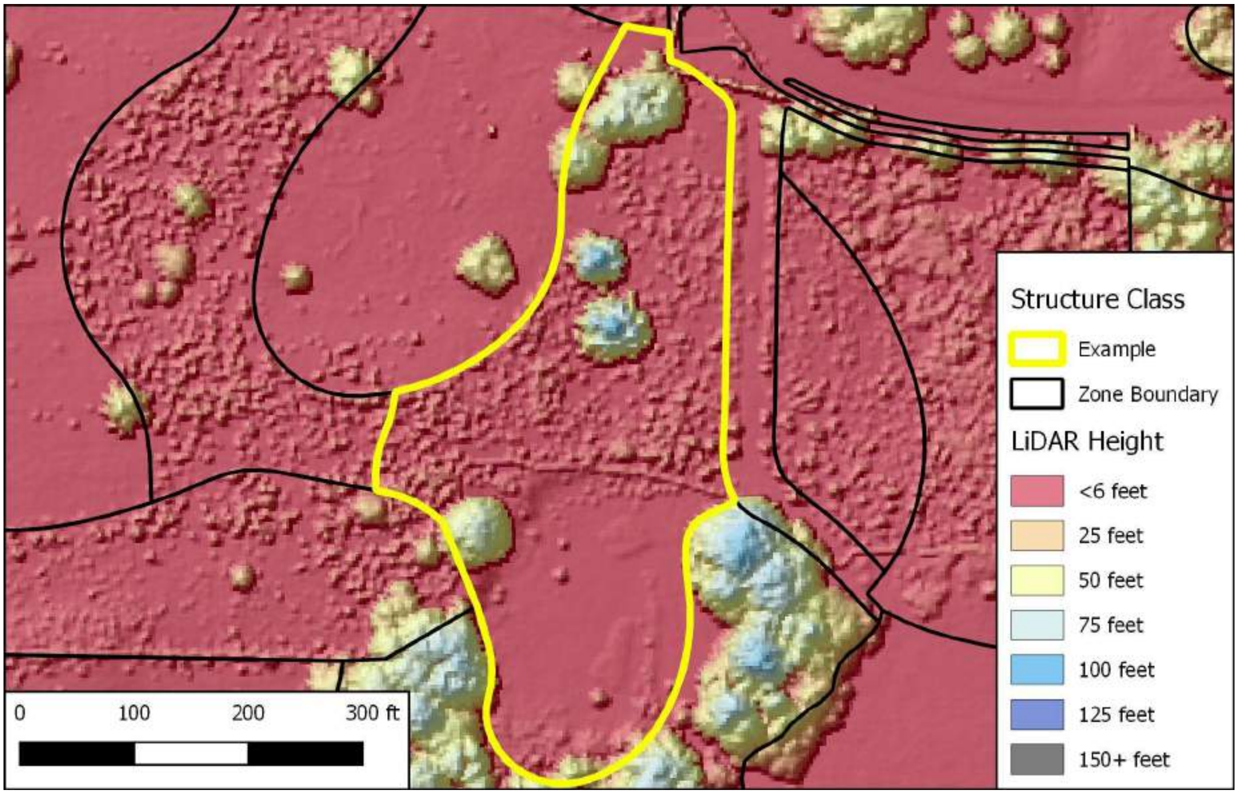


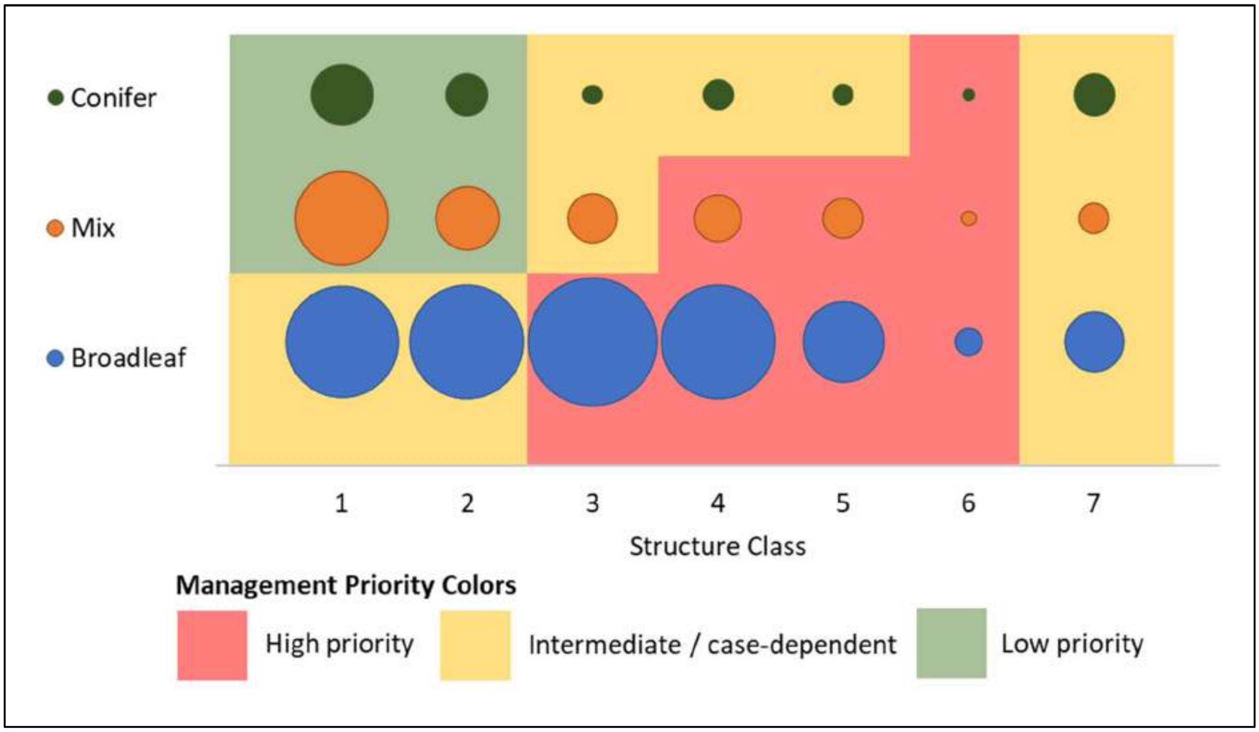
Photo: Ecological structure class 7. Discovery Park, Zone Capehart 1A.

ESCs add a dimension of complexity to management planning. Ecological structure classes are not inherently good or bad. Generally, tall, multi-canopied forests like ESC 1 and ESC 2 best meet SPR's objectives. However, higher ESCs provide unique habitat niches that are important in Seattle's greenspaces. The distribution of ESCs for conifer-dominated forests and mixed-dominated forests are a reasonable distribution: about half of the acreage of these canopy classes are in ESCs 1 and 2, with diminishing acreage in the higher ESCs except for the highly variable structure class 7. Conifer and mixed canopy classes with ESC 1 and ESC 2 are a low management priority – they are generally achieving SPR's management objectives.

Broadleaf canopy classes have a disproportionate acreage in mid-level ESCs. We know these ESCs correlate to high invasive weed cover and more open canopies. Combined with the resilience risks inherent in many broadleaf species (see the vulnerable species assessment in Section IV.2.b), ESCs 3 through 6 are a high management priority for broadleaf canopy classes. Other Forest Type (canopy class-structure class combinations) are an intermediate management priority. Many zones with these characteristics will prove to be healthy forests providing a range of niches for wildlife and other ecosystem functions. Others will need active management to improve the structure and species composition to align with SPR objectives.

Details of management actions for high-priority ESCs are described in the Prescriptions and Best Management Practices section VIII.

Figure 12: Management priority breakdown for canopy classes and ESCs ("Forest Types"). This bubble graph shows the acres of each Forest Type by the size of the bubble – bigger bubbles show there are more acres in that Forest Type. The background colors indicate management priorities. Generally, higher-number ESCs and broadleaf forest types have more urgent management priorities.



Snags and Downed Logs

Snags and downed logs are forest structural elements that LiDAR cannot detect. These structural elements are important features for wildlife and nutrient cycling. Snags are dead, standing trees. Downed logs, also called "large woody debris" or LWD, are dead tree trunks or large branches lying on the ground. Dead wood provides habitat and nutrients to a wide range of wildlife. Some species of tree provide longer-lasting and more ecologically valuable dead wood. Slow-to-decompose western redcedar and Douglas-fir provide dead wood habitat for much longer than bigleaf maple and red alder. Size matters as well; larger-diameter and taller snags experience more cavity nesting activity than shorter and narrower trees. Pileated woodpecker, for example, typically requires snags greater than 12" DSH and 60 feet tall or taller to create nesting cavities.

Inventory data on coarse woody debris indicates low amounts of dead downed wood. Feller (2003) reported high LWD in old-growth forests of western British Columbia, and observed the lowest amount of LWD in mid-aged managed forests, similar to Seattle's post-clearcut regenerating forests. Gerzon et al (2011) found it took 200 years or longer for second-growth forests to reach the LWD levels of old-growth forests; we would expect Seattle parks to have lower-than-desired LWD. SPR had set LWD as a target to move zones into Phase 4 restoration status, but the lack of snags and downed wood proved too restrictive a criterion in zones that were otherwise in good condition. Some evidence indicates lack of LWD can limit natural tree regeneration for species that depend on nurse logs and exposed soil when trees tip over (Ettinger et al. 2017).

3. Current Conditions: Density

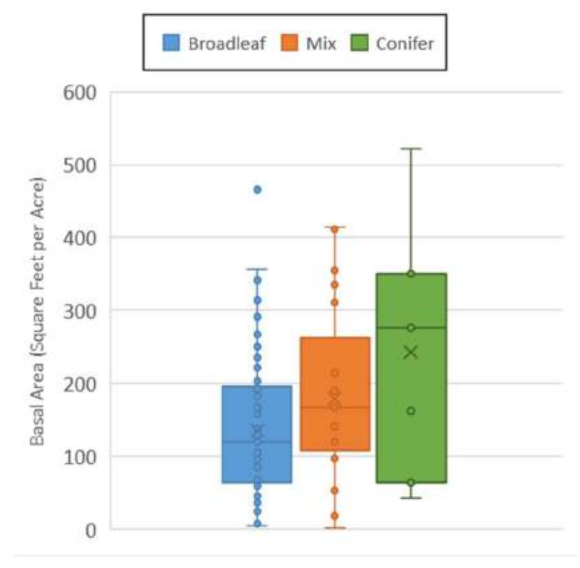
Forest density is an important concept for understanding forest condition and tracking changes in forests over time. Density (number and size of trees per area) influences competition-related tree survival, insect and disease outbreaks, trees' responses to drought stress, and understory vegetation survival and density. Field-based measurements are the most accurate method of assessing forest density. We rely on the GSP monitoring data to inform density measurements.

SPR has installed a network of detailed long-term monitoring plots. Monitoring plots are 1/10th acre (37.25-foot radius), with a monumented plot center for repeat visits to track conditions into the future. The tree data include species, diameter, height, canopy cover, and regeneration. Other information includes soil moisture and texture, percent shrub and ground cover by species including bare ground and duff, and coarse woody debris. Repeat visit are made periodically. There is a total of 169 plots across 153 zones, though SPR is focusing on 150 plots for long-term monitoring. These 150 plots are located within 138 zones (Green Seattle Partnership 2013).

Results of the monitoring plot data are shown in detail in Appendix C (XI.3) including density for cover types and ESCs, species diameter distributions by structure class, and the monitoring plot data for each zone that has data. The monitoring data are limited relative to the diversity of SPR forest conditions, but provide excellent data where they do occur. Extrapolating monitoring data across ESCs or canopy cover types may not capture all the variability within an ecological structure class or cover type, but are still useful for providing general density information.

A low-density forest will have widely spaced trees, or clumped trees amid larger openings, resulting in a very open canopy. Due to the low canopy and stem coverage, a lot of sunlight reaches the forest floor, stimulating dense shrub and forb growth. Invasive species are also more common in open canopy conditions, most often as a result of soil disturbance. Natural tree regeneration is typically difficult in dense shrub conditions, because seedlings struggle to take root and receive sufficient sun amid the thick vegetation. However, once tree seedlings are established and are clear of competing shrubs, they will have abundant light to grow rapidly.

Figure 13: Distribution of basal area in monitoring plot data.



Box-and-whisker graphs:

- "x" indicates the average
- Horizontal line indicates the median
- Rectangles show the 25th percentiles above and below median (middle 50th percentile)
- Whiskers (vertical lines) extend to the 95th percentile highest and lowest observations
- Dots show the individual data points

A high-density forest is composed of tightly packed trees with a closed canopy. Very little light filters down to the forest floor, and forbs and shrubs are less dense and typically less diverse. Trees compete for limited sun and water resources, resulting in stress and a greater likelihood of mortality. Too much understory planting could exacerbate crowded conditions in the future.

Using density to inform forest stewardship involves several measurements unique to forests. The following measurements are important pieces of information used to develop the forest stewardship recommendations in this Report.

- Diameter at Standard Height (DSH): Tree diameter in inches at 4.5 feet from the ground.
- Trees Per Acre (TPA): The count of trees per acre, typically extrapolated from a smaller sample area.
- Basal Area (BA): The cross-sectional area of a tree at standard height, in square feet. BA is commonly reported as the sum of the basal area per acre.
- Quadratic Mean Diameter (QMD): A calculated measure of average tree diameter. QMD is the diameter of the statistically-calculated tree with average basal area.
- Relative Density (RD): A calculation of density using the Curtis (1982) method that includes BA and QMD. It was developed for Douglas-fir forests but is generally useful for density in any forest. RD in a unitless value ranging from zero (no trees) to over 100 in the densest conditions.

Table 7: Density Measurements for Canopy Classes Using Monitoring Plot Data

Density	# Plots	Trees per Acre	Basal Area per Acre (ft^2)	Diameter of Avg Tree (inches)	Relative Density
Broadleaf	89	84	136	18.1	31
Mix	21	97	179	19.3	40
Conifer	7	54	243	28.8	44

Detailed density data for cover types and ESCs are shown in Appendix C (XI.3). This break-down of data were used to develop forest stewardship recommendations for each canopy type. Table 7 shows general trends in density among the three canopy classes. Canopy classes exhibit moderate density on average. The Conifer Canopy Class has the largest trees and most basal area, although there are fewer trees than in the other classes.

Conifer relative density is somewhat high; forests managed for wildlife typically have relative densities between 25 and 35. A relative density of 44 indicates trees are in competition with each other, likely leading to some density-related mortality. The relative densities of the Mix and Broadleaf classes are lower. Broadleaf forests, particularly bigleaf maples, have very broad tree crowns compared to conifers. Lower densities of bigleaf maple can still result in deeply shaded understories that limit tree regeneration and shrub growth. The forest stewardship recommendations in Section VIII will address ways to increase light to the forest floor and promote regeneration of longer-lived conifers.

COMPARING CARBON

There are many ways to measure forest carbon. Among the most widely-used methods are those approved by the California Air Resources Board for use in the California Cap-and-Trade program (C&T). Forest carbon projects in the C&T are measured for live tree biomass (tree trunk, top, bark, branches, roots) and dead snag biomass (dead trunk, top, branches, and bark, and roots) (CARB 2018). Other parts of the forest that store carbon are assumed to be static.

C&T publishes regional forest carbon averages. For the Puget Sound region, forest carbon averages 123 MT CO_2e per acre for productive forests. Looking at Seattle's forests, they stack up pretty well – all forest classes store more carbon than the regional average (Table 8).

Table 8: Live and dead tree carbon storage in Seattle parks (MT CO_2e/Acre)

Canopy Class	Carbon (live and dead trees + roots)
Broadleaf	159
Mix	241
Conifer	267
Puget Sound regional avg	**123**

4. Forest Carbon Storage

Forest management practices can influence uptake and storage of C in woody biomass and soils (Pan et al. 2011). Large, long-lived conifers, a climate that favors slow decomposition, and infrequent large-scale natural disturbance (Pregitzer et al. 2004) result in Washington forests serving as some of the most important U.S. carbon stores (Hudiberg et al. 2009). In forests that are experiencing a high rate of mortality, removing ailing trees and replanting with long-lived conifers can improve long-term forest carbon storage. Young trees in good light and moisture conditions take up carbon from the atmosphere at a faster rate than old trees (Malmsheimer et al. 2008, Peckham et al. 2012), but old trees store so much more carbon in their biomass that a forest's total carbon profile benefits from larger, older trees (Hudiberg et al. 2009, Janisch and Harmon 2002).

Forest carbon is primarily dependent on two factors: species and density. Conifer species tend to be able to store more carbon in the long-term than broadleaf species due to their longer life and ability to grow much larger. At the same time, a higher density forest will generally store more carbon than a forest of a lower density with similar species composition. A forest that is too dense may halt tree growth and cause mortality, either slowing carbon sequestration or releasing it due to mortality. A moderate density conifer-dominated forest is ideal for long-term carbon storage in western Washington (Hudiberg et al. 2009).

This Report presents carbon in metric tons of carbon dioxide equivalents (MT CO_2e), shown in Table 9. CO_2e is the mass of atmospheric carbon, and is the standard unit for the California Cap-and-Trade carbon market (CARB 2018). Monitoring plot data were modeled in the U.S. Forest Vegetation Simulator (FVS), a computer growth model for forests produced and maintained by the US Forest Service (Dixon 2002). FVS was used to generate carbon reports for total forest carbon storage including live biomass (tree trunk, top, bark, branches), live and dead roots, snags, downed dead wood, forest floor (organic soil layer but not deep soil carbon), and shrubs. FVS uses biomass equations developed in primary literature and selected by Forest Service model developers to calculate carbon (Rebain 2010).

Table 9: Total forest carbon storage in Seattle forests – metric tons of carbon dioxide equivalents (MT CO_2e) per acre. Results are summarized by canopy classes (Broadleaf, Mix, and Conifer) and ecological structure classes. Ecological structure classes 1 through 4 are grouped together, and 5 through 7 are averaged together due to limited coverage in the monitoring plot data from which these values are calculated. Weighted average is the acreage-adjusted average for the 1-2-3-4 and 5-6-7 ecological structure class groups.

Total forest carbon (MT CO_2e)[1]	Ecological Structure Classes		
Canopy Class	**1-2-3-4**	**5-6-7**	**Weighted Average**
Broadleaf	242	140	225
Mix	417	42	365
Conifer	482	76	380

[1]Includes live and dead trees and roots, soil A horizon, and non-tree vegetation (forbs, shrubs, etc.)

Conifer-dominated forests store the most carbon, and around 70% more carbon than broadleaf forests.

Soil carbon is an important component of forest carbon, storing as much as 2/3 of forest ecosystem carbon (Dixon et al. 1994). The accrual of forest soil carbon is based on the relationship between inputs (from vegetation) and outputs (from decomposition or disturbance), though forest soil carbon is relatively stable as long as existing tree canopies are maintained (D'Amore and Kane 2016). This Report did not attempt to quantify soil carbon. In degraded soil conditions where topsoil has been removed, is compacted, and/or tree cover has been removed resulting in increased rates of soil decomposition, amending the soil can improve soil carbon.

VI. RISKS TO FOREST HEALTH AND RESILIENCE

Section Highlights

SPR forested parks face several risks: species composition (low diversity, climate-vulnerable species, under-represented forest types), topographic features (aspect, slope, coastal or stream-adjacent), forest patch size (small contiguous areas of forest), adjacent land uses, and forest density. These risks are quantified at the zone scale and ranked. Results for each zone where data are available are provided in a geodatabase to aid in SPR's stewardship priorities.

We identified eight factors that contribute to the risk of a zone's long-term forest resilience and created a Risk Score to assess the combinations of factors. We assessed a ninth risk factor (high density zones), but the extent of high-density zones is minor such that it was not included in the Risk Score. All risk results and risk scores for each of the eight risk factors are available in a geodatabase that allows SPR to located at-risk zones and drill down on the individual factors that contribute to a zone's risk score.

1. Low-Diversity Zones

Low diversity zones are at greater risk to long-term forest resilience because the zones are vulnerable to a species-specific disturbance, particularly insect or disease outbreaks. Zones with a high proportion of a single species could experience widespread mortality if an aggressive species- or genus-specific insect or disease occurs. We have learned from other regions' experiences with Dutch elm disease, emerald ash borer, and other similar non-natives that over-reliance on a single species, or genus, can lead to ecosystem collapse. In Seattle Parks, common native species are nearly entirely of different genera, such that evaluating diversity at the species level is sufficient.

Our analysis established four thresholds for the maximum proportion of canopy that a single species occupies (described in Section V.1 - Current Conditions: Species Composition), ranging from very low (0 to 25% of the canopy occupied by a single species) up to high (75% to 100% of the canopy occupied by a single species) (Table 11). The rest of the canopy is composed of several other species, none of which occupy as much canopy as the max species. We also looked at the species break-down of low-diversity zones (Table 10).

Table 10: Acreage of the eight most common species that make up the majority composition of canopy cover in Seattle Park zones. The 50%-to-74% and 75%-to-100% categories show the acreage at greatest risk to resilience.

Canopy Cover	Bigleaf maple	Red alder	Douglas-fir	Black cottonwood	Madrone	Western redcedar	Other
50% to 74%	258	69	48	24	10	5	29
75% to 100%	158	54	17	9	5	3	17
Total Acres	**416**	**123**	**65**	**33**	**15**	**8**	**46**

About 23% of SPR forested parks are at a high risk due to low species diversity (Table 11). Bigleaf maple is the most common species occupying the maximum portion of a canopy. Red alder is also common. Diversifying these zones will involve creating density and light conditions that are suitable for planting different species. Removing overstory maples and/or alders is often necessary to allow sufficient light, usually in "opening" treatments where 1/10th to ½ acre or more of overstory maple or red alder are cut.

Risk Score

Table 11 shows the risk score associated with each diversity threshold.

Table 11: Acreage and proportion of canopy cover of a single species in Seattle Parks zones. Threshold indicates the maximum proportion of canopy that a single species occupies. For example, the 25% to 49% category shows zones where the maximum percent canopy a single species occupies is between 25% and 49%, and the rest of the canopy is composed of several other species, none of which occupy as much canopy at the max species.

Canopy Cover Threshold	Risk Score	Acres	% of Acres	# of Zones	% of Zones
0 to 24%	0 (very low risk)	215	12%	61	6%
25% to 49%	1 (low risk)	908	50%	394	40%
50% to 74%	2 (moderate risk)	445	24%	295	30%
75% to 100%	3 (high risk)	266	14%	224	23%
Total	-	**1,835**	**100%**	**974**	**100%**

2. Proportion of Vulnerable Tree Species at Risk Due to Climate Change

This vulnerability assessment assigned species vulnerability rankings for drought tolerance and disease/insect resistance. We relied primarily on two studies of tree species vulnerability for Western Washington to assess the risk of low survivability of common native tree species in Seattle. First, the Climate Change Sensitivity Database (CCSD), a part of the Pacific Northwest Climate Change Vulnerability Assessment (Lawler and Case 2010), assigned a vulnerability rank to common tree species, including assessing vulnerability to disturbance (such as drought, disease, fire, or flood). We also used a US Forest Service vulnerability assessment (Aubry et al. 2011) that defined five risk categories that affect species at a region-wide scale, including distribution throughout the region, reproductive capacity, habitat specificity, genetic variation, and insect-disease threats. To best apply these results to Seattle (rather than a species' risk in a regional context), we focus on species ranking for resilience to drought and insect-disease. We supplement the two vulnerability studies with Minore (1979) literature review of drought tolerance among native trees in the Pacific Northwest, Silvics of North America (Burns and Honkala 1990) descriptions of trees species, and various other sources (cited in the tables below) for species that weren't included in other risk assessments.

We developed a vulnerability score specific to Seattle trees by:

1. Rating a species' susceptibility to drought on a 1 through 3 scale, and
2. Projecting a species' susceptibility to insects and disease on a 1 through 3 scale.

We added the two ratings to get the species vulnerability rating for 13 common native species (Table 13). See Appendix D (XI.4) for details on the insect and disease vulnerability scoring. Species with vulnerability rating of 1 or 2 are not vulnerable, rating of 3 or 4 are moderately vulnerable, and 5 or 6 are highly vulnerable. Vulnerable species are: western hemlock, bigleaf maple, and grand fir.

Using this Species Vulnerability Assessment, we calculated the proportion of canopy occupied by species that are highly vulnerable to climate change: western hemlock, bigleaf maple, grand fir, and western white pine. We chose not to include species that are moderately vulnerable in order to limit SPR's focus to the most critical zones. 10% of SPR forested park acreage is at a high risk due to a high proportion of climate-vulnerable species (vulnerable species occupy 75% to 100% of the canopy), and another 20% is at moderate risk (vulnerable species occupy 50% to 74.9% of the canopy).

Table 12: Acreage and proportion of canopy cover composed of species that have a "High" vulnerability to climate change, based on the Species Vulnerability assessment score of 5 or 6 in this Report. High vulnerability species are: western hemlock, bigleaf maple, and grand fir.

Proportion of vulnerable species' canopy cover	Score	Acres	% of Acres	# of Zones	% of Zones
0 to 24%	0 (very low risk)	782	43%	457	47%
25% to 49%	1 (low risk)	497	27%	191	20%
50% to 74%	2 (moderate risk)	368	20%	180	18%
75% to 100%	3 (high risk)	188	10%	146	15%
Total	-	**1,835**	**100%**	**974**	**100%**

Tree species vulnerability needs to be considered along with landform position. A zone that has a high proportion of vulnerable species is at-risk on dry sites with southern to western aspect but may not be at risk on a north-facing ravine with mesic or wet soils. This information is recorded in the Implementation Geodatabase so SPR forest managers can assess appropriate stewardship actions for a particular zone's species composition and landform position.

Table 13: Climate vulnerability score for 13 native trees.

Rank[a]	Code	Scientific Name	Common Name	Type	Drought Risk[b]	Insect and Disease Risk[b]	Vulnerability Score[c]	Source[d]
1	ACMA3	*Acer macrophyllum*	Bigleaf maple	Broadleaf	**2**	**3**	**High (5)**	1, 2
2	ALRU2	*Alnus rubra*	Red alder	Broadleaf	**3**	**1**	**Moderate (4)**	1, 2
3	THPL	*Thuja plicata*	Western redcedar	Conifer	**2**	**2**	**Moderate (4)**	1, 2, 4
4	PSME	*Pseudotsuga menziesii*	Douglas-fir	Conifer	**1**	**2**	**Moderate (3)**	1, 2
5	POTR15	*Populus trichocarpa*	Black cottonwood	Broadleaf	**3**	**1**	**Moderate (4)**	2
6	ARME	*Arbutus menziesii*	Pacific madrone	Broadleaf	**1**	**3**	**Moderate (4)**	3, 7
7	TSHE	*Tsuga heterophylla*	Western hemlock	Conifer	**3**	**2**	**High (5)**	1, 2
13	FRLA	*Fraxinus latifolia*	Oregon ash	Broadleaf	**2**	**2**	**Moderate (4)**	3
18	PICOC	*Pinus contorta* var. *contorta*	Shore pine	Conifer	**1**	**1**	**Low (2)**	5, 6
Native	QUGA	*Quercus garryana*	Garry oak	Broadleaf	**1**	**2**	**Moderate (3)**	1, 6
Native	PISI	*Picea sitchensis*	Sitka spruce	Conifer	**3**	**1**	**Moderate (4)**	1, 2, 6
Native	ABGR	*Abies grandis*	Grand fir	Conifer	**2**	**3**	**High (5)**	1, 2, 6
Native	PIMO	*Pinus monticola*	Western white pine	Conifer	**1**	**3**	**Moderate (4)**	1, 2, 6

[a] Rank indicates the relative commonality of the species based on percent cover data. “Native” are not in the top 20 most common species.

[b] Risk indicates increased susceptibility due to climate change, where 1 = low susceptibility and 3 = high susceptibility. n/a = non-native/invasivs

[c] The sum of drought risk and disease risk. 1-2 is low vulnerability, 3-4 moderate, 5-6 high.

[d] 1 = Aubrey et al. 2011, 2 = Lawler and Case 2010, 3 = Burns and Honkal 1990, 4 = Rippey 2018, 5 = Pojar and MacKinnon 2004, 6 = Minore 1979, 7 = Elliot et al. 2002

3. Under-Represented Forest System

Zones that have a substantial proportion of tree species that indicate uncommon forest habitats (see Section VII.7 on Target Forest Ecosystems) can be considered for special treatment. We identified zones that have at least 10% relative canopy closure for the following tree species that indicate unique forest ecosystems. Five zones have two under-represented species each greater than 10% canopy cover.

Table 14: Uncommon species that indicates under-represented forest habitats

	Madrone	Garry Oak	Shore Pine	Oregon Ash	Western White Pine
Zone Count	89	3	22	17	7
Acres	230.2	1.6	55.2	19.0	18.0

These zones are identified in the implementation geodatabase. These may be good candidates for special restoration management actions. Favoring under-represented species may involve removing (cutting) adjacent common overstory species that are crowding the under-represented species. For example, mature bigleaf maple adjacent to a Pacific madrone may be cut to free more sun and water resources to the relatively scarce madrone.

Risk Scoring

Zones that have least 10% relative canopy closure for madrone, Garry oak, shore pine, Oregon ash, or western white pine are scored as 1. All other zones are zero.

4. Landform Position at Risk Due to Climate Change

A zone's location on the landscape strongly influences the forested communities that reside there. This analysis focuses on four landform factors:

- Aspect (sun exposure)
- Coastal areas (storm surge and sea level rise)
- Adjacent to streams (flood risk)
- Steep slopes (operational difficulty of restoration work)

a. Aspect

Southern and western aspects are likely to become hotter and drier in the future. We calculated average aspect for zones using LiDAR terrain models.

Table 15 shows the break-down of aspects in SPR zones. Very few zones have a northerly aspect, while 60% of the zone acreage averages a westerly or southerly aspect. Seattle's topography includes many moraines (elongated hills formed by glaciers) that are oriented north-south, which means there is somewhat less land with a northern aspect. SPR's property happens to further underrepresent the limited amount of northern aspect.

Table 15: Aspects. South and West aspects are more vulnerable to the effects of climate change.

Aspect	Risk Score	Acres	% of Acres	Zone Count	% of Zones
North	0	75	3%	79	5%
East	0	1,331	48%	688	45%
South	3	566	21%	320	21%
West	3	775	28%	442	29%
Total		**2,747**	**100%**	**1529**	**100%**

b. Coastal Areas and Stream-Adjacent Zones

Coastal areas are zones within 100 feet of Puget Sound or the Duwamish River. These are areas that are likely to be impacted by storm surges and sea level rise. Similarly, bigger floods are expected following stronger winter storms in streams. Zones that are near coasts and streams will need special management considerations to accommodate these severe events. Zones that have both a stream and the coast within 100 feet use a risk score of 2.

