From Forest Nursery Notes, Winter 2012

91. Climate change and forest biodiversity: a vulnerability assessment and action plan for National Forests in western Washington. Aubry, C., Devine, W., Shoal, R., Bower, A., and Miller, J. USDA Forest Service, Pacific Northwest Region. 2011.

UNITED STATES
DEPARTMENT OF
AGRICULTURE

FOREST SERVICE

PACIFIC NORTHWEST
REGION

APRIL 2011

CLIMATE CHANGE AND FOREST BIODIVERSITY:

A VULNERABILITY ASSESSMENT AND ACTION PLAN FOR NATIONAL FORESTS IN WESTERN WASHINGTON

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COVER PHOTO

Subalpine habitat, Norse Peak Wilderness, Mt. Baker-Snoqualmie National Forest, Robin Shoal, U.S. Forest Service.

CLIMATE CHANGE AND FOREST BIODIVERSITY:

A VULNERABILITY ASSESSMENT AND ACTION PLAN FOR NATIONAL FORESTS IN WESTERN WASHINGTON

APRIL 2011

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EXECUTIVE SUMMARY

INTRODUCTION

Climate change predictions for the Pacific Northwest include overall warming, increased winter precipitation, and decreased summer precipitation, resulting in warmer, wetter winters and warmer, drier summers (Mote and Salathe 2009). The extent and duration of the regional snowpack is projected to decrease, particularly at lower elevations (Elsner et al. 2009, Mote 2003). Seasonal stream flow patterns are likely to shift to earlier spring peak flows and lower summer flows, especially for snowmelt-dominated watersheds (Barnett et al. 2005). There is a limited amount of information on climatic tolerance for many tree species and even less information on what complex interactions could result from ecosystem-wide exposure to a changing environment.

OUR GOAL

The goals of this analysis are to conduct a climate change vulnerability assessment of forest tree species, assess the vulnerability of non-forested habitats to climate change, and propose practical management actions that will work under a variety of future climate scenarios and can be implemented by the national forests in western Washington in cooperation with other land managers.

HOW CAN THE THREE NATIONAL FORESTS IN WESTERN WASHINGTON CONSERVE BIODIVERSITY AND INCREASE RESILIENCY GIVEN THE PREDICTED CHANGES IN TEMPERATURE AND PRECIPITATION?

OBJECTIVES

The specific objectives of this analysis are to:

1. Assess the potential impacts of predicted changes in climate on both forest trees and selected vulnerable habitats: alpine and subalpine habitats, dry grasslands, and wetlands.
2. Evaluate tools that have been developed to assess vulnerability and mitigate the expected stressors of a warming climate.
3. Recommend actions that will improve understanding of changes taking place among tree species and non-forested habitats, maintain and increase biodiversity and increase resilience, and prepare for an uncertain future.
4. Collaborate in the implementation of these actions with the two other predominant public land management agencies in western Washington: the National Park Service and the Washington State Department of Natural Resources.

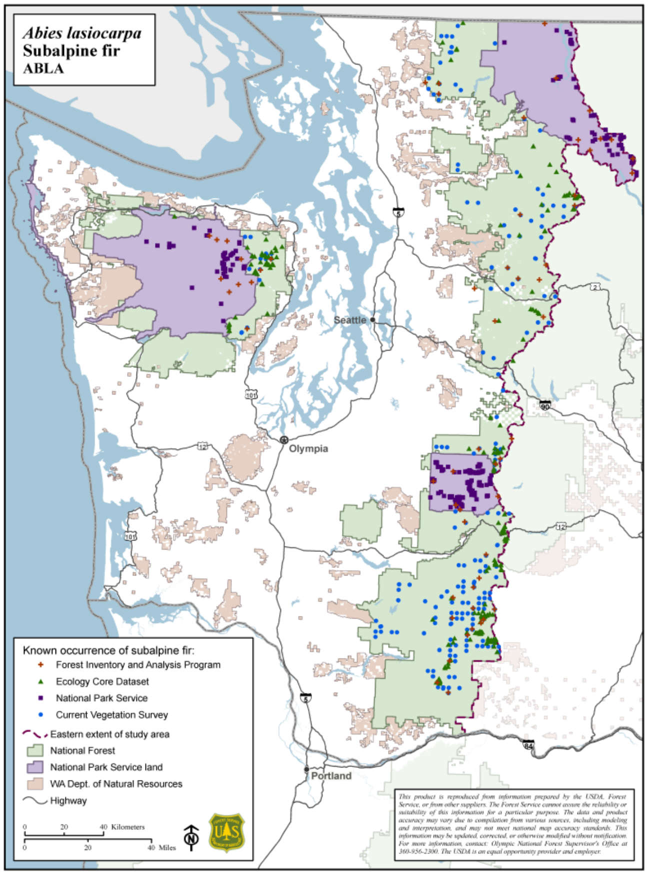
FORESTS OF WESTERN WASHINGTON

The forests of western Washington, defined here as the portion of the state west of the Cascade Range crest, includes the Olympic, Mt. Baker-Snoqualmie, and Gifford Pinchot national forests comprising 3.7 million ac (1.5 million ha), and the Olympic, North Cascades, and Mount Rainier national parks, comprising 1.8 million ac (0.7 million ha). An additional 1.6 million ac (0.6 million ha) of forest land is administered by the Washington State Department of Natural Resources. Nearly 3 million acres (1.6 million ha) are protected either as national parks or congressional designated wilderness areas on nation forests.

Vegetation management on western Washington’s National Forests is focused on thinning forest stands and restoring plant communities with an emphasis on fish and wildlife habitat. On these three forests, either pre-commercial or commercial tree thinning is conducted on a combined total of approximately 7,000 ac (2,800 ha) each year, most often with the objective of improving wildlife habitat. Tree planting is infrequent; a combined total of fewer than 300 ac (120 ha) is reforested each year.

FOREST TREE SPECIES

We organized the tree species of western Washington into three groups (see table on next page). Group 1 consists of 15 overstory tree species that are common in major portions of western Washington and are thus important components of the forest canopy and overall forest structure. These Group 1 species are a major focus of this report because changes in their distribution or health could affect forest structure and habitat at a broad scale. Group 2 includes trees that are not significant components of the forest canopy owing to small size or to limited occurrence in western Washington; these species may occur infrequently across broad areas or may be common within a limited habitat. Group 3 consists of trees that are rare in western Washington or are represented by disjunct populations.



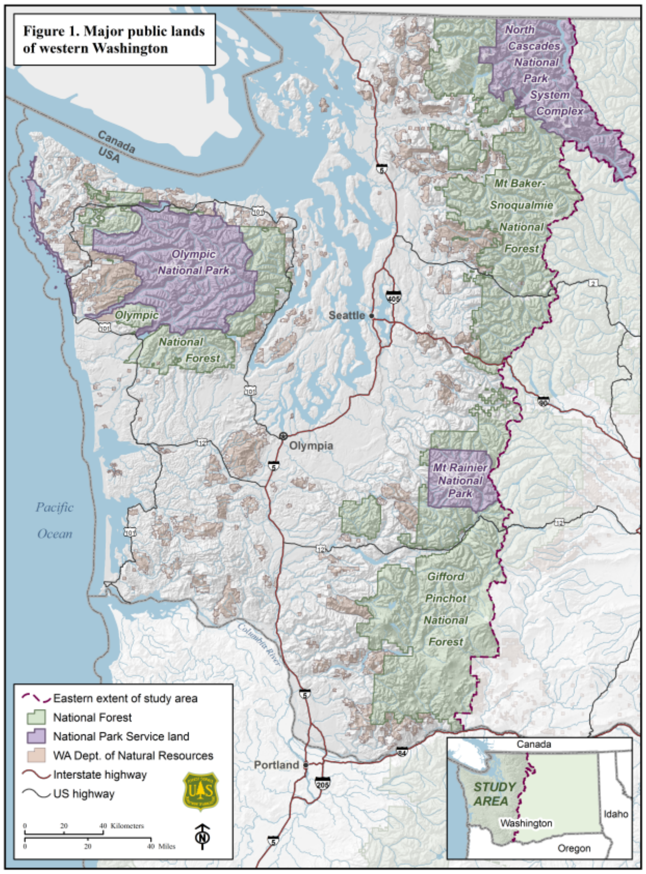


Figure 1. Major public lands of western Washington

We created distribution maps for all tree species of western Washington to show documented occurrences using the latest available data (appendix A).

Drawing on information from a variety of published sources, we compiled profiles of the western Washington tree species (appendix B). These profiles emphasize biological and ecological characteristics that were deemed relevant to the trees' potential adaptation to predicted changes in climate.

NATIVE TREE SPECIES OF WESTERN WASHINGTON

Group 1: Widespread forest canopy species

- Pacific silver fir
- Grand fir
- Subalpine fir
- Noble fir
- Bigleaf maple
- Red alder
- Alaska yellow-cedar
- Engelmann spruce
- Sitka spruce
- Western white pine
- Black cottonwood
- Douglas-fir
- Western redcedar
- Western hemlock
- Mountain hemlock

Group 2: Less-common or non-canopy species

- Douglas maple
- Pacific madrone
- Paper birch
- Pacific dogwood
- Black hawthorn and Suksdorf's hawthorn
- Cascara
- Oregon ash
- Western crab apple
- Shore pine and lodgepole pine
- Quaking aspen
- Bitter cherry
- Oregon white oak
- Pacific willow
- Scouler's willow
- Pacific yew

Group 3: Species rare in western Washington

- Golden chinquapin
- Rocky mountain juniper
- Whitebark pine
- Ponderosa pine

FOREST TREE VULNERABILITY ASSESSMENT

Methods

A vulnerability assessment is a systematic process of identifying and quantifying the areas of vulnerability within a system (Glick and Stein 2010), or in this case, forest tree species. Our objectives for vulnerability assessment were to: (1) select a method that is straightforward to apply, transparent, flexible, and provides for easy application of sensitivity analysis, and (2) rank the tree species of Group 1 (see table) according to their vulnerability to climate change impacts.

After testing several methods, we choose the Forest Tree Genetic Risk Assessment System which rates each species according to intrinsic attributes and external threats that can influence the species' vulnerability to climate change (Potter and Crane 2010). We ranked tree species for a number of characteristics organized into five risk factors: distribution, reproductive capacity, habitat affinity, adaptive genetic variation, and threats from insects and disease. Each risk factor contained multiple variables quantifying each tree species' vulnerability to climate change.

We calculated an overall climate change vulnerability score (0 to 100) for each species by averaging the five risk factors, which were weighted equally. A higher score indicates higher climate change vulnerability as measured by these risk factors.

Group 1 Tree Species

Several trends were evident in the vulnerability scores:

- Trees fell into two general groups: species with scores above and below 50.
- All four of the true fir species, Pacific silver fir, subalpine fir, noble fir, and grand fir, were in the higher-risk group.
- All species in the higher-risk group, except grand fir, had disjunct or geographically separated populations, a variable in the adaptive genetic variation risk factor.
- There was a general trend in increasing vulnerability with increasing mean elevation of occurrence.
- Douglas-fir, western hemlock, and western redcedar, predominant species in areas under active management, had low vulnerability scores.
- The three broadleaf tree species, red alder, black cottonwood, and bigleaf maple, also had low vulnerability scores

Results: Group 1 species (widespread forest canopy trees) of western Washington, ranked by overall climate change vulnerability score; higher scores indicate greater vulnerability

Tree species	Overall vulnerability score
Pacific silver fir	81
Subalpine fir	71
Engelmann spruce	66
Noble fir	61
Grand fir	54
Mountain hemlock	51
Alaska yellow-cedar	51
Western white pine	38
Douglas-fir	31
Bigleaf maple	29
Black cottonwood	28
Sitka spruce	26
Western redcedar	26
Western hemlock	22
Red alder	20

The results of this vulnerability assessment suggest that high-elevation tree species are at risk under a changing climate and thus should be a focus of conservation and monitoring.

Group 2 and Group 3 Tree Species

Group 2 tree species were predominantly non-commercial, and, relative to Group 1 species, little biological information was available for many of them. Therefore, instead of a formal vulnerability assessment, we examined general habitat requirements and reproductive characteristics relevant to climate change vulnerability. Patterns that emerged included:

- Most species regenerate rapidly following stand-replacing disturbance, usually through both vegetative and sexual reproduction.
- Many of the species are insect-pollinated and thus vulnerable to climate-induced changes in insect behavior.
- Because many Group 2 species occur in canopy gaps, forest edges, or understories, they will likely be influenced by changes in the growth and reproduction of the dominant forest canopy species.

Group 3 tree species are known to be rare within western Washington, and, owing to their limited distribution, all of these species are already deemed vulnerable to the effects of climate change. The four Group 3 species are golden chinquapin (listed in the regional Interagency Special Status/Sensitive Species Program), Rocky Mountain juniper, whitebark pine, and ponderosa pine. Each of these species has unique habitat requirements and a distribution that could be influenced by climate change.

NON-FORESTED HABITATS

Non-forested habitats vulnerable to climate change were identified using the scientific literature and advice from regional experts. Vulnerable non-forested habitats in western Washington are:

- Alpine and subalpine ecosystems
- Dry grasslands (prairies, savannas, and oak woodlands) and balds
- Freshwater and coastal wetlands

For each non-forested habitat, we assessed the attributes that contributed to climate change, we identified the ecosystem goods and services provided, and we determined information needs.

Vulnerability was defined as the likelihood that a habitat type, either as a whole or in individual occurrences, might change in size and distribution, undergo significant changes in vegetative community composition, or disappear from the landscape in response to changes in climate.

Cheryl Bartlett, USFS

Wetland, Three Peaks Botanical Area, Olympic National Forest

David Peter, USFS

Oak savanna, Joint Base Lewis-McChord, Washington

KEY VULNERABILITIES

For each habitat type, we identified key climate change vulnerabilities:

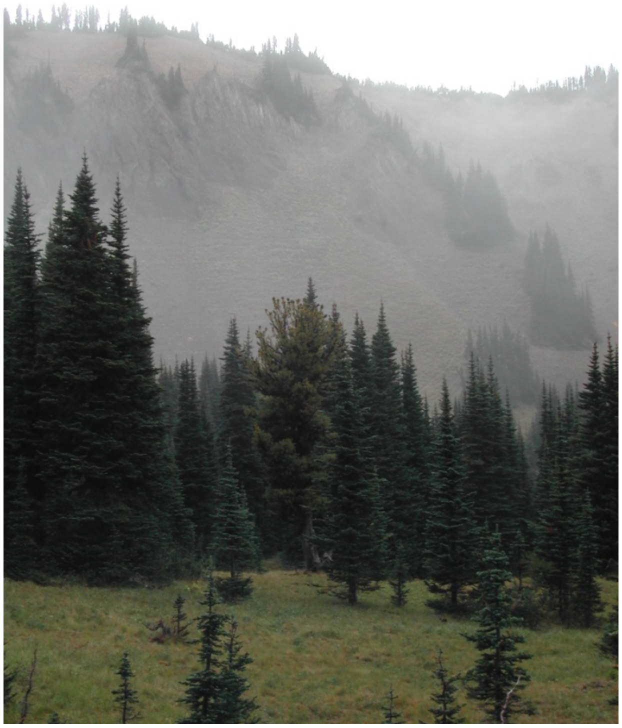
Alpine and subalpine ecosystems: Vegetation is vulnerable to changes in the duration and extent of the winter snowpack, which is influenced by summer temperatures (Mote 2003, Mote et al. 2005, Nolin and Daly 2006). Increased habitat fragmentation is anticipated under a warmer climate (Walther et al. 2005). Increases are expected in native and non-native insect and pathogen outbreaks and related disturbances (Dale et al. 2001).

Dry grasslands: Vulnerability is high owing to prior degradation resulting from human land use. Stress associated with changes in climate may favor non-native invasive species over native species.

Wetlands: Vulnerability is high as a result of past degradation and susceptibility to invasive species. Relative vulnerability of wetlands depends on water source (Winter 2000). Some wetlands may experience significantly greater seasonal extremes in water availability.

Alpine and subalpine ecosystems, dry grasslands, and wetlands are very different habitat types, but they have much in common: limited, patchy distributions; a high degree of fragmentation or isolation between occurrences; and very high biodiversity, including many species of plants and animals not adapted to other habitats. All three habitats also are especially susceptible to invasion by non-native plants, insects, and other animals. This combination of factors makes each of these habitats particularly vulnerable to disturbances resulting from climate change.

Recommended actions for these habitats centered on the need for baseline data, improving maps and inventories, and prioritizing sites for conservation, restoration, and monitoring.



Robin Shoal, USFS

Subalpine habitat, Norse Peak Wilderness, Mt. Baker-Snoqualmie National Forest

RECOMMENDATIONS

The recommendations developed during the course of this project fall into three categories:

1. **Learn about and track changes in plant communities as the climate changes.** Collect baseline data where needed. Monitor the impacts of a warming climate on the distribution and health of forest tree species and non-forested habitats. Look for triggers, such as an increase in the frequency of large-scale disturbance, which will indicate a need to change our management approach.

2. **Maintain and increase biodiversity and increase resiliency.** Focus on increasing stand diversity of native forest trees through thinning and planting. Initiate restoration activities in priority non-forested habitats. Increase disease resistance. Preserve genetic diversity, especially of isolated populations, and implement *ex situ* gene conservation where appropriate.

3. **Prepare for the future**. Given uncertainty about how climate changes will unfold, a number of future scenarios are possible. Select activities that will work under a variety of scenarios including a potential increase in disturbances such as fires, wind storms, and floods, which could be followed by greater spread of invasive plant species.

TOP 10 PRIORITY ACTION ITEMS

Forest Trees

- Assess stand health and regeneration of subalpine fir, mountain hemlock, and Alaska yellow-cedar, the high-elevation tree species that were found to be most at risk based on the vulnerability assessment. This will establish baseline information that can be used to track changes over time and form the basis for a conservation and monitoring plan.
- Develop a pilot program to monitor vegetative and reproductive phenology in seed orchards.
- Develop a pilot project to plant blister rust resistant western white pine in gaps or openings created in pre-commercially thinned stands and young-growth stands.
- Partner with other land managers in western Washington to create a virtual cooperative tree seed bank to facilitate reforestation after large-scale disturbances such as fire or insect outbreaks.
- Maintain an inventory of high-quality seed for tree species that are likely to be needed over the next 20 years. Place a priority on species that can be planted after disturbance.
  - Assess the viability of stored seed, discard non-viable seed, and make new and replacement collections as needed.
  - Maintain the national forest conifer seed orchards which serve as a gene conservation area and is the Forest's most efficient source of high quality tree seed.

Non-Forested Habitats

- For alpine and subalpine meadows:
  - Map and inventory.
  - Review historic aerial photography to identify potential trends in tree establishment in meadows and tree line change over time.
  - Select individual meadows for monitoring and initiate photo-point monitoring and/or periodic aerial photography of selected alpine meadows to track changes in tree establishment.
- For native dry grasslands, including Oregon white oak woodlands and savannas, and balds:
  - Map and inventory existing occurrences.
  - Use soil maps, aerial photos, and historical information to identify potential historical extent of these habitats on national forest lands.
- For wetlands:
  - Initiate a systematic inventory program to locate and describe wetlands and assess their condition.
  - Use historic information and aerial photography to identify changes to individual wetlands over time.
  - Initiate on-going photo-point monitoring of selected wetlands.
  - Using wetland inventory results, select at-risk wetlands for conservation and restoration.
- Collect foundation seed and initiate seed increase as needed of native grassland and wetland plant species. Target both rare and "workhorse" species for *ex situ* gene conservation and restoration purposes.
- For all three habitat types, continue to inventory, prevent and treat non-native invasive plant species.

> *"The results of this vulnerability assessment suggest that high-elevation tree species are at risk under a changing climate and therefore should be a focus of conservation and monitoring; Douglas-fir, western hemlock, and western redcedar, predominant species in areas under active management, have a lower vulnerability to a changing climate."*

INTRODUCTION

ASSESSING CLIMATE CHANGE EFFECTS ON PACIFIC NORTHWEST VEGETATION

Anthropogenic climate change is a great challenge to sustainable management of forests and grasslands because the rate of climatic change will likely exceed some species' capability to adapt, which in turn will alter plant communities and ecosystems. Climate change predictions for the Pacific Northwest include overall warming, increased winter precipitation, and decreased summer precipitation, resulting in warmer, wetter winters and warmer, drier summers (Mote and Salathe 2009). The extent and duration of the regional snowpack is projected to decrease, particularly at lower elevations (Elsner et al. 2009, Mote 2003). Seasonal stream flow patterns are likely to shift to earlier spring peak flows and lower summer flows, especially for snowmelt-dominated watersheds (Barnett et al. 2005). The effects of long-term climate changes on the composition and structure of western Washington's plant communities are difficult to predict. There is a limited amount of information on climatic tolerance for many species and even less information on what complex interactions could result from ecosystem-wide exposure to a changing environment.

In 2008, a study was initiated to determine how best to adapt federal land management on the Olympic Peninsula, Washington, to enhance the resilience of federal lands to the effects of climate change (Halofsky et al., in press). The Olympic Climate Change Case Study—a partnership of the U.S. Department of Agriculture (USDA), Forest Service, Pacific Northwest Research Station and Olympic National Forest, with the U.S. Department of Interior (USDI), National Park Service, Olympic National Park—examined hydrological processes and management of vegetation, fish and wildlife habitat, and roads to determine strategies and actions for adaptation to climate change. The adaptation strategies for managing vegetation under climate change included gene conservation, disease resistance, increasing biodiversity through planting and thinning, and increasing preparedness for large disturbances including potential increases in invasive species.

The present effort is the next step in addressing vegetation management and climate change. The area of analysis has been expanded to western Washington State (fig. 1), and the focus is on two central questions: (1) how will climate change affect forest biological diversity? and (2) what are the management implications of these potential impacts? Biodiversity is often viewed from a global perspective (Wilson 1988), but in this analysis, biodiversity is defined as "genetic variation within species, the variety of species in an area, and the variety of habitat types within a landscape" (Duffy and Lloyd 2010). As components of biodiversity, individual species, habitats, and ecosystems can be conservation targets for vulnerability assessments (Glick and Stein 2010). It is critical to address the effects of a changing climate at the level of individual plant species because individual species respond differently to climate, with potential shifts in distribution resulting in novel species associations (Lovejoy and Hannah 2005, Williams et al. 2007). Also of particular interest in this project are plant communities already known to be vulnerable to changes in climate, such as those at high elevations and those that are disturbance-dependent.

The target audience for this report is vegetation managers on the Mt. Baker-Snoqualmie, Olympic, and Gifford Pinchot National Forests. However, this report will also provide useful information for other land managers in the Pacific Northwest who manage, restore, and conserve forests and non-forested habitats under a changing climate. Land managers in other parts of the country will find that the methods used here can be applied to their plant communities using local information. Researchers will find signposts to the many questions yet to be answered concerning the impacts of climate change not only on forests and terrestrial habitats, but also on fundamental biological processes.

Figure 1. Major public lands of western Washington

AREA OF STUDY

The area of study is the forests of western Washington; analysis was done on data collected on all forest lands regardless of ownership. Management options presented here are intended for National Forest System lands but also may be applied to other land management agencies. Recommendations developed in partnership with other agencies are identified.

National Forest System lands of western Washington have been managed under the Northwest Forest Plan (NWFP) since its adoption in 1994 (Moeur et al. 2005). The NWFP was created with the vision of protecting forest habitat while simultaneously ensuring a sustainable supply of timber products. The plan was developed with a primary focus on late successional dependent species and aquatic habitat after a management impasse occurred when the northern spotted owl (*Strix occidentalis caurina*) was designated threatened under the Endangered Species Act. The 1994 Record of Decision amends the planning documents of lands administered by the USDA Forest Service and USDI Bureau of Land Management within the range of the northern spotted owl. The NWFP established a system of standards and guidelines to provide habitat management direction for these agencies.

Six allocation classes were designated within the land covered by the NWFP (table 1), each with standards and guidelines based on specific objectives. Of the 24.5 million ac (9.9 million ha) included in the NWFP in Washington, Oregon, and northern California, 84 percent of the land is allocated to one of six designated classes, with the remaining 16 percent designated as matrix land, where timber harvest and silvicultural activities may potentially be implemented (figs. 2, 3, and 4). The congressional reserves class includes national parks and monuments, wildernesses, and other areas where timber is not harvested. Similarly, administratively withdrawn areas are lands previously designated for non-timber uses, and include recreation and visual areas. On late successional reserves, the objective is to protect and enhance conditions of late successional habitat, while on riparian reserves, riparian-dependent resources are emphasized. The remaining land is in adaptive management areas, which are designated for testing new management approaches to achieve ecological and economic health. Timber harvest may potentially occur in this class and on matrix land; additionally, young forests in managed late successional reserves may be thinned.

In western Washington, defined here as the portion of the state west of the Cascade Range crest, the NWFP covers Olympic, Mt. Baker-Snoqualmie, and Gifford Pinchot National Forests, comprising 3.7 million ac (1.5 million ha); and Olympic, North Cascades, and Mount Rainier National Parks, comprising 1.8 million ac (0.7 million ha). Figures 2, 3, and 4 show the distribution of NWFP allocation classes within western Washington's national forests; the national parks fall within the congressional reserves class. An additional 1.6 million ac (0.6 million ha) of forest land administered by the Washington State Department of Natural Resources (WADNR) is not included in the NWFP.

Vegetation management on western Washington's national forests is focused on thinning forest stands and restoring plant communities with an emphasis on fish and wildlife habitat. On these three forests either pre-commercial or commercial tree thinning is conducted on close to 7,000 ac (2,800 ha) each year combined, most often with the objective of improving wildlife habitat. Tree planting is infrequent because thinning on these forests is not applied as a regeneration harvest; a combined total of fewer than 300 ac (120 ha) per year are reforested by planting in western Washington's three national forests. A small number of planting opportunities are created when

Table 1. Allocation of Northwest Forest Plan land in Washington, Oregon, and northern California

Designation	Allocation (%)
Congressional reserves	30
Administratively withdrawn areas	6
Late successional reserves	30
Managed late successional areas	1
Riparian reserves	11
Adaptive management areas	6
Matrix land	16

timber is harvested after windstorms on the Olympic Peninsula and after lightning-caused fires in the Cascade Range. Each year many miles of roads are decommissioned, which entails restoration activities such as restoring natural drainage, improving soil condition, seeding, and mulching to reduce soil erosion and noxious weeds and to facilitate the return of the native plant community.

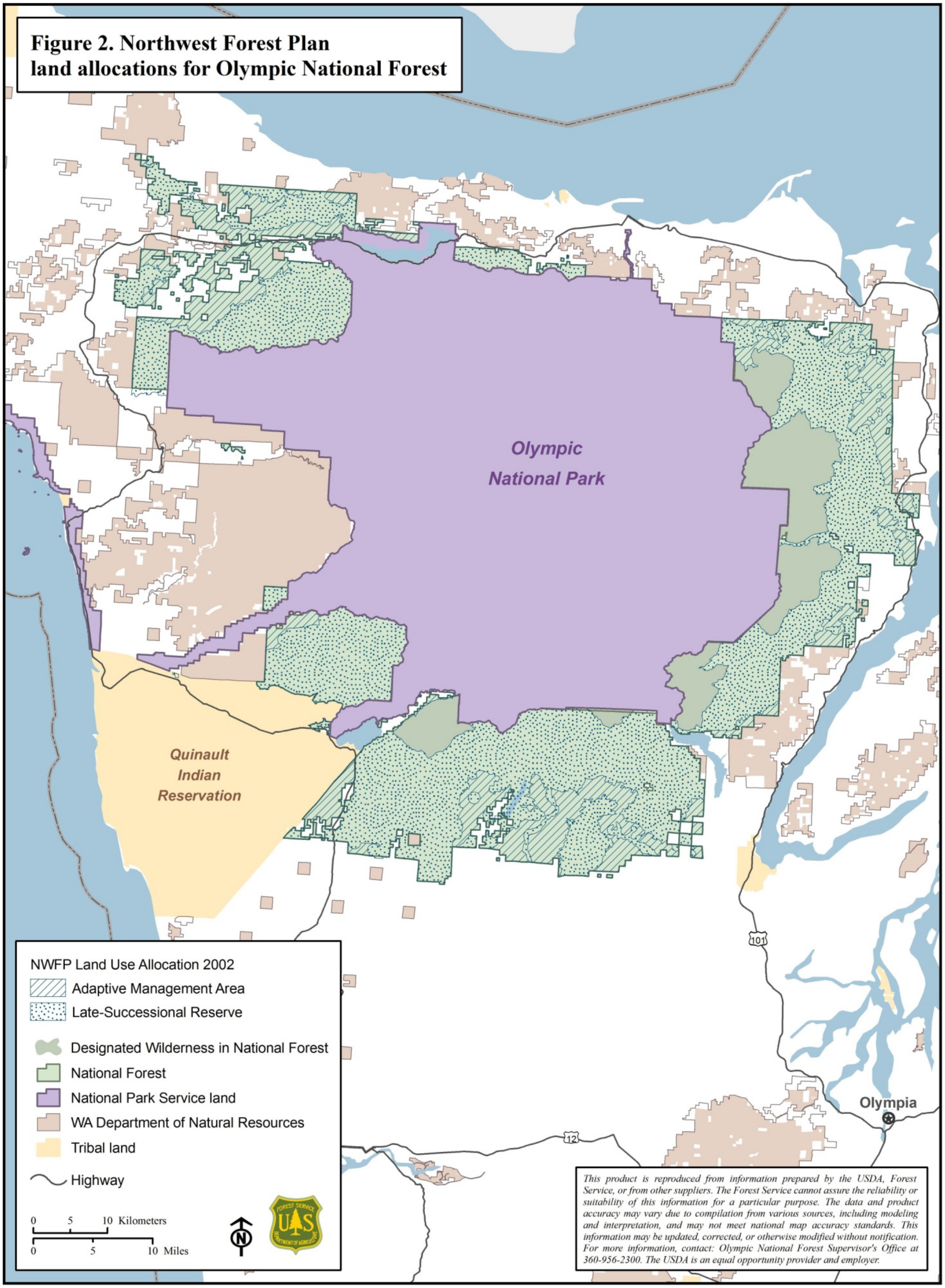


Figure 2. Northwest Forest Plan land allocations for Olympic National Forest

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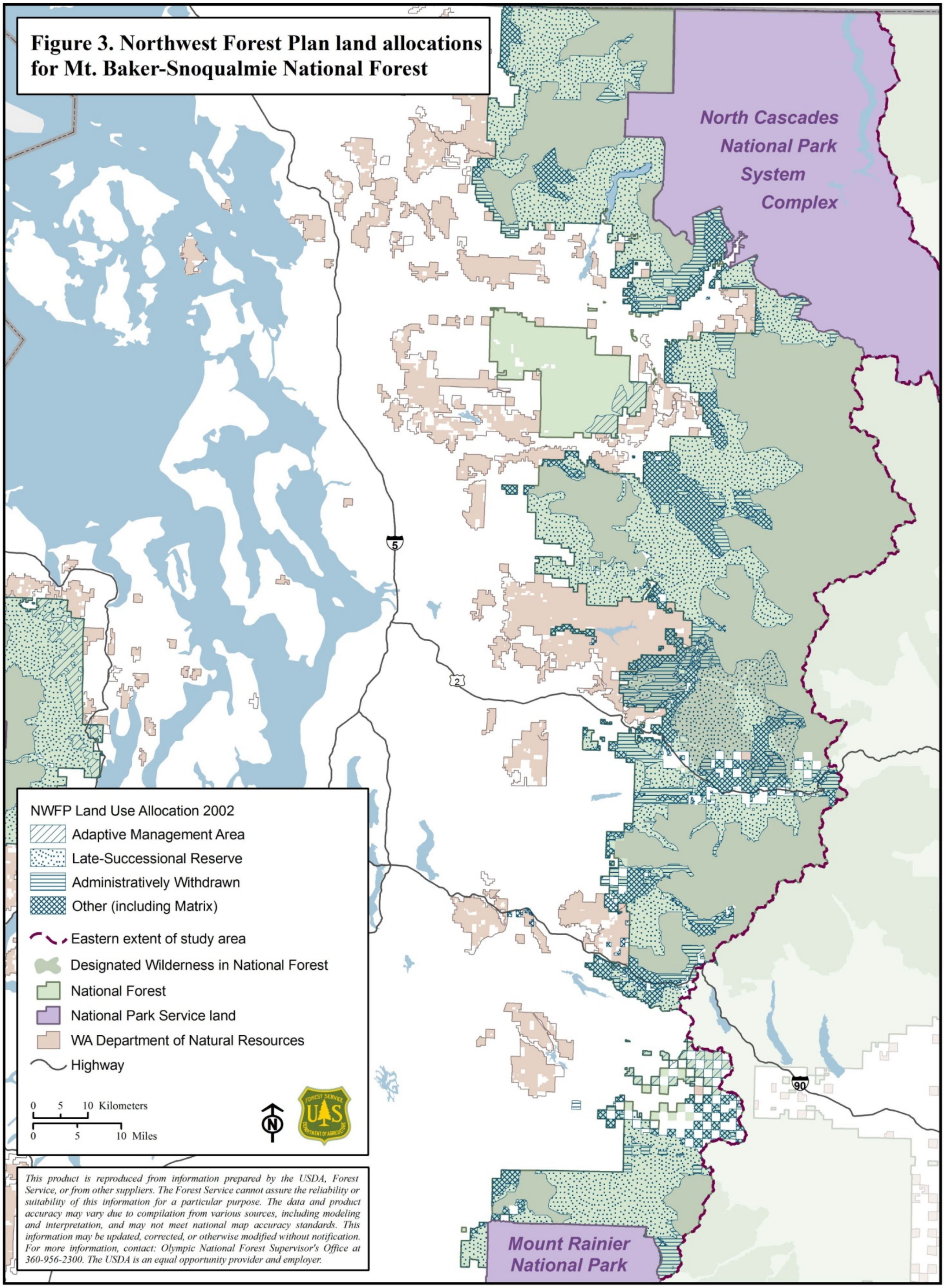
Figure 3. Northwest Forest Plan land allocations for Mt. Baker-Snoqualmie National Forest



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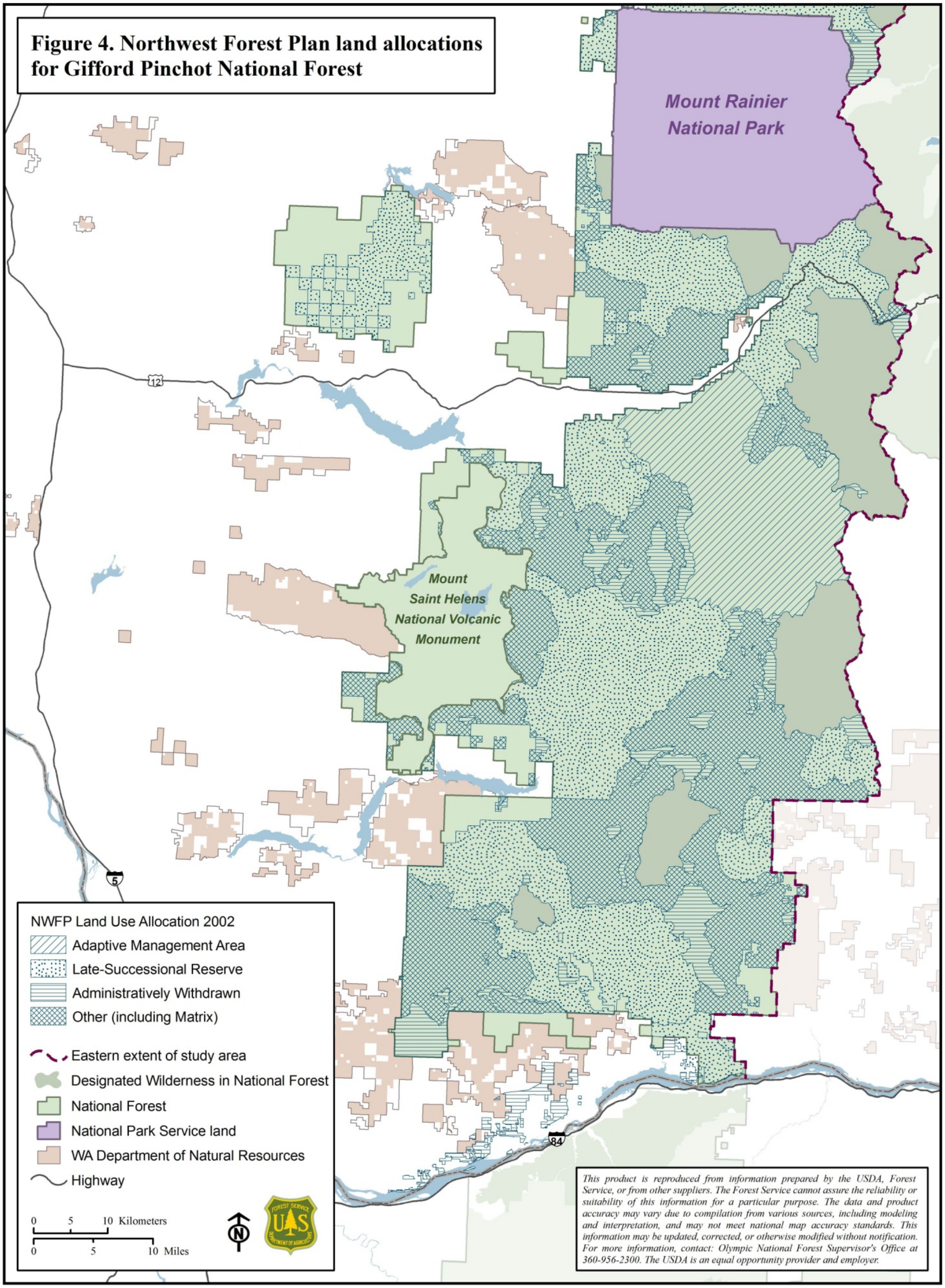

Figure 4. Northwest Forest Plan land allocations for Gifford Pinchot National Forest

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GOALS, ASSESSMENT TARGETS, AND OBJECTIVES

The goal of this analysis is to conduct an assessment of the vulnerability of forest tree species and non-forested habitats to climate change.

Forest Tree Species

Forest trees are the first priority for analysis of the impacts of climate change on individual plant species. Trees provide stand structure and dictate the composition of plant communities in the forests of the Pacific Northwest. Many of these tree species also have high economic or cultural value. Because trees are long-lived and have long generational intervals, they may be slower to adapt and migrate and thus may be more at risk to changes in climate than forb or grass species. Grasses, forbs, and shrubs that are at risk because of habitat loss or other factors (though not specifically because of predicted changes in climate) are protected, monitored, and often restored under the Endangered Species Act and the Interagency Special Status/Sensitive Species Program (ISSSSP) (USDA Forest Service 2010c). There is only one tree species evaluated in this project that is under any special protection: *Chrysolepis chrysophylla*, golden chinquapin, has sensitive species status for the Olympic and Gifford Pinchot National Forests.

Selected Vulnerable Non-Forested Habitats: Alpine and Subalpine Habitats, Dry Grasslands, and Wetlands

Certain non-forested habitats, and their associated species, are more vulnerable to climate change owing to geographic location (e.g., high elevation) or to expected climate-induced changes in hydrology. These vulnerable habitats warrant specific adaptation strategies in response to projected changes in climate. In this analysis, alpine and subalpine, dry grassland, and wetland habitats are evaluated.

Objectives

The specific objectives of this analysis are to:

- Assess the potential impacts of predicted changes in climate on both forest trees and selected vulnerable habitats: alpine and subalpine habitats, dry grasslands, and wetlands.
- Evaluate tools that have been developed to assess vulnerability and mitigate the expected stressors of a warming climate.
- Recommend actions that will improve understanding of changes taking place among tree species and non-forested habitats, maintain and increase biodiversity and increase resilience, and prepare for an uncertain future.
- Collaborate in the implementation of these actions with the two other predominant public land management agencies in western Washington: the National Park Service and the Washington Department of Natural Resources.

These objectives follow the guidelines for agency accountability in the USDA Forest Service National Roadmap for Responding to Climate Change (USDA Forest Service 2010d).

PART 1:
FOREST TREE SPECIES

TREE SPECIES OF WESTERN WASHINGTON

Introduction

In this report, we evaluate the climate change vulnerability of the 34 native tree species that occur on western Washington's national forests, national parks, and lands managed by Washington Depart of Natural Resources. Here, trees are defined as woody perennials capable of producing a single stem with apical dominance and reaching at least 20 ft (6 m) in height. Of the 34 native tree species occurring in western Washington (table 2), 17 are coniferous and 17 are broadleaf species. The *Abies* and *Pinus* genera contain the greatest number of species, four each. All the western Washington conifers are evergreen, and all but two of the broadleaf trees (Pacific madrone and golden chinquapin) are deciduous.

Grouping

To facilitate analysis, we organized the tree species of western Washington into three groups (table 2). Group 1 consists of 15 overstory tree species that are common in major portions of western Washington and are thus important components of the forest canopy and overall forest structure. This group includes species that are widespread across western Washington (e.g., western hemlock and western redcedar at low- to mid-elevations) and species that are common within more limited zones (e.g., subalpine fir and mountain hemlock in mid- to high-elevation habitat). These Group 1 species are a major focus of this report because changes in their distribution or health could affect forest structure and habitat at a broad scale. Group 2 includes trees that are not significant components of the forest canopy owing to small size (e.g., cascara, Scouler's willow, and Pacific dogwood) or to limited occurrence in western Washington (e.g., quaking aspen, paper birch, and Oregon white oak). Within the latter category, trees may occur infrequently across broad areas or may be common within a limited habitat.

The third species group consists of trees that are rare in western Washington or are represented by disjunct populations. The species in this group are golden chinquapin, whitebark pine, Rocky Mountain juniper, and ponderosa pine.

Habitats

Most of the forests of western Washington are dominated by large, long-lived conifers, while broadleaf trees are generally confined to the forest understory and edges, canopy gaps, disturbed areas, riparian zones, and very wet or dry sites. Many of the broadleaf species typically occur individually or in groves and are not major components of forest stands. Only a small number of the broadleaf trees, including red alder, bigleaf maple, black cottonwood, and Oregon white oak, are often significant components of a forest canopy.

Distribution

The diverse physiography of western Washington is associated with a wide variety of ecological niches and vegetation types. The major forest types can be described as potential natural vegetation zones (Henderson 2009): the climax vegetation types that would develop under the current climate in the absence disturbance (figs. 5, 6, and 7). Given projected changes in climate, future zones are likely to differ from those shown for current conditions.

Some of the most common conifers of western Washington—including western hemlock, western redcedar, and grand fir—have ranges restricted to the Pacific Northwest maritime zone, which includes the coastal strip from southeastern Alaska to northern California and the moist western slopes of the northern Rocky Mountains. The high-elevation conifers of western Washington—such as whitebark pine, Engelmann spruce, and subalpine fir—are tolerant of

Table 2. Native tree species of western Washington[1]

Scientific name	Common name	Symbol	Group[2]	Division	Type
Abies amabilis	Pacific silver fir	ABAM	1	Conifer	Evergreen
Abies grandis	Grand fir	ABGR	1	Conifer	Evergreen
Abies lasiocarpa	Subalpine fir	ABLA	1	Conifer	Evergreen
Abies procera	Noble fir	ABPR	1	Conifer	Evergreen
Acer macrophyllum	Bigleaf maple	ACMA3	1	Broadleaf	Deciduous
Alnus rubra	Red alder	ALRU2	1	Broadleaf	Deciduous
Cupressus nootkatensis	Alaska yellow-cedar	CUNO	1	Conifer	Evergreen
Picea engelmannii	Engelmann spruce	PIEN	1	Conifer	Evergreen
Picea sitchensis	Sitka spruce	PISI	1	Conifer	Evergreen
Pinus monticola	Western white pine	PIMO3	1	Conifer	Evergreen
Populus balsamifera ssp. *trichocarpa*	Black cottonwood	POBAT	1	Broadleaf	Deciduous
Pseudotsuga menziesii	Douglas-fir	PSME	1	Conifer	Evergreen
Thuja plicata	Western redcedar	THPL	1	Conifer	Evergreen
Tsuga heterophylla	Western hemlock	TSHE	1	Conifer	Evergreen
Tsuga mertensiana	Mountain hemlock	TSME	1	Conifer	Evergreen
Acer glabrum var. *douglasii*	Douglas maple	ACGLD4	2	Broadleaf	Deciduous
Arbutus menziesii	Pacific madrone	ARME	2	Broadleaf	Evergreen
Betula papyrifera	Paper birch	BEPA	2	Broadleaf	Deciduous
Cornus nuttallii	Pacific dogwood	CONU4	2	Broadleaf	Deciduous
Crataegus douglasii and *C. suksdorfii*[3]	Black hawthorn and Suksdorf's hawthorn	CRDO2 CRSU16	2	Broadleaf	Deciduous
Frangula purshiana	Cascara	FRPU7	2	Broadleaf	Deciduous
Fraxinus latifolia	Oregon ash	FRLA	2	Broadleaf	Deciduous
Malus fusca	Western crab apple	MAFU	2	Broadleaf	Deciduous
Pinus contorta var. *contorta* and var. *latifolia*	Shore pine and lodgepole pine	PICOC PICOL	2	Conifer	Evergreen
Populus tremuloides	Quaking aspen	POTR5	2	Broadleaf	Deciduous
Prunus emarginata	Bitter cherry	PREM	2	Broadleaf	Deciduous
Quercus garryana	Oregon white oak	QUGA4	2	Broadleaf	Deciduous
Salix lucida ssp. *lasiandra*	Pacific willow	SALUL	2	Broadleaf	Deciduous
Salix scouleriana	Scouler's willow	SASC	2	Broadleaf	Deciduous
Taxus brevifolia	Pacific yew	TABR2	2	Conifer	Evergreen
Chrysolepis chrysophylla	Golden chinquapin	CHCH7	3	Broadleaf	Evergreen
Juniperus scopulorum	Rocky mountain juniper	JUSC2	3	Conifer	Evergreen
Pinus albicaulis	Whitebark pine	PIAL	3	Conifer	Evergreen
Pinus ponderosa	Ponderosa pine	PIPO	3	Conifer	Evergreen

[1] *Nomenclature follows the U.S. Department of Agriculture Plants Database (USDA NRCS 2010); in cases where multiple common names exist, regionally favored names are used here.*

[2] *Group 1 = overstory trees with widespread distribution in western Washington; Group 2 = trees that are not major overstory components owing to limited distribution or small size; Group 3 = trees that are rare in western Washington or that are represented only by disjunct populations.*

[3] *Black hawthorn and Suksdorf's hawthorn are described together because much of the available data on these species were published when they were known as varieties of the same species. For convenience, the two species are simply referred to as "black hawthorn" in the text.*

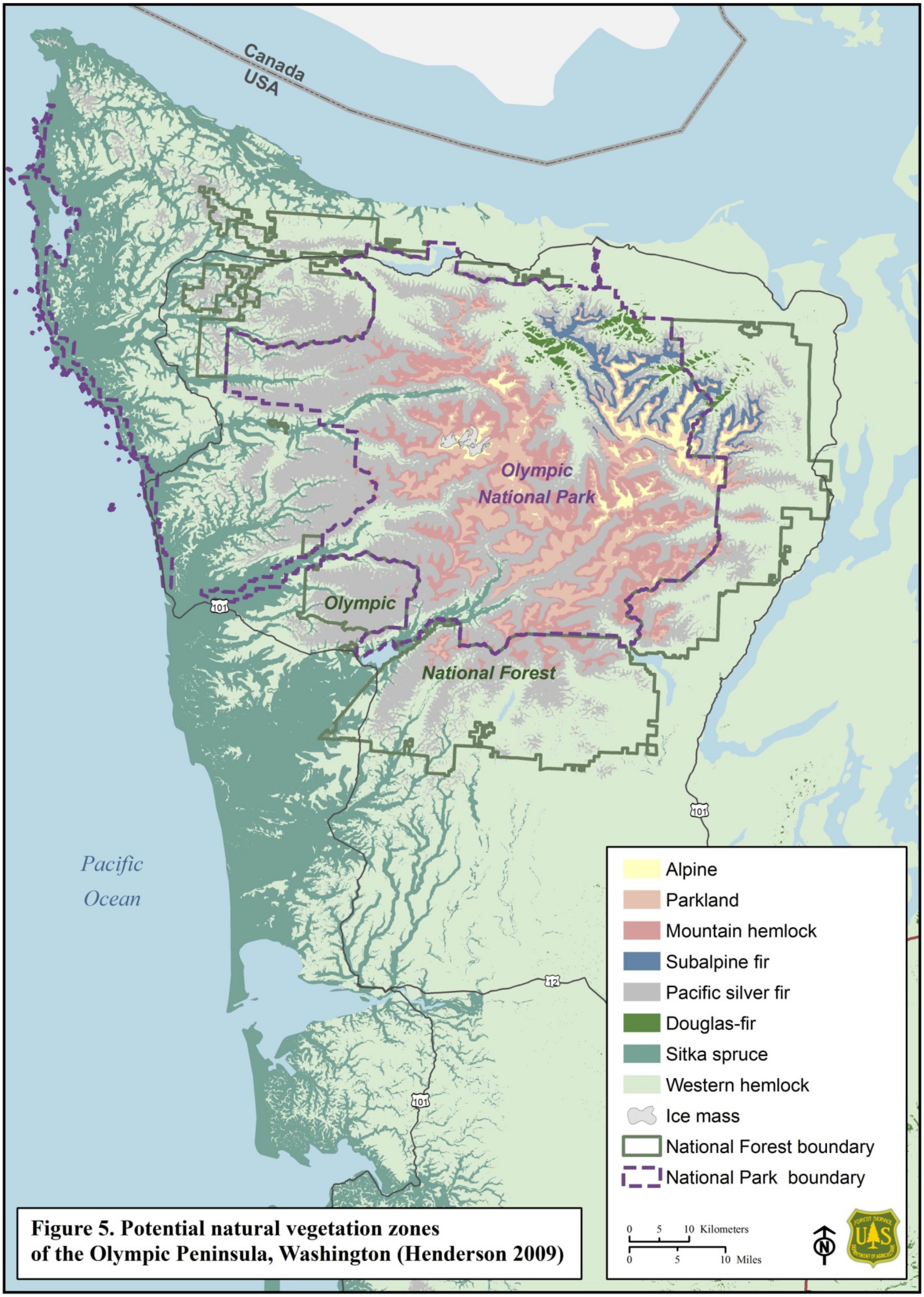

Figure 5. Potential natural vegetation zones of the Olympic Peninsula, Washington (Henderson 2009)

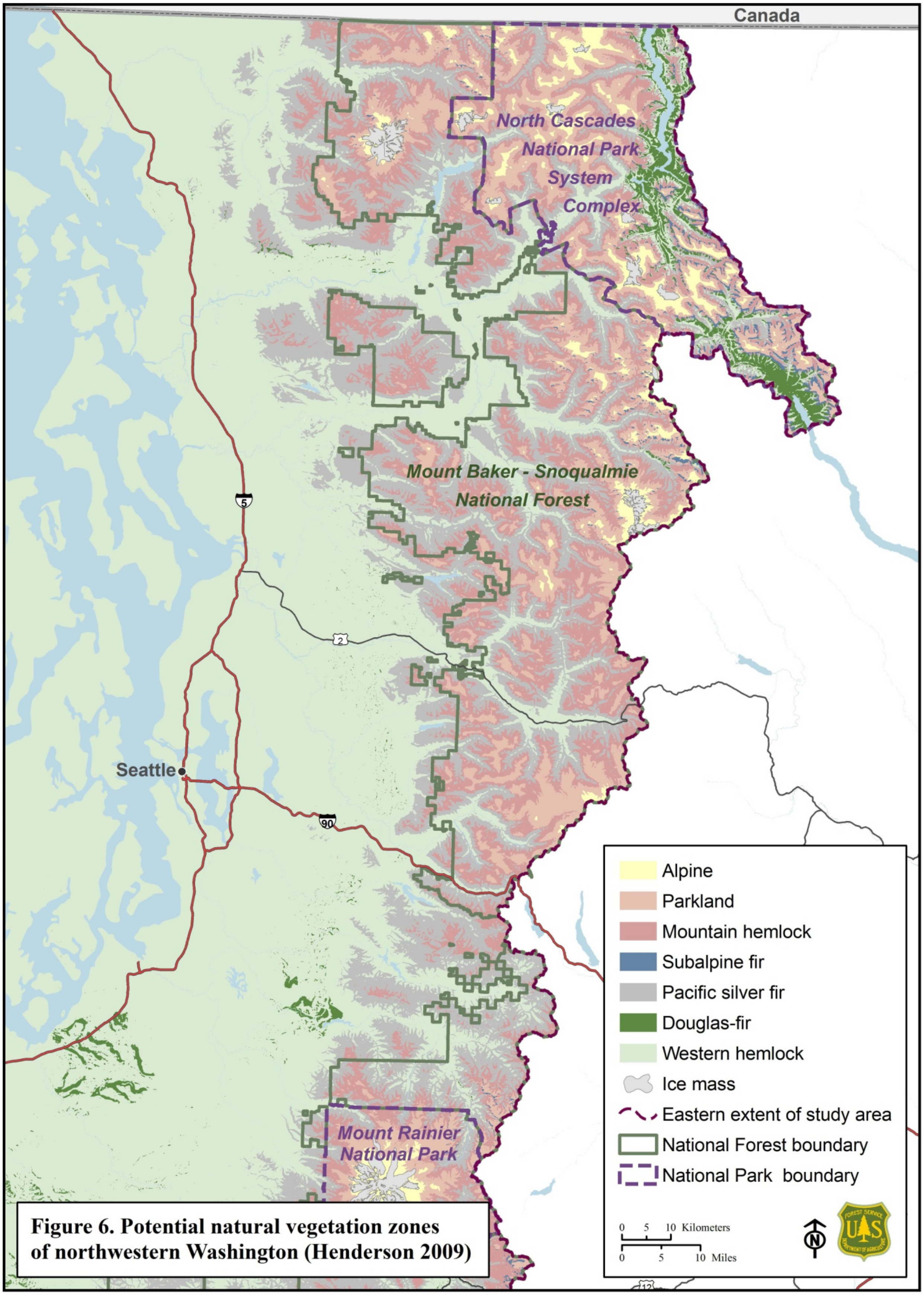

Figure 6. Potential natural vegetation zones of northwestern Washington (Henderson 2009)

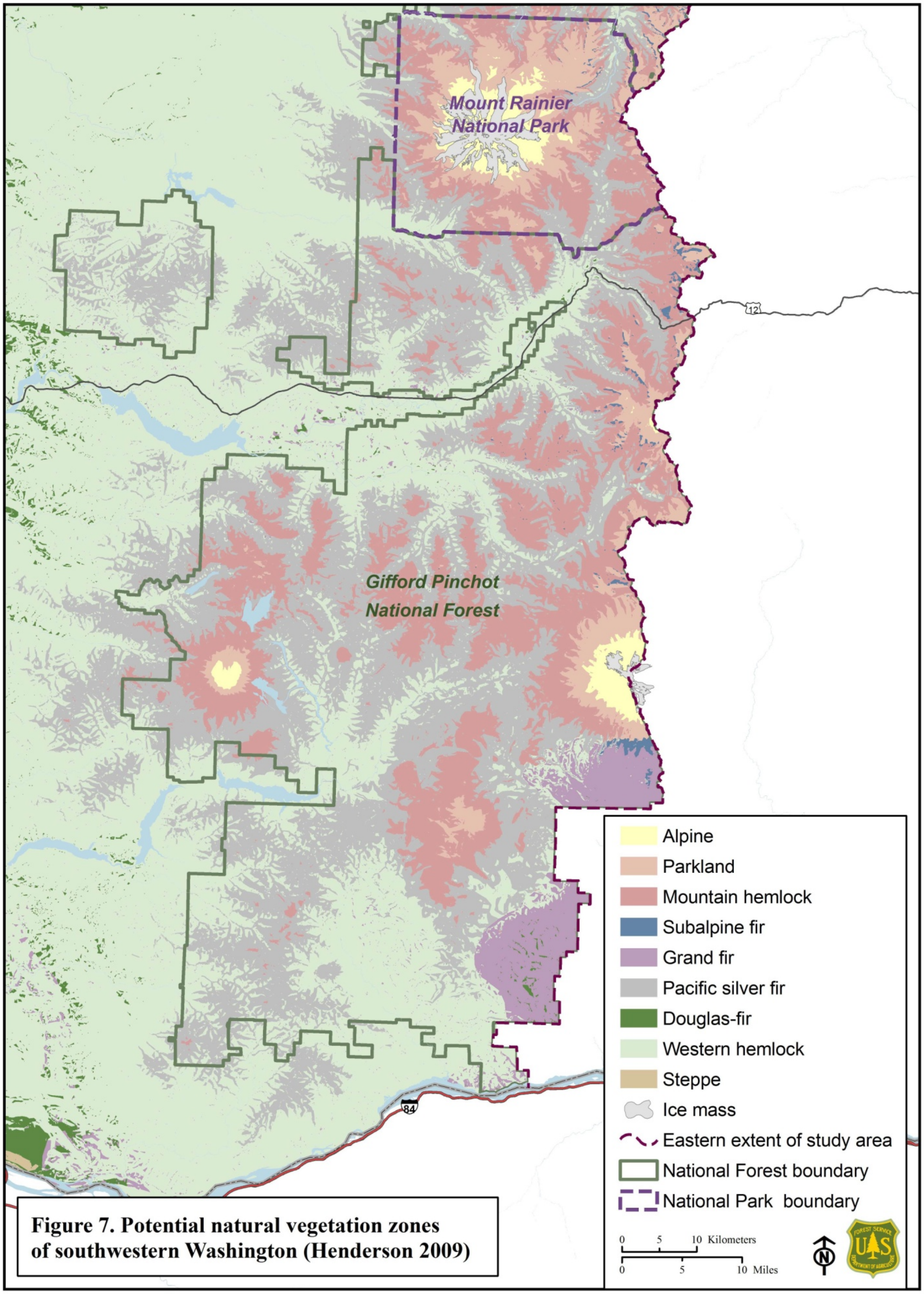

Figure 7. Potential natural vegetation zones of southwestern Washington (Henderson 2009)

low temperatures, and their ranges stretch northward into interior Canada and eastward across the U.S. Rocky Mountains. Other conifer species with broader ecological amplitudes—including Douglas-fir, ponderosa pine, and lodgepole pine—have expansive ranges that stretch from Canada, throughout the western United States, and into Mexico.

The broadleaf trees of western Washington include species found predominantly in the Pacific Northwest, such as red alder and bigleaf maple, as well as species covering substantial portions of North America, such as quaking aspen, paper birch, and Scouler's willow.

Distribution maps

Distribution maps for tree species of western Washington were created with the intention of showing documented occurrences using the latest available data (appendix A). For most of these species, high-quality range maps are available elsewhere (e.g., Little 1971, 1976); however, at the scale of this assessment, such range maps lack the desired resolution. Alternatively, computer models have been used to predict changes in tree species' habitat based on climate and other environmental variables (e.g., Crookston 2010, Hargrove and Hoffman 2005). While these model predictions are useful for many purposes, they are designed to produce maps predicting suitable habitat rather than current species distributions.

Map data were acquired from a variety of sources (table 3). The majority of the data shown on the maps in appendix A are from three Forest Service sources and from the National Park Service. The sources of Forest Service data are: Forest Inventory and Analysis (FIA) (USDA Forest Service 2010b), the Current Vegetation Survey (CVS) (USDA Forest Service 2008), and the Forest Service Region 6 Ecology Program Core Dataset (USDA 2010a) (plot locations for each data source are shown on pages A-3 through A-6). Inventory data from WADNR were not in a format conducive to the mapping of individual species occurrences; thus, these data generally were not used for species maps. In some instances, however, data collected by WADNR were used when the FIA dataset failed to adequately represent known occurrences of a species on WADNR lands (e.g., golden chinquapin and noble fir).

While the combined data of the major inventories described the distributions of most species well, sampling protocols occasionally excluded certain species. For example, small trees such as black hawthorn and pacific willow were considered to be shrubs according to some tree inventory protocols. For such species, data from FIA, CVS, or Park Service inventories might be absent from one or more of the national parks or national forests. In other cases, known ranges of infrequently occurring species were poorly represented in inventories simply because they rarely occurred on the sample plots (e.g., Oregon white oak). For species underrepresented in the four major inventories, data were drawn from other sources including herbarium specimens collected from documented locations and species-specific surveys conducted by public agencies. These additional data sources were not added for species with ranges already fully represented by data from the four major inventories.

Interpreting maps

Data collection protocols differed among inventories; thus, several factors should be considered when interpreting maps. First, plot density varied by inventory; therefore, the density of points on a map does not necessarily correspond to the density at which a tree species occurs. For example, if the range of a species encompasses a national forest and an adjacent national park, the density of mapped points could be much greater in the national park than in the national forest. But this higher density of mapped occurrences may be a result of a higher density of sampling locations in the park and unrelated to an actual difference in the frequency of the species' occurrence. Additionally, the density of mapped species occurrences is affected by sample plot size, which varied among inventories. An inventory that uses larger plots is likely to sample a given species more frequently on its plots compared to an inventory that uses smaller plots. Finally, the density of mapped species occurrences is a function of inventory design. An inventory of regularly spaced plots on a grid (e.g., FIA) is much less likely to sample a particular species than an inventory with an objective of locating and sampling that species (e.g, herbarium collections or species-specific Forest Service surveys). Owing to influences of such factors, mapped species occurrences should be interpreted as representing the extent of a species' distribution rather than as representing its density within that distribution.

Tree Species Profiles

Drawing on information from a variety of published sources, we compiled profiles of the 34 western Washington tree species (appendix B). These profiles emphasize biological and ecological characteristics that were deemed relevant to the trees' potential adaptation to predicted changes in climate. The amount of published information available for each species varied significantly. A substantial body of literature is available for commercially valuable species including Douglas-fir, western hemlock, and ponderosa pine. However, other species such as western crab apple, bitter cherry, and Scouler's willow have not received much attention despite their ecological importance. As a result, the level of detail provided in these profiles varies by species.

The tree profiles presented in appendix B focus on the ecological characteristics, reproduction and growth, genetics, and threats and management considerations relevant to each species. The ecological description contains information on each species' distribution, habitat, and ecological amplitude; this information may assist in predicting a species' potential response to climate-induced changes in its habitat. Reproductive characteristics such as seed production, reproductive age, and seed dispersal distance affect the rate at which a species evolves and migrates. Threats and management considerations include disturbances such as insects, diseases, and wildfire, which may be exacerbated by a change in climate.

Table 3. Explanation of data sources used to create tree species distribution maps for western Washington

Dataset	Source	Coverage	Inventory design	Data priority for maps
Forest Inventory and Analysis (FIA)	USDA Forest Service, Region 6	All public and private lands[1]	Regularly spaced plots	Always used[2]
Current Vegetation Survey (CVS)	USDA Forest Service, Region 6	National forests	Regularly spaced plots	Always used[2]
USFS Region 6 Ecology Program	USDA Forest Service, Region 6	National forests	Plots located according to plant community type	Always used
National parks	USDI National Park Service	Lands managed by the National Park Service	Irregularly spaced plots	Always used[2]
University of Washington Herbarium	Burke Museum, University of Washington	Public and private land in Washington	Species collections by many individuals with various objectives	Used when other data sources did not adequately represent known distribution
National forest surveys	USDA Forest Service, Region 6	National forests	Surveys based on individual species of interest	Used in cases where surveys were conducted
Other	WADNR; USDA Forest Service Pacific Northwest Research Station; Department of Defense	Various	Surveys based on individual species of interest	Used when other data sources did not adequately represent known distribution

[1] A small amount of random error was intentionally added to the FIA plot locations to protect the identity of landowners.

[2] In a few cases, these datasets did not include species that, at the time of data collection, were considered shrubs rather than trees. Thus, inventory data for a given species might be absent from one or more of the national forests or national parks.

VULNERABILITY ASSESSMENT OF WESTERN WASHINGTON TREE SPECIES

Introduction

Each tree species has a unique set of factors that determines its vulnerability to climate change. Among the many such factors are inherent sensitivity to changes in temperature and precipitation patterns, genetic capacity to adapt to changing habitat, and seed dispersal sufficient for the species to follow geographic shifts in habitat.

A vulnerability assessment is a systematic process of identifying and quantifying the areas of vulnerability within a system (Glick and Stein 2010), or in this case, forest tree species. We chose to use vulnerability assessment models to address the following questions about the vulnerability of western Washington's tree species to projected climate change:

- How vulnerable to climate change are the tree species of western Washington?
- How do we identify the underlying causes of a species' vulnerability?
- Can vulnerability of tree species to climate change be quantified in a way that facilitates ranking to prioritize management response?

Our objectives for vulnerability assessment were to: (1) select a method that is straightforward to apply, transparent, flexible, and provides for easy application of sensitivity analysis; and (2) rank the tree species of Group 1 (table 2) according to their vulnerability to climate change impacts. Group 2 species were not subjected to formal vulnerability assessment ranking because most lacked sufficient data in the scientific literature. Group 3 species were not ranked because all are rare in western Washington and therefore considered vulnerable to climate change.

Climate Change Vulnerability Assessment Systems

Selecting a Vulnerability Assessment System

We first evaluated two publicly available climate change vulnerability assessment systems: the NatureServe Climate Change Vulnerability Index (NSVI) version 2.0 (NatureServe 2010a) and the Climate Change Sensitivity Database (CCSD), a part of the Pacific Northwest Climate Change Vulnerability Assessment (Lawler and Case 2010b). Both of these systems were developed recently (since 2009), and at this time there are few published reviews based on their application (Glick and Stein 2010, NatureServe 2010a). In our evaluations, we applied these climate change vulnerability assessment systems to six western Washington tree species. We examined the results and critically evaluated the suitability of these systems for assessing the tree species of western Washington. In our evaluations, we considered each system's ease of use, transparency, flexibility, and sensitivity. The full evaluations of the NSVI and CCSD systems appear in appendices C and D, and a general comparison of the two systems is shown in table 4.

Our evaluations revealed that neither the NSVI nor the CCSD met all of our requirements for assessing tree species' vulnerability. The CCSD contained a relatively small, fixed set of variables and lacked the detail desired for our assessment. Although the NSVI contained many of the variables that we deemed important for assessing climate change vulnerability, it did not allow us to add new variables that we considered vital for assessing tree species of western Washington. Furthermore, the NSVI's calculations and variable weightings were not clear. After concluding that the NSVI and CCSD were not well-suited to our objectives, we examined a third model, the Forest Tree Genetic Risk Assessment System (GRAS) (Potter and Crane 2010). We determined that the Forest Tree GRAS provided the best option for developing a vulnerability assessment system suited to our regional needs and data availability. It offered the flexibility to add and remove variables as needed, and its

Table 4. Comparison of the NatureServe Climate Change Vulnerability Index (NSVI) and the Climate Change Sensitivity Database (CCSD) vulnerability assessments and their suitability for evaluating the tree species of western Washington

	Model		
Attribute	**NSVI**	**CCSD**	**Evaluation**
Required data	The model requires relatively detailed biological data that may not be available for some species	The model is based on general ecological traits and habitat requirements	Both systems allow flexibility for missing data; it is unclear whether the detailed data required by NSVI produces more accurate results
Ease of use	Relatively easy to use; the spreadsheet model was accompanied by detailed instructions and ran with few glitches	Easy to use; the online model was simple and straightforward but provided minimal guidance for rating sensitivity factors	NSVI was far more complex but provided substantial documentation in the model and as a separate publication
Model transparency	Low transparency; it is unclear how rating factors are weighted and how scores are calculated	Calculation of the sensitivity index score is simple and clearly described	The high transparency of CCSD increases user confidence in the model output
Flexibility	Up to 26 relatively specific factors may be rated; users may rate fewer factors based on availability of data; weighting of factors cannot be adjusted	Up to eight general factors may be rated; users may rate fewer based on availability of data; weighting of factors may be adjusted by users	Adjustable weighting of factors was advantageous for CCSD; both systems had some factors intended for animal species; only NSVI provided detailed guidance on applying the model to plant species
Output format	A categorical vulnerability rating (6 categories) and a categorical score of confidence in rating (4 categories)	A sensitivity index score (0 to 100) and a confidence index score (0 to 100)	The scores calculated by NSVI reflect the precision of the input data, while those of CCSD suggest greater precision than was present in the data
Applicability to trees of western Washington	Scores are calculated from a large amount of detailed information, although a few of these factors are not applicable; other potentially important factors are not included	This simple index uses rating factors that are very general; guidance for rating is minimal and thus ratings are more susceptible to user bias	Neither model included all of the factors that we believe affect vulnerability of western Washington trees; NSVI is a useful starting point, as it requires users to compile and organize relevant data

calculations were simple and transparent. Therefore, we selected the Forest Tree GRAS to assess climate change vulnerability of the 15 Group 1 tree species. The process of applying the Forest Tree GRAS, and the results, are described in detail in the following sections.

The Forest Tree Genetic Risk Assessment System

The Forest Tree GRAS rates each species according to intrinsic attributes and external threats that can influence the species’ vulnerability to climate change (Potter and Crane 2010). Intrinsic attributes include population structure, fecundity, and mechanism of seed dispersal; external threats include projected climate change and major insects and diseases. These attributes and threats are quantified using six risk factors, each of which produces a numeric score. The factor scores are then used to calculate an overall risk score for the species within a given region.

Completing the GRAS entails four steps (Potter and Crane 2010):

- First, the user identifies the area and species of interest.
- Second, the user selects the appropriate risk factors.

- Third, for each species, the user collects relevant data that are used to calculate risk factor scores.
- Finally, the user weights factor scores, calculates final scores for each species, and then ranks the species based on the final scores.

The Forest Tree GRAS is presented in the form of a user-friendly guide to developing and scoring risk factors. The system provides flexibility in the choice of risk factors and variables within factors; however, using all factors requires gathering a significant amount of information that can be time-consuming. Our evaluation of the Forest Tree GRAS is summarized in table 5.

In applying the Forest Tree GRAS to the climate change vulnerability of the major tree species of western Washington (i.e., species Group 1), we incorporated variables into five risk factors: distribution, reproductive capacity, habitat affinity, adaptive genetic variation, and threats from insects and diseases. Table 6 summarizes these risk factors, the variables selected for each risk factor, and how each variable was rated. Most of the information used to rate these variables came from published literature and is included in the tree profiles in appendix B. Following the procedure in the GRAS user's guide (Potter and Crane 2010), we used FIA inventory data to describe the distribution of the tree species within western Washington. We used some of the life history and genetic variation variables described by Potter and Crane (2010), although we also added additional variables that had greater regional relevance. Information on insect and disease threats was provided by an expert panel from the USDA Forest Service, Pacific Northwest Region (Region 6) Forest Health Protection Program.