Table 16: Zones within 100 feet of Puget Sound and Duwamish coast, and within 100 feet of streams

Feature	Risk Score	Zone Count	Acres
Stream 100ft	1	458	888
Coast 100ft	2	137	214

c. Steep Slopes

Zones with an average slope of 66% or greater require special consideration for restoration activities due to the difficulty and safety concerns of working on steep slopes.

Table 17: Zones with an average slope of 66% and greater

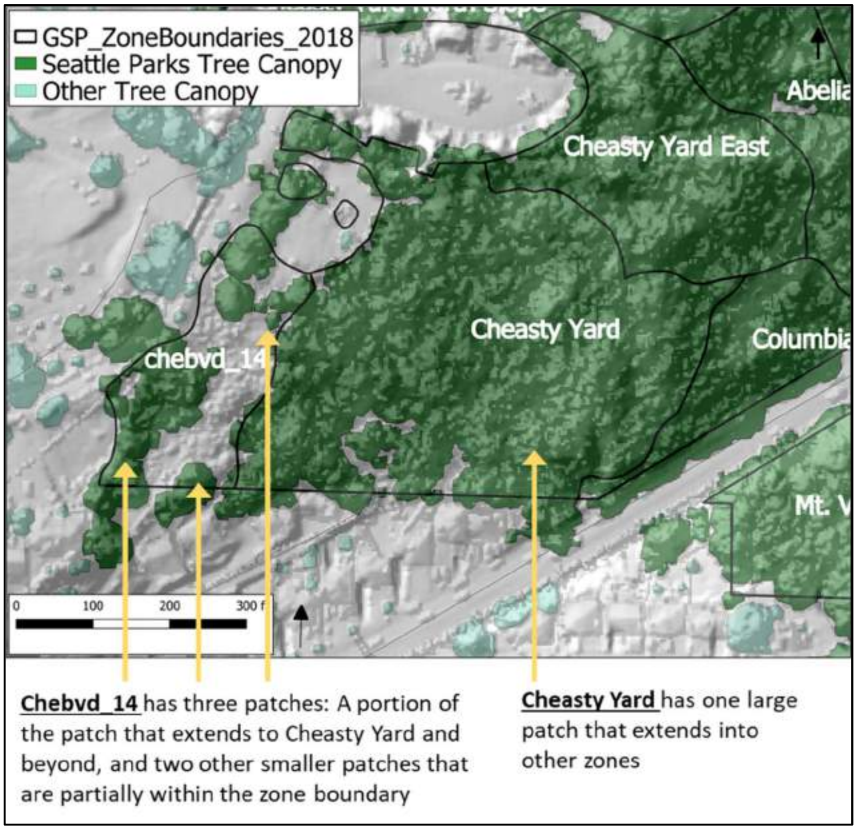
Average Slope	Risk Score	Count	Acres	% Acres
<66%	0	1331	2454	89%
66%+	1	198	293	11%
Total	-	**1,529**	**2,747**	**100%**

5. Forest Patch Size and Edge Effect

a. Patch Size

Urban areas retain heat more effectively than vegetated areas (known as the urban heat island effect), to the detriment of urban inhabitants in hot weather. Forests are particularly good at reflecting heat, an effect called urban cooling (Bazinet 2015). Trees absorb and reflect much of the heat energy, and transpire (release water vapor through their leaves) which cools the air. The impact is substantial; temperatures decreased around 2.5 degrees F for every 10% increase in green space coverage (Wu and Zhang 2018). Generally, the larger the area of the forested patch, the more cooling takes place, but the greatest cooling benefit comes with patches more than 1 acre in size. Patches less than 1 acre rapidly diminish in capacity to cool the adjacent urban heat island.

Figure 14: Example of patch sizes among zones.



Using the City's 2016 analysis of canopy cover (O'Neil-Dunne 2016), we assessed the forested patches that make up SPR forested parks. To do this, we identified all forested patches that are contained within or overlap with SPR zones (Figure 14) to understand how SPR parks fit within the forested canopy in Seattle. This information includes forested areas that extend beyond SPR property onto adjacent lands. Adjacent parcels may be owned privately or managed by other government agencies. SPR zones include a wide range of patch sizes, from individual trees to multi-hundred-acre complexes that span SPR and private land.

Forested patches that are smaller than 1 acre in size total 4.2% of the acreage of patches that are included within or overlap with SPR zones. However, in terms of total count of zones, 90% of the count of patches that are included within or overlap with SPR zones are small patches. Many of these small patches are individual trees or isolated clumps of trees nearby larger contiguous forested areas. Having many isolated trees is not necessarily a problem, as long as much of SPR forested parks also have larger contiguous forested areas. The remaining forested patches within or overlapping with SPR zones are the ballast of SPR forested landscape cover, contributing substantially to urban cooling.

Figure 15: Forest patch size distribution for contiguous forested areas within or overlapping Seattle Parks zones. Both number of patches (blue) and acreage of patches (red) exceed the number and acreage of zones because a zone can have multiple patches, and patches extend beyond the zone boundaries.

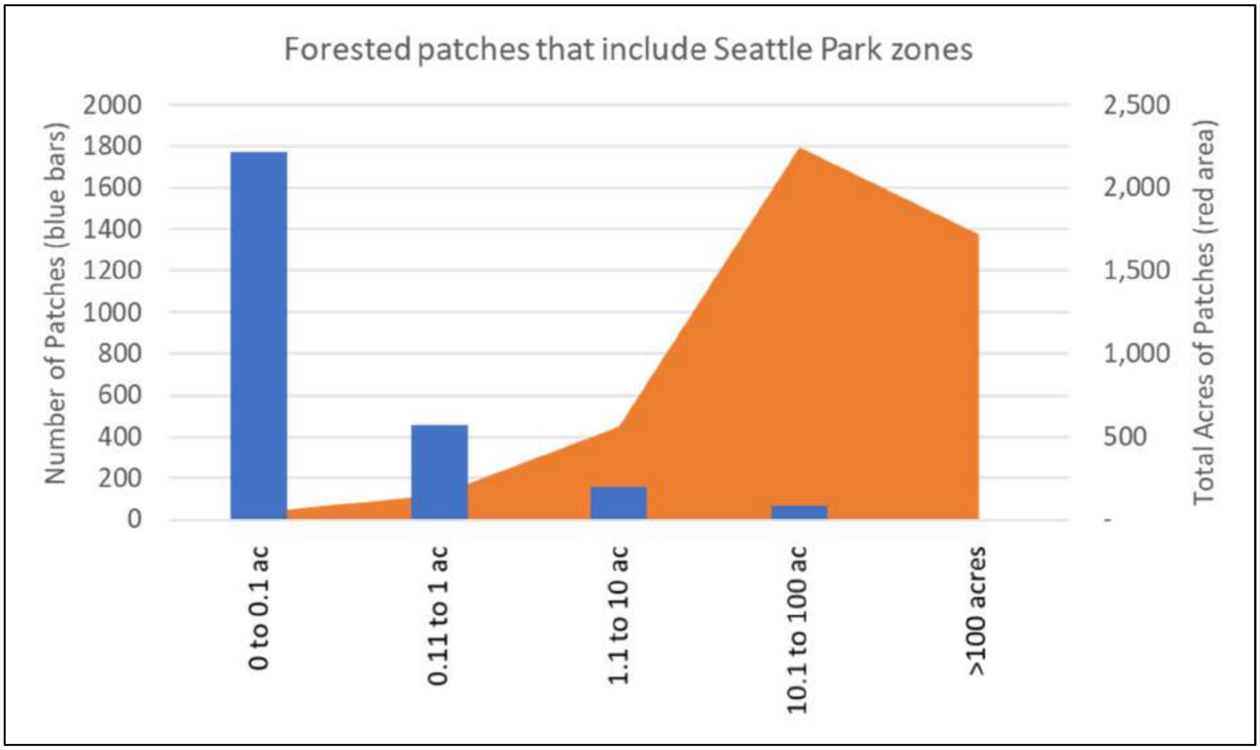


Table 18: Distribution of forested patches that are contained in or overlap with Seattle Parks' zones. Note that the number and acres of patches exceed the number and acres of zones. Some zones contain several small patches and many patches extend beyond the Parks property boundary.

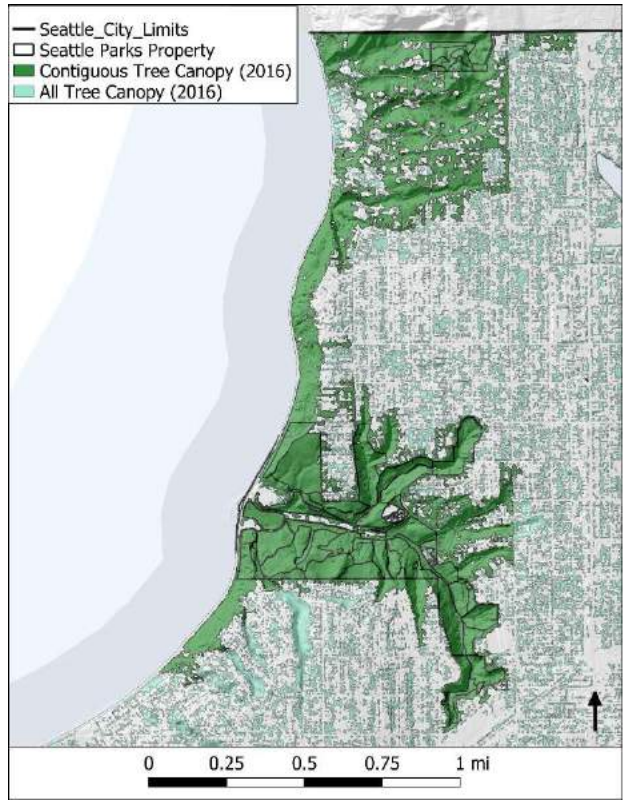
Patch Size (acres)	# of Patches	% of Patches	Acres	% of Acres	Description
0 to 0.1	1,769	72.0%	41	0.9%	Individual trees and small isolated clumps of trees
0.11 to 1	454	18.5%	155	3.3%	Small patches of forest with little urban cooling benefit
1.1 to 10	161	6.6%	559	11.8%	Medium patches of forest, urban cooling effect strengthens
10.1 to 100	66	2.7%	2,241	47.5%	Large forested areas that span parks and private land

100+	7	0.3%	1,722	36.5%	The largest forested areas including large parks and private land

Seven forest patches that are greater than 100 acres include Seattle's largest parks. The Carkeek patch includes 448 acres stretching from south of Carkeek up to and including Llandover Woods at the city's northern border (Figure 16 inset this page). The Discovery patch includes 332 acres spanning most of the park, and another 58-acre patch covering the south west part of the park and beyond. The West Duwamish Greenbelt includes 313 contiguous forested acres, with another 187 acres immediately south, divided only by Highland Park Way SW. Seward Park contains 169 contiguous forested acres. The Duwamish Head Greenbelt that wraps around the northern West Seattle peninsula along a forested bluff totals 145 forested acres. The Arboretum is 124 acres of contiguous forest, though most of the Arboretum is not included in GSP programming. Other notable forested blocks include Woodland Park (99 acres), Lincoln Park (95 acres), the forested bluffs along Golden Gardens Park (86 acres) and the Boren-Interlaken Parks complex (83 acres).

Figure 16: Seattle's largest contigous forested patch.

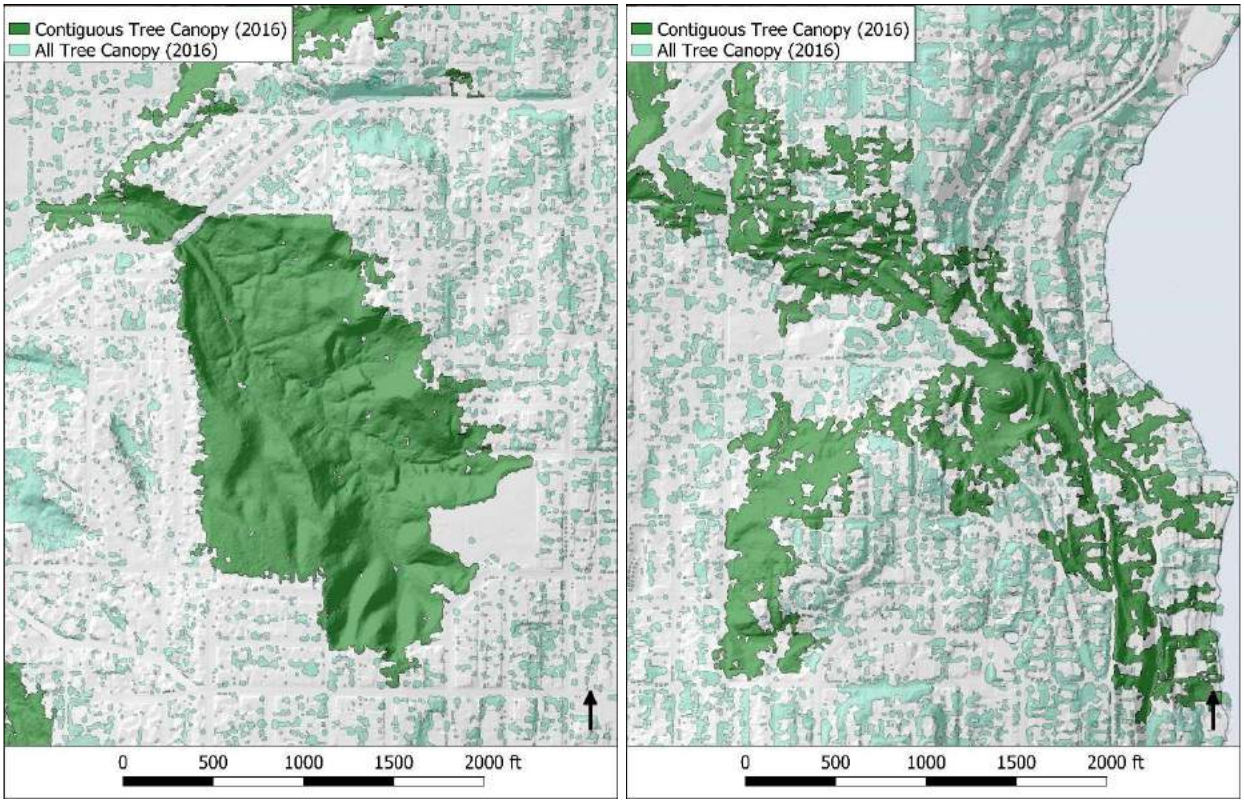
The largest contiguous forested area in Seattle is 448 acres from Carkeek Park to Llandover Woods. This also contains the tallest trees in the city, in Llandover Woods.



b. Edge Effect

Edge effect is another important consideration in SRP forested parks. A high proportion of edge relative to a forest patch's acreage increases the opportunity for invasive weeds to enter the patch and increases the risk of wind toppling trees (windthrow) in urban settings. We calculate edge effect as the ratio of area to perimeter. Areas that have a large area relative to their perimeter have low edge effect (Figure 17). Ratios of area (in square feet) to perimeter (in feet) were calculated for all forested patches. Ratios ranged from 131 to 4. Small patches inevitably have a higher edge effect, so we analyzed forest patches that are 0.5 acres in size and greater. We established thresholds for edge effect at low (ratio of 60 or greater), moderate (ratio of 30 to 60), and high (ratio less than 30). Of the forested patches 0.5 acres and larger, 16% of the acreage has high edge effect, 52% is moderate, and 32% is low. Edge is not a characteristic that SPR can easily improve because adjacent land is not under their management. Instead, this information is recorded in the zone implementation geodatabase and is considered a risk factor when choosing stewardship actions and their frequency.

Figure 17: Examples of forested patches with low edge effect (left, Schmidt Park with 66.2 acres and about 22,000 perimeter feet with an area:edge ratio of 132) and high edge effect (right, Lakeview Park, Harrison Ridge Greenbelt, and surrounding forested area with 55.3 acres and over 110,000 perimeter feet with an area:edge ratio of 22).



Risk scoring

Risk scoring focuses on edge effect at the zone level. We identified the ratio of non-canopy area compared to the total area of the zone. Zones that are entirely included in a contiguous forest patch have no edge effect. Zones that have several small forested patches or a boundary of a forested patch with many undulations have a high edge effect.

Table 19: Proportion of zone that is canopy cover

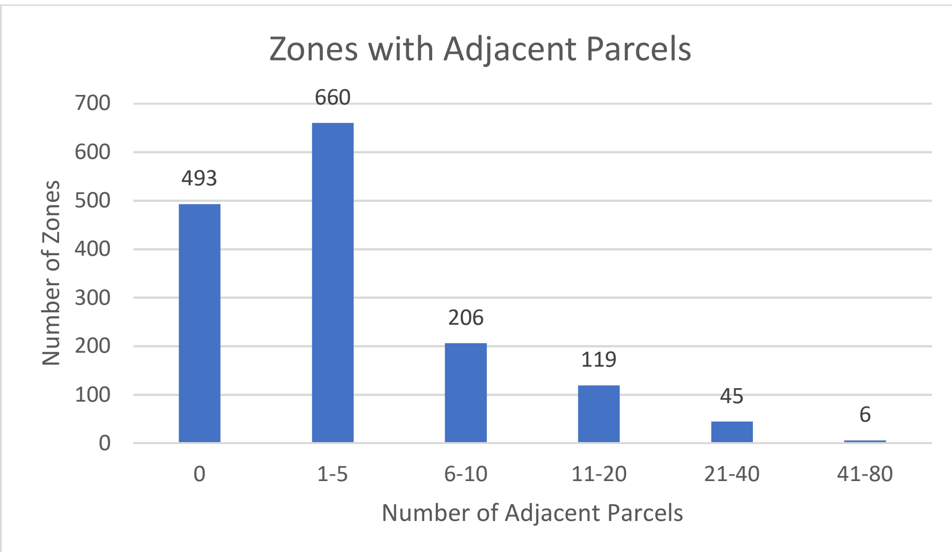
Canopy Cover	0-24%	25-49%	50-74%	75-99%	100%
Risk Score	3	3	2	1	0
Zone Count	5,215	94	169	991	194
Sum of Zone Acres	160	104	180	2,010	292
% of Zone Acres	6%	4%	7%	73%	11%

We considered using total patch size as the metric to identify patches less than 1 acre as they offer low urban cooling effect. However, at the zone scale, SPR has little control over total contiguous forested patch size. Instead, focusing on the proportion of a particular zone that is forested indicates both edge effect, and identifies zones with low forest cover where increasing forest cover may be appropriate.

6. Proportion of Boundary Alongside to Multiple Ownerships

Non-SPR property adjacent to SPR forested parks have the opportunity to introduce invasive plant species. Residential ownerships have a high proportion of invasive tree cover (Cieko 2012). For this analysis we assume that zones that have many adjacent parcels have more chances for invasive plant seed dispersal. SPR has 170 zones (6%) with more than 10 adjacent parcels (Table 20). Six zones have more than 40 adjacent parcels; these are long, linear zones such as the Burke Gillman Trail and Lake Washington Boulevard. 493 zones (18%) have no adjacent parcels; these zones are surrounded by other SPR property and city rights-of-way.

Table 20: Count of parcels adjacent to zones. Zero adjacent parcels indicates zones that are surrounded by other city-owned property and rights-of-way.



Risk Scoring

For risk scoring, zones that have no adjacent parcels are scored 0, one to five adjacent parcels are 1, six to ten adjacent parcels are 2, and 11 or more adjacent parcels are 3.

7. High Density Zones

High tree densities result in stressed trees that are more likely to die in drought conditions or disease and insect outbreaks, or simply from the lack of available resources due to competition. Generally, high density thresholds are where zones exceed:

- 250 trees per acre for a mature stand
- 350 to 500 trees per acre for young stands less than 20 years old or small-diameter stands with average diameter less than 10 inches
- 300 square feet basal area per acre
- Relative Density of 50 or higher

Conifer and Mix cover classes with low ecological structure classes (1 or 2) and/or large average tree diameter or QMD (greater than 20 inches DSH) can support higher basal area and relative densities. Monitoring data indicate that high density is uncommon. Since density data is limited to monitoring plots that cover only a relatively small portion of SPR, we did not find strong enough trends in high density in the canopy or structure class categories to extrapolate high density conditions. Thus, high density is not included in risk scoring. High density is a concern where it occurs, but its limited extent in SPR zones does not justify its inclusion in risk scoring. Ecologically, occasional dense areas in an otherwise uncrowded landscape add to habitat variability and are a desirable part of the overall forest.

Climate change and drier conditions may necessitate less-dense conditions than are currently considered healthy. Trees that are growing in low-competition conditions are likely to better withstand the effects of climate change. Similarly, excessive seedling plantings for restoration, or plantings in already dense forests, will create high-density problems if seedling survival is high.

Basal area, trees per acre, QMD, and relative density are included in Appendix 3 (XI.3.c): Monitoring Plot Data – Zone so SPR can identify the few high-density zones and forest types.

8. Risk Score

Risk scoring is summarized in Table 21. The maximum possible score for the most vulnerable zones is 19, while the minimum possible score is 0. Three variables in the risk score are only available for zones that have species composition data from inventory assessments: diversity, vulnerable species, and under-represented species. We scaled the results for all zones data excluding those variables (Figure 18) out of a maximum score of 12. Separately, we used the full score of 19 for the subset of zones that have inventory data where we can include those three variables (Figure 19).

Table 21: Risk Scoring rubric. Cell formatting is as follows: Risk score: description of the range of values.

19-Point Score (no data for 1/3 of zones)			12-Point Score and 19- Point Score (data available for all zones)				
Diversity (% of single species)[1]	**Vulnerable Species[1]**	**Under-Rep Species 10%+[1]**	**Aspect**	**Coast- or Stream-Adjacent**	**Average Slope**	**Forested Patch % Coverage**	**Adjacent Properties**
0: 0-24%	0: 0-24%	0: Not present	0: N	0: Neither	0: <66%	0: 100%	0: None
1: 25-49%	1: 25-49%	1: present	0: E	1: Stream	1: 66%+	1: 75-99%	1: 1 to 5
2: 50-77%	2: 50-77%		3: S	2: Coast		2: 50-74%	2: 6 to 10
3: 75-100%	3: 75-100%		3: W			3: 0-49%	3: 11+

[1] Scores are available for zones that have inventory assessment data.

Relatively low total risk scores can translate to substantial real-life risk to a forested zone. For example, a total risk score of 6 means that at least two factors are at a high risk, or a combination of factors are at a moderate risk. Total scores of 3 or less are low risk. Including species composition data spreads the distribution of zones across more factors, but relatively low total risk scores still mean there can be multiple high-risk variables. We recommend interpreting the total risk score as a way to indicate zones that have several vulnerabilities, and then using the zone-level data to drill down on specific factors for that site. Using 6 as a threshold for at-risk zones results in 49% of SPR acres at risk when considering the species composition, and 84% of acres when looking at all zones but not considering the species composition data.

Figure 18: Cumulative total risk scores for all zones, excluding factors that depend on species composition data (excludes diversity, vulnerable species, and under-represented species). Maximum possible score is 12.

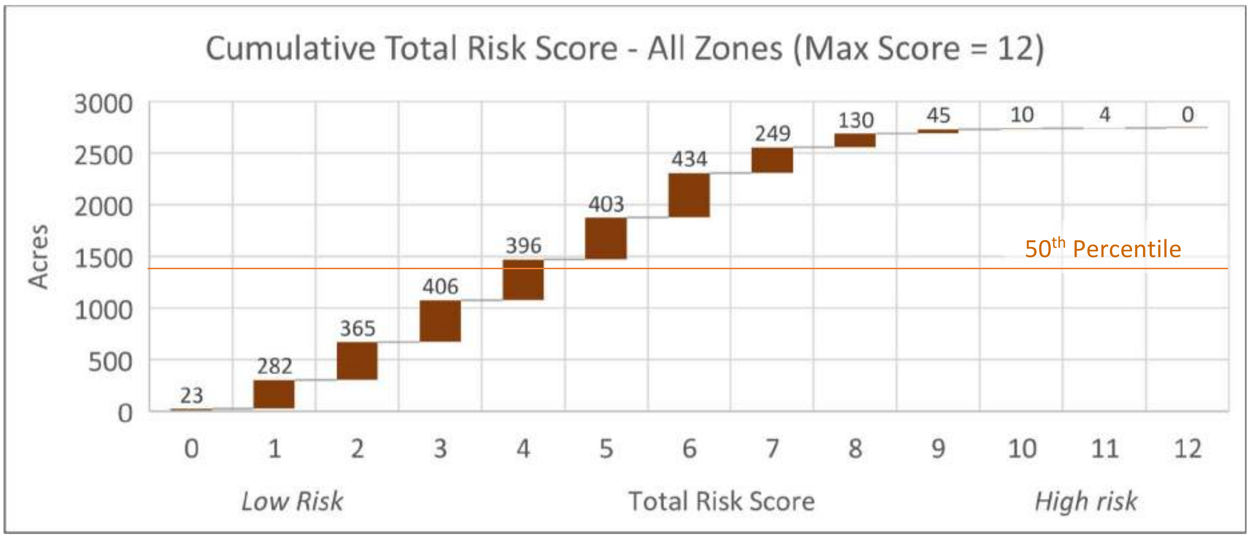
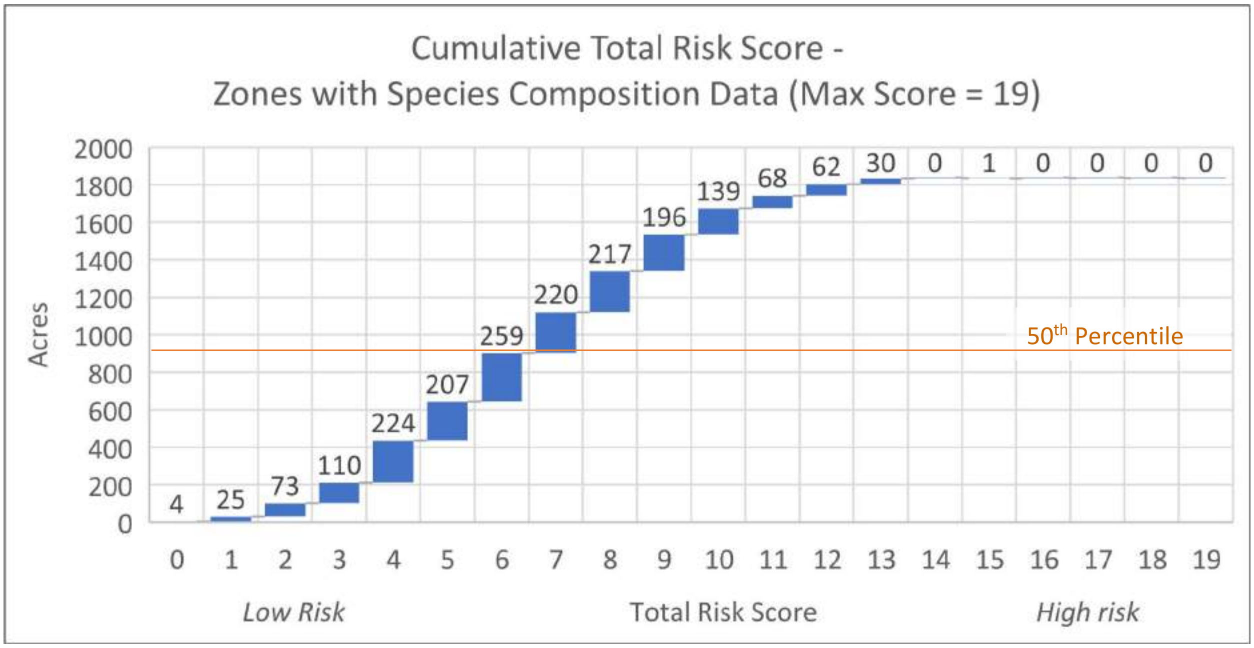


Figure 19: Cumulative total risk scores for zones that have species composition data (including diversity, vulnerable species, and under-represented species). Maximum possible score is 19.



Section Highlights

SPR has developed high-quality classifications and descriptions of target forest ecosystems. This Report provides additional detail quantifying target systems that will help SPR manage for intermediate and long-term density and species composition objectives. LiDAR metrics that define ecological structure classes are also provided.

VII. TARGET FOREST ECOSYSTEMS

An important principle of restoration ecology is the identification of a reference ecological community to serve as a guide for planning projects and a benchmark for evaluating success. For each zone, SPR has identified two levels of reference conditions based on classifications of forest communities in the region.

A zone's forested Target System is a broad classification of the plant community that SPR would like to see in the future. SPR previously identified seven Target Systems for natural areas in Seattle parks that correspond to the NatureServe Ecological Systems (Comer et al. 2003) and Washington State Natural Heritage Ecological Systems (Rocchio and Crawford 2015) (Table 14). Within a Target System, there are a number of possible plant associations that may occur. SPR has termed these Target Forest Types (TFT). The TFTs are based on the Chappell (2006) system of plant associations, developed for upland ecosystems in the Puget Trough Ecoregion and on Kunze (1994) for riparian and wetland systems, with other sources for less-common plant associations documented on the Washington State Natural Heritage Ecological Systems guide (Rocchio and Crawford 2015).

SPR has developed benchmarks for Target Systems to measure progress towards SPR stewardship objectives. These benchmarks are good standards for forest development. We provide additional details for Target Systems, providing metrics for forest conditions relevant to long-term (multi-decade) timeframes and rely on LiDAR metrics to tie into the Ecological Structure Classes. This Report includes brief descriptions of desired future conditions based on Target Systems, acknowledging SPR's good descriptions online [9]. The Target ecosystems represent examples of mature forests found in the Puget Trough Ecoregion that are relevant to the current conditions, restoration goals, and management practices of GSP and SPR forested properties.

1. Late Seral Mixed Conifer and Deciduous Mixed Forest

Late seral mixed conifer forest in the Puget Sound Ecoregion are populated with a varied age and species composition of Douglas-fir, western hemlock, and western redcedar as the dominant species (Franklin et al. 1981, Franklin et al. 2002). Secondary conifer species include Sitka spruce, grand fir, western white pine, shore pine and others. Broadleaf species are also present including red alder, bigleaf maple, bitter cherry, Pacific madrone, and others as individuals or in small groups, and sometimes as the dominant species. Variability in species can create many different age classes due to different life spans of conifer and broadleaf species. These forests exist on a spectrum of conditions ranging from dry to moist, with Douglas-fir chiefly representing the drier end of the spectrum and western redcedar and western hemlock more common in mesic and moist sites.

With the exception of old-growth relics (such as Seward Park and portions of Llandover Woods and Lincoln Park), Seattle's forests are regenerating following clearcuts and range from 120 years old to a few decades old, and sometimes younger. Comparing Seattle's forests to majestic centuries-old old growth does not provide realistic intermediate density targets for SPR. We rely on research of four forests that are considered "intermediate" old growth. These sites are regenerating from natural disturbances like fire and are approximately 190 to 200 years old (Freund et al. 2015). Table 22 shows density and tree size distribution for this data set, where basal area averages 338 square feet per acre and there are 93 trees per acre. A more limited data set reported in Luoma (1991) measured a 130-year old stand that had never been harvested and found similar but slightly denser conditions, though this forest was located at over 3,000 feet elevation. Basal area was reported to be 309 square feet per acre, there were 165 trees per acre, and there was an average DSH of 17.6 inches. These averages are a good long-term target (20 to 50 year timeframe) for Seattle's mixed conifer forests, though broadleaf species will likely remain a more substantial component of Seattle's forests in this timeframe.