We initially planned to use the climate pressure factor as designed by Potter and Crane (2010), in our

Table 5. Evaluation of the Forest Tree Genetic Risk Assessment System (GRAS) developed by Potter and Crane (2010)

Attribute	Description	Evaluation
Required data	All risk factors and variables within risk factors are selected by the user; use of information on tree distribution and density requires knowledge of and ability to extract data from existing data sources such as the FIA database; assistance is available from the FIA program	Allows flexibility for missing data; all information must be compiled by the user, which can require significant time reviewing literature and performing calculations depending on the number of variables selected
Ease of use	Very easy to use	The instructions in the guide are clear and well-organized; the use of spreadsheets to summarize information and calculate indices makes this approach very accessible; the example of the assessment of trees in the sensitivity analysis is very useful
Model transparency	High transparency; all ratings appear in tables and score calculations are described	This high transparency increases user confidence in the model output; sensitivity analysis is easy and can be done quickly
Flexibility	Any number of risk factors and variables within risk factors can be used, and factor and variable weighting is adjustable	The boundless choice of risk factors and adjustable weighting of factors is very advantageous but also requires knowledge of species biology, genetics, and climate prediction systems to make sound choices; expert advice is critical when the user lacks knowledge in a specific subject area, but interpreting and incorporating this information can be time-consuming
Output format	Scores for each risk factor (0 to 100) and an overall vulnerability score and ranking for each species	The calculated scores reflect the precision of the input data and the weighting used
Applicability to trees of western Washington	All factors were chosen for their relevance to tree species of western Washington, assuring applicability	Compiling and organizing relevant data and discussing candidate factors resulted in a greater understanding of the vulnerability of trees to climate changes

application of the Forest Tree GRAS. This risk factor incorporates climate change pressure using modeled changes in suitable habitat for each tree species, which are based on projected changes in future climate. Maps showing predicted present and future habitat distribution were acquired for Group 1 tree species (Hargrove et al. 2010, Rehfeldt et al. 2006). Using these maps of present and future habitat distributions, we developed a system to combine the results of these two modeling approaches and to classify each species' projected habitat distribution as increasing, decreasing, or not changing. However, during our peer review process, concerns were raised over the level of uncertainty associated with the workings of these models and the use of bioclimatic envelope models in species distribution predictions. After further consideration, we decided to drop this risk factor from the analysis. A detailed account of the development of the climate pressure risk factor and discussion of the issues associated with its use are given in appendix E.

Results of Applying the Forest Tree Genetic Risk Assessment System to Group 1 Tree Species

The following subsections include descriptions of each of the five risk factors used in the Forest Tree GRAS, key observations made during the assessment, and tables showing the risk factor variables and scores for the 15 Group 1 tree species. Within each table, tree species are ranked based on the score for that risk factor; higher scores indicate higher risk given projected changes in climate. Both raw scores and scaled scores are presented for each factor. The purpose of the scaled scores is to provide equal weighting to each of the five factors (i.e., scores ranging from 0 to 100) for calculation of an overall vulnerability score for each species. These overall vulnerability scores are presented at the end of this section.

Distribution

Approach

The distribution factor is derived from both qualitative and quantitative assessments of the distribution of each species in western Washington (table 7). The factor's qualitative assessment variable, Distribution Within Western Washington, is based on visual examination of a species' distribution map (appendix A). A vulnerability rating is assigned to this variable according to the overall extent of a species' distribution, regardless of the point density. The variable is based on the general assumption that a broader distribution is at lower risk of climate change effects. The quantitative variable, Frequency of Occurrence, is the percentage of FIA plots on which a species occurs, regardless of how the occurrences are distributed across western Washington. The second quantitative variable, Portion of All Canopy Trees on Plots, is the average percentage of all canopy trees (defined here as trees coded by FIA as in the dominant, co-dominant, or open-grown crown classes) that a given species represents on the FIA plots on which it occurs. Canopy trees are generally the trees with the greatest vigor and reproductive capacity because they receive more sunlight and typically have larger crowns than trees in intermediate and suppressed crown classes. Thus, species occupying a greater portion of the forest canopy are assigned lower vulnerability scores.

Our distribution factor is based on two of the factors of Potter and Crane's (2010) original risk assessment system: Population Structure and Rarity/Density. Distribution Within Western Washington is a surrogate for Potter and Crane's (2010) variable quantifying the size of a species' range within the area of interest (from their population structure factor), and our Frequency of Occurrence variable is calculated in the same manner as the corresponding variable in Potter and Crane's (2010) rarity/density factor. Portion of All Canopy Trees on Plots is a modification of the density variable from Potter and Crane's (2010) rarity/density factor.

Table 6. Risk factor and variable descriptions and scoring system for the Forest Tree GRAS; higher scores indicate greater vulnerability

Risk factor	Variable	Description	Scoring system
Distribution	Distribution within western Washington	Qualitative assessment, scored by examining distribution maps[1]	Wide = 0 Moderate = 25 Narrow = 50 Rare = 100
	Frequency of occurrence	Percentage of FIA plots with species present	Rank of each value as a percentage of the data set
	Portion of canopy trees on plots	Mean portion of all canopy trees (dominant, co-dominant, and open grown crown classes) of a given species in all FIA plots with that species present	Rank of each value as a percentage of the data set
Reproductive capacity[2]	Dioecy	Breeding system	Monoecious = 0 Dioecious = 100
	Sound seed	Proportion of filled seeds in mature cones or fruits	High = 0 Medium = 50 Low = 100
	Minimum seed-bearing age	Age at which seed production begins under good growing conditions	< 10 years = 0 10 to 20 years = 50 > 20 years = 100
	Seed dispersal capacity	Distance within which most seed is dispersed	> 0.5 mile = 0 400 ft to 0.5 miles = 50 < 400 ft = 100
Habitat affinity	Mean elevation	Mean elevation (ft) of all occurrences on FIA plots	Rank of each value as a percentage of the data set
	Successional stage[2]	Successional stage(s) in which the species commonly occurs	Early = 0 Early to late = 50 Late = 100
	Habitat specificity[2]	Habitat specificity relative to all other western Washington tree species	Low = 0 Medium = 50 High = 100
	Drought tolerance[2]	Drought tolerance relative to all other western Washington tree species	High = 0 Medium = 50 Low = 100
Adaptive genetic variation[2]	Pollen dispersal vector	Wind or insects	Wind = 0 Insects = 100
	Disjunct or geographically separated populations	Populations that are disjunct or geographically separated from the main portion of the species range	No disjunct or geographically separated populations = 0 One or more such populations = 100
	Elevation band width of seed zones[3]	Range in elevation within which movement of maladaption due to seed movement is minimized	no elevation bands = 0 ≥ 1,500 ft = 33 1,000 to 1,500 ft = 67 ≤ 1,000 ft = 100

Table 6, continued

Risk factor	Variable	Description	Scoring system
Major insect and disease threats[4]	Threat	Insect or disease that impacts the health or survival of the species	Score for each threat is calculated as the product of the severity and immediacy scores
	Severity	A rating of the present impact of insect or disease threats	Minor mortality, usually of already-stressed trees = 1 Moderate mortality in association with other threats = 3 Moderate mortality of mature trees = 5 Significant/complete mortality in related species = 6 Significant mortality of mature trees = 8 Complete mortality of all mature trees = 10
	Immediacy	Threats weighted based on present or expected exacerbation by a changing climate	Potential to reach region of interest = 1 Present in region = 2 Present in region and climate change appears to be a contributing factor in increases in distribution and impact = 3

[1] See distribution maps in appendix A.

[2] Unless otherwise noted, all information is taken from published literature, which is summarized in the tree profiles in appendix B.

[3] Randall and Berrang (2002).

[4] Information provided by expert panel, U.S. Forest Service Pacific Northwest (Region 6) Forest Health Protection Program.

Key observations

- All tree species are widely distributed across western Washington, with the exception of Engelmann spruce and noble fir, which have moderate distributions. This is a result of the area of analysis encompassing the western edge of Engelmann spruce's range and the northern edge of noble fir's range. Because the wide and moderate distribution categories were assigned scores of 0 and 25, respectively, Distribution Within Western Washington had little effect on species' overall factor scores. If this analysis were applied to all western Washington tree species, rather than Group 1 only, scores for this variable would have a wider range and therefore a greater influence on factor scores and rankings.
- Frequency of Occurrence was based on a ranking of Group 1 species; thus, potential scores for this variable ranged from 0 to 100. Percentage of plots on which individual species occurred ranged from less than 1 percent (Engelmann spruce) to 70 percent (Douglas-fir).
- The variable, Portion of All Canopy Trees on Plots, provided an approximation of a species' dominance and reproductive potential independent of the total number of plots on which that species occurred. Species with high risk scores (e.g., Engelmann spruce and western white pine) often occurred in small numbers and composed only a minor component of the forest canopy. The species with the lowest risk scores were those often occupying major portions of the forest canopy where they occurred: Douglas-fir, subalpine fir, Pacific silver fir, and red alder.

Table 7. Risk factor based on species' distributions in a climate change vulnerability assessment of 15 major western Washington tree species; higher scores indicate greater vulnerability

Species	Distribution within western Washington	FIA data		Score				
		Frequency of occurrence (% of plots)	Portion of all canopy trees on plots (%)	Distribution within western Washington[1]	Frequency of occurrence[2]	Portion of all canopy trees on plots[2]	Raw factor score	Scaled factor score
Picea engelmannii	Moderate	0.8	11.5	25	100	100	75	100
Pinus monticola	Wide	1.7	12.5	0	93	93	62	83
Populus balsamifera ssp. *trichocarpa*	Wide	4.2	17.7	0	71	71	48	63
Cupressus nootkatensis	Wide	3.5	20.2	0	86	57	48	63
Abies procera	Moderate	5.5	20.9	25	57	50	44	59
Abies grandis	Wide	4.4	20.0	0	64	64	43	57
Picea sitchensis	Wide	9.1	14.2	0	43	86	43	57
Thuja plicata	Wide	34.5	17.6	0	21	79	33	44
Tsuga mertensiana	Wide	7.9	35.7	0	50	36	29	38
Abies lasiocarpa	Wide	3.8	40.3	0	79	7	29	38
Acer macrophyllum	Wide	15.4	28.0	0	36	43	26	35
Alnus rubra	Wide	39.1	36.9	0	14	29	14	19
Abies amabilis	Wide	24.3	39.9	0	29	14	14	19
Tsuga heterophylla	Wide	60.3	37.5	0	7	21	10	13
Pseudotsuga menziesii	Wide	70.0	50.2	0	0	0	0	0

[1] *Wide distribution = 0; moderate distribution = 25.*

[2] *Score based on species ranking.*

Table 8. Risk factor based on reproductive capacity in a climate change vulnerability assessment of 15 major western Washington tree species; higher scores indicate greater vulnerability

				Score					
Species	Dioecy	Seed dispersal vector	Seeds/ pound	Dioecy[1]	Sound seed[2]	Minimum seed-bearing age[3]	Seed dispersal capacity[4]	Raw factor score	Scaled factor score
Abies amabilis	Monoecious	Wind, gravity	11,000	0	100	100	100	75	100
Abies grandis	Monoecious	Wind, mammals	18,400	0	100	50	100	63	67
Abies lasiocarpa	Monoecious	Wind	34,800	0	100	50	100	63	67
Abies procera	Monoecious	Wind	13,500	0	50	100	100	63	67
Cupressus nootkatensis	Monoecious	Wind	108,000	0	100	50	100	63	67
Picea engelmannii	Monoecious	Wind	135,000	0	50	100	100	63	67
Pseudotsuga menziesii	Monoecious	Wind	39,300	0	50	100	100	63	67
Thuja plicata	Monoecious	Wind	414,000	0	50	100	100	63	67
Picea sitchensis	Monoecious	Wind	210,000	0	50	100	50	50	33
Pinus monticola	Monoecious	Wind	27,000	0	50	50	100	50	33
Tsuga mertensiana	Monoecious	Wind	114,000	0	50	100	50	50	33
Acer macrophyllum	Monoecious	Wind	3,200	0	50	0	100	38	0
Alnus rubra	Monoecious	Wind, water	666,000	0	50	0	100	38	0
Populus balsamifera ssp. *trichocarpa*	Dioecious	Wind, water	350,000	100	50	0	0	38	0
Tsuga heterophylla	Monoecious	Wind	260,000	0	50	100	0	38	0

[1] *Monoecious = 0; dioecious = 100.*

[2] *Based on typical percentage of sound seed: high = 0; medium = 50; low = 100.*

[3] *Less than 10 years = 0; 10 to 20 years = 50; more than 20 years = 100.*

[4] *Greater than 0.5 mile = 0; 400 ft to 0.5 miles = 50; less than 400 ft = 100.*

Engelmann spruce, western white pine, and black cottonwood had the highest distribution vulnerability scores of the assessed tree species. Conversely, western hemlock, Pacific silver fir, Douglas-fir, western redcedar, and red alder had the lowest scores. With two exceptions, Frequency of Occurrence and Portion of All Canopy Trees on Plots scores were not widely disparate. The exceptions were subalpine fir and western redcedar. Subalpine fir occurred on a relatively low number of plots owing to the limited extent of its habitat, but it occupied a major portion of the canopy where it occurred. Western redcedar occurred on a relatively large number of plots but, likely as a result of its shade tolerance and capacity to survive in sub-canopy positions, averaged less than 18 percent of canopy trees on those plots.

Reproductive Capacity

Approach

The variables in this risk factor relate to regeneration and seed dispersal: Dioecy (breeding system), Percentage Sound Seed, Minimum Seed-Bearing Age, and Seed Dispersal Capacity (table 8). At greater risk are species with lower seed production, shorter seed dispersal distances, and more complex breeding systems. These scores are based on present seed biology and wind patterns, both of which may change over the next century as the climate changes and trees acclimate. Therefore, we must keep in mind that the information presented here is appropriate for the near future only and must be updated as new information becomes available.

As noted earlier, disturbances that create large openings are presently at low levels, and fewer than 300 ac (120 ha) per year are reforested across the three national forests combined. Because many of the tree species need openings to reproduce, ranking species for reproductive capacity in this case represents the relative ability of species to migrate and regenerate if large disturbances become more frequent in the future under a changing climate (Littell et al. 2010).

Key observations

- All species in Group 1 are monoecious (both male and female reproduction on the same individual) except for black cottonwood, which is dioecious (male and female reproduction on different individuals); therefore, the Dioecy variable had little effect on factor scores and species rankings.
- Because seed of all species assessed is primarily wind-dispersed (secondary dispersal agents included animals and water), all species would have received the same score if a seed dispersal vector variable were included; therefore, this variable would have had no impact on species' rankings. Although this attribute is important for evaluating reproductive capacity, we did not include it in our application of the index because there was no variation among species.
- We evaluated the use of interval between heavy seed crops (years) as a variable, but the within-species variation was too great to adequately classify species.
- Scores for Percentage Sound Seed were medium or high (50 or 100) for all species assessed.
- Minimum Seed-Bearing Age was classified into three groups: under 10 years, 10 to 20 years, and over 20 years.
- For 11 of the 15 species, most seed falls within 400 ft (120 m) of the tree. Although long-distance dispersal has been recorded for some of these species, the viability of this seed is unknown and accounts for a small percentage of total seed production.

The four species of fir (*Abies*) ranked in the highest-scoring group for this risk factor, with Pacific silver fir at the top. Also in this group were Alaska yellow-cedar, Engelmann spruce, Douglas-fir, and western redcedar. Species with the lowest scores were western hemlock, black cottonwood, red alder, and bigleaf maple. Each of these four species had either a low value for Minimum Seed-Bearing Age or a great dispersal distance.

Habitat Affinity

Approach

The habitat affinity score was calculated from four variables selected to characterize species' habitat, with specific attention to aspects of habitat expected to be influenced by projected climate change (table 9). Higher mean elevation increases vulnerability to climate change because the amount of potential habitat generally decreases with increasing elevation and because a warming climate could further reduce the extent of this habitat (Hamann and Wang 2006, Parmesan 2006). The successional stage variable was included because species adapted to late successional stages generally have greater within-population genetic diversity than species of early successional stages (Hamrick et al. 1992) and thus are assumed to be more vulnerable to loss of genetic diversity (Myking 2002, Potter and Crane 2010). The Habitat Specificity variable represents the specificity of a given species' habitat requirements relative to all other western Washington tree species. Species with low habitat specificity were assigned low vulnerability scores because it was assumed that they were less vulnerable to climate-related changes in habitat.

Our habitat affinity factor was based on the habitat affinity factor of Potter and Crane's (2010) risk assessment system, with the addition of the variable drought tolerance. Species with low drought tolerance were assigned higher vulnerability scores because seasonal drought is projected to increase. In addition to drought, there are numerous other potential stressors and disturbances (e.g., fire, windthrow, frost damage) that may be exacerbated by climate change. However, we chose to add only the drought tolerance variable in this analysis because projected increases in temperature, and associated increases in growing-season drought, are widely accepted, whereas there is less certainty of the degree to which climate change may exacerbate other stressors and disturbances (Littell et al. 2009b). Information on each species' response to these other stressors is listed in appendix B.

Key observations

- Subalpine fir and mountain hemlock had the highest mean elevations, whereas red alder, Sitka spruce, and bigleaf maple had the lowest mean elevations. Mean elevation scores were based on a ranking of all Group 1 species and ranged from 0 to 100.
- One species, the highly shade-tolerant Pacific silver fir, was classified as late successional. Ten species commonly occur in both early and late successional stages, and four species are predominantly found in early successional stages.
- Habitat specificity ranged from low to medium for Group 1 species. Because all of these species are major forest canopy components in western Washington, it was not surprising that none of them had a high level of habitat specificity.
- Drought tolerance was rated medium to low for all species in Group 1. Species with high drought tolerance, such as Oregon white oak and ponderosa pine, also occur in western Washington but to an insufficient extent to be included in Group 1.

The species receiving the highest vulnerability scores was Pacific silver fir (score of 100), followed by mountain hemlock (88), and subalpine fir (65). The high vulnerability score of Pacific silver fir resulted from its late successional stage, its low drought tolerance, and its moderate habitat specificity and mean elevation values. Western redcedar, grand fir, and Douglas-fir had the lowest habitat affinity vulnerability scores, owing in part to low habitat specificity and relatively low mean elevations.

Table 9. Risk factor based on habitat affinity in a climate change vulnerability assessment of 15 major western Washington tree species; higher scores indicate greater vulnerability

				Score					
Species	Mean elevation (ft)[1]	Successional stage	Drought tolerance	Mean elevation[2]	Successional stage[3]	Habitat specificity[4]	Drought tolerance[5]	Raw factor score	Scaled factor score
Abies amabilis	3,272	Late	Low	64	100	50	100	79	100
Tsuga mertensiana	4,380	Early to late	Low	93	50	50	100	73	88
Abies lasiocarpa	4,831	Early to late	Medium	100	50	50	50	63	65
Cupressus nootkatensis	3,816	Early to late	Medium	86	50	50	50	59	58
Picea engelmannii	3,792	Early to late	Medium	79	50	50	50	57	54
Abies procera	3,448	Early	Low	71	0	50	100	55	50
Picea sitchensis	509	Early to late	Low	0	50	50	100	50	39
Tsuga heterophylla	1,680	Early to late	Low	50	50	0	100	50	39
Populus balsamifera ssp. *trichocarpa*	1,025	Early	Low	21	0	50	100	43	23
Alnus rubra	917	Early	Low	14	0	50	100	41	19
Acer macrophyllum	787	Early to late	Low	7	50	0	100	39	15
Pinus monticola	2,312	Early	Medium	57	0	50	50	39	15
Pseudotsuga menziesii	1,476	Early to late	Medium	43	50	0	50	36	8
Abies grandis	1,466	Early to late	Medium	36	50	0	50	34	4
Thuja plicata	1,383	Early to late	Medium	29	50	0	50	32	0

[1] *Mean elevations of all occurrences on FIA plots.*

[2] *Score based on species ranking.*

[3] *Early = 0; early to late = 50; late = 100.*

[4] *Low = 0; medium = 50; high = 100.*

[5] *High = 0; medium = 50; low = 100.*

Table 10. Risk factor based on variables affecting adaptive genetic variation in a climate change vulnerability assessment of 15 major western Washington tree species; higher scores indicate greater vulnerability

		Score				
Species	**Pollen dispersal vector**	**Seed zone elevation band width[1]**	**Pollen dispersal vector[2]**	**Disjunct or geographically separated populations[3]**	**Raw factor score**	**Scaled factor score**
Abies amabilis	Wind	100	0	100	67	100
Abies procera	Wind	100	0	100	67	100
Abies lasiocarpa	Wind	67	0	100	56	84
Picea engelmannii	Wind	67	0	100	56	84
Cupressus nootkatensis	Wind	33	0	100	44	67
Tsuga mertensiana	Wind	33	0	100	44	67
Abies grandis	Wind	100	0	0	33	50
Acer macrophyllum	Insects	0	100	0	33	50
Alnus rubra	Wind	100	0	0	33	50
Pseudotsuga menziesii	Wind	100	0	0	33	50
Populus balsamifera ssp. *trichocarpa*	Wind	67	0	0	22	34
Tsuga heterophylla	Wind	67	0	0	22	34
Thuja plicata	Wind	33	0	0	11	17
Picea sitchensis	Wind	0	0	0	0	0
Pinus monticola	Wind	0	0	0	0	0

[1] *No seed zone elevation bands = 0; bands wider than 1,500 ft = 33; bands 1,000 to 1,500 ft = 67; bands less than 1,000 ft = 100.*

[2] *Primarily abiotic pollination vectors = 0; primarily biotic pollination vectors = 100.*

[3] *No disjunct or geographically separated populations = 0; one or more such populations = 100.*

Adaptive Genetic Variation

Approach

The adaptive genetic variation factor is based on elements that describe a tree species' ability to adapt to a changing climate: genetic diversity, gene flow, and population structure (table 10). Genetic variation in adaptive traits is important because it provides the raw materials for populations to cope with climate change through evolution (Aitken et al. 2008). Forest trees generally have high levels of both within- and among-population genetic diversity for quantitative traits related to adaptation. A wealth of information has been collected on this type of genetic variation in commercially important trees species through common garden experiments. This information has been critical in developing seed zones and elevation bands to guide seed movement (Randall and Berrang 2002).

Rehfeldt (1994b) used the term *specialist* to describe species in which genetic variability is organized into numerous local populations, each of which is physiologically specialized for a particular range of environments. Conversely, the term *generalist* describes species in which individuals, and therefore populations, are attuned to a broad range of environments. Because specialist species are closely adapted to their local environment and do not have the necessary adaptive genetic variation within populations to rapidly adapt to a changing climate, they are more susceptible to changes in climate. The general characteristics of these alternative evolutionary strategies are shown in table 11.

Genetic variation in traits related to local adaptation is critically important in assessing vulnerability to climate change. Seed zones that have been delineated for commercially important tree species are reflective of levels of genetic variation in adaptive traits; however, the number and size of these seed zones also are dependent on the distribution of the species. Therefore, in this risk factor, we used seed zone elevation band width as a surrogate for adaptive genetic variation (table 11). Species with one or no elevation band are considered generalists with wide climatic tolerances, whereas species with several narrow elevation bands are specialists, highly adapted to their local environment, with specific climatic requirements. For example, elevation bands within seed transfer zones for Douglas-fir, a specialist species, are 1000 ft (305 m), whereas for western white pine, a generalist species, there are no elevation restrictions on seed transfer (Randall and Berrang 2002). Because specialist species are more vulnerable to changes in climate, species with narrow elevation bands were given a higher score. In several cases, the geographic scale of this assessment influenced a species' score. For example, Sitka spruce has substantial population differentiation on a range-wide scale but not within its range in Western Washington (Mimura and Aitken 2007b).

Evolution and response to natural selection depends on a number of factors including genetic diversity within populations and gene flow from adjacent populations (Aitken et al. 2008). For example, gene flow into a population from adjacent populations growing at warmer temperatures, such as populations at lower elevations or farther south, can introduce genetic variation that is pre-adapted to a warmer climate. Gene flow occurs through movement of seed and pollen; however, neither of these vectors is easy to measure on a quantitative basis. We considered including seed dispersal vector as a variable in this assessment, but because all 15 Group 1 species had the same seed-

Table 11. Comparison of alternative evolutionary strategies.

	Evolutionary strategy	
Characteristic	**Specialist**	**Generalist**
Factor controlling physical expression of adaptive traits	Genotype	Environment
Mechanism for accommodating environmental heterogeneity	Genetic variation	Phenotypic plasticity
Range of environments across which physiological processes function optimally	Small	Large
Slope of gradients for adaptive traits	Steep	Flat

Source: Rehfeldt 1994b

dispersal vector, wind, this variable would not have affected the results and for that reason was not added. However, seed dispersal distance was included in the reproductive capacity risk factor. Another vector of gene flow, pollen, is usually dispersed by wind or insects. For insect-pollinated trees, pollen dispersal could be affected if climate change influences the seasonal pattern of insect activity and disrupts the synchrony between the insect and the time of flowering. Insect-pollinated trees were assigned a higher vulnerability score because of this required interaction with another organism.

Populations that are disjunct or geographically separated from other parts of a species' distribution may evolve to be genetically distinct due to the lack of exchange of genetic material among populations. This may or may not be reflected in adaptive genetic variation, but regardless, this genetic uniqueness makes these populations high priorities for conservation. Additionally, gene flow into populations that are isolated or fragmented is often interrupted, which reduces opportunities for such populations to receive novel adaptive genetic variation. For these reasons, species with disjunct or geographically separated populations were assigned a higher vulnerability score.

Data for all variables in this risk factor were obtained from the scientific literature. Elevation band widths were obtained from the Washington Tree Seed Transfer Zones guidebook (Randall and Berrang 2002) for all species with the exception of mountain hemlock, subalpine fir, and bigleaf maple. Seed zones and elevation bands for these species have not been delineated, so information on adaptive genetic variation (Benowicz and El-Kassaby 1999; Benowicz et al. 2001b; Iddrisu and Aitken, n.d.; Warwell 2011) was used in combination with the elevational range of these species in Western Washington (appendix B) to estimate appropriate elevation bands.

Key observations

- High-elevation species had the highest factor scores (i.e., Pacific silver fir, noble fir, Engelmann spruce, subalpine fir, Alaska yellow-cedar, and mountain hemlock). This primarily reflects the combination of populations that are closely adapted to the often harsh environments that they inhabit (the narrow seed zone elevation bands of specialist species) and the presence of disjunct populations isolated by topography.
- Sitka spruce and western white pine, which are widespread species with no disjunct populations and broad environmental tolerances (i.e., generalist species), had the lowest scores in this factor.
- All of the species, with the exception of bigleaf maple, have wind-dispersed pollen; therefore, this item had a minimal effect on the factor scores. Because it is insect pollinated, bigleaf maple ranked in the middle with the same factor score as species that are wind-pollinated but have narrow seed zone elevation bands (e.g., Douglas-fir, grand fir, and red alder)
- The six species with disjunct populations ranked highest; within this species group, species with attributes of specialists ranked higher than those with attributes of generalists. The same ranking pattern occurred in the group of species without disjunct populations.

Insects and Diseases

Approach

This risk factor includes insects and diseases that presently affect the tree species under assessment or are expected to exacerbate the negative impacts of climate changes on tree survival, growth, or vigor (table 12). For each tree species, the most important insect and disease threats within the area of analysis were determined by entomologists and pathologists of USFS Forest Health Protection who rated each insect and disease according to the severity and immediacy of the threat.

Table 12. Risk factor based on major insect and disease threats in a climate change vulnerability assessment of 15 major western Washington tree species; higher scores indicate greater vulnerability

	Threat 1				Threat 2				Threat 3			
Species	Threat	Severity[1]	Immediacy[2]	Score[3]	Threat	Severity	Immediacy	Score	Threat	Severity	Immediacy	Score
Abies lasiocarpa	Balsam woolly adelgid	5	3	15	Western balsam bark beetle	5	2	10	Annosus root disease	3	2	6
Abies grandis	Balsam woolly adelgid	8	2	16	Fir engraver	3	2	6	Annosus root disease	3	2	6
Abies amabilis	Balsam woolly adelgid	8	2	16	Silver fir beetle	1	2	2	Armillaria root disease	3	2	6
Pinus monticola	Mountain pine beetle	3	2	6	White pine blister rust	8	2	16				
Acer macrophyllum	Verticllium wilt	3	3	9	*Armillaria mellea*	3	3	9				
Tsuga mertensiana	Laminated root rot	3	2	6	Annosus butt rot	3	2	6				
Abies procera	Armillaria root disease	3	2	6	Annosus root disease	3	2	6				
Pseudotsuga menziesii	Douglas-fir beetle	1	2	2	Laminated root rot	3	2	6	Swiss needle cast	1	3	3
Picea engelmannii	Spruce beetle	1	2	2	Tomentosus root rot	1	2	2	Annosus root disease	3	2	6
Tsuga heterophylla	Annosus butt rot	3	2	6	Western hemlock looper	1	2	2	Western blackheaded budworm	1	2	2
Populus balsamifera ssp. *trichocarpa*	Cytospora canker	3	2	6	Melampsora rust	1	2	2				
Alnus rubra	*Pytophthora ulni*	3	2	6								
Picea sitchensis	Spruce beetle	1	2	2								
Thuja plicata	Armillaria root disease	1	2	2								
Cupressus nootkatensis	Alaska yellow-cedar decline	1	1	1								

[1] *Minor mortality, usually of already-stressed trees = 1; moderate mortality in association with other threats = 3; moderate mortality of mature trees = 5; significant/complete mortality in related species = 6; significant mortality of mature trees = 8; complete mortality of all mature trees = 10.*

[2] *Potential to reach region of interest = 1; present in region = 2; present in region and climate change appears to be a contributing factor in increases in distribution and impact = 3.*

[3] *Score is the product of multiplying severity and immediacy values.*

Table 12, continued

	Threat 4				Threat 5				Score	
Species	Threat	Severity	Immediacy	Score	Threat	Severity	Immediacy	Score	Raw factor score[4]	Scaled factor score
Abies lasiocarpa	Armillaria root disease	3	2	6					37	100
Abies grandis	Armillaria root disease	3	2	6					34	92
Abies amabilis	Annosus root disease	3	2	6	Fir engraver	1	2	2	32	86
Pinus monticola									22	58
Acer macrophyllum									18	47
Tsuga mertensiana									12	31
Abies procera									12	31
Pseudotsuga menziesii									11	28
Picea engelmannii									10	25
Tsuga heterophylla									10	25
Populus balsamifera ssp. *trichocarpa*									8	20
Alnus rubra									6	14
Picea sitchensis									2	3
Thuja plicata									2	3
Cupressus nootkatensis									1	0

[4] *Calculated by summing the five threat scores.*

We made one modification to Potter and Crane's (2010) original format for this risk factor; we altered their threat immediacy rating scale to better represent threats in western Washington. We changed the definition of immediacy score 2, "approaching region of interest," to "present in region," and we changed the definition of immediacy score 3, "present in region," to "present in region and climate change appears to contribute to increases in distribution and impact." Although species-specific predictions for the future remain uncertain, these changes were made because there are indications that the current trend in climate warming has already exacerbated the effects of several insects and diseases on western Washington trees.

Key observations

The three tree species with the highest vulnerability rankings were true fir species (subalpine fir, grand fir, and Pacific silver fir). Each of these were affected by at least two important insect pests and two root diseases. The threat receiving the highest score for these three fir species was the non-native balsam wooly adelgid (*Adelges piceae*). Among all of the other tree species, the only threat receiving a similarly high score was white pine blister rust, affecting fourth-ranked western white pine. The species with the lowest scores were Alaska yellow-cedar, Sitka spruce, and western redcedar.

Ranking Based on Overall Score

The vulnerability score for each risk factor and the overall vulnerability score for each species are displayed in table 13. The overall vulnerability score was calculated by averaging the five risk factors, which were weighted equally. Higher overall scores indicate higher vulnerability to the effects of climate change as influenced by a species' distribution, reproductive capacity, habitat affinity, adaptive genetic variation, and threats from insects and diseases. Among the 15 Group 1 tree species, overall vulnerability scores ranged from 20 to 81 (lowest and highest scores possible were 0 and 100, respectively). When species were ranked by score, the scores were distributed relatively evenly between the highest and lowest. There were only two gaps of 10 or more points: (1) Pacific silver fir had the highest score by 10 points, and (2) there was a gap of 13 points between Alaska yellow-cedar and western white pine. The latter gap divided the tree species into two groups: species with scores above and below 50. Several trends were evident in the vulnerability scores shown in table 13:

- All four of the true fir species—Pacific silver fir, subalpine fir, noble fir, and grand fir—were in the higher-risk group (i.e., the seven species with overall scores above 50). The four true fir species had the highest scores for the reproductive capacity factor (due in part to a low percentage of sound seed and a relatively high minimum seed bearing age) and usually had high scores for the adaptive genetic variation and insect and disease factors.
- The highest species scores within each of the five risk factors nearly always fell within the higher-risk species group. The most notable exception was the distribution factor score of 83 for western white pine (overall score of 38), which was a result of its low frequency of occurrence on FIA plots and the small portion of canopy trees that it represented on those plots.
- All species in the higher-risk group, except grand fir, had disjunct or geographically separated populations in the genetics factor. Grand fir's overall vulnerability ranking was increased by its high score for the insects and diseases risk factor, which resulted from a relatively high number and severity of insect and disease threats.
- There was a general trend in increasing vulnerability with increasing mean elevation of FIA plot occurrences (fig. 8). With the exception of grand fir, all species with overall vulnerability scores over 50 had mean FIA plot elevations of more than 3,200 ft (975 m) (table 9). Conversely, the species with the lowest overall vulnerability scores (31 or lower) had mean FIA plot elevations of less

Table 13. Summary of risk factor scores, and overall scores, in a climate change vulnerability assessment of 15 major western Washington tree species; higher scores indicate greater vulnerability

		Risk factor scores					
Species	**Common name**	**Distribution**	**Reproductive capacity**	**Habitat affinity**	**Adaptive genetic variation**	**Insects and disease**	**Overall score[1]**
Abies amabilis	Pacific silver fir	19	100	100	100	86	81
Abies lasiocarpa	Subalpine fir	38	67	65	84	100	71
Picea engelmannii	Engelmann spruce	100	67	54	84	25	66
Abies procera	Noble fir	59	67	50	100	31	61
Abies grandis	Grand fir	57	67	4	50	92	54
Tsuga mertensiana	Mountain hemlock	38	33	88	67	31	51
Cupressus nootkatensis	Alaska yellow-cedar	63	67	58	67	0	51
Pinus monticola	Western white pine	83	33	15	0	58	38
Pseudotsuga menziesii	Douglas-fir	0	67	8	50	28	31
Acer macrophyllum	Bigleaf maple	35	0	15	50	47	29
Populus balsamifera ssp. *trichocarpa*	Black cottonwood	63	0	23	34	20	28
Picea sitchensis	Sitka spruce	57	33	39	0	3	26
Thuja plicata	Western redcedar	44	67	0	17	3	26
Tsuga heterophylla	Western hemlock	13	0	39	34	25	22
Alnus rubra	Red alder	19	0	19	50	14	20

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[1] *Calculated by averaging the scores from the five risk factors, each with a range of 0 to 100.*

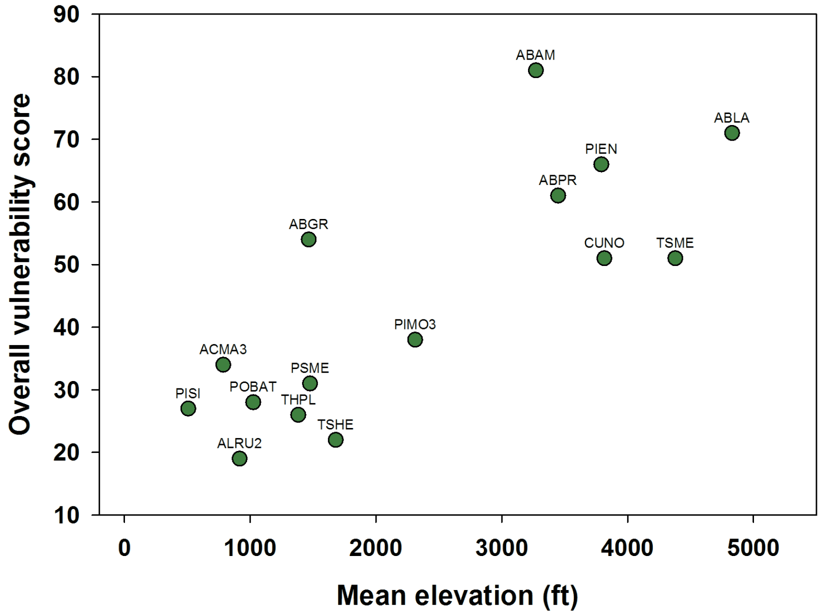

Figure 8. Relationship between overall climate change vulnerability score and mean elevation of FIA plots on which each of the 15 Group 1 tree species occurred in western Washington

than 1,700 ft (520 m). Because mean FIA plot elevation is part of the habitat affinity risk factor (table 9), it had an effect on species ranking but was not an overwhelming driver, as evidenced by the ranking of scores within the habitat affinity risk factor when species are ranked by overall vulnerability score in table 13.

- The three broadleaf tree species all had low overall vulnerability scores: red alder (20), black cottonwood (28), and bigleaf maple (29). This was the result of generally low scores for all risk factors; for the broadleaf species, the only factor score greater than 50 was the distribution factor for black cottonwood.

Conclusions

The results of this assessment can be used to prioritize vegetation management and conservation activities according to the relative climate change vulnerability of tree species. However, given the nature of vulnerability indices, the most appropriate way to apply the results of this type of analysis is to consider the trends that present themselves rather than placing too much emphasis on the score of one species compared to another. Potential management responses are discussed in Part 3 of this report.

The results of this vulnerability assessment suggest that high-elevation tree species are at risk under a changing climate and therefore should be a focus of conservation and monitoring. Alpine and subalpine plant communities also were selected as one of the three most vulnerable habitats in western Washington (see Part 2 of this report).

This vulnerability analysis provided an opportunity to gather information on the forest tree species, to map species distributions based on several sources of potential risk factors, and to select factors considered most important in determining vulnerability to climate change. Centralizing this information provided a framework for considering the relative importance of various life history traits. The calculation of an overall risk score provided insight on the combined impact of various risk factors that could not have been gained by examining risk factors individually.

For the Pacific Northwest region, this type of vulnerability analysis is most effective when applied to a geographic area the size of western or eastern Washington State. This scope of analysis would be impractical, and broader trends would be lost, if it were applied to individual national forests. For example, if the analysis included only the Olympic National Forest, it would not account for the geographical separation between Olympic Peninsula and Cascade Range populations of mid- to high-elevation tree species. Conversely, if the area of analysis were too large and ecologically diverse, a single set of risk factors would not be applicable to the entire area and would mask regional differences. In the case of Washington, combining eastern and western portions of the state in a single analysis would involve simultaneously evaluating the influences of substantially different disturbance regimes and climates.

Development of the individual risk factors helped identify the geographic and ecological patterns exhibiting unique challenges within the analysis area. For example, the Olympic Peninsula presents a challenge because populations of some tree species found at mid to high elevations (e.g., Alaska yellow-cedar, Engelmann spruce, mountain hemlock, Pacific silver fir, and subalpine fir) are genetically isolated from the larger populations in the Cascade Range (appendix A). This pattern is identified by the variable “disjunct or geographically separated populations” within the genetic risk factor (table 11). It is evident that these species warrant special attention when planning conservation activities such as *ex situ* seed collections and monitoring.

The potential impact of climate change may be just one of a number of considerations when planning the restoration and conservation of a particular species. For example, a look beyond the overall ranking scores is needed for western white pine, Douglas-fir, and red alder. In the case of western white pine, the species received a medium overall index score of 38. This was due in part to a low risk rating for the adaptive genetic variation factor, as this species has seed zones with no elevation bands: seed can be moved up and down without risk of maladaption. This species also has large seed zones—although this was not part of the adaptive genetic variation factor—and a wide distribution (no disjunct of geographically separated populations). Yet, western white pine mortality has been very high due to the introduced pathogen *Cronartium ribicola*, which causes white pine blister rust (Kinloch 2003). The impacts of this disease and mountain pine beetle were reflected in the insects and disease factor; however, the score for this factor was only 58 because other species were affected by a greater number of threats with greater immediacy. Nonetheless, national forests will continue to screen western white pine trees to find rust-resistant families and to develop and maintain orchards for the production of rust-resistant seed (Sniezko 2005). This work is critical for the restoration of western white pine across the landscape.

Douglas-fir and red alder also had relatively low overall index scores (table 13). As discussed earlier (see adaptive genetic variation factor), these species are considered specialists and are highly adapted to their local environment. Because of narrow seed zone elevation band widths, both species were assigned the highest score for that variable (100); however, because their distributions are continuous (no disjunct of geographically separated populations), their factor scores were only 50, lower than the six species that also had disjunct or geographically separated populations. At the forest level, the high degree of local adaptation of Douglas-fir and red alder may be critical in the development of monitoring programs and in seed source selection.

These examples illustrate the need to consider all aspects of vulnerability to a warming climate at the appropriate scale when designing projects at the local level.

Vulnerability of Group 2 and 3 Species

Group 2 consists of trees that are not significant forest overstory components owing to their small size or to their limited extent in western Washington forests. Because many of these species are of limited commercial value, they have not been extensively researched. Little or no information was available for many of the risk factor variables used in the Forest Tree GRAS; thus, it was most efficient to exclude the Group 2 tree species from the formal vulnerability assessment that was applied to the Group 1 species. As noted earlier, the Group 3 species—golden chinquapin, Rocky Mountain juniper, whitebark pine, and ponderosa pine—were not included in the vulnerability assessment because they are already known to warrant special management attention in western Washington, which should include consideration of potential impacts of climate change. For example, whitebark pine is under threat not only from a warming climate but also from white pine blister rust and mountain pine beetle, and a regional strategy is in place to address these challenges (Aubry et al. 2008). Specific management recommendations for these two groups of tree species are given in Part 3 of this report.

Group 2 Species

The species of Group 2 vary widely in habitat requirements and habitat specificity. The objective of this section is to make a general assessment of these species' vulnerability to climate change by reviewing their habitat and reproductive characteristics. The attributes discussed were deemed relevant to species' adaptation to climate-related habitat changes, including disturbances.

In table 14, the Group 2 tree species are organized according to their drought and shade tolerance. Among these trees, the ten species of low shade tolerance all occupy early seral stages; most depend upon forest canopy disturbance (e.g., fire, flood, or insect mortality) to become established. However, tolerance of extreme soil moisture conditions also allows some of these species to persist where most other trees cannot survive. Four trees within the low-shade-tolerance group are highly drought-tolerant: Pacific madrone, Oregon white oak, and shore and lodgepole pine. Each of these four trees has a competitive advantage over other tree species on relatively harsh, dry sites, given the region's typically droughty summers. However, this competitive advantage may not be relevant on sites that are currently marginal, where even these species may not survive under drier conditions. At the other extreme is Pacific willow, and, to a somewhat lesser extent, Oregon ash. These species tolerate seasonally flooded soils that most other tree species cannot survive. The remaining species of low shade tolerance—quaking aspen, bitter cherry, Scouler's willow, and paper birch—are not as tolerant of drought or flooding and thus rely primarily on disturbance to become established.

The five species of medium shade tolerance are capable of surviving beneath a partial forest canopy, although their growth is faster under full sunlight. These species may establish at forest edges or where small gaps occur in the forest canopy following the death of one or more overstory trees. The species of medium shade tolerance also occur following large-scale disturbances, although their growth is slower than that of the species in the low-shade-tolerance group. With the exception of western crab apple, these five species are of moderate drought tolerance and occur in a variety of forest types in western Washington. Western crab apple is most prevalent on wet sites where it is favored owing to its tolerance of seasonal flooding.

Table 14. Shade tolerance and drought tolerance of Group 2 tree species

Drought tolerance	Shade tolerance		
	Low	**Medium**	**High**
Low	Pacific willow Oregon ash Quaking aspen Bitter cherry	Western crab apple	
Medium	Scouler's willow Paper birch	Cascara Douglas maple Pacific dogwood Black hawthorn	Pacific yew
High	Pacific madrone Oregon white oak Shore pine Lodgepole pine		

Within the Group 2 species, only Pacific yew is classified as highly shade-tolerant. Pacific yew occurs on a wide range of sites, from full sunlight to the shade beneath a dense conifer overstory. This species is unique in that it is well-adapted to growing and reproducing under complete shade. In northern California, Pacific yew was found to become increasingly common in older conifer stands, where stand-replacing fires were rare (Scher and Jimerson 1989).

The Group 2 species can be divided into four groups based on seed type and dispersal mechanism (table 15), although detailed information on attributes such as dispersal distance and level of seed production is unavailable for most of these species. Pacific willow, Scouler's willow, and quaking aspen produce significant numbers of very small, light seeds bearing fine hairs; this seed is capable of traveling long distances via wind or water. Lodgepole pine, shore pine, and paper birch regenerate via small, winged seeds that typically fall within several hundred yards of the parent tree. This seed is usually dispersed by wind, although less frequently it also is dispersed by animals. In the case of lodgepole pine, individuals within some populations are serotinous, opening to release seeds only following the heat of a fire. Douglas maple and Oregon ash produce large, winged seed usually dispersed by wind. Because it is relatively heavy, the seed of these two species likely has a limited dispersal distance. The fourth species group is defined by the fact that it is typically dispersed by animal vectors. Seeds of these eight species often are cached or dropped within several hundred yards of the parent tree, but there is potential for the seed to be transported great distances. Of the Group 2 species, approximately half are predominantly insect-pollinated; thus, their production of seed is strongly influenced on the presence of insect species during flowering.

All Group 2 tree species, with the exception of the two pines, are capable of reproducing both vegetatively and sexually. In many types of vegetative reproduction, a developed root system already exists, potentially facilitating rapid growth in the initial months and years following a disturbance. Forms of vegetative reproduction among various Group 2 species include stump sprouts, root collar (i.e., the base of the stem) sprouts, root sprouts, and layering (i.e., sprouting of branches that have drooped and contacted the soil). Vegetative reproduction is clonal and thus does not create the variety of genotypes that are produced by sexual reproduction. For this reason, vegetative reproduction does not facilitate genetic adaptation to a changing environment.

In addition to the habitat and reproductive characteristics that influence potential response to projected climate change, some of the species in this group have other relevant management considerations. For example, a species' distribution in western Washington, relative to its overall distribution, could affect management decisions. Species such as quaking aspen, paper birch, and Engelmann spruce are found infrequently in western Washington (appendix A), but this region represents only the western edge of their distributions (USDA NRCS 2010). Other tree species in this group are significantly affected by human activities. In the case of Oregon white oak, the species' native distribution occurs primarily where the region's population density is highest; therefore, it is heavily impacted by urban and agricultural land use decisions. Cascara, which has bark with medicinal properties, has been harvested extensively for this reason for more than a century. Although cascara is a commonly occurring species, preferential harvest of the largest trees has significantly altered size and age structures of some populations over time (NatureServe 2010b).

All Group 2 species are well-adapted to reproducing after disturbance, although Pacific yew typically reaches its greatest density in undisturbed conifer stands. Some of the Group 2 species grow best under regimes of frequent, stand-replacing disturbance, while others require only small canopy gaps in which to establish. However, most species in this group are scattered across western Washington as minor components of multiple forest types and therefore will be influenced by changes that occur in those forests.

Table 15. Reproductive characteristics of Group 2 tree species

Species	Pollination vector	Seed type and dispersal	Primary seed dissemination vector
Pacific willow Scouler's willow Quaking aspen	Insect Insect Wind	Abundant, very small seeds; may be dispersed miles (kilometers)	Wind
Lodgepole pine Shore pine Paper birch	Wind Wind Wind	Abundant, small seeds; may be dispersed 100s of yards (meters)	Wind
Douglas maple Oregon ash	Insect, wind Wind	Large, heavy seeds; probably limited dispersal distance	Wind
Pacific madrone Western crab apple Black hawthorn Bitter cherry Cascara Pacific dogwood Oregon white oak Pacific yew	Insect Insect Insect Insect Insect Insect Wind Wind	Seed type varies; may occasionally be dispersed miles (kilometers) depending on vector	Birds and small mammals

Group 3 Species

Each of the four Group 3 species exhibits specific attributes that may affect influence vulnerability to climate change; these are summarized in table 16.

Golden chinquapin occurs in two disjunct populations in Washington: in Mason County on the southeastern Olympic Peninsula and in Skamania County on the Gifford Pinchot National Forest (appendix A-11). These populations are the two northernmost occurrences of golden chinquapin; the species' range is predominantly in Oregon and California. Because the range of golden chinquapin occurs primarily in warmer, drier climates, there is no evidence that it will suffer directly from the changes in climate that are projected for western Washington. However, the origin and genetics of the relatively small, disjunct populations occurring in Washington are unknown. Therefore, any indirect consequences of climate change affecting these populations, such as increased competitiveness of associated tree species, are of concern because of the potential loss of unique genotypes in these populations.

Rocky Mountain juniper occurs sporadically in the northern Puget Sound region and on the San Juan Islands near sea level and infrequently at elevations as high as 5,500 ft (1,670 m) in the northern Olympic Range (appendix A-17). Recent research of genetic, morphological, and ecological properties indicates that the Rocky Mountain juniper occurring in these locations is a unique species, known as seaside juniper (*Juniperus maritima* R. P. Adams) (Adams 2007, Adams et al. 2010). Regardless of whether seaside juniper is widely accepted as a separate species, the populations in western Washington remain genetically distinct from Rocky Mountain juniper in the Rocky Mountains. This fact, combined with its limited occurrence in western Washington, suggests that these populations may be vulnerable to climate-related changes in habitat.

Whitebark pine was the subject of a recent report that evaluated a wide range of threats to the species and reviewed potential effects of climate change (Aubry et al. 2008). The primary concern for whitebark pine is the fact that it occupies high-elevation habitat that, because of its limited and isolated occurrence, is particularly susceptible to climate change. If the alpine and subalpine habitats currently occupied by whitebark pine become unsuitable, the amount of higher elevation habitat to which the species could migrate is very limited in extent. The Tree Climate Viability Maps (TCVM) (Rehfeldt et al. 2006, 2009) and Multivariate Spatio-Temporal Clustering (MSTC) (Hargrove and Hoffman 2005, Hargrove et al. 2010) models both show substantial decreases in whitebark pine habitat in the Cascade Range under projected climate change.

Ponderosa pine in western Washington is primarily restricted to one location: a 1,900-ac (775-ha) area on Joint Base Lewis-McChord, near the city of Tacoma (Foster 1997). Beyond scattered populations and individuals in the vicinity of Joint Base Lewis-McChord, other ponderosa pine populations west of the Cascade crest occur only near the crest of the Cascade Range, and likely are the result of seed transported by animals from east of the crest (Peter 2010). Ponderosa pine is adapted to warm, dry environments; therefore, like similarly adapted species (e.g., Pacific madrone, Oregon white oak, and Rocky Mountain juniper), projected changes in climate are themselves not likely to reduce the extent of suitable habitat in western Washington. On some sites, increased summer drought may even give these species a competitive advantage. Factors other than climate, however, may have significant influences on their habitat. In the case of ponderosa pine, the primary threat to the Joint Base Lewis-McChord population is encroachment of Douglas-fir, which has accelerated substantially since World War II (Foster 1997). Prior to European settlement in the mid-1800s, frequent burning by Native Americans prevented Douglas-fir and other tree species from encroaching on these ponderosa pine forests. Without regular fire, Douglas-fir regenerates within these western Washington ponderosa pine stands, dramatically changing the composition and structure of the stands. Additionally, the invasive, nonnative understory species Scot's broom (*Cytisus scoparius*) impedes regeneration of ponderosa pine by forming a shrub layer and thereby altering the seedbed environment. Since the mid-1990s, Joint Base Lewis-McChord has conducted ecological restoration activities, including Douglas-fir and Scot's broom removal and prescribed burning, to return the ponderosa pine forests to a condition similar to that which existed prior to European settlement (Foster 1997).

Table 16. Summary of possible climate change vulnerabilities of Group 3 species

Species	Possible vulnerabilities to climate change	Other notes
Golden chinquapin	Western WA populations are inherently vulnerable owing to the fact that they are disjunct and of relatively small size; genetic uniqueness of these populations is unknown; Olympic Peninsula population occurs on Forest Service, WADNR, and private land; therefore, management will require a coordinated effort	Golden chinquapin is adapted to warm, dry climates
Rocky Mountain juniper	Although it occurs across a wide elevation range, western WA populations are small and disjunct; Rocky Mountain juniper in western WA is likely a different species than that which occurs inland	Rocky Mountain juniper tolerates extreme environments including heat and drought
Whitebark pine	Occupies high-elevation habitat that is projected to decrease under a warmer climate; limited potential for migration	Whitebark pine is also threatened by white pine blister rust, mountain pine beetle, and large high-severity fires
Ponderosa pine	Restricted primarily to one disjunct population in western WA	Ponderosa pine is adapted to warm, dry climates; the primary western WA population is actively managed by Joint Base Lewis-McChord

TOOLS AND MANAGEMENT OPTIONS

Introduction

This section describes potential actions that can be used to identify and respond to the effects of long-term climate change on forest trees of western Washington. We discuss four topics: (1) monitoring climate change effects, (2) vegetation management options, (3) gene conservation, and (4) the Seedlot Selection Tool. Monitoring of climate change effects produces quantitative information that provides a basis for deciding what responses may be necessary. Vegetation management options for western Washington's national forests are discussed in the context of projected climate change effects. Both *in situ* and *ex situ* conservation of genetic resources are discussed in the third section. The recently developed Seedlot Selection Tool, designed to match seedlots to local climate, is reviewed in the final section.

Monitoring Climate Change Effects on Forest Trees

The Role of Monitoring

Monitoring enables us to quantify the influences of climate on forest trees; such information is needed to support decisions on mitigating potential climate impacts and to inform long-term management direction. Data from monitoring also can be used to validate model predictions and to test assumptions of preliminary adaptation strategies. Potential effects of climate change on trees include altered reproductive and vegetative phenology and growth, impacts on biotic seed and pollen vectors, and effects on genetic variation and population structure. In the following discussion, we address potential effects of climate change, as well as resources for monitoring.

Climate Effects on Tree Phenology and Growth

In plants, phenology is the annual cycle of development, as influenced by seasonal and annual variations in climate. Phenological variables include the timing of budbreak, flowering, leaf abscission, bud set, and the onset of cold hardiness. Although relationships between climate and phenological events occur at the plant community level, responses to climate vary among individual co-occurring species (Hoffmann et al. 2010, Miller-Rushing and Primack 2008, Post et al. 2008).

The effects of climate change on different stages of the annual development cycle may vary. A warming climate could influence phenological sequences in a variety of ways, advancing or delaying all events together or advancing or delaying individual events while leaving others unchanged. In addition to seasonal timing, the annual duration of reproductive or vegetative events may increase, decrease, or remain unchanged (Post et al. 2008). Climate change will not alter the photoperiodic cues for bud set and height growth cessation but might affect phenological events that are triggered by accumulation of degree-days. It may also alter the synchrony of flowering among populations, affecting the potential for long-distance gene flow via pollen (Aitken et al. 2008).

Because many species of plants and animals have shown changes in phenology associated with climate patterns, phenology is very susceptible to the influence of climate change (Beaubien and Freeland 2000, Cayan et al. 2001, Morisette et al. 2008). Models of North American tree species predict that, during the 21st century, climate change will advance vegetative phenological events by 5 to 9 days in the spring, depending on the climate model scenario (Morin et al. 2009). Early spring warming leading to earlier budbreak exposes new plant growth to an increased risk of frost damage (Augspurger 2009, Inouye 2008). In Alaska, climate has been implicated in Alaska yellow-cedar decline, as warmer temperatures lead to earlier melting of the snowpack and dehardening of roots on sites where rooting depth is limited by a shallow water table. Without the insulating snowpack, tree roots have greater susceptibility to freezing damage (Schaberg et al. 2008).

Climate during the growing-season influences a tree's radial growth. Environmental variables including temperature and water availability influence the amount of wood that is formed during the growing season (the year's tree ring) as well as characteristics of the wood within that ring. Tree ring data from recent years can be compared to historical records to better understand the influence of climate on tree growth.

Climate Effects on Seed and Pollen Vectors

Most of the Group 1 species are wind-pollinated and have wind-dispersed seed, while most of the Group 2 and 3 species are insect-pollinated and/or have animal-dispersed seed (table 17). Species that are insect-pollinated or have animal-dispersed seed are more susceptible to climate change impacts because their reproduction is dependent on interactions with animal species that also are subject to climate change influences (Hegland et al. 2009). Insect pollinators are predicted to be particularly susceptible to changing temperature regimes; if phenological responses to climate change in plants and insects are not parallel, this will result in mismatches between these mutalistic partners, potentially causing reductions in pollination (Hegland et al. 2009). For insect-pollinated tree species, reductions in seed production or seed viability are indicators that monitoring may be needed to assess pollination vectors.

Genetic Variation and Population Structure

It will be challenging to measure the effect of climate change on genetic diversity of trees owing to long generation times and the fact that adaptation is likely to lag behind environmental change (Aitken et al. 2008, Lynch and Lande 1993, Savolainen et al. 2004). Genetic change in trees occurs very slowly; changes in genetic variation as a result of projected climate change are likely to be too slow to detect in the next 100 years (Savolainen et al. 2004).

Tree species have repeatedly adapted to climate during their evolutionary history as a result of glaciations and subsequent warming patterns. For many species, this has led to steep genetic gradients across the landscape for some climate-related traits such as phenology (i.e., the timing of periodic events such as budburst, budset, and flowering) (Hamrick 2004, Savolainen et al. 2004). For a locally adapted population, a change in environment toward less suitable conditions leads initially to reductions in reproductive capacity and/or survival as a result of maladaptation. Because almost all quantitative characters exhibit some genetic variation, prolonged directional change in environment will generally result in adaptive evolution; however, any substantial reduction in population size will reduce the opportunities for such adaptation (Lynch and Lande 1993).

Forest trees, and conifers in particular, exhibit many of the life-history traits associated with high levels of genetic variation in molecular markers, such as high fecundity, outcrossing, and wind pollination (Hamrick et al. 1979), and they generally have high levels of genetic variation for traits related to adaptation. Although genetic diversity of many commercially important conifer species has been well-studied (using both selectively neutral molecular markers and adaptive quantitative traits), for some tree species this information is either completely lacking or does not fully cover the species' distribution. Measuring the long-term effects of climate change on genetic diversity will require baseline data on genetic variation both within populations (observed and expected heterozygosity [H_o and H_e]) and among populations (population differentiation [F_{ST} or G_{ST}]) for tree species for which these parameters are currently unknown.

Information on genetic variation is especially important for species with disjunct populations. For more than half of the tree species in Western Washington with disjunct or geographically separated populations, there is no genetic information available

Table 17. Forest tree pollen and seed dispersal vectors

Species	Species group	Geographic distribution in western Washington	Pollen vector	Seed dispersal vector
Alaska yellow-cedar	1	Wide/disjunct	Wind	Wind
Bigleaf maple	1	Wide	Insects	Wind
Black cottonwood	1	Wide	Wind	Wind
Douglas-fir	1	Wide	Wind	Wind
Engelmann spruce	1	Moderate/disjunct	Wind	Wind
Grand fir	1	Wide	Wind	Wind
Mountain hemlock	1	Wide/disjunct	Wind	Wind
Noble fir	1	Moderate/disjunct	Wind	Wind
Pacific silver fir	1	Wide/disjunct	Wind	Wind
Red alder	1	Wide	Wind	Wind
Sitka spruce	1	Wide	Wind	Wind
Subalpine fir	1	Wide/disjunct	Wind	Wind
Western hemlock	1	Wide	Wind	Wind
Western redcedar	1	Wide	Wind	Wind
Western white pine	1	Wide	Wind	Wind
Bitter cherry	2	Wide	Insects	Birds and mammals
Black hawthorn and Suksdorf's hawthorn	2	Wide	Insects	Birds and mammals
Cascara	2	Wide	Insects	Birds
Douglas maple	2	Wide	Insects	Wind
Lodgepole pine and shore pine	2	Wide	Wind	Wind
Oregon ash	2	Wide	Wind	Wind
Oregon white oak	2	Moderate	Wind	Birds and mammals
Pacific dogwood	2	Wide	Insects	Birds and mammals
Pacific madrone	2	Narrow	Insects	Birds and mammals
Pacific willow	2	Moderate	Insects	Wind
Pacific yew	2	Wide	Wind	Birds and mammals
Paper birch	2	Narrow	Wind	Wind
Quaking aspen	2	Wide	Wind	Wind
Scouler's willow	2	Wide	Insects	Wind
Western crab apple	2	Wide	Insects	Birds and mammals
Golden chinquapin	3	Rare/disjunct	Wind	Birds and mammals
Ponderosa pine	3	Rare/disjunct	Wind	Wind
Rocky mountain juniper	3	Rare/disjunct	Wind	Birds and mammals
Whitebark pine	3	Narrow/disjunct	Wind	Birds and mammals

Table 18. Information available on factors influencing tree species' genetic vulnerability to climate change

Species	Species group	Disjunct or geographically separated population(s)	Genetic data available for disjunct or geographically separated population(s)	No genetic information available	Limited genetic information available	Range-wide genetic information available
Alaska yellow-cedar	1	X	Yes			X
Bigleaf maple	1					X
Black cottonwood	1				X	
Douglas-fir	1					X
Engelmann spruce	1	X	No		X	
Grand fir	1				X	
Mountain hemlock	1	X	No		X	
Noble fir	1	X	No		X	
Pacific silver fir	1	X	No		X	
Red alder	1				X	
Sitka spruce	1					X
Subalpine fir	1	X	No		X	
Western hemlock	1				X	
Western redcedar	1					X
Western white pine	1					X
Bitter cherry	2			X		
Black hawthorn and Suksdorf's hawthorn	2				X	
Cascara	2			X		
Douglas maple	2			X		
Lodgepole pine and shore pine	2					X
Oregon ash	2			X		
Oregon white oak	2					X
Pacific dogwood	2				X	
Pacific madrone	2				X	
Pacific willow	2			X		
Pacific yew	2					X
Paper birch	2				X	
Quaking aspen	2				X	
Scouler's willow	2			X		
Western crab apple	2				X	
Golden chinquapin	3	X	No	X		
Ponderosa pine	3	X	Yes			X
Rocky mountain juniper	3	X	Yes		X	
Whitebark pine	3	X	Yes			X

to determine if these populations are genetically distinct from populations in the contiguous portion of the species' range (table 18). Of the species with geographically separated populations, some species on the Olympic Peninsula have relatively large distributions there that remain separated from the Cascade Range distribution by a lack of suitable habitat (e.g., high-elevation sites) between the two areas. The large, disjunct Olympic Peninsula distributions of these species (e.g., Pacific silver fir, subalpine fir, and mountain hemlock) are likely better able to adapt to a changing climate than the much smaller disjunct populations of other species. However, even for these large disjunct distributions, it is important to know whether they are genetically distinct from the Cascade Range distributions in order to determine whether movement of seed between the two should be restricted because of genetic differences. The species with small disjunct populations, such as noble fir in the Willapa Hills and Engelmann spruce and Rocky Mountain juniper on the Olympic Peninsula, may require active and intense conservation efforts for protection. An understanding of whether these disjunct populations differ genetically will be crucial in determining whether it will be suitable to move seed from other areas into these populations in efforts to increase population size. This is especially relevant in situations where the seed supply from within a disjunct population is limited.

In the topographically varied environment of western Washington, there is a high likelihood that refugia exist that could buffer changes in climate. Identification and conservation of such refugia are critical to maintain seed sources and natural biodiversity. Conservation efforts will be a priority for any population that is geographically isolated because it may represent a current or future refuge for a species. Conversely, if such a population is genetically distinct, then it may not be an appropriate refuge for a species because of its genetic distinctness. An understanding of the genetic similarities and differences between isolated populations and the contiguous portion of a species' range will be critical in prioritizing limited conservation resources.

Resources For Monitoring Climate Change Effects On Trees

Long-term monitoring of tree health and species distributions is essential to understanding how these factors are influenced by climate. Currently, the Forest Service and National Park Service have monitoring programs that collect forest vegetation data in western Washington. Data from these programs may provide some of the information necessary to understand the scope of potential climate change effects, but these existing programs do not address other anticipated biological impacts on trees. The most comprehensive monitoring program is the Forest Service Pacific Northwest Research Station's Forest Inventory and Analysis (FIA) program, which collects data on all forests in the region, regardless of ownership (USDA Forest Service 2010b). Within the national parks of western Washington, the North Coast and Cascades Network uses a program specifically designed to monitor the effects of ecological change, using protocols similar to those of the FIA program (Woodward et al. 2009). The Monitoring on the Margins initiative of the USDA Forest Service Forest Health Monitoring program is an example of an effort designed to identify early effects of climate change on already-threatened tree species (Smith et al., n.d.). In the Pacific Northwest region, Monitoring on the Margins will focus on high-elevation, five-needle pines (including whitebark pine in western Washington) because these species are threatened by white pine blister rust as well as climate change, which is projected to have a greater impact on high-elevation species.

Owing to the variety of influences that climate has on forests, variables that may be affected range from the scale of population-level phenology to landscape-scale species distributions (table 19). Because relatively little is known about the effects of climate on many of the region's tree species, the choice of which species to monitor, and thus where to allocate limited resources, is particularly important. The vulnerability assessment made with the Forest Tree GRAS was designed to provide information that may be useful in prioritizing tree species for monitoring.

Table 19. Options for assessing potential climate change effects on tree species of western Washington

Potential climate change effect			
Effect	**Importance**	**Examples**	**How to assess effect**
Genetic variation	Genetic variation is associated with life-history traits related to a species' capacity to adapt to environmental change; to understand change in genetic variation, baseline data are needed	Within-population variation Among-population variation	Prioritize those species for which baseline genetic information does not exist; initiate programs to assess baseline genetic data
Vegetative phenology	Growing season length depends on growing-season temperature and soil moisture availability; duration of dormancy is affected by winter temperature	Budbreak date Bud set date	Monitoring in seed orchards or natural stands; WADNR, PNW, and R6 initiated pilot program of seed orchard monitoring; assessments also may be done by researchers
Reproductive phenology	In many species, synchrony of flowering, which influences pollination, is affected by temperature; insect-pollinated trees are dependent on the presence of insects which, in turn, is influenced by environmental conditions	Flowering dates Fruit maturation	Monitoring in seed orchards or natural stands; assessments also may be done by researchers
Regeneration	Regeneration allows colonization of new habitat and replacement of dead trees	Germination Seedling survival Vegetative reproduction	Forest Service FIA and National Park Service NCCN currently monitor tree seedlings >15 cm (6 in.) tall; species-specific assessments will require work of researchers
Insect and disease damage and mortality	Some tree species in the Pacific Northwest have incurred widespread injury and mortality	Mountain pine beetle White pine blister rust Balsam woolly adelgid	Requires region-wide surveys; FIA Phase 3, Forest Health and Protection monitoring, and WWETAC are involved in assessments
Long-term growth rate	Inter-annual climate variation affects tree growth and other tree ring properties; multi-year growth trends can predict mortality	Tree ring width Ratio of earlywood to latewood within a ring	Researchers use dendrometers to measure annual diameter growth; tree core samples can be extracted to assess past growth
Species' frequency of occurrence	A reduction in suitable habitat within a species' range would lead to a decline in occurrences	Density (trees per ac [ha])	Requires region-wide surveys conducted at regular intervals; FIA inventory is the only current example
Species' range	A shift in a species' range alters forest composition, structure, and wildlife habitat	Researchers predict that the range of some tree species will shift northward	Requires region-wide surveys conducted at regular intervals; FIA inventory is the only current example

Annual phenology can be monitored using a variety of techniques including repeated observation during the growing season, automated photography, and remote sensing. In 2009, the Pacific Northwest Research Station, Olympic National Forest, and WADNR collaborated on a pilot program to monitor tree phenology in seed orchards. Trees in seed orchards are well-suited to monitoring because they are usually of known parentage and are easily accessed by seed orchard personnel. Presently, Forest Service seed orchards throughout Washington and Oregon contain 13 of the native tree species of western Washington (table 20). These seed orchards have significant potential for monitoring climate effects on phenology, because many orchards contain multiple individuals from 50 to 200 unrelated families. Furthermore, trees of the same species from multiple seed zones are located in orchards across a broad range of geographic and climatic zones. The seed orchard pilot monitoring program assesses timing of spring vegetative budbreak, a variable known to be associated with climate, although additional variables may be monitored in the future. Relationships between climate and tree phenology also are the subject of ongoing research conducted by the Forest Service Pacific Northwest Research Station (Gould et al. 2011, Harrington et al. 2010).

Relationships between climate and tree growth can be assessed by monitoring tree radial growth. Forest Service FIA data can be used to examine growth patterns at broad spatial and temporal scales (the remeasurement interval is 10 years in Washington), but assessment of relationships between inter-annual climate patterns and tree growth requires annual growth data. Such data are most often acquired by coring trees and then analyzing tree rings or by installing dendrometers on trees. Dendrometers provide precise measurements of a tree’s radial growth and can be used to assess intra-annual or inter-annual growth patterns. Measurements of annual growth are relatively resource-intensive; therefore, it is important to select trees that are representative of the populations of interest. For example, because populations at the extremes of a species’ habitat may be the most likely to experience climate change effects, sampling may need to include trees at the edges of the species’ range or at the extremes of its elevation range.

Table 20. Seed orchards and clone banks in Washington and Oregon

Species	Number of seed orchards or clone banks in Washington and Oregon	Total acres
Black cottonwood	2	5
Douglas-fir	62	853
Engelmann spruce	2	16
Grand fir	1	1
Lodgepole pine	7	48
Noble fir	4	89
Pacific silver fir	3	32
Ponderosa pine	37	549
Quaking aspen	1	N/A
Sitka spruce	1	2
Western hemlock	1	5
Western redcedar	2	6
Western white pine	14	127

N/A = number of acres not recorded.

Landscape-level monitoring of species frequency and range is a substantial undertaking, and the best current assessment is FIA’s annual inventory, which covers both public and private lands. The FIA program monitors forest composition, regeneration, and a variety of forest health indicators. While this is the best dataset available for monitoring range-wide tree species distributions, it uses a relatively low sampling intensity and is designed to provide information at broad scale (e.g., western Washington). One permanent plot is established per 6,000 ac (2,400 ha), and 10 percent of plots are remeasured annually, resulting in a 10-year remeasurement interval.

Long-term data from the FIA inventory will likely be an important component of monitoring climate change impacts on forest composition, but as specific impacts are identified, additional, targeted monitoring programs could be needed. For example, Alaska yellow-cedar, understood to be suffering from climate-related decline, is the subject of intensive monitoring in Alaska (Hennon et al. 2008, Snyder and Lundquist 2007).

The FIA annual inventory is not designed to provide information on tree reproduction with the precision necessary to monitor all climate change effects. Assessment of long-term climate effects on abundance of tree reproduction and on spatial trends in reproduction would require a significantly more intensive sampling scheme designed specifically for that objective.

The potential effect of insects and pathogens under a changing climate is recognized as a major threat to forests (Bentz et al. 2010, Littell et al. 2010). Research and relatively intensive monitoring are conducted by the Forest Service and other agencies to understand the impact of biological threats in combination with environmental stressors such as drought. Currently, tree mortality and damage on all Washington forest lands is monitored annually by aerial surveys conducted through a cooperative effort by the WADNR and the Forest Service Pacific Northwest Region (Region 6) Forest Health Protection program. Additionally, research on insects, pathogens, and their interactions with climate change is conducted by the Forest Service Pacific Northwest Research Station’s Western Wildland Environmental Threat Assessment Center based in Oregon.

Summary

- Susceptibility to climate change impacts is increased for tree species dependent on biotic vectors for pollination or seed dispersal. Monitoring may be necessary to evaluate reproductive limitations resulting from these biotic vectors.
- To understand long-term effects of climate change on genetic diversity, baseline data are still needed for many tree species. Collection of this information should prioritize rare species and species with disjunct or geographically separated populations.
- Seed orchards are well-suited for monitoring the influence of climate on phenological variables. Vegetative phenology of trees is known to be influenced by climate, but reproductive phenology is complex and the long-term effects of climate change are unknown.
- The Forest Service FIA annual inventory provides the most comprehensive landscape-scale data on the distribution of tree species; however, data cannot be used to make inferences at a local level. Specialized surveys may be required to assess changes in distribution of species that are of particular interest.
- The FIA inventory data on tree reproduction are not precise enough to assess effects of climate change; such an assessment would require a more intensive inventory design.
- Insects and pathogens are believed to be a substantial threat to regional forests, given predicted changes in climate. Currently the Forest Service and other agencies are monitoring these threats and studying their potential interactions with climate change.

Vegetation Management Options

Introduction

The two primary ways that vegetation management can increase tree species diversity and change species distribution are through planting and thinning. Most recommended methods for building resiliency in forest stands involve planting (Millar et al. 2007). Thinning can be used to change species composition, modify stand structure and age composition, and reduce stress through density control, increasing vigor of residual trees. However, all silvicultural treatments on regional national forests must be applied under the directives of the Northwest Forest Plan, under which the focus of vegetation management is terrestrial and aquatic habitat restoration and enhancement (Moeur et al. 2005). Forest management under the Northwest Forest Plan varies with land allocation (figs. 2, 3, and 4) and has resulted in the planting and thinning programs described below.

Tree planting is done on a relatively small scale on the Mt. Baker-Snoqualmie, Olympic, and Gifford Pinchot National Forests: 50, 20 and 220 ac (20, 8, and 90 ha) per year, respectively. Trees are often planted during restoration projects such as road decommissioning and wildlife habitat improvement. Species planted are selected based on a number of site factors including elevation, aspect, slope, presence of insects and diseases, site preparation capabilities, tree species and plant associations in the surrounding stands, as well as relative shade tolerance of the planted species. Trees also are planted after disturbances such as wildfire and wind storms; however, these events are uncommon and affect a relatively small number of acres.

The thinning program impacts many more acres than planting; each year these three forests thin about 1,000, 1,800, and 4,100 ac (405, 730, and 1,660 ha), respectively, with an emphasis on maintaining species diversity and increasing structural diversity. Even so, the area thinned annually is less than 1 percent of the total land base and has a relatively small impact on the forests of western Washington.

Given the present size and scope of the thinning and planting programs, management options to change the structure and composition of forest stands on national forests in western Washington are limited.

Disturbance

One way to anticipate opportunities to change vegetation is to prepare for major disturbances. Although recent wildfires on western Washington national forests have been small, large stand-replacing fires have occurred in western Washington at long intervals, from about 140 to more than 900 years depending on forest type (Agee 1993, Henderson et al. 1989). Also, there is the potential that fire frequency may increase in parts of the region that may become much drier as the climate warms (e.g., the eastern half of the Olympic Peninsula) (Bachelet et al. 2001), but these changes are predicted to occur at least 40 years into the future and annual variation will remain important.

Disturbances may increase as weather patterns change in the future and result in increasing windstorms, insect and disease mortality, and landslides (see Halofsky et al., in press) for discussion of disturbances in the Pacific Northwest). Windstorms that occur on the western side of the Olympic Peninsula can be severe and result in considerable windfall, including partial or complete stand replacement (Dowling 2011). However, planting is used only after fallen trees are salvaged, and presently salvage operations are performed only after windthrow in Adaptive Management Areas. Although insects and diseases have not caused the level of tree mortality experienced east of the Cascade Mountains in Oregon and Washington, there are a number of insects and diseases that impact forest trees of western Washington (table 12) and may pose greater threats in the future, especially on the drier eastern sides of the Olympic Peninsula and the Gifford Pinchot National Forest.

Given the potential need for seedlings to reforest following major disturbances, it is important to evaluate the forests’ conifer seed inventory and replenish low seed stores for areas that are more likely to experience these types of large-scale disturbances. It is also important to evaluate the area over which seed is collected and combined into seedlots. In order to facilitate the creation of custom seedlots to match possible changes in seed movement guidelines in the future, it would be prudent to collect seed across smaller areas than the current seed zones. This would make it possible to add a percentage of seed from outside the seed zone if and when that becomes advisable.

Assisted Migration and Projecting Future Changes in Tree Distribution

Even when planting programs are relatively small, discussions of climate change inevitably lead to debate over assisted migration: the intentional movement of species or populations outside of their natural range or beyond their recognized area of adaptation (Joly and Fuller 2009, Richardson et al. 2009). Although few are suggesting that tree species should be planted outside their present distribution at this time, there is much discussion of the pros and cons of relaxing seed movement guidelines and adding some seed from sources outside the established seed zone when making a seed lot for sowing (CCSP 2008).

Well-supported changes in seed movement require confidence in predictions of future conditions and the range of adaptability of existing populations. Seed movement in anticipation of climate changes should be supported by experimental evidence and based on replicated planting trials. Although research is underway that will help evaluate alternative futures in plant distribution, this type of information is not yet available (O'Neill et al. 2008, St. Clair et al. 2010). Operational planting sites on National Forest System lands in western Washington are not tree plantations and do not provide the experimental design and homogenous environmental conditions needed for a comparison of the response of seedlings grown from different seed sources. Therefore, it is not possible to "try something" and evaluate the results.

We examined the output of the MC1 dynamic global vegetation model, which provides projections of future scenarios for broad vegetation types based on three general circulation models (GCMs) and two B1 and A2 carbon dioxide emissions scenarios (Bachelet et al. 2001). Predictions are made for vegetation groups and do not include information on individual species. Also, projections reflect changes in climate habitat, and only indirectly indicate potential changes in the distribution of vegetation types. For the Olympic Peninsula, for example, two vegetation types are mapped for the recent past (1971–2000) and for the decade 2010–2020: Subalpine Forest and Maritime Evergreen Needleleaf Forest (fig. 9). The latter encompasses most of the peninsula and does not reflect the many vegetation types that are used for forest management. For 2010-2020, the Subalpine Forest climate habitat is predicted to decrease at all GCMs and emission levels, but no changes are projected for Maritime Evergreen Needleleaf Forest.

Projections for 2040–2060 vary among emission levels and GCMs (fig. 10). For five of the six scenarios, there is a considerable reduction in predicted Subalpine Forest climate habitat. Under CSIRO, A2, the northwest corner of the peninsula shifts to Temperate Warm Mixed Forest, a vegetation type that was not present in the 2010–2020 projections. Under both emission levels for Hadley, there is an increase in Temperate Evergreen Needleleaf Forest along the eastern and northeastern part of the peninsula. In both these cases, these areas are at low elevation and for the most part outside the forest boundary. These maps should be regarded only as trends and managers should not place too much importance on the boundaries of each vegetation type. However, based on the model projections, it is possible that in 30 to 50 years the low-elevation forests of the Olympic National Forest could be drier, resulting in changes in vegetation and increases in fire frequency and extent. For a discussion of the results of MC1 on the Olympic Peninsula, see Halofsky et al., in press. Similar results were found for both the Mt. Baker-Snoqualmie and the Gifford Pinchot National Forests. Projections for 2040–2060 showed an increase in Temperate Evergreen Needleleaf Forest and a decrease in Subalpine Forest on the both forests, but only for the Hadley GCM. More information on model application and projections is also given in appendix E.

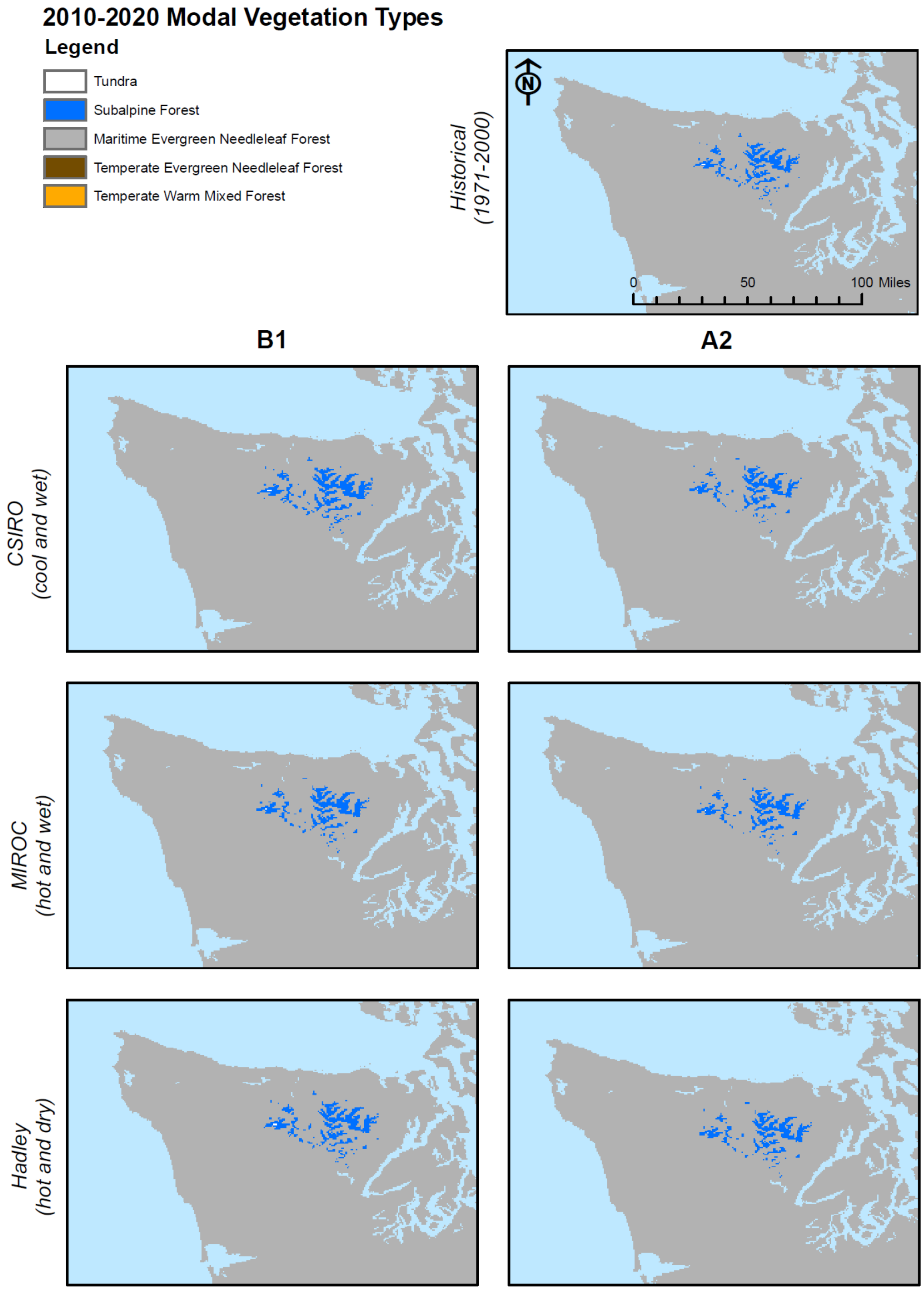

Figure 9. Projected modal vegetation types on the Olympic Peninsula for the 2010–2020 time period compared to modeled historical vegetation types. Projections are from the MC1 model for three general circulation models (GCMs) (rows) and two IPCC SRES carbon dioxide emissions scenarios (columns). The Commonwealth Scientific and Industrial Research Organisation's (CSIRO) GCM projects a relatively cool and wet Pacific Northwest, while the Model for Interdisciplinary Research on Climate (MIROC) projects a hot and wet Pacific Northwest, and the Hadley model projects a hot and dry Pacific Northwest. The B1 emissions scenario is characterized by relatively low future emissions, and the A2 scenario is characterized by relatively high future emissions (Halofsky 2010). Data source: R. Neilson and the MAPSS Team, USDA Forest Service and Oregon State University, Corvallis, Oregon) (Map by J. Muehleck)

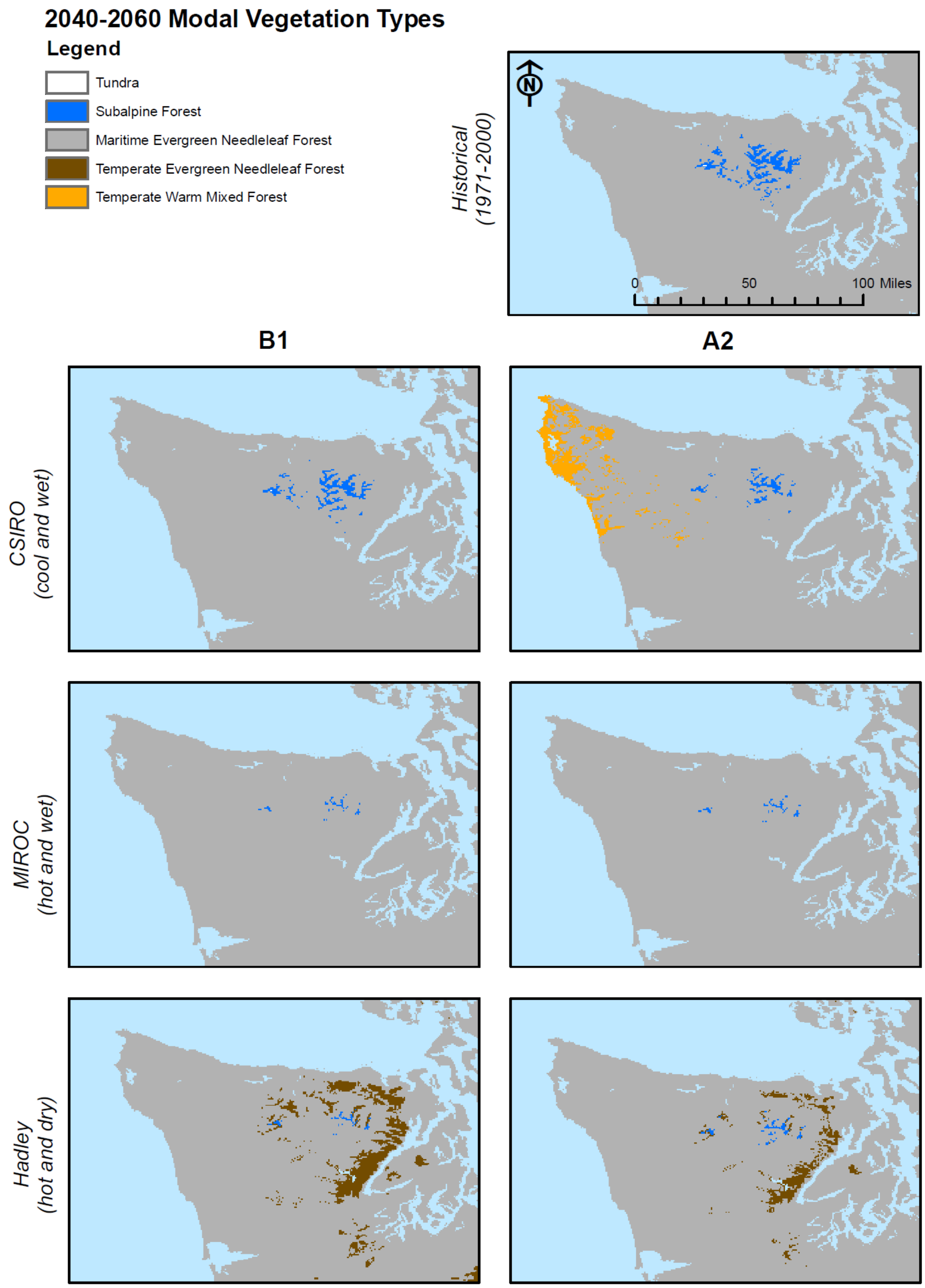

Figure 10. Projected modal vegetation types on the Olympic Peninsula for the 2040–2060 time period compared to modeled historical vegetation types. Projections are from the MC1 model for three general circulation models (GCMs) (rows) and two IPCC SRES carbon dioxide emissions scenarios (columns). The Commonwealth Scientific and Industrial Research Organisation's (CSIRO) GCM projects a relatively cool and wet Pacific Northwest, while the Model for Interdisciplinary Research on Climate (MIROC) projects a hot and wet Pacific Northwest, and the Hadley model projects a hot and dry Pacific Northwest. The B1 emissions scenario is characterized by relatively low future emissions, while the A2 scenario is characterized by relatively high future emissions (Halofsky 2010). Data from R. Neilson and the MAPSS Team, USDA Forest Service and Oregon State University, Corvallis, Oregon) (Map by J. Muehleck)

The silviculturists and geneticists of these three national forests agree that seed movement outside present seed zones will be considered only when a shift in climate is shown to be having a negative impact on vegetation and when it becomes apparent that active intervention is needed to maintain healthy stands and provide wildlife and aquatic habitats. This might happen though reduced survival, vigor, and growth or changes in life history traits such as phenology or pollen and seed production. The movement of seed of native tree species from forests to the south or from lower elevations risks implementing an approach that is not self-tending. (A self-tending action is one that won't need to be changed later if our projections are incorrect.) Novel seed movements could produce trees that are not well-adapted, and at maturity these trees could produce seed and pollen that could reduce the adaptability of trees in surrounding stands, a scenario that would be impossible to reverse. It could also upset ecological processes in unforeseen ways.

Another consideration regarding seed movement is that trees are most susceptible to unfavorable environmental conditions during the seedling and sapling stages; at maturity, trees can withstand much greater ranges in temperature and precipitation. Thus, we favor seed source selection for present conditions because this will increase the likelihood of early survival. To make informed decisions, it is imperative that we develop a system to assess climate-related changes in forest tree growth and survival. These triggers can then be used to implement new planting and thinning practices that meet changing climate patterns.

New Management Opportunities

One way to increase resiliency in forest stands is to create new opportunities to plant species that are presently under-represented due to insects, disease, or past harvest practices. Historically, western white pine was widespread throughout the forests of western Washington. Since the introduction of the exotic disease *Cronartium ribicola*, which causes white pine blister rust, the presence of western white pine has been dramatically reduced. High quality seed of rust-resistant western white pine is produced at seed orchards on each national forest. The Olympic National Forest has initiated a pilot program to create artificial gaps or openings in young-growth stands to provide opportunities to plant rust-resistant western white pine seedlings. Planting may also be implemented in older young-growth stands in natural openings created by wind or in root rot pockets where competing vegetation is not a prohibitive problem.

A genetic common garden study of western white pine indicated that a single seed zone for the Olympic Peninsula is sufficient to assure that seedlings are adapted to their environment (Campbell and Sugano 1989). There is a high level of genetic variation in this species, but that variation is unrelated to geographic location or elevation within the peninsula. Therefore, the use of rust-resistant seed orchard seed produced from tested families selected throughout the peninsula poses no dilemmas over seed movement guidelines.

The results of the vulnerability assessment presented in this report indicate that conifer species that occur more often at high elevations are most vulnerable to a changing climate (fig. 8). Model results clearly show a predicted reduction in subalpine forest type by year 2040 (fig. 10). In the past, when trees were harvested at sites over 3,000 ft (910 m) elevation, noble fir and Pacific silver fir were commonly planted, and thus seed processing and seedling production techniques were perfected. For efficient production of high quality seed, orchards were established for both these species (see tables 21, 22, and 23 in the next section). However, there is no seed in inventory for the other at-risk high elevation species: subalpine fir, Engelmann spruce, mountain hemlock, and Alaska yellow-cedar. There may be a need to increase restoration of high-elevation stands in the future. This will require a review of the state of knowledge of seed collection and storage as well as growing and planting requirements. It may also be prudent to collect seed of these species for long-term storage at the National Center for Genetic Resources Preservation, in Fort Collins, CO.

In summary,

- The primary silvicultural activity on national forests in western Washington is thinning for multiple goals including improvement in wildlife habitat, diversification of forest stand structure, and an increase in biodiversity.

- Planting opportunities are limited, and planting prescriptions are based on a number of factors, the potential for climate change being only one of them.
- We will continue to use locally adapted conifer seed sources for the limited number of acres planted until changes in weather, growth, and survival indicate that that relaxing seed movement guidelines is warranted.
- It is critical to investigate opportunities to increase stand resilience to climate change, such as the creation of gaps to plant underrepresented or absent species such as western white pine.

Gene Conservation

Introduction

Genetic diversity within and among populations is important for a number of reasons, and its conservation has become a priority for many species. Genetic diversity provides the raw material for adapting to changing environments; therefore, conservation of genetic diversity protects a population's evolutionary potential, which may be especially important under climate change or increasing pressures from insects and diseases. Gene conservation refers to the tools used to protect and maintain genetic diversity. Gene conservation can be *ex situ*, meaning that resources are maintained "off site" or outside of a species' native range (e.g., seed banks, seed orchards, off-site plantings); or *in situ*, meaning that resources are maintained "on site" or within the native range or source of the population (e.g., parks, preserves, and unmanaged lands).

Ex situ **Genetic Resources**

Seed Orchards

Tree seed orchards in western Washington provide an excellent resource for *ex situ* gene conservation for a limited number of species. This resource is shown by orchard and species for the three national forests in tables 21, 22, and 23. The WADNR also maintains forest tree seed orchards for needs on Washington state lands (table 24).

Seed Storage

Seed storage for the national forests in Western Washington is maintained at two facilities. Bulked reforestation seed lots, which include seed from multiple parent trees, are stored at the J. Herbert Stone nursery in Medford, Oregon. Of the Group 1 species, bulk seedlots are available for all species with the following exceptions:

- Olympic National Forest lacks grand fir, subalpine fir, Engelmann spruce, and mountain hemlock;
- Mt. Baker-Snoqualmie National Forest lacks Alaska yellow-cedar; and
- Gifford Pinchot National Forest lacks Sitka spruce (species not present on the forest).

Across all species on all forests, more than 1,000 lbs (450 kg) of seed are currently in storage. However, some of this seed is more than 25 years of age and of questionable viability. The seed should be tested and unusable seed removed from the inventory.

Select tree seedlots, which are seed from a single, source-identified tree usually with some desirable qualities, are maintained at the Dorena Genetic Resources Center in Cottage Grove, Oregon (table 25). As with the bulk seedlots, many of these select tree seedlots are old, and viability testing is needed to assess their condition.

Table 21. ***Ex situ*** **genetic resources in seed orchards on the Gifford Pinchot National Forest**

Orchard Name	Species	Breeding zone	Elevation (ft)	Orchard area (ac)	Families in orchard
Cispus	Douglas-fir	202-03011	0-1,500	6	130
		202-03012	1,500-2,500	10	222
		202-03013	2,500-3,500	10	301
Planting Creek	Douglas-fir	202-03021	0-1,500	5	50
		202-03022	1,500-2,500	12	240
		202-03023	2,500-3,500	12	270
White Salmon	Douglas-fir	202-03031	0-1,500	5	56
		202-03032	1,500-2,500	5	50
		202-03042	1,500-2,500	5	50
French Butte	Noble fir	022-03064	3,500-4,500	23	125
		022-03065	>4,500	23	125
Coyote	Western white pine	119-06020	All	23	356
TOTAL				139	1,975

Table 22. ***Ex situ*** **genetic resources in seed orchards on the Mt. Baker-Snoqualmie National Forest**

Orchard Name	Species	Breeding zone	Elevation (ft)	Orchard area (ac)	Families in orchard
Darrington	Pacific silver fir	011-05013	2,500-3,000	12	135
		011-05014	>3,500	11	137
	Douglas-fir	205-05012	1,000-2,000	10	200
		205-05013	2,000-3,000	10	162
R.N. McCullough	Noble fir	022-05022	<4,000	10	129
		022-05023	>4,000	10	241
	Western white pine	119-05010	All	6	100
		119-17110	All	6	175
	Douglas-fir	205-05022	1,700-2,800	14	388
		205-05023	>2,800	10	179
TOTAL				99	2,055

Table 23. ***Ex situ*** **genetic resources in seed orchards on the Olympic National Forest**

Orchard Name	Species	Breeding zone	Elevation (ft)	Orchard area (ac)	Families in orchard
Dennie Ahl	Pacific silver fir	West	1,500-3,000	4.5	45
		Both	>3,000	3	50
Dennie Ahl	Douglas-fir	West	<1,500	6	200
		West	1,500-3,000	16	179
		East	<1,500	5	50
		East	1,500-3,000	7.5	180
		East	>3,000	4.5	50
Dennie Ahl	Western white pine	Both	All	5	50
Dennie Ahl	Sitka spruce	098-09011	All	2	47
Dennie Ahl	Western hemlock	098-09011	>3,000	5	50
TOTAL				51.5	804

Table 24. ***Ex situ*** **genetic resources in seed orchards managed by the Washington Department of Natural Resources**

Species	Orchard block	Breeding zone	Elevation (ft)	Orchard area (ac)	Families in orchard
Douglas-fir	Cascades North	Cascades North	1,500-3,000	5.9	50
	Cascades South	Cascades South	1,500-3,000	7.8	50
	Central	DNR-Central	<2,000	6.0	53
	Coast	DNR-Coast	<2,000	6.0	51
	Coastal North	Coastal North	<2,000	7.0	50
	Forks	Forks	<2,000	7.0	50
	Northwest	Northwest	<2,000	5.5	49
	Puget Sound North	Puget Sound North	<1,500	5.3	50
	Puget Sound South	Puget Sound South	<1,500	8.1	50
	South Puget	South Puget	<2,000	3.3	51
	Southwest	Southwest	<2,000	5.5	53
Noble fir	Cascades	Lewis	<4,000	5.2	67
Ponderosa pine	Colville Ponderosa	Northeast	2,500-4,000	4.2	58
	Ft. Lewis Ponderosa	Puget Sound	<1,000	7.6	50
	Klickitat Ponderosa	White Salmon	2,000-3,200	4.0	50
Western redcedar	Puget Sound Cedar	Puget Sound	<2,000	1.0	50
	Twin Harbors Cedar	Twin Harbors	<2,000	1.3	50
Western white pine	Westside WWP	W. Washington	<5,000	0.5	158
TOTAL				91.2	1,188

In situ Genetic Resources

There are extensive areas of protected habitat in western Washington that serve as reserves of *in situ* genetic resources. On public lands, more than 3 million acres (1.6 million ha) are set aside in national parks (North Cascades, Mt. Rainier, and Olympic National Parks) and congressionally designated wilderness areas on national forests. Other protected areas include research natural areas and late successional reserves administered by the U.S. Forest Service, as well as state parks and WADNR-administered natural area preserves and natural resource conservation areas.

White Pine Blister Rust Resistance Screening

White pine blister rust, caused by the fungus *Cronartium ribicola*, is an exotic disease that was unintentionally introduced to western North America a century ago (Benedict 1981). It infects all five-needle pines and has had severe impacts on both western white pine and whitebark pine in Washington. Infection level varies considerably by stand and can range from less than 5 percent to nearly 75 percent of trees (Shoal and Aubry 2006). Natural levels of resistance to blister rust are relatively low. However, a program was initiated in the late 1950s to screen individual western white pine trees for resistance and to produce seed for production of rust-resistant seedlings for reforestation efforts in Oregon and Washington. Similar work on whitebark pine was started in the late 1990s. Genetic resistance to blister rust is the key to maintaining viable populations of whitebark pine in the presence of the pathogen, and planting blister rust-resistant whitebark pine is an integral element of the U.S. Forest Service Pacific Northwest Region whitebark pine restoration program (Aubry et al. 2008). There is no direct evidence that levels of blister rust infection will either increase or decrease with projected climate change; however, promoting resilience in forest ecosystems is key in adapting to climate change, and preserving and enhancing biodiversity is a key to resilience. Identifying blister rust resistant individuals of both western white pine and whitebark pine, so that seed can be collected from them and used to grow seedlings for reforestation, will be one of the most effective ways of ensuring the presence of these species on the landscape. In addition, both these species do well after disturbance, so if climate change results in an increase in size and/or frequency of disturbance, this could increase opportunities to put these species back into the landscape.

Table 25. ***Ex situ*** **genetic resources in single-tree seedlots in storage at the Dorena Genetic Resources Center**

National forest	Species	Seed lots (no.)
Gifford Pinchot	Pacific silver fir	121
	Grand fir	53
	Subalpine fir	37
	Noble fir	448
	Western larch	96
	Whitebark pine	14
	Engelmann spruce	63
	Western white pine	853
	Ponderosa pine	184
	Douglas-fir	1,335
	Western redcedar	30
	Western hemlock	69
	Mountain hemlock	52
Mt. Baker-Snoqualmie	Pacific silver fir	273
	Noble fir	293
	Whitebark pine	4
	Western white pine	171
	Douglas-fir	638
	Western redcedar	242
Olympic	Whitebark pine	16
	Western white pine	99
	Douglas-fir	88
TOTAL		5,179

Western white pine—On the three national forests in western Washington, there are 1,437 individual western white pine trees that have been selected in the field for potential blister rust resistance. Since 1971, 1,300 of these families (individual parent trees) have been screened at the Dorena Genetic Resources Center (Table 26). Of the 1,300 families screened, 12 percent (159 families) have shown some resistance including high survival in screening, outstanding slow-rusting resistance mechanisms, or high survival in seed orchards. More than 90 percent of these families have seed in storage at Dorena, although many of these seed collections are 25 to 30 years old. Of these 159 resistant families, 153 are represented in at least one seed orchard in the region.

Whitebark pine—Since 2005, whitebark pine seed from 119 individual trees has been collected in western Washington (table 27). About 40 percent of these lots have been sown to grow seedlings that were inoculated with blister rust in 2007. Early results show a large amount of variation in potential resistance. Increasing mortality from progression of the disease was evident during the summer of 2010, 2 years after inoculation. Screening results and relative rankings will be updated as additional assessments are performed, but there are indications of higher relative resistance in families from the Cascades (Mt. Adams on the Gifford Pinchot National Forest, Mt. Rainier National Park, and Mt. Baker-Snoqualmie National Forest) and lower relative resistance in families from the Olympic Peninsula.

Table 26. Western white pine blister rust screening in western Washington

National forest	Number of families screened	Number of families rated resistant
Gifford Pinchot	1,001	78
Mt. Baker-Snoqualmie	178	49
Olympic	121	32
Total	1,300	159

Table 27. Whitebark pine blister rust screening in western Washington

Location	Number of families from which seed was collected	Number of families in rust resistance screening
National forest		
Gifford Pinchot	14	12
Mt. Baker-Snoqualmie	4	3
Olympic	16	7
All national forests	34	22
National park		
North Cascades	26	N/A
Mt. Rainier	59	N/A
All national parks	85	27
All locations	119	49

N/A = Information not available at the park level

Evaluation of the Seedlot Selection Tool

The Seedlot Selection Tool (SST) (http://sst.forestry.oregonstate.edu/PNW/index.html) is an online GIS program designed to help forest managers match seedlots with planting sites by using climate information. The SST incorporates either current climate or predicted future climates based on selected climate change scenarios. In addition to providing planting information, it is designed to be of use to anyone desiring maps of present or future climates, as defined by temperature and precipitation (OSU and USDA 2010). We evaluated the SST to assess the potential for its application in examining possible habitat suitability for tree seed under future climate change scenarios.

The SST is being developed for the deployment of tree seed or seedlings of commercially valuable tree species. It predicts either: (1) locations with a climate suitable for planting a given seedlot, or (2) the appropriate seedlots to plant in a given location. It incorporates numerous user-selected inputs to provide broad flexibility and applicability across species and landscapes. It allows the user to select location, seed zone, species, climate data, seed transfer limits, future climate scenario models, and emission scenarios. Climate data can be based on a specific location (latitude and longitude) or based on an entire seed zone for a given elevation band. The boundaries of existing seed zones can be provided to the SST developers for inclusion in the program, which will then use these boundaries to calculate the average value of climate variables over the entire seed zone. The ultimate output of the program is maps of where climate is considered suitable for a given seedlot, based on climate variables and seed transfer limits selected by the user.

Because the SST uses climate data to match seedlots to planting sites, species-specific information such as genetic variation, adaptation, and habitat are not considered. Forest genetics research has shown that local adaptation in forest trees is strongly influenced by climate (St. Clair et al. 2005). The SST operates on the principle that adaptive genetic variation in trees—which is difficult and time-consuming to measure and map—is strongly correlated with climate, so mapping climate data across the landscape gives an indication of genetic variation across the landscape (Howe 2010). To produce accurate maps, however, it is necessary for the user to have some knowledge of which climate variables are important drivers of local adaptation and what the appropriate seed transfer limits are for a given species. The SST provides 20 different climate variables for the user to select, including variables related to temperature, precipitation, aridity, growing season length, and heat sum accumulation. However, when multiple variables are selected, habitat mapped as suitable is restricted to areas that fall within the transfer limits of all selected variables, so increasing the number of variables selected usually decreases the area mapped. If appropriate transfer limits are not known *a priori*, then the SST can use existing seed zones to define transfer limits based on the range in climatic values (transfer limit = maximum – minimum) present within the boundaries of the seed zone. For example, for a specific location on the Mt. Baker-Snoqualmie National Forest (47.83897° N; 121.57059° W; elevation 1,817 ft [554 m]), the annual precipitation is 99.0 in (2,514 mm). The range between the maximum and minimum values for the Douglas-fir seed zone 1,700 to 2,800-ft elevation band is 44.2 in (1,122 mm); therefore, any area where annual precipitation is between 54.8 in (1,392 mm) and 143.2 in (3,636 mm) is considered suitable habitat.

The SST is still under development, and it may prove useful to land managers seeking guidance on movement of seed. However, the accuracy of the maps produced by the SST depends on the user’s knowledge of which climate variables are important and what transfer limits are appropriate for a given species. As with all models of potential climate change effects, there is inherent uncertainty as a result of uncertainty in projections and in species- and community-level responses. As stated on the SST website,

> Because of the uncertainty in climate change projections, the tool is really a planning and educational tool. It can be used to explore alternative future conditions, assess risk, and plan potential responses, but cannot tell the user exactly which seedlots will be optimally adapted to a particular planting site in the future. The tool allows the user to control many input parameters so the results are appropriate for the management practices, climate change assumptions, and risk tolerance of the user.

(http://sst.forestry.oregonstate.edu/PNW/index.html)

PART 2:
NON-FORESTED HABITATS VULNERABLE TO CLIMATE CHANGE

INTRODUCTION

Climate is considered the dominant controlling factor for plant distribution (Woodward 1987). Those ecosystems or habitat types in western Washington that are the most sensitive to changes in temperature or hydroperiod (seasonal patterns of water availability) will have the greatest vulnerability to climate change. The term “vulnerability” is used here to denote the likelihood that a habitat type, either as a whole or in individual occurrences, might change in size and distribution, undergo significant changes in vegetative community composition, or disappear from the landscape in response to changes in climate.

This section discusses the vulnerability to climate change of three primarily non-forested habitat types (ecosystems): alpine and subalpine habitats; dry grasslands (prairies, savannas, and oak woodlands); and freshwater and coastal wetlands. These three broad habitat types were selected based on a review of the current climate change literature and on a survey of natural resource scientists from major land management agencies— U.S. Forest Service, National Park Service (NPS), and the Washington Natural Heritage Program (WNHP) of the WADNR. These habitat types were identified in 2009 by Forest Service botanists and biologists as focal habitats for the draft terrestrial restoration strategy for the Forest Service Pacific Northwest Region (Region 6, Oregon and Washington). Interviews conducted in summer 2010 with Forest Service botanists and biologists on the three western Washington national forests, with WNHP ecologists, and with NPS personnel further highlighted the concern that natural resource scientists and managers express about the potential vulnerability of these non-forested habitats to the effects of predicted future climate scenarios.

Wetlands, dry grasslands, and alpine and subalpine ecosystems are three very different western Washington habitat types, but they have much in common: limited, patchy distributions; a high degree of fragmentation or isolation between occurrences; and very high biodiversity, including many species of plants and animals not adapted to other habitats. All three habitats also are especially susceptible to invasion by non-native plants, insects, and other animals. This combination of factors makes each of these habitats particularly vulnerable to disturbances resulting from climate change.

In general, management recommendations for habitats vulnerable to climate change emphasize resiliency and adaptive capacity. They include reducing existing stressors, maintaining existing intact ecosystems, reducing habitat fragmentation, and improving habitat connectivity to facilitate adaptive migration of plants and animals. Additional recommendations include identifying and tracking key species or controlling factors, identifying and protecting potential refugia, protecting particular habitats and species at risk, and ensuring that the full range of genetic variability is maintained within species (Blate et al. 2009, Harris et al. 2006, Spies et al. 2010).

ALPINE AND SUBALPINE HABITATS

Alpine habitats occupy the highest vegetated elevations, above the open subalpine parkland and below the glaciers, permanent snowfields, talus slopes, rocky peaks, or other non-vegetated surfaces. Alpine vegetation, also called tundra, is adapted to a short growing season controlled by factors including temperature, extent and duration of the snowpack, and desiccation by wind and sun. Alpine plant species are typically slow-growing perennial forbs (wildflowers), grasses, sedges, lichens, and mosses (Grabherr et al. 2010).

Subalpine habitats occur between forest line (the highest extent of continuous closed-canopy forest) and tree line (the highest extent of individual upright trees) and thus occupy the transition zone between closed forest and treeless alpine tundra. In western Washington, forest line and tree line elevations vary, with the transition between forested and subalpine habitat generally taking place between 5,000 and 6,000 ft (1,520 and 1,830 m) and alpine tundra beginning between 1,000 and 1,500 ft (300 and 460 m) above that. Above forest line, forest cover becomes discontinuous, with trees occurring in clumps of diminishing distribution and stature as elevation increases. Adult trees often have a shrubby krummholz or wind-shaped dwarf form. Tree species composition also may change as conditions become harsher and more exposed.

Of the three western Washington habitats considered here, alpine and subalpine are the most extensive, covering approximately 859,000 ac (348,000 ha) (fig. 11). Nearly all of this habitat is located within the boundaries of national forests and national parks, and much of it is within the boundaries of congressionally designated wilderness areas.

The western Washington alpine and subalpine habitat represented in figure 11 is from the modeled potential natural vegetation zones (PNV) of Washington and Oregon (Henderson 2009). The zones represent the environmental capability of a land area in the absence of significant disturbance. The ice masses depicted on the map are from the U.S. Geological Survey National Hydrography Dataset (NHD) (USGS 2010). Using a geographic information system (ESRI ArcMap 9.3), we removed the portions of the PNV's alpine and subalpine parkland zones overlain by NHD "ice masses" to calculate the total acreage for alpine and subalpine habitats. Of those approximately 859,000 ac (348,000 ha), 719,000 ac (291,000 ha) are classified as subalpine parkland, and 140,000 ac (56,700 ha) are classified as alpine.

An example of a subalpine habitat vulnerable to climate change is the whitebark pine community found in all three of western Washington's national forests. On the Mt. Baker-Snoqualmie and Gifford Pinchot National Forests, whitebark pine populations occur primarily near the Cascade Crest, and to a greater extent east of the crest. On the Olympic National Forest, the Buckhorn Wilderness contains the only known population of whitebark pine on the forest, as well as the Buckhorn Research Natural Area (RNA), both of which provide areas for assessing current condition and monitoring climate change effects on high-elevation ecosystems.

Vulnerability

Alpine plants are considered highly vulnerable to impacts associated with a warming climate (Guisan and Theurillat 2000) and already serve as an "early warning" system for climate change effects (Grabherr et al. 2010). Summer temperatures and the duration and extent of winter snowpack are key controlling factors for plant establishment, distribution, and survival in high-elevation landscapes, although specific limiting factors vary locally and regionally (Millar et al. 2004, Peterson et al. 2002, Woodward et al. 1995). In western Washington, summer temperatures are predicted to increase during the 21st century, and the extent and duration of snowpack is predicted to decrease (Mote 2003, Mote et al. 2005, Nolin and Daly 2006), resulting in seasonal shifts to earlier spring conditions and a longer growing season.

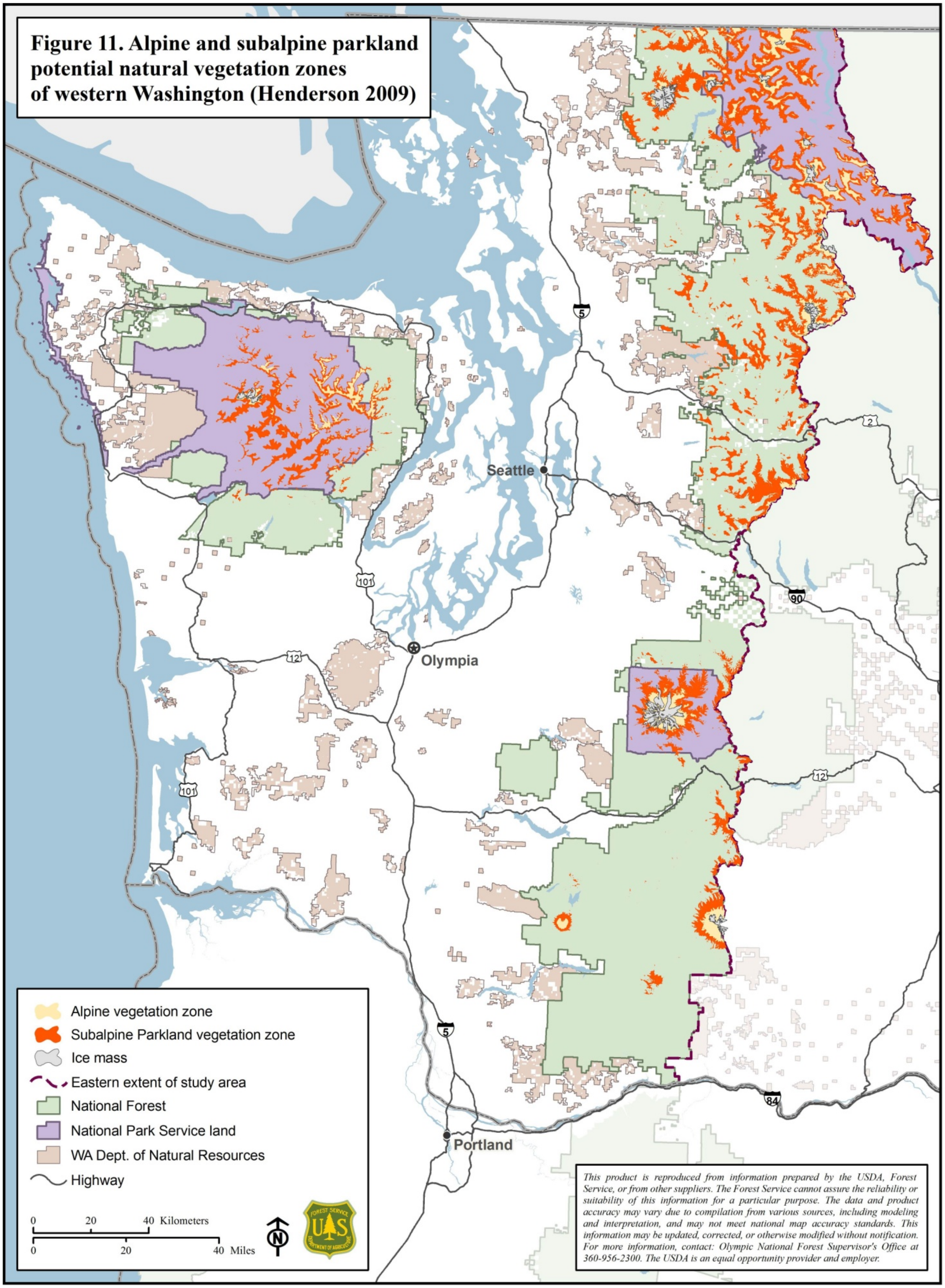

Figure 11. Alpine and subalpine parkland potential natural vegetation zones of western Washington (Henderson 2009)

Because of the high degree of topographic relief and the wide range of local conditions in mountainous environments, alpine and subalpine biodiversity is high, and habitat types are discontinuous and fragmented across the landscape. High-elevation habitats are expected to experience increased habitat fragmentation and increased competition from lower elevation species as a result of climate change (Walther et al. 2005). Conditions are expected to change more rapidly than alpine plant species will be able to adapt (Grabherr 2003), and plant community composition is likely to change as different species respond differently to changing conditions. In the forest tree vulnerability assessment described earlier in this report, several high-elevation tree species ranked among the most vulnerable to climate change. Among those species, subalpine fir and mountain hemlock are associated with subalpine habitat. They are important components of the patchy habitat structure of subalpine environments, and are commonly dominant species below the subalpine zone. In the case of mountain hemlock, habitat affinity was the greatest contributor to its high overall vulnerability score; for subalpine fir, insects and disease was the most influential factor. These results demonstrate some of the potential differences among species in relative vulnerability to climate change.

A review of coarse-scale climate envelope modeling or tree climate viability maps for high-elevation tree species may lead to the conclusion that climate change will force upward migration, and ultimately these species will reach the uppermost extent of habitable space and will have nowhere to go. However, the high degree of fine-scale microhabitat variability in mountain ecosystems may provide some localized protection from climate change influences for species with slow migration rates, although the prevalence of this “refugia” effect is uncertain (Randin et al. 2009). Relatively mobile species, such as those with light, wind-dispersed seeds, may be able to migrate locally to more hospitable locations, shifting to cooler, moister microhabitats or to more northerly aspects (Millar et al. 2007). Subalpine meadow habitat may decrease—conifer advancement into subalpine meadows is a documented impact of climate change, with treeline advancing unevenly upward into meadow sites that become more favorable to tree establishment (Holtmeier and Broll 2005, Millar et al. 2004, Peterson et al. 2002, Rochefort and Peterson 1996, Woodward et al. 1995, Zolbrod and Peterson 1999).

Reductions in snowpack extent and duration may result in loss of habitat and increased risk of desiccation and freezing


Robin Shoal, USFS

Subalpine habitat, Norse Peak Wilderness, Mt. Baker-Snoqualmie National Forest

for frost-sensitive plant species adapted to wintering in the stable, near-freezing conditions found under snow (Grabherr et al. 2010). Alpine and subalpine wetlands and stream headwaters may experience more pronounced with earlier spring peak flows and increased summer drought altering habitat for both plants and animals.

An additional threat associated with projected climate change is the potential for increased native and non-native insect and pathogen outbreaks and related disturbances (Dale et al. 2001). For example, recent warming trends resulted in range expansion and population outbreaks of mountain pine beetle (*Dendroctonus ponderosae*), a native bark beetle, that have led to widespread mortality in high-elevation pines (Logan et al. 2003, Williams and Leibhold 2002) and led to a short-term risk of increased fire intensity. In western Washington, whitebark pine, western white pine, and lodgepole pine are all associated with high-elevation forests, and whitebark pine and lodgepole pine are often found in subalpine habitats. Fire frequency is expected to increase with future climate warming (Littell et al. 2009a, Westerling et al. 2006), and may be exacerbated in subalpine habitats by increased tree mortality from mountain pine beetle (Littell et al. 2009b). In contrast to the other two habitat types considered in this section, alpine and subalpine habitats in western Washington are relatively pristine in that they are generally free of direct human impacts beyond the developed ski areas, trail systems, and popular camping destinations. While dry grassland and wetland habitats are included in the Priority Habitats and Species List maintained by the Washington Department of Fish and Wildlife (WDFW), alpine and subalpine habitats are not, primarily because they are not considered to be directly threatened by human activities (Azerrad 2010). However, these highest of habitats are not without anthropogenic stressors, including recreation pressure, air pollution, fire suppression, grazing, and non-native pathogens, plants, and animals.

Ecosystem Goods and Services

Alpine and subalpine habitats support a high level of both plant and animal biodiversity, and also serve as summer habitats for many species of wildlife, including migratory birds. They are important recreation areas, valued for their scenic views, wildlife, seasonal wildflower displays, and physical challenges. Recreation pressure is increasing in these areas as human populations grow, and as advances in technology make backcountry recreation more accessible. Snowpack conditions will continue to vary annually, but a trend toward later snow accumulation in fall and earlier snowmelt in spring is likely to extend the recreation season, allowing earlier trail access in the spring and more snow-free territory in late summer. This may result in an increase in high-elevation recreation, which may place additional stresses on alpine and subalpine ecosystems, including sanitation issues and an increased risk of introduction and spread of non-native invasive plant species, particularly near heavily used areas such as water sources.

Information Gaps

Site-specific management requires site-specific information, but alpine and subalpine habitats are not well-mapped, due in part to difficulties of scale. Figure 11 shows the modeled alpine and subalpine parkland vegetation zones from the current Forest Service vegetation zone map. However, this map representation cannot provide information about the locations and extent of the widely varied small-scale ecosystems that occur within the larger alpine and subalpine environments as a result of local factors—factors that include geology, soils, aspect, slope, concavity, position on a hillside, proximity to permanent or seasonal snowfields, proximity to other vegetation, local drainage patterns, and exposure to sun and wind. These localized habitats include dry meadows, wet meadows, wetlands, seasonal ponds, lichen-covered rocks and cliffs, talus slopes, krummholz, shrub thickets, tree islands, and other small ecosystems (Malanson et al. 2007).

Current climate modeling is limited to resolutions too coarse to be useful in complex high-elevation topography, and also misses these important small-scale landscape and habitat variations (Bachelet 2010a). While models can predict generalized trends, local responses to climate change will vary (Malanson et al. 2007). Direct monitoring of climate-sensitive factors will provide better information for assessing alpine and subalpine responses to climate change. For instance, the duration and extent of annual snowpack can be tracked using existing aerial imagery and remote sensing. Changes in tree density and establishment in subalpine meadows can also be tracked using aerial imagery. Valuable information already exists in the form of historic photographs, both aerial and from known locations on the ground such as established viewpoints and fire lookout towers. Local temperature and precipitation data are available from the existing system of weather stations maintained by various agencies, such as the Western Regional Climate Center (www.wrcc.dri.edu/index.html). Consistent observation of these data, combined with a review of historical data, would offer clues as to which elements of alpine and subalpine habitats might be most vulnerable to the effects of climate change. Gaps in the network of weather stations could be identified and filled to provide a more complete picture of patterns of climate change in alpine and subalpine habitats.

Also lacking are inventories of existing non-native invasive plant (noxious weed) infestations in high-elevation environments.

NATIVE DRY GRASSLAND HABITATS

In western Washington, native dry grassland habitats occur in the Puget Lowlands and Willamette Valley Ecoregions (Chappell et al. 2001), which span the north-to-south length of the Puget Trough from the border with British Columbia to the Oregon border (fig. 12). Dry grassland habitats include native prairies, Oregon white oak woodlands, conifer savannas, and balds and herbaceous bluffs (Chappell 2006, Chappell et al. 2001). Native prairies are found on glacial outwash and other well-drained soils, and are defined by the presence of certain diagnostic grasses, forbs, and sedges (Washington Department of Fish and Wildlife 2008). Oregon white oak woodlands are characterized by an open canopy dominated by oak and scattered conifers with an understory of grasses, forbs, and some shrubs. Conifer savannas are grasslands that support sparsely scattered conifers—Douglas-fir and lodgepole pine but also ponderosa pine in a small portion of Pierce County (Chappell and Crawford 1997). Herbaceous balds and bluffs are usually relatively small, and occur on very dry, sloping sites with thin soils (Chappell 2006); they are dominated by grasses, lichens, forbs, and low-growing shrubs. The elevations at which these habitats occur are generally low— from sea level for coastal grasslands and herbaceous bluffs, to at least 700 ft (215 m) (the highest site reported by Peter and Shebitz [2006]) for oak woodlands and conifer savannas. Balds may occur at somewhat higher elevations (Chappell 2006).

Most South Puget Sound dry grassland habitats are susceptible to encroachment and eventual dominance by conifers (Chappell and Crawford 1997). While soil conditions that limit the growth of conifers explain the presence and persistence of some of these habitats, historically many of these grassland habitats were actively maintained by Native American burning (Peter and Shebitz 2006, Shebitz et al. 2009). Prairie habitats also occur on San Juan National Historic Park and Ebey's Landing National Historic Reserve on Whidbey Island (Rochefort et al., n.d.). It is likely that some of these island grasslands persist as a result of limiting soil conditions and the prevailing dry climate (Rochefort 2010).

Dry grassland habitats are the least extensive of the three habitat types considered in this report. The WNHP map representation of current oak and grassland habitats in the Puget Trough Ecoregion encompasses about 41,500 ac (16,800 ha), much of which is degraded. It is possible to estimate the potential historical extent of dry grassland habitats by mapping the soil types associated with these habitats. Historically, native grassland habitat was considerably more extensive. In the southern Puget Sound area, urban development, forest invasion, agriculture, and conversion to other land uses have reduced grassland habitat to about 10 percent of its original (pre-European settlement) extent (Chappell et al. 2001, Crawford and Hall 1997). The range of Oregon white oak may also serve as a surrogate for the potential historical range of grassland habitat in western Washington (Thilenius 1968).

On National Forest System lands in western Washington, prairie remnants occur on the Olympic and possibly the Gifford Pinchot National Forests. The Gifford Pinchot sites are suspected to have once supported grassland habitat based on the presence of scattered vegetation plots containing Oregon white oak. The occurrence and extent of native grassland, historical or current, on the Mt. Baker-Snoqualmie National Forest is unknown.

The prairie remnants on the Olympic National Forest are in the southeast corner of the forest, adjacent to other savanna habitat under private ownership, and have been well-documented (Peter and Shebitz 2006). The forest initiated a 32-ac (13-ha) prairie restoration project in 1995. The project site, which had become covered by young Douglas-fir forest, was thinned in 2001 and burned in 2003, with the intent to continue prescribed burning on a 3- to 5-year interval (Peter and Shebitz 2006). No further restoration activity has occurred, although vegetation on the site is periodically monitored. The nearby Forest Service Dennie Ahl tree seed orchard, which has been mown for decades and includes portions maintained in an open state, contains remnant populations of prairie-

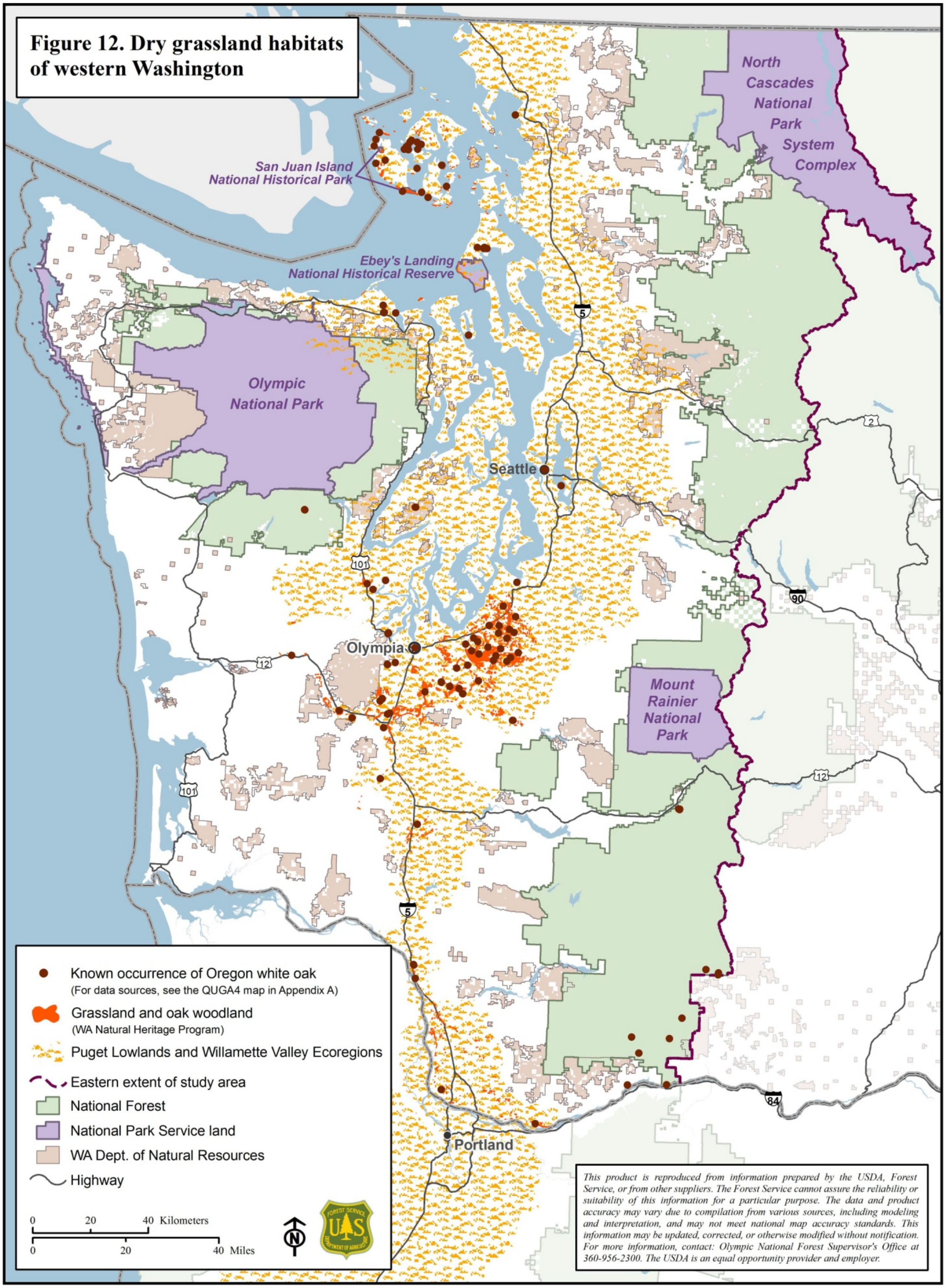

Figure 12. Dry grassland habitats of western Washington

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associated species such as tough-leaf iris (*Iris tenax*), beargrass (*Xenophyllum tenax*), the native grasses California oatgrass (*Danthonia californica*) and poverty oatgrass (*Danthonia spicata*), and other dry grassland plant species. Roemer's fescue (*Festuca idahoensis* var. *roemerii*) is suspected on the orchard site, but must be confirmed. Several vegetation plots in the same watershed contain Oregon white oak. There are also known examples of bald habitat on the Olympic National Forest, including areas in the Hamma Hamma and Dungeness watersheds.

On the Gifford Pinchot National Forest, Weigle Hill Botanical Special Interest Area is an Oregon white oak grassland that is proposed for RNA designation in the forest's 1990 Land and Resource Management Plan.

David Peter, USFS

Oak savanna, Joint Base Lewis-McChord, Washington

The Chelatchie Prairie, on National Forest System land adjacent to the Mt. St. Helens National Volcanic Monument Headquarters, is an example of a remnant of at-risk native grassland that provides an opportunity for restoration of native prairie vegetation, as well as opportunities for partnership and public education.

There is a high level of interest in preserving and restoring native dry grassland habitats in western Washington. The Department of Defense Joint Base Lewis-McChord, The Nature Conservancy, the WADNR Natural Heritage Program, and several other agencies and organizations are actively managing and restoring native prairies and oak woodlands in the South Puget Sound area, and have developed a successful ecological fire program with specialized skill in the application of fire as a restoration tool (McKinley 2010). Restoration activities have taken place at some of the National Park Service prairie sites in the San Juan Islands and at Ebey's Landing National Historic Preserve on Whidbey Island, where the emphasis is to restore habitat for the federally threatened golden paintbrush (*Castilleja levisecta*). National Park Service is developing a protocol to monitor prairie vegetation (Rochefort et al., n.d.).

Vulnerability

In western Washington, dry grassland habitats have been drastically reduced by human land use including agriculture and development. With European settlement came the cessation of systematic burning by Native American peoples, and many former prairies are now covered by conifer forests that regenerated in the absence of fire. Many dry grassland remnants are heavily degraded. Crawford and Hall (1997) conservatively estimate a loss of over 91 percent of the pre-settlement areal extent of grassland habitat, with less than 3 percent of the original habitat still in good condition. Grassland habitats have been invaded by non-native species such as Scot's broom (*Cytisus scoparius*), non-native blackberries (*Rubus* spp.), and a wide range of non-native grasses including the highly invasive pasture grass tall oatgrass (*Arrhenatherum elatius*) (Chappell et al. 2001; Dunwiddie et al. 2006; Rochefort et al., n.d.). Dry grasslands in western Washington are part of a larger complex of dry grassland ecosystems of the Willamette Valley– Puget Trough– Georgia Basin ecoregion, and are ranked among the most endangered ecosystems in the United

States (Noss et al. 1995). The warmer, drier summer conditions predicted for western Washington are likely to exacerbate existing stressors, particularly the presence and continued spread of invasive grasses and other plant species. Because intact native dry grassland habitats in western Washington have become so rare, and because many of their remnants are in poor condition, it may be difficult to separate recent climate effects from the dramatic changes that these habitats have undergone during the 20th century. Given predictions of warmer and drier summer conditions and increased fire frequency that will ultimately favor grasses over trees (Bachelet 2010b, Woodward et al. 2004), projected climate changes, combined with ongoing restoration efforts, may benefit dry grassland ecosystems in western Washington. If that is the case, early identification and active conservation and management of these areas may set the groundwork for these habitats to thrive, adapt, and expand as conditions change.

Ecosystem Goods and Services

Western Washington native grasslands are of great cultural importance for many Native American tribes who actively managed these habitats to enhance grazing opportunities for deer and elk, for the production of food such as bulbs of the camas lily (*Camassia quamash*), and for plant materials such as beargrass (Shebitz et al. 2009). In addition to providing habitat for many plant and animal species not found in other western Washington ecosystems, ecological goods and services associated with native dry grassland habitats include erosion control, flood control, fire resilience, and recreation. Native grasslands also are highly efficient at sequestering and storing atmospheric carbon (Bachelet 2010b, Neely et al. 2009). They provide important seasonal habitat for migratory birds (Altman 2000), and are popular birdwatching and hunting destinations.

Information Gaps

Other than the work of Peter and Shebitz (2006) and Shebitz et al. (2009), little is known about the historical extent of dry grassland habitat on National Forest System lands in western Washington. Data from vegetation inventories such as the Forest Service’s western Washington Area Ecology database and the Forest Inventory and Analysis (FIA) program provide clues to current vegetation; all occurrences of Oregon white oak are mapped in appendix A. However, both these vegetation databases were developed primarily to identify and track conditions in coniferous forest stands, and thus they do not well represent Oregon white oak stands, which are usually classified as non-forest land owing to their low densities. Additionally, most Oregon white oak woodlands and grasslands that were once maintained by anthropogenic fire were encroached upon by conifer forests before these inventories began. A review of historical data, including herbarium records, historical maps and photographs, and tribal history, would provide additional information about the historical extent and composition of dry grasslands on lands now managed by the Forest Service. Caplow and Miller (2004) performed a similar review to identify historical prairie sites in southwestern Washington.

WETLANDS

WETLAND CLASSIFICATION

The wetland classification systems used by botanists and ecologists contacted for this project and by the literature cited in this section vary. The Canadian Wetland Classification System (CWCS) (National Wetlands Working Group 1997) was the most frequently used system among the specialists contacted. For consistency, the discussion below generally follows the CWCS classifications when specific wetland types are mentioned.

Wetlands occur in places on the landscape where groundwater, surface water, or precipitation collects and persists long enough for aquatic processes and water-dependent communities to develop. Wetlands, which are relatively shallow, are distinct from deepwater habitats such as lakes, rivers, and oceans, which are permanently flooded lands where surface water is deep enough to provide a fully aquatic environment in which “water, rather than air, is the principal medium within which the dominant organisms live” (Cowardin et al. 1979).

The term wetlands encompasses a broad range of environments. Wetlands may be associated with deepwater habitats, such as the fringe of emergent vegetation surrounding a lake or pond, or with riparian settings. They may be tiny or extensive, forested or non-forested, freshwater or marine. Some wetlands contain standing or flowing water year-round; some are tidal; some are seasonal; and some are ephemeral, noticeably wet only after heavy precipitation events.

Wetlands occur throughout western Washington, at all elevations. The wetlands distribution represented in figure 13 is from the National Wetland Inventory, created by the U.S. Fish and Wildlife Service (http://www.fws.gov/wetlands/data/). In this representation there are approximately 238,000 ac (96,360 ha) of estuarine and marine wetlands, and approximately 367,000 ac (148,600 ha) of varied freshwater wetlands and ponds. Lakes and rivers cover approximately 223,000 ac (90,300 ha).

Among the botanists and ecologists contacted during the research for this report (see list in Acknowledgments section), concern about wetland vulnerability to climate change was stratified by wetland class. All wetland types were considered vulnerable to climate change, but bogs, fens, wet meadows, isolated ponds, and wetlands associated with headwater streams and alpine ecosystems were of consistently greater concern than wetlands directly associated with rivers or lakes. This stratification of concern is reflected in the scientific literature on freshwater wetlands and climate change, as discussed below.

The Canadian Wetland Classification System (CWCS) identifies five classes of wetlands: bogs, fens, swamps, marshes, and shallow open water. All five wetland classes occur in western Washington.

- Bogs and fens are both characterized by organic soils, primarily derived from mosses of the genus *Sphagnum*. Bogs have high water tables and acid-tolerant vegetation. While bogs may receive water from a variety of sources, there are no significant inflows or outflows. Fens, which also have organic soils, depend on groundwater for their primary water source. This sets fens apart from the other classes, which generally receive water inputs from surface water as well as ground water.
- Swamps are forested wetlands, generally with mineral soils but often with some decomposed woody organic material in the substrate. Swamps are associated with streams or other water bodies, and usually have some water movement through them. While swamps are wooded, marshes are characterized by emergent herbaceous vegetation.
- Marshes generally have mineral soils and may experience wide fluctuations in water levels. In the Canadian classification system, wet meadows are a type of marsh.

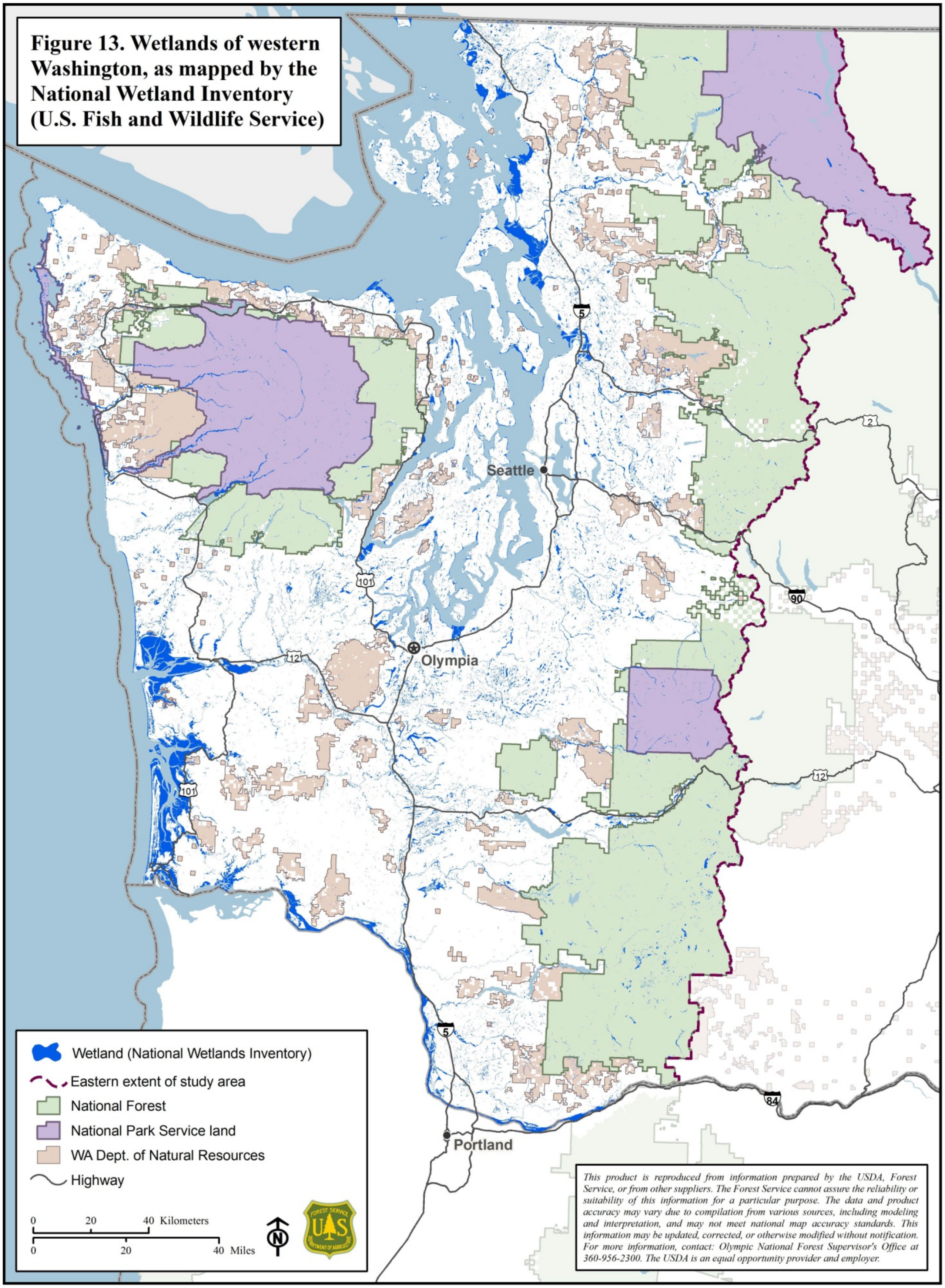

Figure 13. Wetlands of western Washington, as mapped by the National Wetland Inventory (U.S. Fish and Wildlife Service)

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- Shallow open waters (ponds) are small bodies of standing or gently flowing water that represent a transitional stage between lakes and marshes. They are usually connected to sources of groundwater and receive additional input from surface water and precipitation.

Among the many examples of wetlands in western Washington are the mid-elevation headwater wetland and wet meadow complexes on the Olympic National Forest, which may be in relatively pristine condition and could serve as potential reference sites for monitoring long-term climate change effects. On the Mt. Baker-Snoqualmie National Forest, the wetlands associated with Lake Isabel are home to rare wetland plant species at the southern edges of their ranges.

Vulnerability

Wetlands of all types have a long history of being directly and indirectly degraded by human activity. Existing stressors include pollution, logging, grazing, land conversion to agriculture or housing, unauthorized motorized recreation, and anthropogenic disruptions to hydrology on many scales, including water diversion, roads, ditches, irrigation, flood control structures, and trapping or removal of beavers. Wetlands also are susceptible to invasion by aggressive non-native plants, such as knotweed species (*Polygonum* spp.), reed canary grass (*Phalarus arundinaceae*), and competitive native species such as rose spiraea (*Spiraea douglasii*).

The vulnerability of wetlands to climate change depends primarily on their water source (Winter 2000), which may be precipitation, snowmelt, surface water (streams or runoff), ground water, or a combination of these sources. The size of the upgradient watershed is of great importance, as is the wetland's position in the watershed. Potential impacts range from changes in plant community structure and composition to changes in ecological function, and the results range from wetland loss to enhancement (Burkett and Kusler 2000).

Increased winter precipitation, especially precipitation that falls as rain rather than snow, may cause more frequent winter flooding and full inundation. In the summer, reduced precipitation may reduce water availability, while increased summer temperatures may simultaneously speed evaporation from wetlands and from their water sources, resulting in more extreme summer drying (U.S. Congress, Office of Technology Assessment 1993). In western Washington, the overall trend toward warming, with drier summers and wetter winters, may therefore be expressed in many freshwater wetlands by more pronounced seasonal extremes in water levels, particularly in the wetland types with greater dependence on precipitation.

High-elevation alpine and subalpine wetlands are extremely vulnerable to climate change because their contributing ground and surface watersheds are very small. These wetlands have small catchment basins and depend almost entirely on snowmelt in the forms of localized groundwater, surface water, or direct input. Earlier snowmelt and drier summers may result in earlier spring inundation and more summer drying. Plants and animals dependent on these wetlands will need to be able to adapt their lifecycles to these shifts in timing, or migrate elsewhere. Migration


Cheryl Bartlett, USFS

Wetland, Three Peaks Botanical Area, Olympic National Forest

opportunities may be extremely restricted in fragmented mountainous terrain, and even small degrees of warming may eliminate populations of "relic" species currently resident in alpine wetlands (Burkett and Kusler 2000).