Table 22: Density and size of "intermediate" old-growth forests (180 to 200 year-old trees)(Freund et al. 2015).

Species	Basal Area (sq ft/ac)	Density (trees/ac)	Average DSH (inches)	Minimum DSH (inches)	Maximum DSH (inches)
Douglas-fir	259	30	37.9	9.2	66.5

[9] https://www.greenseattle.org/information-for/forest-steward-resources/restoration-resources/reference-ecosystems/

Western hemlock	44	45	11.7	2.0	35.4
Western redcedar	22	5	20.1	6.2	50.1
Other	12	11	11.6	2.4	39.6
Total or Average	**338 (total)**	**92 (total)**	**20.3 (average)**	**4.9 (average)**	**47.8 (average)**

Although most trees will be large overstory trees, multiple tree strata are expected, including shade tolerant regeneration and natural repopulation of canopy openings created by disturbance events. Late seral conifer forests have a diverse understory, and are often dominated by sword fern, salal, and/or dwarf Oregon grape. Secondary shrub species include trailing blackberry, red huckleberry, vine maple, and many others (Chappell 2004).

Climate change may have a significant impact on the development of late seral conifer forests (Mauger et al. 2015). The wetter warmer winters coupled with the hotter and drier summers will promote summer mortality of drought intolerant species such as western hemlock and decreased annual growth due to water stress.

2. Riparian Forest and Broadleaf-Dominated Forests

Riparian forests are often populated with broadleaf species that tolerate, or rapidly regenerate, following flooding and erosion that commonly takes place in riparian zones and steep banks leading down to streams and rivers. Red alder and black cottonwood typically dominate, though bigleaf maple, Oregon ash, Pacific dogwood, and willows are common. Sitka spruce and western redcedar are often also present, with more native conifers as soil moisture and flood risk decreases with distance from the riparian zone. Over time, if present, cottonwoods emerge from the red alder canopy and alder begin to show decline including broken tops and decay. Moderately shade-tolerant bigleaf maple and occasional Sitka spruce and western redcedar may develop in the understory, and over the long-term will intersperse the patchwork of early-to-late seral red alder and black cottonwood that re-establish after major flood events. Sunlight from canopy openings will increase shrub diversity; tree regeneration will be difficult due to shrubs. Density and tree size guidelines for broadleaf-dominated floodplain forests for various age classes are reported in Fierke and Kauffman (2005).

Table 23: Stand characteristics of broadleaf-dominated floodplain forests of increasing ages from Fierke and Kauffman (2005). Stand averages and ranges *(parentheses)* are shown. This information serves as a guide for density for Seattle's broadleaf-dominated forests influenced by flooding in riparian areas.

Age (years)	2	5	13	39	65
Large tree (>=4.0in DSH) TPA	0 *(0,0)*	117 *(0,4654)*	397 *(256,546)*	168 *(123,236)*	110 *(74,158)*
Small tree (<3.9in DSH) TPA	3440 *(0,55037)*	19915 *(1639,38931)*	328 *(61,789)*	501 *(40,1133)*	597 *(61,1396)*
Total density TPA	3440 *(0,55037)*	20032 *(1639,43585)*	725 *(317,1335)*	669 *(163,1369)*	707 *(135,1554)*

Basal area (ft^2/ac)	1 *(0,17)*	85 *(17,148)*	148 *(105,192)*	161 *(131,201)*	205 *(126,270)*

Broadleaf-dominated Target Systems on upland sites are uncommon. More often, wet seeps or recently disturbed areas host pockets of red alder, bitter cherry, and bigleaf maple among mixed broadleaf-conifer forests. In these areas, red alder succumbs to age-related mortality at around 60 to 80 years of age and do not regenerate under the dense shrubs that often associate with broadleaf-dominated habitats.

3. Madrone

Madrone-dominated forests are often located on steep slopes with loose, dry, rocky soils in adjacent to large bodies of water. Madrone forests establish in sites with open sunlight and grow to maturity in mixed conifer-broadleaf forests, commonly with Douglas-fir, bigleaf maple, and western hemlock. Madrone typically does not exceed about half of a site's tree species composition, though nearly-pure stands are found in the region. At a maximum age of 400 years, madrone forests are long lived relative to other broadleaf forests.

4. Scrub-Shrub

Scrub-shrub systems are defined by a lack of overstory trees, typically less than 10 percent canopy cover. Scrub-shrub systems provide important songbird and small mammal habitat and are a healthy component in forested landscapes. The high light environment is prone to invasive weed species colonization. Shrub-scrub habitats should be a minor portion of the landscape (less than 10%).

5. Oak Woodland: Garry Oak

Garry oak ecosystems are often classified as woodland with less than 25% canopy cover. Garry oak can also be a part of a denser forest, cohabiting with Douglas-fir and Pacific madrone. Common shrubs include snowberry, tall Oregon grape, ocean spray, and beaked hazelnut, with significant cover of herbs and grasses. Garry oak woodlands are susceptible to invasive Scotch broom colonization. Sites are flat and sunny with dry and nutrient rich soils. Succession most often occurs through the invasion of Garry oak into prairie. In Seattle's case, Garry oak would supplant drought-intolerant species on dry soils and south- and west-facing slopes.

Desired future conditions for this forest type in Seattle's environment include a mix of Garry oak with Douglas-fir and other drought-tolerant species. The mature cohort would range between 50 and 100 TPA. Younger trees, particularly Douglas-fir, would occur around 30 TPA total. The trees would exhibit patchy distribution, with clumps of large old trees and openings ranging from 1/10 to 1 acre in size.

6. Bogs and Fens

Bogs and fens are fed by mineral-rich groundwater and host unique or rare plant communities. Shore pine often, but not always, grow on or adjacent to bogs and fens. Management for these resources focuses on avoiding invasive species encroachment.

7. Non-Target Ecosystems

Some sites require non-target management objectives. The following non-target systems summarize Buchner (2016) and Cieko (personal communication).

- Zones adjacent to powerlines are height restricted because trees will be cut or heavily pruned that grow under powerlines.
- Visibility restrictions occur in zones that border the Burke-Gilman trail. Zones alongside the trail need to have high visibility so path users can see each other when paths merge. Visibility is also helpful at intersections.
- Designated blackberry patches on the Burke-Gilman trail. Because of the desire of Seattle's residents to pick blackberries from Himalayan blackberry bushes, some patches have become "designated blackberry patches," and are protected.
- Pollinator habitat promoting native shrubs and forbs rather than tree canopies.
- Zones adjacent to road rights-of-way that require limited tree encroachment.
- Zones adjacent to golf courses and high-use recreation areas where recreational uses and public safety are driving forest use objectives.
- Crime prevention through environmental design (CPTED) principles including pruning and vegetation removal for visibility.[10]

[10] https://www.greenseattle.org/information-for/forest-steward-resources/reporting-encampments/

Table 24: Seattle Parks Cover Types, Target Forest Systems, and Target Forest Types (Plant Associations)

Cover Type	Forest System	#Zones	Acres	Target Forest Type Plant Association Common Name	Target Forest Type Latin Code	#Zones	Acres
Conifer-PSME Mix-PSME	Dry-Mesic Conifer and Conifer Deciduous Mixed Forest	636	1,152	Douglas-fir / salal / sword fern	PSME/GASH/POMU	170	380
				Douglas-fir - western hemlock / salal / sword fern	PSME-TSHE/GASH/POMU	319	568
				Douglas-fir - western hemlock / salal - dwarf Oregon grape	PSME-TSHE/GASH-MANE	147	203
Broadleaf-ACMA3 Conifer-THPL Conifer-TSHE Mix-ACMA3	Mesic-Moist Conifer and Conifer Deciduous Mixed Forest	459	885	Big leaf maple - red alder / sword fern - fringecup	ACMA-ALRU/POMU-TEGR	14	34
				Douglas-fir - western hemlock / dwarf Oregon grape - sword fern	PSME-TSHE/MANE-POMU	358	635
				Western red cedar - western hemlock / devils club / sword fern	THPL-TSHE/OPHO/POMU	47	113
				Western hemlock - Douglas-fir / sword fern - spreading woodfern	TSHE-PSME/POMU-DREX	40	104
Broadleaf-ALRU2 Broadleaf-POTR15 Conifer-PICOC Mix-THPL Mix-TSHE	Riparian Forest and Shrubland	248	405	Big leaf maple - Douglas-fir / vine maple / sword fern	ACMA-PSME/ACCI/POMU	18	16
				Big leaf maple - Douglas-fir / beaked hazelnut / Pacific waterleaf	ACMA-PSME/COCO/HYTE	23	30
				Big leaf maple - western redcedar / Indian plum	ACMA-THPL/OECE	77	120
				Red alder / salmonberry / slough sedge - skunk cabbage	ALRU/RUSP/CAOB-LYAM	72	138
				Oregon ash - black cottonwood / salmonberry	FRLA-POBA/RUSP	5	6
				Black cottonwood / red oiser dogwood	POBA/COSE	10	15
				Black cottonwood / snowberry	POBA/SYAL	10	14
				Black cottonwood - red alder / salmonberry	POBA-ALRU/RUSP	12	22
				Western hemlock-western redcedar-big leaf maple/vine maple/skunk	TSHE-THPL-ACMA/ACCI/LYAM	21	44
Broadleaf-ARME	Conifer Broadleaf Evergreen Mixed Forest	119	217	Douglas-fir - Pacific madrone / salal	PSME-ARME/GASH	49	72
				Douglas-fir - Pacific madrone / oceanspray / hairy honeysuckle	PSME-ARME/HODI/LOHI	50	104
				Douglas-fir - Pacific madrone / evergreen huckleberry	PSME-ARME/VAOV	20	42
Broadleaf-Salix	Scrub Shrub Wetland	35	53	Willow / Douglas spirea - red oiser dogwood - twinberry honeysuckle	SA/SPDO-COSE-LOIN	19	25
				Sitka willow / Douglas spirea	SASI/SPDO	16	28
Mix-PSME Conifer-PICOC	Oak Woodland	23	26	Oregon white oak - Douglas-fir / common snowberry / sword fern	QUGA-PSME/SYAL/POMU	22	25
				Oregon white oak - Douglas-fir / common snowberry / sword fern	QUGA-PSME/SYAL/POMU (VP)	1	1
-	Bog and Fen	5	6	Shore pine / Labrador tea / sphagnum spp.	PICO/LEGR/SP	5	6
	No system defined	4	3	Unclassified	UNCLASSIFIED	4	3
Cover Type	**Total**	**1,529**	**2,747**			**1,529**	**2,747**

VIII. STEWARDSHIP PRESCRIPTIONS AND BEST MANAGEMENT PRACTICES

Section Highlights

Prescriptions are the methods for moving a zone's current conditions towards the target forest system. These include the following categories of management actions:

- Alleviating Crowded Forests to Give Trees Room to Grow: Where forests are dense with tree species that are vulnerable to climate change, removing some trees makes light and water available to trees with the best chance of long-term success. Tree releases, density management, and small tree thinning, work to achieve this objective.
- Shifting Tree Composition Towards Long-Lived, Climate-Resilient Species: Achieved through tree releases, canopy opening with planting, small tree thinning, and other plantings.
- Creating Habitat with Large Woody Debris: Standing dead trees and downed dead trees are critical for wildlife habitat, and Seattle lacks these features.
- Special Management Considerations for Unique Forest Habitats: Madrone forests, bogs and wetlands, Garry oak forests, and riparian forests have unique management needs.

Management recommendations are designed to move current conditions towards achieving SPR's target future conditions, in line with the stewardship outcomes defined in Section II: FOREST ECOSYSTEM STEWARDSHIP OUTCOMES. Prescriptions call for action where clear ecological benefits will result relative to a non-action approach. Prescriptions are provided for Forest Types (canopy type – structure class combinations), or groups of Forest Types with the same management approaches. SPR will ultimately decide if the prescriptions are appropriate for any particular zone. These prescriptions generally apply to forests in Phase 4 restoration – forests where invasive plant cover has been controlled and where native species are prevalent in the understory and overstory.

1. Prioritizing Management and Deciding on Management Actions

Prescriptions fall into the following nine categories. Table 25 shows the suitable actions for each Forest Type. Detailed descriptions of the management actions are in the following sub-sections.

Maintenance: Conduct invasive weed control and opportunistic planting in canopy openings as needed (with appropriate follow up).

Release: Drop-and-leave/create snag trees adjacent to a target retention species, typically long-lived conifers or madrone. This management action makes room for big or unique trees.

Canopy Opening (+ planting): In order to shift species composition in vulnerable species compositions, particularly in bigleaf maple- and red alder-dominated zones, cut (drop-and-leave) trees with poor crowns and poor canopy position to increase light to forest floor in 1/10th to 1 acre openings. Replant with resilient long-lived conifers.

Density Management: Thin (cut trees) to reduce stand density. Typically retain biggest and best trees. Suitable where density exceeds 250 trees per acre, 300 square feet basal area per acre, or Curtis relative density of 50 or higher. Low ESCs (1 or 2) can support higher density.

Small Tree Thinning: Reduce small tree/tall shrub density around planted seedlings and preferred established trees to ensure their success. Shrubs typically regrow rapidly.

Planting: Plant site-appropriate seedlings where canopy openings allow sufficient light to ensure the species has good growth. Commit to follow-up with cutting back adjacent shrubs and invasive weed control until the tree height is greater than 6 feet tall. Planting seedlings under existing dense canopies is typically not recommended.

LWD: In zones that are in line with the target conditions, increase LWD through girdling, herbicide injection, or drop-and-leave cutting. Choose trees at least 12" in diameter but with subordinate canopy positions, preferably western hemlock or suppressed Douglas-fir.

Site-Specific: Conditions are variable, assess each zone for its own needs.

Unique Prescription: Unique management objectives based on unique habitats, such as wetlands, madrone, etc.

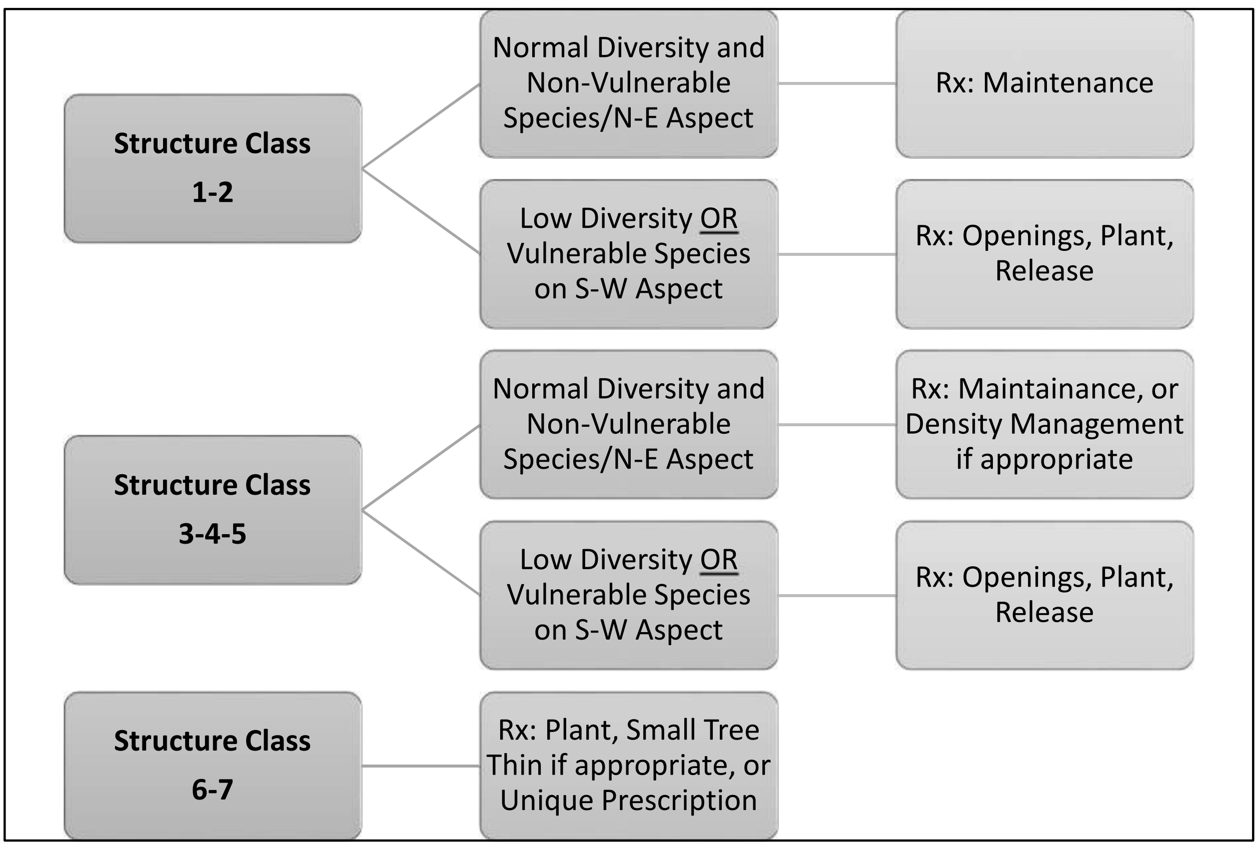
Table 25: Management guidelines for Phase 4 forests, by Forest Type (canopy type and structure class combination). See Prescription section for explanations. Background shading indicates management priority: green is low priority, orange is intermediate, and red is a high management priority.

Canopy		Structure Class						
		1	2	3	4	5	6	7
CONIFER	Conifer-PSME	LWD, Maintenance	LWD, Maintenance	Site-Specific, Density Management, LWD	Site-Specific, Density Management, LWD	Planting, Small Tree Thinning	Planting	Site-spec.
	Conifer-THPL	LWD, Maintenance	LWD, Maintenance	Site-Specific, Density Management, LWD	Site-Specific, Density Management, LWD	Planting, Small Tree Thinning	Planting	Site-spec.
	Conifer-TSHE	LWD, Maintenance	LWD, Maintenance	Site-Specific, Density Management, LWD	Site-Specific, Density Management, LWD	Planting, Small Tree Thinning	Planting	Site-spec.
	Conifer-PICOC	Maintenance, Unique	Maintenance, Unique	Unique	Unique	Unique, Planting	Planting	Site-spec.
	Conifer-Other	LWD, Maintenance	LWD Recruitment, Maintenance	Site-Specific, Density Management, LWD	Site-Specific, Density Management, LWD	Planting, Small Tree Thinning	Planting	Site-spec.
MIX	Mix-ACMA3	Release, Opening, Planting	Release, Opening, Planting	Release, planting	Release, Planting	Planting, Small Tree Thinning	Planting	Site-spec.
	Mix-THPL	Density Management, LWD, Maintenance	Density Management, LWD, Maintenance	Density Management, LWD, Maintenance	Density Management, LWD, Maintenance	Planting, Small Tree Thinning	Planting	Site-spec.
	Mix-TSHE	Release, Density Management, LWD	Release, Density Management, LWD	Density Management, LWD, Maintenance	Density Management, LWD, Maintenance	Planting, Small Tree Thinning	Planting	Site-spec.
	Mix-PSME	Density Management, LWD, Maintenance	Density Management, LWD, Maintenance	Density Management, LWD, Maintenance	Density Management, LWD, Maintenance	Planting, Small Tree Thinning	Planting	Site-spec.
	Mix-Other	Release, Opening, Planting	Release, Opening, Planting	Release, planting	Density Management	Planting, Small Tree Thinning	Planting	Site-spec.
BROADLEAF	Broadleaf-ACMA3	Opening, Planting	Opening, Planting	Opening, Planting	Opening, Planting	Planting, Small Tree Thinning	Planting	Site-spec.
	Broadleaf-ALRU2	Opening, Planting	Opening, Planting	Opening, Planting	Opening, Planting	Planting, Small Tree Thinning	Planting	Site-spec.
	Broadleaf-POTR15	Maintenance, Planting	Maintenance, Planting	Opening, Planting	Opening, Planting	Planting, Small Tree Thinning	Planting	Site-spec.
	Broadleaf-ARME	Release	Release	Release, Unique	Release, Unique	Unique, Planting	Planting	Site-spec.
	Broadleaf-Other	Opening, Planting, Release	Opening, Planting, Release	Opening, Planting, or Release	Opening, Planting, or Release	Planting, Small Tree Thinning	Planting	Site-spec.

Management priorities and management actions follow trends in Forest Types. Generally, Broadleaf Forest Types are more at-risk of tree loss than Mixed and Conifer Forest Types, and higher ESCs (classes 3 and higher) are often farther from their target conditions than ESCs 1 and 2. Unique forest habitats like bogs, madrone forests, forested wetlands, oak woodlands, or non-target zones will follow management guidelines unique to that forest type or even specific to the conditions and management objectives for an individual zone.

Within Forest Types, zones have a wide range of variation in their species composition and density. Prioritizing management actions depends on several zone-specific variables. SPR should use the Risk Score to identify the most vulnerable zones and assess the factors that contribute to the risk. Using the management priority (Table 25), SPR can further filter what zones need management actions as a priority. Thereafter, SPR will consider non-ecological factors including cost of management actions, access, public use, and safety in deciding if a zone should undergo a management action. Finally, SPR can use the decision-making flow chart in Figure 20 to decide on management actions.

Figure 20: Management Action Decision Tree for most Canopy Classes. Unique habitats should follow habitat-specific restoration guidelines.



2. Prescription Best Management Practices

a. Maintenance

Maintenance means general care-taking of healthy forests. Maintenance involves active invasive weed control and seeking opportunistic planting in canopy openings (with appropriate shrub control follow up) as needed. Maintenance is most often prescribed for conifer and mixed canopy classes with structure class 1 and 2, where species composition is diverse and does not include vulnerable species. Maintenance is a critical management action to maintain healthy, resilient forests.

b. Release

Release actions are a way to give the biggest and best trees room to grow, or help unique species that need a lot of light. Big Douglas-fir or western redcedar in dense stands, madrone in dense stands, and other less-common sun-loving species that are desirable such as Sitka spruce and western white pine are good candidate species. To conduct the release, cut down or otherwise kill trees adjacent to the release tree. Optionally retain desirable species or individual trees even if they are adjacent to the release tree – for example, if a madrone and a large, healthy Douglas-fir are next to each other amid several western hemlock, retain both madrone and Douglas-fir while removing the hemlock. Drop-and-leave, girdling, and topping are suitable ways to kill the adjacent trees. This management action makes room for released trees or unique trees to grow larger and develop diverse forest structure over time.

c. Opening + Planting

Openings are intentionally-created canopy openings that range in size from 1/10th to 1 acre or larger and are intended to shift species composition towards long-lived, climate-adapted species. This action is most appropriate in bigleaf maple- and red alder-dominated zones, but can be used in high-density stands that are dominated with species that are vulnerable to climate change and disease, frequently in the Broadleaf Canopy Class. Cut (drop-and-leave) most or all trees of the target species (such as bigleaf maple, red alder, or western hemlock), retaining desirable sun-loving species such as madrone, healthy well-formed Douglas-fir, etc. Active planting is an essential part of creating openings due to the lag or undependable establishment of natural regeneration. Replant in the opening with a mix of resilient long-lived species that are adapted to the site conditions, approximately 300 trees per acre but up to 400 trees per acre or more where invasive species are a concern or high seedling mortality is anticipated. High planting density leads to very shady conditions that reduce invasive species and allows for a high proportion of seedling mortality while still achieving an adequate long-term tree density. Seedling density after 5 to 10 years should be 200 to 300 trees per acre on most sites. Overly dense sites will limit tree health and survival in the long-term. Overly dense sites should undergo Small Tree Thinning approximately 15 years after planting.

d. Density Management

Thin non-desirable tree species to reduce stand density. This action is suitable where density exceeds:

- 250 trees per acre for a mature stand
- 350 to 500 trees per acre for young stands less than 20 years old or small-diameter stands with average diameter less than 10 inches
- 300 square feet basal area per acre
- Relative Density of 50 or higher

Conifer and Mix cover classes with low ESCs (1 or 2) and/or large average tree diameter or QMD (above 20 inches DSH) can support higher basal area and relative densities.

This is most likely to occur in ESCs 3, 4, and 5 but will not be a common management action. Typically, retain the biggest and best trees that are well-adapted to the site conditions and resilient to changes in the climate. Cut (drop-and-leave) trees of the target species (such as bigleaf maple, red alder, or western hemlock), retaining desirable species such as madrone, healthy well-formed Douglas-fir, etc. Ensure that a range of tree diameters are present, and the pattern of density is variable – some areas will have dense patches, some areas will be more open. Avoid cutting all small trees, or retaining trees in an even grid pattern. Girdling and topping are also acceptable methods to increase the large woody debris component. Typically, thin the area to between 100 and 200 trees per acre if they are mature trees, equating to 150-250 square feet of basal area and relative densities around 35.

e. Small Tree Thinning

Reduce small tree/tall shrub density in thickets and around planted seedlings and preferred established trees to ensure their success. Shrubs are typically robust and regrow rapidly. This is similar in concept to the density management action, but intended for young, dense trees (500 trees per acre or more) or where desirable trees are suffering from dense tall shrub competition such as salmonberry, evergreen huckleberry, or elderberry. Retain around 200 to 250 trees per acre.

f. Planting

Plant site-appropriate seedlings where canopy conditions allow sufficient light to ensure the species has good growth. Commit to follow-up shrub control, which involves cutting back adjacent shrubs (even native shrubs) within a 5- to 10-foot radius of each seedling, and controlling invasive weeds until the tree height is greater than 6 feet tall. Planting under shaded canopies is typically not effective. Even shade-tolerant seedlings will not gain much height, even if they survive. Sun-loving trees species typically die within five years of planting in shaded conditions. Consider long-term tree density when designing plantings – creating crowded conditions will reduce long-term forest health and resilience. Restoration activities sometimes create future density problems where overzealous planting leads to inter-tree competition and mortality.

g. Large Woody Debris (LWD)

Increasing snag and LWD density over time (without creating dangers or hazards to structures, public infrastructure, or human health and safety) is an important management objective. Intentionally girdling or otherwise killing some trees in dense growing conditions, and retaining dead wood on site, will speed forests' progress to high snag and LWD levels.

In zones that are in line with the target conditions, increase LWD (snags and dead downed logs) through girdling, herbicide injection, or drop-and-leave cutting less-desirable live trees. Choose trees at least 12" in diameter but with subordinate canopy positions, preferably western hemlock or suppressed Douglas-fir. Where tree removal management actions are taking place (openings, release, density management), create up to 5 quality snags per acre (12"+ DSH, 30 feet+ tall) to promote wildlife habitat, and up to 5 dead downed logs per acre (12"+ large-end diameter, 30 feet+ length). In areas where zone density is not high, SPR could optionally create one or two snags per acre. Create snags only in areas far from structures, public infrastructure such as roads and power lines, and high-use recreation areas.

h. Site-Specific Prescriptions

Where the data SPR has on a zone's condition is incomplete, additional field work is needed to assess conditions and choose best management practices. Structure class 7 is particularly variable and difficult to develop general best management practices.

i. Unique Target Systems Prescriptions

Madrone forests: mature forests should have densities similar to Dry-Mesic Mixed Conifer-Broadleaf Target Systems. Mature forests should have 70 to 150 trees per acre with QMDs greater than 15" of mixed species. Madrones that are crowded by other trees should undergo release treatments to promote their success.

Bogs and fens: Management for these resources focuses on avoiding invasive species encroachment and protecting rare plant communities. Bogs have wide range of densities and species, though they harbor species with high soil moisture tolerance such as shore pine.

Garry oak: Garry oak is uncommon in Seattle, and will be a part of SPR's planting pallet in the future as SPR shifts species composition in the driest and most climate-vulnerable zones. Plant oak in canopy openings where the seedlings receive full sun, and mulch if possible. In the 0- to 10-year term, encroaching shrubs (even native shrubs) and possibly naturally regenerating Douglas-fir or other native trees will need to be cut back within 5 to 10 feet of the seedlings to promote their survival. This dry system can support up to 100 TPA in maturity. Long-term, management and maintenance of this ecosystem may require active monitoring and removal of Douglas-fir and other tree species encroachment. Low intensity, low severity ground fire has historically been required for maintenance of Garry oak ecosystems. Prescribed fire achieves this disturbance regime but is not feasible in urban areas for air quality and safety concerns. Periodic (every few years) mowing can substitute the effect of fire in Garry oak woodlands.

Riparian forests in flood risk zones: Managing flood risk zones involves anticipating flood disturbances. Ensure any tree removals comply with local and state regulations, particularly the Seattle's Shoreline Master Plan and the Washington Department of Natural Resources Forest Practices regulations. These regulations limit or prohibit cutting trees within certain distances of waterbodies. Broadleaf trees growing in dense conditions (more than 500 TPA in small-diameter stands where the QMD is less than 8 inches) are good candidates for small tree thinning. For more mature stands, conduct release treatments around Sitka spruce, western redcedar, or other unique long-lived species. For low-diversity conditions, opening + planting treatments with the goal of increasing species diversity are suitable.