Bogs and fens are peat-forming wetlands, and share a well-developed organic substrate layer (Zoltai and Vitt 1995). By definition, fens depend primarily on groundwater, while bogs may have a mix of water sources. Stable groundwater, surface water, or precipitation inputs are crucial for maintaining the integrity of these organic soils (Rocchio and Crawford 2009). Peatlands are very effective at carbon storage, but become emitters of both carbon dioxide and methane if they dry or drain (Burkett and Kusler 2000).

Marshes and swamps differ from bogs and fens in that they have non-organic (mineral) substrates and generally greater water movement within and through them. Marshes and swamps may receive water from multiple sources. Marsh and swamp vegetation is adapted to a wide range of seasonal water level fluctuation (Zoltai and Vitt 1995). Because of this, marshes and swamps are considered less vulnerable to effects of climate change than fens or bogs. However, they are likely to experience greater seasonal extremes than they have historically, and may expand or contract in response, depending on their hydrologic setting (Burkett and Kusler 2000).

Isolated wetlands that depend primarily on precipitation and runoff for their water source are highly vulnerable to climate change (Winter 2000). In western Washington this group includes vernal ponds, wooded kettles, some wet meadows, and other seasonally wet areas that occur in small depressions on the landscape. These habitats are often crucial in the reproductive lifecycles of frogs and other amphibians. Climate change may pose a serious challenge to the health and persistence of many amphibian species (Corn 2005). Early summer drying of these wetlands may expose amphibian eggs to desiccation, and higher water temperatures may reduce amphibian immunity to pathogens (Raffel et al. 2006).

Wetlands associated with rivers and lakes in valley bottoms are likely to be relatively less exposed to effects of climate change, because they have larger catch basins and more sustained water input from both groundwater and surface water sources. However, wetlands located on terraces above the valley bottom may be more vulnerable if they are fed only by localized groundwater flow (Winter 2000).

Finally, coastal and estuarine wetlands are highly vulnerable to sea level rise if they have no ability to migrate inland, or if the rate of sediment accretion lags behind the rate of sea level rise (Burkett and Kusler 2000). Water quality in coastal and estuarine wetlands is expected to decline as a result of decreased summer stream flows and higher water temperatures (Poff et al. 2002). Rising sea levels may inundate coastal wetlands, and introduce brackish water into freshwater tidal areas and near-shore wetlands (U.S. Congress, Office of Technology Assessment 1993).

Ecosystem Goods and Services

In addition to having high plant and animal biodiversity, wetlands perform valuable functions that can be grouped into three categories: functions that improve water quality such as filtration, removal of pollution and nutrients, and the slowing and settling of sediment; functions that affect the water regime in a watershed such as flood storage and storm surge protection; and functions that provide habitat for plants and animals (Sheldon et al. 2005). Wetlands also provide direct goods and services in western Washington in the form of food production (i.e., fish, shellfish, cranberries), and recreation (i.e., boating, hunting, bird watching).

Information Gaps

The National Wetland Inventory (NWI, depicted in fig. 13) is currently the best mapped inventory of wetlands in western Washington. NWI maps are strongest at identifying open-water wetlands associated with rivers and lakes, but omit many small, vegetated wetlands, including wet meadows, bogs, fens, some marshes, and most forested wetlands. Other than NWI, wetlands on public lands have not been consistently inventoried, mapped, or classified, although some information is generally recorded informally when an individual wetland is encountered during other management activities.

Identifying which wetlands are naturally more resilient to climate change and which are more vulnerable would help in prioritizing wetland habitats for monitoring, active conservation, and restoration.

PART 3: RECOMMENDATIONS

RECOMMENDATIONS

The recommendations developed during the course of this project fall into three categories:

1. **Learn about and track changes in plant communities as the climate changes.** Collect baseline data where needed. Monitor the impacts of a warming climate on the distribution and health of forest tree species and non-forested habitats. Look for triggers, such as an increase in the frequency of large-scale disturbance, that will indicate a need to change our management approach.
2. **Maintain and increase biodiversity and increase resiliency.** Focus on increasing stand diversity of native forest trees through thinning and planting. Initiate restoration activities in priority non-forested habitats. Increase disease resistance. Preserve genetic diversity, especially of isolated populations, and implement *ex situ* gene conservation where appropriate.
3. **Prepare for the future**. Given uncertainty about how climate changes will unfold, a number of future scenarios are possible. Select activities that will work under a variety of scenarios including a potential increase in disturbances such as fires, wind storms, and floods, which could be followed by greater spread of invasive plant species.

Recommendations, and action items listed in tables 28 through 32, are focused on present conditions with the assumption that existing policy and law will continue to guide land managers over the next few years.

ACTION ITEMS

Based on the findings of our analysis, we created action items for all western Washington national forests, as well as action items specific to each of the three national forests that were the focus of this project. Action items for forest trees and non-forested habitats are listed separately within each of the three recommendation categories.

Historically, management on the three western Washington national forests has emphasized tree species, forest stands, and, more recently, riparian areas. As a result, little information exists about the location and condition of non-forested habitats on these national forests. Much of the work needed to understand the vulnerabilities and potential responses of these habitats to projected trends in climate change is the collection of baseline information about their location, historical extent, and current condition. Because of this, the action items for non-forested habitats are more general than the action items for forest tree species.

There are four recurring themes in the recommended action items for non-forested habitats:

- Locate, map, describe, and assess the condition of these habitat types;
- Select instances of these habitat types on which to focus monitoring and/or restoration efforts;
- Identify and monitor potential vulnerabilities to or indicators of climate change; and
- Manage to maintain or restore resilience to climate change.

Action items for non-forested habitats are intended to contribute to management's preparedness for adapting to climate change effects on these habitats. Many of the action items can be accomplished through coordination or partnership with existing organizations or established programs. Some of these resources are listed following the action item tables. It is recommended that forests begin by using remote assessment—GIS, aerial photography, local knowledge, existing datasets, etc.—to develop preliminary priorities for more intensive inventories, field assessments, and restoration and adaptation planning. Priorities are likely to vary among forests, and may be based on habitat type, wildlife presence, or other forest-level considerations.

WASHINGTON STATE'S CLIMATE CHANGE WORK

The Washington State Department of Ecology formed four topic advisory groups in 2010 to assist with development of the state's climate change response strategy. The Natural Resources: Working Lands and Waters topic advisory group produced a set of recommendations for genetic preservation and development in adapting to climate change (NRWLW 2011). Several of the action items in this report are closely aligned with the recommendations of the topic advisory group; these action items are marked with an asterisk in the tables that follow.

TOP 10 PRIORITY ACTION ITEMS

As a focus for planning and accomplishment, the top 10 action items (table 28) were selected based on the following criteria:

- Items reflect the results of vulnerability assessments of forest trees and non-forested habitats.
- Items benefit the three national forests in western Washington.
- Items can be accomplished in 5 years.
- Items reflect new efforts.
- Where possible, items combine activities under common goals or themes.
- Items provide opportunities for partnership with the National Park Service, WADNR, and other land managers.

GUIDE TO ACTION ITEM TABLES

Tables 28 through 32 list all of the action items created for the national forests of western Washington.

- Table 28 lists the top 10 priority action items that apply to all three of the national forests of western Washington.
- Table 29 is a comprehensive list of all the action items for the three national forests. Each item is labeled with the initials of the national forest(s) to which it applies.
- Tables 30 though 32 contain forest-specific lists of action items for the three national forests of western Washington.

Table 28. Top 10 Priority Action Items

Forest Trees

◆	1B	Assess stand health and regeneration of subalpine fir, mountain hemlock, and Alaska yellow-cedar, the high-elevation tree species that were found to be most at risk based on the vulnerability assessment. This will establish baseline information that can be used to track changes over time and form the basis for a conservation and monitoring plan.
◆	1D*	Develop a pilot program to monitor vegetative and reproductive phenology in seed orchards.
◆	2G*	Develop a pilot project to plant blister rust resistant western white pine in gaps or openings created in pre-commercially thinned stands and young-growth stands.
◆	3A*	Partner with other land managers in western Washington to create a virtual cooperative tree seed bank to facilitate reforestation after large-scale disturbances such as fire or insect outbreaks.
◆	3B* - 3F	Maintain an inventory of high-quality seed for tree species that are likely to be needed over the next 20 years. Place a priority on species that can be planted after disturbance. Assess the viability of stored seed, discard non-viable seed, and make new and replacement collections as needed.

Non-Forested Habitats

◆	1G 1H 1I	For alpine and subalpine meadows: • Map and inventory. • Review historic aerial photography to identify potential trends in tree establishment in meadows and tree line change over time. • Select individual meadows for monitoring and initiate photo-point monitoring and/or periodic aerial photography of selected alpine meadows to track changes in tree establishment.
◆	1K 1L	For native dry grassland, Oregon white oak woodlands and savannas, and balds: • Map and inventory existing occurrences. • Use soil maps, aerial photos, and historical information to identify potential historical extent of these habitats on national forest lands.
◆	1O 1P 1R	For wetlands: • Initiate a systematic inventory program to locate and describe wetlands and assess their condition. • Use historic information and aerial photography to identify changes to individual wetlands over time. • Initiate on-going photo-point monitoring of selected wetlands. • Using wetland inventory results, select at-risk wetlands for conservation and restoration.
◆	1Q	Collect foundation seed and initiate seed increase as needed of native grassland and wetland plant species. Target both rare and “workhorse” species for *ex situ* gene conservation and restoration purposes.
◆	3G 3I	For all three habitat types, continue to inventory, prevent, and treat non-native invasive plant species

Note: *Item numbers correspond to the action items described in detail in the following tables. In some cases items were combined.*

** Action item is aligned with a similar recommendation by the Washington Department of Ecology’s Natural Resources Topic Advisory Group adaptation strategy for genetic preservation and development.*

Table 29. Action Items for All Western Washington National Forests

Forest Trees		
No.	**Forest**	**Action**
1. Learn about and track changes in plant communities as the climate changes		
1A	GP MBS OLY	Continue and expand the survey and mapping program for whitebark pine, with the participation by all land management agencies with whitebark pine habitat in Washington state. This effort should include a refinement of the existing state-wide GIS layer of whitebark pine occurrences. Readily accessible data on whitebark pine's present distribution is essential for monitoring and managing the species under climate change and pathogen threats.
1B	GP MBS OLY	Develop a conservation and monitoring plan for the three high elevation tree species that ranked highest in vulnerability to climate change but that have not been managed in the past: subalpine fir, mountain hemlock, and Alaska yellow-cedar.
1C	GP MBS OLY	Catalog information on all known off-site forest plantations on the national forests, and create a GIS layer of these plantations. In the past, seed sources used for reforestation were sometimes not well matched to the seed zones in which the seedlings were planted. Some of these off-site plantations may now provide valuable information on response of trees to climatic stressors comparable to those predicted to occur under future climate change scenarios.
1D*	OLY	Monitor vegetative and reproductive phenology in seed orchards. Timing of phenology is closely linked to climate, and collecting data on annual phenology and microclimate will allow us to determine if there are trends in how trees are responding to annual climate variation. A pilot program will be established in 2011 in the Dennie Ahl seed orchard to develop protocols for monitoring phenology in western white pine and Pacific silver fir in partnership with Dr. Constance Harrington of PNW Research Station and the WADNR. These two species were chosen because: 1) Pacific silver fir had the highest overall vulnerability in our index, 2) these species are present in the orchard, and 3) Douglas-fir and western red cedar phenology monitoring has already been implemented at the WADNR Meridian Seed Orchard.
1E	GP OLY	Measure population genetics of golden chinquapin. Golden chinquapin is one of the four Group 3 species (table 2) and is listed by the US Forest Service as a sensitive species in Washington; however, nothing is known about the genetics of this species (table 18). To develop a conservation plan for golden chinquapin in Washington, it is necessary to know how genetically similar these populations are to the core of the species' range in California and Oregon. In 2010, leaf samples were collected for genetic analysis from the two golden chinquapin populations in Washington. Additional leaf samples will be collected from other parts of the species' range to determine the genetic diversity and population structure of: 1) the north-south extent of the species' distribution, and 2) the Washington populations. This project includes partnerships with the Washington Department of Natural Resources (WADNR) (chinquapin is present on WADNR land on the Olympic Peninsula) and USFS National Forest Genetic Electrophoresis Lab (NFGEL) where genetic analysis will be performed.
1F	OLY	Assess genetic variation and population structure in three species with small, isolated disjunct populations: Engelmann spruce on the Olympic Peninsula and noble fir and Pacific silver fir in the Willapa Hills. These disjunct populations, as well as a range of populations from across the full distribution of the species, should be sampled for genetic analysis. These projects would include partnerships with the Olympic National Park, WADNR, and the USDA NFGEL, where genetic analysis would be performed. Assessing genetic variation and population structure

Forest Trees

No.	Forest	Action
		of species with disjunct populations is necessary to determine if these populations are genetically distinct from populations within the contiguous part of the species’ distribution. This information is important because these disjunct populations could end up as refugia under predicted climate change scenarios or, conversely, they might be more severely impacted because lack of gene flow would limit opportunities for immigration of more highly adapted genes from other populations. This lack of gene flow could limit their adaptive genetic variation. In either case, it will be critical to know whether these populations are genetically distinct as this would lead to restrictions on the movement of seed both into and out of them.
2. Maintain and enhance biodiversity and increase resilience		
2A	GP MBS OLY	Continue the national forests’ thinning programs. These programs achieve: 1) promotion of greater biodiversity by increasing the proportion of less abundant conifer and hardwood tree species, 2) the development of understory vegetation, 3) enhancement of the habitat value provided by forest stands, and 4) increased stand resistance and resilience to disturbance and environmental stressors.
2B*	GP MBS OLY	Continue to include a variety of tree species in planting prescriptions, with an emphasis on under-represented tree species.
2C	OLY	Produce an interagency plan, involving the Forest Service and National Park Service, to map occurrences and evaluate management options for Rocky Mountain juniper on the Olympic Peninsula. One product of this plan should be a GIS layer of all known occurrences of this species on the Peninsula. Recent genetic research indicates that the Olympic Peninsula and Puget Sound Region populations of Rocky Mountain juniper represent a unique species, seaside juniper (*Juniperus maritima* R. P. Adams) (Adams 2007, Adams et al. 2010). Management of this species should be re-evaluated in the context of this new information and the potential effects of climate change on the species’ habitat. Additional genetic analyses should be conducted, if determined necessary, to verify the classification of this species.
2D	OLY	Develop a partnership between the Forest Service, WADNR, and private landowners to map, conserve, and restore golden chinquapin on the Olympic Peninsula. Golden chinquapin is the only Washington tree species currently listed by the Interagency Special Status / Sensitive Species Program (USDA 2010c). This effort should include the creation of a GIS layer documenting locations of golden chinquapin on the Olympic Peninsula. These disjunct Olympic Peninsula populations represent the northernmost occurrence of the species and may be genetically different from populations in the contiguous portion of the species’ range (see item 1E). The Olympic Peninsula populations therefore have the potential to contain adaptive genetic variation not present elsewhere in the range of golden chinquapin.
2E	OLY	In a collaborative effort between Olympic National Forest and Olympic National Park, map occurrences of Engelmann spruce on the Olympic Peninsula. Engelmann spruce occurs in at least one small, disjunct population on the Olympic Peninsula. This population is potentially important for the adaptive genetic variation that it may contain. This collaborative effort should include field verification of several other reported but unconfirmed occurrences of this species on the Olympic Peninsula (see map in appendix A).

Forest Trees

No.	Forest	Action
2F	GP	Continue to actively manage golden chinquapin sites to promote growth and survival of the species. As with the Olympic Peninsula populations, these disjunct populations may differ genetically from those in the contiguous portion of the species' range and therefore may contain unique adaptive genetic variation.
2G*	OLY	Develop a pilot project to plant blister rust resistant western white pine in gaps or openings created in pre-commercially thinned stands and young-growth stands. Planting also could be implemented in older young-growth stands in natural openings created by wind and root rot pockets with low quantities of competing vegetation.
2H*	OLY	Expand gene conservation collections. Seed from rare species and disjunct populations should be collected for long-term *ex situ* gene conservation. These efforts are already under way for whitebark pine, but to-date no collections have been made for other species. Seed should be collected and sent to the USDA ARS National Center for Germplasm Preservation in Ft. Collins, CO for western Washington populations of Rocky Mountain juniper, golden chinquapin, Engelmann spruce, noble fir (from the Willapa Hills), Pacific silver fir (from the Willapa Hills), and ponderosa pine. This project would include partnerships with Olympic National Park, WADNR, and Dept. of Defense Joint Base Lewis-McChord.
3. Prepare for the future		
3A*	GP MBS OLY	Partner with other land managers in western Washington to create a virtual cooperative tree seed bank. This would increase the likelihood that appropriate seed will be available for reforestation after large-scale disturbances such as fire or insect outbreaks. Landowners can maintain their own seed inventories, but enter in cooperative agreements to share seed in the event of a major disturbance. As a first step, Forest Service personnel should form a partnership with silviculturists, geneticists, and seed managers from the WADNR and the National Park Service and others to develop an approach for sharing information and seed.
3B*	GP MBS OLY	Maintain an inventory of high-quality seed for tree species that are likely to be needed over the next 20 years. Place a priority on species that can be planted after disturbance. Accomplish this through the following steps: • Assess the viability of seed stored at the Forest Service storage facility at JH Stone Nursery • Retest viability as needed • Discard non-viable seed • Update Seed Procurement Plans to include new and replacement collections
3C	OLY	Maintain the Dennie Ahl seed orchard which serves as a gene conservation area and is the Forest's most efficient source of high quality tree seed for Douglas-fir, Pacific silver fir, and rust resistant western white pine.
3D	GP	Maintain the White Salmon, Planting Creek, Coyote, Cispus, and French Butte seed orchards which serve as gene conservation areas and are the Forest's most efficient source of high quality tree seed for Douglas-fir, noble fir and rust resistant western white pine.
3E	MBS	Maintain the McCullough seed orchard which serves as gene conservation areas and is the Forest's most efficient source of high quality tree seed for Douglas-fir, noble fir and rust resistant western white pine.

Forest Trees

No.	Forest	Action
3F	GP MBS OLY	Assess seed viability of individual selected tree lots in storage. The three national forests in western Washington have over 5,000 single tree seedlots from selected trees in storage at the Dorena Genetic Resources Center (table 25). Many of these seedlots have been in storage for one or more decades and their viability is unknown. Viability testing is expensive and time consuming so it is impractical to test every seed lot. Geneticists and silviculturists should jointly develop a prioritized list of seedlots for viability testing. Priority for testing should be based on several factors, including: 1) vulnerability rank of the species, 2) initial (or subsequent) viability test results, 3) age of seed, and 4) amount of seed available. Top priority should be given to highly vulnerable species, seedlots with low initial viability, older seed, and lots with a large amount of seed available.

Non-Forested Habitats

No.	Forest	Action
1. Learn about and track changes in plant communities as the climate changes		
Alpine and subalpine		
1G	GP MBS OLY	Map and inventory alpine and subalpine meadows. Select individual meadows for monitoring.
1H	GP MBS OLY	Review historic aerial photography to identify potential trends in tree establishment in meadows and tree line change over time. Initiate photo-point monitoring and/or periodic aerial photography of selected alpine meadows to track changes in tree establishment.
1I	GP MBS OLY	Identify target alpine and subalpine forb, shrub, and/or trees species based on criteria such as keystone function, known vulnerability, or habitat indicator status, and formalize a program for monitoring phenology of these species.
1J	GP MBS OLY	Identify and monitor key high-elevation wildlife species (i.e., pika, Olympic marmot, Clark's nutcracker, pollinators).
Dry grasslands (includes native prairies, balds, and Oregon white oak savannas and woodlands; for the Mt. Baker-Snoqualmie National Forest, the dry grasslands action items apply to balds only)		
1K	GP MBS OLY	Map and inventory existing occurrences of native dry grasslands, balds, and Oregon white oak savannas and woodlands.
1L	GP MBS OLY	Use soil maps, aerial photos, and historical information to identify potential historical extent of these habitats on national forest lands.

Non-Forested Habitats		
No.	**Forest**	**Action**
1M	GP	CONDUCT FIELD RECONNAISSANCE OF FIA AND ECOLOGY PLOTS CONTAINING OREGON WHITE OAK, AND IDENTIFY HABITAT TYPE ASSOCIATED WITH THESE OCCURRENCES. These sites are primarily in the southeast portion of the forest, with a single plot near Highway 12 farther north.
1N	MBS	MAP, INVENTORY, AND ASSESS CONDITION OF EXISTING OCCURRENCES OF BALDS. One example of this habitat is the Greenwater-George Creek Overlook. Because of the generally higher elevations of the Mt. Baker-Snoqualmie National Forest, it is unlikely that there is any significant quantity of native dry grassland or Oregon white oak woodland habitat. There are no known occurrences of Oregon white oak on this forest.
Wetlands		
1O	GP MBS OLY	INITIATE A SYSTEMATIC WETLAND INVENTORY PROGRAM TO LOCATE AND DESCRIBE WETLANDS AND ASSESS THEIR CONDITION.
1P	GP MBS OLY	USE HISTORIC INFORMATION AND AERIAL PHOTOGRAPHY TO IDENTIFY CHANGES TO INDIVIDUAL WETLANDS OVER TIME.
1Q	GP MBS OLY	USING WETLAND INVENTORY RESULTS, SELECT AT-RISK WETLANDS FOR CONSERVATION AND RESTORATION BASED ON CRITERIA SUCH AS WETLAND TYPE; ECOLOGICAL IMPORTANCE; DOWNSTREAM RESOURCES; KNOWN OCCURRENCE OF RARE, SENSITIVE, OR SPECIAL STATUS SPECIES; RESTORATION NEEDS; AND OTHER FOREST-LEVEL CONSIDERATIONS.
1R	GP MBS OLY	INITIATE ON-GOING PHOTO-POINT MONITORING OF SELECTED WETLANDS.
1S	GP MBS OLY	MONITOR WATER LEVEL, WATER TEMPERATURE, AND AMPHIBIAN PRESENCE IN SELECTED WETLANDS.
2. Maintain and enhance biodiversity and increase resilience		
Alpine and subalpine		
2I	GP MBS OLY	IDENTIFY RARE OR UNCOMMON PLANT SPECIES OR SPECIES ON THE EDGES OF THEIR CURRENT RANGES FOR EX SITU GENE CONSERVATION, SEED COLLECTION, AND PRESERVATION.
2J	GP MBS OLY	CONTINUE TO INVENTORY AND TREAT INVASIVE PLANT INFESTATIONS WITHIN AND ALONG ACCESS ROUTES TO ALPINE AND SUBALPINE HABITATS.

Non-Forested Habitats

No.	Forest	Action
Dry grasslands (includes native prairies, balds, and Oregon white oak savannas and woodlands; for the Mt. Baker-Snoqualmie National Forest, the dry grasslands action items apply to balds only)		
2K	GP MBS OLY	Continue to inventory and treat invasive plant infestations in these habitat types, including non-native grasses.
2L	GP MBS OLY	If any degraded grassland, Oregon white oak woodlands, or balds are located, prioritize the sites for restoration/rehabilitation and initiate restoration/rehabilitation plans.
2M	OLY	Continue restoration and monitoring of the Skokomish prairie/savannah site.
Wetlands		
2N	GP MBS OLY	Identify and remove or mitigate artificial barriers, such as roads, culverts, and trails, that disrupt natural wetland hydrology in selected wetlands.
2O	GP MBS OLY	Continue to inventory and treat invasive plant species in selected wetlands.
2P	GP MBS OLY	Implement restoration activities in selected wetlands where needed.
3. Prepare for the future		
Dry grasslands (includes native prairies, balds, and Oregon white oak savannas and woodlands; for the Mt. Baker-Snoqualmie National Forest, the dry grasslands action items apply to balds only)		
3G	GP MBS OLY	Continue seed collection and, if needed, seed increase of native grassland plants, including grasses. Target both rare and “workhorse” species for gene conservation and restoration purposes.
3H	OLY	Continue to inventory and protect and, if needed, enhance remnant populations of dry grassland plant species in the Dennie Ahl Seed Orchard.
Wetlands		
3I	GP MBS OLY	Continue seed collection and, if needed, seed increase of native wetland plants. Target both rare and “workhorse” species for gene conservation and restoration purposes.

** Action item is aligned with a similar recommendation by the Washington Department of Ecology’s Natural Resources Topic Advisory Group adaptation strategy for genetic preservation and development.*

Table 30. Action Items for the Gifford Pinchot National Forest

Forest Trees

No.	Action
1. Learn about and track changes in plant communities as the climate changes	
1A	Continue and expand the survey and mapping program for whitebark pine, with the participation by all land management agencies with whitebark pine habitat in Washington state. This effort should include a refinement of the existing state-wide GIS layer of whitebark pine occurrences. Readily accessible data on whitebark pine's present distribution is essential for monitoring and managing the species under climate change and pathogen threats.
1B	Develop a conservation and monitoring plan for the three high elevation tree species that ranked highest in vulnerability to climate change but that have not been managed in the past: subalpine fir, mountain hemlock, and Alaska yellow-cedar.
1C	Catalog information on all known off-site forest plantations on the national forests, and create a GIS layer of these plantations. In the past, seed sources used for reforestation were sometimes not well matched to the seed zones in which the seedlings were planted. Some of these off-site plantations may now provide valuable information on response of trees to climatic stressors comparable to those predicted to occur under future climate change scenarios.
1E	Measure population genetics of golden chinquapin. Golden chinquapin is one of the four Group 3 species (table 2) and is listed by the US Forest Service as a sensitive species in Washington; however, nothing is known about the genetics of this species (table 18). To develop a conservation plan for golden chinquapin in Washington, it is necessary to know how genetically similar these populations are to the core of the species' range in California and Oregon. In 2010, leaf samples were collected for genetic analysis from the two golden chinquapin populations in Washington. Additional leaf samples will be collected from other parts of the species' range to determine the genetic diversity and population structure of: 1) the north-south extent of the species' distribution, and 2) the Washington populations. This project includes partnerships with the Washington Department of Natural Resources (WADNR) (chinquapin is present on WADNR land on the Olympic Peninsula) and USFS National Forest Genetic Electrophoresis Lab (NFGEL) where genetic analysis will be performed.
2. Maintain and enhance biodiversity and increase resilience	
2A	Continue the national forests' thinning programs. These programs achieve: 1) promotion of greater biodiversity by increasing the proportion of less abundant conifer and hardwood tree species, 2) the development of understory vegetation, 3) enhancement of the habitat value provided by forest stands, and 4) increased stand resistance and resilience to disturbance and environmental stressors.
2B*	Continue to include a variety of tree species in planting prescriptions, with an emphasis on under-represented tree species.
2F	Continue to actively manage golden chinquapin sites to promote growth and survival of the species. As with the Olympic Peninsula populations, these disjunct populations may differ genetically from those in the contiguous portion of the species' range and therefore may contain unique adaptive genetic variation.

Forest Trees

No.	Action
3. Prepare for the future	
3A*	Partner with other land managers in western Washington to create a virtual cooperative tree seed bank. This would increase the likelihood that appropriate seed will be available for reforestation after large-scale disturbances such as fire or insect outbreaks. Landowners can maintain their own seed inventories, but enter in cooperative agreements to share seed in the event of a major disturbance. As a first step, Forest Service personnel should form a partnership with silviculturists, geneticists, and seed managers from the WADNR and the National Park Service and others to develop an approach for sharing information and seed.
3B*	Maintain an inventory of high-quality seed for tree species that are likely to be needed over the next 20 years. Place a priority on species that can be planted after disturbance. Accomplish this through the following steps: • Assess the viability of seed stored at the Forest Service storage facility at JH Stone Nursery • Retest viability as needed • Discard non-viable seed • Update Seed Procurement Plans to include new and replacement collections
3D	Maintain the White Salmon, Planting Creek, Coyote, Cispus, and French Butte seed orchards which serve as gene conservation areas and are the Forest's most efficient source of high quality tree seed for Douglas-fir, noble fir and rust resistant western white pine.
3F	Assess seed viability of individual selected tree lots in storage. The three national forests in western Washington have over 5000 single tree seedlots from selected trees in storage at the Dorena Genetic Resources Center (table 25). Many of these seedlots have been in storage for one or more decades and their viability is unknown. Viability testing is expensive and time consuming so it is impractical to test every seed lot. Geneticists and silviculturists should jointly develop a prioritized list of seedlots for viability testing. Priority for testing should be based on several factors, including: 1) vulnerability rank of the species, 2) initial (or subsequent) viability test results, 3) age of seed, and 4) amount of seed available. Top priority should be given to highly vulnerable species, seedlots with low initial viability, older seed, and lots with a large amount of seed available.

Non-Forested Habitats

No.	Action
1. Learn about and track changes in plant communities as the climate changes	
Alpine and subalpine	
1G	Map and inventory alpine and subalpine meadows. Select individual meadows for monitoring.
1H	Review historic aerial photography to identify potential trends in tree establishment in meadows and tree line change over time. Initiate photo-point monitoring and/or periodic aerial photography of selected alpine meadows to track changes in tree establishment.

Non-Forested Habitats

No.	Action
1I	Identify target alpine and subalpine forb, shrub, and/or trees species based on criteria such as keystone function, known vulnerability, or habitat indicator status, and formalize a program for monitoring phenology of these species.
1J	Identify and monitor key high-elevation wildlife species (i.e., pika, Olympic marmot, Clark's nutcracker, pollinators).
Dry grasslands (includes native prairies, balds, and Oregon white oak savannas and woodlands; for the Mt. Baker-Snoqualmie National Forest, the dry grasslands action items apply to balds only)	
1K	Map and inventory existing occurrences of native dry grasslands, balds, and Oregon white oak savannas and woodlands.
1L	Use soil maps, aerial photos, and historical information to identify potential historical extent of these habitats on national forest lands.
1M	Conduct field reconnaissance of FIA and Ecology Plots containing Oregon white oak, and identify habitat type associated with these occurrences. These sites are primarily in the southeast portion of the forest, with a single plot near Highway 12 farther north.
Wetlands	
1O	Initiate a systematic wetland inventory program to locate and describe wetlands and assess their condition.
1P	Use historic information and aerial photography to identify changes to individual wetlands over time.
1Q	Using wetland inventory results, select at-risk wetlands for conservation and restoration based on criteria such as wetland type; ecological importance; downstream resources; known occurrence of rare, sensitive, or special status species; restoration needs; and other forest-level considerations.
1R	Initiate on-going photo-point monitoring of selected wetlands.
1S	Monitor water level, water temperature, and amphibian presence in selected wetlands.
2. Maintain and enhance biodiversity and increase resilience	
Alpine and subalpine	
2I	Identify rare or uncommon plant species or species on the edges of their current ranges for ex situ gene conservation, seed collection, and preservation.
2J	Continue to inventory and treat invasive plant infestations within and along access routes to alpine and subalpine habitats.

Dry grasslands (includes native prairies, balds, and Oregon white oak savannas and woodlands; for the Mt. Baker-Snoqualmie National Forest, the dry grasslands action items apply to balds only)

2K Continue to inventory and treat invasive plant infestations in these habitat types, including non-native grasses.

2L If any degraded grassland, Oregon white oak woodlands, or balds are located, prioritize the sites for restoration/rehabilitation and initiate restoration/rehabilitation plans.

Wetlands

2N Identify and remove or mitigate artificial barriers, such as roads, culverts, and trails, that disrupt natural wetland hydrology in selected wetlands.

2O Continue to inventory and treat invasive plant species in selected wetlands.

2P Implement restoration activities in selected wetlands where needed.

3. Prepare for the future

Dry grasslands (includes native prairies, balds, and Oregon white oak savannas and woodlands; for the Mt. Baker-Snoqualmie National Forest, the dry grasslands action items apply to balds only)

3G Continue seed collection and, if needed, seed increase of native grassland plants, including grasses. Target both rare and "workhorse" species for gene conservation and restoration purposes.

Wetlands

3I Continue seed collection and, if needed, seed increase of native wetland plants. Target both rare and "workhorse" species for gene conservation and restoration purposes.

** Action item is aligned with a similar recommendation by the Washington Department of Ecology's Natural Resources Topic Advisory Group adaptation strategy for genetic preservation and development.*

Table 31. Action Items for the Mt. Baker-Snoqualmie National Forest

Forest Trees

No.	Action
1. Learn about and track changes in plant communities as the climate changes	
1A	Continue and expand the survey and mapping program for whitebark pine, with the participation by all land management agencies with whitebark pine habitat in Washington state. This effort should include a refinement of the existing state-wide GIS layer of whitebark pine occurrences. Readily accessible data on whitebark pine's present distribution is essential for monitoring and managing the species under climate change and pathogen threats.
1B	Develop a conservation and monitoring plan for the three high elevation tree species that ranked highest in vulnerability to climate change but that have not been managed in the past: subalpine fir, mountain hemlock, and Alaska yellow-cedar.
1C	Catalog information on all known off-site forest plantations on the national forests, and create a GIS layer of these plantations. In the past, seed sources used for reforestation were sometimes not well matched to the seed zones in which the seedlings were planted. Some of these off-site plantations may now provide valuable information on response of trees to climatic stressors comparable to those predicted to occur under future climate change scenarios.
2. Maintain and enhance biodiversity and increase resilience	
2A	Continue the national forests' thinning programs. These programs achieve: 1) promotion of greater biodiversity by increasing the proportion of less abundant conifer and hardwood tree species, 2) the development of understory vegetation, 3) enhancement of the habitat value provided by forest stands, and 4) increased stand resistance and resilience to disturbance and environmental stressors.
2B*	Continue to include a variety of tree species in planting prescriptions, with an emphasis on under-represented tree species.
3. Prepare for the future	
3A*	Partner with other land managers in western Washington to create a virtual cooperative tree seed bank. This would increase the likelihood that appropriate seed will be available for reforestation after large-scale disturbances such as fire or insect outbreaks. Landowners can maintain their own seed inventories, but enter in cooperative agreements to share seed in the event of a major disturbance. As a first step, Forest Service personnel should form a partnership with silviculturists, geneticists, and seed managers from the WADNR and the National Park Service and others to develop an approach for sharing information and seed.
3B*	Maintain an inventory of high-quality seed for tree species that are likely to be needed over the next 20 years. Place a priority on species that can be planted after disturbance. Accomplish this through the following steps: • Assess the viability of seed stored at the Forest Service storage facility at JH Stone Nursery • Retest viability as needed • Discard non-viable seed • Update Seed Procurement Plans to include new and replacement collections

Forest Trees

No.	Action
3E	Maintain the McCullough seed orchard which serves as gene conservation areas and is the Forest's most efficient source of high quality tree seed for Douglas-fir, noble fir and rust resistant western white pine.
3F	Assess seed viability of individual selected tree lots in storage. The three national forests in western Washington have over 5000 single tree seedlots from selected trees in storage at the Dorena Genetic Resources Center (table 25). Many of these seedlots have been in storage for one or more decades and their viability is unknown. Viability testing is expensive and time consuming so it is impractical to test every seed lot. Geneticists and silviculturists should jointly develop a prioritized list of seedlots for viability testing. Priority for testing should be based on several factors, including: 1) vulnerability rank of the species, 2) initial (or subsequent) viability test results, 3) age of seed, and 4) amount of seed available. Top priority should be given to highly vulnerable species, seedlots with low initial viability, older seed, and lots with a large amount of seed available.

Non-Forested Habitats

No.	Action
1. Learn about and track changes in plant communities as the climate changes	
Alpine and subalpine	
1G	Map and inventory alpine and subalpine meadows. Select individual meadows for monitoring.
1H	Review historic aerial photography to identify potential trends in tree establishment in meadows and tree line change over time. Initiate photo-point monitoring and/or periodic aerial photography of selected alpine meadows to track changes in tree establishment.
1I	Identify target alpine and subalpine forb, shrub, and/or trees species based on criteria such as keystone function, known vulnerability, or habitat indicator status, and formalize a program for monitoring phenology of these species.
1J	Identify and monitor key high-elevation wildlife species (i.e., pika, Olympic marmot, Clark's nutcracker, pollinators).
Dry grasslands (includes native prairies, balds, and Oregon white oak savannas and woodlands; for the Mt. Baker-Snoqualmie National Forest, the dry grasslands action items apply to balds only)	
1K	Map and inventory existing occurrences of native dry grasslands, balds, and Oregon white oak savannas and woodlands.
1L	Use soil maps, aerial photos, and historical information to identify potential historical extent of these habitats on national forest lands.

Non-Forested Habitats

No.	**Action**
1N	Map, inventory, and assess condition of existing occurrences of balds. One example of this habitat is the Greenwater-George Creek Overlook. Because of the generally higher elevations of the Mt. Baker-Snoqualmie National Forest, it is unlikely that there is any significant quantity of native dry grassland or Oregon white oak woodland habitat. There are no known occurrences of Oregon white oak on this forest.
Wetlands	
1O	Initiate a systematic wetland inventory program to locate and describe wetlands and assess their condition.
1P	Use historic information and aerial photography to identify changes to individual wetlands over time.
1Q	Using wetland inventory results, select at-risk wetlands for conservation and restoration based on criteria such as wetland type; ecological importance; downstream resources; known occurrence of rare, sensitive, or special status species; restoration needs; and other forest-level considerations.
1R	Initiate on-going photo-point monitoring of selected wetlands.
1S	Monitor water level, water temperature, and amphibian presence in selected wetlands.
2. Maintain and enhance biodiversity and increase resilience	
Alpine and subalpine	
2I	Identify rare or uncommon plant species or species on the edges of their current ranges for ex situ gene conservation, seed collection, and preservation.
2J	Continue to inventory and treat invasive plant infestations within and along access routes to alpine and subalpine habitats.
Dry grasslands (includes native prairies, balds, and Oregon white oak savannas and woodlands; for the Mt. Baker-Snoqualmie National Forest, the dry grasslands action items apply to balds only)	
2K	Continue to inventory and treat invasive plant infestations in these habitat types, including non-native grasses.
2L	If any degraded grassland, Oregon white oak woodlands, or balds are located, prioritize the sites for restoration/rehabilitation and initiate restoration/rehabilitation plans.
Wetlands	
2N	Identify and remove or mitigate artificial barriers, such as roads, culverts, and trails, that disrupt natural wetland hydrology in selected wetlands.
2O	Continue to inventory and treat invasive plant species in selected wetlands.
2P	Implement restoration activities in selected wetlands where needed.

Non-Forested Habitats

No.	Action
3. Prepare for the future	
Dry grasslands (includes native prairies, balds, and Oregon white oak savannas and woodlands; for the Mt. Baker-Snoqualmie National Forest, the dry grasslands action items apply to balds only)	
3G	Continue seed collection and, if needed, seed increase of native grassland plants, including grasses. Target both rare and “workhorse” species for gene conservation and restoration purposes.
Wetlands	
3I	Continue seed collection and, if needed, seed increase of native wetland plants. Target both rare and “workhorse” species for gene conservation and restoration purposes.

** Action item is aligned with a similar recommendation by the Washington Department of Ecology’s Natural Resources Topic Advisory Group adaptation strategy for genetic preservation and development.*

Table 32. Action Items for the Olympic National Forest

Forest Trees	
No.	**Action**
1. Learn about and track changes in plant communities as the climate changes	
1A	Continue and expand the survey and mapping program for whitebark pine, with the participation by all land management agencies with whitebark pine habitat in Washington state. This effort should include a refinement of the existing state-wide GIS layer of whitebark pine occurrences. Readily accessible data on whitebark pine's present distribution is essential for monitoring and managing the species under climate change and pathogen threats.
1B	Develop a conservation and monitoring plan for the three high elevation tree species that ranked highest in vulnerability to climate change but that have not been managed in the past: subalpine fir, mountain hemlock, and Alaska yellow-cedar.
1C	Catalog information on all known off-site forest plantations on the national forests, and create a GIS layer of these plantations. In the past, seed sources used for reforestation were sometimes not well matched to the seed zones in which the seedlings were planted. Some of these off-site plantations may now provide valuable information on response of trees to climatic stressors comparable to those predicted to occur under future climate change scenarios.
1D*	Monitor vegetative and reproductive phenology in seed orchards. Timing of phenology is closely linked to climate, and collecting data on annual phenology and microclimate will allow us to determine if there are trends in how trees are responding to annual climate variation. A pilot program will be established in 2011 in the Dennie Ahl seed orchard to develop protocols for monitoring phenology in western white pine and Pacific silver fir in partnership with Dr. Constance Harrington of PNW Research Station and the WADNR. These two species were chosen because: 1) Pacific silver fir had the highest overall vulnerability in our index, 2) these species are present in the orchard, and 3) Douglas-fir and western red cedar phenology monitoring has already been implemented at the WADNR Meridian Seed Orchard.
1E	Measure population genetics of golden chinquapin. Golden chinquapin is one of the four Group 3 species (table 2) and is listed by the US Forest Service as a sensitive species in Washington; however, nothing is known about the genetics of this species (table 18). To develop a conservation plan for golden chinquapin in Washington, it is necessary to know how genetically similar these populations are to the core of the species' range in California and Oregon. In 2010, leaf samples were collected for genetic analysis from the two golden chinquapin populations in Washington. Additional leaf samples will be collected from other parts of the species' range to determine the genetic diversity and population structure of: 1) the north-south extent of the species' distribution, and 2) the Washington populations. This project includes partnerships with the Washington Department of Natural Resources (WADNR) (chinquapin is present on WADNR land on the Olympic Peninsula) and USFS National Forest Genetic Electrophoresis Lab (NFGEL) where genetic analysis will be performed.
1F	Assess genetic variation and population structure in three species with small, isolated disjunct populations: Engelmann spruce on the Olympic Peninsula and noble fir and Pacific silver fir in the Willapa Hills. These disjunct populations, as well as a range of populations from across the full distribution of the species, should be sampled for genetic analysis. These projects would include partnerships with the Olympic National Park, WADNR, and the USDA NFGEL, where genetic analysis would be performed. Assessing genetic variation and population structure of species with disjunct populations is necessary to determine if these populations are genetically distinct from populations within the contiguous part of the species' distribution. This information is important because these disjunct populations could end up as refugia under predicted climate change scenarios or, conversely, they might be more severely impacted because lack of gene flow would limit opportunities for immigration of more highly adapted genes from other populations. This

Forest Trees

No.	Action
	lack of gene flow could limit their adaptive genetic variation. In either case, it will be critical to know whether these populations are genetically distinct as this would lead to restrictions on the movement of seed both into and out of them.
2. Maintain and enhance biodiversity and increase resilience	
2A	Continue the national forests’ thinning programs. These programs achieve: 1) promotion of greater biodiversity by increasing the proportion of less abundant conifer and hardwood tree species, 2) the development of understory vegetation, 3) enhancement of the habitat value provided by forest stands, and 4) increased stand resistance and resilience to disturbance and environmental stressors.
2B*	Continue to include a variety of tree species in planting prescriptions, with an emphasis on under-represented tree species.
2C	Produce an interagency plan, involving the Forest Service and National Park Service, to map occurrences and evaluate management options for Rocky Mountain juniper on the Olympic Peninsula. One product of this plan should be a GIS layer of all known occurrences of this species on the Peninsula. Recent genetic research indicates that the Olympic Peninsula and Puget Sound Region populations of Rocky Mountain juniper represent a unique species, seaside juniper (*Juniperus maritima* R. P. Adams) (Adams 2007, Adams et al. 2010). Management of this species should be re-evaluated in the context of this new information and the potential effects of climate change on the species’ habitat. Additional genetic analyses should be conducted, if determined necessary, to verify the classification of this species.
2D	Develop a partnership between the Forest Service, WADNR, and private landowners to map, conserve, and restore golden chinquapin on the Olympic Peninsula. Golden chinquapin is the only Washington tree species currently listed by the Interagency Special Status / Sensitive Species Program (USDA 2010c). This effort should include the creation of a GIS layer documenting locations of golden chinquapin on the Olympic Peninsula. These disjunct Olympic Peninsula populations represent the northernmost occurrence of the species and may be genetically different from populations in the contiguous portion of the species’ range (see item 1E). The Olympic Peninsula populations therefore have the potential to contain adaptive genetic variation not present elsewhere in the range of golden chinquapin.
2E	In a collaborative effort between Olympic National Forest and Olympic National Park, map occurrences of Engelmann spruce on the Olympic Peninsula. Engelmann spruce occurs in at least one small, disjunct population on the Olympic Peninsula. This population is potentially important for the adaptive genetic variation that it may contain. This collaborative effort should include field verification of several other reported but unconfirmed occurrences of this species on the Olympic Peninsula (see map in appendix A).
2G*	Develop a pilot project to plant blister rust resistant western white pine in gaps or openings created in pre-commercially thinned stands and young-growth stands. Planting also could be implemented in older young-growth stands in natural openings created by wind and root rot pockets with low quantities of competing vegetation.
2H*	Expand gene conservation collections. Seed from rare species and disjunct populations should be collected for long-term *ex situ* gene conservation. These efforts are already under way for whitebark pine, but to-date no collections have been made for other species. Seed should be collected and sent to the USDA ARS National Center for Germplasm Preservation in Ft. Collins, CO for western Washington populations of Rocky Mountain juniper, golden chinquapin, Engelmann spruce, noble fir (from the Willapa Hills), Pacific silver fir (from the Willapa Hills), and ponderosa pine. This project would include partnerships with Olympic National Park, WADNR, and Dept. of Defense Joint Base Lewis-McChord.

Forest Trees

No.	Action
3. Prepare for the future	
3A*	Partner with other land managers in western Washington to create a virtual cooperative tree seed bank. This would increase the likelihood that appropriate seed will be available for reforestation after large-scale disturbances such as fire or insect outbreaks. Landowners can maintain their own seed inventories, but enter in cooperative agreements to share seed in the event of a major disturbance. As a first step, Forest Service personnel should form a partnership with silviculturists, geneticists, and seed managers from the WADNR and the National Park Service and others to develop an approach for sharing information and seed.
3B*	Maintain an inventory of high-quality seed for tree species that are likely to be needed over the next 20 years. Place a priority on species that can be planted after disturbance. Accomplish this through the following steps: • Assess the viability of seed stored at the Forest Service storage facility at JH Stone Nursery • Retest viability as needed • Discard non-viable seed • Update Seed Procurement Plans to include new and replacement collections
3C	Maintain the Dennie Ahl seed orchard which serves as a gene conservation area and is the Forest's most efficient source of high quality tree seed for Douglas-fir, Pacific silver fir, and rust resistant western white pine.
3F	Assess seed viability of individual selected tree lots in storage. The three national forests in western Washington have over 5000 single tree seedlots from selected trees in storage at the Dorena Genetic Resources Center (table 25). Many of these seedlots have been in storage for one or more decades and their viability is unknown. Viability testing is expensive and time consuming so it is impractical to test every seed lot. Geneticists and silviculturists should jointly develop a prioritized list of seedlots for viability testing. Priority for testing should be based on several factors, including: 1) vulnerability rank of the species, 2) initial (or subsequent) viability test results, 3) age of seed, and 4) amount of seed available. Top priority should be given to highly vulnerable species, seedlots with low initial viability, older seed, and lots with a large amount of seed available.

Non-Forested Habitats

No.	Action
1. Learn about and track changes in plant communities as the climate changes	
Alpine and subalpine	
1G	Map and inventory alpine and subalpine meadows. Select individual meadows for monitoring.

Non-Forested Habitats

No.	Action
1H	Review historic aerial photography to identify potential trends in tree establishment in meadows and tree line change over time. Initiate photo-point monitoring and/or periodic aerial photography of selected alpine meadows to track changes in tree establishment.
1I	Identify target alpine and subalpine forb, shrub, and/or trees species based on criteria such as keystone function, known vulnerability, or habitat indicator status, and formalize a program for monitoring phenology of these species.
1J	Identify and monitor key high-elevation wildlife species (i.e., pika, Olympic marmot, Clark's nutcracker, pollinators).
	Dry grasslands (includes native prairies, balds, and Oregon white oak savannas and woodlands; for the Mt. Baker-Snoqualmie National Forest, the dry grasslands action items apply to balds only)
1K	Map and inventory existing occurrences of native dry grasslands, balds, and Oregon white oak savannas and woodlands.
1L	Use soil maps, aerial photos, and historical information to identify potential historical extent of these habitats on national forest lands.
	Wetlands
1O	Initiate a systematic wetland inventory program to locate and describe wetlands and assess their condition.
1P	Use historic information and aerial photography to identify changes to individual wetlands over time.
1Q	Using wetland inventory results, select at-risk wetlands for conservation and restoration based on criteria such as wetland type; ecological importance; downstream resources; known occurrence of rare, sensitive, or special status species; restoration needs; and other forest-level considerations.
1R	Initiate on-going photo-point monitoring of selected wetlands.
1S	Monitor water level, water temperature, and amphibian presence in selected wetlands.
	2. Maintain and enhance biodiversity and increase resilience
	Alpine and subalpine
2I	Identify rare or uncommon plant species or species on the edges of their current ranges for ex situ gene conservation, seed collection, and preservation.
2J	Continue to inventory and treat invasive plant infestations within and along access routes to alpine and subalpine habitats.
	Dry grasslands (includes native prairies, balds, and Oregon white oak savannas and woodlands; for the Mt. Baker-Snoqualmie National Forest, the dry grasslands action items apply to balds only)
2K	Continue to inventory and treat invasive plant infestations in these habitat types, including non-native grasses.

Non-Forested Habitats

No.	Action
2L	If any degraded grassland, Oregon white oak woodlands, or balds are located, prioritize the sites for restoration/rehabilitation and initiate restoration/rehabilitation plans.
2M	Continue restoration and monitoring of the Skokomish prairie/savannah site.
Wetlands	
2N	Identify and remove or mitigate artificial barriers, such as roads, culverts, and trails, that disrupt natural wetland hydrology in selected wetlands.
2O	Continue to inventory and treat invasive plant species in selected wetlands.
2P	Implement restoration activities in selected wetlands where needed.
3. Prepare for the future	
Dry grasslands (includes native prairies, balds, and Oregon white oak savannas and woodlands; for the Mt. Baker-Snoqualmie National Forest, the dry grasslands action items apply to balds only)	
3G	Continue seed collection and, if needed, seed increase of native grassland plants, including grasses. Target both rare and “workhorse” species for gene conservation and restoration purposes.
3H	Continue to inventory and protect and, if needed, enhance remnant populations of dry grassland plant species in the Dennie Ahl Seed Orchard.
Wetlands	
3I	Continue seed collection and, if needed, seed increase of native wetland plants. Target both rare and “workhorse” species for gene conservation and restoration purposes.

** Action item is aligned with a similar recommendation by the Washington Department of Ecology’s Natural Resources Topic Advisory Group adaptation strategy for genetic preservation and development.*

RESOURCES FOR NON-FORESTED HABITATS

- **Seed collection:** Seeds of Success (*www.nps.gov/plants/sos*) and Rare Care (*courses.washington.edu/rarecare*) are established seed-collection programs and have been partners with the Forest Service for seed collection and gene conservation efforts.
- **Aerial photography:** The Forest Service's Remote Sensing Application Center (RSAC) annually offers free special purpose aerial photography to R6 forests.
- **Phenology tracking:** USA National Phenology Network (*www.usanpn.org*). The Forest Service is a member of this network.
- **Ecological inventory and assessment:** The Ecological Integrity Assessment (EIA) Framework may be a useful conceptual model for designing an efficient inventory program, and prioritizing locations for quantitative field assessments. This framework uses three levels of assessment—remote, rapid, and intensive. Remote assessment requires the least investment of time and resources; intensive requires the most. See *www1.dnr.wa.gov/nhp/refdesk/communities/eia.html* for more information. The process fosters efficient identification of selected ecological units (e.g., wetlands) to prioritize for further study or management.
- **Oregon white oak and dry grassland/prairie restoration:** South Puget Sound Ecological Fire Program partners, including Joint Base Lewis-McChord, The Nature Conservancy, WA Department of Fish and Wildlife, and WA Department of Natural Resources, are experienced at oak woodland and prairie restoration and maintenance. South Puget Sound Prairie Landscape Working Group (*www.southsoundprairies.org*) is another good resource.

ACKNOWLEDGMENTS

The authors would like to thank Vicky Erickson, Tom DeMeo, and Kathy O’Halloran for providing financial and program support for this project.

We thank the following people for providing technical support and advice during the preparation of this report: Dominique Bachelet, Cheryl Bartlett, Kristen Chadwick, Rex Crawford, Chris Dowling, Gregory Filip, Jeffrey Foster, Joe Gates, Lise Grace, Andrew Gray, Jessica Halofsky, William Hargrove, Bruce Hostetler, Robin Lesher, Laura Potash Martin, Mike Messier, Jeff Muehleck, Marshall Murray, David Peter, Kevin Potter, Iral Ragenovich, Ann Risvold, Joe Rocchio, Regina Rochefort, Andrea Ruchty, Mark Senger, Linda Swartz, Karen Wells, and Beth Willhite.

We thank the following people for providing thoughtful reviews during preparation of this report: Dominique Bachelet, Cheryl Bartlett, Rex Crawford, Tom DeSpain, Vicky Erickson, Jeffrey Foster, Sharon Friedman, John Gross, Jessica Halofsky, Constance Harrington, Matt Horning, Glenn Howe, Laura Potash Martin, Kathy O’Halloran, Greg O’Neill, David Peterson, Susan Piper, Kevin Potter, Iral Ragenovich, Bryce Richardson, Ann Risvold, Joe Rocchio, Regina Rochefort, Brad St. Clair, Marcus Warwell, and Beth Willhite.

We thank Mary Carr of Forest Service Publishing Arts Staff for editorial support.

REFERENCES

Aagaard, J.E.; Krutovskii, K.V.; Strauss, S.H. 1998. RAPDs and allozymes exhibit similar levels of diversity and differentiation among populations and races of Douglas-fir. Heredity. 81: 69-78.

Adams, R.P. 2007. *Juniperus maritima*, the seaside juniper, a new species from Puget Sound, North America. Phytologia. 89(3): 263-283.

Adams, R.P.; Hunter, G.; Fairhall, T.A. 2010. Discovery and SNPs analyses of populations of *Juniperus maritima* in the Olympic Peninsula, a pleistocene refugium? Phytologia. 92(1): 68-81.

Agee, J.K. 1993. Fire ecology of Pacific Northwest forests. Washington, DC: Island Press. 493 p.

Ager, A.A.; Heilman, P.E.; Stettler, R.F. 1993. Genetic variation in red alder (*Alnus rubra*) in relation to native climate and geography. Canadian Journal of Forest Research. 23(9): 1930-1939.

Aitken, S.N.; Adams, W.T. 1996. Genetics of fall and winter cold hardiness of coastal Douglas-fir in Oregon. Canadian Journal of Forest Research. 26(10): 1828-1837.

Aitken, S.N.; Yeaman, S.; Holliday, J.A.; Wang, T.L.; Curtis-McLane, S. 2008. Adaptation, migration or extirpation: climate change outcomes for tree populations. Evolutionary Applications. 1(1): 95-111.

Alexander, R.R.; Shearer, R.C.; Shepperd, W.D. 1990. *Abies lasiocarpa* (Hook.) Nutt., subalpine fir. In: Burns, R.M.; Honkala, B.H., eds. Silvics of North America. Vol. 1, Conifers. Washington, DC: U.S. Department of Agriculture, Forest Service: 60-70.

Alexander, R.R.; Shepperd, W.D. 1990. *Picea engelmannii* Parry ex Engelm., Engelmann spruce. In: Burns, R.M.; Honkala, B.H., eds. Silvics of North America. Vol. 1, Conifers. Washington, DC: U.S. Department of Agriculture, Forest Service: 187-203.

Ally, D.; El-Kassaby, Y.A.; Ritland, K. 2000. Genetic diversity, differentiation and mating system in mountain hemlock (*Tsuga mertensiana*) across British Columbia. Forest Genetics. 7(2): 97-108.

Ally, D.; Ritland, K. 2007. A case study: Looking at the effects of fragmentation on genetic structure in different life history stages of old-growth mountain hemlock (*Tsuga mertensiana*). Journal of Heredity. 98(1): 73-78.

Altman, B. 2000. Conservation strategy for landbirds in lowlands and valleys of western Oregon and Washington. Oregon-Washington Partners in Flight. 80 p.

Anderson, M.D. 2001a. *Acer glabrum*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).

Anderson, M.D. 2001b. *Salix scouleriana*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).

Anderson, M.D. 2003. *Pinus contorta* var. *latifolia*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (18 June 2010).

Anekonda, T.S.; Lomas, M.C.; Adams, W.T.; Kavanagh, K.L.; Aitken, S.N. 2002. Genetic variation in drought hardiness of coastal Douglas-fir seedlings from British Columbia. Canadian Journal of Forest Research. 32(10): 1701-1716.

Arno, S.F.; Hammerly, R.P. 2007. Northwest trees: identifying and understanding our native trees. Seattle, WA: The Mountaineers Books. 245 p.

Arno, S.F.; Hoff, R.J. 1990. *Pinus albicaulis* Engelm., whitebark pine. In: Burns, R.; Honkala, B., eds. Silvics of North America. Vol. 1, Conifers. Washington, DC: U.S. Department of Agriculture, Forest Service: 268-279.

Aubry, C.; Goheen, D.; Shoal, R.; Ohlson, T.; Lorenz, T.; Bower, A.; Mehmel, C.; Sniezko, R. 2008. Whitebark pine restoration strategy for the Pacific Northwest Region, 2009-2013. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 212 p.

Augspurger, C.K. 2009. Spring 2007 warmth and frost: phenology, damage and refoliation in a temperate deciduous forest. Functional Ecology. 23(6): 1031-1039.

Azerrad, J. 2010. Personal communication. Biologist, Washington Department of Fish and Wildlife.

Bachelet, D. 2010a. Personal communication. Senior Climate Change Scientist, Conservation Biology Institute and Department of Biological and Ecological Engineering, Oregon State University, Corvallis, OR.

Bachelet, D. 2010b. Climate change impacts on south Puget lowland prairies [Abstract]. In: Northwest Scientific Association 82nd annual meeting. March 24-27, 2010. Centralia, WA. http://www.centralia.edu/academics/earthscience/nwsa/NWSA_CPOP_2010_Program.pdf. (28 September 2010).

Bachelet, D.; Leniham, J.M.; Daly, C.; Neilson, R.P.; Ojima, D.S.; Parton, W.J. 2001. MC1: A dynamic vegetation model for estimating the distribution of vegetation and associated ecosystem fluxes of carbon, nutrients and water. Technical documentation version 1.0. Gen. Tech. Rep. PNW-GTR-508. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 95 p.

Balduman, L.M.; Aitken, S.N.; Harmon, M.; Adams, W.T. 1999. Genetic variation in cold hardiness of Douglas-fir in relation to parent tree environment. Canadian Journal of Forest Research. 29(1): 62-72.

Barnes, B.V. 1975. Phenotypic variation of trembling aspen in western North America. Forest Science. 21(3): 319-328.

Barnett, T.P.; Adam, J.C.; Lettenmeier, D.P. 2005. Potential impacts of a warming climate on water availability in snow-dominated regions. Nature. 438: 303-309.

Beaubien, E.G.; Freeland, H.J. 2000. Spring phenology trends in Alberta, Canada: links to ocean temperature. International Journal of Biometeorology. 44(2): 53-59.

Beland, J.D.; Krakowski, J.; Ritland, C.E.; Ritland, K.; El-Kassaby, Y.A. 2005. Genetic structure and mating system of northern *Arbutus menziesii* (Ericaceae) populations. Canadian Journal of Botany. 83(12): 1581-1589.

Benedict, W.V. 1981. History of white pine blister rust control – a personal account. USDA Forest Service, Washington, D.C. Publication number FS-355.

Benowicz, A.; El-Kassaby, Y.A. 1999. Genetic variation in mountain hemlock (*Tsuga mertensiana* Bong.): quantitative and adaptive attributes. Forest Ecology and Management. 123(2-3): 205-215.

Benowicz, A.; Guy, R.; Carlson, M.R.; El-Kassaby, Y.A. 2001a. Genetic variation among paper birch (*Betula papyrifera* Marsh.) populations in germination, frost hardiness, gas exchange and growth. Silvae Genetica. 50(1): 7-13.

Benowicz, A.; Guy, R.D.; El-Kassaby, Y.A. 2000. Geographic pattern of genetic variation in photosynthetic capacity and growth in two hardwood species from British Columbia. Oecologia. 123(2): 168-174.

Benowicz, A.; L'Hirondelle, S.; El-Kassaby, Y.A. 2001b. Patterns of genetic variation in mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) with respect to height growth and frost hardiness. Forest Ecology and Management. 154(1-2): 23-33.

Bentz, B.; Régnière, J.; Fettig, C.; Hansen, E.; Hayes, J.; Hicke, J.; Kelsey, R.; Negrón, J.; Seybold, S. 2010. Climate change and bark beetles of the western United States and Canada: direct and indirect effects. BioScience. 60(8): 602-613.

Bergha, J.; Freeman, M.; Sigurdsson, B.; Kellomaki, S.; Laitinen, K.; Niinisto, S.; Peltola, H.; Linder, S. 2003. Modelling the short-term effects of climate change on the productivity of selected tree species in Nordic countries. Forest Ecology and Management. 183: 327-340.

Berube, Y.; Ritland, C.; Ritland, K. 2003. Isolation, characterization, and cross-species utility of microsatellites in yellow cedar (*Chamaecyparis nootkatensis*). Genome. 46(3): 353-361.

Bishaw, B.; DeBell, D.S.; Harrington, C.A. 2003. Patterns of survival, damage, and growth for western white pine in a 16-year-old spacing trial in western Washington. Western Journal of Applied Forestry. 18(1): 35-43.

Blate, G.M.; Joyce, L.A.; Littell, J.S.; McNulty, S.G.; Millar, C.I.; Moser, S.C.; Neilson, R.P.; O'Halloran, K.; Peterson, D.L. 2009. Adapting to climate change in United States national forests. Unasylva 231/232. 60: 57-62.

Boes, T.K.; Strauss, S.H. 1994. Floral phenology and morphology of black cottonwood, *Populus trichocarpa* (Salicaceae). American Journal of Botany. 81(5): 562-567.

Bolsinger, C.L.; Jaramillo, A.E. 1990. *Taxus brevifolia* Nutt., Pacific yew. In: Burns, R.M.; Honkala, B.H., eds. Silvics of North America. Vol. 1, Conifers.

Washington, DC: U.S. Department of Agriculture, Forest Service: 573-579.

Bonner, F.T.; Karrfalt, R.P. (eds.) 2008. The woody plant seed manual. Washington, DC: U.S. Department of Agriculture, Forest Service. 1223 p.

Bower, A.D.; Aitken, S.N. 2006. Geographic and seasonal variation in cold hardiness of whitebark pine. Canadian Journal of Forest Research. 36(7): 1842-1850.

Bower, A.D.; Aitken, S.N. 2007. Mating system and inbreeding depression in whitebark pine (*Pinus albicaulis* Engelm.). Tree Genetics & Genomes. 3: 379-388.

Bower, A.D.; Aitken, S.N. 2008. Ecological genetics and seed transfer guidelines for *Pinus albicaulis* (Pinaceae). American Journal of Botany. 95(1): 66-76.

Bower, A.D.; Hipkins, V.; Aubry, C.A.; Rochefort, R. [N.d.]. Assessment of genetic diversity of whitebark pine in Washington and Oregon. Unpublished data. On file at: USDA Forest Service, Olympic National Forest, 1835 Black Lake Blvd. SW, Suite A, Olympia, WA 98512. 34 p.

Brinkman, K.A. 1974. *Betula* L., birch. In: Schopmeyer, C.S., ed. Seeds of woody plants in the United States. Washington, DC: U.S. Department of Agriculture, Forest Service: 252-257.

Bruederle, L.P.; Tomback, D.F.; Kelly, K.K.; Hardwick, R.C. 1998. Population genetic structure in a bird-dispersed pine, *Pinus albicaulis* (Pinaceae). Canadian Journal of Botany. 76(1): 83-90.

Burkett, V.; Kusler, J. 2000. Climate Change: Potential Impacts and Interactions in Wetlands of the United States. Journal of the American Water Resources Association. 36(2): 313-320.

Burns, R.M.; Honkala, B.H., tech. coords. 1990. Silvics of North America: 1. Conifers; 2. Hardwoods. Agriculture Handbook 654. Washington, DC: U.S. Department of Agriculture, Forest Service. 877 p.

Burton, P.J.; Cumming, S.G. 1995. Potential effects of climate change on some western Canadian forests, based on phenological enhancements to a patch model of forest succession. Air and Soil Pollution. 82: 401-414.

Busing, R.T.; Halpern, C.B.; Spies, T.A. 1995. Ecology of Pacific yew (*Taxus brevifolia*) in western Oregon and Washington. Conservation Biology. 9(5): 1199-1207.

Campbell, R.K.; Pawuk, W.A.; Harris, A.S. 1989. Microgeographic genetic variation of Sitka spruce in southeastern Alaska. Canadian Journal of Forest Research. 19(8): 1004-1013.

Campbell, R.K.; Sugano, A.I. 1989. Seed zones and breeding zones for white pine in the Cascade Range of Washington and Oregon. Res. Pap. PNW-RP-407. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 20 p.

Caplow, F.; Miller, J. 2004. Southwestern Washington Prairies: using GIS to find remnant prairies and rare plant habitat. Natural Heritage Report 2004-02. Olympia, WA: Washington Natural Heritage Program, Department of Natural Resources. 18 p.

Carey, E.V.; Callaway, R.M.; DeLucia, E.H. 1997. Stem respiration of ponderosa pines grown in contrasting climates: implications for global climate change. Oecologia. 111: 19-25.

Cayan, D.R.; Dettinger, M.D.; Kammerdiener, S.A.; Caprio, J.M.; Peterson, D.H. 2001. Changes in the onset of spring in the western United States. Bulletin of the American Meteorological Society. 82(3): 399-415.

Chaisurisri, K.; El-Kassaby, Y.A. 1994. Genetic diversity in a seed production population vs natural populations of Sitka spruce. Biodiversity and Conservation. 3(6): 512-523.

Chaisurisri, K.; Mitton, J.B.; El-Kassaby, Y.A. 1994. Variation in the mating system of Sitka spruce (*Picea sitchensis*) - evidence for partial assortative mating. American Journal of Botany. 81(11): 1410-1415.

Chappell, C.B. 2006. Plant associations of balds and bluffs of western Washington. Natural Heritage Report 2006-02. Olympia, WA: Washington State Department of Natural Resources, Washington Natural Heritage Program. 72 p.

Chappell, C.B.; Crawford, R.C. 1997. Native vegetation of the South Puget Sound prairie landscape. In: Dunn, P.; Ewing, K., eds. Ecology and conservation of the South Puget Sound prairie landscape. Seattle: The Nature Conservancy of Washington: 107–122.

Chappell, C.B.; Gee, M.S.M.; Stephens, B.; Crawford, R.; Farone, S. 2001. Distribution and decline of native grasslands and oak woodlands in the Puget Lowland and Willamette Valley Ecoregions, Washington. In: Reichard, S.H.; Dunwiddie, P.W.; Gamon, J.G.; Kruckeberg, A.R.; Salstrom, D.L., eds. Conservation of Washington's rare plants and ecosystems: proceedings from a conference of the Rare Plant Care & Conservation Program of the University of Washington. Seattle, WA: Washington Native Plant Society: 124-139.

Climate Change Science Program [CCSP]. 2008. Preliminary review of adaptation options for climate-sensitive ecosystems and resources. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Washington, D.C.: U.S. Environmental Protection Agency. 873 p.

Coops, N.C.; Waring, R.H. [In press]. Implications of recent and projected climatic change on the health and distribution of fifteen coniferous tree species in the Pacific Northwest region of North America. Ecological Applications.

Cope, A.B. 1992. *Abies amabilis*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).

Cope, A.B. 1993a. *Abies procera*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).

Cope, A.B. 1993b. *Pinus contorta* var. *contorta*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).

Corn, P.S. 2005. Climate change and amphibians. Animal Biodiversity and Conservation. 28.1: 59-67.

Cowardin, L.M.; Carter, V.; Golet, F.C.; LaRoe, E.T. 1979. Classification of wetlands and deepwater habitats of the United States. FWSIOBS-79/31. Washington D.C.: U.S. Department of the Interior, Fish and Wildlife Service, Office of Biological Services. 131 p.

Crawford, P.D.; Oliver, C.D. 1990. *Abies amabilis* Dougl. ex Forbes, Pacific silver fir. In: Burns, R.; Honkala, B., eds. Silvics of North America. Vol. 1, Conifers. Washington, DC: U.S. Department of Agriculture, Forest Service: 17-25.

Crawford, R.; Hall, H. 1997. Changes in the South Puget prairie landscape. P. 11-16 in Dunn, P. and Ewing, K., eds. Ecology and conservation of the South Puget Sound prairie landscape. Seattle, WA: The Nature Conservancy.

Crookston, N.L. 2010. Plant species and climate profile predictions [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Moscow Forestry Sciences Laboratory. http://forest.moscowfsl.wsu.edu/climate/species/speciesDist/Whitebark-pine/. (6 May 2010).

Crookston, N.L.; Rehfeldt, G.E.; Dixon, G.E.; Weiskittel, A.R. 2010. Addressing climate change in the forest vegetation simulator to assess impacts on landscape forest dynamics. Forest Ecology and Management. 260: 1198-1211.

Dale, V.H.; Joyce, L.A.; Mcnulty, S.; Neilson, R.P.; Ayres, M.P.; Flannigan, M.D.; Hanson, P.J.; Irland, L.C.; Lugo, A.E.; Peterson, C.J.; Simberloff, D.; Swanson, F.J.; Stocks, B.J.; Wotton, B.M. 2001. Climate change and forest disturbances. 51(9): 723-734.

Dang, Q.L.; Xie, C.Y.; Ying, C.; Guy, R.D. 1994. Genetic variation of ecophysiological traits in red alder (*Alnus rubra* Bong.). Canadian Journal of Forest Research. 24(11): 2150-2156.

Daoust, D.K. 1992. An interim guide to the conservation and management of Pacific yew. Technical Report. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 72 p.

Davidson, R.; El-Kassaby, Y.A. 1997. Genetic diversity and gene conservation of Pacific silver fir (*Abies amabilis*) on Vancouver Island, British Columbia. Forest Genetics. 4(2): 85-98.

Davis, A.J.; Jenkinson, L.S.; Lawton, J.H.; Shorrocks, B.; Wood, S. 1998. Making mistakes when predicting shifts in species range in responce to global warming. Nature. 391: 783-786.

De Woody, J.; Rickman, T.H.; Jones, B.E.; Hipkins, V.D. 2009. Allozyme and microsatellite data reveal small clone size and high genetic diversity in aspen in the southern Cascade Mountains. Forest Ecology and Management. 258(5): 687-696.

DeBell, D.S. 1990. *Populus trichocarpa* Torr. & Gray, black cottonwood. In: Burns, R.M.; Honkala, B.H., eds. Silvics of North America. Vol. 2, Hardwoods. Washington, DC: U.S. Department of Agriculture, Forest Service: 570-582.

DeLucia, E.H.; Callaway, R.M.; Schlesinger, W.H. 1994. Offsetting changes in biomass allocation and photosynthesis in ponderosa pine (*Pinus ponderosa*) in response to climate change. Tree Physiology. 14: 669-677.

Despain, D.G. 2001. Dispersal ecology of lodgepole pine (*Pinus contorta* Dougl.) in its native environment as related to Swedish forestry. Forest Ecology and Management. 141: 59-68.

Devine, W.D.; Harrington, C.A.; Kraft, J.M. 2010. Acorn storage alternatives tested on Oregon white oak. Native Plants Journal. 11(1): 65-76.

Dickson, E.E.; Kresovich, S.; Weeden, N.F. 1991. Isozymes in North American *Malus* (Rosaceae) - hybridization and species differentiation. Systematic Botany. 16(2): 363-375.

DiFazio, S.P.; Vance, N.C.; Wilson, M.V. 1997. Strobilus production and growth of Pacific yew under a range of overstory conditions in western Oregon. Canadian Journal of Forest Research. 27: 986-993.

Doede, D.L.; Carroll, E.; Westfall, R.; Miller, R.; Kitzmiller, J.H.; Snader, K.M. 1993. Geographic variation in allozymes and Taxol, and propagation by rooted cutting in Pacific yew. Proceedings of the conference Proceedings of the International Yew Resources Conference: Yew conservation biology and interactions; 1993. Berkeley, CA: Native Yew Conservation Council.

Dowling, C. 2011. Personal communication. Forest silviculturist, U.S. Forest Service Olympic National Forest, Olympia, WA.

Duffy, J.E.; Lloyd, J. 2010. Biodiversity. In: Cleveland, C.J., ed. Encyclopedia of Earth. Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment.

Dunlap, J.M.; Heilman, P.E.; Stettler, R.F. 1994. Genetic variation and productivity of *Populus trichocarpa* and its hybrids. 7. 2-year survival and growth of native black cottonwood clones from 4 river valleys in Washington. Canadian Journal of Forest Research. 24(8): 1539-1549.

Dunlap, J.M.; Heilman, P.E.; Stettler, R.F. 1995. Genetic variation and productivity of *Populus trichocarpa* and its hybrids. 8. Leaf and crown morphology of native *Populus trichocarpa* clones from 4 river valleys in Washington. Canadian Journal of Forest Research. 25(10): 1710-1724.

Dunlap, J.M.; Stettler, R.F. 1996. Genetic variation and productivity of Populus trichocarpa and its hybrids .9. Phenology and Melampsora rust incidence of native black cottonwood clones from four river valleys in Washington. Forest Ecology and Management. 87(1-3): 233-256.

Dunwiddie, P.; Alverson, E.; Stanley, A.; Gilbert, R.; Pearson, S.; Hays, D.; Arnett, J.; Delvin, E.; Grosboll, D.; Marschner, C. 2006. The vascular plant flora of the South Puget Sound prairies, Washington, USA. Davidsonia. 17: 55-69.

Edwards, D.G.W. 2008. *Abies* P. Mill., Fir. In: Bonner, F.T.; Karrfalt, R.P., eds. The woody plant seed manual. Agricultural Handbook no. 727. Washington, DC: U.S. Department of Agriculture, Forest Service.

El-Kassaby, Y.A.; Dunsworth, B.G.; Krakowski, J. 2003. Genetic evaluation of alternative silvicultural systems in coastal montane forests: western hemlock and amabilis fir. Theoretical and Applied Genetics. 107(4): 598-610.

El-Kassaby, Y.A.; Meagher, M.D.; Davidson, R. 1993. Temporal variation in the outcrossing rate in a natural stand of western white pine. Silvae Genetica. 42(2-3): 131-135.

El-Kassaby, Y.A.; Meagher, M.D.; Parkinson, J.; Portlock, F.T. 1987. Allozyme inheritance, heterozygosity and outcrossing rate among *Pinus monticola* near Ladysmith, British Columbia. Heredity. 58: 173-181.

El-Kassaby, Y.A.; Ritland, K. 1996. Genetic variation in low elevation Douglas-fir of British Columbia and its relevance to gene conservation. Biodiversity and Conservation. 5(6): 779-794.

El-Kassaby, Y.A.; Russell, J.; Ritland, K. 1994. Mixed mating in an experimental population of western red cedar, *Thuja plicata*. Journal of Heredity. 85(3): 227-231.

El-Kassaby, Y.A.; Yanchuk, A.D. 1994. Genetic diversity, differentiation, and inbreeding in Pacific yew from British Columbia. Journal of Heredity. 85(2): 112-117.

El-Kassaby, Y.A.; Yeh, F.C.; Sziklai, O. 1981. Estimation of the outcrossing rate of Douglas-fir *Pseudotsuga menziesii* (Mirb) Franco using allozyme polymorphisms Silvae Genetica. 30(6): 182-184.

Elsner, M.M.; Cuo, L.; Voisin, N.; Deems, J.S.; Hamlet, A.F.; Vano, J.A.; Mickelson, K.E.B.; Lee, S.Y.; Lettenmaier, D.P. 2009. Implications of 21st century climate change for the hydrology of Washington State. Climatic Change. 102(1-2): 225-260.

Esser, L.L. 1995. *Prunus emarginata*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).

Ettl, G.J.; Peterson, D.L. 2001. Genetic variation of subalpine fir (Abies lasiocarpa (Hook.) Nutt.) in the Olympic Mountains, WA, USA. SiIvae Genetica. 50(3-4): 145-153.

Fazekas, A.J.; Yeh, F.C. 2006. Postglacial colonization and population genetic relationships in the Pinus contorta complex. Canadian Journal of Botany. 84(2): 223-234.

Fischer, W.C. 2010. Fire Effects Information System [Database]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (6 May 2010).

Foiles, M.W.; Graham, R.T.; Olson Jr., D.F. 1990. *Abies grandis* (Dougl. ex D. Don) Lindl., grand fir. In: Burns, R.M.; Honkala, B.H., eds. Silvics of North America. Vol. 1, Conifers. Washington, DC: U.S. Department of Agriculture, Forest Service: 52-59.

Foster, G.S.; Lester, D.T. 1983. 5th-year height variation in western hemlock open-pollinated families growing on 4 test sites. Canadian Journal of Forest Research. 13(2): 251-256.

Foster, J.R. 1997. Westside story: restoration of a ponderosa pine forest at Fort Lewis Military Reservation. In: Dunn, P.; Ewing, K., eds. Proceedings of the conference Ecology and Conservation of the South Puget Sound Prairie Landscape. Seattle: The Nature Conservancy of Washington: 217-229.

Franklin, J.F. 1990. *Abies procera* Rehd., noble fir. In: Burns, R.M.; Honkala, B.H., eds. Silvics of North America. Vol. 1, Conifers. Washington, DC: U.S. Department of Agriculture, Forest Service: 80-87.

Franklin, J.F.; Krueger, K.W. 1968. Germination of true fir and mountain hemlock seed on snow. Journal of Forestry. 66: 416-417.

Franklin, J.F.; Ritchie, G.A. 1970. Phenology of cone and shoot development of noble fir and some associated true firs. Forest Science. 16(3): 356-364.

Gapare, W.J.; Aitken, S.N. 2005. Strong spatial genetic structure in peripheral but not core populations of Sitka spruce *Picea sitchensis* (Bong.) Carr. Molecular Ecology. 14(9): 2659-2667.

Gapare, W.J.; Aitken, S.N.; Ritland, C.E. 2005. Genetic diversity of core and peripheral Sitka spruce (*Picea sitchensis* (Bong.) Carr) populations: implications for conservation of widespread species. Biological Conservation. 123(1): 113-123.

Girvetz, E.H.; Zganjar, C.; Raber, G.T.; Maurer, E.P.; Kareiva, P.; Lawler, J.J. 2009. Applied climate-change analysis: the Climate Wizard tool. PLoS One. 4(12): e8320.

Glaubitz, J.C.; El-Kassaby, Y.A.; Carlson, J.E. 2000. Nuclear restriction fragment length polymorphism analysis of genetic diversity in western redcedar. Canadian Journal of Forest Research. 30(3): 379-389.

Glick, P.; Stein, B.A.; eds. 2010. Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment (Draft). Washington D.C.: National Wildlife Federation. 164 p.

Godbout, J.; Fazekas, A.; Newton, C.H.; Yeh, F.C.; Bousquet, J. 2008. Glacial vicariance in the Pacific Northwest: evidence from a lodgepole pine mitochondrial DNA minisatellite for multiple genetically distinct and widely separated refugia. Molecular Ecology. 17(10): 2463-2475.

Gooding, G.D. 1998. Genetic variation and mating system of Ponderosa pine in the Willamette Valley of Oregon. M.S. Thesis. Corvallis, OR: Oregon State University. 104 p.

Gornall, J.L.; Guy, R.D. 2007. Geographic variation in ecophysiological traits of black cottonwood (*Populus* *trichocarpa*). Canadian Journal of Botany. 85(12): 1202-1213.

Gould, P.J.; Harrington, C.A.; St. Clair, J.B. 2011. Incorporating genetic variation into a model of budburst phenology of coast Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*). Canadian Journal of Forest Research. 41: 139-150.

Grabherr, G. 2003. Alpine vegetation dynamics and climate change – a synthesis of long-term studies and observations. In: Nagy, L.; Grabherr, G.; Korner, C.; Thompson, D.B.A., eds. Alpine biodiversity in Europe: Ecological Studies 167. Berlin, Heidelberg, DE: Springer: 399-409.

Grabherr, G.; Gottfried, M.; Pauli, H. 2010. Climate change impacts in alpine environments. Geography Compass. 4(8): 1133-1153.

Graham, R.T. 1990. *Pinus monticola* Dougl. ex D. Don., western white pine. In: Burns, R.M.; Honkala, B.H., eds. Silvics of North America. Vol. 1, Conifers. Washington, DC: U.S. Department of Agriculture, Forest Service: 385-394.

Green, D.S. 2005. Adaptive strategies in seedlings of three co-occurring, ecologically distinct northern coniferous tree species across an elevational gradient. Canadian Journal of Forest Research. 35(4): 910-917.

Griffith, R.S. 1992a. *Chamaecyparis nootkatensis*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).

Griffith, R.S. 1992b. *Picea sitchensis*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).

Griffith, R.S. 1992c. *Pinus monticola*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).

Griffiths, R.P.; Chadwick, A.C.; Robatzek, M.; Schauer, K.; Schaffroth, K.A. 1995. Association of ectomycorrhizal mats with Pacific yew and other understory trees in coniferous forests. Plant and Soil. 173: 343-347.

Gucker, C.L. 2005. *Cornus nuttallii*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).

Gucker, C.L. 2007. *Quercus garryana*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).

Guisan, A.; Theurillat, J.-P. 2000. Assessing alpine plant vulnerability to climate change: a modeling perspective. Integrated Assessment. 1: 307-320.

Guries, R.P.; Nordheim, E.V. 1984. Flight characteristics and dispersal potential of maple samaras. Forest Science. 30(2): 434-440.

Habeck, R.J. 1991. *Crataegus douglasii*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).

Habeck, R.J. 1992a. *Pinus ponderosa* var. *ponderosa*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).

Habeck, R.J. 1992b. *Rhamnus purshiana*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).

Halofsky, J.E. 2010. Personal communication. Research ecologist, USDA Forest Service, Pacific Wildland Fire Sciences Laboratory, Seattle, WA.

Halofsky, J.E.; Peterson, D.L.; O’Halloran, K.A.; Hawkins Hoffman, C. [In press]. Adapting to climate change at Olympic National Forest and Olympic National Park. Gen. Tech. Rep. Portland, OR: USDA Forest Service, Pacific Northwest Research Station.

Hamann, A.; Wang, T.L. 2006. Potential effects of climate change on ecosystem and tree species distribution in British Columbia. Ecology. 87(11): 2773-2786.

Hamon, W.R. 1961. Estimating potential evapotranspiration. Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers. 87: 107-120.

Hamrick, J.L. 2004. Response of forest trees to global environmental changes. Forest Ecology and Management. 197(1-3): 323-335.

Hamrick, J.L.; Godt, M.J.W.; Sherman-Broyles, S.L. 1992. Factors influencing levels of genetic diversity in woody plant species. New Forests. 6: 95-124.

Hamrick, J.L.; Linhart, Y.B.; Mitton, J.B. 1979. Relationships between life-history characteristics and electrophoretically detectable genetic variation in plants. Annual Review of Ecology and Systematics. 10: 173-200.

Hannerz, M.; Aitken, S.N.; King, J.N.; Budge, S. 1999. Effects of genetic selection for growth on frost hardiness in western hemlock. Canadian Journal of Forest Research. 29(4): 509-516.

Hargrove, W.W. 2010. Personal communication. Ecologist, U.S. Forest Service Eastern Forest Environmental Threat Assessment Center, Asheville, NC.

Hargrove, W.W.; Hoffman, F.M. 2005. Potential of multivariate quantitative methods for deliniation and visualization of ecoregions. Environmental Management. 34(1): S39-S60.

Hargrove, W.W.; Potter, K.M.; Koch, F.H. 2010. Draft Multivariate Spatio-Temporal Clustering (MSTC) maps of current and future tree range distributions under two global climate models and two climate change scenarios. http://www.geobabble.org/~hnw/global/treeranges/climate_change/index.html. (18 November 2010).

Harrington, C.A. 1990. *Alnus rubra* Bong., red alder. In: Burns, R.M.; Honkala, B.H., eds. Silvics of North America. Vol. 2, Hardwoods. Washington, DC: U.S. Department of Agriculture, Forest Service: 117-123.

Harrington, C.A. 2006. Biology and ecology of red alder. In: Deal, R.L.; Harrington, C.A., eds. Red alder—a state of knowledge. Gen. Tech. Rep. PNW-GTR-669. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: 21-43.

Harrington, C.A. (tech. coord.) 2010. A tale of two cedars – International symposium on western redcedar and yellow-cedar. Gen. Tech. Rep. PNW-GTR-828. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 177 p.

Harrington, C.A.; Gould, P.J.; St. Clair, J.B. 2010. Modeling the effects of winter environment on dormancy release of Douglas-fir. Forest Ecology and Management. 259(4): 798-808.

Harrington, C.A.; Kraft, J.M. 2004. Cold stratification of pacific madrone seeds. Native Plants Journal. 5(1): 66-74.

Harris, A.S. 1990a. *Chamaecyparis nootkatensis* (D. Don) Spach, Alaska-cedar. In: Burns, R.; Honkala, B., eds. Silvics of North America. Vol. 1, Conifers. Washington, DC: U.S. Department of Agriculture, Forest Service: 97-102.

Harris, A.S. 1990b. *Picea sitchensis* (Bong.) Carr., Sitka spruce. In: Burns, R.M.; Honkala, B.H., eds. Silvics of North America. Vol. 1, Conifers. Washington, DC: U.S. Department of Agriculture, Forest Service: 260-267.

Harris, J.A.; Hobbs, R.J.; Higgs, E.; Aronson, J. 2006. Ecological restoration and global climate change. Restoration Ecology. 14(2): 170-176.

Hawkins, B.J. 2007. Family variation in nutritional and growth traits in Douglas-fir seedlings. Tree Physiology. 27(6): 911-919.

Hawkins, B.J.; Russell, J.; Shortt, R. 1994. Effect of population, environment, and maturation on the frost hardiness of yellow-cedar (*Chamaecyparis nootkatensis*) Canadian Journal of Forest Research. 24(5): 945-953.

Hawkins, B.J.; Stoehr, M. 2009. Growth, phenology, and cold hardiness of 32 Douglas-fir full-sib families. Canadian Journal of Forest Research. 39(10): 1821-1834.

Hegland, S.J.; Nielsen, A.; Lazaro, A.; Bjerknes, A.L.; Totland, O. 2009. How does climate warming affect plant-pollinator interactions? Ecology Letters. 12(2): 184-195.

Henderson, J. 2009. Modeled potential natural vegetation zones of Washington and Oregon. Olympia, WA: USDA Forest Service, Pacific Northwest Region.

Henderson, J.A.; Peter, D.H.; Lesher, R.D.; Shaw, D.C. 1989. Forested plant association of the Olympic National Forest. R6 Ecol. Tech. Paper 001-88. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region.

Hennon, P.E.; D'Amore, D.; Wittwer, D.; Caouette, J. 2008. Yellow-cedar decline: conserving a climate-sensitive tree species as Alaska warms. In: Deal, R.(ed.). Integrated restoration of forested ecosystems to achieve multi-resource benefits: proceedings of the 2007 national silviculture workshop. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, General Technical Report PNW-GTR-733. Portland, OR: 233–245.

Hermann, R.K.; Lavender, D.P. 1990. *Pseudotsuga menziesii* (Mirb.) Franco, Douglas-fir. In: Burns, R.M.; Honkala, B.H., eds. Silvics of North America. Vol. 1, Conifers. Washington, DC: U.S. Department of Agriculture, Forest Service: 527-540.

Hibbs, D.E.; Chan, S.S.; Castellano, M.; Niu, C.-H. 1995. Response of red alder seedlings to CO2 enrichment and water stress. New Phytologist. 129(4): 569-577.

Hijmans R.J.; Graham, C.H. 2006. The ability of climatic envelope models to predict the effect of climate change on species distributions. Global Change Biology. 12: 2272-2281.

Hoffman, F.M.; Hargrove, W.W.; Erickson, D.J.; Oglesby, R.J. 2005. Using clustered climate regimes to analyze and compare predictions from fully coupled general circulation models. Earth Interactions. 9(10): 1-27.

Hoffmann, C.; Geburek, T. 1995. Allozyme variation of indigenous Douglas-fir *Pseudotsuga menziesii* (MIRB) FRANCO populations and their descendants in Germany). Silvae Genetica. 44(5-6): 222-225.

Holtmeier, F.; Broll, G. 2005. Sensitivity and response of northern hemisphere altitudinal and polar treelines to environmental change at landscape and local scales. Global Ecology and Biogeography. 14: 395-410.

Howard, J.L. 1996. *Populus tremuloides*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).

Howard, J.L. 2002. *Pinus albicaulis*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).

Howard, J.L.; Aleksoff, K.C. 2000. *Abies grandis*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).\

Howe, G. 2010. Personal communication. Associate Professor, Oregon State University, Corvallis, OR.

Hubert, C.; Aitken, S.N. [N.d.]. Unpublished data. On file at: University of British Columbia, Vancouver, British Columbia, Canada.

Iddrisu, M.N.; Aitken, S.N. [N.d.]. Unpublished data. On file at: University of British Columbia, Vancouver, British Columbia, Canada.

Iddrisu, M.N.; Ritland, K. 2004. Genetic variation, population structure, and mating system in bigleaf maple (*Acer macrophyllum* Pursh). Canadian Journal of Botany. 82(12): 1817-1825.

Inouye, D.W. 2008. Effects of climate change on phenology, frost damage, and floral abundance of montane wildflowers. Ecology. 89(2): 353-362.

Jacobs, J.H.; Clark, S.J.; Denholm, I.; Goulson, D.; Stoate, C.; Osborne, J.L. 2009. Pollination biology of fruit-bearing hedgerow plants and the role of flower-visiting insects in fruit-set. Annals of Botany. 104: 1397-1404.

Jelinski, D.E.; Cheliak, W.M. 1992. Genetic diversity and spatial subdivision of *Populus tremuloides* (Salicaceae) in a heterogeneous landscape. American Journal of Botany. 79(7): 728-736.

Joly, J.L.; Fuller, N. 2009. Advising Noah: A Legal Analysis of Assisted Migration. Environmental Law. 39: 10413-10425.

Jorgensen, S.M.; Hamrick, J.L. 1997. Biogeography and population genetics of whitebark pine, *Pinus albicaulis*. Canadian Journal of Forest Research. 27(10): 1574-1585.

Kanaga, M.K.; Ryel, R.J.; Mock, K.E.; Pfrender, M.E. 2008. Quantitative-genetic variation in morphological and physiological traits within a quaking aspen

(*Populus tremuloides*) population. Canadian Journal of Forest Research. 38(6): 1690-1694.

Kier, K.; Aitken, S.N. [n.d.] Unpublished data. On file at: University of British Columbia, Vancouver, British Columbia, Canada.

Kim, M.S.; Brunsfeld, S.J.; McDonald, G.I.; Klopfenstein, N.B. 2003. Effect of white pine blister rust (*Cronartium ribicola*) and rust-resistance breeding on genetic variation in western white pine (*Pinus monticola*). Theoretical and Applied Genetics. 106(6): 1004-1010.

Kinloch, B.B., Jr. 2003. White pine blister rust in North America: Past and Prognosis. Phytopathology. 93(8): 1044-1047.

Kinloch, B.B., Jr.; Sniezko, R.A.; Barnes, G.D.; Greathouse, T.E. 1999. A major gene for resistance to white pine blister rust in western white pine from the Western Cascade Range. Genetics and Resistance. 89(10): 861-867.

Klinka, K.; Worrall, J.; Skoda, L.; Varga, P. 2000. The distribution and synopsis of ecological and silvical characteristics of tree species of British Columbia’s forests. Coquitlam, Canada: Canadian Cartographics Ltd. 180 p.

Konnert, M.; Reutz, W.F. 1997. Genetic variation among the provenances of *Abies grandis* from the Pacific Northwest. Forest Genetics. 4(2): 77-84.

Krakowski, J.; Aitken, S.N.; El-Kassaby, Y.A. 2003. Inbreeding and conservation genetics in whitebark pine. Conservation Genetics. 4(5): 581-593.

Krakowski, J.; Stoehr, M.U. 2009. Coastal Douglas-fir provenance variation: patterns and predictions for British Columbia seed transfer. Annals of Forest Science. 66(8).

Kranabetter, J.M.; Durall, D.M.; MacKenzie, W.H. 2009. Diversity and species distribution of ectomycorrhizal fungi along productivity gradients of a southern boreal forest. Mycorrhiza. 19(2): 99-111.

Krutovsky, K.V.; Clair, J.B.S.; Saich, R.; Hipkins, V.D.; Neale, D.B. 2009. Estimation of population structure in coastal Douglas-fir *Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii* using allozyme and microsatellite markers. Tree Genetics & Genomes. 5(4): 641-658.

Kurz, W.A.; Dymond, C.C.; Stinson, G.; Rampley, G.J.; Neilson, E.T.; Carroll, A.L.; Ebata, T.; Safranyik, L. 2008. Mountain pine beetle and forest carbon feedback to climate change. Nature. 452: 987-990.

Kuser, J.E.; Ching, K.K. 1980. Provenance variation in phenology and cold hardiness of western hemlock seedlings. Forest Science. 26(3): 463-470.

Kuser, J.E.; Ching, K.K. 1981. Provenance variation in seed weight, cotyledon number, and growth rate of western hemlock seedlings. Canadian Journal of Forest Research. 11(3): 662-670.

Lawler, J.; Case, M. 2010a. Pacific Northwest climate change vulnerability assessment. Fact sheet. University of Washington, Seattle.

Lawler, J.; Case, M. 2010b. Climate change sensitivity database. University of Washington, Seattle. http://courses.washington.edu/ccdb/drupal/. (14 August 2010).

Leopold, E.B.; Nickmann, R.J.; Hedges, J.I.; Ertel, J.R. 1982. Pollen and lignin records of late Quaternary vegetation, Lake Washington. Science. 218: 1305-1307.

Li, P.; Adams, W.T. 1989. Range-wide patterns of allozyme variation in Douglas-fir (*Pseudotsuga menziesii*). Canadian Journal of Forest Research. 19: 149-161.

Littell, J.S.; McKenzie, D.; Peterson, D.L.; Westerling, A.L. 2009a. Climate and wildfire area burned in western U.S. ecoprovinces, 1916–2003. Ecological Applications. 19: 1003-1021.

Littell, J.S.; Oneil, E.E.; McKenzie, D.; Hicke, J.A.; Lutz, J.A.; Norheim, R.A.; Elsner, M.M. 2009b. Forest ecosystems, disturbances, and climate change in Washington State, USA. In: Climate Impacts Group, The Washington Climate Change Impacts Assessment. University of Washington, Joint Institute for the Study of the Atmosphere and Oceans, Center for Science in the Earth System. http://www.cses.washington.edu/db/pdf/wacciach7forests650.pdf. (15 March 2010).

Littell, J.S.; McGuire Elsner, M.; Whitely Binder, L.C.; Snover, A.K. (eds). 2009c. The Washington climate change impacts assessment: evaluating Washington's future in a changing climate - executive summary. In: The Washington climate change impacts assessment: evaluating Washington's future in a changing climate. Seattle, WA: University of Washington Climate Impacts Group.

Littell, J.; Oneil, E.; McKenzie, D.; Hicke, J.; Lutz, J.; Norheim, R.; Elsner, M. 2010. Forest ecosystems, disturbance, and climatic change in Washington State, USA. Climatic Change. 102(1-2): 129-158.

Little, E.L., Jr. 1971. Atlas of United States trees, volume 1. Conifers and important hardwoods. Miscellaneous Publication 1146. Washington, D.C.: USDA Forest Service.

Little, E.L., Jr. 1976. Atlas of United States trees, volume 3. Minor western hardwoods. Miscellaneous Publication 1314. Washington, D.C.: USDA Forest Service.

Lo, E.Y.Y.; Stefanovic, S.; Dickinson, T.A. 2009. Population genetic structure of diploid sexual and polyploid apomictic hawthorns (Crataegus; Rosaceae) in the Pacific Northwest. Molecular Ecology. 18(6): 1145-1160.

Logan, J.A.; Powell, J.A. 2001. Ghost forests, global warming, and the mountain pine beetle (Coleoptera: Scolytidae). American Entomologist. 47(3): 160-172.

Logan, J.A.; Regniere, J.; Powell, J.A. 2003. Assessing the impacts of global warming on forest pest dynamics. Frontiers in Ecology and Environment. 1(2): 130-137.

Lorenz, T.J.; Aubry, C.; Shoal, R. 2008. A review of the literature on seed fate in whitebark pine and the life history traits of Clark's nutcracker and pine squirrels. Gen. Tech. Rep. PNW-GTR-742. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 62 p.

Lorenz, T.J.; Sullivan, K.A. 2009. Seasonal differences in space use by Clark’s nutcrackers in the Cascade Range. The Condor. 111(2): 326-340.

Lotan, J.E.; Critchfield, W.B. 1990. *Pinus contorta* Dougl. ex. Loud., lodgepole pine. In: Burns, R.M.; Honkala, B.H., eds. Silvics of North America. Vol. 1, Conifers. Washington, DC: U.S. Department of Agriculture, Forest Service: 302-325.

Lovejoy, T.; Hannah, L., eds. 2005. Climate change and biodiversity. New Haven: Yale. 418 p.

Lynch, M.; Lande, R. 1993. Evolution and extinction in response to environmental change. In: Kareiva, P.; Kingsolver, J.; Huey, R., eds. Biotic Interactions and Global Change. Sunderland, Mass.: Sinauer Assoc., Inc.: 234-250.

Lyons, C.P. 1999. Trees and shrubs of Washington. Edmonton, Canada: Lone Pine Publishing. 160 p.

Malanson, G.P.; Butler, D.R.; Fagre, D.B.; Walsh, S.J.; Tomback, D.F.; Daniels, L.D.; Resler, L.M.; Smith, W.K.; Weiss, D.J.; Peterson, D.L.; Bunn, A.G.; Hiemstra, C.A.; Liptzin, D.; Bourgeron, P.S.; Shen, Z.; Millar, C.I. 2007. Alpine treeline of western North America: linking organism-to-landscape dynamics. Physical Geography. 28(5): 378-396.

Marsico, T.D.; Hellmann, J.J.; Romero-Severson, J. 2009. Patterns of seed dispersal and pollen flow in *Quercus garryana* (Fagaceae) following post-glacial climatic changes. Journal of Biogeography. 36(5): 929-941.

McDonald, P.M.; Tappeiner, J.C., II. 1990. *Arbutus menziesii* Pursh, Pacific madrone. In: Burns, R.M.; Honkala, B.H., eds. Silvics of North America. Vol. 2, Hardwoods. Washington, DC: U.S. Department of Agriculture, Forest Service: 124-132.

McKee, A. 1990. *Castanopsis chrysophylla* (Dougl.) A. DC., giant chinquapin. In: Burns, R.M.; Honkala, B.H., eds. Silvics of North America. Vol. 2, Hardwoods. Washington, DC: U.S. Department of Agriculture, Forest Service: 234-239.

McKenney, D.W.; Pedlar, J.H.; Lawrence, K.; Campbell, K.; Hutchinson, M.F. 2007. Potential impacts of climate change on the distribution of North American trees. BioScience. 57(11): 939-948.

McKinley, M. 2010. South Puget Sound Ecological Fire Program: 2009 summary report, draft 2. http://waconservation.org/dl/dl_SSP_BurnReport2009.pdf. (21 April 2011).

McMurray, N.E. 1989. *Chrysolepis chrysophylla*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).

Means, J.E. 1990. *Tsuga mertensiana* (Bong.) Carr., mountain hemlock. In: Burns, R.M.; Honkala, B.H., eds. Silvics of North America. Vol. 1, Conifers. Washington, DC: U.S. Department of Agriculture, Forest Service: 623-634.

Mehes, M.; Nkongolo, K.K.; Michael, P. 2009. Assessing genetic diversity and structure of fragmented populations of eastern white pine (*Pinus strobus*) and western white pine (*P. monticola*) for conservation management. Journal of Plant Ecology. 2(3): 143-151.

Millar, C.I.; Stephenson, N.L.; Stephens, S.L. 2007. Climate change and forests of the future: managing in the face of uncertainty. Ecological Applications. 17(8): 2145-2151.

Millar, C.I.; Westfall, R.D.; Delany, D.L.; King, J.C.; Graumlich, L.J. 2004. Response of subalpine conifers in the Sierra Nevada, California, USA, to 20th-century warming and decadal variability. Arctic, Antarctic, and Alpine Research. 36(2): 181-200.

Miller-Rushing, A.J.; Primack, R.B. 2008. Global warming and flowering times in Thoreau's concord: A community perspective. Ecology. 89(2): 332-341.

Mimura, M.; Aitken, S.N. 2007a. Adaptive gradients and isolation-by-distance with postglacial migration in *Picea sitchensis*. Heredity. 99(2): 224-232.

Mimura, M.; Aitken, S.N. 2007b. Increased selfing and decreased effective pollen donor number in peripheral relative to central populations in *Picea sitchensis* (Pinaceae). American Journal of Botany. 94: 991-998.

Minore, D. 1983. Western redcedar—a literature review. Gen. Tech. Rep. PNW-GTR-150. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 75 p.

Minore, D. 1990. *Thuja plicata* Donn ex D. Don., western redcedar. In: Burns, R.M.; Honkala, B.H., eds. Silvics of North America. Vol. 1, Conifers. Washington, DC: U.S. Department of Agriculture, Forest Service: 590–600.

Minore, D.; Zasada, J.C. 1990. *Acer macrophyllum* Pursh, bigleaf maple. In: Burns, R.; Honkala, B., eds. Silvics of North America. Vol. 2, Hardwoods. Washington, DC: U.S. Department of Agriculture, Forest Service: 33-40.

Mitton, J.B.; Linhart, Y.B.; Davis, M.L.; Sturgeon, K.B. 1981. Estimation of outcrossing in ponderosa pine, *Pinus ponderosa* Laws. from patterns of segregation of protein polymorphisms and from frequencies of albino seedlings. Silvae Genetica. 30(4-5): 117-121.

Moeur, M.; Spies, T.A.; Hemstrom, M.; Martin, J.R.; Alegria, J.; Browning, J.; Cissel, J.; Cohen, W.B.; DeMeo, T.E.; Healey, S.; Warbington, R. 2005. Northwest Forest Plan-the first 10 years (1994-2003): status and trend of late-successional and old-growth forest. Gen. Tech. Rep. PNW-GTR-646. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 142 p.

Morin, X.; Lechowicz, M.J.; Augspurger, C.; O' Keefe, J.; Viner, D.; Chuine, I. 2009. Leaf phenology in 22 North American tree species during the 21st century. Global Change Biology. 15(4): 961-975.

Morisette, J.T.; Richardson, A.D.; Knapp, A.K.; Fisher, J.I.; Graham, E.A.; Abatzoglou, J.; Wilson, B.E.; Breshears, D.D.; Henebry, G.M.; Hanes, J.M. 2008. Tracking the rhythm of the seasons in the face of global change: phenological research in the 21st century. Frontiers in Ecology and Environment. 7(5): 253-260.

Mote, P.W. 2003. Twentieth-century fluctuations and trends in temperature, precipitation, and mountain snowpack in the Georgia Basin-Puget Sound region. Canada Water Resources Journal. 28(4): 567-585.

Mote, P.W.; Hamlet, A.F.; Clark, M.P.; Lettenmaier, D.P. 2005. Declining mountain snowpack in western North America. Journal Of The American Meteorological Society. (January): 35-49.

Mote, P.W.; Salathé, E.P. 2009. Future climate in the Pacific Northwest. In: Elsner, M.M.; Littell, J.; Binder, L.W., eds. Climate Impacts Group, 2009. The Washington Climate Change Impacts Assessment. Seattle, WA: Center for Science in the Earth System, Joint Institute for the Study of the Atmosphere and Oceans, University of Washington.

Mote, P.; Salathé, E.P.; Dulière, V.; Jump, E. 2008. Scenarios of future climate for the Pacific Northwest. Climate Impacts Group, University Washington. http://cses.washington.edu/db/pdf/moteetal2008scenarios628.pdf. (15 March 2010).

Murray, M.D.; Treat, D.L. 1980. Pacific silver fir in the Coast Range of southwestern Washington. Northwest Science. 54(2): 119-120.

Myking, T. 2002. Evaluating genetic resources of forest trees by means of life history traits - a Norwegian example. Biodiversity and Conservation. 11(9): 1681-1696.

Namroud, M.C.; Park, A.; Tremblay, F.; Bergeron, Y. 2005. Clonal and spatial genetic structures of aspen (*Populus tremuloides* Michx.). Molecular Ecology. 14(10): 2969-2980.

Natural Resources: Working Lands and Waters Topic Advisory Group [NRWLW]. 2011. Washington State Climate Change Response Strategy. Interim Recommendations of the Natural Resources: Working Lands and Waters Topic Advisory Group. Interim Report. http://www.ecy.wa.gov/climatechange/2011TAGdocs/R2011_interimreport.pdf. (25 March 2011).

National Wetlands Working Group. 1997. Canadian wetland classification system, 2nd ed. Warner, B.G.; Rubec, C.D.A. (eds.). Waterloo, Canada: Wetlands Research Centre, University of Waterloo. 68 p.

NatureServe 2010a. Confronting climate change. http://www.natureserve.org/prodServices/climatechange/ccvi.jsp. (23 December 2010).

NatureServe 2010b. NatureServe conservation status. http://www.natureserve.org/explorer/ranking.htm. (6 May 2010).

Neely, C.; Bunning, S.; Wilkes, A., eds. 2009. Review of evidence on drylands pastoral systems and climate change. Rome: FAO. 38 p.

Niebling, C.R.; Conkle, M.T. 1990. Diversity of Washoe pine and comparisons with allozymes of ponderosa pine races. Canadian Journal of Forest Research. 20: 298-308.

Nielsen, C.C.N.; Rasmussen, H.N. 2009. Frost hardening and dehardening in *Abies procera* and other conifers under differing temperature regimes and warm-spell treatments. Forestry. 82: 43-59.

Noble, D.L. 1990. *Juniperus scopulorum* Sarg., Rocky Mountain juniper. In: Burns, R.; Honkala, B., eds. Silvics of North America. Vol. 1, Conifers. Washington, DC: U.S. Department of Agriculture, Forest Service: 116-126.

Nolin, A.W.; Daly, C. 2006. Mapping “at risk” snow in the Pacific Northwest. Journal of Hydrometeorology. 7(5): 1164-1171.

Noss, R.F.; LaRoe, E.T.; Scott, J.M. 1995. Endangered ecosystems of the United States; a preliminary assessment of loss and degradation. Washington D.C.: US National Biological Service. 83 p.

O'Connell, L.M.; Ritland, K.; Thompson, S.L. 2008. Patterns of post-glacial colonization by western redcedar (Thuja plicata, Cupressaceae) as revealed by microsatellite markers. Botany-Botanique. 86(2): 194-203.

O'Connell, L.M.; Russell, J.; Ritland, K. 2004. Fine-scale estimation of outcrossing in western redcedar with microsatellite assay of bulked DNA. Heredity. 93(5): 443-449.

O'Connell, L.M.; Viard, F.; Russell, J.; Ritland, K. 2001. The mating system in natural populations of western redcedar (*Thuja plicata*). Canadian Journal of Botany. 79(6): 753-756.

O’Neill, G.A. 2011. Personal communication. Research scientist, Ministry of Forests, Lands and Natural Resources Operations, Kalamalka, Canada.

O’Neill, G.A.; Carlson, M.R.; Berger, V.; Ukrainetz, N.K. 2008. Assisted migration adaptation trial: workplan [updated February 2011]. [Location of publisher unknown]: British Columbia Ministry of Forests, Lands and Natural Resources Operations. http://www.for.gov.bc.ca/hre/forgen/interior/AMAT.htm. (10 March 2011).

Oliver, W.W.; Ryker, R.A. 1990. *Pinus ponderosa* Dougl. ex Laws., ponderosa pine. In: Burns, R.M.; Honkala, B.H., eds. Silvics of North America. Vol. 1, Conifers. Washington, DC: U.S. Department of Agriculture, Forest Service: 413-424.

Oregon State University and U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station [OSU and USDA]. 2011. Seedlot selection tool. http://sst.forestry.oregonstate.edu/PNW/index.html. (21 April 2011).

Ostry, M.E.; Anderson, N.A. 2009. Genetics and ecology of the *Entoleuca mammata-Populus* pathosystem: implications for aspen improvement and management. Forest Ecology and Management. 257: 390-400.

Owens, J.N. 1984. Bud development in grand fir (*Abies grandis*). Canadian Journal of Forest Research. 14: 575-588.

Owens, J.N. 2004. The reproductive biology of western white pine. Extension note 4. Victoria, Canada: Forest Genetics Council of British Columbia. 40 p.

Owens, J.N. 2006. The reproductive biology of lodgepole pine. Extension note 7. Victoria, Canada: Forest Genetics Council of British Columbia. 62 p.

Owens, J.N.; Blake, M.D. 1985. Forest tree seed production. Government of Canada, Canadian Forestry Science, Information Report PI-X-53. Chalk River, Canada: Petawawa National Forestry Institute. 161 p.

Owens, J.N.; Molder, M. 1977a. Sexual reproduction of *Abies amabilis*. Canadian Journal of Botany. 55: 2653-2667.

Owens, J.N.; Molder, M. 1977b. Vegetative bud development and cone differentiation in *Abies amabilis*. Canadian Journal of Botany. 55(8): 992-1008.

Owens, J.N.; Molder, M. 1984. The reproductive cycles of western and mountain hemlock. Victoria, Canada: British Columbia Ministry of Forests Information Services Branch. 32 p.

Owens, J.N.; Singh, H. 1982. Vegetative bud development and the time and method of cone initiation in subalpine fir (*Abies lasiocarpa*). Canadian Journal of Botany. 60: 2249-2262.

Owston, P.W. 1990. *Fraxinus latifolia* Benth., Oregon ash. In: Burns, R.; Honkala, B., eds. Silvics of North America. Vol. 2, Hardwoods. Washington, DC: U.S. Department of Agriculture, Forest Service: 339-343.

Packee, E.C. 1990. *Tsuga heterophylla* (Raf.) Sarg., western hemlock In: Burns, R.M.; Honkala, B.H., eds. Silvics of North America. Vol. 1, Conifers. Washington, DC: U.S. Department of Agriculture, Forest Service: 613-622.

Parmesan, C. 2006. Ecological and evolutionary responses to recent climate change. Annual Review of Ecology, Evolution, and Systematics. 37: 637-669.

Pearson, R.G.; Dawson, T.P. 2003. Predicting the impacts of climate change on the distribution of species: are bioclimate envelope models useful? Global Ecology and Biogeography. 12: 361-371.

Pearson, R.G.; Thuiller, W.; Araújo, M.B.; Martinez-Meyer, E.; Brotons, L.; McClean, C.; Miles, L.; Segurado, P.; Dawson, T.P.; Lees, D.C. 2006. Model-based uncertainty in species range prediction. Journal of Biogeography. 33: 1704–1711.

Perala, D.A. 1990. *Populus tremuloides* Michx., quaking aspen. In: Burns, R.M.; Honkala, B.H., eds. Silvics of North America. Vol. 2, Hardwoods. Washington, DC: U.S. Department of Agriculture, Forest Service: 555-569.

Perry, D.A. 1978. An estimate of the effective range of pollen dispersal in lodgepole pine (*Pinus contorta* Dougl.). Annals of Botany. 42: 1001-1002.

Perry, D.J.; Dancik, B.P. 1986. Mating system dynamics of lodgepole pine in Alberta, Canada. Silvae Genetica. 35(5-6): 1986.

Peter, D.H. 2010. Personal communication. Ecologist, U.S. Forest Service Pacific Northwest Research Station, Olympia, WA.

Peter, D.H.; Harrington, C.A. 2002. Site and tree factors in Oregon white oak acorn production in western Washington and Oregon. Northwest Science. 76(3): 189-201.

Peter, D.H.; Harrington, C.A. 2009. Synchronicity and geographic variation in Oregon white oak acorn production in the Pacific Northwest. Northwest Science. 83(2): 117-130.

Peter, D.H.; Shebitz, D. 2006. Historic anthropogenically maintained bear grass savannas of the southeastern Olympic Peninsula. Restoration Ecology. 14(4): 605-615.

Peterson, D.W.; Peterson, D.L.; Ettl, G.J. 2002. Growth responses of subalpine fir to climatic variability in the Pacific Northwest. Canadian Journal of Forest Research. 32(9): 1503-1517.

Poff, N.L.; Brinson, M.M.; Day, J.W. 2002. Aquatic Ecosystems and Global Climate Change: Potential Impacts on Inland Freshwater and Coastal Wetland Ecosystems in the United States. Arlington, VA: Pew Center on Global Climate Change. 44 p.

Post, E.S.; Pedersen, C.; Wilmers, C.C.; Forchhammer, M.C. 2008. Phenological sequences reveal aggregate life history response to climatic warming. Ecology. 89(2): 363-370.

Potter, K.M.; Crane, B.S. 2010. Forest Tree Genetic Risk Assessment System: A Tool for Conservation Decision-Making in Changing Times. Version 1.2. http://www.forestthreats.org/current-projects/project-summaries/genetic-risk-assessment-system. (25 February 2011).

Raffel, T.R.; Rohr, J.R.; Kiesecker, J.M.; Hudson, P.J. 2006. Negative effects of changing temperature on amphibian immunity under field conditions. Functional Ecology. 20(5): 819-828.

Rajora, O.; Dancik, B.P. 2000. Population genetic variation, structure, and evolution in Engelmann spruce, white spruce, and their natural hybrid complex in Alberta. Canadian Journal of Botany. 78(6): 768-780.

Randall, W.K.; Berrang, P. 2002. Washington tree seed tree seed transfer zones. Olympia, Washington: Washington Department of Natural Resources.

Randin, C.F.; Engler, R.; Normand, S.; Zappa, M.; Zimmermann, N.E.; Pearman, P.B.; Vittoz, P.; Thuiller, W.; Guisan, A. 2009. Climate change and plant distribution: local models predict high-elevation persistence. Global Change Biology. 15: 1557-1569.

Reeves, S.L. 2007. *Arbutus menziesii*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).

Rehfeldt, G.E. 1991. A model of genetic variation for *Pinus ponderosa* in the Inland Northwest (USA) - applications in gene resource-management. Canadian Journal of Forest Research. 21(10): 1491-1500.

Rehfeldt, G.E. 1994a. Adaptation of *Picea engelmannii* populations to the heterogeneous environments of the Intermountain West. Canadian Journal of Botany. 72(8): 1197-1208.

Rehfeldt, G.E. 1994b. Evolutionary genetics, the biological species, and the ecology of the Interior cedar-hemlock forests. In: Symposium proceedings of Interior Cedar-Hemlock-White Pine Forests: ecology and management. March 2-4, 1993, Spokane, WA; Dept. of Natural Resource Sciences, Washington State University, Pullman, WA: 91-100.

Rehfeldt, G.E. 2004. Interspecific and intraspecific variation in Picea engelmannii and its congeneric cohorts: biosystematics, genecology, and climate change. Gen. Tech. Rep. RMRS-GTR-134. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 18 p.

Rehfeldt, G.E.; Crookston, N.L.; Warwell, M.V.; Evans, J.S. 2006. Empirical analyses of plant-climate relationships for the western United States. International Journal of Plant Sciences. 167(6): 1123-1150.

Rehfeldt, G.E.; Ferguson, D.E.; Crookston, N.L. 2009. Aspen, climate, and sudden decline in western USA. Forest Ecology and Management. 258: 2353–2364.

Rehfeldt, G.E.; Hoff, R.; Steinhoff, R. 1984. Geographic patterns of genetic variation in *Pinus monticola*. Botanical Gazette. 145(2): 229-239.

Rehfeldt, G.E.; Wykoff, W.R.; Ying, C.C. 2001. Physiologic plasticity, evolution, and impacts of a changing climate on *Pinus contorta*. Climate Change. 50(3): 355-376.

Rehfeldt, G.E.; Ying, C.C.; Spittlehouse, D.L.; David A. Hamilton, J. 1999. Genetic responses to climate in *Pinus contorta*: niche breadth, climate change, and reforestation. Ecological Monographs. 69(3): 375-407.

Richardson, B.A.; Brunsfeld, J.; Klopfenstein, N.B. 2002a. DNA from bird-dispersed seed and wind-disseminated pollen provides insights into postglacial colonization and population genetic structure of whitebark pine (*Pinus albicaulis*). Molecular Ecology. 11(2): 215-227.

Richardson, B.A.; Klopfenstein, N.B.; Brunsfeld, S.J. 2002b. Assessing Clark's nutcracker seed-caching flights using maternally inherited mitochondrial DNA of whitebark pine. Canadian Journal of Forest Research. 32(6): 1103-1107.

Richardson, B.A.; Rehfeldt, G.E.; Kim M.-S. 2009. Congruent climate-driven genecological responses from molecular markers and quantitative traits for western white pine (*Pinus monticola*). International Journal of Plant Sciences. 170: 1120-1131.

Richardson, B.A.; Warwell, M.V.; Kim, M-S.; Klopfenstein, N.B.; McDonald, G.I. 2010. Integration of population genetic structure and plant response to climate change: sustaining genetic resources through evaluation of projected threats. In: Pye, J.M.; Rauscher, M.H.; Sands, Y.; Lee, D.C.; Beatty, J.S., tech. eds. Advances in threat assessment and their application to forest and rangeland management. Gen. Tech. Rep. PNW-GTR-802. Portland OR: USDA Forest Service, Pacific Northwest and Southwest Research Stations. 708 p. 2 vol.

Richardson, D.M.; Hellmann, J.J.; McLachlan, J.S.; Sax, D.F.; Schwartz, M.W.; Gonzalez, P.; Brennon, E.J.; Camacho, A.; Root, T.L.; Sala, O.E.; Schneider, S.H.; Ashe, D.M.; Clark, J.R.; Early, R.; Etterson, J.R.; Fielder, E.D.; Gill, J.L.; Minteer, B.A.; Polasky, S.; Safford, H.D.; Thompson, A.R.; Vellend, M. 2009. Multidimensional evaluation of managed relocation. PNAS. 106(24): 9721-9724.

Ritland, C.; Pape, T.; Ritland, K. 2001. Genetic structure of yellow cedar (*Chamaecyparis nootkatensis*). Canadian Journal of Botany. 79(7): 822-828.

Ritland, K.; Meagher, L.D.; Edwards, D.G.W.; El-Kassaby, Y.A. 2005. Isozyme variation and the conservation genetics of Garry oak. Canadian Journal of Botany. 83: 1478-1487.

Ritland, K.; Travis, S. 2004. Inferences involving individual coefficients of relatedness and inbreeding in natural populations of Abies. Forest Ecology and Management. 197(1-3): 171-180.

Robinson, D.C.E.; Beukema, S.J.; Greig, L.A. 2008. Vegetation Models and Climate Change: Workshop Results. ESSA Technologies Ltd. http://www.essa.com/documents/Vegetation%20Models%20and%20Climate%20Change%20-%20Workshop%20Results.pdf. (15 March 2009).

Rocchio, F.J.; Crawford, R.C. 2009. Monitoring desired ecological conditions on Washington state wildlife areas using an ecological integrity assessment framework. Olympia, WA: Washington Natural Heritage Program, Washington Department of Natural Resources.

Rochefort, R. 2010. Personal communication. Science advisor, North Cascades National Park Service Complex.

Rochefort, R.M.; Bivin, M.; Boetsch, J.R.; Grace, L.; Acker, S.A.; Thompson, C.C.; Whiteaker, L. [N.d.] Prairie Vegetation Monitoring Protocol for the North Coast and Cascades Network. Natural Resource Report NPS/NCCN/NRR—2010/XXX. Manuscript in preparation. On file at: U.S. Department of the Interior, National Park Service, Natural Resource Program Center, Fort Collins, CO.

Rochefort, R.M.; Peterson, D.L. 1996. Temporal and spatial distribution of trees in subalpine meadows of Mount Rainier National Park, Washington, U.S.A. Arctic and Alpine Research. 28(1): 52-59.

Rogers, D.L.; Millar, C.I.; Westfall, R.D. 1999. Fine-scale genetic structure of whitebark pine (*Pinus albicaulis*): Associations with watershed and growth form. Evolution. 53(1): 74-90.

Rotach, P. 1997. Multivariate patterns of genetic variation in ponderosa pine (*Pinus ponderosa* Doug1. ex Laws.), based on allozyme scores and seedling quantitative traits. Ph.D. Dissertation. Zurich: Swiss Federal Institute of Technology.

Royle, D.J.; Ostry, M.E. 1995. Disease and pest control in the bioenergy crops poplar and willow. Biomass and Bioenery. 9: 69-79.

Ruchty, A. 2008. Golden chinquapin element occurrence survey report. Gifford Pinchot National Forest. 9 p.

Rweyongeza, D.M.; Dhir, N.K.; Barnhardt, L.K.; Hansen, C.; Yang, R.-C. 2007. Population differentiation of the lodgepole pine (*Pinus contorta*) and jack pine (*Pinus banksiana*) complex in Alberta: growth, survival, and responses to climate. Canadian Journal of Botany. 85(6): 545-556.

Rygiewicz, P.T.; Johnson, M.G.; Ganio, L.M.; Tingey, D.T.; Storm, M.J. 1997. Lifetime and temporal occurrence of mycorrhizae on ponderosa pine (*Pinus ponderosa* Laws.) seedlings grown under varied CO2 and nitrogen levels. Plant and Soil. 189: 275-287.

Safford, L.O.; Bjorkbom, J.C.; Zasada, J.C. 1990. *Betula papyrifera* Marsh., paper birch. In: Burns, R.; Honkala, B., eds. Silvics of North America. Vol. 2, Hardwoods. Washington, DC: U.S. Department of Agriculture, Forest Service: 158-171.

Savolainen, O.; Bokma, F.; Garcia-Gil, R.; Komulainen, P.; Repo, T. 2004. Genetic variation in cessation of growth and frost hardiness and consequences for adaptation of Pinus sylvestris to climatic changes. Forest Ecology and Management. 197(1-3): 79-89.

Schaberg, P.G.; Hennon, P.E.; D'Amore, D.V.; Hawley, G.J. 2008. Influence of simulated snow cover on the cold tolerance and freezing injury of yellow-cedar seedlings. Global Change Biology. 14(6): 1282-1293.

Scher, J.S. 2002. *Juniperus scopulorum*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).

Scher, S.; Jimerson, T.M. 1989. Does fire regime determine the distribution of Pacific yew in forested watersheds? In: Berg, N.H., ed. Proceedings of the conference Symposium on Fire and Watershed Management; 26-28 October 1988; Sacramento, CA. Berkeley, CA: U.S. Department of Agriculture, Forest

Service, Pacific Southwest Forest and Range Experiment Station: 160-161.

Schmidt, R.G. 1957. The silvics and plant geography of the genus *Abies* in the coastal forests of British Columbia. Technical Publication T.46. Victoria, Canada: Department of Lands and Forests, British Columbia Forest Service. 31 p.

Shafer, S.L.; Bartlein, P.J.; Thompson, R.S. 2001. Potential Changes in the Distributions of Western North America Tree and Shrub Taxa under Future Climate Scenarios. Ecosystems. 4: 200-215.

Shaw, D.V.; Allard, R.W. 1982. Estimation of outcrossing rates in Douglas-fir using isozyme markers. Theoretical and Applied Genetics. 62(2): 113-120.

Shea, K.L. 1987. Effects of population structure and cone production on outcrossing rates in Engelmann spruce and subapline fir. Evolution. 41(1): 124-136.

Shea, K.L. 1990. Genetic variation between and within populations of Engelmann spruce and subalpine fir. Genome. 33(1): 1-8.

Shebitz, D.J.; Reichard, S.H.; Dunwiddie, P.W. 2009. Ecological and cultural significance of burning beargrass habitat on the Olympic, Peninsula, Washington. Ecological Restoration. 20(3): 306-319.

Sheldon, D.; Hruby, T.; Johnson, P.; Harper, K.; McMillian, A.; Granger, T.; Stanley, S.; Stockdale, E. 2005. Wetlands in Washington State - Volume 1: A Synthesis of the Science. Publication #05-06-006. Olympia, WA: Washington State Department of Ecology. 532 p.

Shoal, R.Z. 2009. Occurrence and habitat status evaluation for Golden Chinquapin (*Chrysolepis chrysophylla* (Dougl. ex Hook.) Hjelmqvist) on the Olympic National Forest. Report prepared for Interagency Special Status Species Program. 7 p.

Shoal, R.Z.; Aubry, C.A. 2004. The status of whitebark pine on four national forests in Washington state. Olympia, WA: U.S. Department of Agriculture, Forest Service, Olympic National Forest. 23 p.

Shoal, R.Z.; Aubry, C.A. 2006. Assessment of whitebark pine health on eight national forests in Oregon and Washington. Olympia, WA: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 22 p.

Siegismund, H.R.; Kjaer, E.D. 1997. Outcrossing rates in two stands of noble fir (*Abies procera* Rehd.) in Denmark. Silvae Genetica. 46(2-3): 144-146.

Silen, R.R. 1963. Effect of altitude on factors of pollen contamination on Douglas-fir seed orchards. Journal of Forestry. 61: 281-283.

Smith, E.L.; Cruz, R.; Fischer, L.; Hostetler, B.; Starkey, D.; Steinman, J. [N.d.]. Monitoring on the Margins plan for high elevation 5-needle pines: executive summary. Unpublished report.

Sniezko, R.A. 2006. Resistance breeding against nonnative pathogens in forest trees—current successes in North America. Canadian Journal of Forest Pathology. 28: S270-S279.

Snyder, C.; Lundquist, J. 2007. Forest health conditions in Alaska—2006. Protection Report R10-PR-11. U.S. Department of Agriculture Forest Service, Alaska Region, Juneau, AK. 96 p.

Sorensen, F.C. 1994a. Frequency of seedlings from natural self-fertilization in Pacific Northwest ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) Silvae Genetica. 43(2-3): 100-108.

Sorensen, F.C. 1994b. Genetic variation and seed transfer guidelines for ponderosa pine in central Oregon. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station Research Paper 472.

Spies, T.A.; Giesen, T.W.; Swanson, F.J.; Franklin, J.F.; Lach, D.; Johnson, K.N. 2010. Climate change adaptation strategies for federal forests in the Pacific Northwest, USA: ecological, policy, and socio-economic perspectives. Landscape Ecology. 25(8): 1185-1199.

St. Clair, J.B. 2006. Genetic variation in fall cold hardiness in coastal Douglas-fir in western Oregon and Washington. Canadian Journal of Botany. 84(7): 1110-1121.

St. Clair, S.B.; Guyon, J.; Donaldson, J. 2009. Quaking aspen's current and future status in western North America: the role of succession, climate, biotic agents, and its clonal nature. Progress in Botany. 71: 371-400.

St. Clair, J.B.; Harrington, C.A.; Gould, P.J. 2010. Regional agenda 2020 progress report: seed source movement study: performance of Douglas-fir as determined by climatic differences between seed sources and planting sites. On file with: USDA Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, Corvallis, OR.

St. Clair, J.B.; Mandel, N.L.; Vance-Boland, K.W. 2005. Genecology of Douglas fir in western Oregon and Washington. Annals of Botany. 96(7): 1199-1214.

Stein, W.I. 1990. *Quercus garryana* Dougl. ex Hook., Oregon white oak. In: Burns, R.M.; Honkala, B.H., eds. Silvics of North America. Vol. 2, Hardwoods. Washington, DC: U.S. Department of Agriculture, Forest Service: 650–660.

Steinberg, P.D. 2001. *Populus balsamifera* subsp. *trichocarpa*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).

Steinhoff, R.J.; Joyce, D.G.; Fins, L. 1983. Isozyme variation in *Pinus monticola*. Canadian Journal of Forest Research. 13(6): 1122-1132.

Taylor, R.J.; Boss, T.R. 1975. Biosystematics of Quercus garryana in relation to its distribution in the state of Washington. Northwest Science. 49(2): 49-57.

Tesky, J.L. 1992a. *Thuja plicata*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).

Tesky, J.L. 1992b. *Tsuga heterophylla*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).

Tesky, J.L. 1992c. *Tsuga mertensiana*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).

Thelinius, J.F. 1968. The *Quercus garryana* forests of the Willamette Valley, Oregon. Ecology. 49(6): 1124-1133.

Thompson, R.S.; Hostetler, S.W.; Bartlein, P.J.; Anderson, K.H. 1998. A strategy for assessing potential future changes in climate, hydrology, and vegetation in the western United States. U.S. Geological Survey Circular 1153. Denver, CO: U.S. Geological Survey. 20 p.

Tirmenstein, D.A. 1990. *Taxus brevifolia*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).

Uchytil, R.J. 1989a. *Acer macrophyllum*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).

Uchytil, R.J. 1989b. *Alnus rubra*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).

Uchytil, R.J. 1989c. *Salix lucida* subsp. *lasiandra*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).

Uchytil, R.J. 1991a. *Abies lasiocarpa*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).

Uchytil, R.J. 1991b. *Betula papyrifera*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).

Uchytil, R.J. 1991c. *Picea engelmannii*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).

Uchytil, R.J. 1991d. *Pseudotsuga menziesii* var. *menziesii*. In: Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. http://www.fs.fed.us/database/feis/. (15 February 2010).

U.S. Congress, Office of Technology Assessment. 1993. Preparing for an uncertain climate-Volume II, OTA-O-568. Washington, DC: US Government Printing Office.

U.S. Department of Agriculture [USDA], Forest Service. 2008. Current vegetation survey, Pacific Northwest Region Forest Inventory and Monitoring. http://www.fs.fed.us/r6/survey/. (15 October 2010).

U.S. Department of Agriculture [USDA], Forest Service. 2010a. Ecology core dataset, western Washington, Region 6 Ecology Program. http://www.reo.gov/ecoshare/datasets/. (15 October 2010).

U.S. Department of Agriculture [USDA], Forest Service 2010b. Forest Service Pacific Northwest Forest Inventory and Analysis FIA DataMart FIADB version 4.0 U.S. Department of Agriculture Forest Service. http://199.128.173.17/fiadb4-downloads/datamart.html. (4 October 2010).

U.S. Department of Agriculture [USDA], Forest Service. 2010c. Interagency Special Status /Sensitive Species Program (ISSSSP). http://www.fs.fed.us/r6/sfpnw/issssp/. (12 October 2010).

U.S. Department of Agriculture [USDA], Forest Service. 2010d. National roadmap for responding to climate change. http://www.fs.fed.us/climatechange/pdf/roadmap.pdf. (12 October 2010).

U.S. Department of Agriculture [USDA], Natural Resources Conservation Service [NRCS]. 2010. The PLANTS database. National Plant Data Center. http://plants.usda.gov. (23 July 2010).

U.S. Geological Survey [USGS]. 2010. National Hydrography Dataset. http://nhd.usgs.gov/index.html. (14 October 2010).

Van Den Berg, D.A.; Lanner, R.M. 1971. Bud development in lodgepole pine. Forest Science. 17: 479-486.

Viard, F.; El-Kassaby, Y.A.; Ritland, K. 2001. Diversity and genetic structure in populations of *Pseudotsuga menziesii* (Pinaceae) at chloroplast microsatellite loci. Genome. 44(3): 336-344.

Wagg, C.; Pautler, M.; Massicotte, H.B.; Peterson, R.L. 2008. The co-occurrence of ectomycorrhizal, arbuscular mycorrhizal, and dark septate fungi in seedlings of four members of the Pinaceae. Mycorrhiza. 18(2): 103-110.

Wallander, E. 2008. Systematics of *Fraxinus* (Oleaceae) and evolution of dioecy. Plant Systematics and Evolution. 273: 25-49.

Walther, G.-R.; Beiβner, S.; Pott, R. 2005. Climate change and high mountain vegetation shifts. In: Broll, G.; Keplin, B., eds. Mountain ecosystems: Studies in treeline ecology. New York: Springer: 75-96.

Ward, K.; Shoal, R.; Aubry, C. 2006. Whitebark pine in Washington and Oregon: a synthesis of current studies and historical data. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. 22 p.

Warwell, M.V. 2011. Personal communication. Research geneticist, USDA Forest Service, Rocky Mountain Research Station, Moscow, ID.

Warwell, M.V.; Rehfeldt, G.E.; Crookston, N.L. 2006. Modeling contemporary climate profiles of whitebark pine (*Pinus albicaulis*) and predicting responses to global warming. In: Goheen, E., ed. Proceedings of the conference Proceedings of the Conference Whitebark Pine: A Pacific Coast Perspective; Ashland, OR. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Region: 139-142.

Washington Department of Fish and Wildlife [WDFW]. 2008. Priority habitat and species list. Olympia, WA: Washington Department of Fish and Wildlife. 176 p.

Washington Department of Natural Resources [WADNR]. 2010. Plant associations in Washington's Puget Trough ecoregion: paper birch - red alder / sword fern. http://www1.dnr.wa.gov/nhp/refdesk/communities/pdf/bepa-alru-pomu.pdf. (23 July 2010).

Weber, J.C.; Stettler, R.F. 1981. Isozyme variation among 10 populations of *Populus trichocarpa* Torr et. Gray in the Pacific Northwest. Silvae Genetica. 30(2-3): 82-87.

Wellman, H.; Pritchard, E.; Benowicz, A.; Ally, D.; Ritland, C. 2003. Microsatellite markers in western hemlock *Tsuga heterophylla* (Raf.) Sarg. Molecular Ecology Notes. 3(4): 592-594.

Wellman, H.; Ritland, C.; Ritland, K. 2004. Genetic effects of domestication in western hemlock, *Tsuga heterophylla*. Forest Genetics. 10(3): 229-239.

Westerling, A.L.; Hidalgo, H.G.; Cayan, D.R.; Swetnam, T.W. 2006. Warming and earlier spring increase Western U.S. forest wildfire activity. Science. 313: 940-943.

Wheeler, N.C.; Guries, R.P. 1982a. Biogeography of lodgepole pine. Canadian Journal of Botany. 60(9): 1805-1814.

Wheeler, N.C.; Guries, R.P. 1982b. Population structure, genetic diversity, and morphological variation in *Pinus contorta* Dougl. Canadian Journal of Forest Research. 12: 595-606.

Wheeler, N.C.; Jech, K.S.; Masters, S.A.; O'Brien, C.J.; Timmons, D.W.; Stonecypher, R.W.; Lupkes, A. 1995. Genetic variation and parameter estimates in *Taxus brevifolia* (Pacific yew). Canadian Journal of Forest Research. 25: 1913-1927.

Williams, D.W.; Liebhold, A.M. 2002. Climate change and the outbreak ranges of two North American bark beetles. Agriculture and Forest Entomology. 4: 87-99.

Williams, J.W.; Jackson, S.T.; Kutzbach, J.E. 2007. Projected distributions of novel and disappearing climates by 2100 AD. Proceedings of the National Academy of Sciences. 104(14): 5738-5742.

Wilson, E.O. 1988. Biodiversity. Washington D.C.: National Academy Press. 521 p.

Winter, T.C. 2000. The Vulnerability of Wetlands to Climate Change: A Hydrologic Landscape Perspective. Journal of the American Water Resource Association. 36(2): 305-311.

Woodward, A.; Hutten, K.; Boetsch, J.; Acker, S.; Rochefort, R.; Bivin, M.; Kurth, L. 2009. Forest vegetation monitoring protocol for National Parks in the North Coast and Cascades Network. Reston, VA: U.S. Department of the Interior, U.S. Geological Survey. 228 p.

Woodward, A.; Schreiner, E.G.; Silsbee, D.G. 1995. Climate, geography, and tree establishment in subalpine meadows of the Olympic Mountains, Washington, USA. Arctic and Alpine Research. 27(3): 217-225.

Woodward, A.; Silsbee, D.G.; Schreiner, E.G.; Means, J.E. 1994. Influence of climate on radial growth and cone production in subalpine fir (*Abies lasiocarpa*) and mountain hemlock (*Tsuga mertensiana*). Canadian Journal of Forest Research. 24: 1133-1143.

Woodward, F.I. 1987. Climate and plant distribution. New York: Cambridge University Press. 177 p.

Woodward, F.I.; Lomas, M.R.; Kelly, C.K. 2004. Global climate and the distribution of plant biomes. Philosophical transactions of the Royal Society B – biological sciences. 359: 1465-1476.

Xie, C.Y. 2008. Ten-year results from red alder (*Alnus rubra* Bong.) provenance-progeny testing and their implications for genetic improvement. New Forests. 36(3): 273-284.

Xie, C.Y.; El-Kassaby, Y.A.; Ying, C.C. 2002. Genetics of red alder (*Alnus rubra* Bong.) populations in British Columbia and its implications for gene resources management. New Forests. 24(2): 97-112.

Xie, C.Y.; Ying, C.C. 1994. Adaptedness of noble fir (*Abies procera* Rehd.) beyond its northern limit. Forest Science. 40(3): 412-428.

Yang, R.C.; Yeh, F.C. 1993. Multilocus structure in *Pinus contorta* Dougl. Theoretical and Applied Genetics. 87(5): 568-576.

Yeh, F.C. 1988. Isozyme variation of *Thuja plicata* (Cupressacese) in British Columbia. Biochemical Systematics and Ecology. 16(4): 373-377.

Yeh, F.C.; Cheliak, W.M.; Dancik, B.P.; Illingworth, K.; Trust, D.C.; Pyrhitka, B.A. 1985. Population differentiation in lodgepole pine, *Pinus contorta* spp. *latifolia*: a discriminant analysis of allozyme variation. Canadian Journal of Genetics and Cytology. 27: 210-218.

Yeh, F.C.; Chong, D.K.X.; Yang, R.C. 1995. RAPD variation within and among natural populations of trembling aspen (*Populus tremuloides* Michx) from Alberta. Journal of Heredity. 86(6): 454-460.

Yeh, F.C.; El-Kassaby, Y.A. 1980. Enzyme variation in natural populations of Sitka spruce (*Picea sitchensis*). 1. Genetic variation patterns among trees from 10 IUFRO provenances. Canadian Journal of Forest Research. 10(3): 415-422.

Yeh, F.C.; Hu, X.S. 2005. Genetic structure and migration from mainland to island populations in *Abies procera* Rehd. Genome. 48(3): 461-473.

Yeh, F.C.; Layton, C. 1979. Organization of genetic variability in central and marginal populations of lodgepole pine *Pinus contorta* spp. *latifolia*. Canadian Journal of Genetics and Cytology. 21(4): 487-503.

Ying, C.C. 1991. Performance of lodgepole pine provenances at sites in southwestern British Columbia. Silvae Genetica. 40(5-6): 215-223.

Ying, C.C.; Liang, Q.W. 1994. Geographic pattern of adaptive variation of lodgepole pine (*Pinus contorta* Dougl) within the species coastal range - field performance at age 20 years. Forest Ecology and Management. 67(1-3): 281-298.

Zolbrod, A.N.; Peterson, D.L. 1999. Response of high-elevation forests in the Olympic Mountains to climate change. Canadian Journal of Forest Research. 29: 1966-1978.

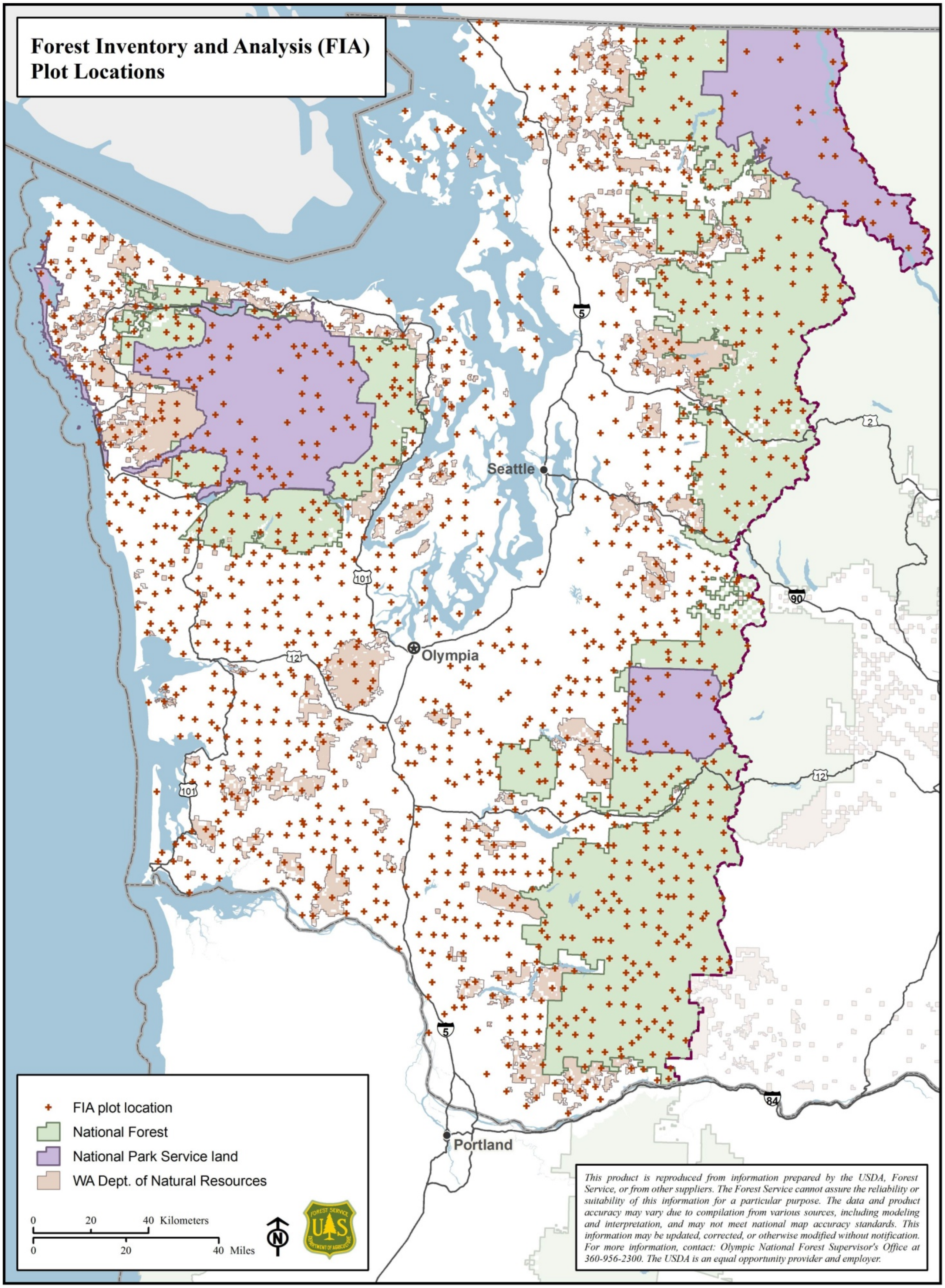
Zoltai, S.C.; Vitt, D.H. 1995. Canadian wetlands: environmental gradients and classification. Vegetatio. 118: 131-137.