3. Implementation

a. Phase 4 Restoration and Long-Term Forest Management

Phase-4 forests are forests that have met GSP's restoration criteria, particularly low invasive vegetation cover and high tree regeneration. The management priorities and prescriptions in this Report are intended for Phase-4 forests. The analyses in this Report include all zones where data are available, including zones in Phase 1 through Phase 3. The management priorities and climate change considerations are equally applicable to Phase 1 through Phase 3 forests, and SPR will consider the risk scores when deciding restoration activities, planting pallet species composition and seedling stock, and planting densities.

b. Applying Prescriptions to Zones: Site Expertise and Zone-Level Variability

This Report relies on the best available data to develop management priorities and prescriptions; however, SPR's dedicated network of staff, volunteers, and contractors have first-hand in-forest experience that we cannot replicate in our analysis. People who have working knowledge of a zone's conditions are best suited to interpret the prescription guidelines and determine how best to implement management actions. Forests are variable, and zones that are classified as similar in this Report may exhibit a range of conditions on-site that could justify deviations from the prescription recommendations. SPR forest ecologists may choose prescriptions that are different from what this Report recommends based on site conditions, where the management outcomes are in-line with the management objectives described in this Report.

c. Improving Management Practices with Experience and Actual Climate Impacts

As SPR builds experience with the prescription recommendations, we recommend a feedback cycle to edit and improve prescriptions based on actual stewardship outcomes that are tailored to Seattle's forested parks. Further, climate impact forecasts are predictions and actual future climate may be different, or of greater or lesser magnitude than predicted. SPR must account for the actual impacts as they occur and adjust management actions and timeline accordingly.

d. Prescriptions for Zones with No Inventory Data

For the one-third of SPR acres that do not have inventory data, SPR can rely on the non-species-specific risk scores to identify sites that may be a high priority for management actions, but species composition is a critical factor in forest management prescriptions. SPR will need to collect species composition and density before deciding what management pathways are appropriate and choosing a prescription. Prioritize inventory assessments in zones that have no field data where risk scores are highest. We recommend conducting inventory assessments on all zones, but recognize that SPR must prioritize limited field resources. See Section IX.1: Recommendations for Inventory Assessment Methods for recommendations on improvements to the inventory analysis methods.

e. Recommendations for Creating Canopy Openings

Creating canopy openings is an effective way to transition species composition away from climate-vulnerable, low-diversity zones towards more sun-dependent, drought-tolerant resilient forests. We identified zones that have the following traits as potential gap treatment sites:

- Broadleaf-AMCA or Broadleaf-ALRU cover types

- Conifer-TSHE cover type on south- and west-facing slopes only
- Zones that are outside of 100 feet of a coast or stream
- Zones with average slopes less than 66%

Zones that meet this criteria are saved in a GIS shapefile associated with this Report.

f. Implementation Cost

This Report does not address cost of implementation. We therefore do not define implementation targets or quotas, acknowledging instead that SPR 1) balances many competing objectives beyond the technical ecological objectives of this Report, all of which compete for financial and person-hour resources; and 2) has a variable budget which they do not control. SPR will prioritize management actions using the strategies and implementation practices described in this report as best they can within the financial limits.

IX. FUTURE ANALYSIS, MONITORING, AND REPORTING

1. Recommendations for Inventory Assessment Methods

Inventory assessments are generally a good way to provide an overview of a zone's condition. We identified two ways to improve the usefulness of inventory assessment data collection: standardize density data measurements, and increase coverage of inventory assessments.

Density data: We found inconsistencies in the density data that led us to not use that data set, despite its broad coverage. A standard fixed-radius plot will provide the most useful and reliable data. We recommend a 1/10th-acre (37.2-foot radius) plot to capture forest conditions.

- In dense zones where tree density exceeds 300 trees per acre (30 trees per 1/10th acre plot), measurers may use a 1/20th acre plot (26.3-foot radius) to avoid excessive time collecting data.
- Since randomized sampling is beyond the scope of inventory assessments, choose a plot center that is a representative example of the conditions in the zone.
- If the zone includes more than one distinct forest condition, multiple plots may be necessary for each distinct condition. Don't install more than one plot per 2 acres.
- Data measurements should include: tree species, DSH, and signs of insect or disease damage for every tree. SPR can include additional data such as tree regeneration to help with specific questions they may have for forest conditions.

Zone coverage: Attempt to gather inventory assessment data for most zones. Currently SPR has no data for 912 acres of forested parks. Prioritize data collection by:

- Zones with a high risk score
- Larger zones: *This gives SPR information for a larger proportion of their forested parks*
- Zones that are adjacent to other SPR forested park zones: *This allows larger contiguous park areas to be managed together*
- Zones that are likely to have a lower Tree-iage score: *These zones will be better candidates for restoration action*

2. How to Measure Success

There are two main ways to measure the success of management activities in the park zones: recollecting data and using LiDAR.

Re-Collecting Data

Re-collecting the plot data, ideally using the same plots from prior data collection, is good for empirically seeing how the forest has changed since management actions. Re-measuring the plots and comparing the results, such as trees per acre, basal area per acre, average diameter, species composition, and others, will show directly how a zone has moved from its initial forest type to the target forest type. A good example would be comparing current conditions data of a red alder and bigleaf maple dominated zone, to the data collected after management actions to transition the zone to a mixed conifer-dominated forest. The data would explicitly show a difference species mix, tree size and density. That follow-up data can be used to track the success of the transition to the target forest type of that zone.

LiDAR

Comparing LiDAR through time provides a high-level view of changes in the canopy structure, and although it cannot provide specifics on species mix, it does directly show the height and coverage of vegetation and helps infer tree density. Using the same zone transition example as above, a subsequent LiDAR data set would show a canopy that is much more open and shorter than the current conditions LiDAR. Depending on the spatial variability of the data, the LiDAR can also show areas where the management was more successful and areas where it was less successful. The LiDAR can be used to target areas that need subsequent treatments in order to realize a more complete transition to the target forest type.

Future LiDAR analysis should consider simplifying ESCs into four classes rather than seven: combine 1 and 2, 3 and 4, 5 and 6, and leave 7 its own class. While there are structural differences among the classes, management recommendations tend to address these ECSs in pairs since they are more similar ecologically than they are different.

X. GLOSSARY

Basal Area	**BA** - The cross-sectional area of a tree at breast height (4.5 feet from the ground). BA is also used to mean basal area per acre (BAPA or BA/Ac).
Canopy Class	The dominant overstory tree type by percent canopy cover: broadleaf, conifer, or mixed broadleaf and conifer.
Canopy Type	Canopy Class further subdivided by the dominant species, for example Broadleaf-ACMA for the Broadleaf Canopy Class that has bigleaf maple as the most common species by percent canopy cover.
Forest Type	Cover Type – Ecological Structure Class combinations. For example, Broadleaf-ACMA-2 id broadleaf-dominated, has bigleaf maple as the most common species by percent canopy cover, and has a structure class of 2.
Coarse Woody Debris	**CWD** – Large-diameter dead wood on the ground.
Cohort	A group of trees that established at the same time, typically after disturbance such as clearcut logging, fire, or blow down.
Diameter at Standard Height	**DSH** – Tree diameter at 4.5 feet from the ground on the uphill side of the tree. This is the standard for tree diameter measurements. Also commonly called DBH for diameter at breast height.
Dominant	An individual or set of trees whose crowns occupy the upper position of the canopy.
Emergent	Trees that break through (emerge) from the canopy of dominant trees in a stand.
Forest System	A classification of a forest that may incorporate a number of different factors such as dominant species, soil types, shrubs, and other characteristics
Green Wildlife Tree	A live tree that provides good wildlife habitat, such as cavities on the truck, large branches, or complex canopy structure.
Hazard Tree	Hazard trees include dead trees, trees that are clearly stressed due to disease or damage, trees with weakly connected branches, tops or stems, and any other tree that poses the increased risk of falling and damaging property or injuring people.
Height to Diameter Ratio	**HDR** - Tree height divided by tree DBH, and indicates the competitive conditions in which a tree developed. High HDRs, where trees are very tall relative to their girth, indicate trees that grew in crowded conditions, allocating energy to height. Open-grown trees tend to have low HDRs. High HDRs correlate to increased risk of windthrow.
Live Crown Ratio	**LCR** - The ratio of live canopy to the total height of the tree. For example, if a 100' tall tree has a live crown in the top 45' and bare trunk for the remaining 55', the tree has a live crown ratio of .45 or 45%. Crown ratios of .5 and greater are considered healthy; ratios of less than .3 are very unhealthy. This may also be expressed as the percent live crown.

Patch	A patch is an area within a stand. Patches typically call out a distinction in forest type that is at too fine of a scale to be considered its own stand.
Park	An area of land owned by the City of Seattle that is developed and maintained for the purposes of public recreation.
Quadratic Mean Diameter	**QMD** - A calculation of the diameter of the statistical tree with average basal area.
Relative Density	**RD** - Basal area divided by the square root of the QMD, and indicates the proportion of biomass relative to a theoretical maximum biomass of 100.
Release	A method of thinning where surrounding trees are removed from a desired tree, with the intention of increasing the released tree's health and vigor.
Stand	A grouping of trees into a logical management unit typically based on consistency in factors such as species composition, age, topography, aspect, disturbance history, or natural or artificial boundaries like a river or a road. Can be used interchangeably with "unit."
Ecological Structure class	**ESC -** Classification system in which similar forests are groups based on structure elements including being dominated by broadleaf or conifer species, or a mix of the two, and the primary tree species by basal area.
Thin	To harvest a portion of the trees in a stand. Harvest may or may not include sale or profit from trees.
Thin from Below	A method of thinning where the smallest trees in terms of diameter or height are removed, leaving the biggest and typically healthiest trees.
Trees Per Acre	**TPA** - The average number of trees per acre calculated from a sample of plots within the stand.
Unit	A specific forestry management unit typically based on consistency in factors such as species composition, age, topography, aspect, disturbance history, or natural or artificial boundaries like a river or a road. Generally interchangeable with "stand."
Variable Density Thin	**VDT** - A method of harvest based on the retention of trees in patterns other than regular spacing, involving patchy or irregular distribution of retention trees.
Windthrow	Wind-caused tree mortality due to toppling or snapping.
Zone	A subdivision of a park organized as a management unit.

XI. APPENDICES

1. Appendix 1: Comparison of GNN to Measured Data

We investigated the accuracy of GNN data for this application. GNN data is typically used for landscape – scale analyses. This application tested GNN data at scales finer than the intended use. We hypothesized that using GNN data at its coarsest level of detail (Conifer, Mix, and Broadleaf classes) would result in sufficient quality for fine-scale applications.

This analysis compared the canopy cover classification where both GNN and field-measured inventory assessment data sets exist, totaling 1,512 acres of GPS parks. Data sources with "Measured" indicates the canopy cover class from field-measured inventory assessment data. "GNN" indicates the GNN canopy cover classification.

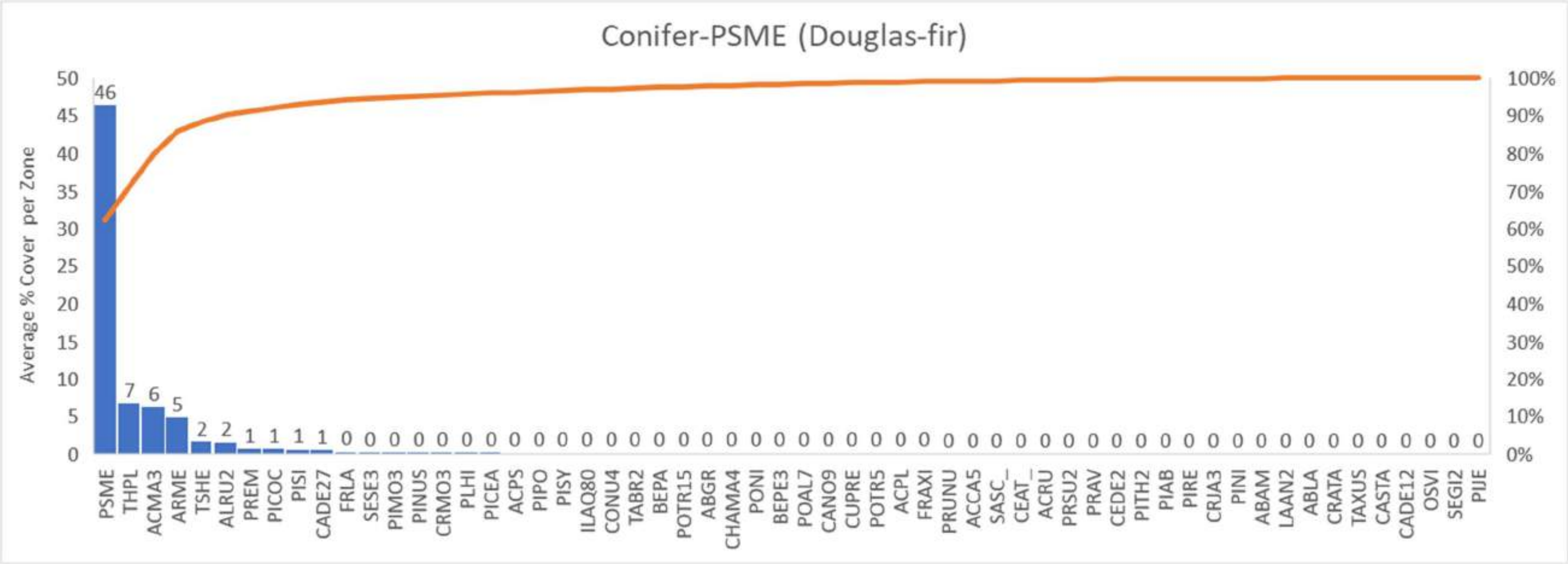
Appendix A Table 1: Measured and GNN-derived canopy cover for 1,512 acres of forested Seattle Parks.

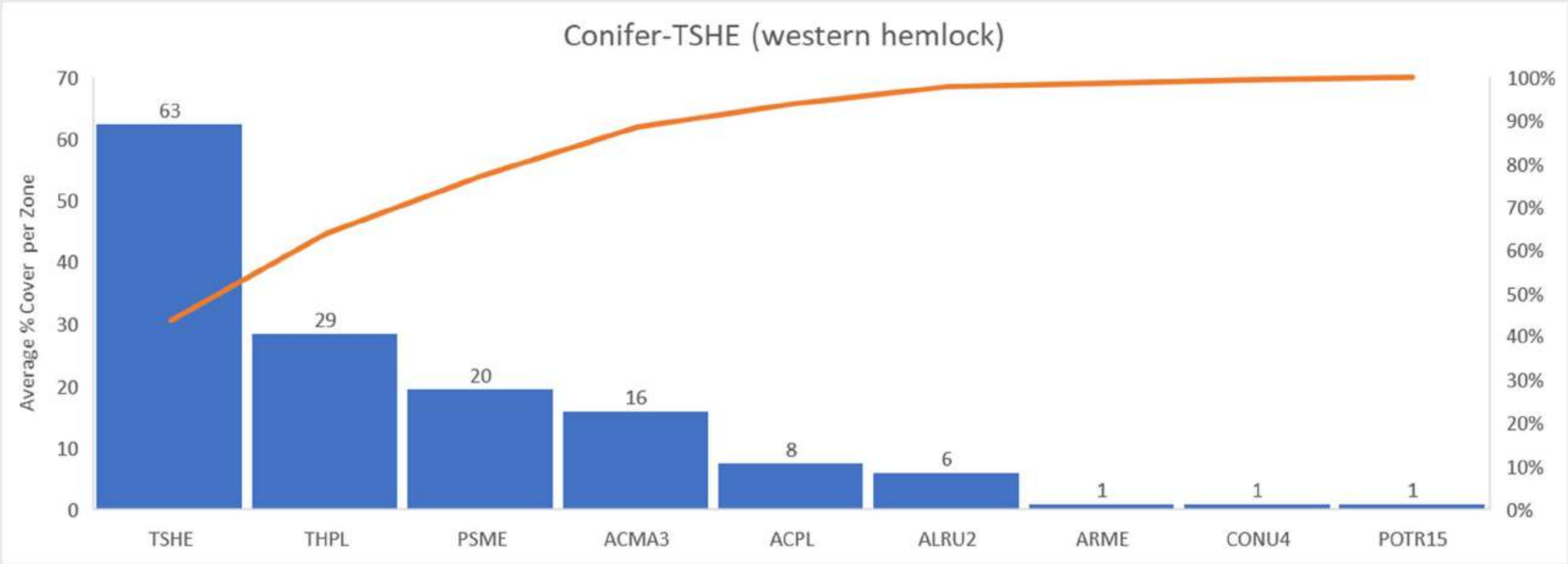
Canopy Cover	Data Source	Zones	Acres	% of Acres
Broadleaf	*Measured*	524	1,040	69%
Broadleaf	*GNN*	49	67	4%
Mix	*Measured*	127	331	22%
Mix	*GNN*	439	1,028	68%
Conifer	*Measured*	60	141	9%
Conifer	*GNN*	223	417	28%
Total		**711**	**1,512**	**100%**

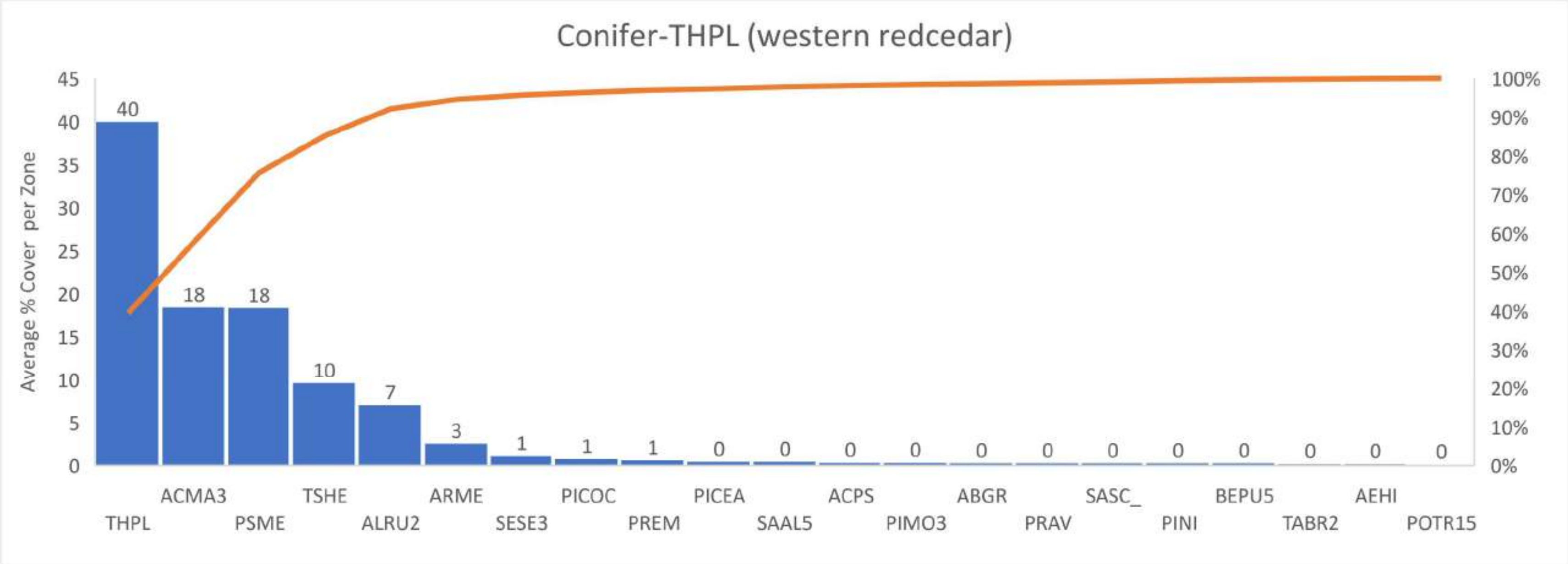
Assuming field-observed measurements are more accurate than satellite-derived classifications, GNN greatly under-classifies broadleaf forest, instead designating it mixed forest. As a result, mixed forest is overcalculated in GNN. GNN somewhat overcalculates conifer forest. The magnitude of these differences and the likelihood of misclassification using GNN data led us to not use the GNN data for this Report.

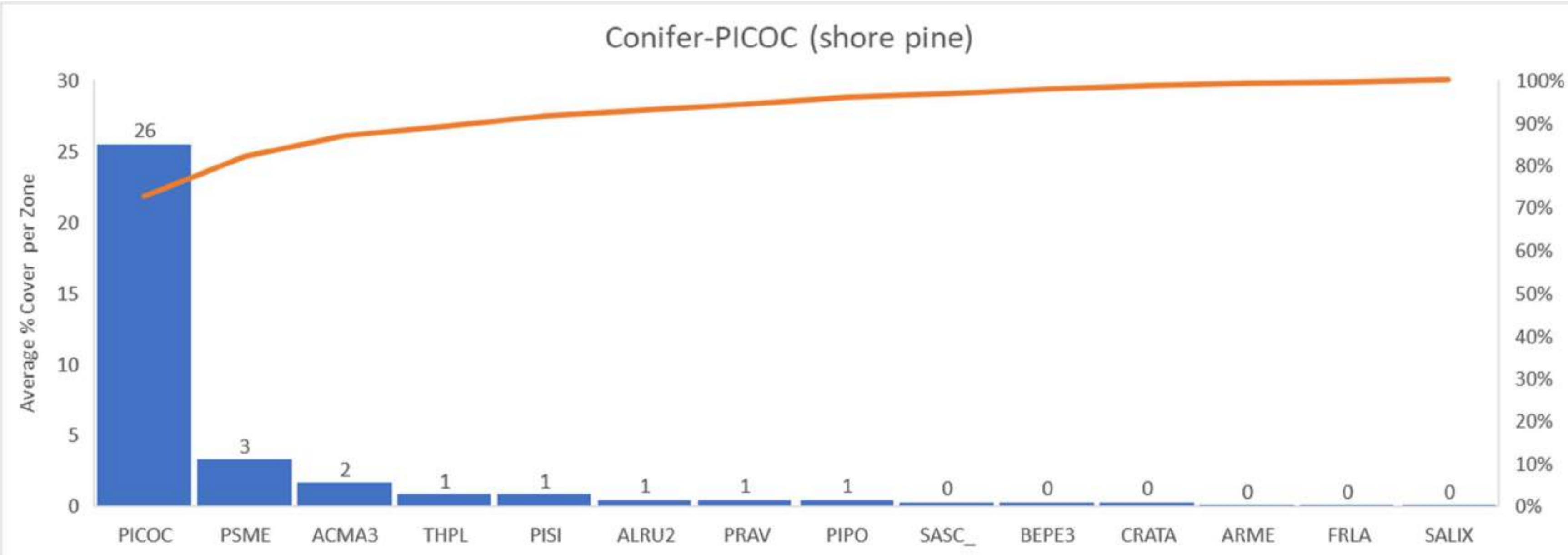
2. Appendix 2: Species Distribution Curves of Canopy Cover Types

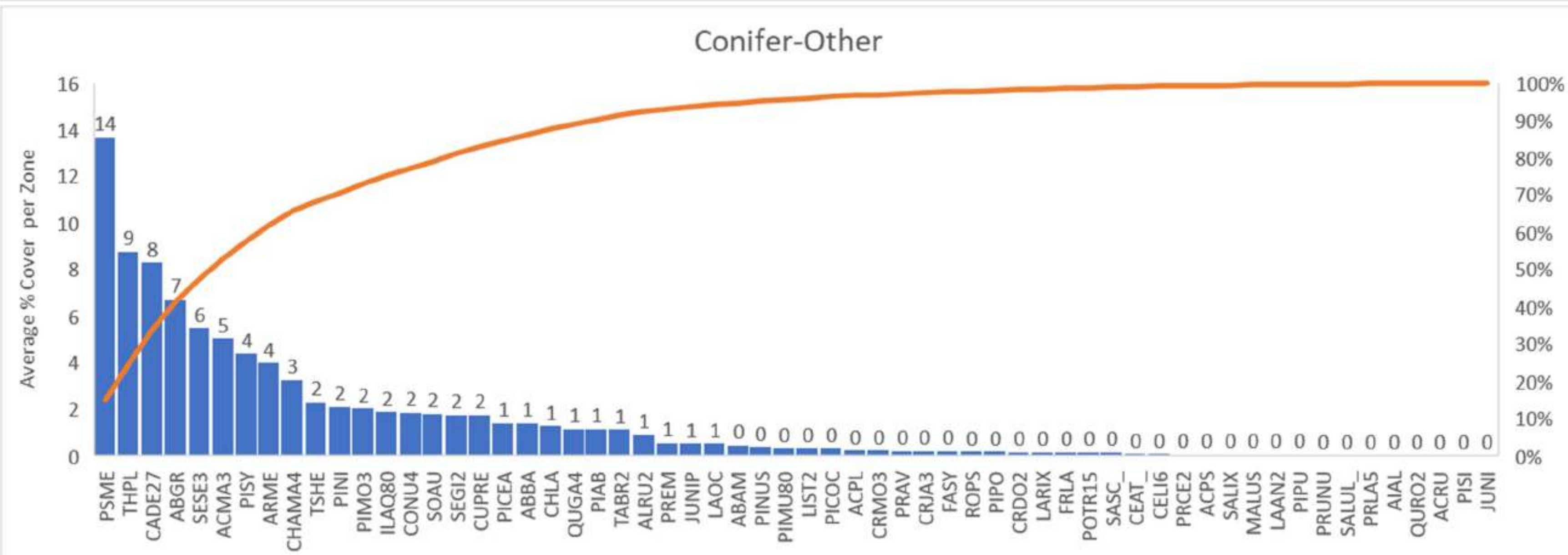
The following graphs show the average percent cover of all species present in Inventory data for each canopy cover type. The blue bars in the chart show the average percent cover for each tree species for the canopy cover class indicated in the chart title. Data labels of 0 indicate species that are present, but average less than one percent canopy cover. Inventory assessment procedures allow percent cover to exceed 100% where canopy layers overlap. Only species that were present are included in each chart. The red line shows the cumulative percent cover.

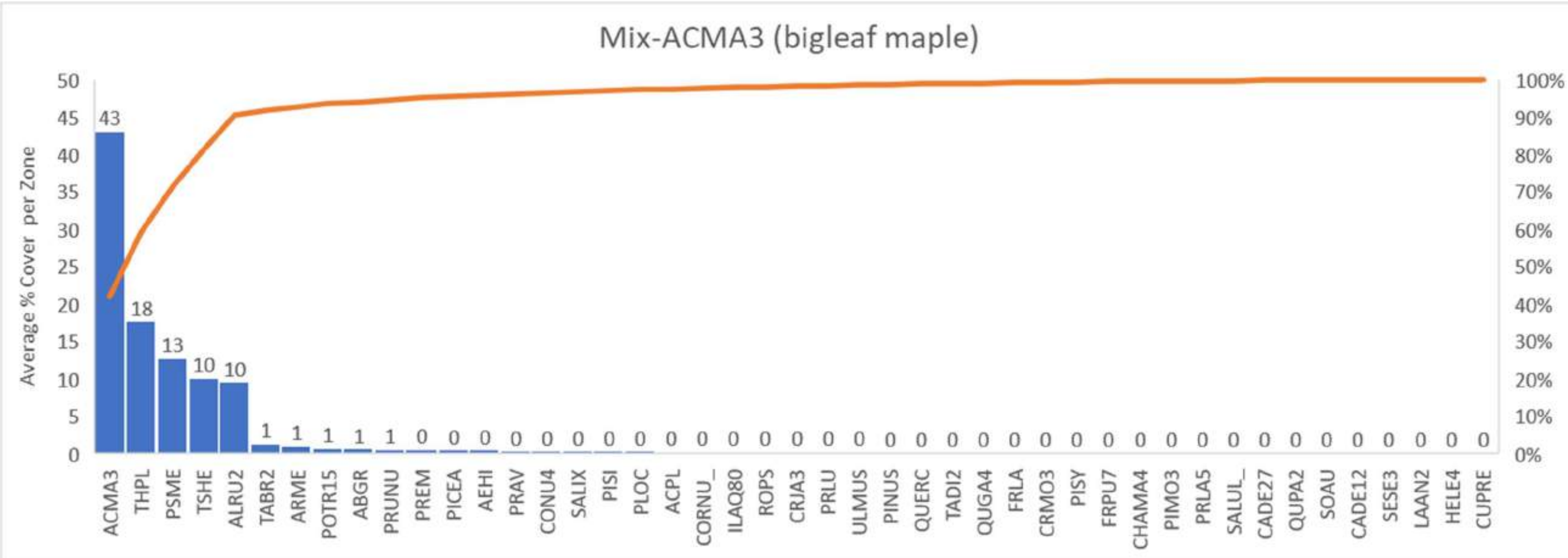


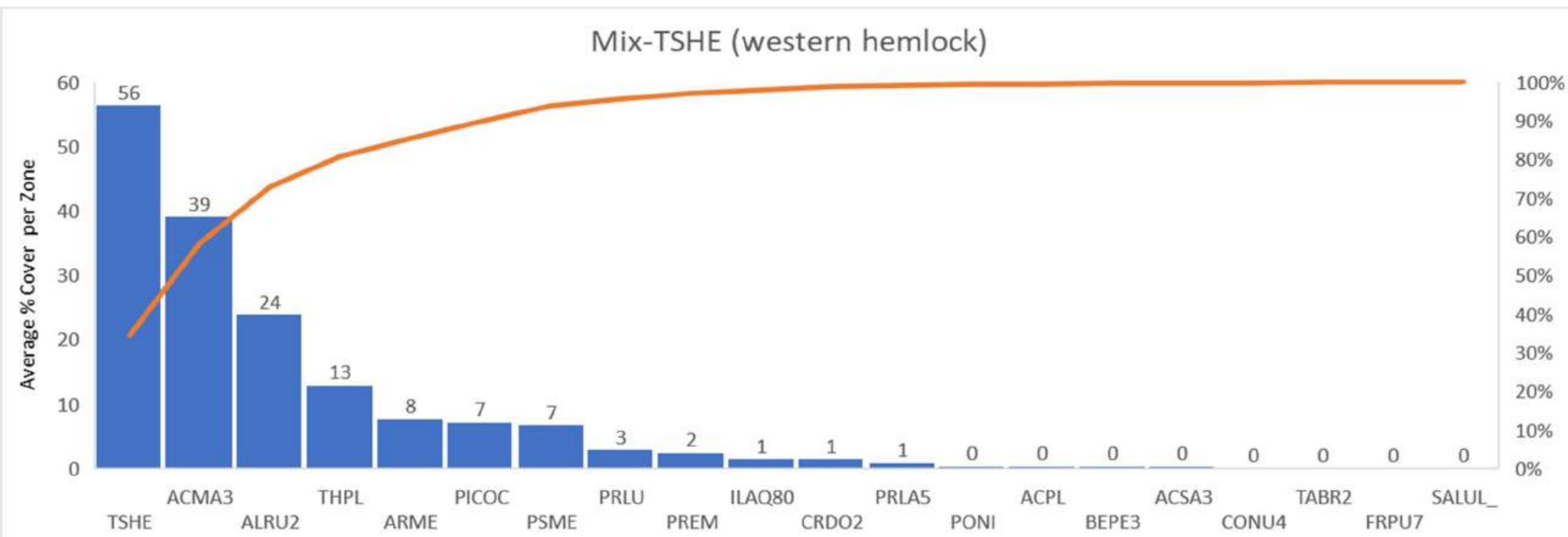

Conifer-TSHE (western hemlock)
Average % Cover per Zone
70
60
50
40
30
20
10
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
63
29
20
16
8
6
1
1
1
TSHE
THPL
PSME
ACMA3
ACPL
ALRU2
ARME
CONU4
POTR15