APPENDIX A:
TREE SPECIES DISTRIBUTION MAPS

Table A-1. List of distribution maps for tree species of western Washington. The species distribution maps are prefaced by four maps (pages A-3 through A-6) showing the locations of all plots surveyed in each of the four major data sources.

Map			**Page**
Forest Inventory and Analysis plot locations			A-3
Ecology Core Dataset plot locations			A-3
Current Vegetation Survey (CVS) plot locations			A-5
National Park Service plot locations			A-6
Scientific name	**Common name**	**Symbol**	
Abies amabilis	Pacific silver fir	ABAM	A-7
Abies grandis	Grand fir	ABGR	A-8
Abies lasiocarpa	Subalpine fir	ABLA	A-9
Abies procera	Noble fir	ABPR	A-10
Acer glabrum var. *douglasii*	Douglas maple	ACGLD4	A-11
Acer macrophyllum	Bigleaf maple	ACMA3	A-12
Alnus rubra	Red alder	ALRU2	A-13
Arbutus menziesii	Pacific madrone	ARME	A-14
Betula papyrifera	Paper birch	BEPA	A-15
Chrysolepis chrysophylla	Golden chinquapin	CHCH7	A-16
Cornus nuttallii	Pacific dogwood	CONU4	A-17
Crataegus douglasii and *C. suksdorfii*	Black hawthorn and Suksdorf's hawthorn	CRDO2, CRSU16	A-18
Cupressus nootkatensis	Alaska yellow-cedar	CUNO	A-19
Frangula purshiana	Cascara	FRPU7	A-20
Fraxinus latifolia	Oregon ash	FRLA	A-21
Juniperus scopulorum	Rocky mountain juniper	JUSC2	A-22
Malus fusca	Western crab apple	MAFU	A-23
Picea engelmannii	Engelmann spruce	PIEN	A-24
Picea sitchensis	Sitka spruce	PISI	A-25
Pinus albicaulis	Whitebark pine	PIAL	A-26
Pinus contorta var. *contorta* and var. *latifolia*	Shore pine and lodgepole pine	PICOC, PICOL	A-27
Pinus monticola	Western white pine	PIMO3	A-28
Pinus ponderosa	Ponderosa pine	PIPO	A-29
Populus balsamifera ssp. *trichocarpa*	Black cottonwood	POBAT	A-30
Populus tremuloides	Quaking aspen	POTR5	A-31
Prunus emarginata	Bitter cherry	PREM	A-32
Pseudotsuga menziesii	Douglas-fir	PSME	A-33
Quercus garryana	Oregon white oak	QUGA4	A-34
Salix lucida var. *lasiandra*[1]	Pacific willow	SALUL	A-35
Salix scouleriana	Scouler's willow	SASC	A-36
Taxus brevifolia	Pacific yew	TABR2	A-37
Thuja plicata	Western redcedar	THPL	A-38
Tsuga heterophylla	Western hemlock	TSHE	A-39
Tsuga mertensiana	Mountain hemlock	TSME	A-40

[1] *Individual occurrence data not available for this species; instead a general range map is shown.*


Forest Inventory and Analysis (FIA) Plot Locations
Seattle
Olympia
Portland
5
101
12
2
90
84
FIA plot location
National Forest
National Park Service land
WA Dept. of Natural Resources
0
20
40 Kilometers
0
20
40 Miles
N
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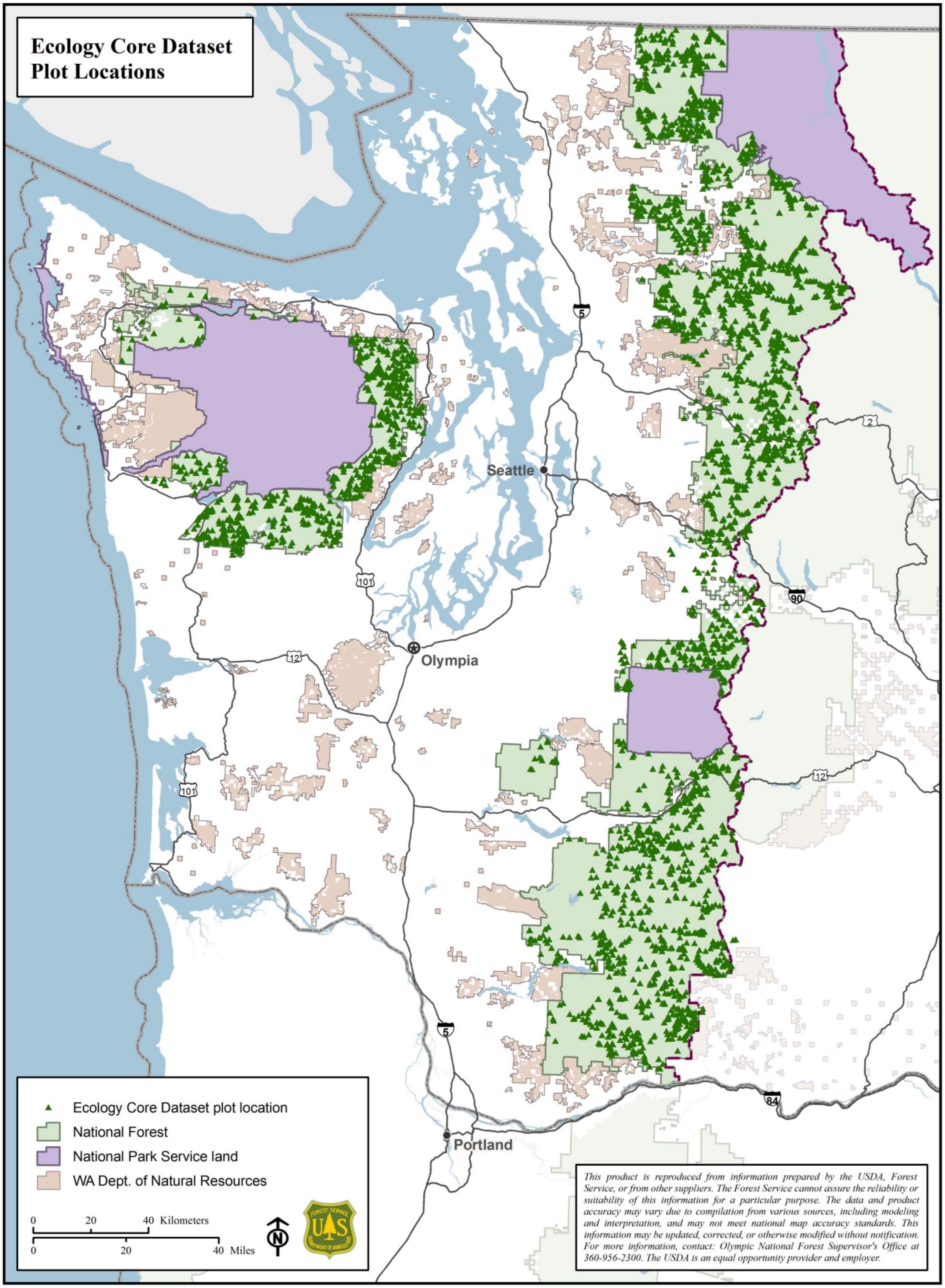

Ecology Core Dataset Plot Locations

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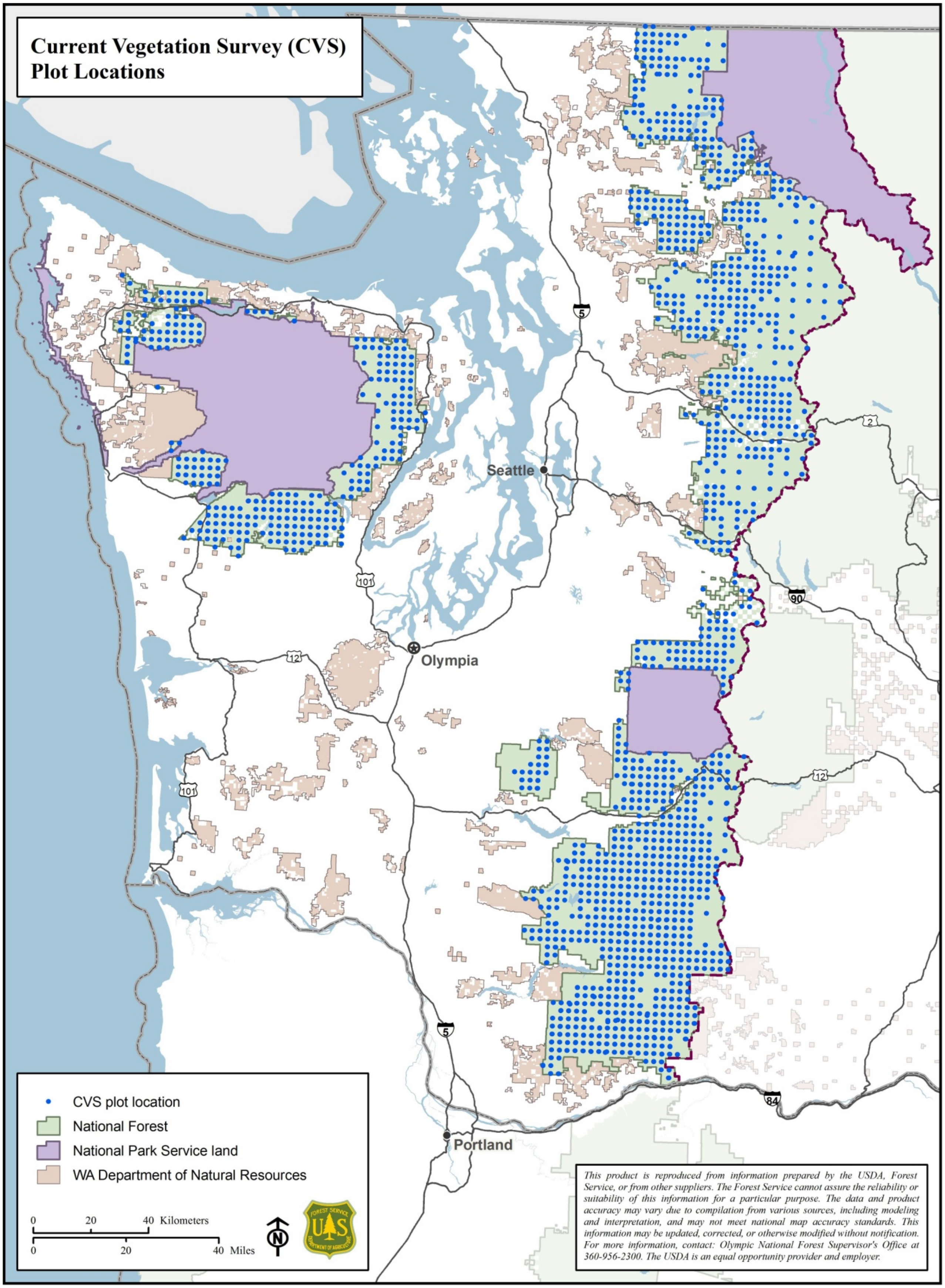

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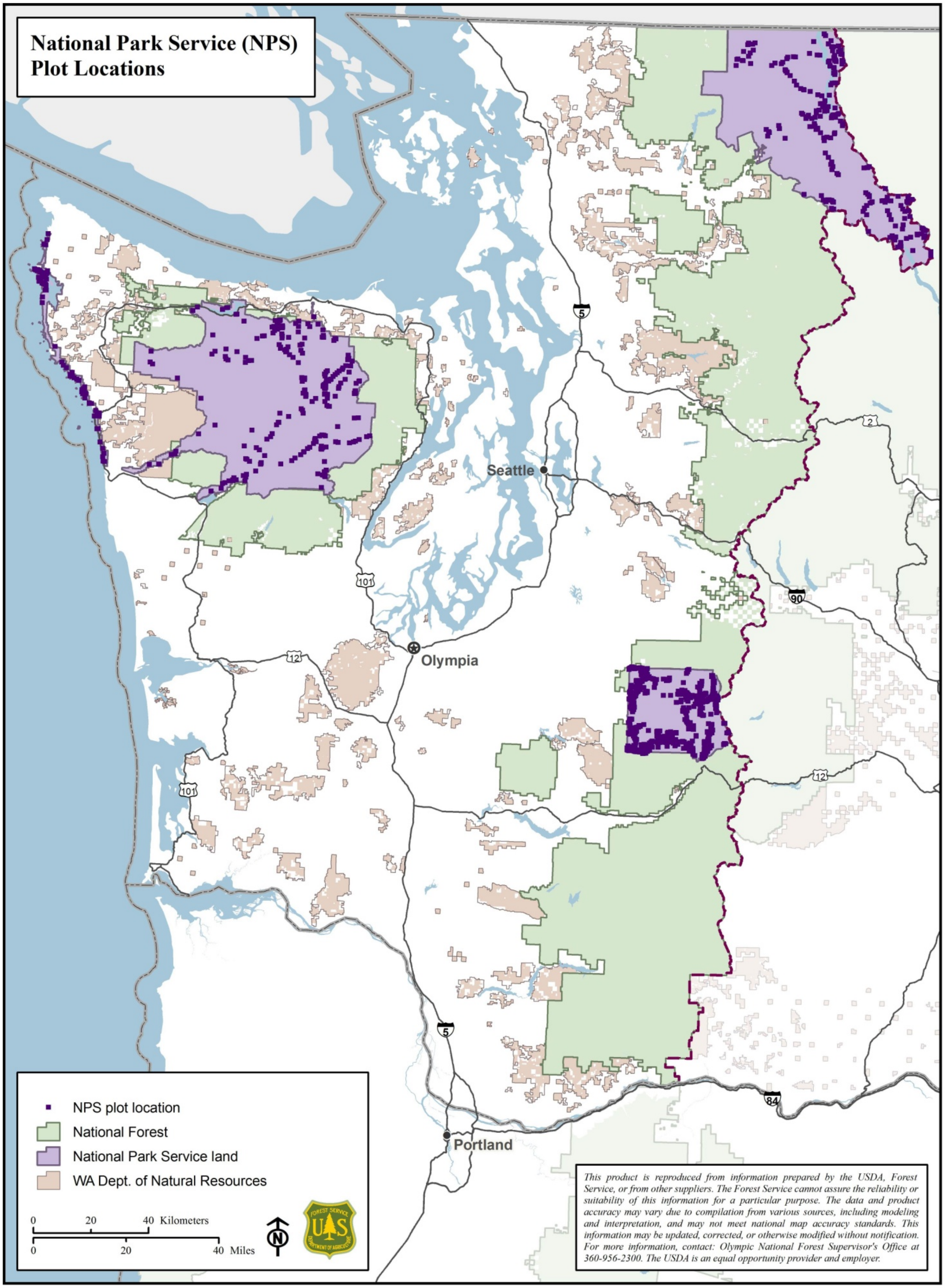

National Park Service (NPS) Plot Locations

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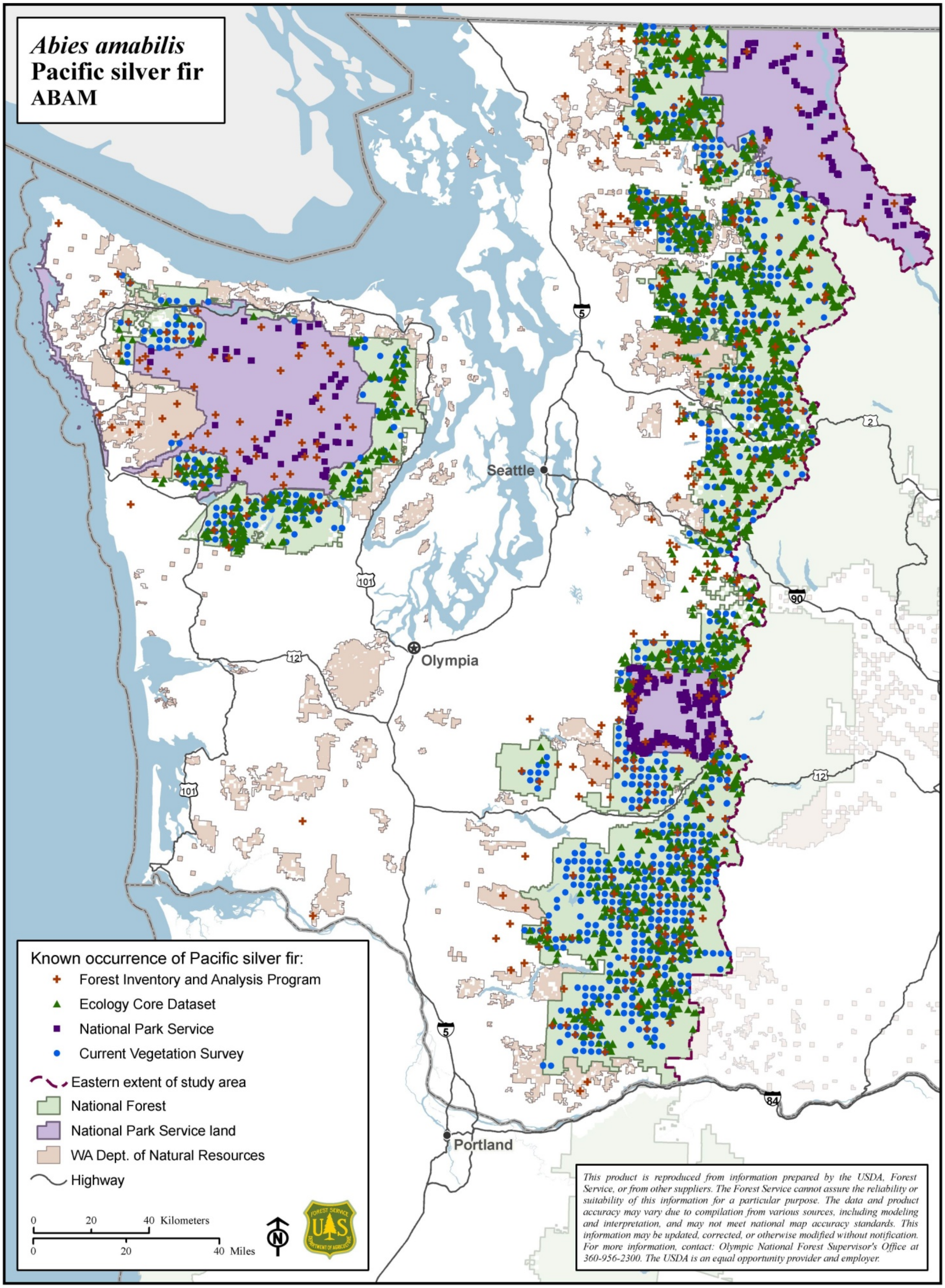
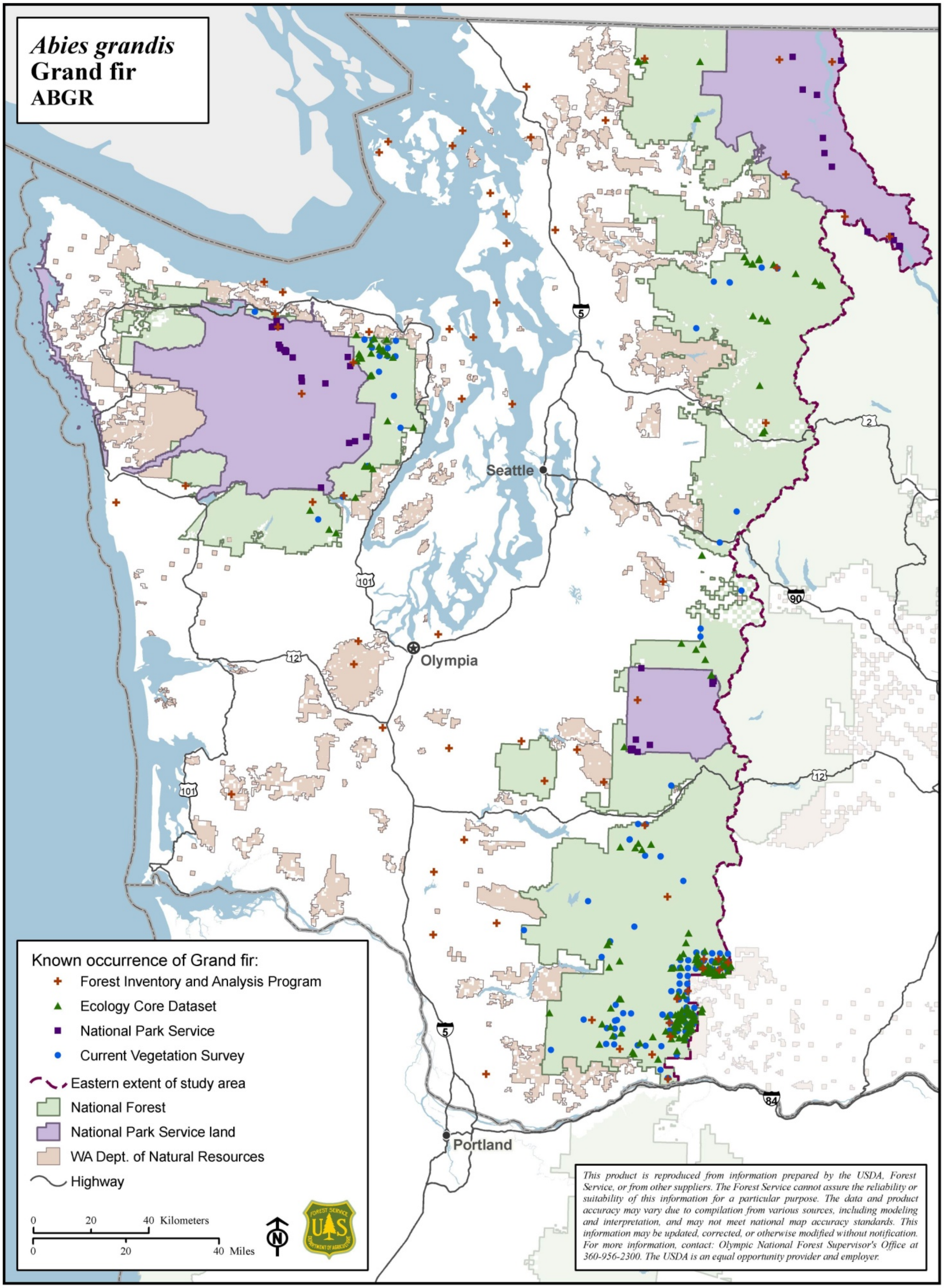


Abies amabilis
Pacific silver fir
ABAM



Abies grandis
Grand fir
ABGR

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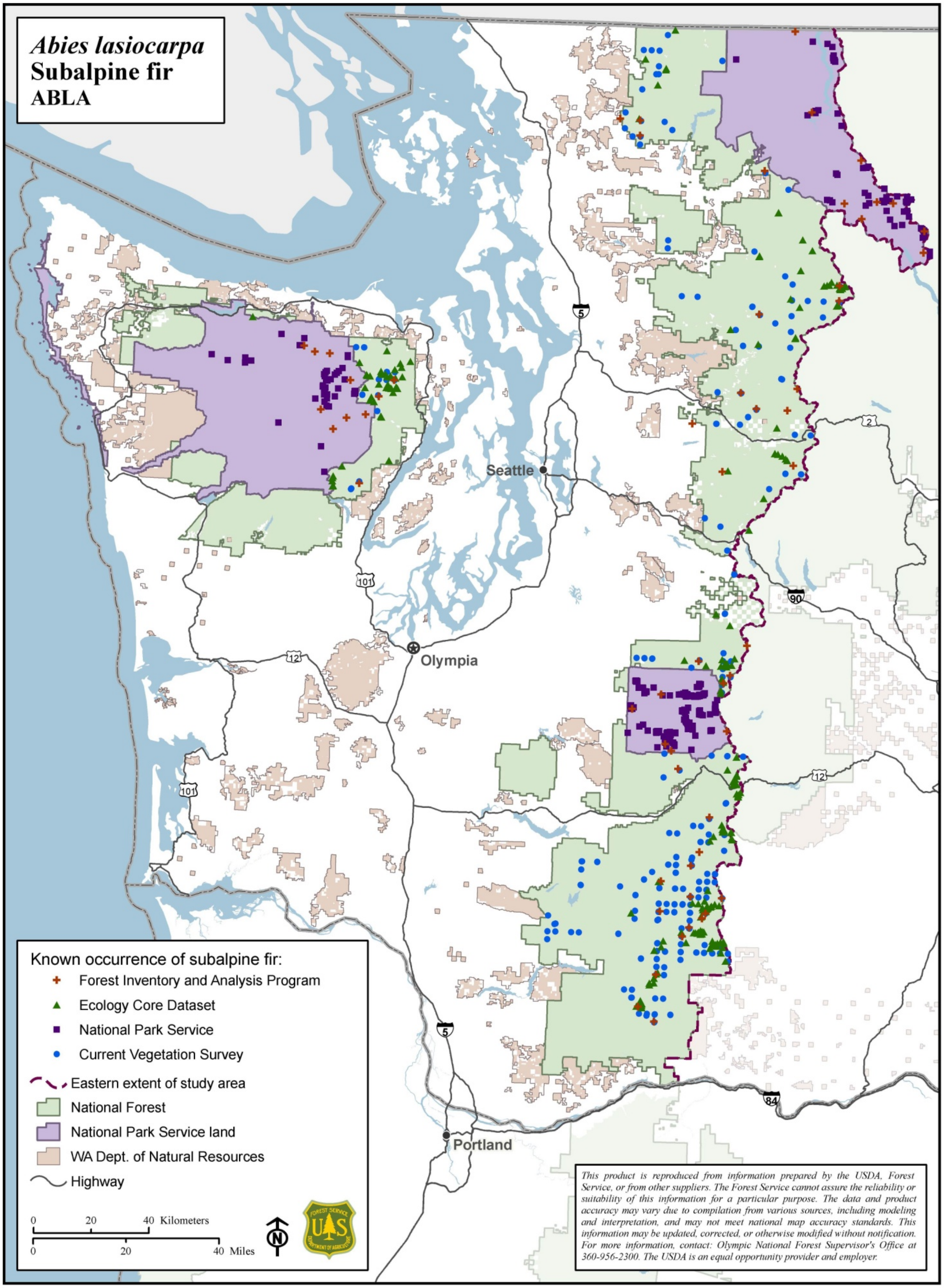

Abies lasiocarpa
Subalpine fir
ABLA

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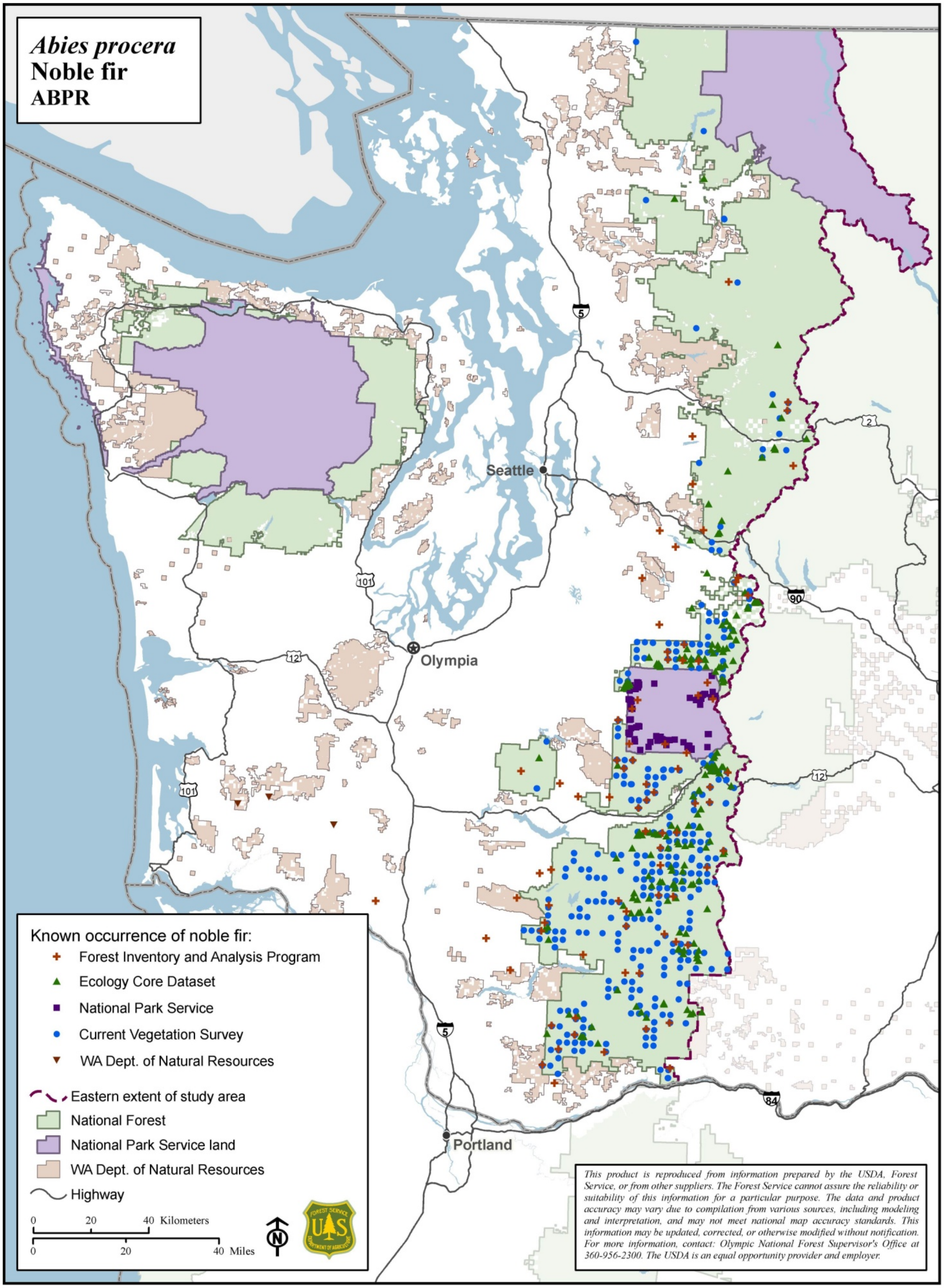

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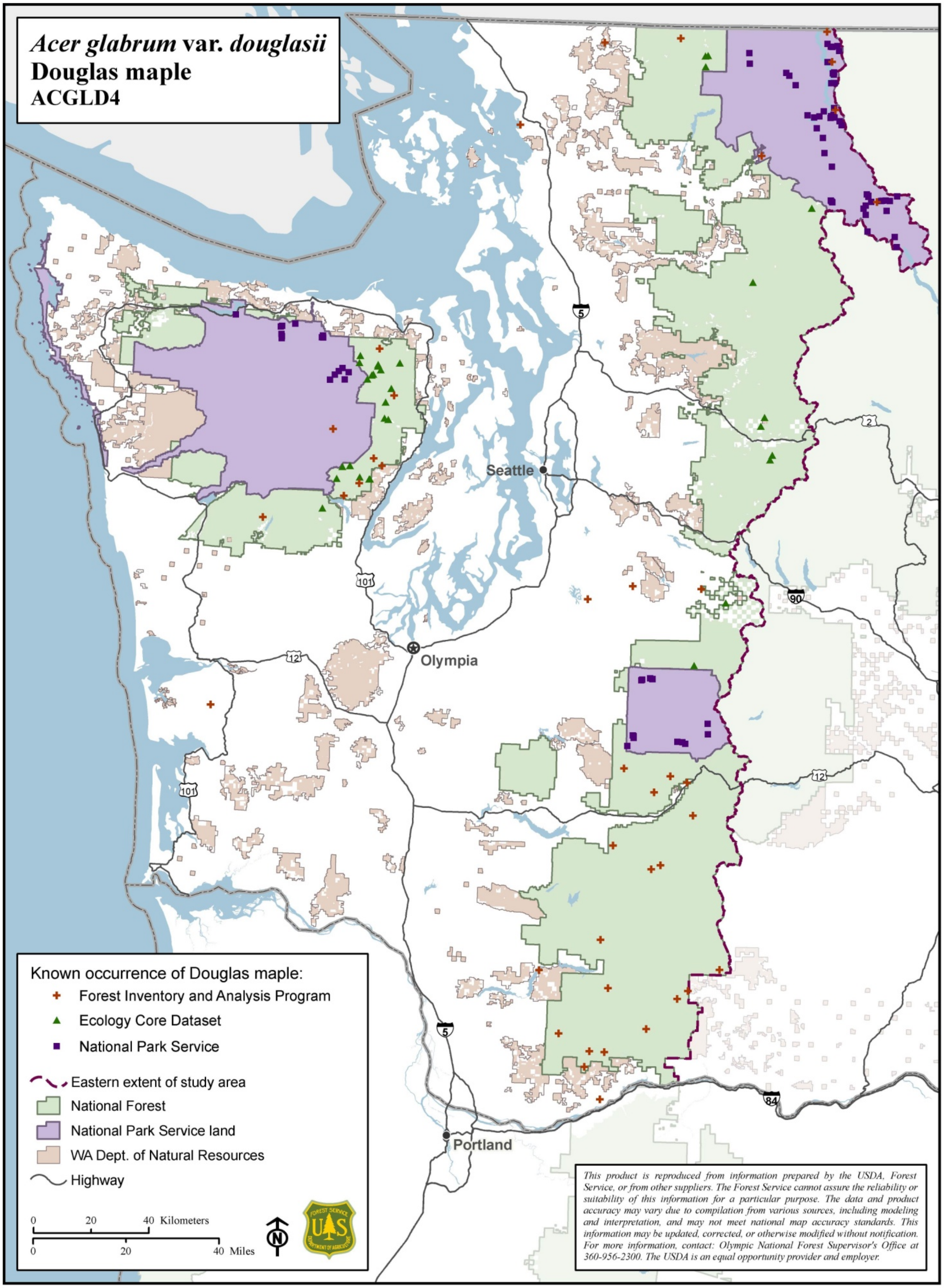

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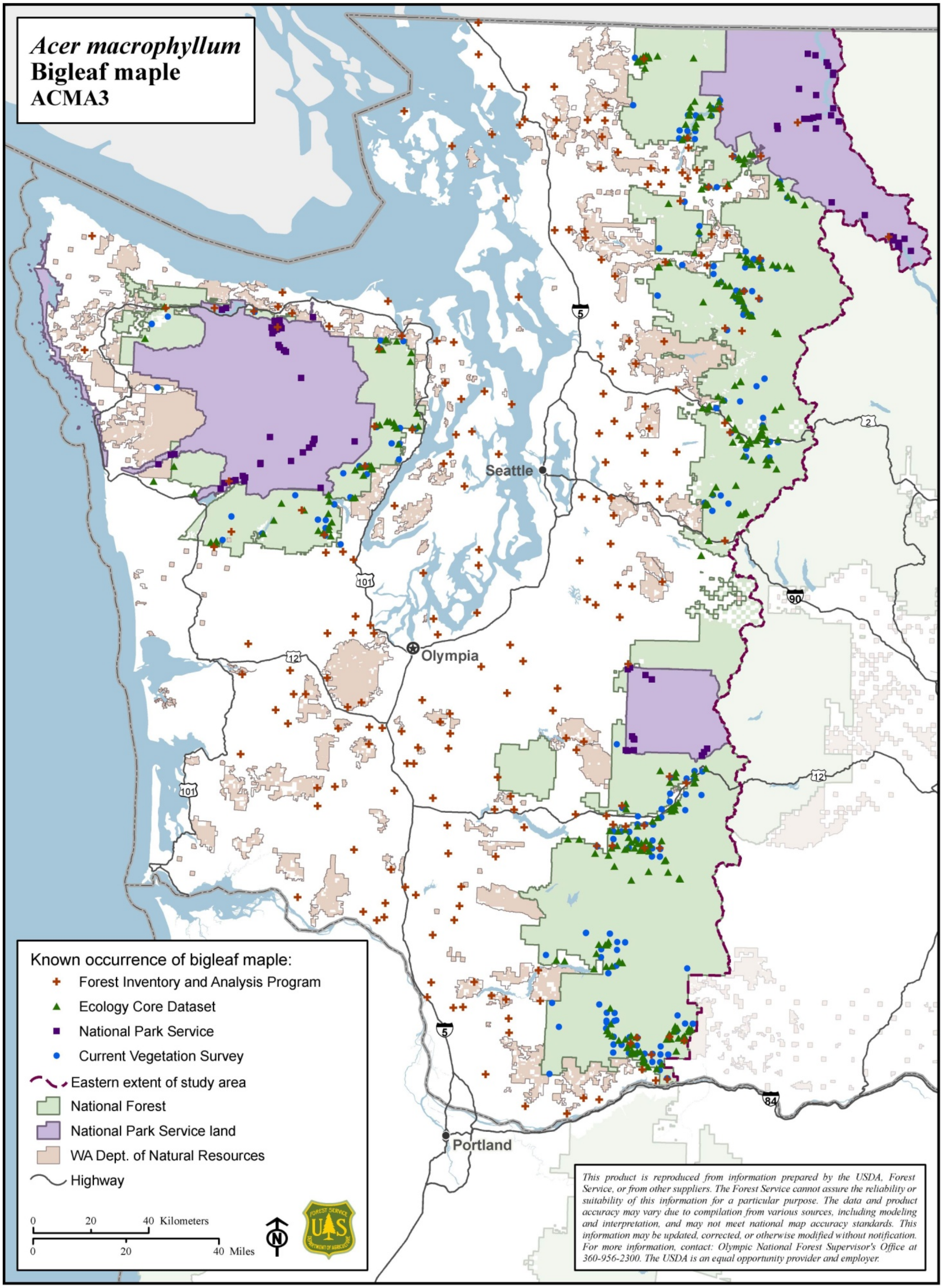

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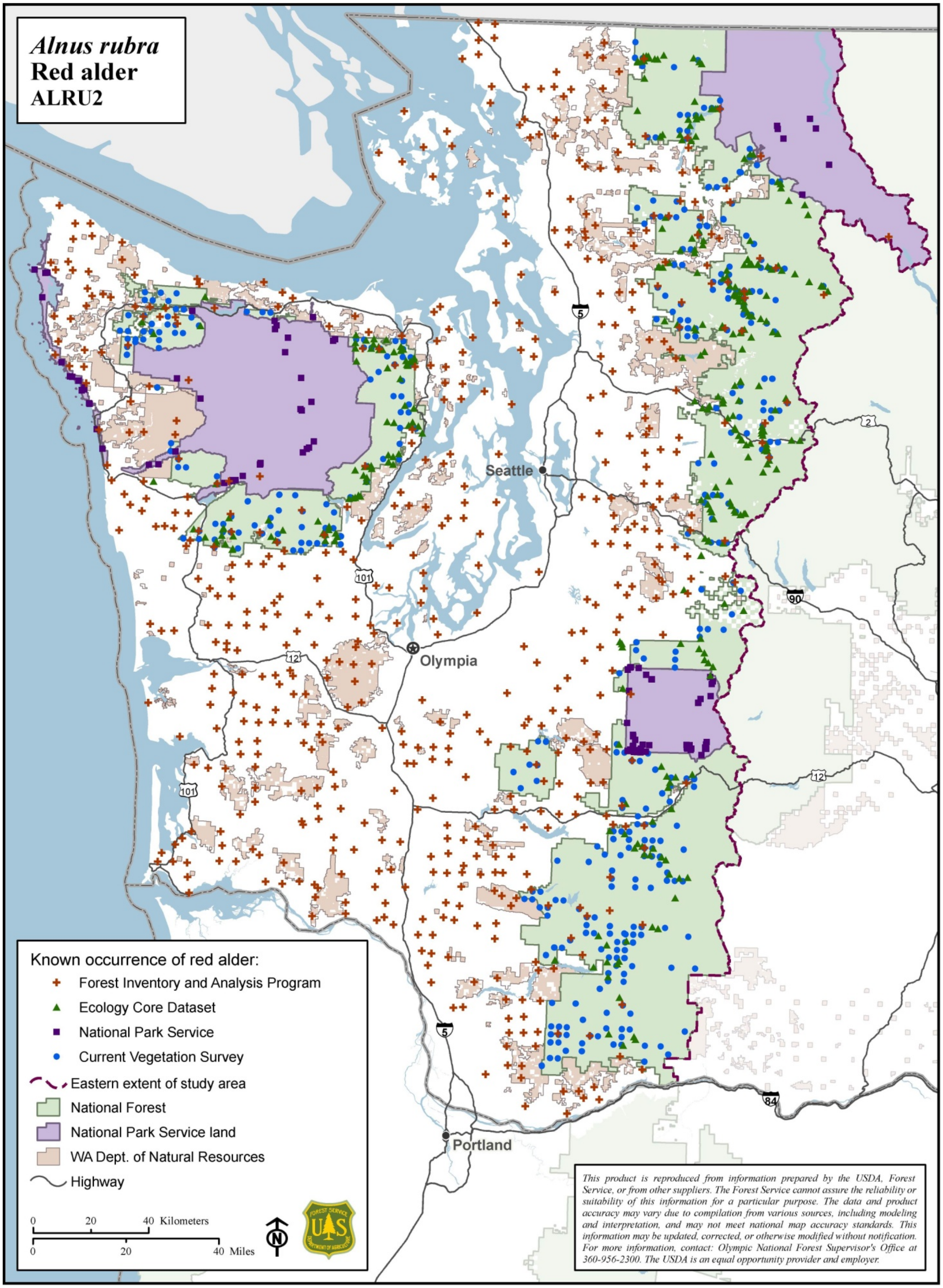

Alnus rubra
Red alder
ALRU2

Known occurrence of red alder:
- + Forest Inventory and Analysis Program
- ▲ Ecology Core Dataset
- ■ National Park Service
- ● Current Vegetation Survey

Eastern extent of study area
🟩 National Forest
🟪 National Park Service land
🟫 WA Dept. of Natural Resources
Highway

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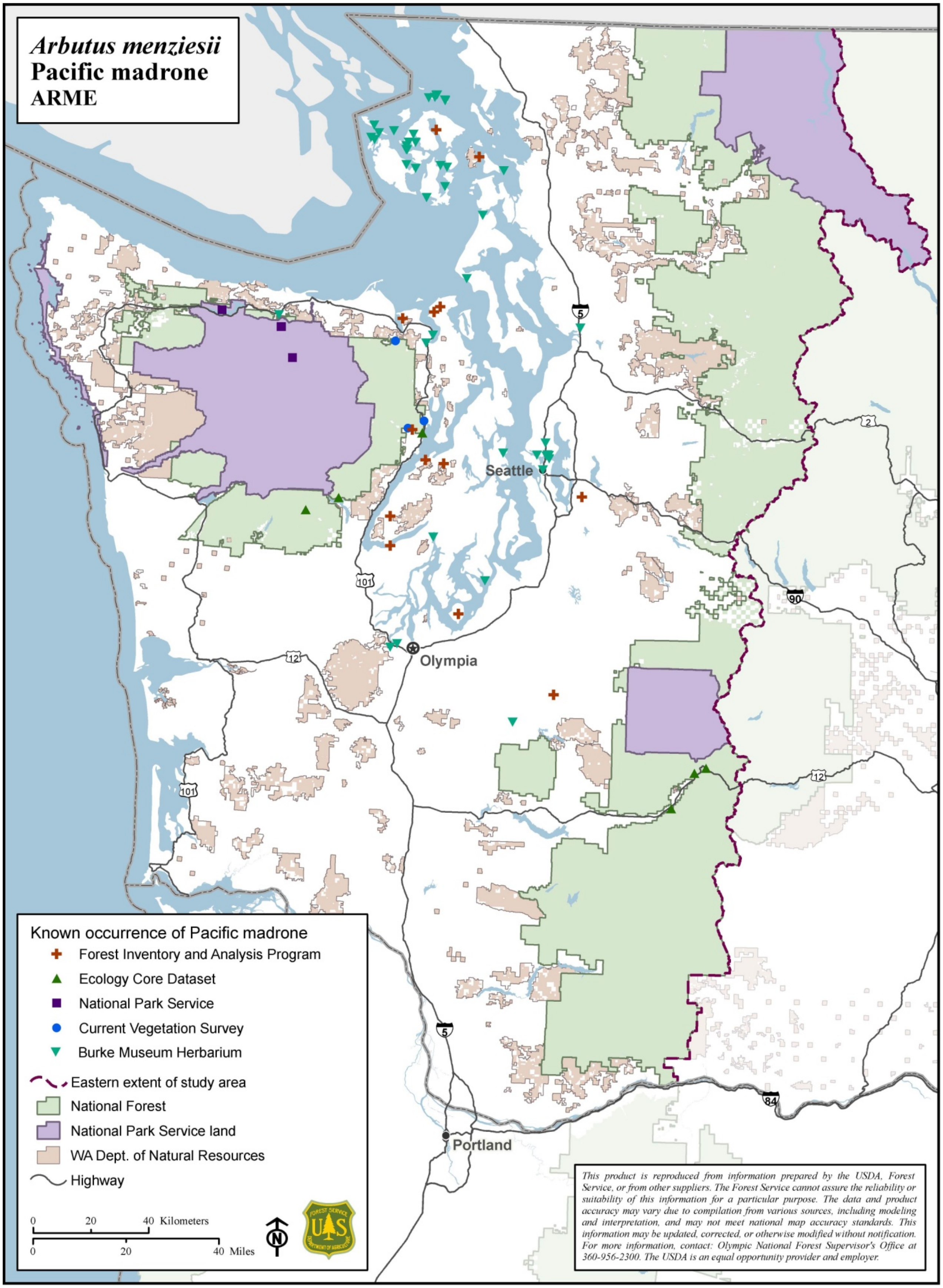

Arbutus menziesii
Pacific madrone
ARME

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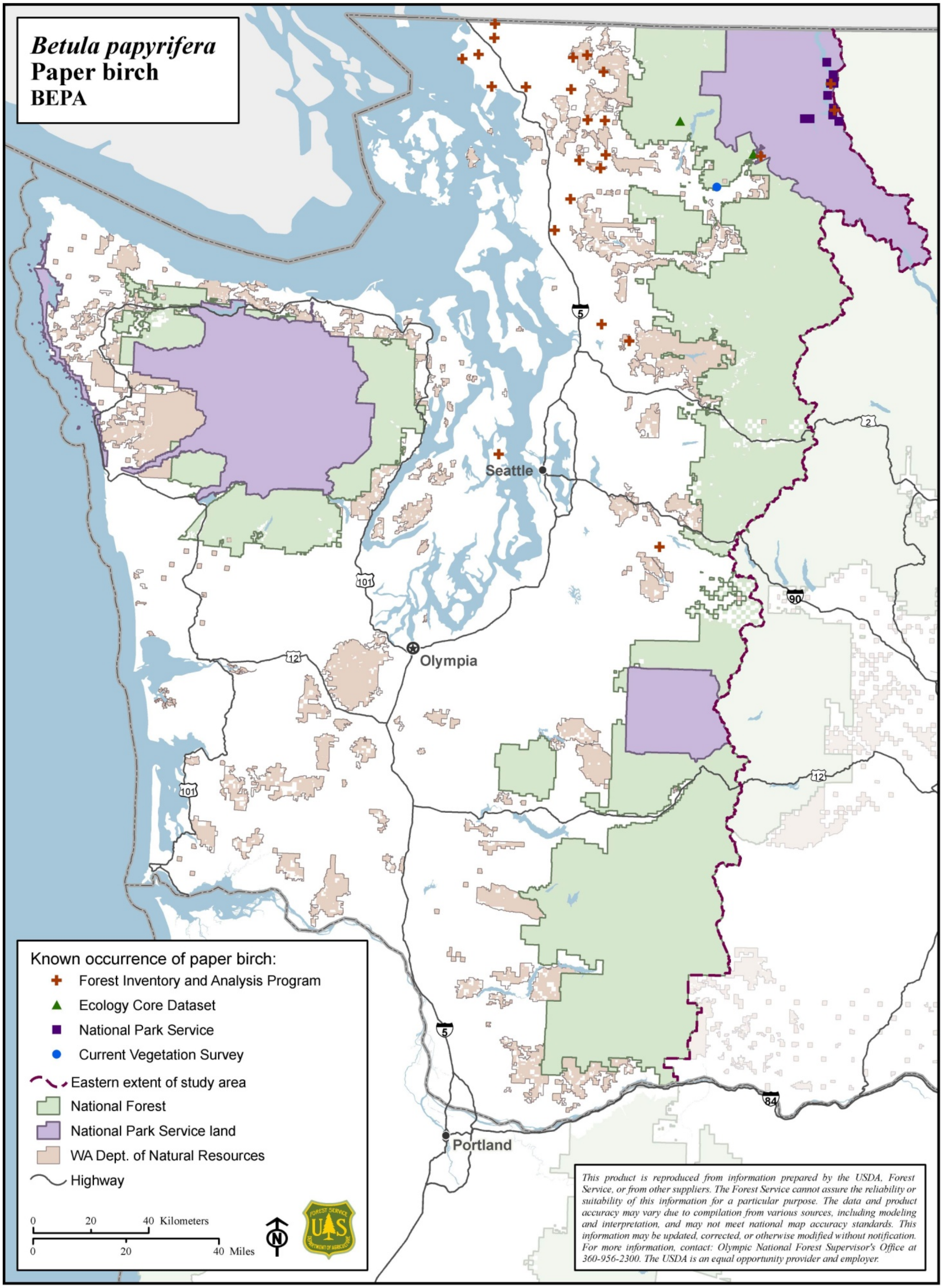

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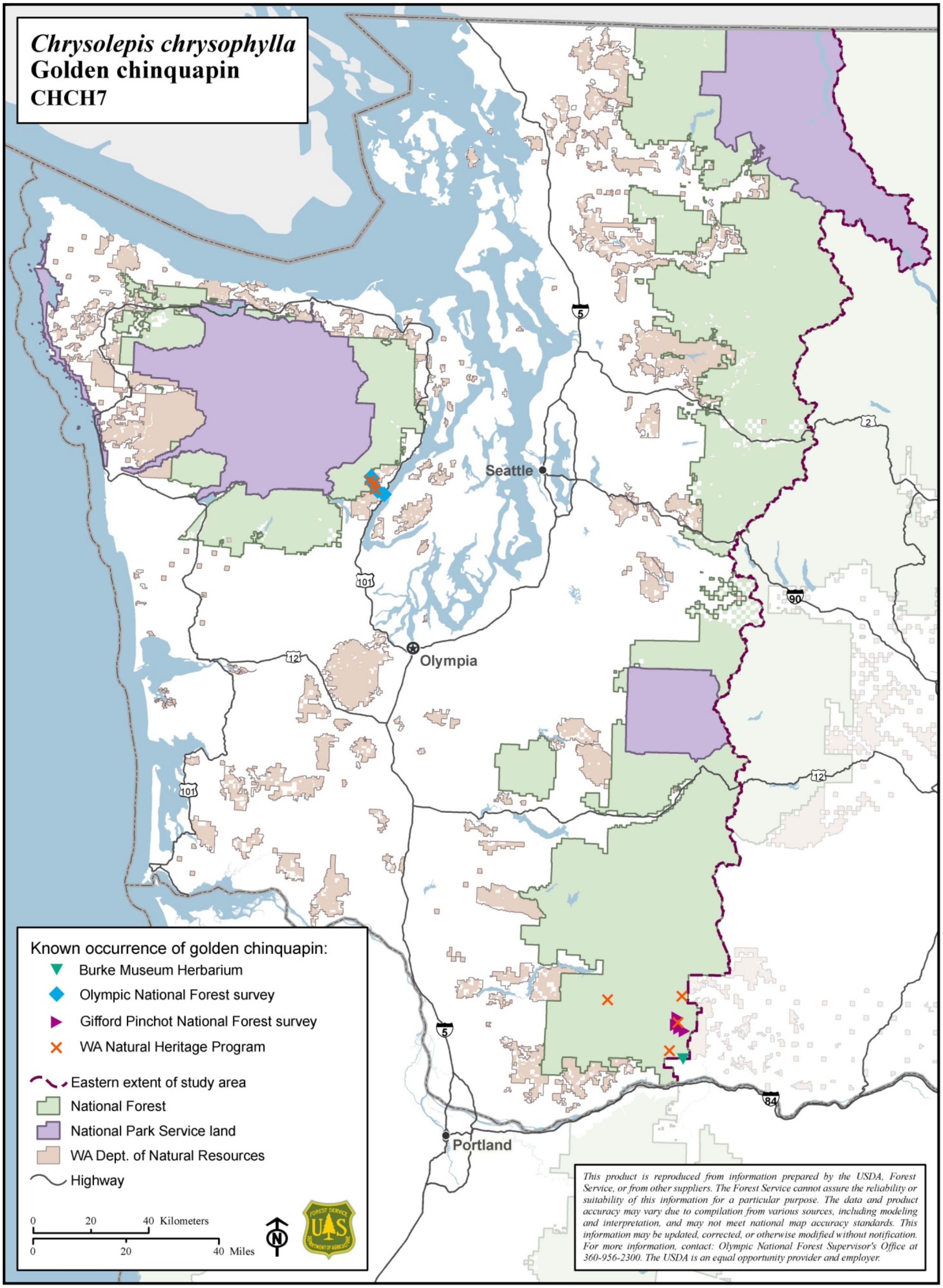

Chrysolepis chrysophylla
Golden chinquapin
CHCH7

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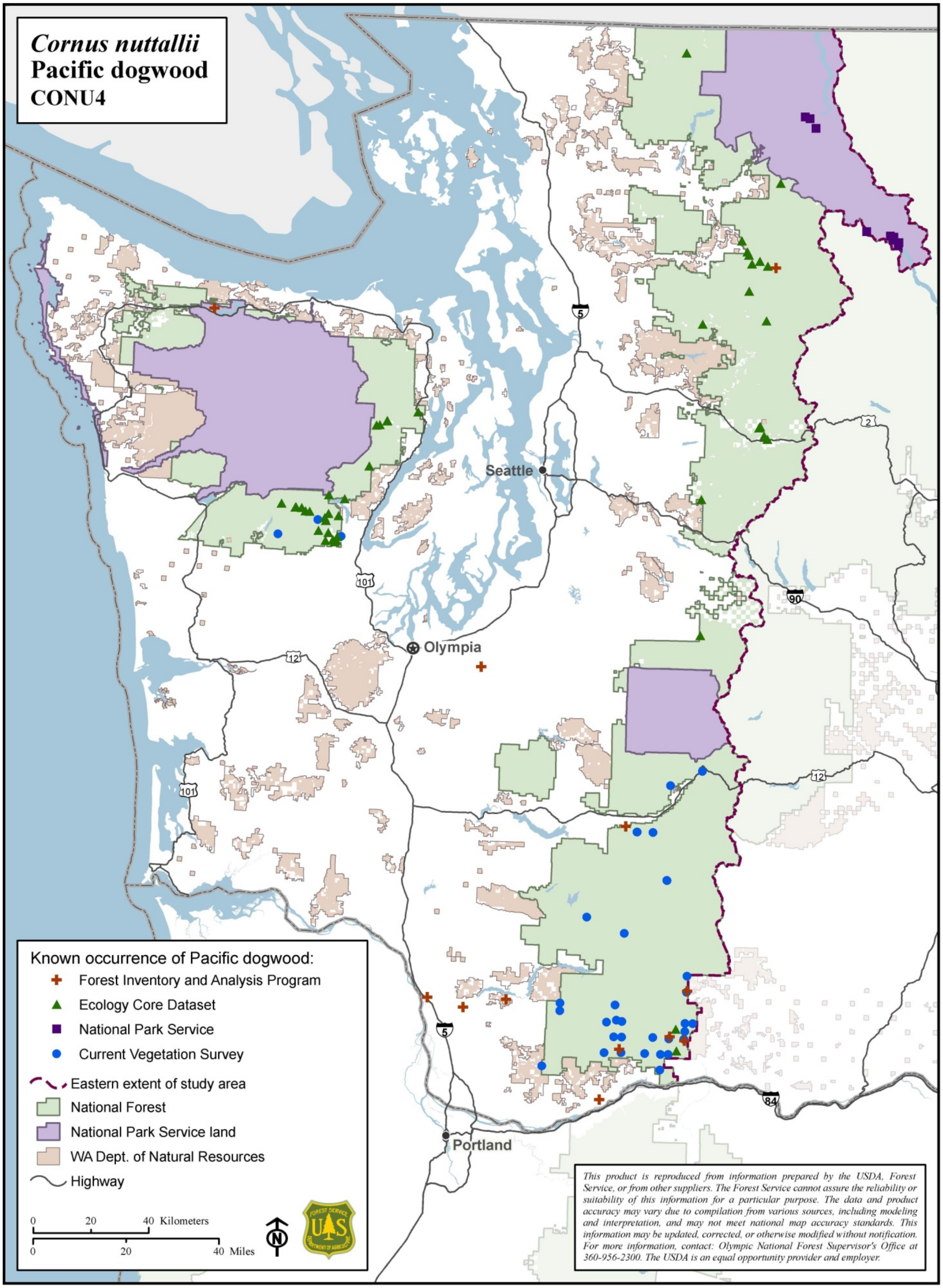

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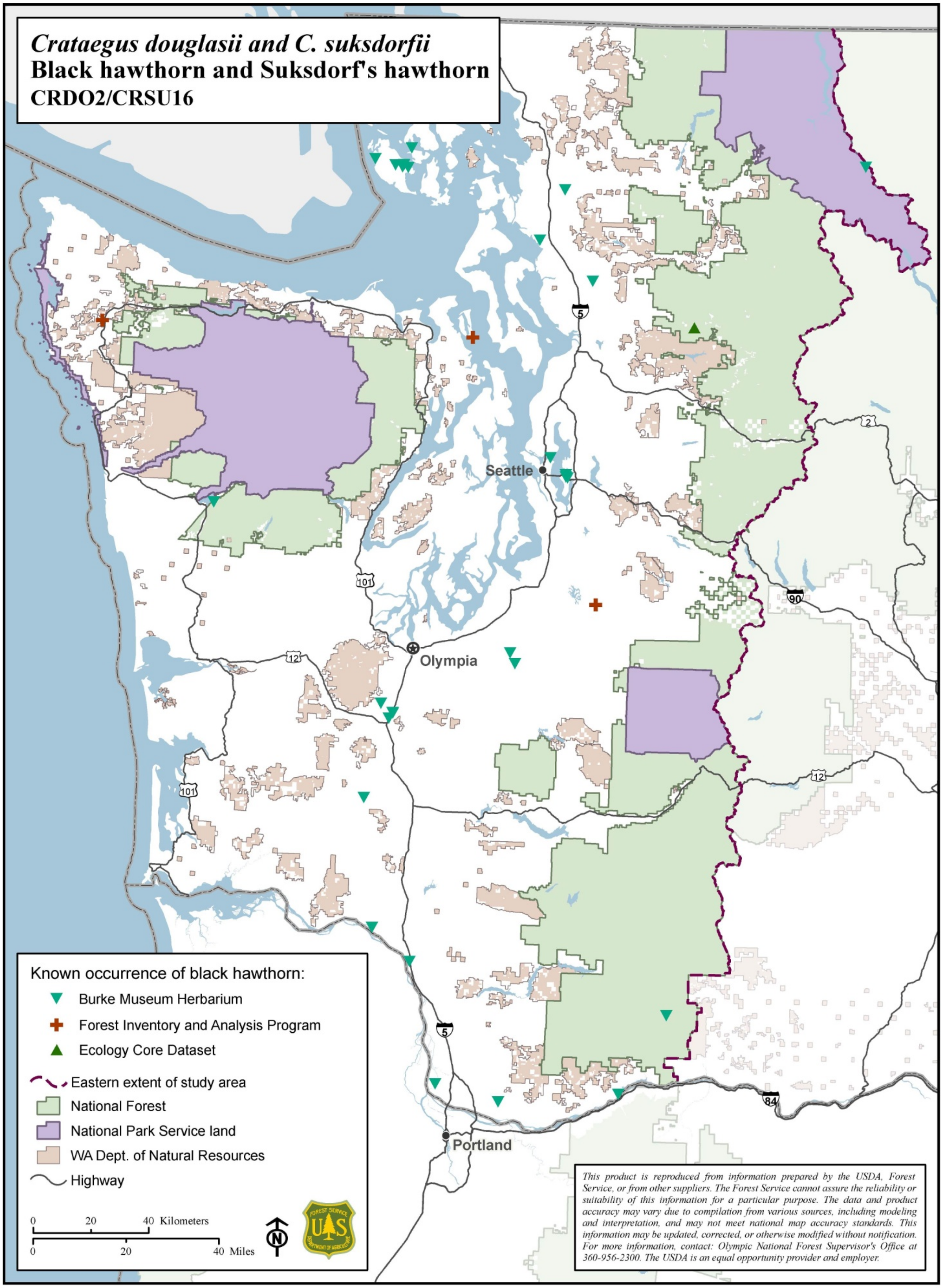
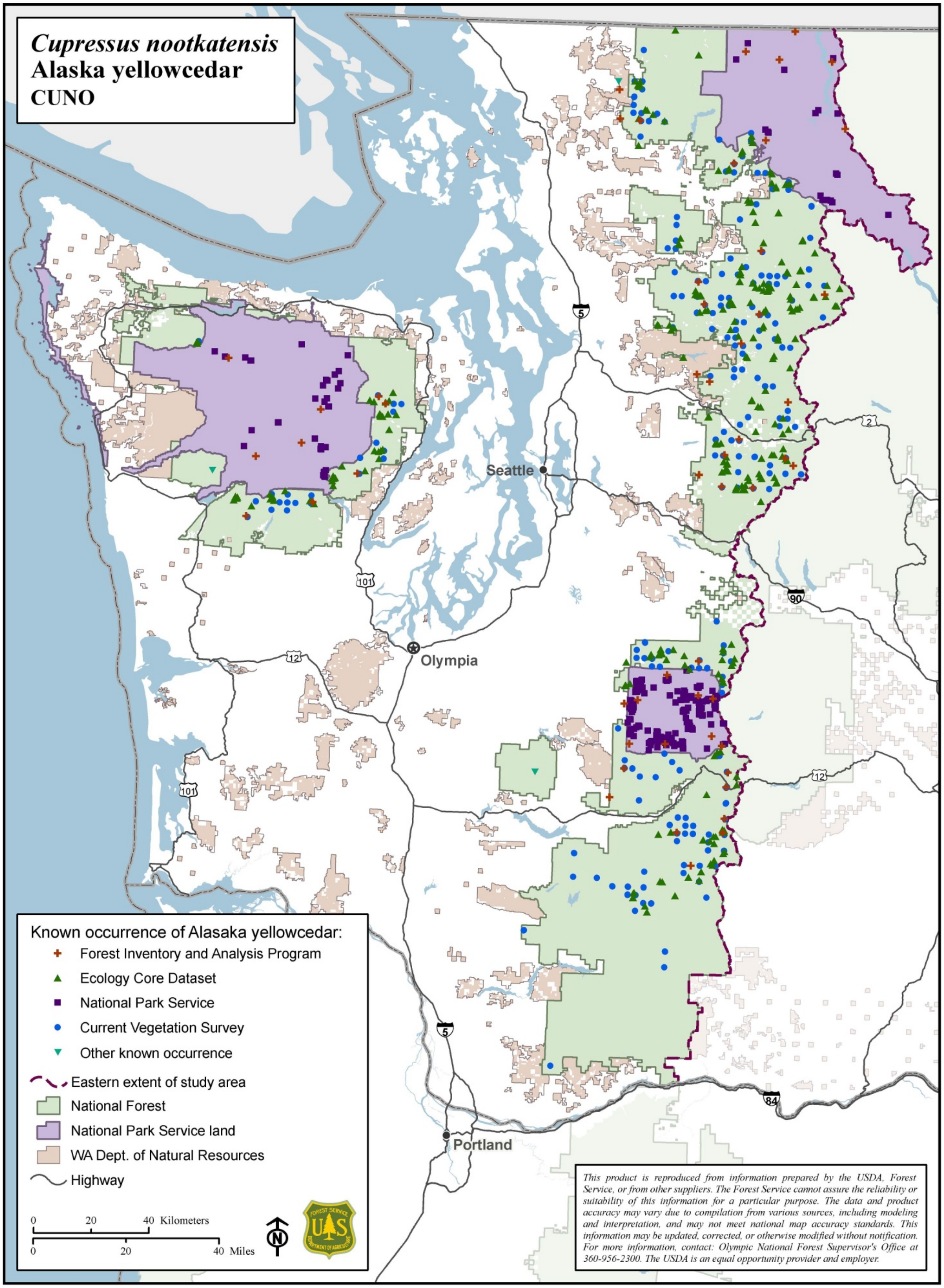


Crataegus douglasii and C. suksdorfii
Black hawthorn and Suksdorf's hawthorn
CRDO2/CRSU16



Cupressus nootkatensis
Alaska yellowcedar
CUNO

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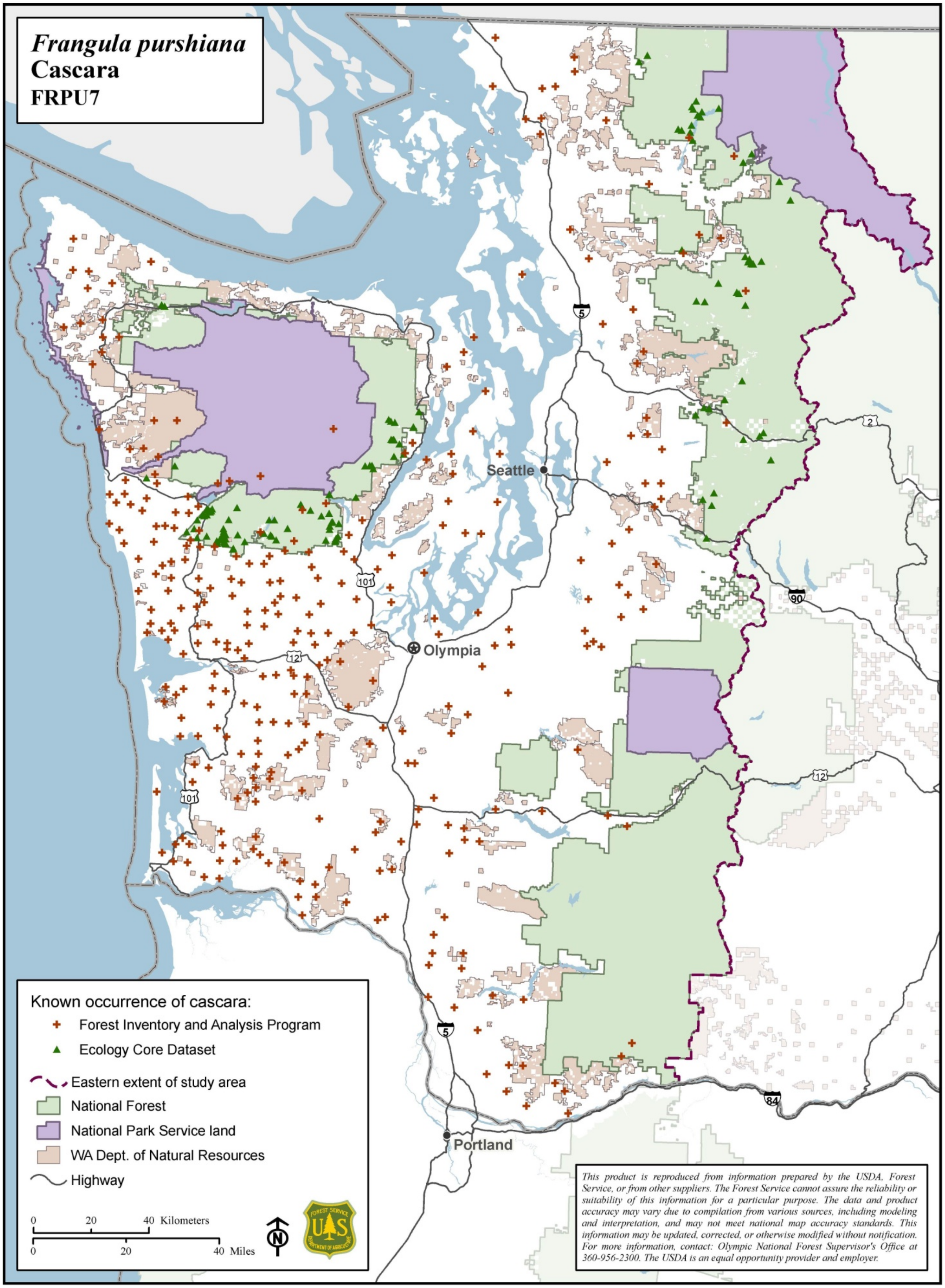

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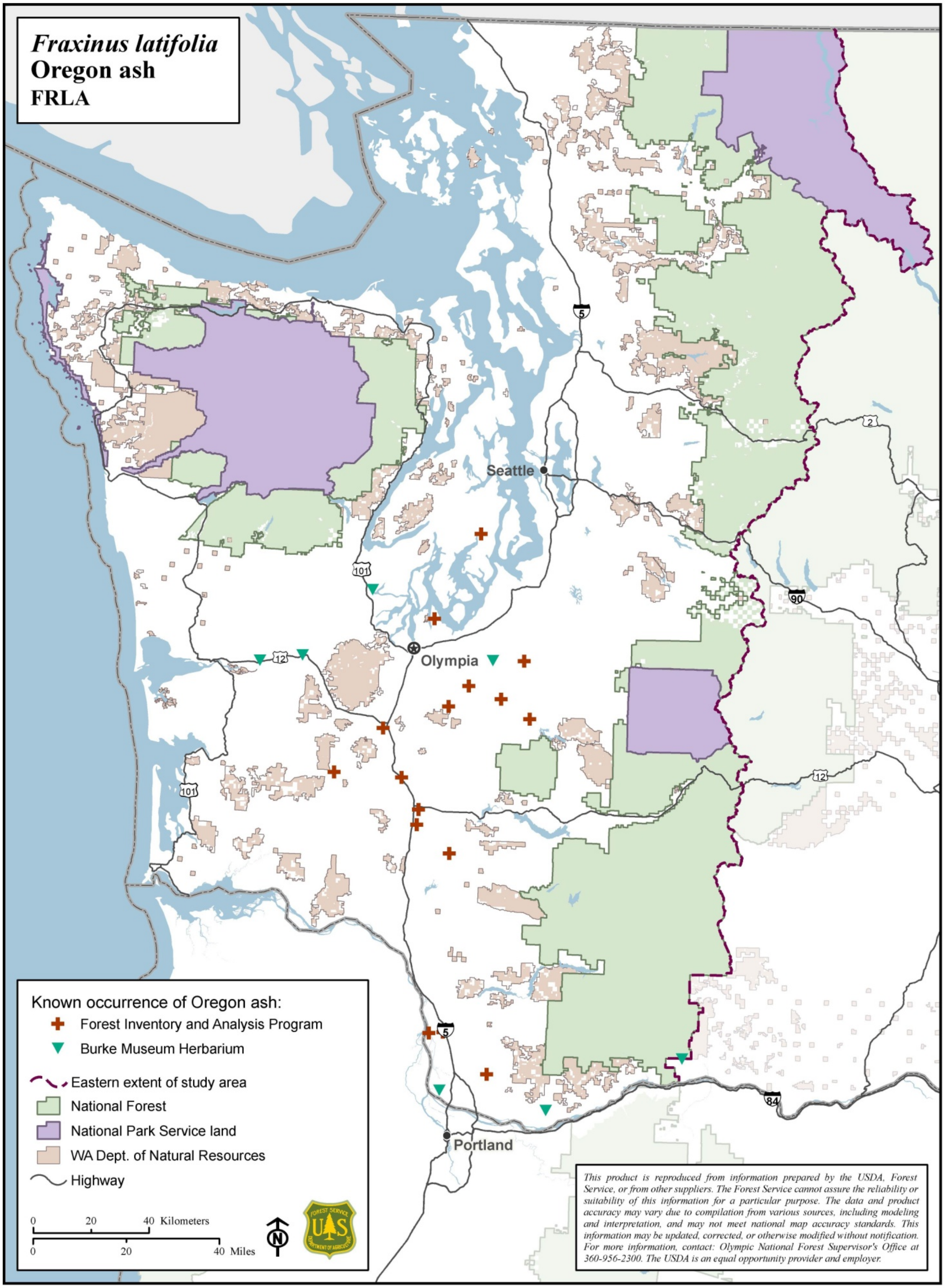

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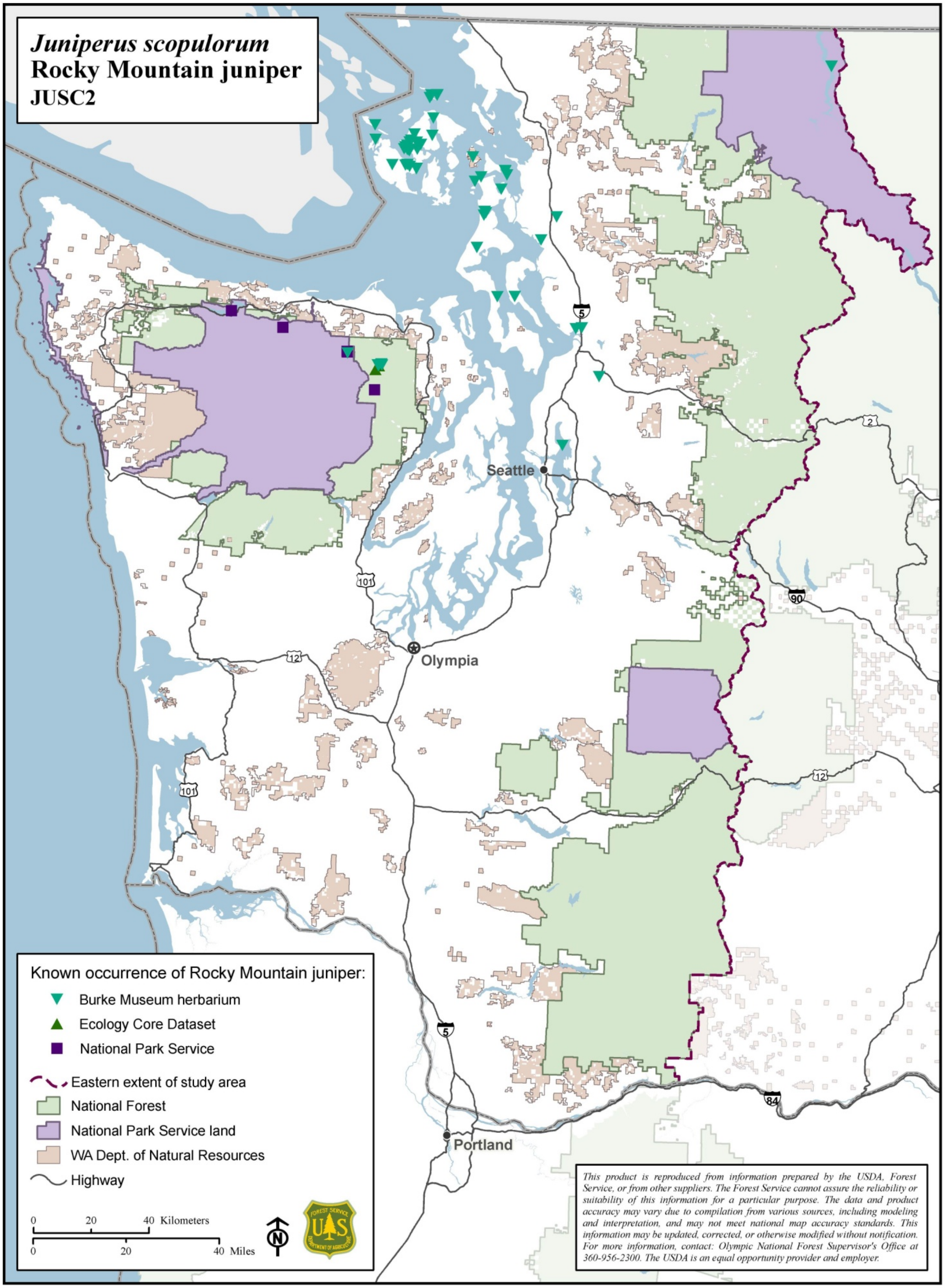
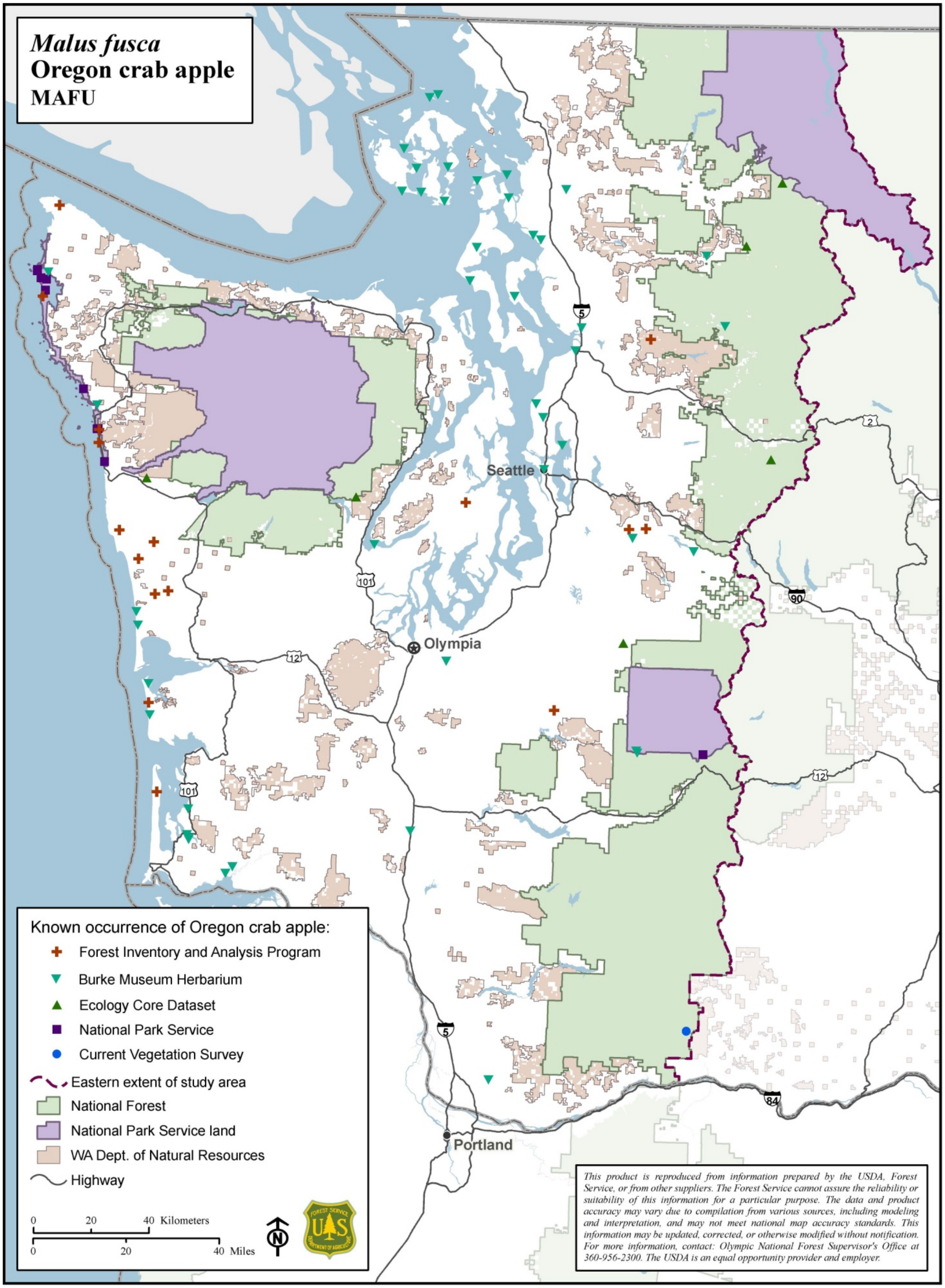
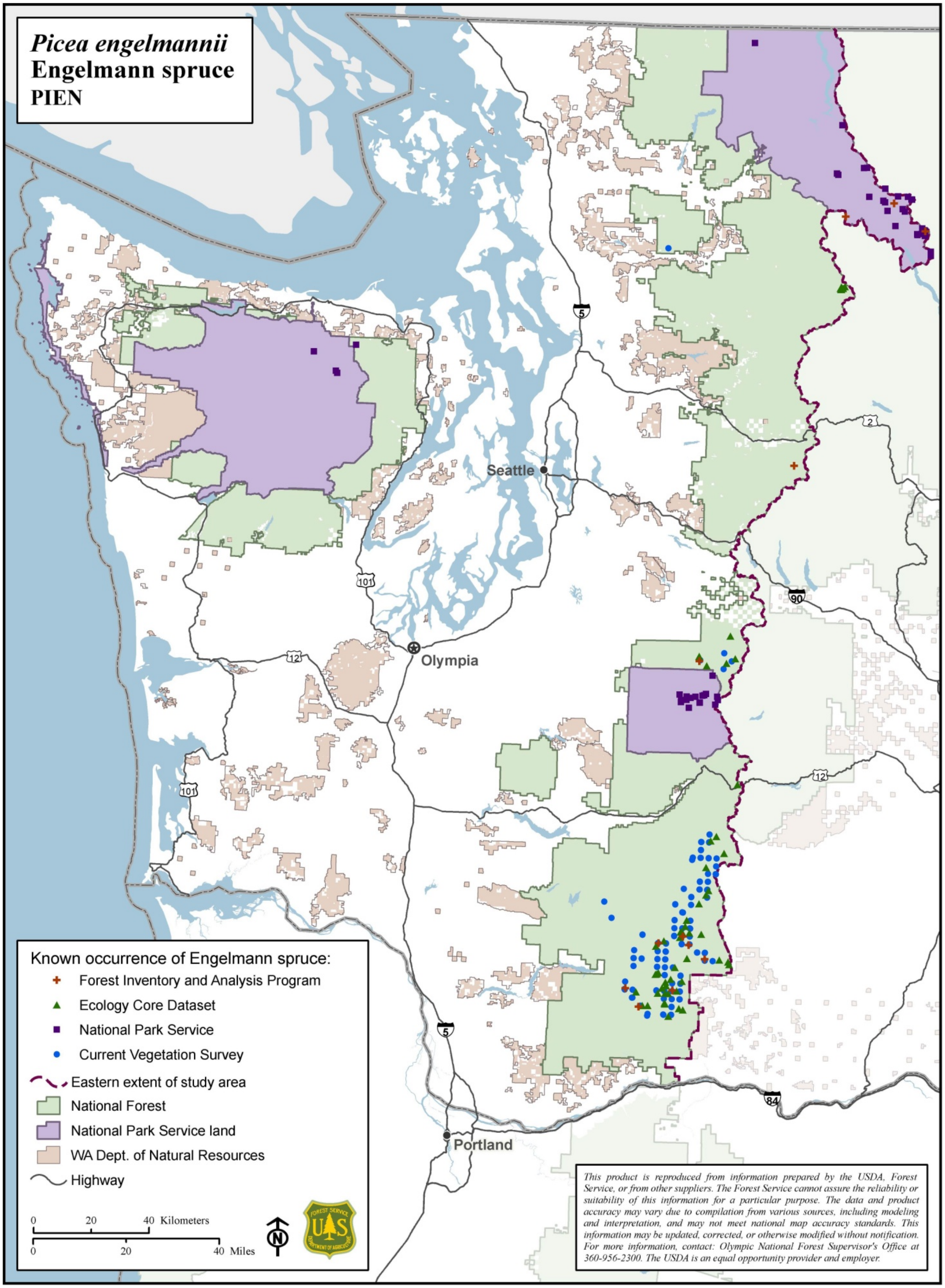


Juniperus scopulorum
Rocky Mountain juniper
JUSC2



Malus fusca
Oregon crab apple
MAFU



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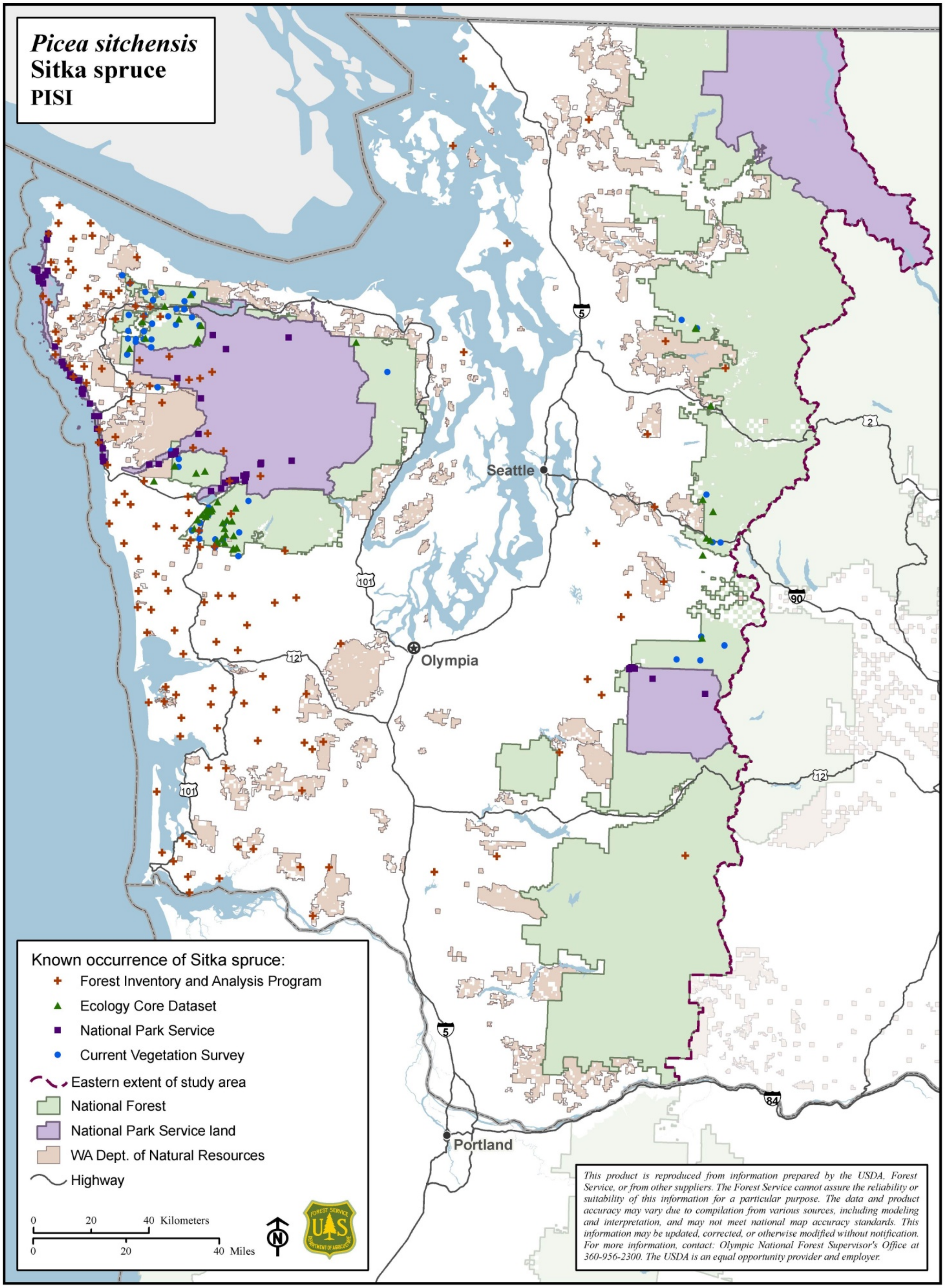
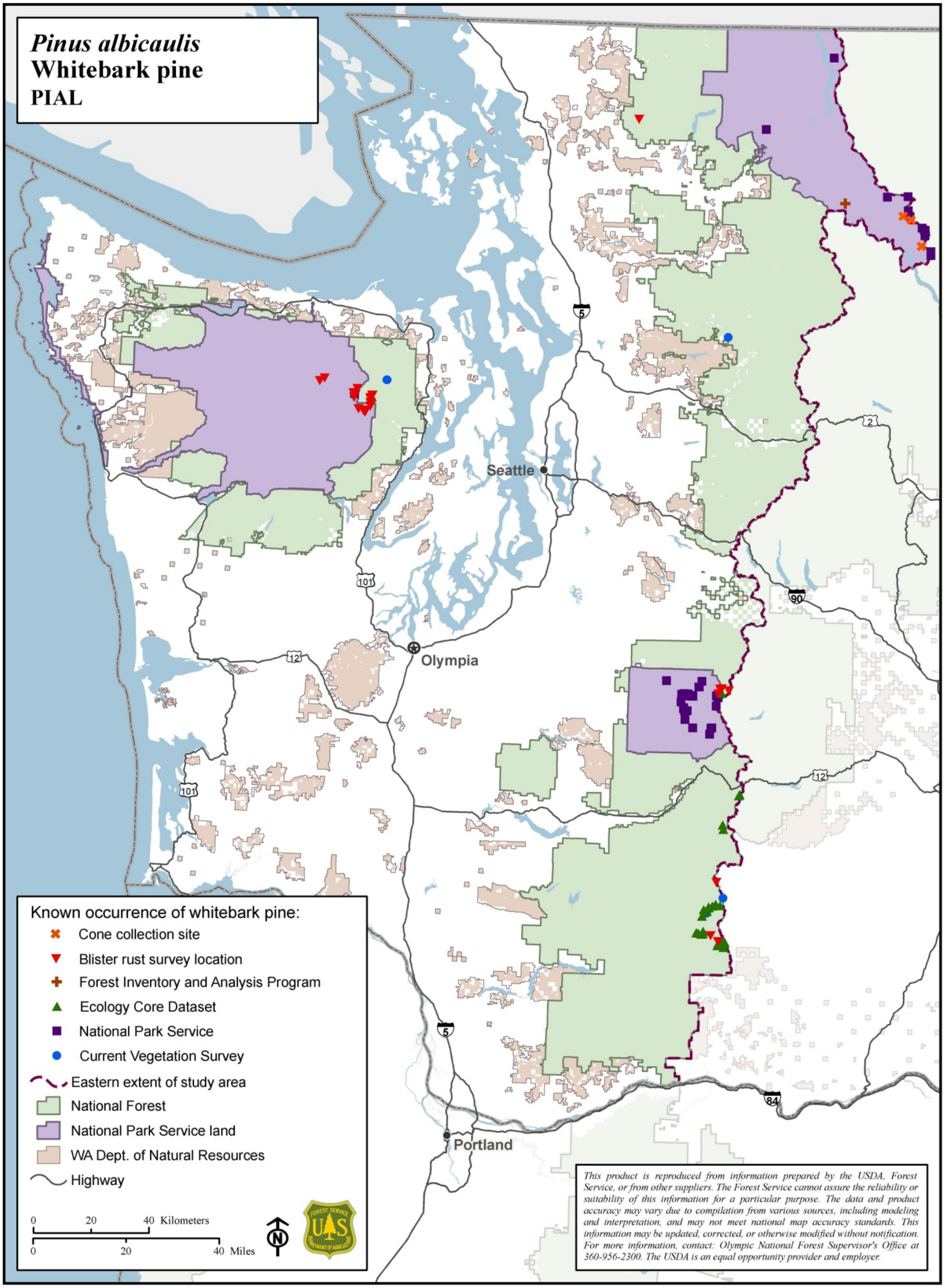

Picea sitchensis
Sitka spruce
PISI
Seattle
Olympia
Portland
5
101
12
2
90
84
Known occurrence of Sitka spruce:
+ Forest Inventory and Analysis Program
▲ Ecology Core Dataset
■ National Park Service
● Current Vegetation Survey
Eastern extent of study area
National Forest
National Park Service land
WA Dept. of Natural Resources
Highway
0 20 40 Kilometers
0 20 40 Miles
N



Pinus albicaulis
Whitebark pine
PIAL

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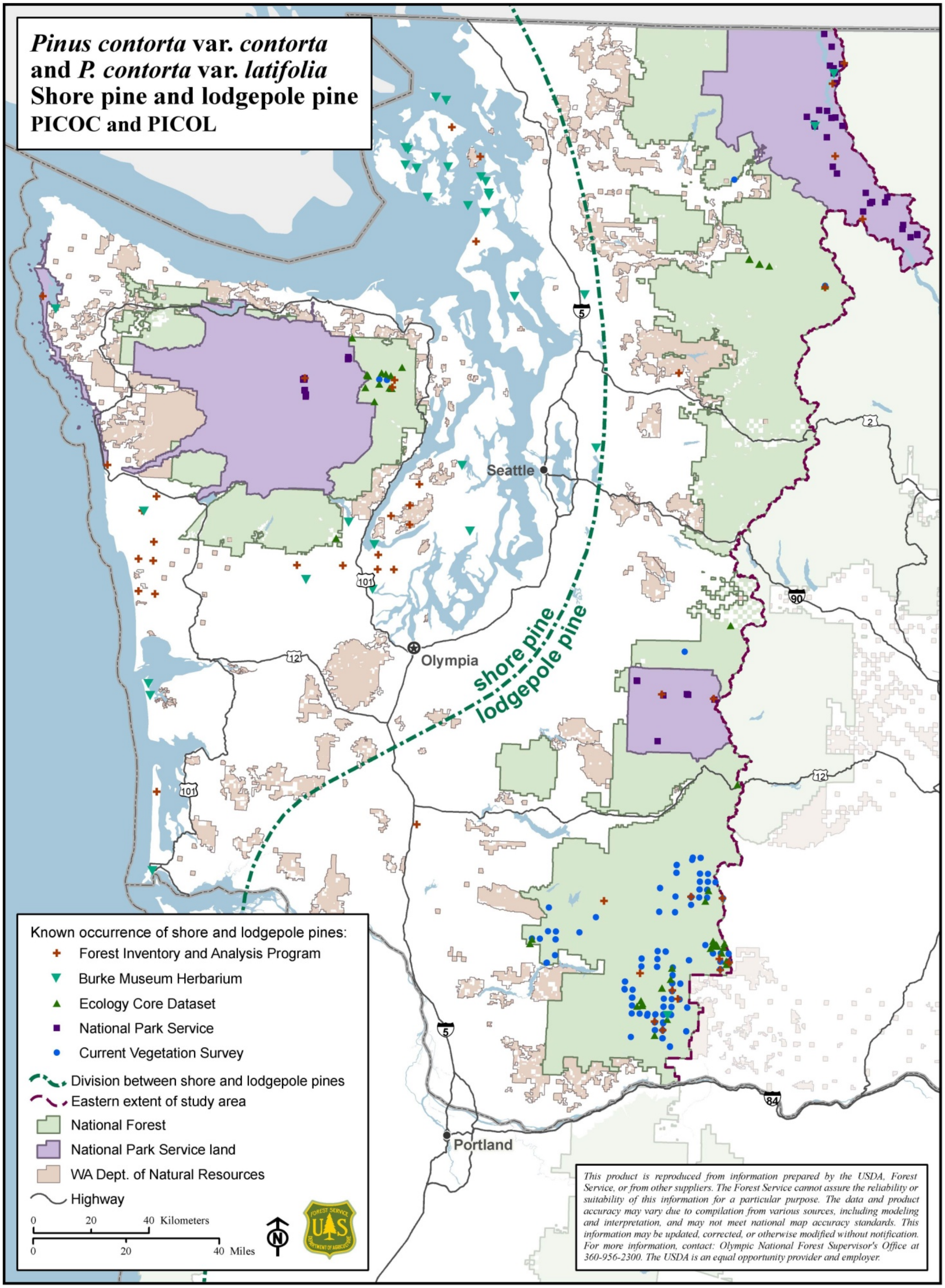
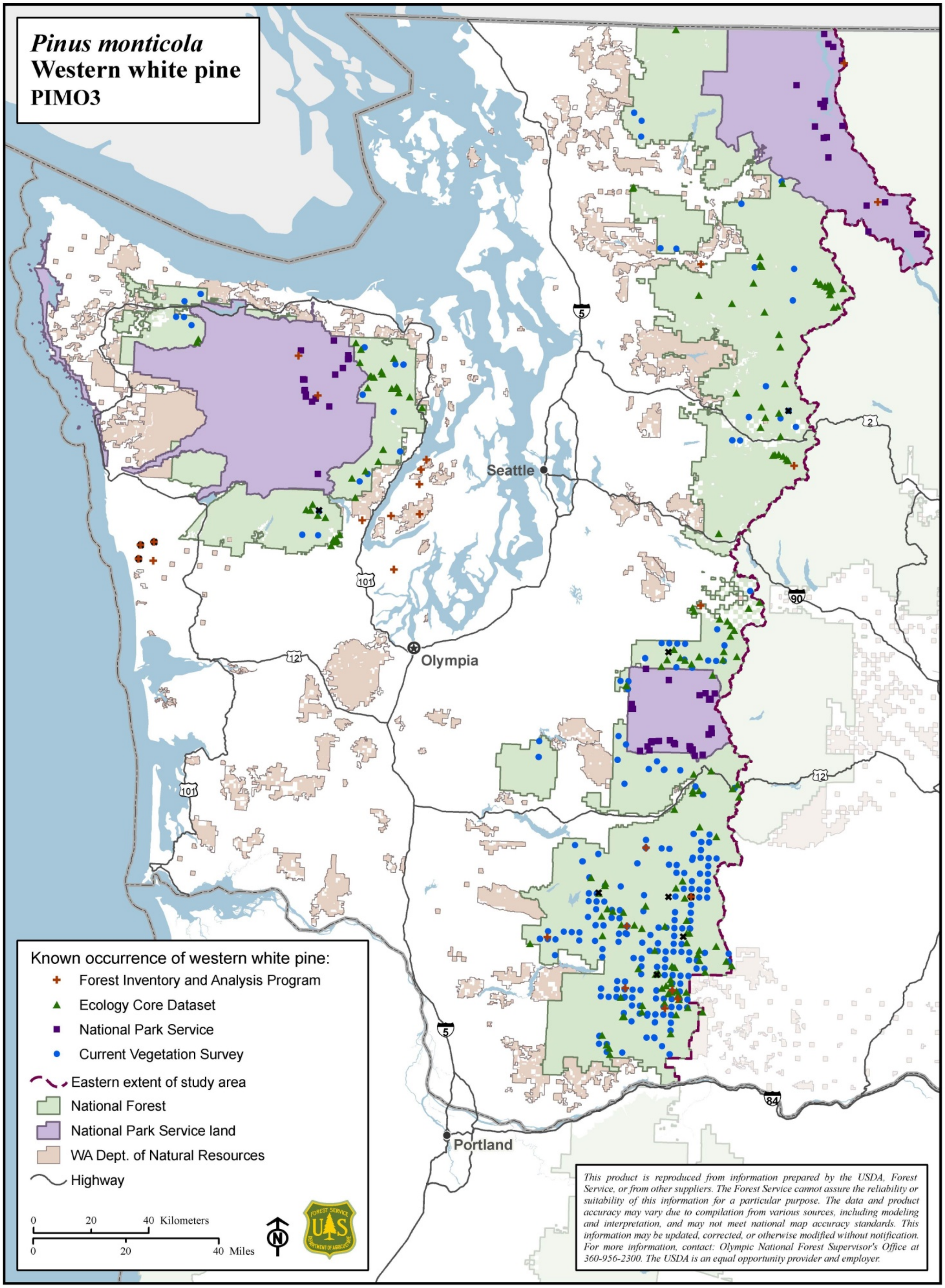

Pinus contorta var. *contorta*
and *P. contorta* var. *latifolia*
Shore pine and lodgepole pine
PICOC and PICOL
Seattle
Olympia
Portland
shore pine
lodgepole pine
5
101
12
2
90
84
Known occurrence of shore and lodgepole pines:
Forest Inventory and Analysis Program
Burke Museum Herbarium
Ecology Core Dataset
National Park Service
Current Vegetation Survey
Division between shore and lodgepole pines
Eastern extent of study area
National Forest
National Park Service land
WA Dept. of Natural Resources
Highway
0
20
40 Kilometers
0
20
40 Miles
N



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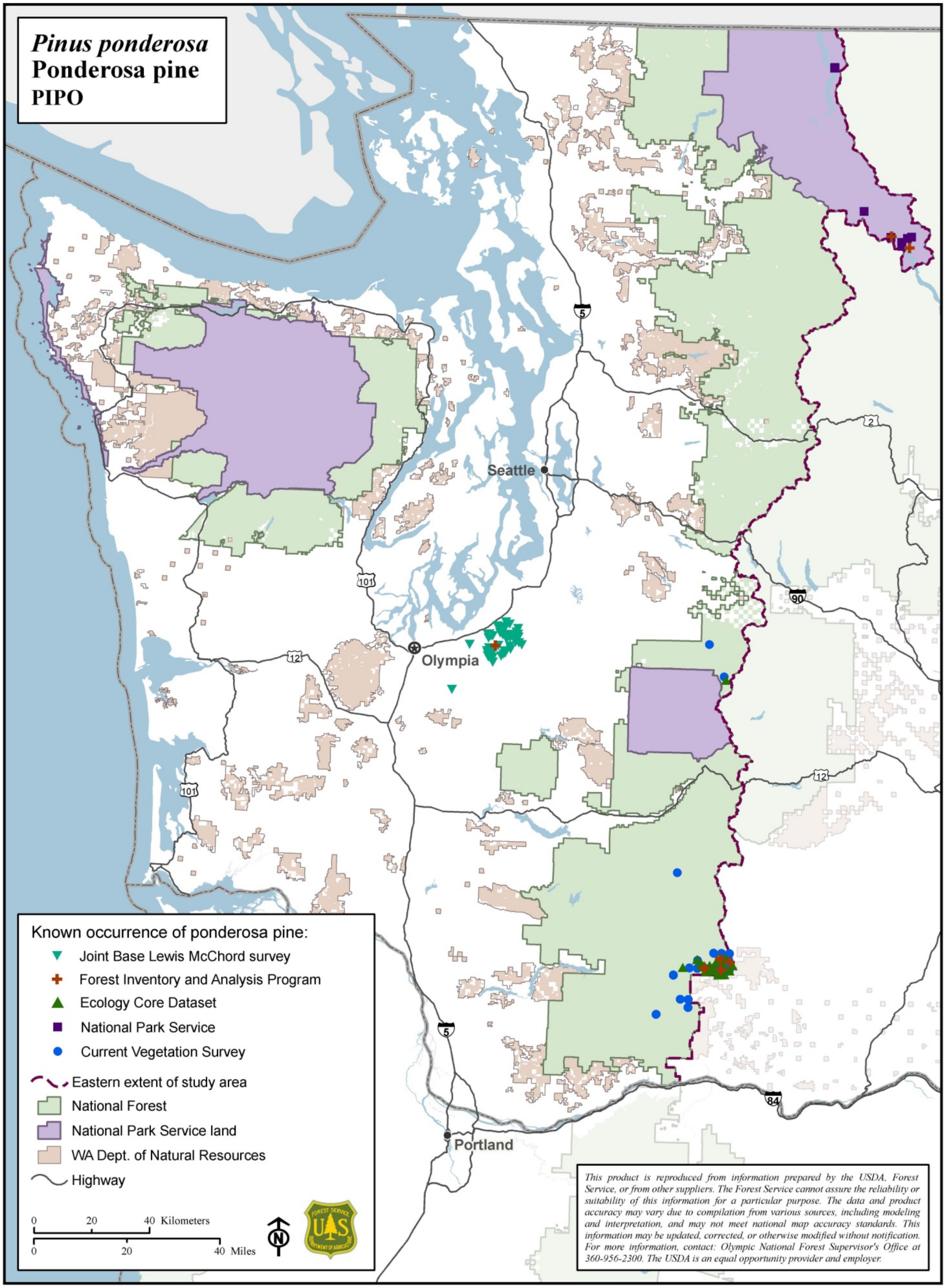
Pinus ponderosa
Ponderosa pine
PIPO
Seattle
Olympia
Portland
5
101
12
2
90
84
Known occurrence of ponderosa pine:
▼ Joint Base Lewis McChord survey
✚ Forest Inventory and Analysis Program
▲ Ecology Core Dataset
■ National Park Service
● Current Vegetation Survey
Eastern extent of study area
National Forest
National Park Service land
WA Dept. of Natural Resources
Highway
0 20 40 Kilometers
0 20 40 Miles
N
FOREST SERVICE
U S
DEPARTMENT OF AGRICULTURE
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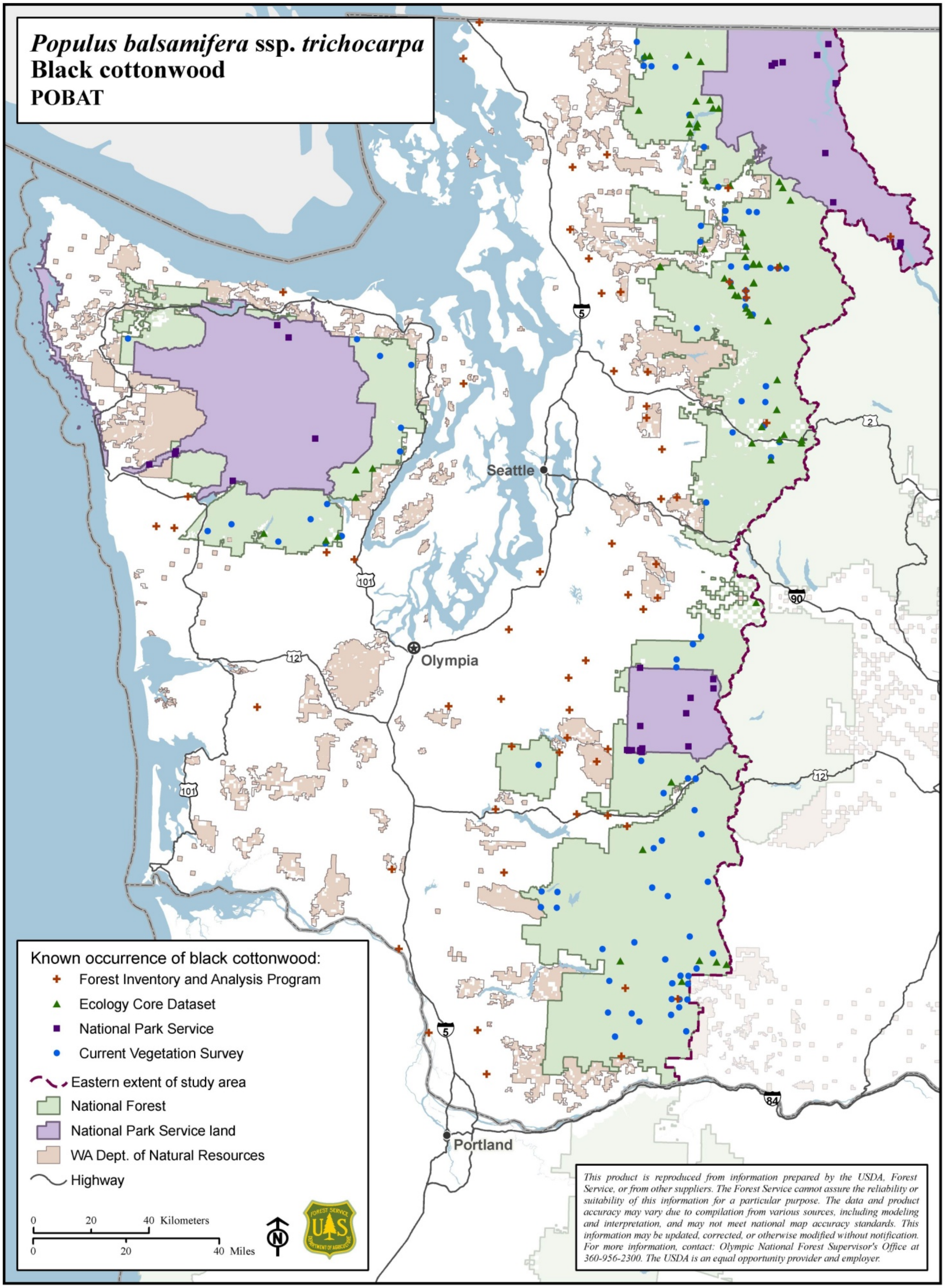

Populus balsamifera* ssp. *trichocarpa
Black cottonwood
POBAT

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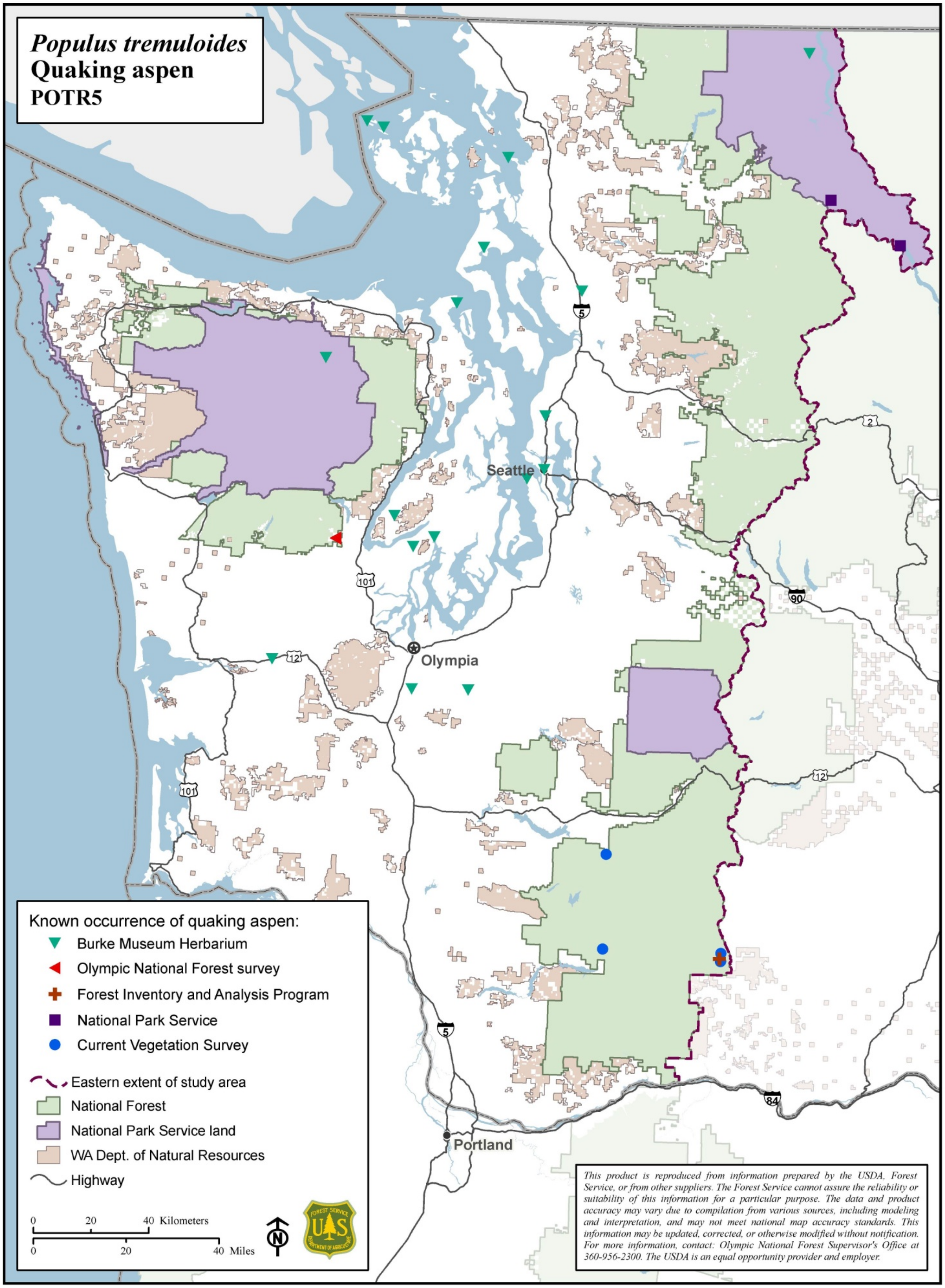

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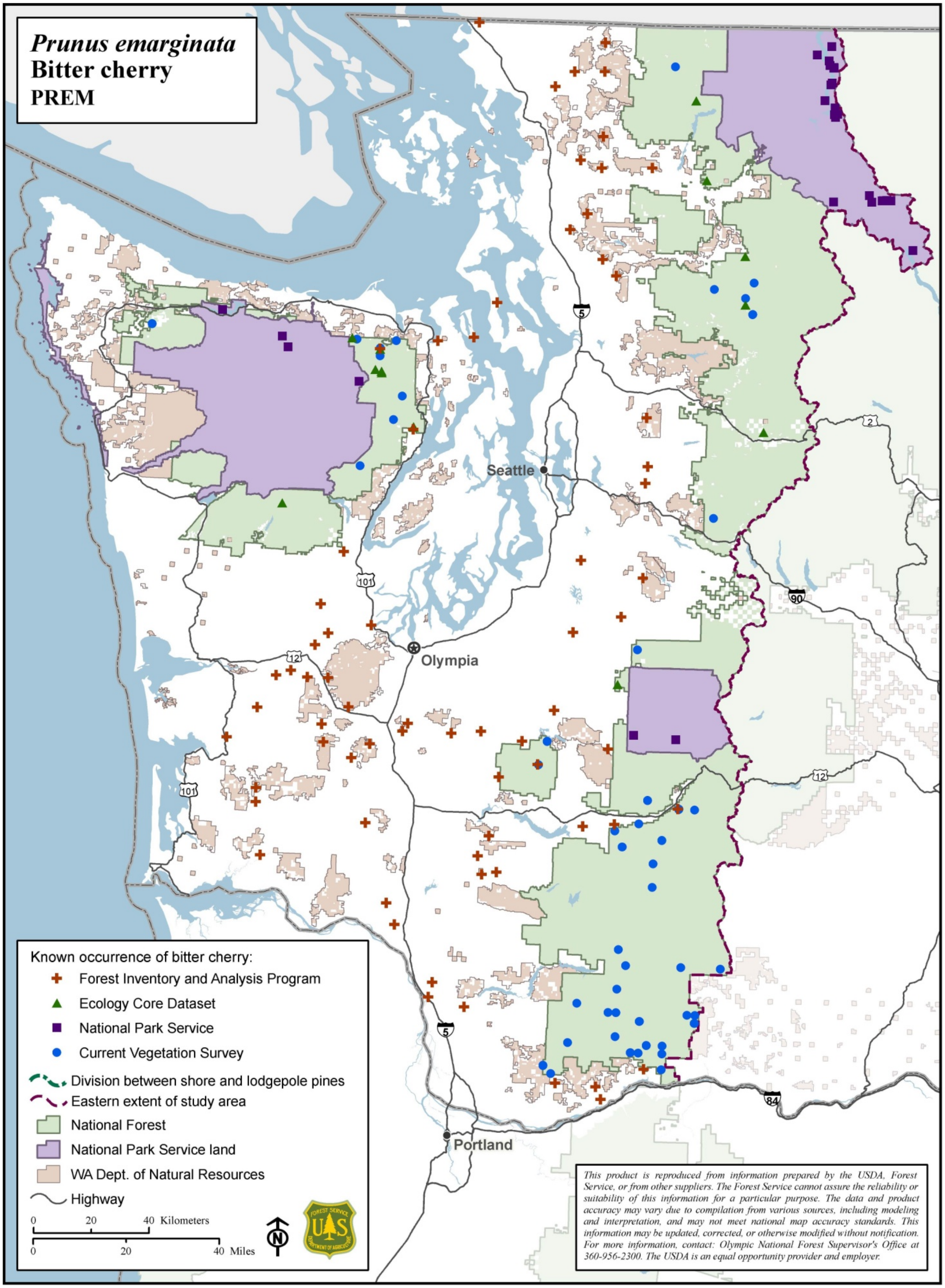

Prunus emarginata
Bitter cherry
PREM

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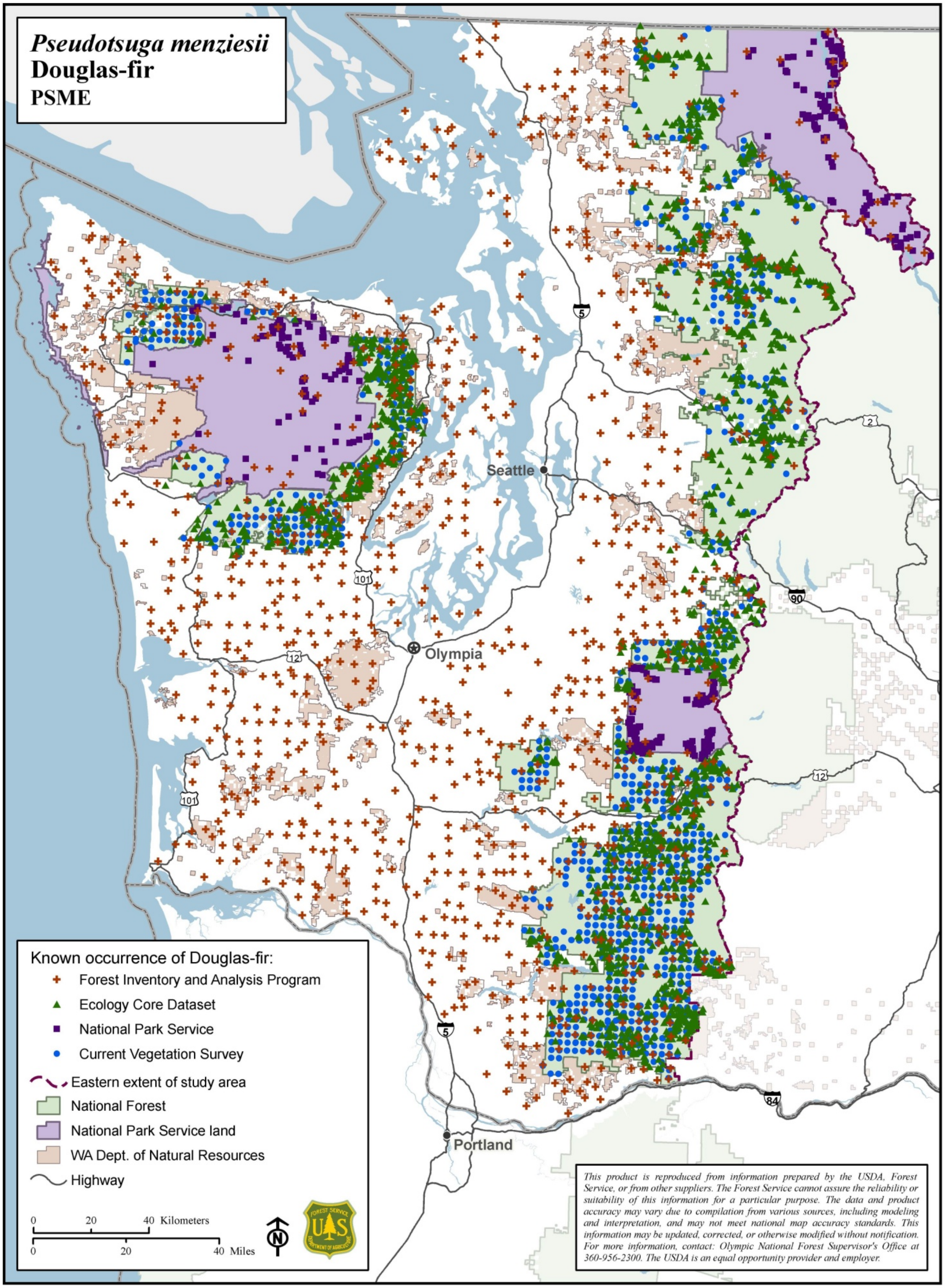
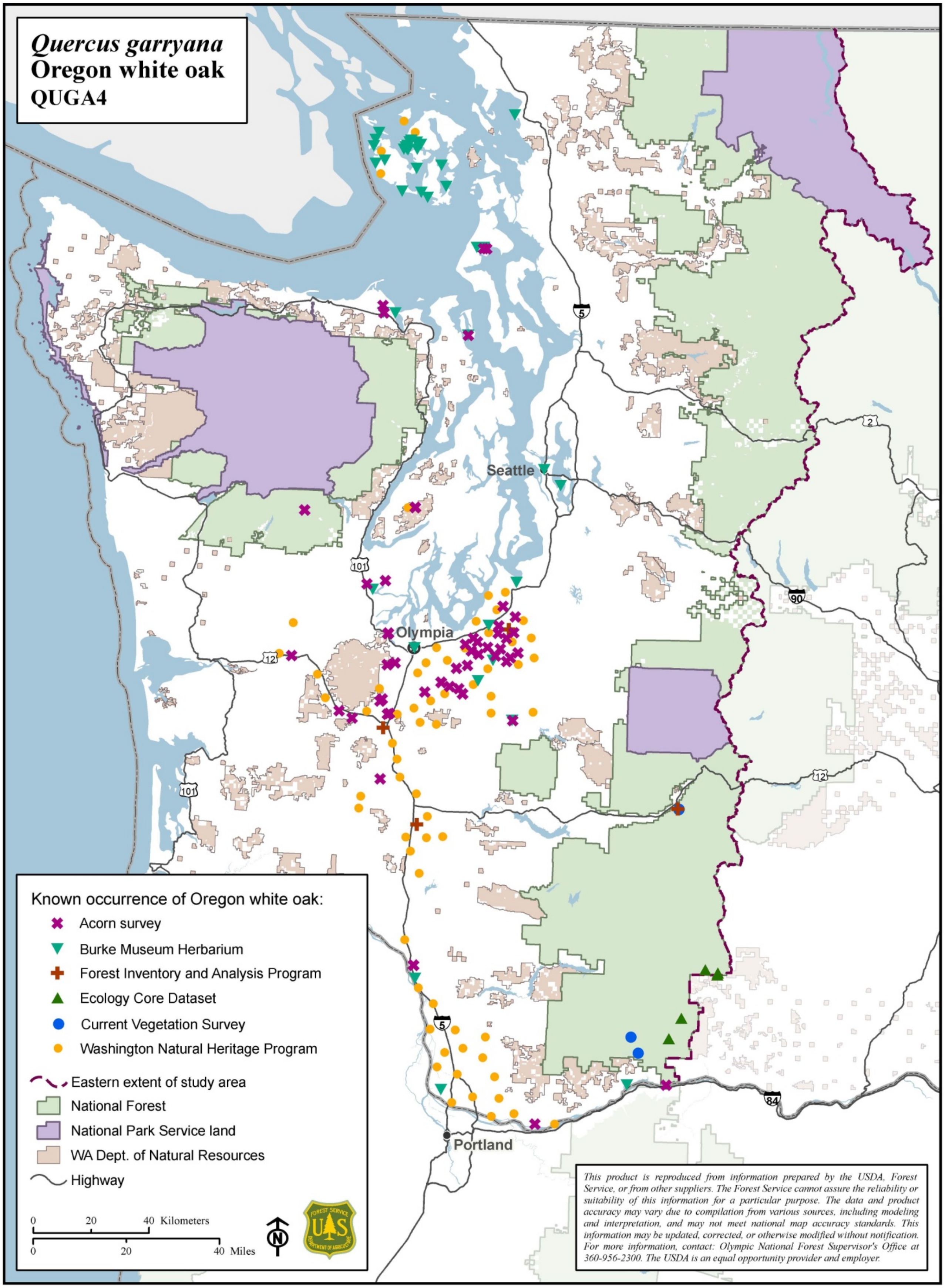
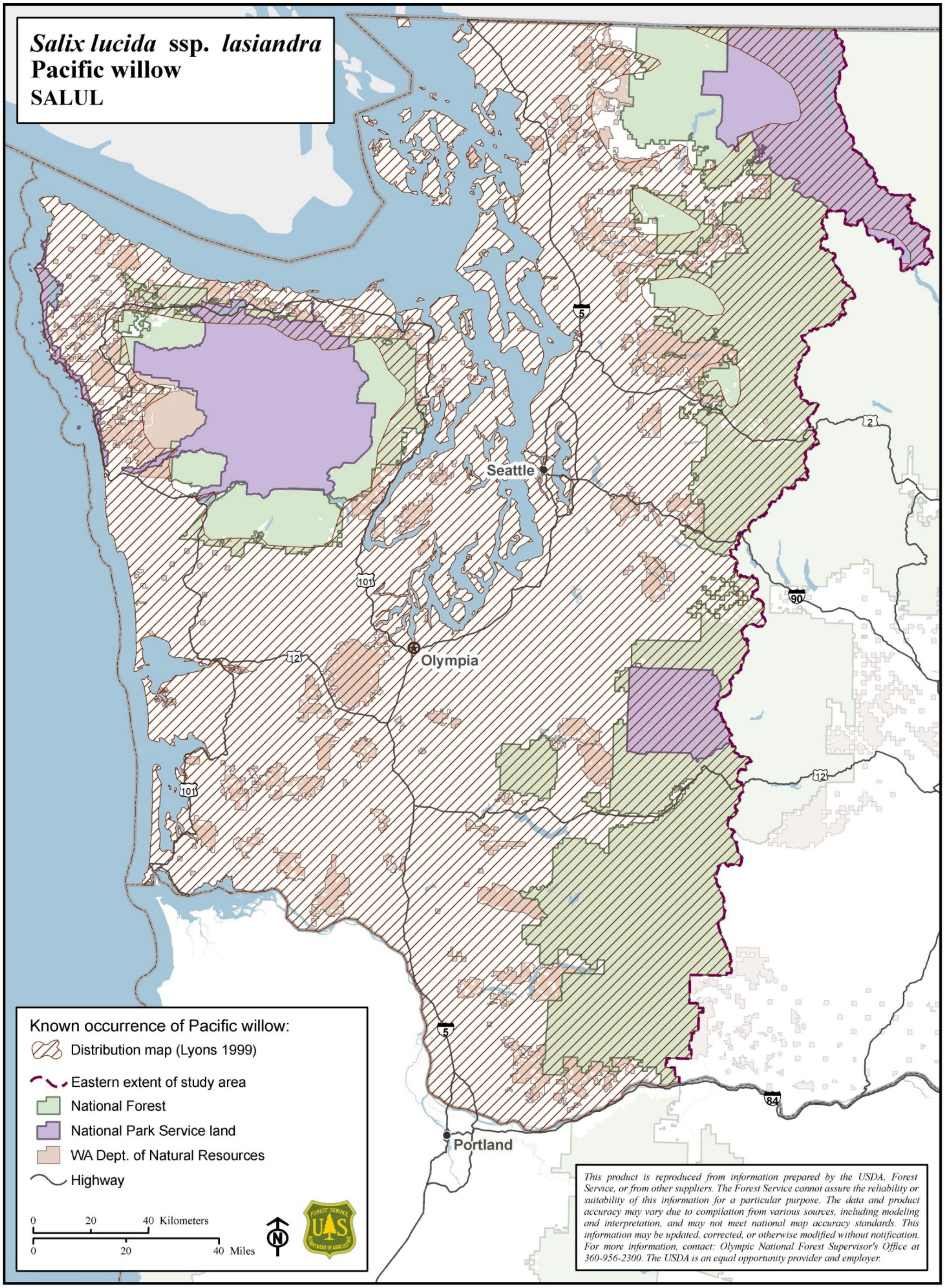

Pseudotsuga menziesii
Douglas-fir
PSME
Seattle
Olympia
Portland
5
101
12
2
90
84
Known occurrence of Douglas-fir:
Forest Inventory and Analysis Program
Ecology Core Dataset
National Park Service
Current Vegetation Survey
Eastern extent of study area
National Forest
National Park Service land
WA Dept. of Natural Resources
Highway
0 20 40 Kilometers
0 20 40 Miles
N



Quercus garryana
Oregon white oak
QUGA4



Salix lucida* ssp. *lasiandra
Pacific willow
SALUL

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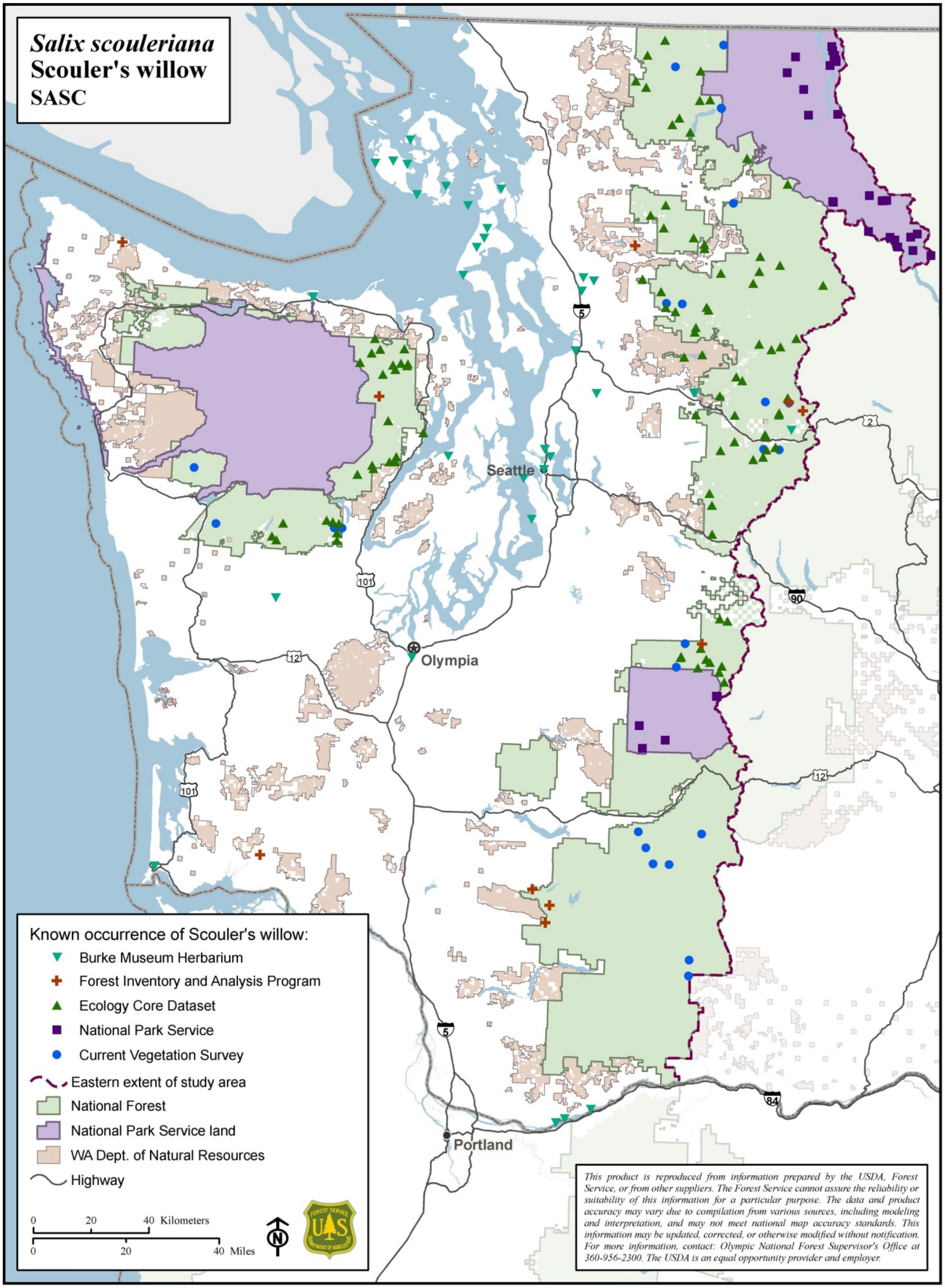
Salix scouleriana
Scouler's willow
SASC
Seattle
Olympia
Portland
5
101
12
90
2
84
Known occurrence of Scouler's willow:
Burke Museum Herbarium
Forest Inventory and Analysis Program
Ecology Core Dataset
National Park Service
Current Vegetation Survey
Eastern extent of study area
National Forest
National Park Service land
WA Dept. of Natural Resources
Highway
0 20 40 Kilometers
0 20 40 Miles
N
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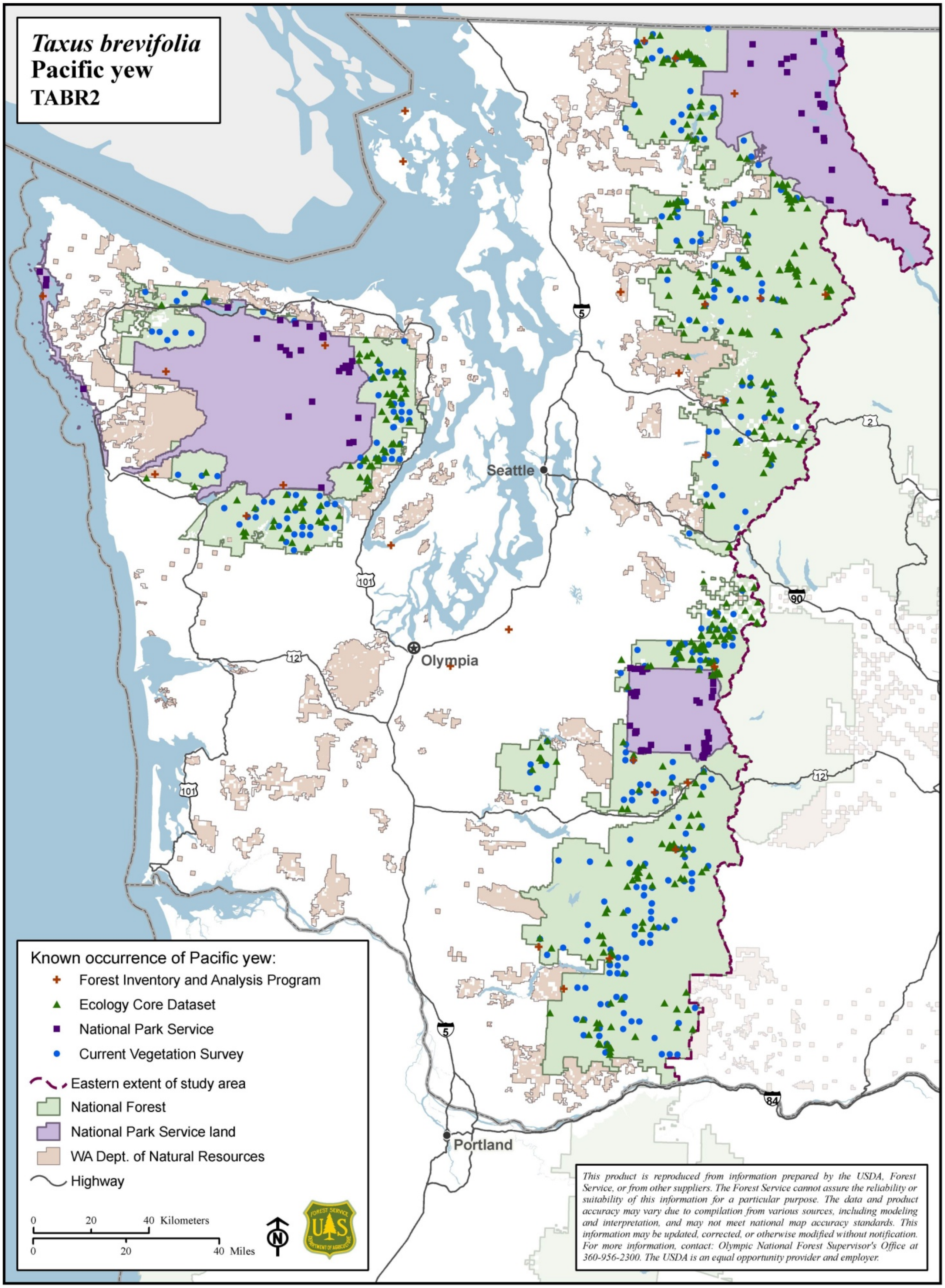

Taxus brevifolia
Pacific yew
TABR2

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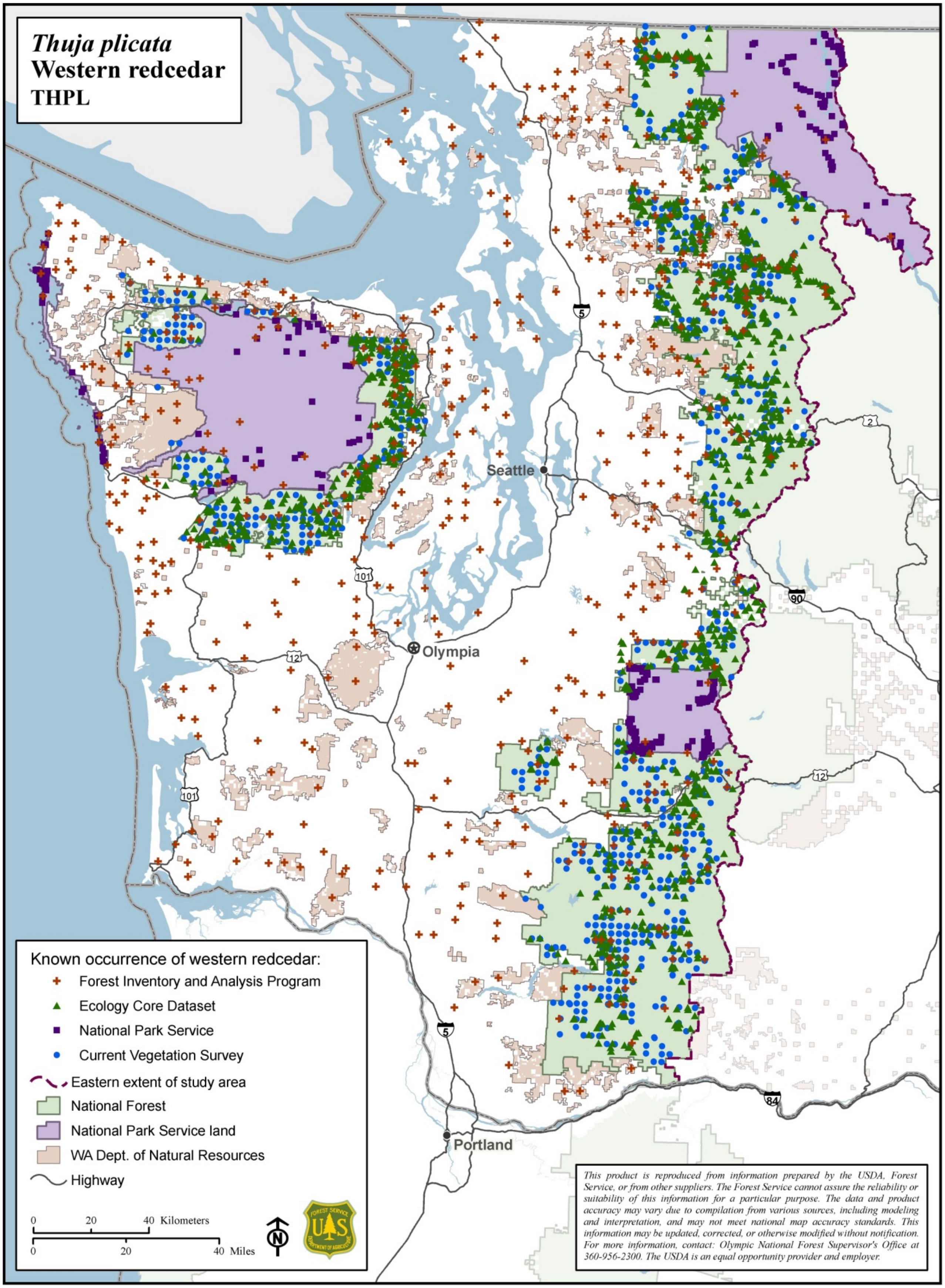

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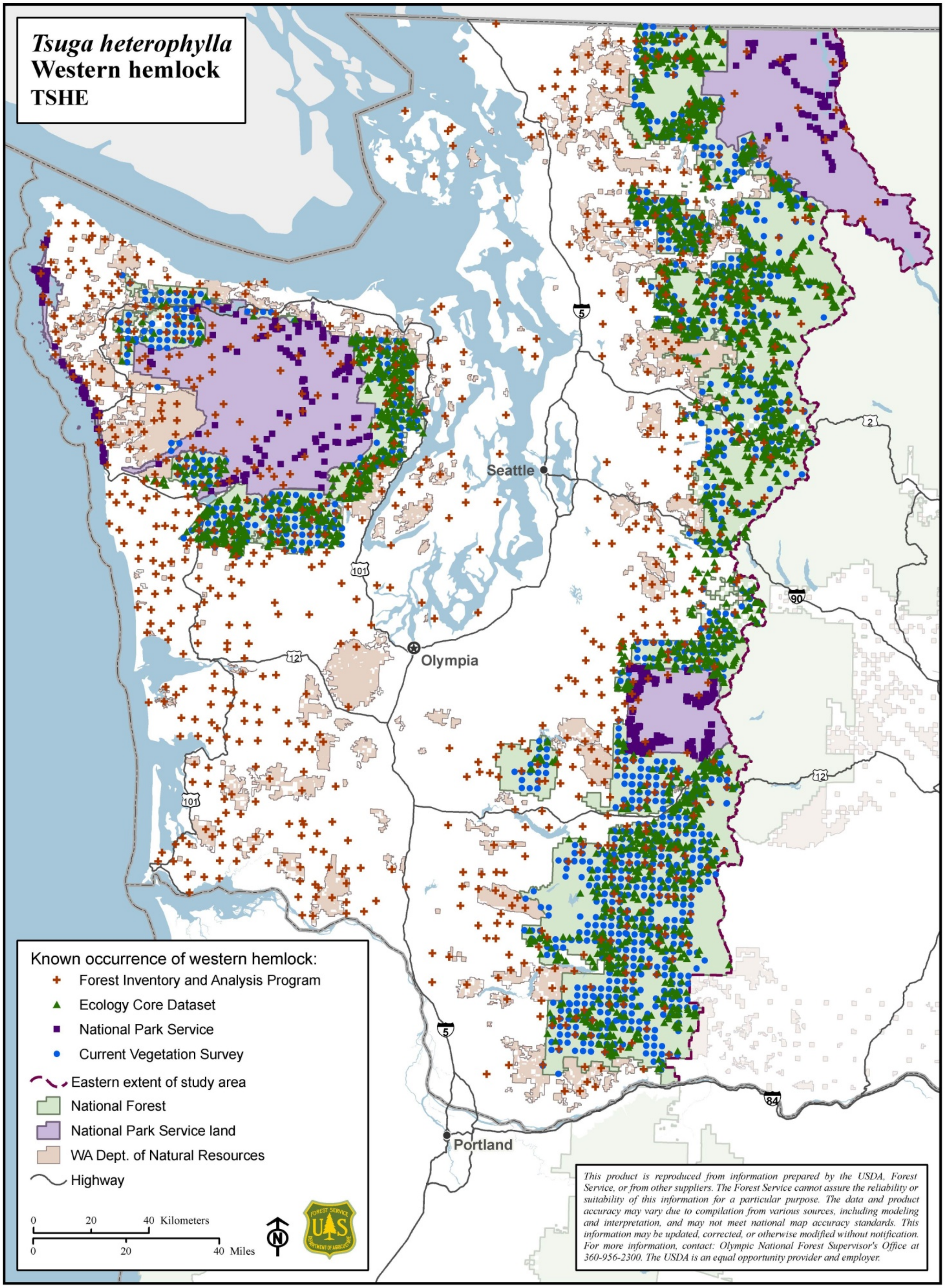