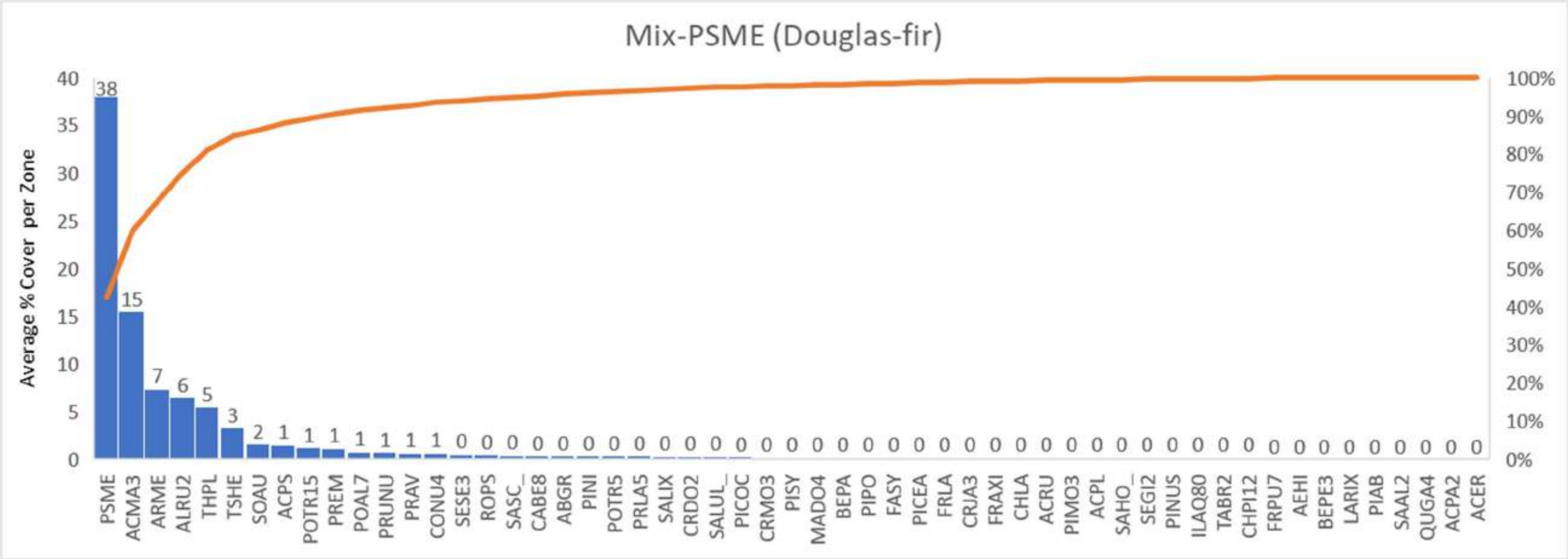

Conifer-THPL (western redcedar)
Average % Cover per Zone
45
40
35
30
25
20
15
10
5
0
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
40
18
18
10
7
3
1
1
1
0
0
0
0
0
0
0
0
0
0
0
0
THPL
ACMA3
PSME
TSHE
ALRU2
ARME
SESE3
PICOC
PREM
PICEA
SAAL5
ACPS
PIMO3
ABGR
PRAV
SASC_
PINI
BEPU5
TABR2
AEHI
POTR15

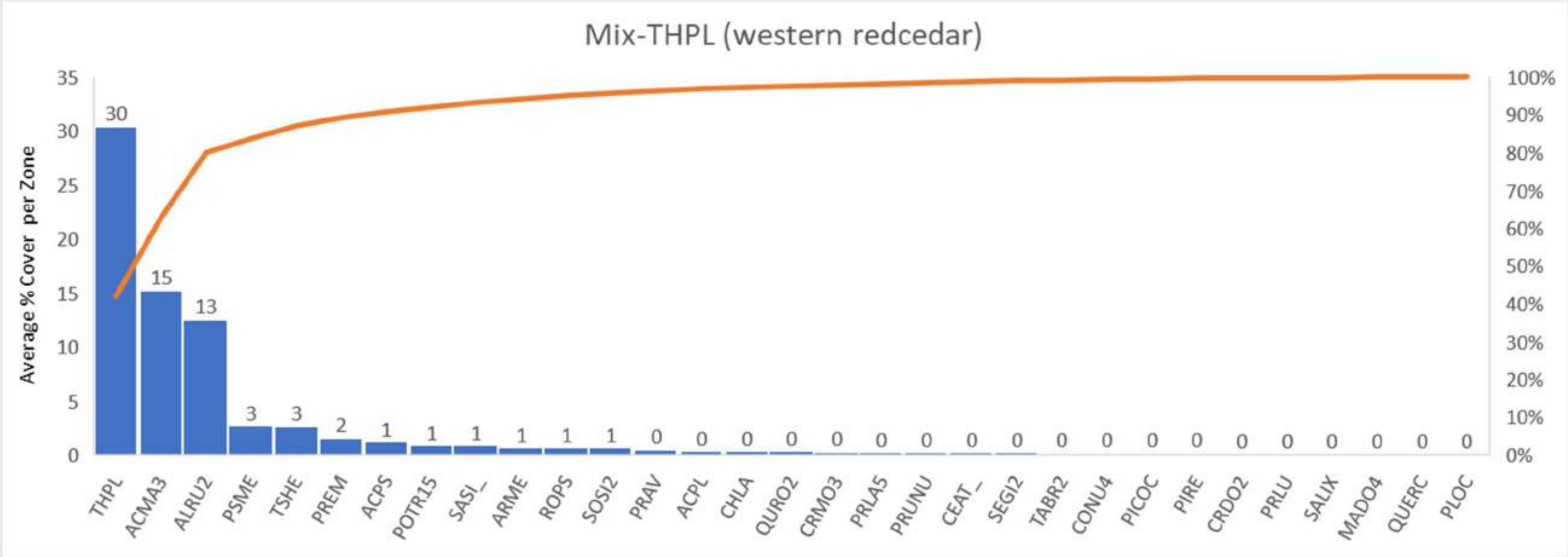

Conifer-PICOC (shore pine)
Average % Cover per Zone
26
3
2
1
1
1
1
1
0
0
0
0
0
0
PICOC
PSME
ACMA3
THPL
PISI
ALRU2
PRAV
PIPO
SASC_
BEPE3
CRATA
ARME
FRLA
SALIX

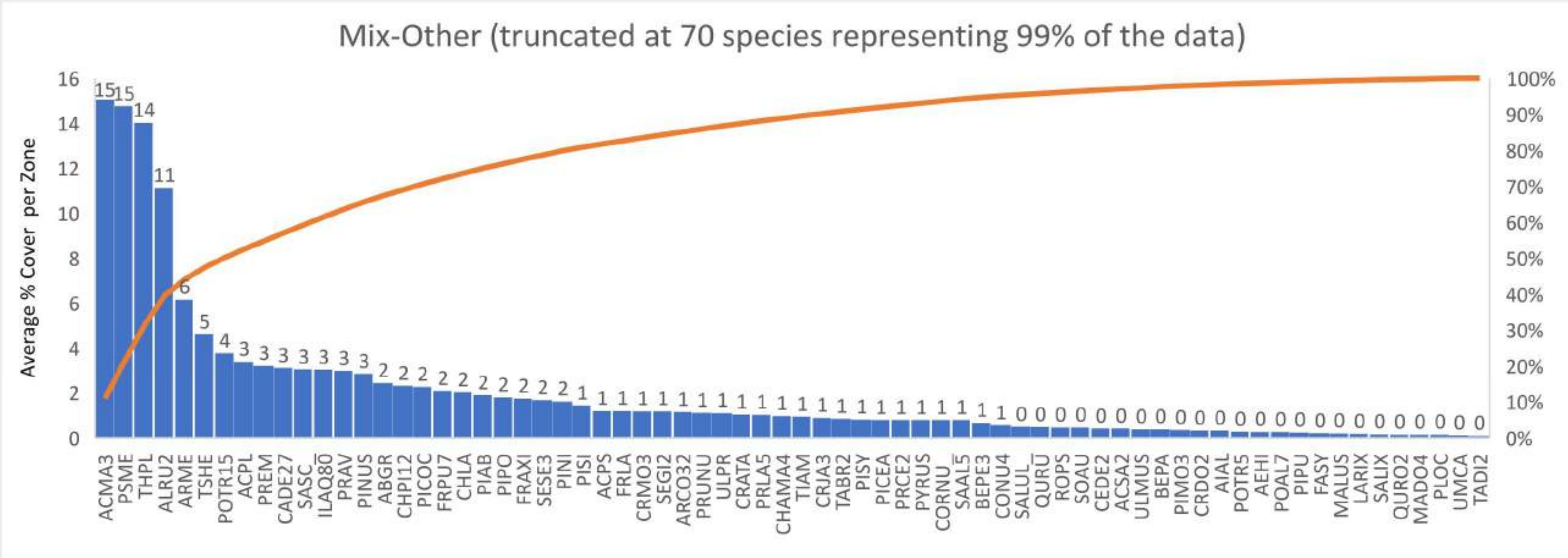

Conifer-Other
Average % Cover per Zone
PSME
THPL
CADE27
ABGR
SESE3
ACMA3
PISY
ARME
CHAMA4
TSHE
PINI
PIMO3
ILAQ80
CONU4
SOAU
SEGI2
CUPRE
PICEA
ABBA
CHLA
QUGA4
PIAB
TABR2
ALRU2
PREM
JUNIP
LAOC
ABAM
PINUS
PIMU80
LIST2
PICOC
ACPL
CRMO3
PRAV
CRJA3
FASY
ROPS
PIPO
CRDO2
LARIX
FRLA
POTR15
SASC_
CEAT_
CELI6
PRCE2
ACPS
SALIX
MALUS
LAAN2
PIPU
PRUNU
SALUL_
PRLA5
AIAL
QURO2
ACRU
PISI
JUNI

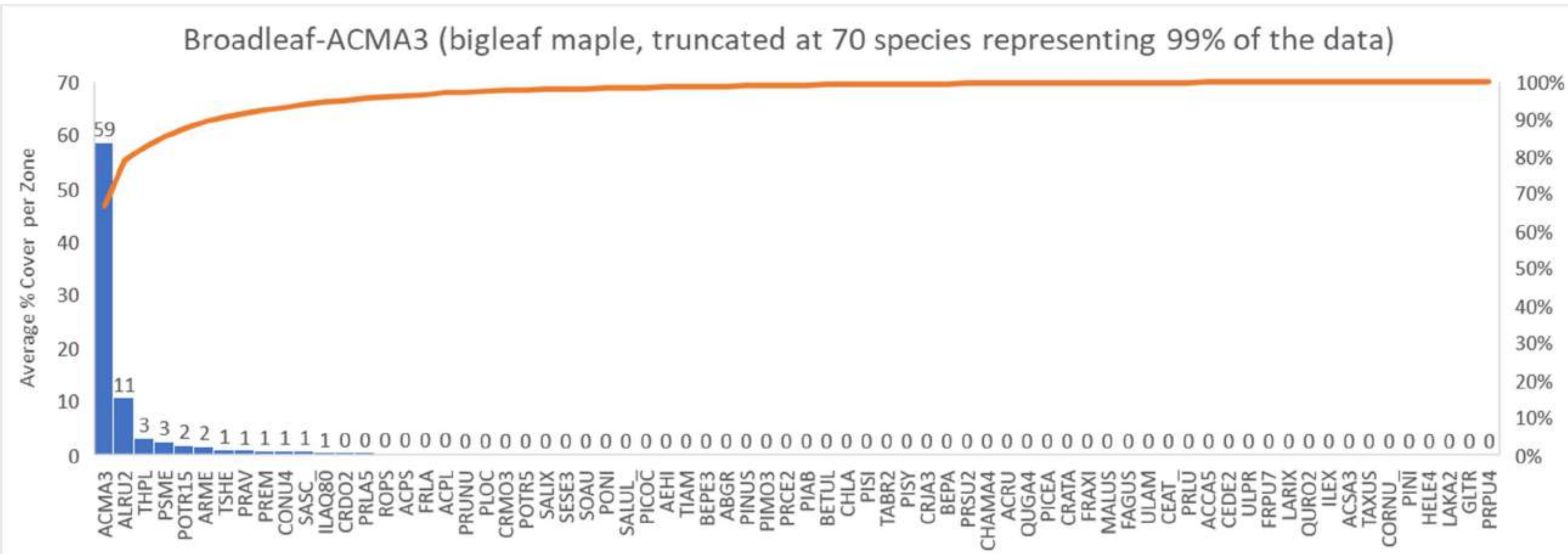

Mix-ACMA3 (bigleaf maple)
Average % Cover per Zone
43
18
13
10
10
ACMA3
THPL
PSME
TSHE
ALRU2
TABR2
ARME
POTR15
ABGR
PRUNU
PREM
PICEA
AEHI
PRAV
CONU4
SALIX
PISI
PLOC
ACPL
CORNU_
ILAQ80
ROPS
CRJA3
PRLU
ULMUS
PINUS
QUERC
TADI2
QUGA4
FRLA
CRMO3
PISY
FRPU7
CHAMA4
PIMO3
PRLA5
SALUL_
CADE27
QUPA2
SOAU
CADE12
SESE3
LAAN2
HELE4
CUPRE

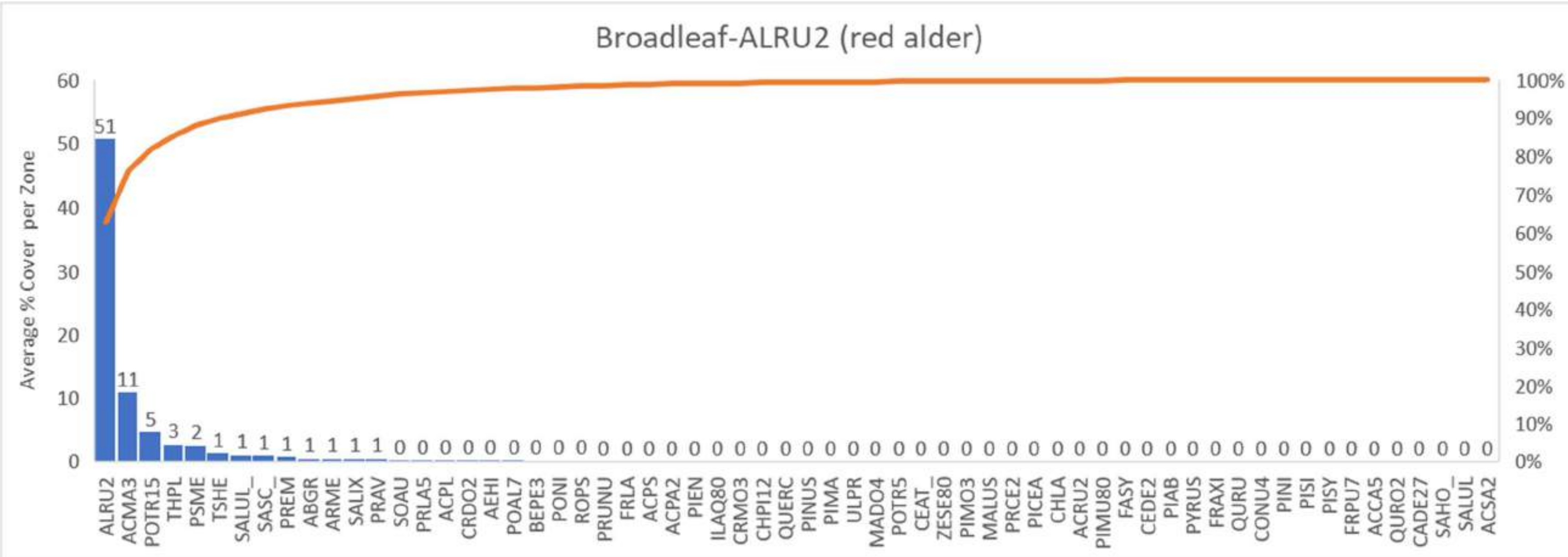

Mix-TSHE (western hemlock)
Average % Cover per Zone
56
39
24
13
8
7
7
3
2
1
1
1
TSHE
ACMA3
ALRU2
THPL
ARME
PICOC
PSME
PRLU
PREM
ILAQ80
CRDO2
PRLA5
PONI
ACPL
BEPE3
ACSA3
CONU4
TABR2
FRPU7
SALUL_

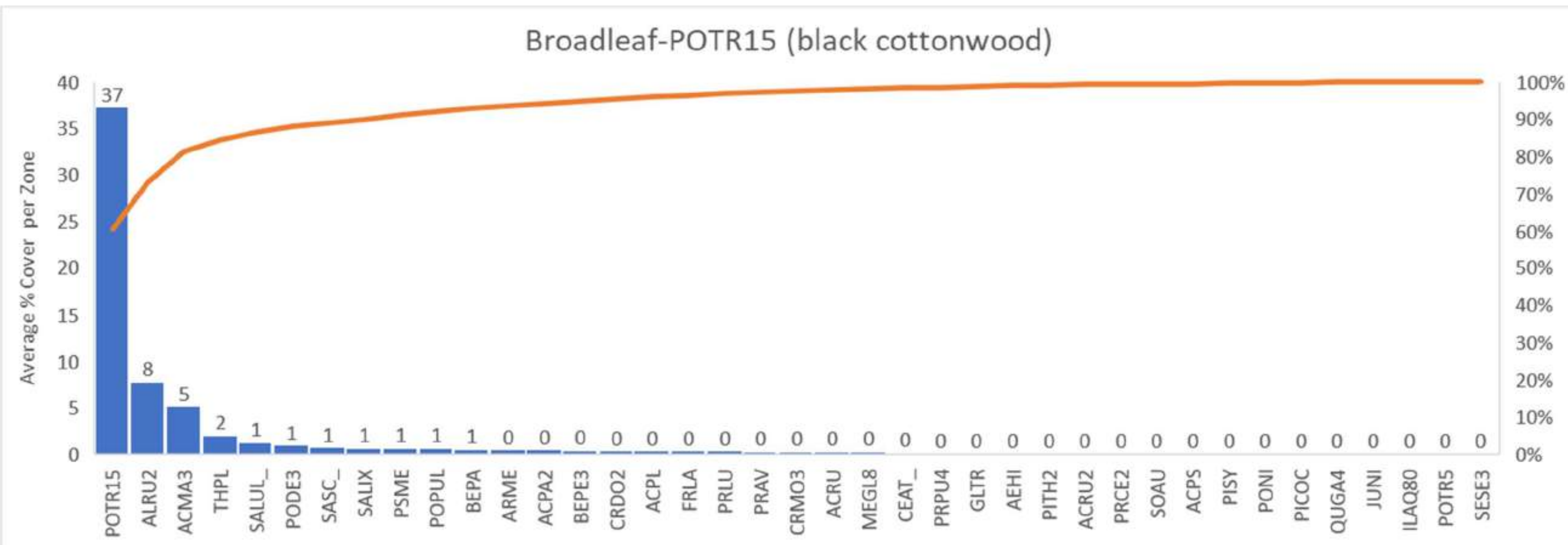

Mix-PSME (Douglas-fir)
Average % Cover per Zone
38
15
7
6
5
3
2
PSME
ACMA3
ARME
ALRU2
THPL
TSHE
SOAU
ACPS
POTR15
PREM
POAL7
PRUNU
PRAV
CONU4
SESE3
ROPS
SASC_
CABE8
ABGR
PINI
POTR5
PRLA5
SALIX
CRDO2
SALUL_
PICOC
CRMO3
PISY
MADO4
BEPA
PIPO
FASY
PICEA
FRLA
CRJA3
FRAXI
CHLA
ACRU
PIMO3
ACPL
SAHO_
SEGI2
PINUS
ILAQ80
TABR2
CHPI12
FRPU7
AEHI
BEPE3
LARIX
PIAB
SAAL2
QUGA4
ACPA2
ACER

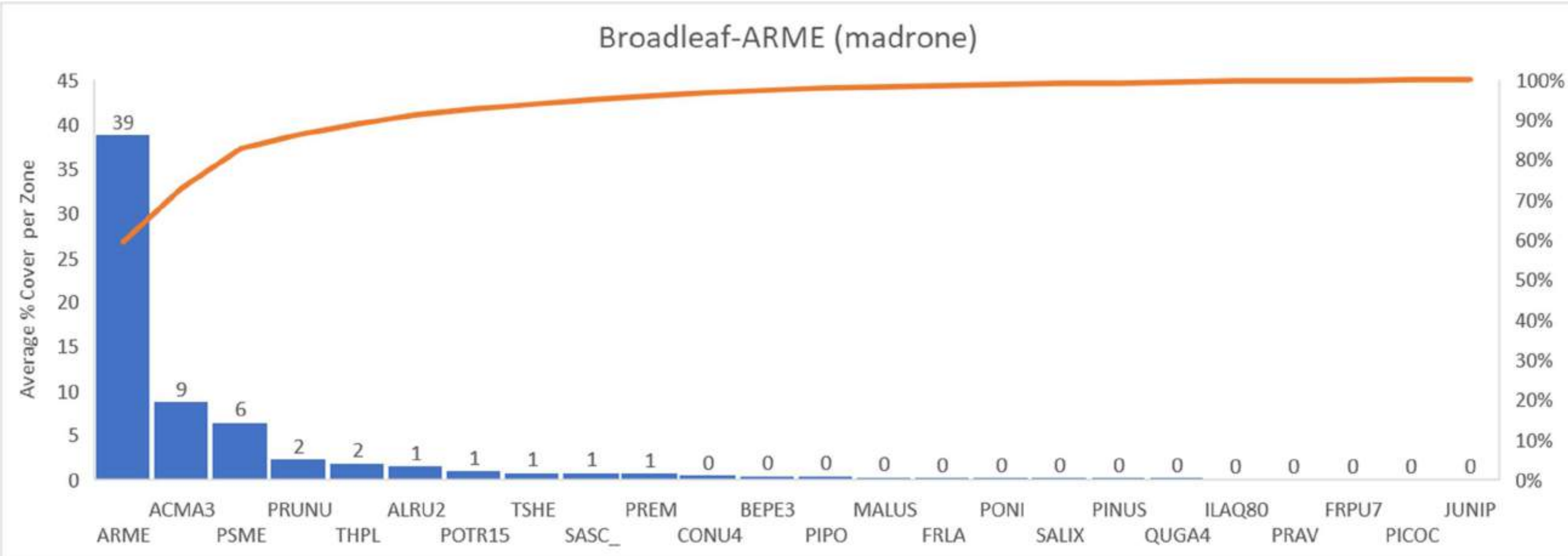

Mix-THPL (western redcedar)
Average % Cover per Zone
30
15
13
3
3
2
THPL
ACMA3
ALRU2
PSME
TSHE
PREM
ACPS
POTR15
SASI_
ARME
ROPS
SOSI2
PRAV
ACPL
CHLA
QURO2
CRMO3
PRLA5
PRUNU
CEAT_
SEGI2
TABR2
CONU4
PICOC
PIRE
CRDO2
PRLU
SALIX
MADO4
QUERC
PLOC

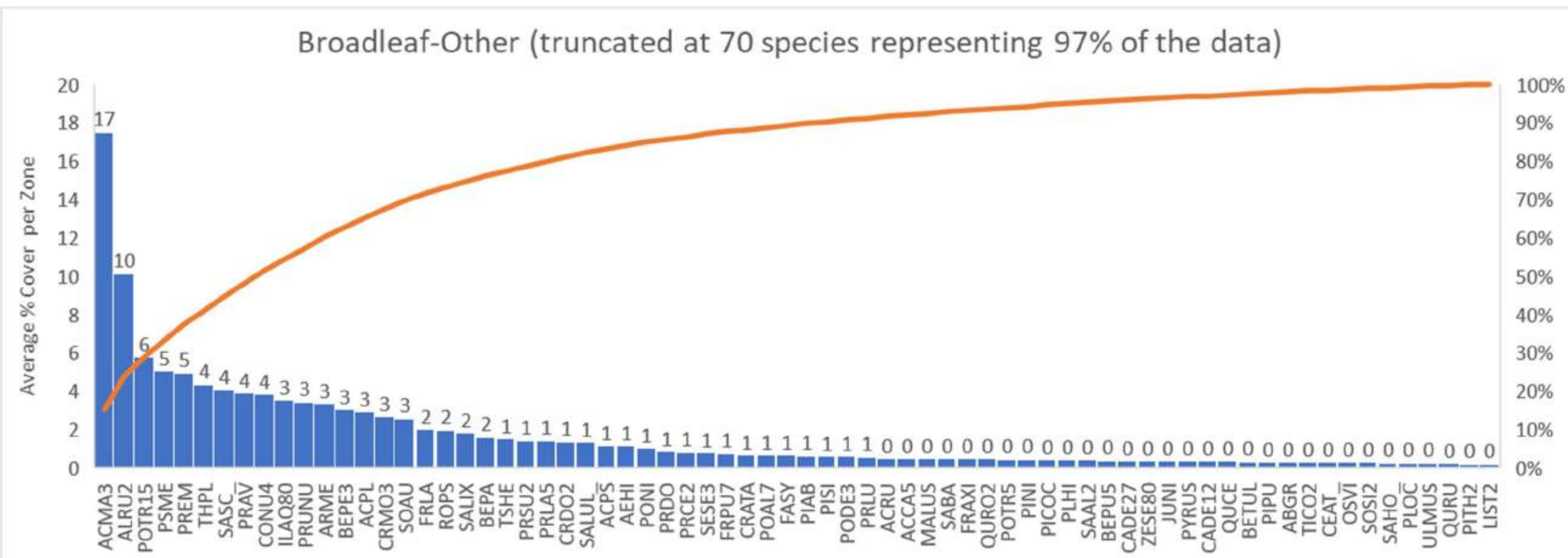

Mix-Other (truncated at 70 species representing 99% of the data)
Average % Cover per Zone


Broadleaf-ACMA3 (bigleaf maple, truncated at 70 species representing 99% of the data)
Average % Cover per Zone


Broadleaf-ALRU2 (red alder)
Average % Cover per Zone
0
10
20
30
40
50
60
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
51
11
5
3
2
ALRU2
ACMA3
POTR15
THPL
PSME
TSHE
SALUL_
SASC_
PREM
ABGR
ARME
SALIX
PRAV
SOAU
PRLA5
ACPL
CRDO2
AEHI
POAL7
BEPE3
PONI
ROPS
PRUNU
FRLA
ACPS
ACPA2
PIEN
ILAQ80
CRMO3
CHPI12
QUERC
PINUS
PIMA
ULPR
MADO4
POTR5
CEAT_
ZESE80
PIMO3
MALUS
PRCE2
PICEA
CHLA
ACRU2
PIMU80
FASY
CEDE2
PIAB
PYRUS
FRAXI
QURU
CONU4
PINI
PISI
PISY
FRPU7
ACCA5
QURO2
CADE27
SAHO_
SALUL
ACSA2

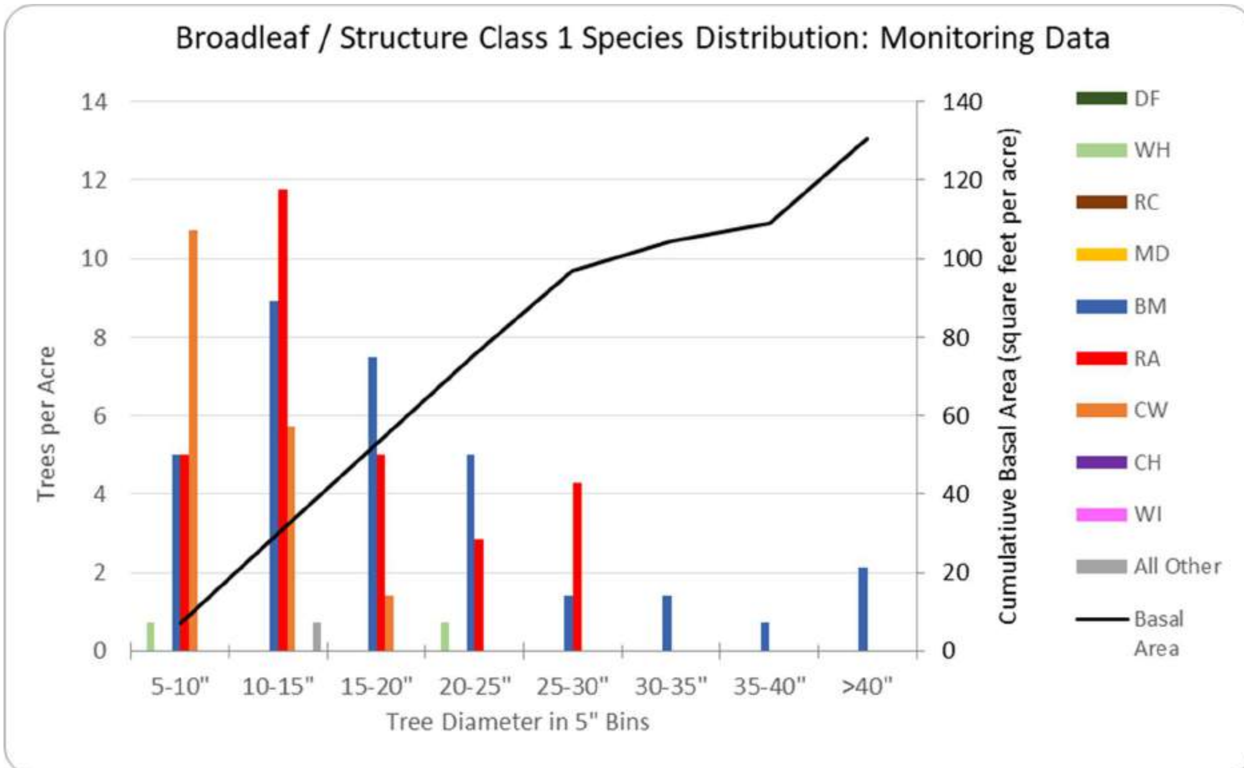

Broadleaf-POTR15 (black cottonwood)
Average % Cover per Zone
0
5
10
15
20
25
30
35
40
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
37
8
5
2
POTR15
ALRU2
ACMA3
THPL
SALUL_
PODE3
SASC_
SALIX
PSME
POPUL
BEPA
ARME
ACPA2
BEPE3
CRDO2
ACPL
FRLA
PRLU
PRAV
CRMO3
ACRU
MEGL8
CEAT_
PRPU4
GLTR
AEHI
PITH2
ACRU2
PRCE2
SOAU
ACPS
PISY
PONI
PICOC
QUGA4
JUNI
ILAQ80
POTR5
SESE3

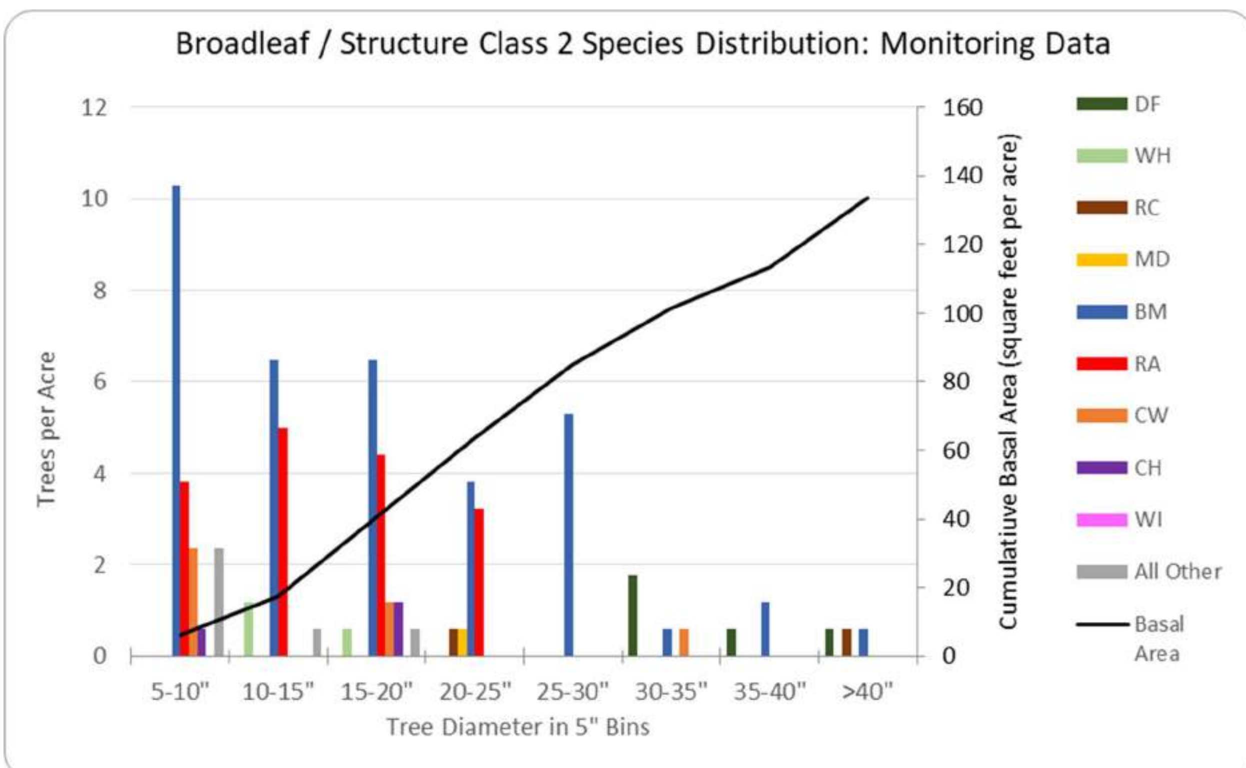

Broadleaf-ARME (madrone)
Average % Cover per Zone
ARME ACMA3 PSME PRUNU THPL ALRU2 POTR15 TSHE SASC_ PREM CONU4 BEPE3 PIPO MALUS FRLA PONI SALIX PINUS QUGA4 ILAQ80 PRAV FRPU7 PICOC JUNIP

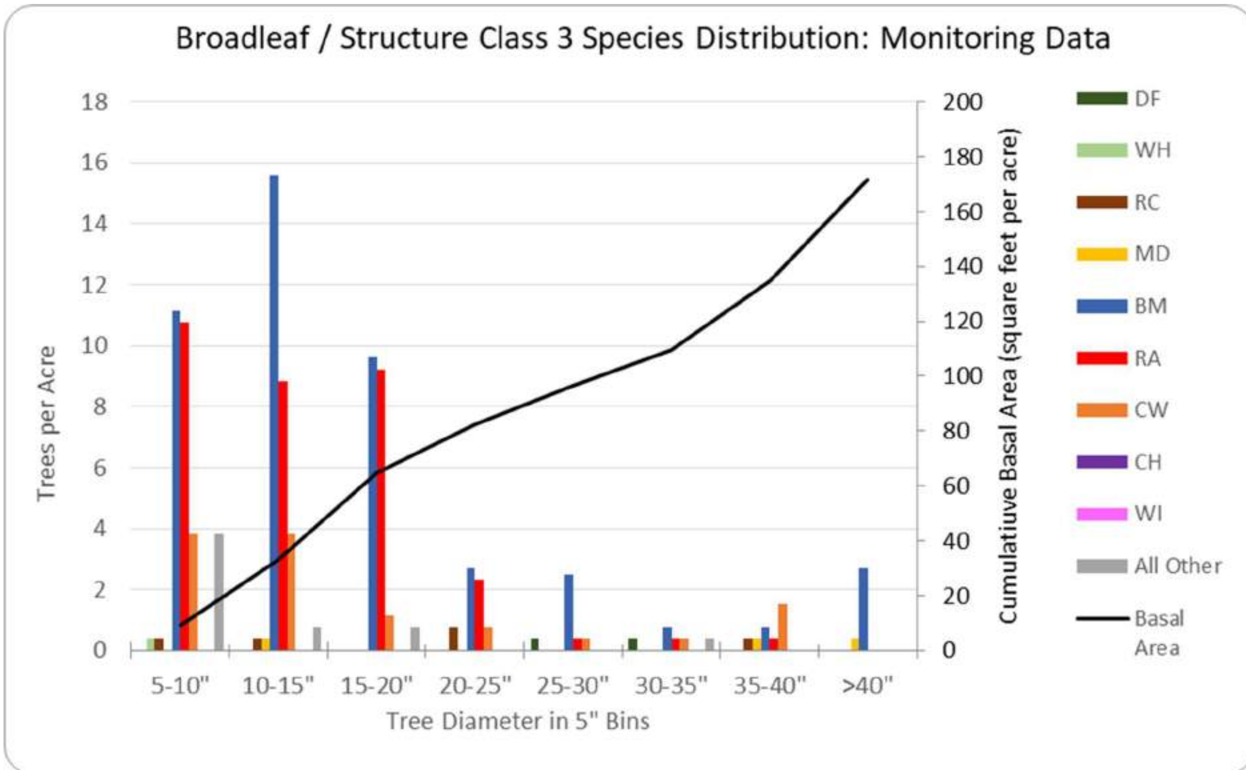

Broadleaf-Other (truncated at 70 species representing 97% of the data)
Average % Cover per Zone
ACMA3 ALRU2 POTR15 PSME PREM THPL SASC_ PRAV CONU4 ILAQ80 PRUNU ARME BEPE3 ACPL CRMO3 SOAU FRLA ROPS SALIX BEPA TSHE PRSU2 PRLA5 CRDO2 SALUL_ ACPS AEHI PONI PRDO PRCE2 SESE3 FRPU7 CRATA POAL7 FASY PIAB PISI PODE3 PRLU ACRU ACCA5 MALUS SABA FRAXI QURO2 POTR5 PINI PICOC PLHI SAAL2 BEPU5 CADE27 ZESE80 JUNI PYRUS CADE12 QUCE BETUL PIPU ABGR TICO2 CEAT_ OSVI SOSI2 SAHO_ PLOC ULMUS QURU PITH2 LIST2

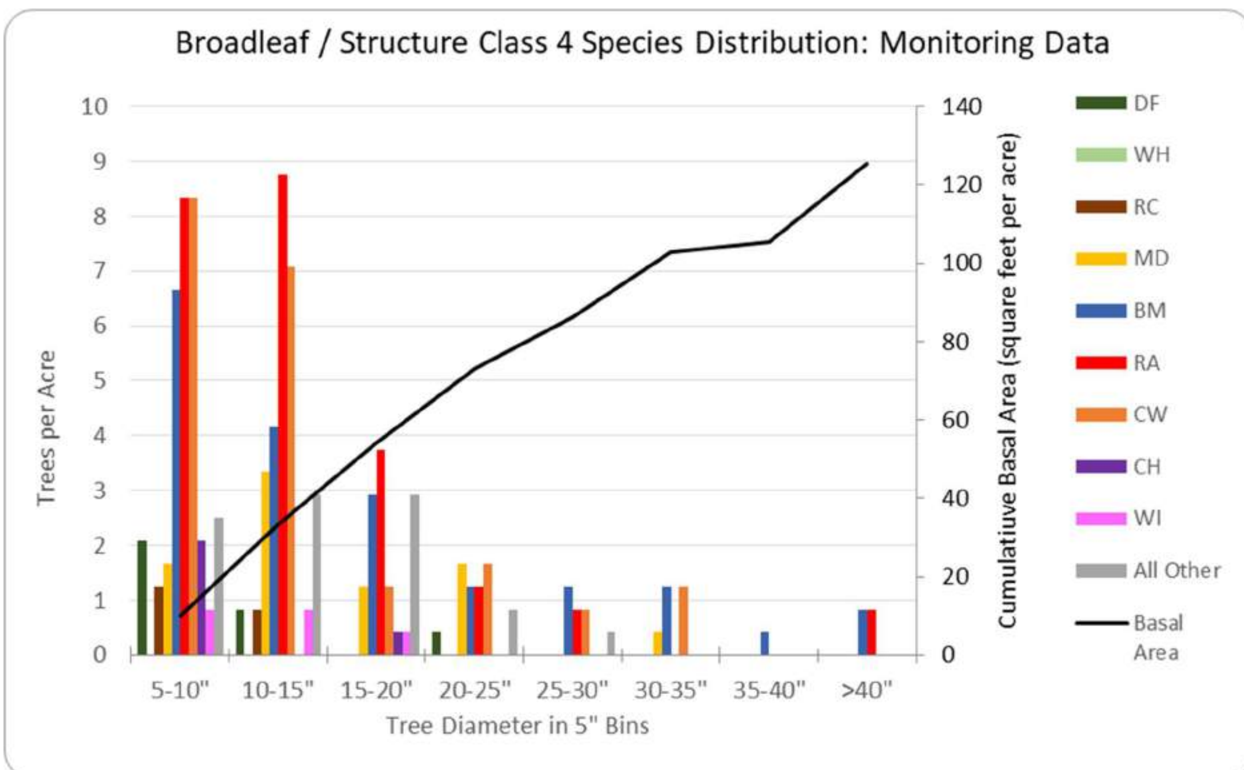
3. Appendix 3: Monitoring Plot Data Summaries

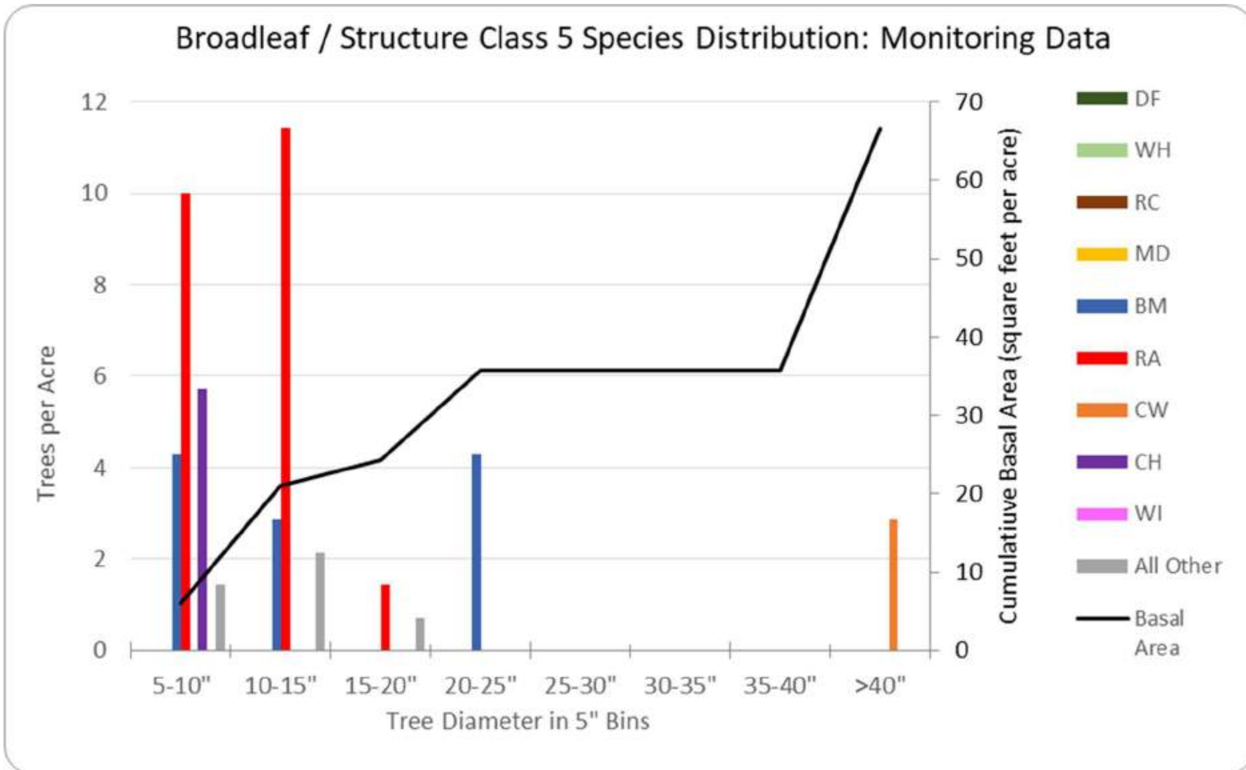
a. Tree Size and Basal Area Distributions for Monitoring Plot Canopy and Structure Classes



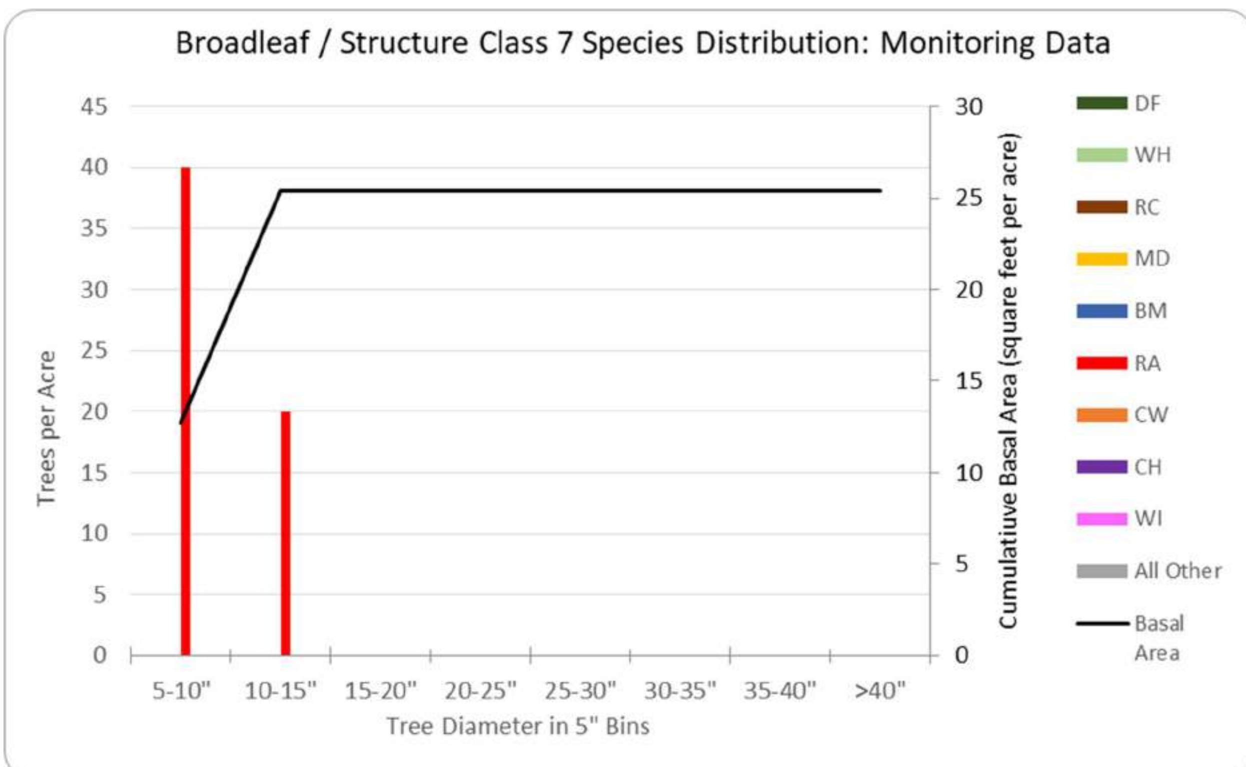


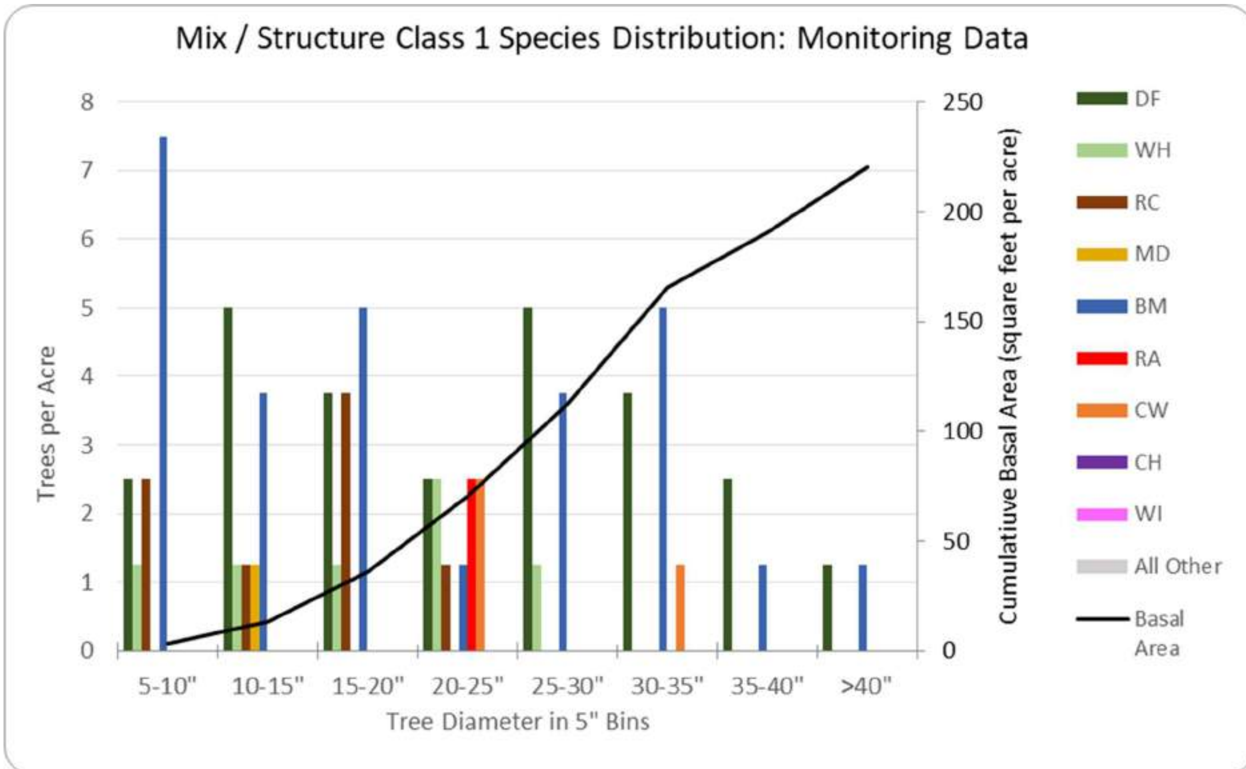

Broadleaf / Structure Class 3 Species Distribution: Monitoring Data
Trees per Acre
0
2
4
6
8
10
12
14
16
18
Cumulatiuve Basal Area (square feet per acre)
0
20
40
60
80
100
120
140
160
180
200
5-10"
10-15"
15-20"
20-25"
25-30"
30-35"
35-40"
>40"
Tree Diameter in 5" Bins
DF
WH
RC
MD
BM
RA
CW
CH
WI
All Other
Basal Area

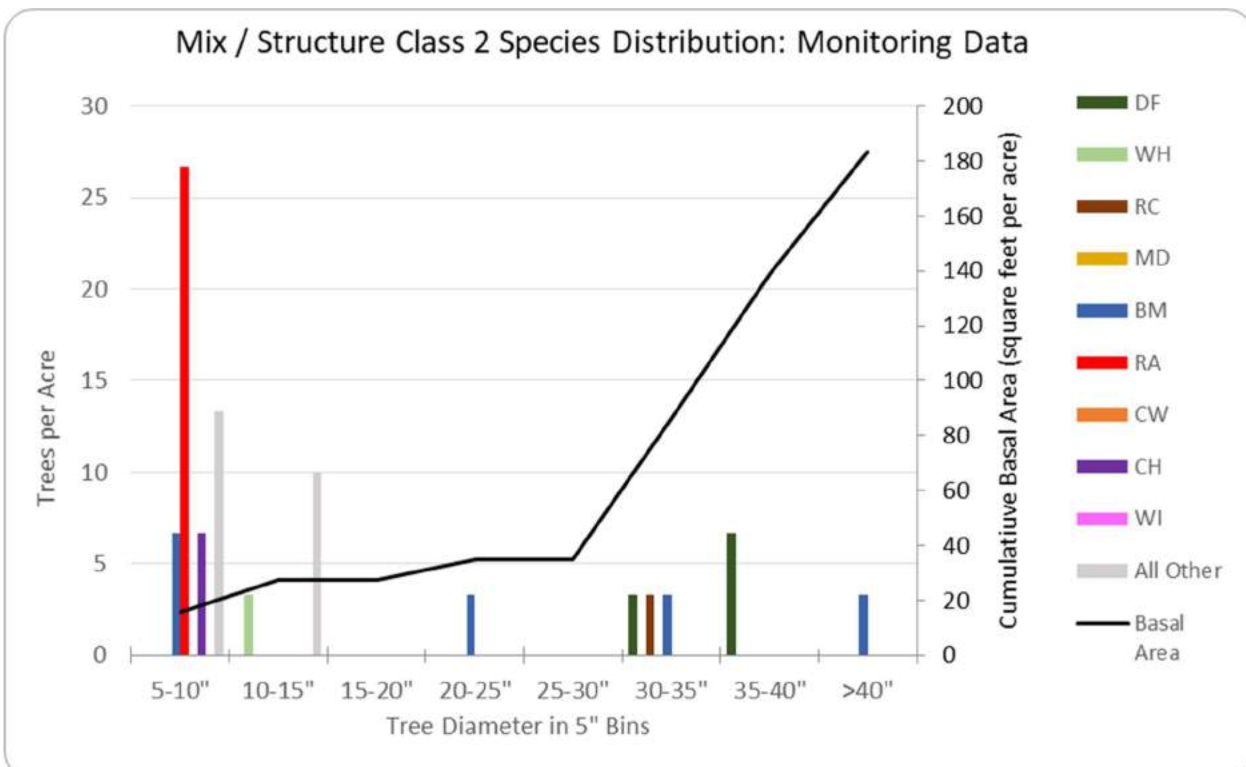

Broadleaf / Structure Class 4 Species Distribution: Monitoring Data
Trees per Acre
0
1
2
3
4
5
6
7
8
9
10
Cumulatiuve Basal Area (square feet per acre)
0
20
40
60
80
100
120
140
5-10"
10-15"
15-20"
20-25"
25-30"
30-35"
35-40"
>40"
Tree Diameter in 5" Bins
DF
WH
RC
MD
BM
RA
CW
CH
WI
All Other
Basal Area

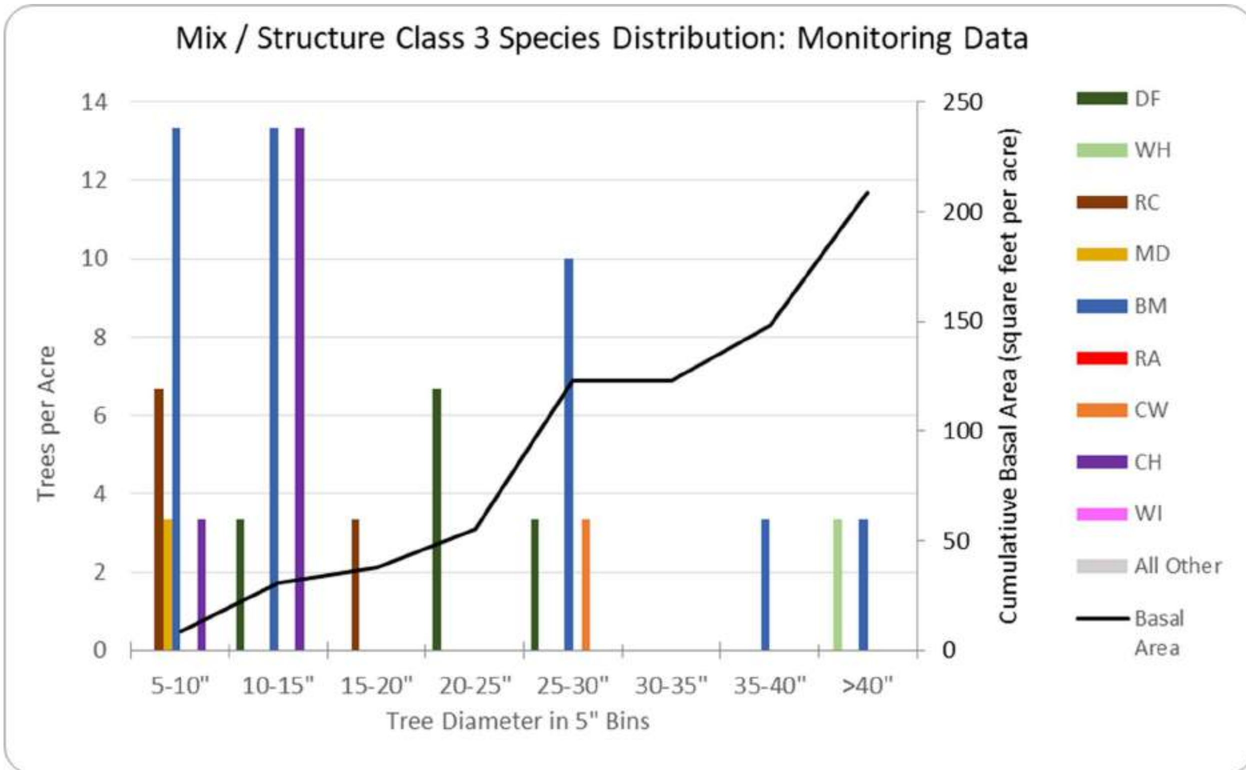


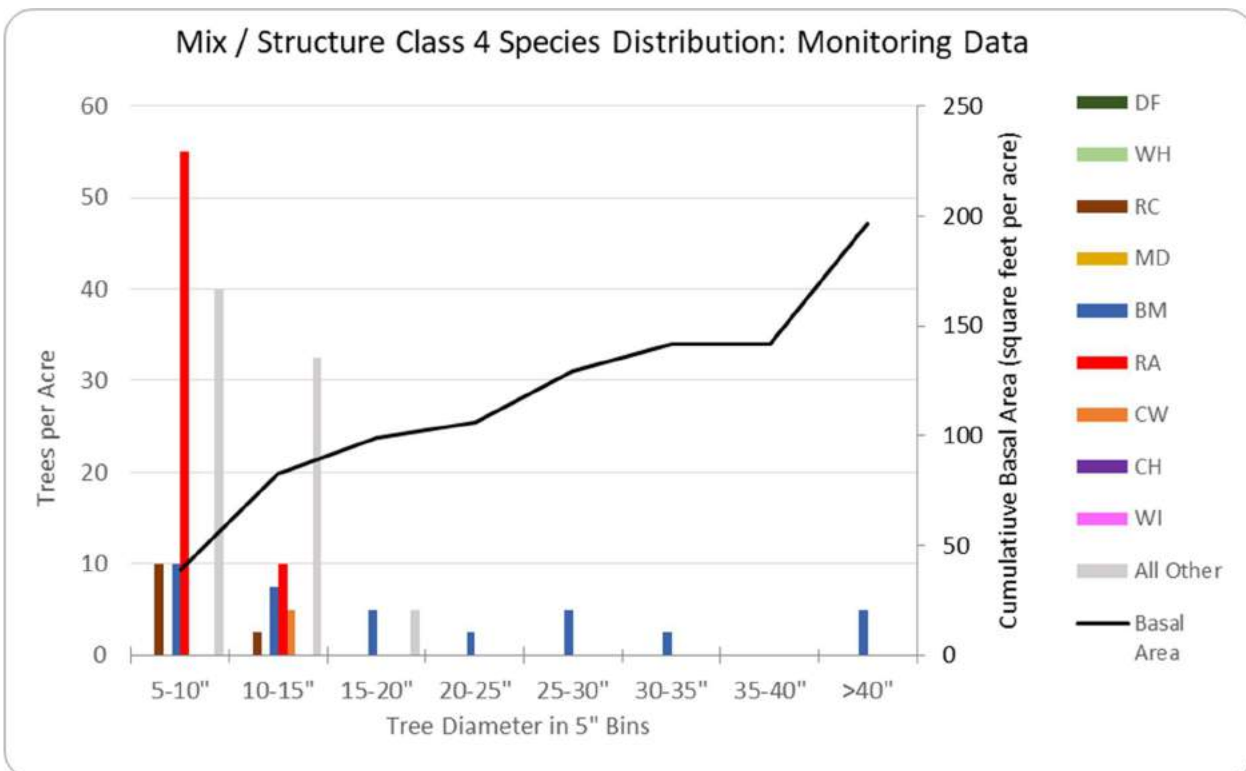
Broadleaf / Structure Class 6: No Data

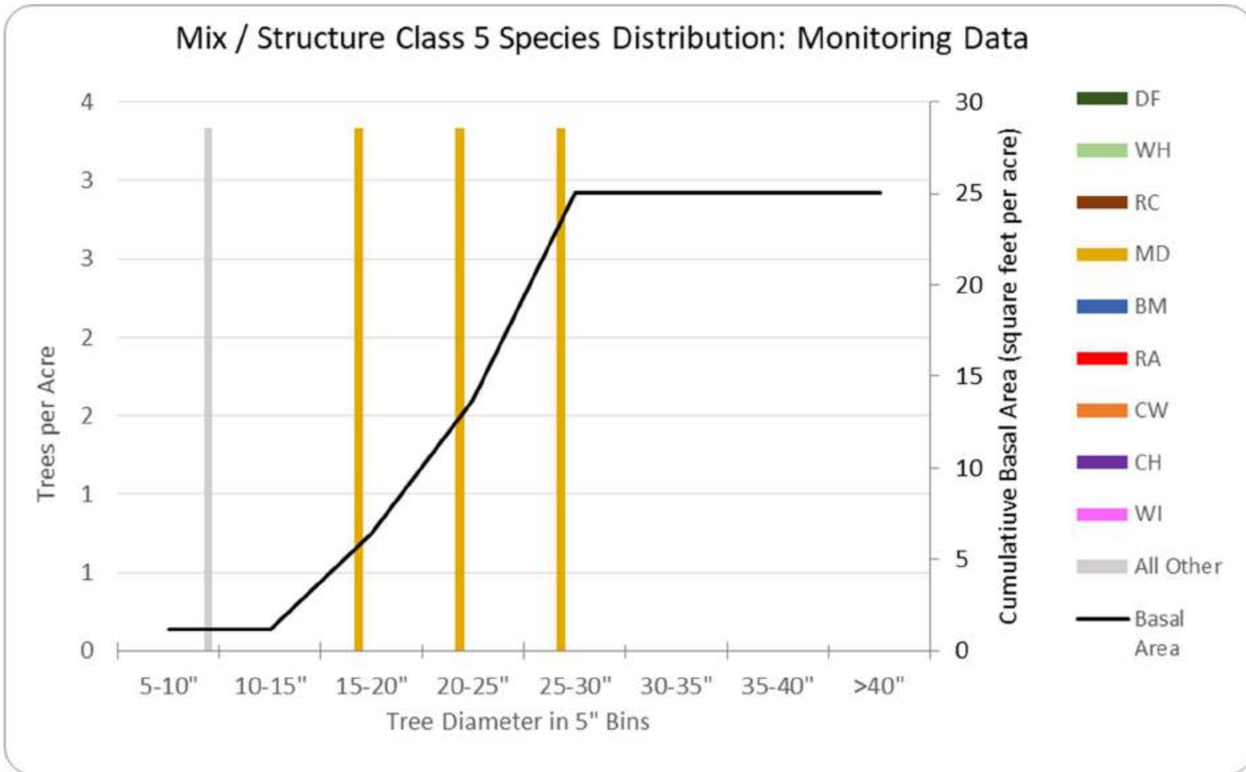



Mix / Structure Class 1 Species Distribution: Monitoring Data
Trees per Acre
Cumulatiuve Basal Area (square feet per acre)
0
1
2
3
4
5
6
7
8
50
100
150
200
250
5-10"
10-15"
15-20"
20-25"
25-30"
30-35"
35-40"
>40"
Tree Diameter in 5" Bins
DF
WH
RC
MD
BM
RA
CW
CH
WI
All Other
Basal Area

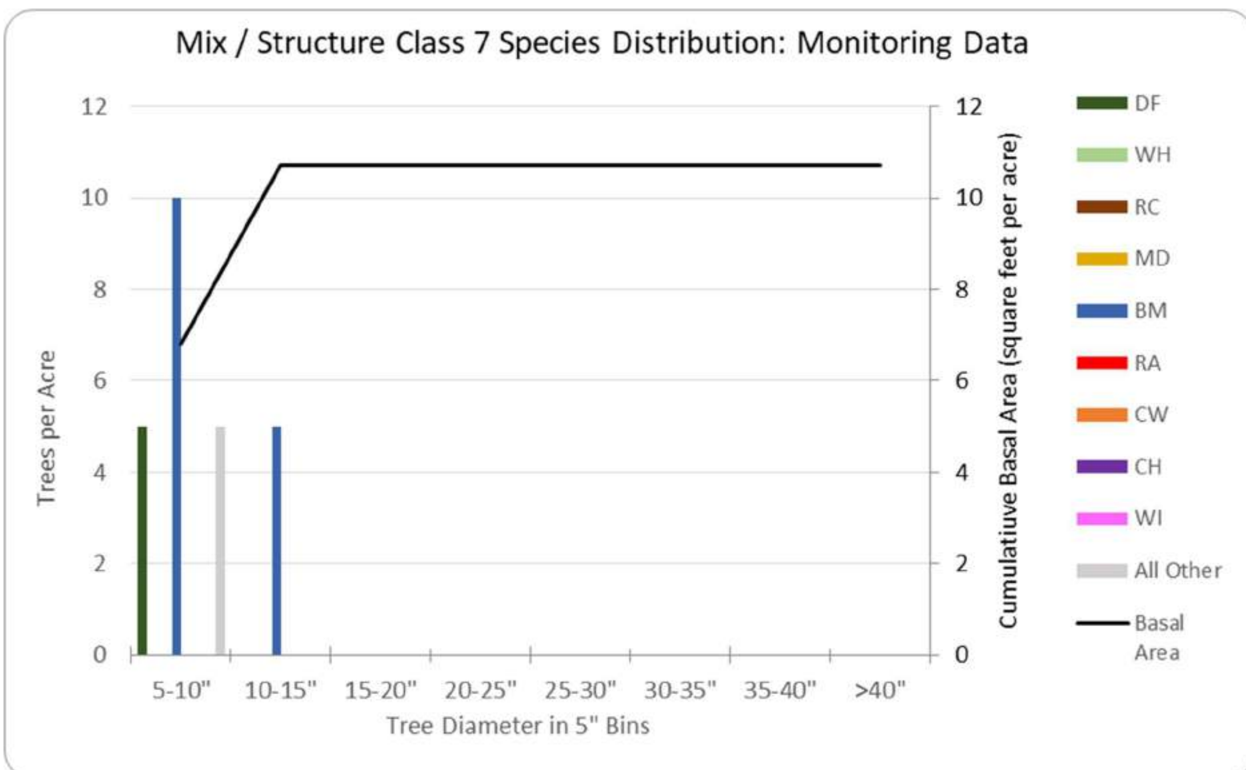

Mix / Structure Class 2 Species Distribution: Monitoring Data
Trees per Acre
Cumulatiuve Basal Area (square feet per acre)
0
5
10
15
20
25
30
20
40
60
80
100
120
140
160
180
200
5-10"
10-15"
15-20"
20-25"
25-30"
30-35"
35-40"
>40"
Tree Diameter in 5" Bins
DF
WH
RC
MD
BM
RA
CW
CH
WI
All Other
Basal Area

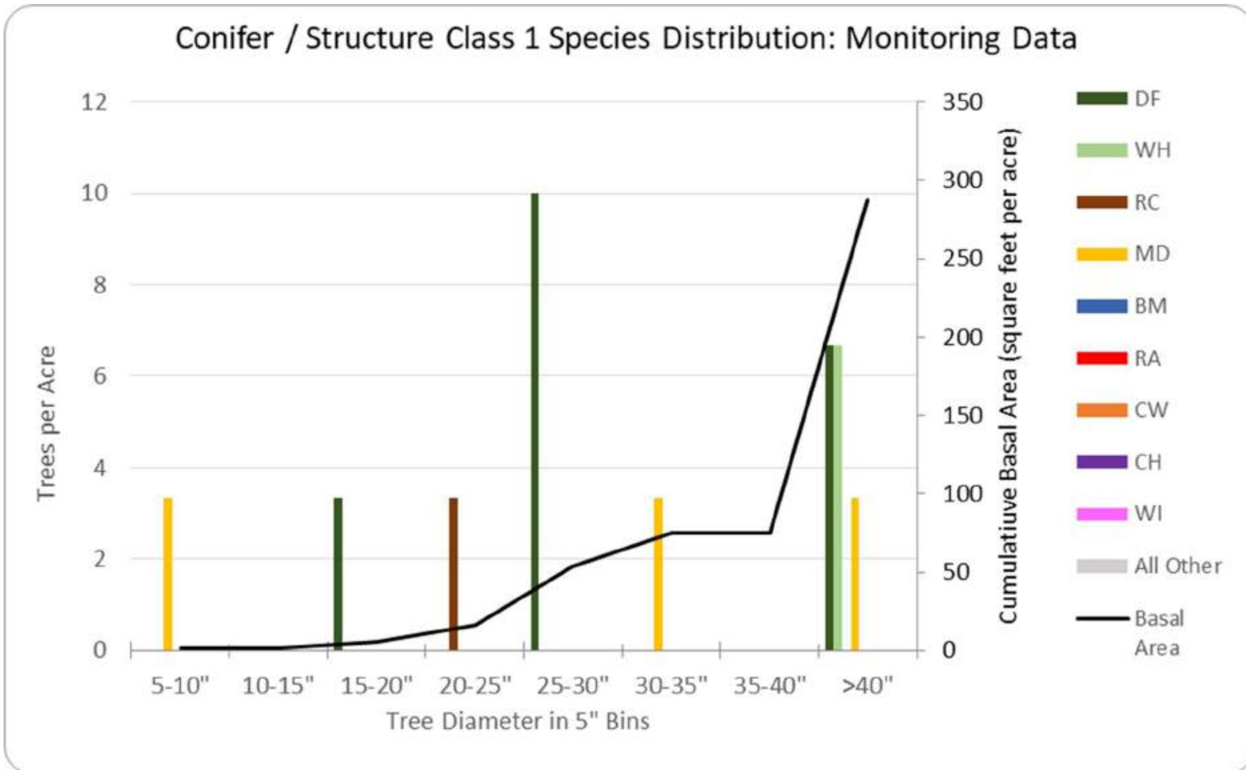

Mix / Structure Class 3 Species Distribution: Monitoring Data
Trees per Acre
0
2
4
6
8
10
12
14
Cumulatiuve Basal Area (square feet per acre)
0
50
100
150
200
250
5-10"
10-15"
15-20"
20-25"
25-30"
30-35"
35-40"
>40"
Tree Diameter in 5" Bins
DF
WH
RC
MD
BM
RA
CW
CH
WI
All Other
Basal Area

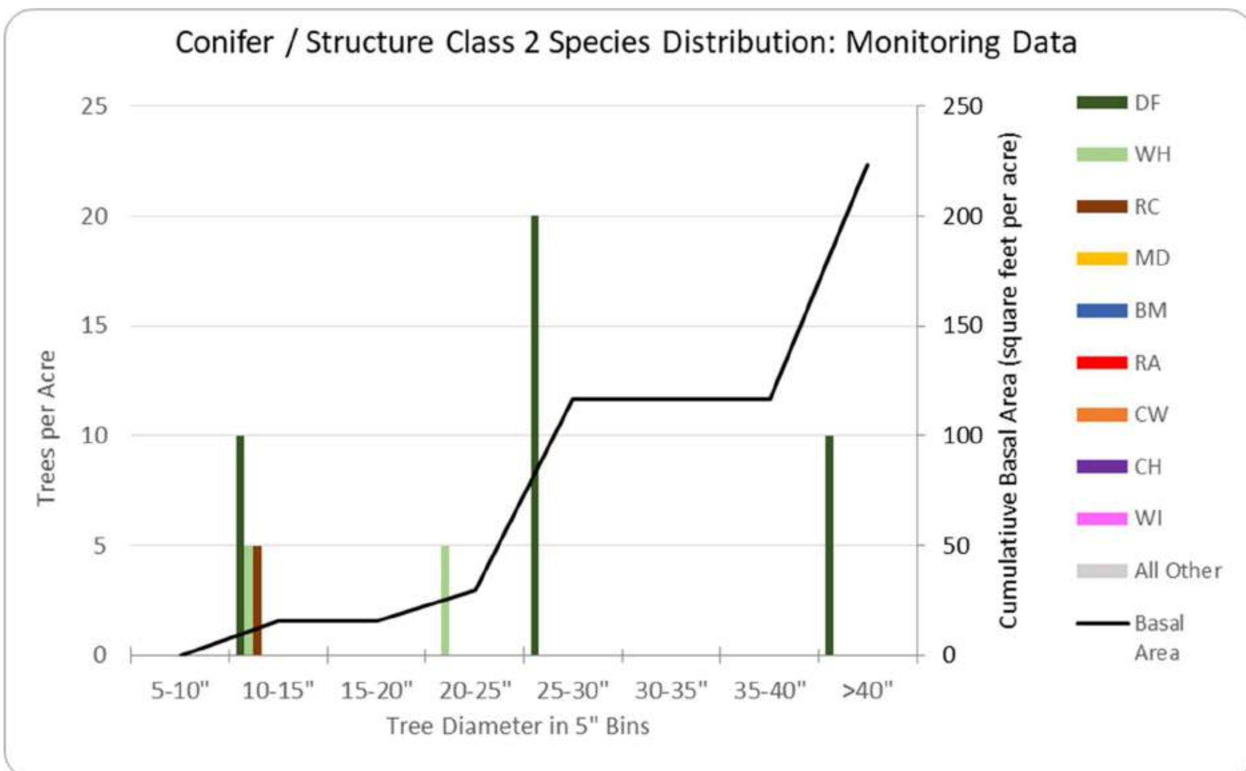

Mix / Structure Class 4 Species Distribution: Monitoring Data
Trees per Acre
0
10
20
30
40
50
60
Cumulatiuve Basal Area (square feet per acre)
0
50
100
150
200
250
5-10"
10-15"
15-20"
20-25"
25-30"
30-35"
35-40"
>40"
Tree Diameter in 5" Bins
DF
WH
RC
MD
BM
RA
CW
CH
WI
All Other
Basal Area

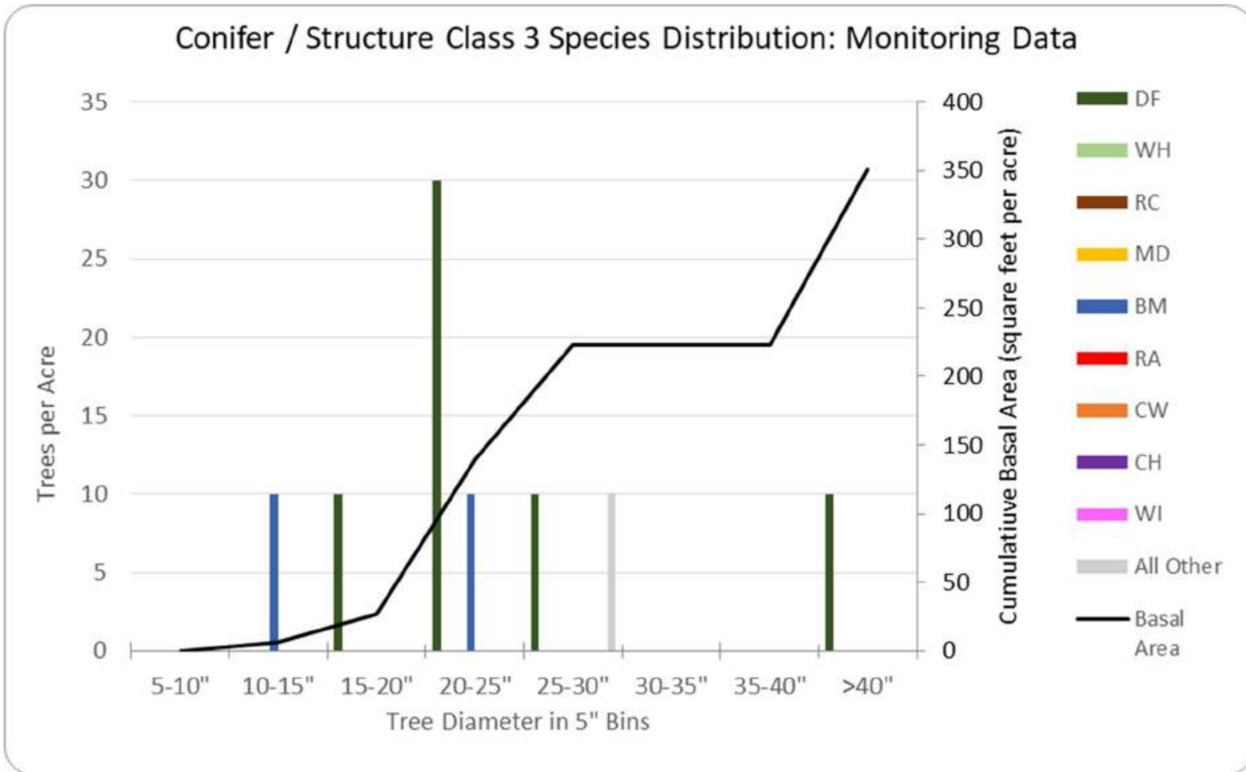


Mix / Structure Class 6: No Data




Conifer / Structure Class 1 Species Distribution: Monitoring Data
Trees per Acre
0
2
4
6
8
10
12
Cumulatiuve Basal Area (square feet per acre)
0
50
100
150
200
250
300
350
5-10"
10-15"
15-20"
20-25"
25-30"
30-35"
35-40"
>40"
Tree Diameter in 5" Bins
DF
WH
RC
MD
BM
RA
CW
CH
WI
All Other
Basal Area


Conifer / Structure Class 2 Species Distribution: Monitoring Data
Trees per Acre
0
5
10
15
20
25
Cumulatiuve Basal Area (square feet per acre)
0
50
100
150
200
250
5-10"
10-15"
15-20"
20-25"
25-30"
30-35"
35-40"
>40"
Tree Diameter in 5" Bins
DF
WH
RC
MD
BM
RA
CW
CH
WI
All Other
Basal Area



Conifer / Structure Class 4: No Data

Conifer / Structure Class 5: No Data

Conifer / Structure Class 6: No Data

Conifer / Structure Class 7: Insufficient Data

b. Data Table for Average Basal Area, Trees per Acre, and Diameter of Average Tree (QMD) for zones with monitoring plot data by structure class and canopy cover

	Basal Area Per Acre							Trees Per Acre							Diameter of Avg Tree (QMD)						
Structure Class	**1**	**2**	**3**	**4**	**5**	*6*	**7**	**1**	**2**	**3**	**4**	**5**	*6*	**7**	**1**	**2**	**3**	**4**	**5**	*6*	**7**
Broadleaf	**131**	**133**	**172**	**125**	**67**	**-**	**25**	**81**	**67**	**100**	**91**	**47**	**-**	**60**	**20.4**	**19.9**	**18.6**	**17.2**	**12.0**	**-**	**8.8**
Broadleaf-Other	120	61	207	133	72	-	25	230	65	78	96	52	-	60	9.8	13.5	23.3	16.7	10.9	-	8.8
Broadleaf-ARME	-	-	187	175	-	-	-	-	-	40	130	-	-	-	-	-	29.3	15.7	-	-	-
Broadleaf-POTR15	-	-	193	158	-	-	-	-	-	140	165	-	-	-	-	-	15.9	14.3	-	-	-
Broadleaf-ALRU2	132	123	154	88	-	-	-	75	63	154	73	-	-	-	20.3	18.3	13.5	13.8	-	-	-
Broadleaf-ACMA3	131	156	163	119	52	-	-	66	70	90	73	35	-	-	21.9	22.4	18.2	19.5	14.6	-	-
Mix	**220**	**183**	**208**	**197**	**25**	**-**	**11**	**79**	**90**	**93**	**197**	**13**	**-**	**25**	**22.9**	**21.0**	**22.2**	**14.4**	**18.6**	**-**	**8.1**
Mix-Other	159	97	123	197	25	-	11	65	70	30	197	13	-	25	21.5	16.0	27.5	14.4	18.6	-	8.1
Mix-THPL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mix-TSHE	144	-	-	-	-	-	-	45	-	-	-	-	-	-	24.1	-	-	-	-	-	-
Mix-PSME	327	226	167	-	-	-	-	117	100	150	-	-	-	-	22.8	23.5	14.3	-	-	-	-
Mix-ACMA3	175	-	335	-	-	-	-	60	-	100	-	-	-	-	23.1	-	24.8	-	-	-	-
Conifer	**287**	**223**	**351**	**-**	**-**	**-**	**44**	**40**	**55**	**90**	**-**	**-**	**-**	**60**	**35.3**	**28.5**	**26.7**	**-**	**-**	**-**	**11.5**
Conifer-Other	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Conifer-TSHE	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Conifer-PICOC	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Conifer-THPL	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Conifer-PSME	287	223	351	-	-	-	44	40	55	90	-	-	-	60	35.3	28.5	26.7	-	-	-	11.5

c. Monitoring Plot Data – Zone

Zone	Visit Date	Structure Class	Canopy Class	Canopy Cover	TPA	QMD	BA	Height to Diameter Ratio	SDI	Curtis RD
8	5/17/2012	3	Broadleaf	Broadleaf-ACMA3	160	13.7	164	88	245	44
16-05	7/25/2012	7	Conifer	Conifer-PSME	60	11.5	44	55	76	13
19-01	4/3/2012	7	Mix	Mix-Other	40	9.3	19	47	35	6
1C4	11/10/2013	1	Broadleaf	Broadleaf-ALRU2	65	19.8	139	49	205	31
2A-4	9/28/2012	2	Broadleaf	Broadleaf-ACMA3	100	15.4	130	73	196	33
2A6	10/19/2012	1	Broadleaf	Broadleaf-ALRU2	80	17.1	127	69	196	31
35th and East Alder	10/2/2013	3	Broadleaf	Broadleaf-ACMA3	110	10.0	60	63	109	19
3B1	8/8/2013	1	Broadleaf	Broadleaf-ACMA3	40	18.4	74	29	108	17
56th Ave	4/1/2014	4	Mix	Mix-Other	100	27.6	415	28	528	79
8th Ave	10/1/2013	5	Mix	Mix-Other	13	18.6	25	32	37	6
Adams Highway	8/7/2013	3	Broadleaf	Broadleaf-ACMA3	130	17.0	205	61	284	50
Area 3	7/11/2012	1	Conifer	Conifer-PSME	60	40.0	523	40	610	83
Arroyos South Bluffs	10/12/2016	5	Broadleaf	Broadleaf-ACMA3	10	12.0	8	60	14	2
Bernice Slope - Zone 5-3	10/3/2013	3	Mix	Mix-Other	30	27.5	123	39	157	24
Big Firs	10/9/2015	2	Mix	Mix-PSME	50	33.8	312	46	382	54
Big Toe	9/9/2012	1	Mix	Mix-PSME	130	22.4	355	69	466	75
Bird Flats	10/12/2015	3	Broadleaf	Broadleaf-ACMA3	30	26.0	111	36	152	22
Boren Park	10/2/2013	3	Broadleaf	Broadleaf-Other	20	19.6	42	51	61	9
Central Greensward	7/11/2012	4	Mix	Mix-Other	310	10.6	191	83	335	58
Central McClellan	5/17/2013	2	Broadleaf	Broadleaf-ACMA3	90	20.8	211	40	304	46
central mixed forest	10/12/2016	1	Mix	Mix-TSHE	50	24.8	167	50	228	34
Central Riparian	8/13/2013	1	Mix	Mix-Other	80	19.9	172	80	245	39
Cheasty Yard	7/24/2012	3	Broadleaf	Broadleaf-Other	80	25.0	273	54	364	55
chebvd_06	10/12/2015	2	Broadleaf	Broadleaf-ACMA3	130	15.5	169	67	268	43
Cottonwood Grove	8/2/2012	4	Broadleaf	Broadleaf-POTR15	230	10.4	135	79	231	42
Dearborn Wetland	9/30/2013	3	Broadleaf	Broadleaf-ACMA3	100	21.0	241	48	337	53
Delridge and Myrtle	6/25/2013	3	Broadleaf	Broadleaf-ACMA3	70	26.1	259	26	331	51
Delridge East-Central	8/23/2012	2	Broadleaf	Broadleaf-ALRU2	60	18.3	109	60	156	26
duhegs_19	9/5/2013	2	Broadleaf	Broadleaf-Other	40	14.8	48	63	74	12
E Interlaken Ravine	7/2/2012	2	Broadleaf	Broadleaf-ACMA3	20	20.0	44	48	65	10
East PB Lakeshore	8/16/2012	4	Broadleaf	Broadleaf-Other	210	17.7	357	55	512	85

Zone	Visit Date	Structure Class	Canopy Class	Canopy Cover	TPA	QMD	BA	Height to Diameter Ratio	SDI	Curtis RD
East Slope	8/29/2013	4	Broadleaf	Broadleaf-ALRU2	30	14.9	36	63	59	9
Egan House Turnout	7/5/2012	4	Broadleaf	Broadleaf-ACMA3	40	21.2	98	63	140	21
Fairway Estates E	9/18/2015	4	Broadleaf	Broadleaf-ACMA3	80	19.5	166	56	235	38
Forest Transition Zone	9/16/2015	4	Broadleaf	Broadleaf-Other	70	16.9	110	88	169	27
gogapk_12	7/17/2012	2	Broadleaf	Broadleaf-ACMA3	100	17.0	158	74	227	38
Golf Course Woods South	8/29/2013	3	Broadleaf	Broadleaf-ALRU2	190	13.9	201	53	324	54
Inner Arch	8/25/2012	1	Conifer	Conifer-PSME	50	31.8	276	24	343	49
Jacobsen Rd GS	4/2/2014	4	Broadleaf	Broadleaf-Other	100	20.2	222	48	312	49
John C. Little	10/20/2016	5	Broadleaf	Broadleaf-Other	30	9.4	15	60	26	5
Kennedy 500	9/21/2011	5	Broadleaf	Broadleaf-Other	50	7.0	13	54	27	5
Knoll - Zone 5-1	8/12/2013	2	Broadleaf	Broadleaf-ALRU2	60	18.1	107	44	162	25
KRE 1	10/4/2012	3	Broadleaf	Broadleaf-ACMA3	20	18.3	37	29	53	9
KRE 3	10/4/2012	2	Broadleaf	Broadleaf-ACMA3	70	25.8	253	68	314	50
KRM 1	10/5/2012	2	Broadleaf	Broadleaf-ALRU2	60	22.2	162	78	218	34
KRM 2	10/5/2012	1	Broadleaf	Broadleaf-ACMA3	110	23.9	342	63	456	70
KRM 4	10/5/2012	2	Broadleaf	Broadleaf-ACMA3	70	18.7	134	74	201	31
KRS a	10/4/2012	4	Broadleaf	Broadleaf-ACMA3	50	29.8	243	35	311	44
KRW 4	10/4/2012	4	Broadleaf	Broadleaf-ACMA3	50	16.3	72	48	108	18
LaVilla Meadows W	11/13/2010	4	Mix	Mix-Other	90	10.5	54	65	95	17
LE2	9/30/2013	4	Broadleaf	Broadleaf-Other	120	12.5	102	71	169	29
LE3	7/18/2013	1	Conifer	Conifer-PSME	10	34.2	64	21	81	11
LE4	8/5/2013	1	Mix	Mix-Other	50	23.1	146	62	193	30
LE5	9/30/2013	1	Mix	Mix-PSME	150	22.4	411	47	566	87
lincpk_H4	5/1/2013	3	Mix	Mix-PSME	150	14.3	167	66	261	44
lincpk_H8	10/3/2013	3	Broadleaf	Broadleaf-ARME	40	29.3	187	41	242	35
Lower Taylor Creek Ravine (North of Hairpin)	9/30/2013	3	Broadleaf	Broadleaf-ACMA3	180	21.8	466	52	621	100
Maduzia Gap Project	11/9/2013	1	Broadleaf	Broadleaf-ALRU2	50	26.7	194	34	262	38
Meadowbrook Wetlands	8/7/2013	4	Mix	Mix-Other	290	9.0	127	84	237	42
MF11	11/21/2013	3	Broadleaf	Broadleaf-POTR15	140	15.9	193	38	295	48
Mgmt Unit 4 Central - Eastside	10/6/2015	5	Broadleaf	Broadleaf-Other	10	9.0	4	47	8	1
Mgmt Unit 4 Central - Westside	7/31/2012	7	Mix	Mix-Other	10	7.0	3	67	5	1
N of Water Towers	4/13/2012	1	Mix	Mix-PSME	70	23.7	214	55	299	44

Zone	Visit Date	Structure Class	Canopy Class	Canopy Cover	TPA	QMD	BA	Height to Diameter Ratio	SDI	Curtis RD
North Bluff Slope South	9/11/2012	2	Broadleaf	Broadleaf-ACMA3	40	33.3	242	40	307	42
Park's Problem	7/12/2012	3	Mix	Mix-ACMA3	100	24.8	335	54	442	67
Patrick's Gulch	8/13/2012	3	Broadleaf	Broadleaf-Other	40	36.6	292	56	326	48
Pigeon Point 03	5/5/2011	4	Broadleaf	Broadleaf-ACMA3	30	15.6	40	44	61	10
Pigeon Point 04	2/27/2013	7	Broadleaf	Broadleaf-Other	60	8.8	25	35	48	9
Pigeon Point 05	7/6/2012	3	Broadleaf	Broadleaf-ACMA3	70	13.5	69	37	114	19
PPGS 02	11/9/2013	3	Broadleaf	Broadleaf-ACMA3	110	19.8	236	38	330	53
PPGS 03	11/9/2013	3	Broadleaf	Broadleaf-ACMA3	30	16.3	44	61	64	11
PPGS 07	6/5/2013	2	Broadleaf	Broadleaf-ACMA3	10	35.0	67	34	84	11
PPGS 08	1/23/2012	2	Broadleaf	Broadleaf-ALRU2	40	17.1	63	79	95	15
Promontory Point Basin	8/22/2012	4	Broadleaf	Broadleaf-POTR15	100	18.3	182	58	266	43
Riverview 11-02 (REI Site)	8/10/2012	1	Broadleaf	Broadleaf-ACMA3	100	13.9	105	65	172	28
Riverview 13	10/1/2013	5	Broadleaf	Broadleaf-Other	130	21.1	315	68	419	69
Riverview 20	7/24/2013	1	Broadleaf	Broadleaf-Other	230	9.8	120	93	217	38
Riverview 22	6/7/2013	3	Broadleaf	Broadleaf-ACMA3	130	17.0	204	34	304	50
Rustic Rd	10/24/2012	4	Broadleaf	Broadleaf-ACMA3	140	10.5	85	118	149	26
S Creek Forest West	10/21/2012	2	Conifer	Conifer-PSME	30	31.5	162	50	208	29
SE Ravenna Forest	10/6/2015	4	Broadleaf	Broadleaf-ACMA3	100	10.9	65	72	110	20
SE Ravine West - Zone 12	10/11/2016	2	Broadleaf	Broadleaf-ALRU2	80	24.0	251	68	338	51
Soap Box	10/21/2016	4	Broadleaf	Broadleaf-Other	10	30.0	49	4	65	9
Soundway 04	2/1/2013	1	Broadleaf	Broadleaf-ACMA3	20	16.0	28	37	43	7
Soundway 05	1/4/2013	4	Broadleaf	Broadleaf-ARME	130	15.7	175	41	270	44
Soundway 06	8/21/2012	3	Broadleaf	Broadleaf-ALRU2	240	11.3	167	63	282	50
Soundway 07	11/30/2012	4	Broadleaf	Broadleaf-Other	70	8.8	29	69	55	10
Soundway 08	11/9/2012	4	Broadleaf	Broadleaf-Other	70	13.4	68	34	110	19
Soundway 09-01	12/14/2012	5	Broadleaf	Broadleaf-Other	40	8.2	15	34	28	5
Soundway 09-02	7/18/2012	4	Broadleaf	Broadleaf-ALRU2	110	18.2	198	35	278	46
Soundway 09-03	10/11/2012	2	Broadleaf	Broadleaf-ALRU2	80	10.3	46	88	82	14
Soundway 09-04	2/2/2013	3	Broadleaf	Broadleaf-ALRU2	70	12.8	63	62	100	17
Soundway 10	5/29/2012	1	Broadleaf	Broadleaf-ALRU2	20	25.5	71	47	98	14
Soundway 12	10/13/2016	4	Broadleaf	Broadleaf-ACMA3	120	11.4	85	83	145	25
Soundway 14	1/29/2013	1	Broadleaf	Broadleaf-ACMA3	160	11.9	124	75	211	36
Soundway 14-02	2/20/2013	1	Broadleaf	Broadleaf-ALRU2	160	12.2	131	72	220	37

Zone	Visit Date	Structure Class	Canopy Class	Canopy Cover	TPA	QMD	BA	Height to Diameter Ratio	SDI	Curtis RD
Sout Fork Riparian	10/3/2013	1	Mix	Mix-TSHE	40	23.5	120	39	163	25
South of Stairs	6/25/2013	4	Broadleaf	Broadleaf-ACMA3	100	14.2	109	49	175	29
SW Conifer Forest	10/9/2011	2	Mix	Mix-Other	70	16.0	97	52	142	24
SW Queen Anne 07	7/13/2013	4	Broadleaf	Broadleaf-ACMA3	20	45.2	223	32	248	33
Tom Palm Site	10/8/2015	2	Conifer	Conifer-PSME	80	25.5	284	55	371	56
TR2 Unit 9	8/23/2013	3	Broadleaf	Broadleaf-ACMA3	70	11.0	46	91	80	14
Trail8	8/7/2012	3	Conifer	Conifer-PSME	90	26.7	351	56	462	68
Upper Leschi NE	5/31/2012	1	Broadleaf	Broadleaf-ACMA3	60	23.7	183	50	254	38
W of Dog Park	10/1/2013	2	Mix	Mix-PSME	150	13.1	141	70	210	39
wdgban_05	4/30/2014	1	Broadleaf	Broadleaf-ACMA3	30	23.1	87	45	123	18
West Howe Park	7/10/2012	5	Broadleaf	Broadleaf-ACMA3	60	17.1	96	83	145	23
West Kubota Edge	9/25/2013	3	Broadleaf	Broadleaf-ACMA3	50	22.7	141	47	196	30
Wetland Forest 1	9/22/2012	4	Broadleaf	Broadleaf-ALRU2	80	8.4	31	53	59	11
Wolf Tree SE	8/9/2013	1	Mix	Mix-ACMA3	60	23.1	175	74	241	36
WYCO Fund	8/13/2012	1	Broadleaf	Broadleaf-ACMA3	10	44.0	106	29	124	16
Zone 1 Area I	10/1/2015	3	Broadleaf	Broadleaf-ALRU2	70	13.6	71	68	115	19
Zone 15_17 SE Forest	10/31/2011	3	Broadleaf	Broadleaf-Other	170	17.9	298	49	434	70
Zone 18 S Forest	10/12/2016	3	Broadleaf	Broadleaf-Other	80	17.2	129	56	194	31
Zone 2 N Forest	4/30/2013	4	Broadleaf	Broadleaf-Other	120	13.9	127	56	207	34
Zone 4_5 Animal Tracks Nature Trail	8/11/2012	2	Broadleaf	Broadleaf-Other	90	12.2	73	52	121	21
Zone 6	5/18/2012	3	Broadleaf	Broadleaf-ALRU2	200	15.7	268	81	398	68

4. Appendix 4: Insect and Disease Climate Change Risk Assessment

a. Insect and Disease Climate Change Risk Assessment adapted from Aubrey et al 2011 for common species in Seattle Parks.

Rank	Scientific Name	Threat1 (Aubrey et al. 2011)	Sev[a]	Immed[b]	Score1	Threat2 (Aubrey et al. 2011)	Sev[a]	Immed[b]	Score2
1	*Acer macrophyllum*	*Verticllium* wilt	3	3	9	*Armillaria mellea*	3	3	9
2	*Alnus rubra*	*Pytophthora ulni*	3	2	6				
3	*Thuja plicata*	*Armillaria* root disease	1	2	2				
4	*Pseudotsuga menziesii*	Douglas-fir beetle	1	2	2	Laminated root rot	3	2	6
5	*Populus trichocarpa*	*Cytospora* canker	3	2	6	*Melempsora* rust	1	2	2
6	*Arbutus menziesii*								
7	*Tsuga heterophylla*	*Annosus* butt rot	3	2	6	Western hemlock looper	1	2	2
8	*Prunus avium*								
9	*Salix scouleriana*								
10	*Prunus emarginata*								
11	*Ilex aquifolium*								
12	*Prunus sp.*								
13	*Fraxinus latifolia*								
14	*Cornus nuttalli*								
15	*Acer platanoides*								
16	*Crataegus monogyna*								
17	*Prunus laurocerasus*								
18	*Pinus contorta var. contorta*								
19	*Robinia pseudoacacia*								
20	*Betula pendula*								
Native	*Abies grandis*	Balsam wooly adelgid	8	2	16	Fir engraver	3	2	6
Native	*Taxus brevifolia*								
Native	*Pinus monticola*	Mountain pine beetle	3	2	6	White pine blister rust	8	2	16
Native	*Picea sitchensis*	Spruce beetle	1	2	2				
Native	*Quercus garryana*								
Native	*Callitropsis nootkatensis*	Yellow cedar decline	1	1	1				

[a] Severity: 1= minor mortality in stressed trees, 3= moderate mortality when with other threats, 5=moderate mortality in mature trees, 6=significant/complete mortality in related species, 8=significant mortality of all mature trees, 10=complete mortality of all trees

[b] Immediacy: 1=potential to reach area of interest, 2=present in region, 3=present and climate change appears to be contributing factor in increase

Insect and Disease Climate Change Risk Assessment Continued

Rank	Scientific Name	Theat3 (Aubrey et al. 2011)	Sev[a]	Immed[b]	Score3	Threat4 (See source column)	Sev[a]	Immed[b]	Score4	Source[c]
1	*Acer macrophyllum*					Bigleaf maple dieback	5	2	10	1, 2
2	*Alnus rubra*									
3	*Thuja plicata*					cedar bark beetles	1	2	2	1
4	*Pseudotsuga menziesii*	Swiss needle cast	1	3	3	Twig weevils , branch and stem cankers	1	2	2	1
5	*Populus trichocarpa*									
6	*Arbutus menziesii*					*Fusicoccum aesculi*, *Phellinus igniarius, Poria subacida*	5	3	15	3
7	*Tsuga heterophylla*	Western blackhead budworm	1	2	2					
8	*Prunus avium*									
9	*Salix scouleriana*									
10	*Prunus emarginata*									
11	*Ilex aquifolium*									
12	*Prunus sp.*									
13	*Fraxinus latifolia*									
14	*Cornus nuttalli*									
15	*Acer platanoides*									
16	*Crataegus monogyna*									
17	*Prunus laurocerasus*									
18	*Pinus contorta var. contorta*									
19	*Robinia pseudoacacia*									
20	*Betula pendula*									
Native	*Abies grandis*	*Armillaria* root disease	3	2	6					
Native	*Taxus brevifolia*									
Native	*Pinus monticola*									
Native	*Picea sitchensis*									
Native	*Quercus garryana*									
Native	*Callitropsis nootkatensis*									

[a] Severity: 1= minor mortality in stressed trees, 3= moderate mortality when with other threats, 5=moderate mortality in mature trees, 6=significant/complete mortality in related species, 8=significant mortality of all mature trees, 10=complete mortality of all trees

[b] Immediacy: 1=potential to reach area of interest, 2=present in region, 3=present and climate change appears to be contributing factor in increase

[c] 1 = WADNR 2012, 2 = Adams and Hamilton 1999, 3 = Burns and Honkala 1990.

Insect and Disease Climate Change Risk Assessment Continued

Rank	Scientific Name	Score1	Score2	Score3	Score4	Score Sum	Rating[d]
1	*Acer macrophyllum*	9	9		10	28	3
2	*Alnus rubra*	6				6	1
3	*Thuja plicata*	2			2	4	1
4	*Pseudotsuga menziesii*	2	6	3	2	13	2
5	*Populus trichocarpa*	6	2			8	1
6	*Arbutus menziesii*				15	15	2
7	*Tsuga heterophylla*	6	2	2		10	2
8	*Prunus avium*						
9	*Salix scouleriana*						
10	*Prunus emarginata*						
11	*Ilex aquifolium*						
12	*Prunus sp.*						
13	*Fraxinus latifolia*						
14	*Cornus nuttalli*						
15	*Acer platanoides*						
16	*Crataegus monogyna*						
17	*Prunus laurocerasus*						
18	*Pinus contorta var. contorta*						
19	*Robinia pseudoacacia*						
20	*Betula pendula*						
Native	*Abies grandis*	16	6	6		28	3
Native	*Taxus brevifolia*						
Native	*Pinus monticola*	6	16			22	3
Native	*Picea sitchensis*	2				2	1
Native	*Quercus garryana*						
Native	*Callitropsis nootkatensis*	1	9			1	1

[d] Insect and disease vulnerability rating is based on the sum of the disease scores: 0 = No Data, 1 = 1 to 9, 2 = 10 to 19, 3 = 20 to 29

b. List of mortality-causing insects and diseases of native species that are expected to increase with climate change

Douglas-fir (*Pseudotsuga menziesii*)
Douglas-fir is well-research compared to other species due to its commercial value. While its list of insects and disease is long, it may not be at greater risk than other species, but its risks are better identified.

<u>Insects</u>
Twig weevil (*Cylindrocopturus furnissi*) (WA DNR 2017)
Douglas-fir beetle (*Dendroctonus pseudotsugae*) (Aubrey et al. 2011, WA DNR 2017)
Pole beetles (*Pseudohylesinus nebulosus*) (WA DNR 2017)
Engraver beetles (*Scolytus unispinosus, Scolytus monticolae*) (WA DNR 2017)
Flatheaded fir borer (*Melanophila drummondi*) (WA DNR 2017)

<u>Disease</u>
Branch and stem cankers (Dermea boycei, Diaporthe lokoyae) (WA DNR 2017)
Swiss needle cast (*Phaeocryptopus gaeumannii*) (Aubrey et al. 2011)
Laminated root rot *(Phellinus weirii)* (Aubrey et al. 2011)

Western hemlock (*Tsuga heterophylla*)
<u>Insects</u>
Looper (*Lambdina fiscellaria lugubrosa* Hulst) (Aubrey 2011, WA DNR 2017)
Western blackhead budworm (*Acleris gloverana*) (Aubrey et al. 2011)

<u>Disease</u>
Annosus butt rot (*Heterobasidion annosum* and *H. occidentale*) (Aubrey et al. 2011, Ramsey 2018)
Rhizoctonia butinii, a foliar fungus (Ramsey 2018

Grand fir (*Abies grandis*)
<u>Insects</u>
Fir engraver (*Scolytus ventralis*) (WA DNR 2017)
Balsam wooly adelgid (*Adelges piceae*) (Aubrey et al. 2011)

<u>Disease</u>
Armillaria root disease (*Armillaria* spp.) (Aubrey et al. 2011)

Western redcedar (*Thuja plicata*)
<u>Insects</u>
Western cedar borer (*Trachykele blondeli Marseul*) (Rippey 2018)
Cedar bark beetles (*Phloeosinus spp*) (Rippey 2018)

<u>Disease</u>
Armillaria root disease (*Armillaria* spp.) (Aubrey et al. 2011)

Bigleaf maple (*Acer macrophyllum*)
Drought conditions may contribute to bigleaf maple die-back (Omdal and Ramsey-Kroll 2012, WADNR

2017)
<u>Insects</u>
Asian longhorned beetle (*Anoplophora glabripennis*) (Cieko et al. 2012)

<u>Disease</u>
Verticllium wilt (Aubrey et al. 2011)
Armillaria mellea (Aubrey et al. 2011)

Red alder (*Alnus rubra*)
<u>Insects</u>
(None documented as worsening with climate change)

<u>Disease</u>
Root and stump disease (*Pytophthora ulni*) (Aubry et al. 2011)

Madrone (*Arbutus menziesii*)
<u>Insects</u>
Few insects are primary causes of mortality (Elliot 1999)

<u>Disease</u>
Fusicoccum aesculin (Elliot 1999, Elliot et al. 2002)*I*
Phytophthora cactorum (Elliot 1999, Elliot et al. 2002)
Nattrassia mangiferae (Elliot 1999, Elliot et al. 2002)
Other species of heartwood damage are common in warmer regions of madrone's range, potentially becoming more common in Seattle (ex, *Phellinus igniarius*, *Poria subacida*, *Fomitopsis cajanderi*) (McDonald and Tappeinier 1990).

Black cottonwood (*Populus trichocarpa*)
<u>Insects</u>
(None documented as worsening with climate change)

<u>Disease</u>
Cytospora canker
Melempsora rust

Western white pine (*Pinus monticola*)
<u>Insects</u>
Mountain pine beetle (*Dendroctonus ponderosae*) (Aubry et al. 2011)

<u>Disease</u>
White pine blister rust (*Cronartium ribicola*) (Aubry et al. 2011)

Sitka spruce (*Picea sitchensis*)
<u>Insects</u>
Spruce beetle (*Dendroctonus rufipennis*) (Aubry et al. 2011)
Gypsy moth (*Lymantria dispar*) (Cieko et al. 2012).

<u>Disease</u>
(None documented as worsening with climate change)

Garry oak (*Quercus garryana*)
<u>Insects</u>
Gypsy moth (*Lymantria dispar*) (Cieko et al. 2012).

<u>Disease</u>
(None documented as worsening with climate change)

Shore pine (*Pinus contorta* var*. contorta*)
<u>Insects</u>
(None documented as worsening with climate change)

<u>Disease</u>
(None documented as worsening with climate change)

Oregon ash (*Fraxinus latifolia*)
<u>Insects</u>
Emerald ash borer (*Agrilus planipennis*) (Cieko et al. 2012)

<u>Disease</u>
(None documented as worsening with climate change)

5. Appendix 5: Species List

Species that occur in Inventory assessment data.

Code	Scientific Name	Common Name	Native	Type
ABAM	*Abies amabilis*	silver fir	Yes	Conifer
ABBA	*Abies balsamea*	Balsam Fir	No	Conifer
ABGR	*Abies grandis*	grand fir	Yes	Conifer
ABLA	*Abies lasiocarpa*	subalpine fir	No	Conifer
ABPR	*Abies procera*	noble fir	Yes	Conifer
ABIES	*Abies sp.*	fir	No	Conifer
ACCA5	*Acer campestre*	field maple	No	Broadleaf
ACGL	*Acer glabrum*	Rocky Mountain maple	Yes	Broadleaf
ACMA3	*Acer macrophyllum*	bigleaf maple	Yes	Broadleaf
ACPA2	*Acer palmatum*	Japanese maple	No	Broadleaf
ACPL	*Acer platanoides*	Norway maple	No	Broadleaf
ACPS	*Acer pseudoplatanus*	sycamore maple	No	Broadleaf

Code	Scientific Name	Common Name	Native	Type
ACRU	*Acer rubrum*	red maple	No	Broadleaf
ACSA2	*Acer saccharinum*	silver maple	No	Broadleaf
ACSA3	*Acer saccharum*	sugar maple	No	Broadleaf
ACER	*Acer sp.*	maple tree	No	Broadleaf
ACFR	*Acer freemanii*	freeman maple	No	Broadleaf
ACRU2	*Actaea rubra*	baneberry	Yes	Broadleaf
AEHI	*Aesculus hippocastanum*	horse chestnut	No	Broadleaf
AIAL	*Ailanthus altissima*	tree of heaven	No	Broadleaf
ALRU2	*Alnus rubra*	red alder	Yes	Broadleaf
ALNUS	*Alnus sp.*	alder	No	Broadleaf
ALVIS	*Alnus viridis ssp. sinuata*	slide alder	Yes	Broadleaf
ARCO32	*Araucaria columnaris*	New Caledonia pine	No	Conifer
ARME	*Arbutus menziesii*	Pacific madrone	Yes	Broadleaf
ARUN4	*Arbutus unedo*	strawberry tree	No	Broadleaf
BEAL2	*Betula alleghaniensis*	yellow birch	No	Broadleaf
BEOC2	*Betula occidentalis*	water birch	Yes	Broadleaf
BEPA	*Betula papyrifera*	paperbark birch	Yes	Broadleaf
BEPE3	*Betula pendula*	European white birch	No	Broadleaf
BEPU5	*Betula pubescens*	downy birch	No	Broadleaf
BETUL	*Betula sp.*	birch	No	Broadleaf
CANO9	*Callitropsis nootkatensis*	Alaska yellow cedar	Yes	Conifer
CADE27	*Calocedrus decurrens*	incense cedar	No	Conifer
CADE9	*Carex deweyana*	Dewey sedge	Yes	Broadleaf
CABE8	*Carpinus betulus*	European hornbeam	No	Broadleaf
CACA18	*Carpinus caroliniana*	American hornbeam	No	Broadleaf
CADE12	*Castanea dentata*	American chestnut	No	Broadleaf
CASTA	*Castanea sp.*	chestnut	No	Broadleaf
CATAL	*Catalpa sp.*	Catalpa species	No	Broadleaf
CEAT	*Cedrus atlantica*	atlas cedar	No	Conifer
CEDE2	*Cedrus deodara*	Deodar cedar	No	Conifer
CECA4	*Cercis canadensis*	eastern redbud	No	Broadleaf
CHLA	*Chamaecyparis lawsoniana*	Port Orford cedar	No	Conifer
CHOB8	*Chamaecyparis obtusa*	Hinoki false cypress	No	Broadleaf
CHPI12	*Chamaecyparis pisifera var. 'Squarrosa'*	moss false cypress	No	Broadleaf
CHAMA4	*Chamaecyparis sp.*	false cypress	No	Broadleaf
CLKE	*Cladrastis kentukea*	American yellowwood	No	Broadleaf
CONU4	*Cornus nuttalli*	Pacific dogwood	Yes	Broadleaf
CORNU	*Cornus sp.*	dogwood tree	No	Broadleaf
CRDO2	*Crataegus douglasii*	Pacific hawthorn	Yes	Broadleaf
CRMO3	*Crataegus monogyna*	oneseed hawthorn	No	Broadleaf
CRPH2	*Crataegus phippsii*	Phipps' hawthorn	Yes	Broadleaf

Code	Scientific Name	Common Name	Native	Type
CRATA	*Crataegus sp.*	horticultural hawthorne species	No	Broadleaf
CRJA3	*Cryptomeria japonica*	Japanese cedar	No	Conifer
CUPRE	*Cupressus sp.*	Cypress Sp.	No	Broadleaf
EUCAL	*Eucalyptus sp.*	eucalyptus	No	Broadleaf
FAGUS	*Fagus sp.*	beech	No	Broadleaf
FASY	*Fagus sylvatica*	European beech	No	Broadleaf
FRPU7	*Frangula purshiana*	cascara	Yes	Broadleaf
FREX80	*Fraxinus excelsior*	European ash	No	Broadleaf
FRLA	*Fraxinus latifolia*	Oregon ash	Yes	Broadleaf
FRPE	*Fraxinus pennsylvanica*	green ash	No	Broadleaf
FRAXI	*Fraxinus sp.*	ash	No	Broadleaf
GIBI2	*Ginkgo biloba*	maidenhair tree	No	Broadleaf
GLTR	*Gleditsia triacanthos*	honey locust	No	Broadleaf
HELE4	*Hesperotropsis leylandii*	Leyland cypress	No	Broadleaf
ILAQ80	*Ilex aquifolium*	English holly	No	Broadleaf
ILEX	*Ilex sp.*	Holly	No	Broadleaf
JUNI	*Juglans nigra*	black walnut	No	Broadleaf
JURE80	*Juglans regia*	English walnut	No	Broadleaf
JUGLA	*Juglans sp.*	walnut	No	Broadleaf
JUCO6	*Juniperus communis*	common juniper	Yes	Conifer
JUNIP	*Juniperus sp.*	juniper tree	No	Conifer
JUNIP	*Juniperus sp.*	juniper tree	No	Conifer
LAAN2	*Laburnum anagyroides*	golden chain tree	No	Broadleaf
LAKA2	*Larix kaempferi*	Japanese larch	No	Conifer
LAOC	*Larix occidentalis*	western larch	Yes	Conifer
LARIX	*Larix sp.*	larch	No	Conifer
LIST2	*Liquidambar styraciflua*	American sweetgum	No	Broadleaf
LITU	*Liriodendron tulipifera*	tuliptree	No	Broadleaf
MAGR4	*Magnolia grandiflora*	southern magnolia	No	Broadleaf
MAFU	*Malus fusca*	western crabapple	Yes	Broadleaf
MALUS	*Malus sp.*	horticultural apple species	No	Broadleaf
MADO4	*Malus domestica*	domestic apple	No	Broadleaf
MEGL8	*Metasequoia glyptostroboides*	dawn redwood	No	Conifer
OSVI	*Ostrya virginiana*	hophornbeam	No	Broadleaf
PIAB	*Picea Abies*	Norway spruce	No	Broadleaf
PIEN	*Picea engelmannii*	Engelmann's spruce	Yes	Conifer
PIMA	*Picea mariana*	black spruce	No	Conifer
PIPU	*Picea pungens*	blue spruce	No	Conifer
PISI	*Picea sitchensis*	Sitka spruce	Yes	Conifer
PICEA	*Picea sp.*	spruce	No	Conifer
PICOC	*Pinus contorta var. contorta*	shore pine	Yes	Conifer

Code	Scientific Name	Common Name	Native	Type
PIJE	*Pinus jeffreyi*	Jeffrey Pine	No	Conifer
PIMO3	*Pinus monticola*	western white pine	Yes	Conifer
PIMU80	*Pinus mugo*	mugo pine	No	Conifer
PINI	*Pinus nigra*	Austrian pine	No	Conifer
PIPO	*Pinus ponderosa*	ponderosa pine	Yes	Conifer
PIRE	*Pinus resinosa*	red pine	No	Conifer
PINUS	*Pinus sp.*	pine	No	Conifer
PIST	*Pinus strobus*	eastern white pine	No	Conifer
PISY	*Pinus sylvestris*	scotch pine	No	Conifer
PITA4	*Pinus tabuliformis*	Chinese Pine	No	Conifer
PITH2	*Pinus thunbergii*	Japanese black pine	No	Conifer
PIVI2	*Pinus virginiana*	Virginia pine	No	Conifer
PLHI	*Platanus ×hispanica*	London planetree	No	Broadleaf
PLOC	*Platanus occidentalis*	American sycamore	No	Broadleaf
POAL7	*Populus alba*	white poplar	No	Broadleaf
PODE3	*Populus deltoides*	eastern cottonwood	No	Broadleaf
PONI	*Populus nigra*	black poplar	No	Broadleaf
POPUL	*Populus sp.*	horticultural poplar varieties	No	Broadleaf
POTR5	*Populus tremuloides*	aspen	Yes	Broadleaf
POTR15	*Populus trichocarpa*	black cottonwood	Yes	Broadleaf
PRAV	*Prunus avium*	sweet cherry	No	Broadleaf
PRCE2	*Prunus cerasifera*	cherry plum	No	Broadleaf
PRDO	*Prunus domestica*	horticultural plum	No	Broadleaf
PREM	*Prunus emarginata*	bitter cherry	Yes	Broadleaf
PRLA5	*Prunus laurocerasus*	cherry laurel	No	Broadleaf
PRLU	*Prunus lusitanica*	Portugal laurel	No	Broadleaf
PRSE2	*Prunus serotina*	black cherry	Yes	Broadleaf
PRUNU	*Prunus sp.*	horticultural cherry species	No	Broadleaf
PRSU2	*Prunus subcordata*	Klamath plum	Yes	Broadleaf
PRVI	*Prunus virginiana*	chokecherry	Yes	Broadleaf
PRPU4	*Prunus xpugetensis*	hybrid bitter cherry	No	Broadleaf
PSME	*Pseudotsuga menziesii*	Douglas fir	Yes	Conifer
PYCA80	*Pyrus calleryana*	bradford pear	No	Broadleaf
PYRUS	*Pyrus sp.*	ornamental pear	No	Broadleaf
QUCE	*Quercus cerris*	turkey oak	No	Broadleaf
QUDE4	*Quercus dentata*	Daimyo Oak	No	Broadleaf
QUGA4	*Quercus garryana*	Garry oak	Yes	Broadleaf
QUPA2	*Quercus palustris*	pin oak	No	Broadleaf
QURO2	*Quercus robur*	English oak	No	Broadleaf
QURU	*Quercus rubra*	red oak	No	Broadleaf
QUERC	*Quercus sp.*	oak	No	Broadleaf
RHODO	*Rhododendron sp.*	varieties	No	Broadleaf

Code	Scientific Name	Common Name	Native	Type
ROPS	*Robinia pseudoacacia*	black locust	No	Broadleaf
SAAL2	*Salix alba*	white willow	No	Broadleaf
SABA	*Salix babylonica*	weeping willow	No	Broadleaf
SAHO	*Salix hookeriana*	Hooker's willow tree	Yes	Broadleaf
SALUL	*Salix lucida ssp. lasiandra*	Pacific willow tree	Yes	Broadleaf
SALUL	*Salix lucida ssp. lasiandra*	Pacific willow tree	Yes	Broadleaf
SAMA13	*Salix matsudana Koidzumi*	Corkscrew willow	No	Broadleaf
SASC	*Salix scouleriana*	Scouler's willow tree	Yes	Broadleaf
SASI2	*Salix sitchensis*	Sitka willow	Yes	Broadleaf
SALIX	*Salix sp.*	willow	No	Broadleaf
SAAL5	*Sassafras albidum*	common sassafras	No	Broadleaf
SESE3	*Sequoia sempervirens*	coast redwood	No	Conifer
SEGI2	*Sequoiadendron giganteum*	giant sequoia	No	Conifer
SOAR2	*Sonchus arvensis*	perennial sowthistle	No	Broadleaf
SOAU	*Sorbus aucuparia*	European mountain ash	No	Broadleaf
SOSI2	*Sorbus sitchensis*	Sitka mountain ash	Yes	Broadleaf
SORBU	*Sorbus sp.*	mountain ash	No	Broadleaf
TADI2	*Taxodium distichum*	bald cypress	No	Conifer
TABR2	*Taxus brevifolia*	western yew	Yes	Conifer
TAXUS	*Taxus sp.*	yew	No	Conifer
THOC2	*Thuja occidentalis*	American arborvitae	No	Broadleaf
THPL	*Thuja plicata*	western red cedar	Yes	Conifer
TIAM	*Tilia americana*	American basswood	No	Broadleaf
TICO2	*Tilia cordata*	littleleaf linden	No	Broadleaf
TILIA	*Tilia sp.*	linden	No	Broadleaf
TSCA	*Tsuga canadensis*	eastern hemlock	No	Conifer
TSHE	*Tsuga heterophylla*	western hemlock	Yes	Conifer
TSME	*Tsuga mertensiana*	mountain hemlock	Yes	Conifer
ULAM	*Ulmus americana*	American elm	No	Broadleaf
ULPR	*Ulmus procera*	English elm	No	Broadleaf
ULPU	*Ulmus pumila*	Siberian elm	No	Broadleaf
ULMUS	*Ulmus sp.*	elm	No	Broadleaf
UMCA	*Umbellularia californica*	California bay	No	Broadleaf
ZESE80	*Zelkova serrata*	Japanese zelkova	No	Broadleaf

6. Appendix 6: Methods for Updating Current Forest Conditions with New Data

This Report is intended to be a starting point for ongoing review of SPR's forest conditions as they change and progress towards target forest systems. This section is a technical summary of our methods for the key data analysis, intended for analysts to re-create our work on future data sets.

Species composition:
Species composition relies on canopy cover data from inventory assessments.

1) With the new data set, use the species list (Appendix 5: Species List) to look up each species' broadleaf of conifer classification. Sum the percent cover of broadleaf species. If broadleaf cover is greater than 65%, classify as "broadleaf." If broadleaf cover is less than 35%, classify as "conifer." Broadleaf cover between 35 and 65 is classified as "mix."
2) Calculate the relative percent cover for all species (relative percent cover is a species' percent cover divided by the total sum of percent cover for all species in that zone's data set). Identify the species with the highest relative percent cover.
3) Assign a cover type classification using the species with the maximum relative cover combined with the broadleaf-conifer-mix classification. Use the Cover Type classifications (e.g., Broadleaf-ACMA or Conifer-PSME) presented in Section V.1 Current Conditions: Species Composition.

Ecological Structure Class:
The ecological structure classes (ESCs) are calculated using LiDAR data that is processed through a gradient nearest neighbor statistical analysis using a script for R statistical software (https://www.r-project.org/). These ESCs incorporate five forest canopy metrics which represent height, canopy closure, and variability. P95 (95th percentile of tree heights), P25 (25th percentile of tree heights), CC (canopy cover percent), and AvgHgt (average height). Future analysts may wish to include Rumple (height variability) in developing structure classes; we did not use rumple in this analysis.

The values for these metrics are averaged at the zone level for each LiDAR raster cell that falls within a zone boundary. The ESC is then calculated for the zone, based on the average LiDAR values. The number of ESCs is set by the user, depending on how much variability is desired: the more categories, the less variability there is across categories. This analysis selected 8 classes (7 classes and a null value class).

Required Data

- LiDAR
  - P95: 95th percentile of heights
  - P25: 25th percentile of heights
  - CC: canopy cover percent
  - AvgHgt: average height
- Shapefile with zone polygons
- R script (contact the authors if interested in obtaining a copy of the R script)

Steps

<u>Setup</u>

1. Process LiDAR through FUSION LIDAR data analysis software (McGaughy 2013) to produce P95, P25, CC, and AvgHgt data files.
2. Run R Packages, Raster Functions code, and load files into R.
3. Summarize LiDAR by zone and create shapefile with summary data.

<u>Create Ecological Structure Classes</u>

4. Select which LiDAR files to use to create structure classes.

5. Create dendrogram, scree graphs, and select the appropriate number of structure classes. The X-axis value of the scree graph when the slope levels off is an optimal number of structure classes.
6. Update the number of structure classes to calculate in the code, and calculate structure classes. Structure classes are assigned numbers in the R script that do not correlate to ecological utility. User must interpret the data informing the R-assigned structure classes and assign an Ecological Structure Class designation system. In our analysis, we used numeric values that roughly followed decreasing seral stages.
7. Assign each zone its ESC
8. Produce output file with Zone ID, average LiDAR values, and ESC for each zone.

Density:

Monitoring data tree lists including diameter at standard height (DSH) is sufficient for density calculations.

- Trees Per Acre (TPA) is simply the count of trees per 1/10th acre plot x 10.
- Basal Area Per Acre (BA) = $\sum$ Pi * (DSH/2)^2
- Quadratic Mean Diameter (QMD) = $\sqrt{}$(BA/TPA/0.005454)
- Relative Density (RD) = BA/$\sqrt{}$QMD

Carbon:

We used the Forest Vegetation Simulator (FVS) Fire and Fuels Extension (FFE) carbon reports, selecting the FFE biomass predictions for biomass equations. Results are presented in metric tons per acre of carbon. We post-processed the data in Excel and multiplied the carbon values by 44/12 to convert to carbon dioxide equivalents. FVS reports carbon for several biomass elements (above ground live, forest floor, etc.). In Excel, we summed the desired values. For total carbon, we used FVS' total stand carbon value. For carbon values to compare to California's Cap-and-Trade methodologies, we summed above ground live, below ground live, standing dead, and below ground dead. We only used FVS outputs for the year in which data were collected; we did not use FVS's forest growth modeling to project carbon gains or losses into the future.

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