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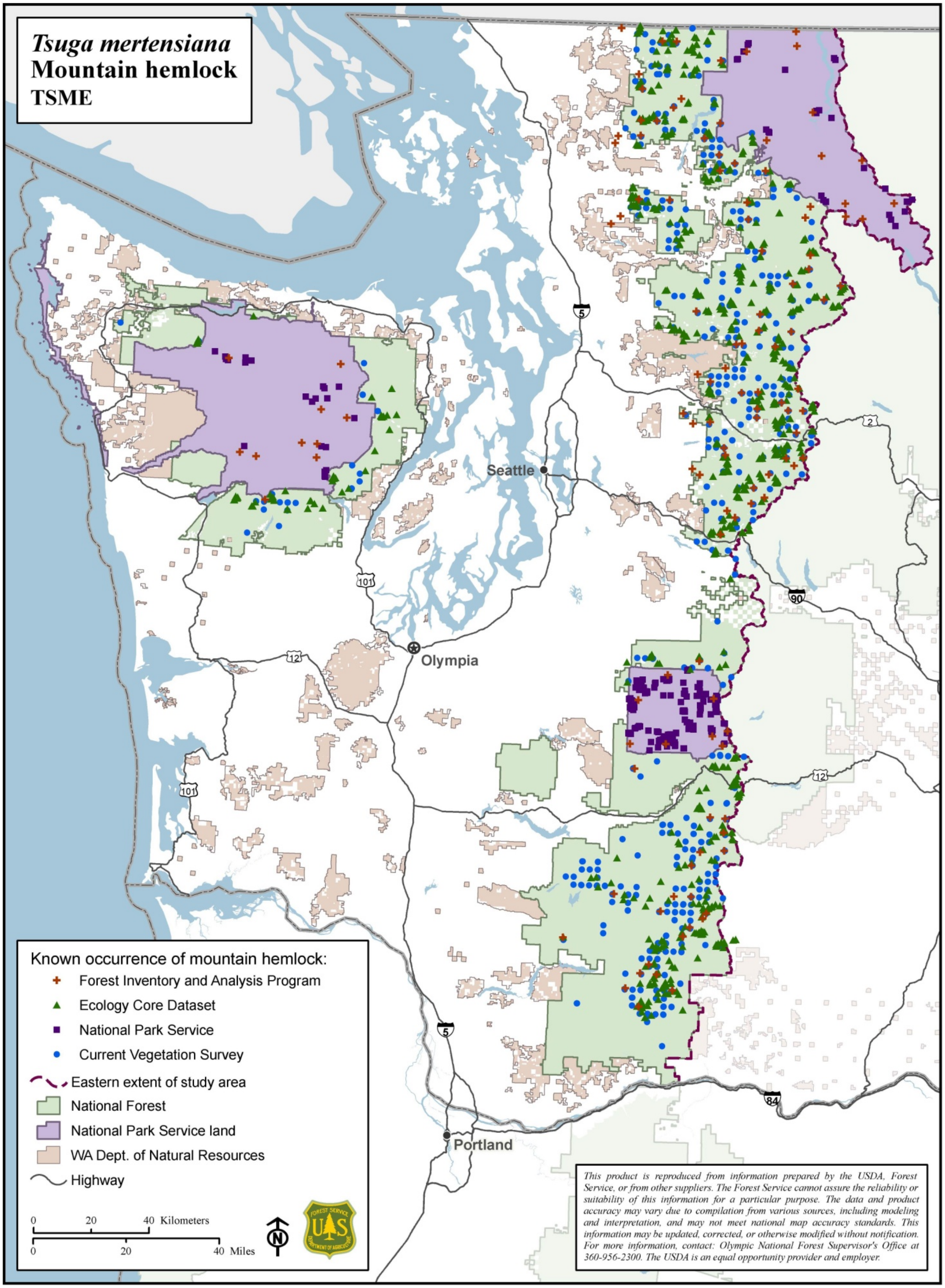

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APPENDIX B:
TREE SPECIES PROFILES

Table B-1. List of profiles for tree species of western Washington

Scientific name	Common name	Symbol	Page
Abies amabilis	Pacific silver fir	ABAM	B-4
Abies grandis	Grand fir	ABGR	B-7
Abies lasiocarpa	Subalpine fir	ABLA	B-10
Abies procera	Noble fir	ABPR	B-13
Acer glabrum var. *douglasii*	Douglas maple	ACGLD4	B-16
Acer macrophyllum	Bigleaf maple	ACMA3	B-18
Alnus rubra	Red alder	ALRU2	B-21
Arbutus menziesii	Pacific madrone	ARME	B-24
Betula papyrifera	Paper birch	BEPA	B-27
Chrysolepis chrysophylla	Golden chinquapin	CHCH7	B-30
Cornus nuttallii	Pacific dogwood	CONU4	B-33
Crataegus douglasii and *C. suksdorfii*	Black hawthorn and Suksdorf's hawthorn	CRDO2, CRSU16	B-35
Cupressus nootkatensis	Alaska yellow-cedar	CUNO	B-37
Frangula purshiana	Cascara	FRPU7	B-40
Fraxinus latifolia	Oregon ash	FRLA	B-42
Juniperus scopulorum	Rocky mountain juniper	JUSC2	B-44
Malus fusca	Western crab apple	MAFU	B-46
Picea engelmannii	Engelmann spruce	PIEN	B-48
Picea sitchensis	Sitka spruce	PISI	B-51
Pinus albicaulis	Whitebark pine	PIAL	B-54
Pinus contorta var. *contorta*	Shore pine	PICOC	B-57
Pinus contorta var. latifolia	Lodgepole pine	PICOL	B-60
Pinus monticola	Western white pine	PIMO3	B-63
Pinus ponderosa	Ponderosa pine	PIPO	B-66
Populus balsamifera ssp. *trichocarpa*	Black cottonwood	POBAT	B-69
Populus tremuloides	Quaking aspen	POTR5	B-72
Prunus emarginata	Bitter cherry	PREM	B-75
Pseudotsuga menziesii	Douglas-fir	PSME	B-77
Quercus garryana	Oregon white oak	QUGA4	B-80
Salix lucida var. *lasiandra*	Pacific willow	SALUL	B-83
Salix scouleriana	Scouler's willow	SASC	B-85
Taxus brevifolia	Pacific yew	TABR2	B-87
Thuja plicata	Western redcedar	THPL	B-90
Tsuga heterophylla	Western hemlock	TSHE	B-93
Tsuga mertensiana	Mountain hemlock	TSME	B-96

Table B-2. NatureServe conservation status ranking and geographic scale definitions. The conservation status ranking and geographic scale of the ranking are listed in each tree species' profile (e.g., G5 indicates the species is secure at the global scale). Additional information on NatureServe rankings is available at: http://www.natureserve.org/explorer/ranking.htm

Variable	Level	Meaning
NatureServe ranking	1	Critically imperiled
	2	Imperiled
	3	Vulnerable
	4	Apparently secure
	5	Secure
Geographic scale	G	Global
	N	National
	S	State

Pacific silver fir (*Abies amabilis*)

Ecology

Description		A medium-to-large, evergreen conifer typically reaching 150 to 200 ft (45 to 60 m) in height; a narrow, symmetrical, conical crown; straight, horizontal branches; smooth, light-gray bark
Distribution		From southeastern Alaska to around Crater Lake, Oregon, and infrequently in northwestern California; from 800 to 6,000 ft (240 to 1,830 m) elevation on the west side of the Cascade Range and from 3,300 to 6,000 ft (1000 to 1830 m) on the east side; occurs in the Olympics from sea level to 4,600 ft (1,400 m); also native to the Coast Range of southwestern Washington in the Willapa Hills, Doty Hills, and Black Hills, from 1,200 to 2,800 ft (370 to 850 m)
Successional stage		Occurs in all seral stages; most prevalent in late seral and climax stands; Pacific silver fir may establish soon after disturbance, but growth is too slow to compete with associated conifers; its high degree of shade tolerance allows it to persist and become an important overstory component of mid- to late-seral stands, sometimes several hundred years after a disturbance
Associated forest cover		Occurs most often with western hemlock, occurs with Douglas-fir on drier sites within its range; found to a lesser extent with a variety of other conifers including western redcedar, Alaska yellow-cedar, noble fir, and grand fir; sometimes occurs in pure stands
Habitat	**Sites**	Found most frequently on submontane to subalpine sites, but occasionally occurs to sea level in the Olympic Range
	Soils	Occurs on a wide range of soil types, from nutrient poor to nutrient rich
	Moisture	Requires an uninterrupted supply of water throughout the year; found predominantly on moderately moist to very moist sites; best growth occurs where moisture is highest, assuming the soil maintains aeration; range is limited by summer drought
	Temperature	Low tolerance of heat; may require protection on harsh sites; moderately frost tolerant; intolerant of frozen soil owing to its winter water requirement; benefits from heavy accumulations of snow that insulate the soil and its shallow roots
	Shade tolerance	Very shade tolerant; requires relatively little growing space for its crown; often overtopped by other species owing to its slower growth
Interspecific interactions	**Animal damage**	May incur damage from browsing by elk or bark-stripping by black bear; animal damage increases susceptibility to pathogens; high incidence of insect damage to seeds and cones
	Mycorrhizal fungi	Roots highly mycorrhizal, particularly at high elevations; *Cenococcum graniforme* frequently associated with Pacific silver fir

Reproduction and Growth

Mode of reproduction	Reproduction is sexual; monoecious

Reproductive phenology		Reproductive cycle begins in May when reproductive primordia are initiated and is completed when seeds reach maturity in late summer of the following year; development enters dormancy beginning in October or November of the first year; development of pollen- and seed-cone buds resumes in early April of the second year, and pollination occurs by late May (about 7 weeks after the end of dormancy), although fertilization does not take place until July; seeds reach maturity in late August or September; the period from pollination to seed maturity is 90 to 120 days; phenology varies by geographic location, elevation, local climate conditions, and snowpack
Pollination		Wind-pollinated
Seed	**Seed type**	Cones 3 to 4 in (8 to 10 cm) long and 1.5 to 2 in (3.5 to 5 cm) wide; seeds 0.4 to 0.5 in (10 to 12 mm) long and 0.2 in (4 mm) wide; seeds have a single wing approximately the same length as the seed body; seeds often fall in pairs
	Seed-bearing age	Cone production begins around age 20 to 30 years
	Seed size/ weight	Averages 11,000 seeds per lb (24,250 seeds per kg); ranges from 7,800 to 20,800 seeds per lb (17,200 to 45,860 seeds per kg), heavier than those of most associated conifers
	Seed longevity/ survivability	Seed viability did not decline after 6 months for seeds stored at ambient temperatures; seed may be stored for 5 years or longer at 1 °F (-17 °C)
	Seed crop and frequency	Trees have low cone-bearing capacity; generally a poor seed producer, produces a low percentage of sound seed, probably a result of frequent years of low pollen production or the long period of time between pollination and fertilization; good seed crops occur approximately every 3 years
Seed dissemination	**Time of year**	Seed dissemination begins in mid-September, relatively early compared to associated species; timing of seedfall is not related to latitude or elevation; seedfall declines by late October, although some seed may continue to fall through April; typically, larger seeds with higher viability are shed first
	Method and dispersal agents	Seeds dispersed by gravity and wind; cones disintegrate as they mature; seeds occasionally dispersed by animals including Douglas squirrel
	Distance	Seeds not carried far by wind because they are relatively heavy; one third of dropped seed falls beyond 125 ft (38 m) of a stand edge; less than 10 percent falls beyond 375 ft (114 m)
Germination requirements		Germination averages 20 to 30 percent; lack of pollination and insect damage are main reasons for low viability; requires a minimum cold stratification period of 3 to 4 weeks; germination greatest in cool, moist locations; germination most likely on mineral soil, but also occurs on organic soil, rotten wood, and litter
Seedling survival		Seedling mortality most often caused by germination on snow, adverse climatic conditions, or competing vegetation; seedlings are sturdy and resistant to being flattened by wet snow or litter after snow melt
Vegetative phenology		At an elevation of 3,280 ft (1,000 m) on Vancouver Island, vegetative bud development began in early April; bud burst occurred in early June; shoot elongation continued until late July; about that time, vegetative buds initiated

	leaf primordia, which developed until entering dormancy in November; in British Columbia, budburst was delayed by 1 day for every 65-ft (20-m) increase in elevation

Genetics

Mating system	Predominantly outcrossing with a moderately high outcrossing rate
Outcrossing % (t_m)	0.875
Genetic diversity	Average levels of genetic diversity
Heterozygosity (H_e)	0.10
Geographic differentiation	Weak genetic differentiation based on molecular markers
F_{st} or G_{st}	0.05
Genetic analysis research results	Relatedness among individuals drops to near zero within distances 20 to 60 m; low levels of inbreeding depression in growth of 2 to 5 percent detected in natural stands

Threats and Management Considerations

Insects and disease	Moderate risk of insect damage; balsam woolly adelgid (*Adelges piceae*) is the most frequent cause of damage and mortality; Pacific silver fir is susceptible to root and butt rots including *Heterobasidion annosum*, *Phellinus weiri*, and *Armillaria mellea*, although these are generally less frequent at high elevations; high incidence of insect damage to seed and cones
Fragmentation	In Washington, Pacific silver fir occupies a relatively large area in the Cascade and Olympic Ranges; it occurs to a somewhat lesser extent in the Coast Range
Fire	Extremely fire-sensitive owing to its thin bark, shallow roots, and highly flammable foliage; given the humidity and precipitation where it typically occurs, surface fires are rare and of low intensity
Other damaging agents	More susceptible to windthrow than associated species
NatureServe conservation status ranking	G5 Secure—Common; widespread and abundant
Silvicultural considerations	An important species in watersheds and is prevalent in wilderness and multiple-use recreation areas; it is invading high-elevation meadows in some locations in the Olympics; nursery seedlings planted in harvested areas have performed poorly

References

Arno and Hammerly 2007, Bonner and Karrfalt 2008, Cope 1992, Crawford and Oliver 1990, Davidson and El-Kassaby 1997, Edwards 2008, El-Kassaby et al. 2003, Klinka et al. 2000, Murray and Treat 1980, Owens and Molder 1977a, Owens and Molder 1977b, Ritland and Travis 2004, USDA NRCS 2010

Grand fir (*Abies grandis*)

Ecology

Description		A medium-sized, evergreen conifer reaching a height of 150 to 200 ft (45 to 60 m); a long, conical crown that is rounded at the top; mature trees tend to lose apical dominance; branches are straight and horizontal; thick, furrowed bark similar to that of Douglas-fir
Distribution		Occurs in separate coastal and interior distributions in the Pacific Northwest; coastal distribution extends from southwestern British Columbia to northern California, from the coast to the Cascade Range; interior distribution extends from southern British Columbia to central Idaho and eastern Oregon; in western Washington, Grand fir occurs most often from below 1,500 ft (450 m) elevation; in the Cascade Range it occurs up to 6,000 ft (1,830 m) on moist sites
Successional stage		A seral or climax species; on moist, lowland sites its growth rate is sufficient for it to achieve overstory status; on dry sites, it grows more slowly and does not become part of the canopy until the stand nears climax conditions; grand fir establishes well on the bare mineral soil of disturbed sites
Associated forest cover		Typically occurs in mixed stands, often as a minor species; in western Washington, grand fir occurs most frequently with Douglas-fir, Sitka spruce, Pacific silver fir, western redcedar, western hemlock, bigleaf maple, red alder, and black cottonwood
Habitat	**Sites**	Occurs most often in lowlands within its western Washington range, frequently in valleys and on floodplains
	Soils	Found on a variety of soil types, but occurs most often on moderately to highly nutrient-rich soils
	Moisture	Tolerant of a greatly fluctuating water table; also tolerant of relatively dry soils at higher elevations, where it forms a deep taproot
	Temperature	Low frost tolerance; moderate heat tolerance
	Shade tolerance	Moderately shade-tolerant, less so than western hemlock, western redcedar, and other true firs; it generally outgrows these species but is outgrown by shade-intolerant species in full sunlight; grand fir is more shade tolerant in dry climates than in wet climates
Interspecific interactions	**Animal damage**	Grand fir is ranked intermediate in browse preference
	Mycorrhizal fungi	*Abies grandis* is ectomycorrhizal and endomycorrhizal

Reproduction and Growth

Mode of reproduction	Reproduction is sexual; monoecious
Reproductive phenology	Flowers between late March and mid-May, although early spring temperatures cause substantial variation in timing; cones mature in August or September and begin to disintegrate and drop seed approximately 1 month later

Pollination		Wind-pollinated
Seed	**Seed type**	Large, winged seeds; sometimes 200 or more seeds per cone
	Seed-bearing age	Begins to produce seed around age 20
	Seed size/ weight	Ranges from 11,900 to 28,700 seeds per lb (26,200 to 63,100 seeds per kg), with an average of 18,400 seeds per lb (40,500 seeds per kg)
	Seed longevity/ survivability	Seeds remain viable only through the first spring; seed may be stored for more than 5 years at 5 °F (-15 °C)
	Seed crop and frequency	Seed production in western Washington is intermediate; produces a low percentage of sound seed; good seed crops occur every 2 to 3 years
Seed dissemination	**Time of year**	Seedfall begins about mid-September
	Method and dispersal agents	Cones disintegrate at maturity and seeds are dispersed by wind and rodents
	Distance	Average dispersal distance is about 150 to 200 ft (46 to 61 m), but adequate seed for regeneration is dispersed up to 400 ft (120 m)
Germination requirements		Germination is quite variable, averaging 50 percent or less; seeds stratify over winter under cool, moist conditions; germination is greatest on mineral soil or duff
Seedling survival		Seedling mortality is highest during the first 2 years after germination, when an average of 40 percent of seedlings die; early mortality is usually a result of fungal infection or summer drought; on exposed or dry sites, seedlings form deep taproots, which reduces their susceptibility to drought
Vegetative phenology		Vegetative buds become mitotically active in mid-March; bud burst occurs about mid-May; shoot elongation occurs through the end of June

Genetics

Genetic diversity	Average levels of genetic diversity
Heterozygosity (H_e)	0.10
Geographic differentiation	Weak differentiation based on molecular markers
F_{st} or G_{st}	0.057
Patterns of variation	Slower growth and higher frost resistance in inland (northern Idaho and eastern Oregon) populations; genetic differences exist among northern and southern provenances, but little difference within
Genetic analysis research results	Several provenance tests established in Europe show variation in growth, survival, and volume production among provenances, with lower elevation provenances usually performing best

Threats and Management Considerations

Insects and disease	Grand fir is relatively high in its susceptibility to insect damage; the most damaging species are balsam wooly adelgid, western spruce budworm and Douglas-fir tussock moth; grand fir is at high risk of fungal damage, particularly from laminated root rot, Armillaria root disease, and Indian paint fungus; insects also feed on grand fir seeds, reducing viability by 10 to 25 percent
Harvest	Marketed with western hemlock and other true firs
Fragmentation	Distributed contiguously throughout western Washington
Fire	At maturity, resistant to low- and moderate-severity fire; less resistant to fire damage than Douglas-fir but more resistant than Pacific silver fir; does not survive crown fire; susceptibility is greater on moist sites than on dry sites where roots are deeper and bark is thicker
Other damaging agents	Moderate tolerance to damage from snow and wind
NatureServe conservation status ranking	G5 Secure—Common; widespread and abundant
Silvicultural considerations	As a moderately shade-tolerant species, grand fir may be suited to multi-aged silvicultural systems; sometimes responds well to release; a valued species for pulpwood

References

Arno and Hammerly 2007, Bonner and Karrfalt 2008, Burton and Cumming 1995, Foiles et al. 1990, Franklin and Krueger 1968, Franklin and Ritchie 1970, Howard and Aleksoff 2000, Klinka et al. 2000, Konnert and Reutz 1997, Nielsen and Rasmussen 2009, Owens 1984, Owens and Blake 1985, USDA NRCS 2010

Subalpine fir (*Abies lasiocarpa*)

Ecology

Description		A medium-sized, evergreen conifer reaching a height of approximately 100 ft (30 m); a narrow, dense crown that extends to the ground; stiff, often downward-angled branches; gray-brown bark forming irregular scales on older trees
Distribution		From Yukon Territory, Canada, southward to New Mexico; a major component of high-elevation forests in the Olympic and Cascade ranges; typically occurs from about 4,000 to 6,500 ft elevation (1,200 to 2,000 m) in the Olympic and Cascade Ranges, although it is found as high as 8,000 ft (2,440 m) on sheltered slopes and as low as 2,000 ft (610 m) along cold stream bottoms
Successional stage		Occurs in all stages of secondary succession and as a climax dominant or codominant species; occurs as a pioneer on disturbed and severe sites
Associated forest cover		Occurs in pure and mixed-species stands; occurs frequently with mountain hemlock, whitebark pine, Pacific silver fir, Engelmann spruce, and lodgepole pine; occurs less frequently with western hemlock, western white pine, grand fir, noble fir, and Sitka spruce
Habitat	**Sites**	Found in cold, mid- to high-elevation forests, typically with very heavy snowpack and short growing seasons
	Soils	Grows on a wide range of soils, including shallow, coarse-textured, and nutrient-poor soils; grows in poorly aerated soils
	Moisture	Occurs on soils ranging from somewhat dry to wet; moderately tolerant of drought; tolerant of flooding and fluctuating water tables
	Temperature	Occupies sites where winters are cold and summers are cool; moderately tolerant of heat; tolerates frozen soil
	Shade tolerance	Shade tolerant; often grows as a seral species that is gradually replaced by trees such as Pacific silver fir, grand fir, and mountain hemlock; often grows in openings at high elevations
Interspecific interactions	**Animal damage**	Insects, small birds, and rodents may consume seeds; occasionally browsed by ungulates
	Mycorrhizal fungi	Subalpine fir is ectomycorrhizal

Reproduction and Growth

Mode of reproduction	Reproduces sexually and vegetatively; monoecious; vegetative reproduction occurs through layering
Reproductive phenology	Reproductive cycle spans two growing seasons; cones are initiated in the spring of the first year; buds differentiate in midsummer; conelets become apparent in early spring of the second year; in late spring or early summer, 8 to 9 weeks after the end of dormancy, pollination occurs; cones open in mid-August to mid-October; seeds ripen from mid-September to late-October
Pollination	Wind-pollinated

Seed	**Seed type**	Seeds are approximately 0.25 in (6 mm) long; seeds have a single, large, terminal wing
	Seed-bearing age	Seed production begins about age 20, but production is low in dense forest conditions
	Seed size/ weight	Averages 34,800 seeds per lb (76,700 seeds per kg)
	Seed longevity/ survivability	Seed remains viable for 1 year under natural conditions; seed may be stored for longer than 5 years at 1 °F (-17 °C)
	Seed crop and frequency	Heavy seed crops occur every 3 to 5 years; between heavy crops are light crops or crop failures; heavy crops may be predicted by good radial growth in the 2 years prior; produces a low percentage of sound seed
Seed dissemination	**Time of year**	Seedfall occurs in October and November, occasionally into December
	Method and dispersal agents	As cones disintegrate, seeds are dispersed by wind; occasionally squirrels disperse seed by caching cones
	Distance	Seeds usually fall within 260 ft (80 m) of the source tree, rarely more than 330 ft (100 m)
Germination requirements		Germination rates average approximately 31 to 38 percent; seeds require stratification under the moist, cold conditions of snow cover; germination occurs within the first few weeks after snow melt
Seedling survival		Seedling survival is highest on mineral soil, but seedlings also survive on duff, litter, and rotting wood; early root growth is rapid, while shoot growth is very slow; seedling mortality results from drought, heat-girdling, competing vegetation, frost heaving, animal damage, and pathogens
Vegetative phenology		Vegetative bud burst occurs about mid-May to mid-June; lateral shoot elongation is rapid for approximately 1 month and then slows and stops by the end of the second month; height and radial growth are very slow at high elevations

Genetics

Mating system	Predominantly outcrossing with moderately high outcrossing rate
Outcrossing % (t_m)	0.89
Genetic diversity	Average genetic diversity
Heterozygosity (H_e)	0.12
Geographic differentiation	Weak differentiation based on molecular markers
F_{st} or G_{st}	0.03
Genetic analysis research results	Seedlings from an elevation gradient of about 3,600 ft (1,100 m) showed strong clinal variation in timing of growth cessation, growth rate, and biomass partitioning related to elevation

Threats and Management Considerations

Insects and disease	Very susceptible to a variety of insects including western spruce budworm, western balsam bark beetle, balsam woolly adelgid; very susceptible to root, heart, and butt rots including laminated root rot and Indian paint fungus
Harvest	Harvest is limited by its accessibility
Fragmentation	Prevalent in high-elevation forests in the Olympic and Cascade Range; isolated and inaccessible stands are often not significantly altered by humans
Fire	very sensitive to fire; highly susceptible to crown fire owing to highly flammable foliage and dense stands; may be slow to re-establish after fire owing to absence of seed source and competing herbaceous vegetation
Other damaging agents	Susceptible to windthrow where exposed by harvest; very tolerant of heavy snowpack
NatureServe conservation status ranking	G5 Secure—Common; widespread and abundant
Silvicultural considerations	Well-suited to mixed-species stands and multi-aged management; natural regeneration usually preferred; planting usually ineffective; very susceptible to Indian paint fungus in pure, natural stands

References

Alexander et al. 1990, Arno and Hammerly 2007, Ettl and Peterson 2001, Franklin and Krueger 1968, Franklin and Ritchie 1970, Green 2005, Klinka et al. 2000, Kranabetter et al. 2009, Owens and Blake 1985, Owens and Singh 1982, Schmidt 1957, Shea 1987, 1990, Uchytil 1991a, USDA NRCS 2010, Woodward et al. 1994

Noble fir (*Abies procera*)

Ecology

Description		A medium-to-large, evergreen conifer; the largest of the true firs, sometimes reaching a height of more than 230 ft (70 m); self-prunes lower limbs resulting in a short, round-topped crown at maturity; gray-brown bark, increasingly reddish and deeply furrowed with age
Distribution		Occurs only in Washington and Oregon, in the Cascade Range and to a lesser extent in the Coast Range; in Washington, noble fir occurs primarily on the western slopes of the Cascades from Stevens Pass southward; scattered populations occur in the peaks of the Willapa Hills in southwestern Washington; noble fir is found primarily at elevations between 3,000 and 5,000 ft (910 and 1520 m)
Successional stage		A pioneer or early seral species that may be replaced over time by more tolerant species including Pacific silver fir and western hemlock
Associated forest cover		Associated with a wide variety of conifers including Douglas-fir, Pacific silver fir, grand fir, subalpine fir, western hemlock, mountain hemlock, western white pine, lodgepole pine, whitebark pine, western redcedar, Engelmann spruce, Sitka spruce, and Alaska yellow-cedar
Habitat	**Sites**	Occurs on a range of topography from gentle to steep slopes; grows best on warm, moist sites with southerly aspects
	Soils	Optimal soils include shallow to deep loams; moisture is more often a limiting factor than nutrients
	Moisture	Relatively low drought tolerance compared to its associates
	Temperature	Typically occurs where mean January temperature ranges from 24 to 30 °F (-4 to -1 °C) and mean July temperature ranges from 56 to 61 °F (13 to 16 °C); high frost tolerance
	Shade tolerance	Intermediate shade tolerance; the least shade-tolerant of all American true firs; cannot establish beneath a closed forest canopy
Interspecific interactions	**Animal damage**	Seedling browse damage less than for Douglas-fir; occasional black bear damage
	Mycorrhizal fungi	Known to be ectomycorrhizal

Reproduction and Growth

Mode of reproduction		Reproduction is sexual; monoecious
Reproductive phenology		Male and female budburst from May to early June; pollination from June to early July; cones ripen in mid- to late-September; phenological events vary by 2 weeks or more depending on weather; spring and summer events are usually 1 to 2 days later for every 100 ft (30 m) increase in elevation
Pollination		Wind-pollinated
Seed	**Seed type**	Cones 4 to 6 in (10 to 15 cm); winged seeds; wing slightly longer than body

	Seed-bearing age	Seed production begins at age 20 to 30; large crops begin to occur approximately 20 years later
	Seed size/ weight	Averages 13,500 seeds per lb (29,750 seeds per kg); seeds 0.5 by 0.25 in (12 by 6 mm)
	Seed longevity/ survivability	Seed viable for one season under natural conditions; seed may be stored for 10 years or longer at -4 °C
	Seed crop and frequency	Good seed crops every 3 to 6 years; 10 or more cones per tree produced in 42 percent of years; older trees may produce large crops; seed crops poor in high Cascades and near the eastern edge of its range
Seed dissemination	**Time of year**	Seeds dispersal begins from late September to early October
	Method and dispersal agents	Seeds dispersed by wind
	Distance	Most seedfall within one or two tree heights of the source tree, although potential dispersal distance is more than 2,000 ft (610 m)
Germination requirements		Seed viability is generally low, averaging 10 percent in natural stands; viability closely related to magnitude of cone crop; cold stratification required; germination epigeal; germination in or on snowbank yields minimal survival; germination highest on mineral soil or moist humus
Seedling survival		Survival highest when germination occurs on a moist microsite; no dominant taproot; frosts and competing vegetation are major sources of mortality
Vegetative phenology		Vegetative budburst from late May to early July

Genetics

Mating system	Predominantly outcrossing with high outcrossing rate (from planted stands in Norway)
Outcrossing % (t_m)	0.94
Genetic diversity	Above average genetic diversity
Heterozygosity (H_e)	0.22
Geographic differentiation	Weak differentiation based on molecular markers
F_{st} or G_{st}	0.05
Patterns of variation	Weak geographic differentiation on needle and cone traits

Threats and Management Considerations

Insects and disease	Insects, including noble fir bark beetle (*Pseudohylesinus nobilis*), not regarded as a significant problem; a variety of fungal pathogens are found on noble fir, although none cause extensive damage
Harvest	Boughs are prized for wreaths and decoration

Fragmentation	Contiguous range in the Cascades; disjunct population in the Willapa Hills of southwestern Washington
Fire	Low resistance to fire when young; low to moderate resistance at maturity; foliage moderately to highly flammable; an early pioneer following stand-destroying fires
Other damaging agents	Very windfirm; tolerant of heavy snow
NatureServe conservation status ranking	G5 Secure—Common; widespread and abundant
Silvicultural considerations	Initial height growth is slow; often occurs in mixed stands where its low amount of taper results in a disproportionately large contribution to stand volume

References

Arno and Hammerly 2007, Bonner and Karrfalt 2008, Cope 1993a, Franklin 1990, Franklin and Krueger 1968, Franklin and Ritchie 1970, Nielsen and Rasmussen 2009, Owens and Blake 1985, Siegismund and Kjaer 1997, USDA NRCS 2010, Xie and Ying 1994, Yeh and Hu 2005

Douglas maple (*Acer glabrum* var. *douglasii*)

Ecology

Taxonomy and nomenclature		Douglas maple is one of six varieties of Rocky Mountain maple (*Acer glabrum*)
Description		A deciduous, broadleaf shrub or small tree growing 20 to 40 ft (6 to 12 m) in height; an irregular crown, often with multiple stems; smooth, reddish bark becoming rougher with age
Distribution		From Alaska south to California and east to Montana and Idaho; common at moderate elevations east of the Cascade Range in Washington; less common west of Washington's Cascades
Successional stage		Found in early seral, shrub-dominated vegetation; occurs in deciduous pioneer forests but also present in late successional and climax floodplain communities
Associated forest cover		An understory species in a variety of conifer forests; often associated with ponderosa pine forests; does not compete with conifers to the extent that vine maple does; grows above the shrub layer
Habitat	**Sites**	Low to middle elevations; moist and dry sites; floodplains, streambanks, and forest edges; dry, open, rocky areas, including avalanche tracks; occurs on drier, more exposed sites than vine maple
	Soils	Occurs on a wide variety of soils, from wetlands to rocky slopes; found on soils of many parent materials; reportedly an indicator of nitrogen-rich soils in British Columbia
	Moisture	Tolerates periodic flooding and moderately high water tables; moderately drought tolerant
	Temperature	Tolerant of heat and cold temperatures
	Shade tolerance	Moderately shade-tolerant
Interspecific interactions	**Animal damage**	An important browse species for deer and elk
	Mycorrhizal fungi	Known to be mycorrhizal

Reproduction and Growth

Mode of reproduction		Sexual and vegetative reproduction; may be monoecious or dioecious; sprouts from root crown after stem damage or top-kill
Reproductive phenology		Flowers from late April to late June, depending on elevation and latitude; fruit develops from June to August; fruit ripens from July to October
Pollination		Insect- and wind-pollinated
Seed	**Seed type**	Paired, winged samaras; 0.8 to 1.2 in (20 to 30 m) long
	Seed-bearing age	Seed production may begin as early as age 10

	Seed size/ weight	Seeds are 0.16 to 0.2 in (4 to 5 mm) long; 7,820 to 20,300 cleaned seeds per lb (17,240 to 44,750 seeds per kg) with an average of 13,430 seeds per lb (29,610 seeds per kg)
	Seed longevity/ survivability	Seeds sometimes remain dormant for one or two growing seasons before germination; seeds may remain viable in storage for up to 3 years
	Seed crop and frequency	Large seed crops occur every 1 to 3 years
Seed dissemination	**Time of year**	Seeds dispersed beginning in September; some seeds may not be dropped until February
	Method and dispersal agents	Seeds are dispersed by wind, whirling sideways
	Distance	Not reported
Germination requirements		Seeds require approximately 6 months of chilling before embryos break dormancy; germination occurs on mineral soil or shallow organic layers, often in partial shade
Seedling survival		Partial shade facilitates seedling establishment; after establishment, early growth is rapid in sunlight
Vegetative phenology		Bud swell in late March or April; budburst in early April to mid-May; leaf growth may continue through June; stem elongation begins in late April and may continue until late August

Threats and Management Considerations

Insects and disease	Little information available; significant damage from insects or disease has not been reported; dull red leaf spots attributed to unknown pathogen; *Eriophyid* mite colonies sometimes occur on the underside of leaves
Harvest	Not a commercial species
Fragmentation	Occurrence is sporadic west of the Cascade Range
Fire	Top-killed by fire; readily sprouts from root crown; a pioneer species in burned areas
Other damaging agents	Not reported
NatureServe conservation status ranking	G5 Secure—Common; widespread and abundant
Silvicultural considerations	Growth is stimulated when the forest overstory is thinned; rapidly sprouts after stem is cut

References

Anderson 2001a, Arno and Hammerly 2007, USDA NRCS 2010

Bigleaf maple (*Acer macrophyllum*)

Ecology

Description		A medium-sized, deciduous, broadleaf tree; the largest North American maple, reaching a height of more than 100 ft (30 m); a broad, outstretched crown with large leaves; light gray bark when young, becoming dark and ridged with age
Distribution		Coastal Pacific Northwest from British Columbia south to near San Francisco Bay in California; occurs in Washington from the coast to the western slope of the Cascade Range; occurs below 1,500 ft (460 m) elevation on the Olympic Peninsula
Successional stage		Often occurs at intermediate or late seral stages in conifer forests; seedlings and sprouts grow rapidly after gap creation or canopy disturbance; follows willow or red alder in riparian succession
Associated forest cover		Frequently found with Douglas-fir, western redcedar, and western hemlock; occurs on moist sites with willow, black cottonwood, and red alder; occurs in the Olympic rain forest with old-growth Sitka spruce and western hemlock
Habitat	**Sites**	Often found where relatively open overstories occur, such as wet sites, and, to a lesser extent, dry sites; sites range from bottomlands to steep slopes; common on hardwood floodplain forests
	Soils	Occurs on a wide range of soil types; does not require high levels of nutrients; soils range from well-drained alluvium to steep talus slopes;
	Moisture	Very flood-tolerant; southern and interior distribution limited by moisture
	Temperature	Northern distribution limited by cold temperatures; moderately tolerant of heat; found on hot, dry sites in the Oregon Cascades
	Shade tolerance	Intermediate in shade tolerance; seedlings establish in conifer stands but usually survive fewer than 15 years unless the canopy is disturbed; mature bigleaf maple is found in conifer stands, where trees originated in canopy openings
Interspecific interactions	**Animal damage**	Seedlings are highly palatable to deer; high level of seed predation by a variety of small mammals and birds; buds and flowers also consumed
	Mycorrhizal fungi	Known to be ectomycorrhizal

Reproduction and Growth

Mode of reproduction		Sexual and vegetative reproduction; monoecious; primarily sexual reproduction on undisturbed sites; sprouts vigorously from stumps
Reproductive phenology		Flowers from March to June depending on elevation and latitude; pollination approximately 2 to 4 weeks after bud burst; seeds become ripe in September or October
Pollination		Insect-pollinated
Seed	**Seed type**	Fused double samaras; wings 1.4 to 2 in (3.5 to 5 cm) long; large triangular or

		oval seeds
	Seed-bearing age	Seed production begins about age 10
	Seed size/ weight	Seeds 0.2 to 0.5 in (4 to 12 mm) long and 0.2 to 0.4 in (4 to 9 mm) thick; averages 3,200 seeds per lb (7,050 seeds per kg); ranges from 2,400 to 3,600 seeds per lb (5,200 to 7,900 seeds per kg); seed coat is 60 to 70 percent of seed weight
	Seed longevity/ survivability	Seeds remain viable for only a few months under natural conditions; seeds have been stored for 1 year at 34 °F (1 °C)
	Seed crop and frequency	Although production varies among individuals, overall production is generally high every year, particularly in open areas
Seed dissemination	**Time of year**	Most seeds dispersed between October and January, some not dropped until March
	Method and dispersal agents	Primarily dispersed by wind; some seeds may be dispersed by small mammals and birds
	Distance	Not documented
Germination requirements		Seeds germinate beginning in winter, from late January through April or May; low temperature threshold for germination; germination epigeal; germination best on mineral soil or moist organic materials; with predation excluded, 30 to 40 percent of viable seed germinates under natural conditions
Seedling survival		Seedling mortality may result from competition, moisture stress, low light, and herbivory; understory seedlings are abundant in some Douglas-fir stands, although growth is very slow until overstory disturbance occurs; seedlings and sprouts have high growth potential, given sufficient sunlight
Vegetative phenology		Leaves appear in late March or April and are retained through October

Genetics

Mating system	High outcrossing rate
Outcrossing % (t_m)	0. 945
Genetic diversity	Average genetic diversity
Heterozygosity (H_e)	0.15
Geographic differentiation	Weak differentiation based on molecular markers
F_{st} or G_{st}	0.05

Threats and Management Considerations

Insects and disease	Overall risk of damage from insects and fungi is low, although over-mature or damaged trees are often infected by root rot (*Armillaria* spp.) and butt rot (*Ganoderma applanatum* and *Oxyporus populinus*)

Harvest	Harvested with Douglas-fir in mixed stands; one of a few commercial hardwood species in the Pacific Northwest; used for veneer, furniture, and specialty products
Fragmentation	Widespread throughout its range in western Washington
Fire	Well-adapted to fire owing to its ability to sprout and grow rapidly after top-kill; only severe fires damage the root crown
Other damaging agents	Boles or limbs may suffer breakage under heavy snow or high winds
NatureServe conservation status ranking	G5 Secure—Common; widespread and abundant
Silvicultural considerations	A serious competitor in Douglas-fir stands, particularly after harvesting; sprouts and seedling grow faster than conifers and fallen leaves smother conifer seedlings

References

Arno and Hammerly 2007, Bonner and Karrfalt 2008, Guries and Nordheim 1984, Hamann and Wang 2006, Iddrisu and Ritland 2004, Klinka et al. 2000, Minore and Zasada 1990, Uchytil 1989a, USDA NRCS 2010, Xie et al. 2002

Red alder (*Alnus rubra*)

Ecology

Description		A medium-sized, short-lived, deciduous, broadleaf tree, often reaching 100 ft (30 m) in height; a narrow, rounded crown; smooth, light gray bark, often mottled due to lichen colonization
Distribution		From southeastern Alaska to southern California; rarely found east of the Cascade Range in the Pacific Northwest; several isolated populations in Idaho
Successional stage		Pioneer; aggressively establishes following natural and human-caused disturbances; on disturbed sites, outgrows its primary natural competitor, Douglas-fir, for approximately 25 years before Douglas-fir achieves equal height; considered a climax species where it occurs in swamps
Associated forest cover		Often found in pure or mixed stands within coniferous forests of Douglas-fir, western redcedar, western hemlock, grand fir, and Sitka spruce; mixed stands are relatively young and may contain other broadleafs and conifers; occurs in riparian communities, in pure stands or mixed with black cottonwood, bigleaf maple, and willow; occurs in swamps with western redcedar
Habitat	**Sites**	Occurs most often in riparian areas, moist bottomlands, and moist lower slopes; prevalent where soil drainage is poor; found on relatively moist upland sites where disturbance has occurred, rarely on dry, south-facing slopes; primarily occurs at elevations below 2,400 ft (750 m)
	Soils	Found on a wide range of soils, from well-drained to poorly drained; has relatively high nutrient requirements, although it fixes nitrogen through bacteria in root nodules
	Moisture	Infrequent on dry soils; low tolerance of drought; growth limited by moisture; tolerates wet sites, flooding, greatly fluctuating water tables
	Temperature	Infrequent on exposed, south-facing slopes; susceptible to frost damage; range limited by low temperatures
	Shade tolerance	Shade intolerant; will not survive if overtopped; must remain in upper canopy in mixed stands
Interspecific interactions	**Animal damage**	Occasional browse damage
	Mycorrhizal fungi and symbiotic bacteria	Roots are ectomycorrhizal, but with only a few fungal species; root nodules contain the nitrogen-fixing actinomycete *Frankia* spp.; annual increases in soil nitrogen in alder stands range from 40 to 300 lb per ac (45 to 355 kg per ha)

Reproduction and Growth

Mode of reproduction	Sexual and occasionally vegetative; monoecious; young trees sprout when stem is damaged
Reproductive phenology	Flowering begins as early as late February and lasts as late as May; fruits ripen from early August though October

Pollination		Wind-pollinated
Seed	**Seed type**	Woody cones, 0.5 to 1 in (1.2 to 2.5 cm) long, containing 50 to 100 seeds; seeds are nutlike, small, flattened, and winged
	Seed-bearing age	Seed production begins as early as age 3 or 4 when open-grown or age 6 to 8 in a stand; seed production peaks about age 25
	Seed size/ weight	Seeds are very light; 666,000 seeds per lb (1,465,000 seeds per kg)
	Seed longevity/ survivability	High rate of mortality for buried seed, but importance of seedbank uncertain; seed may be stored for 10 to 20 years at temperatures of 10 °F (-12 °C) or lower
	Seed crop and frequency	Moderate crops nearly every year; heavy crops every 3 to 5 years
Seed dissemination	**Time of year**	Dispersal begins around late September; most seeds dropped in fall or winter
	Method and dispersal agents	Seeds dispersed by wind and water
	Distance	Several hundred yards (m)
Germination requirements		Germinates in spring; germination highest on moist mineral soil, such as a disturbed seedbed, in full sunlight; germinates on other organic materials if moisture and light are available; germination increased by stratification; germination epigeal; germination ranges from 59 to 84 percent
Seedling survival		Shade tolerated for up to several years; full sunlight required for normal development; small seed makes germinants very susceptible to drought mortality
Vegetative phenology		Strongly influenced by climate and thus exhibits significant annual variation; radial growth lasts from approximately mid-April through mid-September; height growth begins slightly later than radial growth and continues until conditions become unfavorable

Genetics

Mating system	Moderately high outcrossing rate
Outcrossing % (t_m)	0.85
Genetic diversity	Average genetic diversity
Heterozygosity (H_e)	0.11
Geographic differentiation	Weak differentiation based on molecular markers
F_{st} or G_{st}	0.08
Genetic analysis research results	Strong geographic variation has been found in seedlings for top weight, bud flush and leaf abscission. Growth traits were correlated with temperature amplitude and length of the growing season, while phonological traits were

	related to spring thermal sums and fall frost dates. Provenances differ in physiological traits, but not families within provenances.

Threats and Management Considerations

Insects and disease	Insects and disease are not a significant problem, especially in younger stands
Harvest	Harvest has increased in recent decades, and the price of red alder timber is increasing; current supply does not meet demand and a long-term shortage is anticipated; harvested red alder comes primarily from southwestern British Columbia and western Washington and Oregon
Fragmentation	Red alder is widespread throughout western Washington at lower elevations
Fire	Red alder stands generally are not prone to fire, and may serve as natural fire breaks; red alder tolerates light surface fires
Other damaging agents	Ice storms and unseasonable frosts may cause damage; windthrow is not a significant problem
NatureServe conservation status ranking	G5 Secure—Common; widespread and abundant
Silvicultural considerations	Owing in part to its nitrogen-fixing properties, red alder is grown on sites including mine spoils, eroded banks, and other restoration projects; also may be grown in mixture or rotation with Douglas-fir

References

Ager et al. 1993; Arno and Hammerly 2007; Bonner and Karrfalt 2008; Dang et al. 1994; Harrington 1990, 2006; Hibbs et al. 1995; Klinka et al. 2000; Owens and Blake 1985; Uchytil 1989b; USDA NRCS 2010; WDNR 2010; Xie 2008; Xie et al. 2002

Pacific Madrone (*Arbutus menziesii*)

Ecology

Description		A small-to-medium, evergreen, broadleaf tree reaching a height of 50 to 80 ft (15 to 25 m); irregular, umbrella-shaped crown with thick, glossy leaves; stem crooked and often divided; recognizable, smooth, peeling, reddish-brown bark
Distribution		From the eastern coast of Vancouver Island, British Columbia, to San Diego County, California; occurs in the coastal mountains and lowlands; occurs in Washington from sea level to mountain slopes at 3,000 ft (915 m) elevation
Successional stage		An early successional to subclimax species; establishes after disturbance and is not found in the forest understory
Associated forest cover		Occurs individually or in groves, rarely in large stands; often interspersed among conifers including Douglas-fir, lodgepole pine, and western hemlock; also occurs with Oregon white oak, red alder, and bigleaf maple; often found in stands characterized by diverse structure and composition
Habitat	**Sites**	Found on a variety of terrain, from level to steeply sloping; found in canyons and on bluffs; most often found on south- and west-facing aspects
	Soils	Typically found on soils with poor to very poor nutrient availability; soils are typically dry in summer and often rapidly draining
	Moisture	Highly drought-tolerant; frequently occurs on sites with growing-season drought; intolerant of flooding
	Temperature	Very intolerant of frost; high tolerance of hot, exposed sites; in the Pacific Northwest, Pacific madrone occurs where winter temperatures are mild and diurnal temperature fluctuation is limited
	Shade tolerance	Low to intermediate tolerance of shade; shade-tolerant as a seedling; shade-intolerant at maturity
Interspecific interactions	**Animal damage**	Minor damage from deer browsing
	Mycorrhizal fungi	Wide-spreading root system is mycorrhizal

Reproduction and Growth

Mode of reproduction		Sexual and vegetative reproduction; monoecious; sprouts prolifically from dormant buds near the root collar
Reproductive phenology		Flowers in May and June; fruits mature in October
Pollination		Pollinated by bees and possibly hummingbirds
Seed	**Seed type**	Red five-celled berry 0.3 to 0.5 in (8 to 12 mm) in diameter; an average of 20 seeds per berry
	Seed-bearing age	Berries may be produced as early as age 3 to 5

	Seed size/ weight	Fresh berries average 630 to 1,130 per lb (1,390 to 2,490 per kg); seed averages 258,000 per lb (568,800 per kg); seed ranges from 197,000 to 320,000 per lb (434,300 to 705,500 per kg)
	Seed longevity/ survivability	Long-term seed dormancy and viability in the soil, possibly decades; dormancy broken by cool temperatures and moisture
	Seed crop and frequency	Abundant fruit in most years; for individual trees, crop is correlated with size of living crown
Seed dissemination	**Time of year**	Fruits mature in October
	Method and dispersal agents	Seeds dispersed by birds, deer, rodents, and gravity
	Distance	Potential for long dispersal distances; specific data not available
Germination requirements		Strong embryo dormancy; requires cold stratification for germination; epigeal; germination rates are fair to high, although mortality occurs rapidly without moisture of mineral soil
Seedling survival		Seedling mortality is high, particularly in the first year; mortality is caused by drought, fungi, litterfall, and invertebrates; survival is best in partial shade on bare mineral soil; seedlings are generally not abundant; early height growth is slow
Vegetative phenology		Leaf bud swell begins in late March; second-year leaves fall in June or July; bark exfoliates from June through September

Genetics

Mating system	High outcrossing rate
Outcrossing % (t_m)	0.97
Genetic diversity	Average genetic diversity based on AFLP
Heterozygosity (H_e)	0.094
Geographic differentiation	Moderate population differentiation
F_{st} or G_{st}	0.15

Threats and Management Considerations

Insects and disease	Minor risk of insect damage; moderate risk of fungal damage; a major cause of dieback and death is madrone canker; a variety of other fungal diseases, including sudden oak death (*Phytophthora ramorum*) affect Pacific madrone
Harvest	Not a major commercial species; used for firewood or specialty products
Fragmentation	Not a known threat in western Washington
Fire	Seedlings, sprouts, and mature trees are very susceptible to fire; top-killed trees sprout from the root collar or burl; fire favors establishment of Pacific madrone seedlings

Other damaging agents	Invasive species such as Scotch broom (*Cytisus scoparius*) impede regeneration; windfirm
NatureServe conservation status ranking	G5 Secure—Common; widespread and abundant

References

Arno and Hammerly 2007, Beland et al. 2005, Harrington and Kraft 2004, Klinka et al. 2000, McDonald and Tappeiner 1990, Reeves 2007, USDA NRCS 2010

Paper birch (*Betula papyrifera* var. *papyrifera*)

Ecology

Taxonomy and nomenclature		Of the three varieties of *Betula papyrifera*; *Betula papyrifera* var. *papyrifera* is the only variety in the western portion of the contiguous 48 states; west of the continental divide, this variety is sometimes known as *Betula papyrifera* var. *commutata*
Description		A medium-sized, deciduous, broadleaf tree reaching 80 ft (24 m) in height; short-lived; ascending branches form an open crown; single or multiple slender stems with distinctive white, papery bark
Distribution		Occurs throughout the northern half of the United States, including Alaska, and across Canada; occurs in Washington sporadically from the Puget Sound region northward, from low elevations near Puget Sound to the North Cascade Range
Successional stage		An aggressive pioneer species that rapidly colonizes disturbed areas and openings; replaced by shade-tolerant species after one generation
Associated forest cover		Following disturbance, paper birch may dominate or be present as a component of a mixed-species stand; in Washington, it is most often associated with red alder, bigleaf maple, Douglas-fir, grand fir, and cascara; sometimes occurs with western hemlock and western redcedar
Habitat	**Sites**	Found on both upland and alluvial sites; occurs on mountain slopes, rock slides, open woodlands, pastures, river valleys, as well as edges of swamps and other wetlands
	Soils	Found on a wide range of soil types, from nutrient-poor to nutrient-rich; occurs on coarse- to fine-textured soils, as well as bog and peat soils
	Moisture	Tolerates flooding and a strongly fluctuating water table; only moderately tolerant of drought; responds to drought by shedding leaves
	Temperature	Tolerant of growing-season frost; moderately tolerant of high air temperatures
	Shade tolerance	Intolerant of shade
Interspecific interactions	**Animal damage**	A preferred browse species of deer; stems damaged by hares, porcupines, squirrels, and birds; birds and small mammals eat buds and seeds
	Mycorrhizal fungi	Associated with ectomycorrhizae and arbuscular mycorrhizae

Reproduction and Growth

Mode of reproduction	Reproduction is sexual (monoecious) and vegetative; sprouts vigorously from stumps or root collar following harvest or top-kill by fire
Reproductive phenology	Male catkins are partially formed in fall and are dormant during winter; male catkins expand prior to flowering, which begins in April; female catkins appear before leaves are fully expanded in spring; fruit ripens from early August until mid-September
Pollination	Wind-pollinated

Seed	**Seed type**	Fruits are small, double-winged nutlets, 0.06 in (1.5 mm) long by 0.03 in (0.8 mm) wide
	Seed-bearing age	Seed production begins around age 15 years; optimum production occurs from ages 40 to 70 years
	Seed size/ weight	Averages 1,380,000 cleaned seeds per lb (3,042,000 per kg)
	Seed longevity/ survivability	A small percentage of seed may remain viable in the forest floor for several years, particularly if seeds fall during a very dry year; dormant seed in the forest floor may be important in years of poor seed crops; seed has been stored for up to 15 years at 18 °F (-8 °C), although colder storage temperatures may improve viability
	Seed crop and frequency	A prolific seed producer; good seed crops occur every other year on average; some seed produced every year; good seed years vary by location; the following year's seed crop can be predicted by observing male catkins in fall; seed crop estimates range from 1 to 294 million seeds per ac (2.5 to 728 million seeds per ha) in light and heavy years, respectively, although seed crops vary substantially by stand density and location
Seed dissemination	**Time of year**	Seeds ripen from early August until mid-September; dispersal begins soon after ripening; most seed is dispersed by the end of November
	Method and dispersal agents	Seed is primarily disseminated by wind, occasionally by water
	Distance	Majority of seed falls 100 to 200 ft (30 to 61 m) from parent tree; seedfall 330 ft (100 m) from a stand edge is 10 percent of that within the stand
Germination requirements		Seed viability varies greatly by locality, parent tree, and year; seed viability highest during heavy crop years; germination best on disturbed mineral soil or on mineral-organic mixtures; stratification not necessary; small germinants sensitive to soil moisture and temperature; germination might be highest in shade where soil is moist and cool; higher seed viability and germinant survival in good seed years than in poor years; germination epigeal
Seedling survival		Dry soils and competing vegetation lead to early mortality; early growth best on humus seedbeds in partial or full sunlight; browse damage may significantly reduce the quantity and vigor of regeneration
Vegetative phenology		Vegetative bud activity may begin in spring when nighttime temperatures are still below freezing; shoot elongation begins after pollination, which occurs in April; stem expansion is correlated with air temperature in spring

Genetics

Patterns of variation	Populations differ significantly for germination, cold hardiness, and biomass allocation but not for gas exchange; population differences in germination and cold hardiness were related to winter temperature
Genetic analysis research results	Interior British Columbia population was the most frost hardy and seed transfer from warmer to colder environments might result in frost damage

Threats and Management Considerations

Insects and disease	Insects and fungal pathogens are not a major concern in the Pacific Northwest; bronze birch borer *(Agrilus anxius)* is the most serious insect pest, attacking older and weakened trees; a number of defoliators attack paper birch but seldom damage healthy trees
Fire	Fire usually kills or top-kills paper birch trees owing to their thin, flammable bark; fire kills seeds on the ground and immature seeds in catkins; quickly establishes after fire through sprouting and lightweight, abundant seed
Other damaging agents	Sensitive to air pollution
NatureServe conservation status ranking	G5 Secure—Common; widespread and abundant
Silvicultural considerations	A commercial species in boreal regions, either in pure stands or mixed with conifers; requires full sunlight for successful regeneration

References

Arno and Hammerly 2007; Benowicz et al. 2000, 2001a; Bonner and Karrfalt 2008; Brinkman 1974; Klinka et al. 2000; Safford et al. 1990; Uchytil 1991b; USDA NRCS 2010; WDNR 2010

Golden chinquapin (*Chrysolepis chrysophylla*)

Ecology

Taxonomy and nomenclature		Golden chinquapin is known as giant chinquapin in the USDA Plants Database; there are two varieties of *Chrysolepis chrysophylla*: *Chrysolepis chrysophylla* var. *chrysophylla* is the tree form described here, and *Chrysolepis chrysophylla* var. *minor* is the shrub form; the latter occurs in California and Oregon
Description		A small-to-medium, broadleaf, evergreen tree, occasionally reaching a height of 100 to 120 ft (30 to 35 m); stout, spreading branches; crown is conical where open-grown; narrow, leathery leaves; smooth, dark-gray bark when young, becoming furrowed and forming reddish-brown plates with age
Distribution		From Mason County, Washington, to Monterey County, California; from the coast to the crest of the Cascade Range; several small populations in Mason County and an additional disjunct population in Skamania County are its only known occurrences in Washington; found from sea level to over 6,000 ft (1830 m) elevation in the Oregon Cascades
Successional stage		Generally an early successional species, although it may persist on sites where conifers do not form a dense overstory; sprouts after top-kill and is thus favored by fire
Associated forest cover		A minor component of a wide variety of forest types throughout its range; often occupies subcanopy in conifer stands; occurs most frequently in open areas and beneath sparse canopies of conifers; pure stands are rare; in Washington, associated with Douglas-fir, western hemlock, ponderosa pine, and vine maple; on Gifford Pinchot National Forest occurs where overstory is dominated by Douglas-fir or ponderosa pine; on Olympic National Forest occurs under 50 to 60 percent Douglas-fir canopy cover
Habitat	**Sites**	Wide ecological amplitude; most competitive on infertile, droughty sites; on Gifford Pinchot National Forest occurs on convex, mid- to lower-slope sites
	Soils	Occurs on a wide range of soils; growth is best on deep soils; often found on nutrient-poor soils
	Moisture	Very tolerant of droughty sites
	Temperature	Occurs on some of the hottest sites of the western Cascade slopes, as well as near the crest of the Oregon Cascade Range
	Shade tolerance	Intolerant to moderately tolerant of shade; seedlings are shade-tolerant; grows rapidly when released from shade of competition
Interspecific interactions	**Animal damage**	Some browse damage known to occur in California
	Mycorrhizal fungi	Possible mycorrhizal relationship with *Tricholoma magnivelare*

Reproduction and Growth

Mode of reproduction		Sexual and vegetative reproduction; monoecious; sprouts from stumps and basal burls following top-kill
Reproductive phenology		Varies widely across range; flowering occurs from April to June in Pacific Northwest; fruit ripens from August to October; reproductive cycle spans two growing seasons
Pollination		Wind-pollinated; sometimes bee-pollinated
Seed	**Seed type**	Spiny, chestnut-like burs 0.6 to 1 in (15 to 25 mm) in diameter contain one to three hard-shelled nuts
	Seed-bearing age	Stump sprouts may produce seed as early as age 6; trees of seed origin produce seed sometime before age 40
	Seed size/ weight	Averages 960 seeds per lb (2,120 seeds per kg); ranges from 830 to 1,100 seeds per lb (1,800 to 2,400 seeds per kg)
	Seed longevity/ survivability	Seed may be stored for 5 years or longer in a controlled environment
	Seed crop and frequency	Some seed produced every year; relatively heavy production every 2 to 5 years; seed viability may be low; in its shrub form, golden chinquapin flowers infrequently
Seed dissemination	**Time of year**	Seed dispersal peaks around late September and extends into early December
	Method and dispersal agents	Seeds dispersed by gravity, squirrels, and several species of birds; burs may be transported by larger mammals
	Distance	Some long-distance dispersal occurs via animals
Germination requirements		Germination relatively low; 14 to 53 percent viability reported; germination hypogeal, occurring after 16 to 24 days; stratification may not be required; germination observed beneath shallow litter layer in partial shade
Seedling survival		Seedlings often grow in partial shade; relatively cool, moist conditions required; seedling densities are typically low

Threats and Management Considerations

Insects and disease	Susceptible to heart-rot fungi (*Phellinus igniarius*); the filbertworm (*Melissopus latiferreanus*) damages seed, reducing viability
Harvest	Not a commercial timber species
Fragmentation	Small, disjunct populations occur in Washington's Mason and Skamania Counties; these represent the northernmost extent of the species' range
Fire	Well-adapted to frequent fire; sprouts vigorously after light or intense fire; aboveground portion highly susceptible to top-kill after fire; where fire is frequent and conditions are dry, sprouting is the primary form of regeneration
Other damaging agents	Trees suffer from competition of overtopping conifers, a major problem in the

	Gifford Pinchot National Forest; windstorms damage trees, particularly those with heart-rot
NatureServe conservation status ranking and other listings	G5 Secure—Common; widespread and abundant S2 Imperiled—Imperiled in the jurisdiction because of rarity due to very restricted range, very few populations, steep declines, or other factors making it very vulnerable to extirpation from jurisdiction; only two small disjunct populations of golden chinquapin occur in western Washington Golden chinquapin is designated a sensitive species under the USDA Region 6 Interagency Special Status/Sensitive Species Program (ISSSSP)
Silvicultural considerations	Historically most silvicultural efforts have been directed at suppressing golden chinquapin in conifer stands
Importance to wildlife	Only known host of Herr's hairstreak butterfly (*Habrodais grunus herri*), which has NatureServe conservation status ranking G4/G5/T2/T3, N2/N3, S1

References

Arno and Hammerly 2007, Bonner and Karrfalt 2008, McKee 1990, McMurray 1989, Ruchty 2008, Shoal 2009, USDA NRCS 2010

Pacific dogwood (*Cornus nuttallii*)

Ecology

Description		A small-to-medium, deciduous, broadleaf tree reaching a height of 30 to 50 ft (9 to 15 m); many spreading, horizontal branches; thin, light-gray bark
Distribution		Coastal regions from southern British Columbia to southern California; occurs in the Pacific Northwest from the Cascade Range to the coast; disjunct population in northern Idaho; below 5,000 ft (1,520 m) elevation
Successional stage		Found in early to late seral stages; does not follow a distinct successional pattern; appears within 3 years of disturbance; often present in hardwood and second-growth conifer stands in British Columbia
Associated forest cover		Typically a subcanopy species in forests dominated by Douglas-fir, western hemlock, Pacific silver fir, grand fir, western redcedar, and bigleaf maple
Habitat	**Sites**	Often most prevalent in riparian areas and on gentle slopes in low-elevation conifer, hardwood, and mixed forests
	Soils	Moist, well-drained soils; tolerant of acidic, nutrient-poor soils; soil texture ranges from clay to sandy loam
	Moisture	Considered a mesic species but also very drought tolerant; high flood tolerance
	Temperature	Low frost tolerance; moderate heat tolerance; often occurs on exposed slopes
	Shade tolerance	Moderate shade tolerance; often present under partial canopies; maximum photosynthetic potential is reached in 33 percent of full sunlight
Interspecific interactions	**Animal damage**	Browse damage is greatest on sprouts and seedlings established after disturbance
	Mycorrhizal fungi	Other species of the genus *Cornus* are mycorrhizal

Reproduction and Growth

Mode of reproduction		Reproduces sexually and vegetatively; monoecious; readily sprouts after disturbance
Reproductive phenology		May flower twice per growing season; first flowering occurs from April to June; second flowering in late summer or fall may not produce fruit; fruit from first flowering ripens in September or October
Pollination		Primarily insect-pollinated
Seed	**Seed type**	Tight cluster of 20 to 40 slightly flattened red drupe
	Seed-bearing age	Minimum seed-bearing age is 10 to 15 years
	Seed size/ weight	Averages 4,700 seeds per lb (10,360 seeds per kg); drupes are approximately 0.4 to 0.6 in (10 to 15 mm) long
	Seed longevity/	Based on minimal evidence, seed may be part of the soil seed bank; seed of

	survivability	*Cornus florida* has been stored successfully for 7 years at 19 °F (-7 °C)
	Seed crop and frequency	Reports are inconsistent; heavy seed crops may occur every 1 or 2 years
Seed dissemination	**Time of year**	Fruit ripens in September or October
	Method and dispersal agents	Not formally studied, although seed probably dispersed by birds and small mammals
	Distance	Unknown
Germination requirements		Germination is relatively high; exposed mineral soil benefits germination
Seedling survival		Reports conflict; some indicate greater reproduction in shade and some indicate greater reproduction in sunlight

Genetics

Genetic diversity	Low genetic diversity based on microsatellites
Heterozygosity (H_e)	0.468
Geographic differentiation	Very high population differentiation based on microsatellites
F_{st} or G_{st}	0.9

Threats and Management Considerations

Insects and disease	Dogwood anthracnose, caused by the non-native fungus *Discula destructiva*, is the primary pathogen in the Pacific Northwest; spreads rapidly; causes leaf spot, trunk cankers, branch dieback, and sometimes death; fungal activity is greatest when conditions are moist during the growing season
Harvest	Not a commercial timber species
Fragmentation	Widespread in western Washington
Fire	Sprouts from the root crown after fire
NatureServe Conservation Status Ranking	G5 Secure—Common; widespread and abundant
Silvicultural considerations	Frequently planted as an ornamental

References

Arno and Hammerly 2007, Bonner and Karrfalt 2008, Gucker 2005, Kier and Aitken [n.d.], Klinka et al. 2000, USDA NRCS 2010

Black hawthorn and Suksdorf’s hawthorn (*Crataegus douglasii and C. suksdorfii*)

Ecology

Taxonomy and nomenclature		Black hawthorn in Washington was formerly known as a single species (*Crataegus douglasii*) with two varieties: var. *suksdorfii* and var. *douglasii*; these varieties are now accepted as separate species, although inventories and some earlier publications treated these as a single species, called black hawthorn; here we refer to both species where information is available at that level
Description		A deciduous, broadleaf shrub or small tree reaching 20 ft (6 m) in height; often found in thickets; stems crooked; broad, brambly crowns of thorny branches
Distribution		*Crataegus douglasii* occurs in the coastal Pacific Northwest from southeastern Alaska to northern California; inland distribution occurs from Alberta and Saskatchewan south to Utah and Colorado; occurs both west and east of the Cascade Range in Washington; disjunct populations occur as far east as Minnesota, Michigan and Ontario, Canada; *Crataegus suksdorfii* occurs mainly in coastal regions from Alaska to northern California; in Washington it is primarily west of the Cascade crest
Successional stage		Occasionally an early seral species, but typically found in established forest stands
Associated forest cover		Occur in a wide variety of forest types owing to their broad distribution; most often occur as understory species; occasionally found in pure stands
Habitat	**Sites**	Both species occur on a range of sites including open woodlands, riparian areas, and steep slopes; found in moist areas but also on relatively dry southern aspects; occurs at low- to mid-elevations
	Soils	Most often found on deep, moist soils
	Moisture	Achieve best growth on moist sites; found in wetlands and on drier upland sites
	Temperature	Unknown, although the range suggests a degree of cold tolerance
	Shade tolerance	Intermediate shade tolerance; best growth in full sunlight; typically occurs in understory
Interspecific interactions	**Animal damage**	Leaves and twigs are browsed by deer
	Mycorrhizal fungi	Genus *Crataegus* is mycorrhizal

Reproduction and Growth

Mode of reproduction	Sexual and vegetative; both *C. douglasii* and *C. suksdorfii* exhibit polyploidy and are known to reproduce by apomixis; monoecious; sprouts from stumps and roots
Reproductive phenology	Flower around May in Washington; fruits ripen around August
Pollination	Insect-pollinated

Seed	**Seed type**	Cluster of black, fleshy pomes, approximately 0.4 in (11 cm) in diameter; as many as five seeds per fruit
	Seed-bearing age	Unknown
	Seed size/ weight	22,600 cleaned seeds per lb (49,800 seeds per kg)
	Seed longevity/ survivability	Unknown
	Seed crop and frequency	Produce many viable seeds; one British Columbia study found that trees averaged 550 fruits
Seed dissemination	**Time of year**	Beginning around August when fruits ripen and continuing into winter
	Method and dispersal agents	Fruits are an important food source for wildlife; fruits are consumed by deer, small mammals, and birds during fall and winter
	Distance	Unknown
Germination requirements		Cold stratification and acid scarification have been successfully used to break dormancy
Seedling survival		Little information available on natural regeneration; artificial regeneration difficult; seedling growth slow; seedlings develop long taproots

Genetics

Heterozygosity (H_e)	0.73 using chloroplast microsatellites
Geographic differentiation	Strong population differentiation
F_{st} or G_{st}	0.22 using nuclear microsatellites

Threats and Management Considerations

Insects and disease	Insects and diseases are not a major problem, reported diseases include fireblight, cedar-hawthorn rust, cedar-quince rust, leaf blight, fruit rot, and leaf spot
Harvest	Not a commercial species
Fragmentation	Widespread in western Washington
Fire	Top-killed by low- or high-severity fire; sprouts from root crown and roots following top-kill
NatureServe conservation status ranking	G4 Apparently Secure—Uncommon but not rare; some cause for long-term concern due to declines or other factors

References

Arno and Hammerly 2007, Habeck 1991, Jacobs et al. 2009, Lo et al. 2009, USDA NRCS 2010

Alaska yellow-cedar (*Cupressus nootkatensis*)

Ecology

Taxonomy and nomenclature		Also known as *Chamaecyparis nootkatensis*, *Xanthocyparis nootkatensis*, and *Callitropsis nootkatensis*
Description		A medium-sized, evergreen conifer, sometimes reaching a height of more than 130 ft (40 m); a slightly twisted stem with a drooping leader; forms a pyramidal crown at maturity; sparse branches and drooping scale-leaved foliage; thin, purplish bark becoming shaggy and gray at maturity
Distribution		In coastal mountain ranges from south-central Alaska to northern California; in Washington's Olympic and Cascade Ranges; less common south of Mount Rainier; usually at elevations between 2,000 and 7,500 ft (600 to 2,300 m), but occasionally to near sea level in the Olympics
Successional stage		Present in all successional stages; a pioneer species on subalpine, colluvial, and wetland sites; found in climax stands owing in part to its longevity (>700 years)
Associated forest cover		Often occurs individually or in small groups in conifer stands including mountain hemlock, Pacific silver fir, subalpine fir, western hemlock, noble fir, whitebark pine, and western white pine; occasionally found in pure stands
Habitat	**Sites**	Maritime climates, from low elevation to treeline; sometimes found at high elevations where its associates cannot survive; often found on harsh sites, such as thin soils or wet soils where other species grow poorly
	Soils	Thin organic or rocky soils; talus; soils low in nutrients; wet, poorly drained soils; best growth is on deep, well-drained soils but it cannot compete with its faster-growing associates on such sites
	Moisture	Moderately drought tolerant; high tolerance of flooding and saturated soils
	Temperature	Occurs where snow insulates the soil during winter
	Shade tolerance	Shade-tolerant; similar to Pacific silver fir in its shade tolerance; photosynthetic saturation reached at 60 percent of full sunlight
Interspecific interactions	**Animal damage**	Browse damage is uncommon
	Mycorrhizal fungi	Mycorrhizal with vesicular arbuscular species

Reproduction and Growth

Mode of reproduction	Reproduces sexually and vegetatively; monoecious; vegetative reproduction through layering
Reproductive phenology	Reproductive cycle spans three growing seasons in the northern portion of its range, two growing seasons in the southern portion; for the 3-year cycle, cones are initiated in year 1, pollination occurs in year 2, and cones mature in year 3; for the 2-year cycle, cones mature in the second year; flowers from April to June, 1 week after breaking dormancy; flowers earlier with decreasing elevation and latitude; cones reach maturity in September or October

Pollination		Wind-pollinated
Seed	**Seed type**	Globe-shaped cones 0.3 to 0.5 in (8 to 12 mm) in diameter with four to six scales; 2 to 4 winged seeds per scale; a British Columbia study found an average of 7.2 seeds per cone
	Seed size/ weight	Seeds 0.08 to 0.20 in (2 to 5 mm) long; 108,000 seeds per lb (240,000 seeds per kg)
	Seed longevity/ survivability	Seeds may be stored at 32 °F (0 °C) for 3 to 5 years
	Seed crop and frequency	Heavy seed crops occur irregularly, at intervals of 4 or more years; produces a low percentage of sound seed; seed viability is both low and extremely variable
Seed dissemination	**Time of year**	Seed dispersal begins in October and continues through spring; seeds shed during dry periods
	Method and dispersal agents	Wind-dispersed
	Distance	Dispersal distance is likely less than 400 ft (120 m)
Germination requirements		Germination percentage is low; germination epigeal; germination best on mineral soil and well-decomposed organic matter; germination significantly increased by cold stratification after warm stratification
Seedling survival		Seedlings relatively shade-tolerant; regeneration primarily vegetative on open sites and in closed-canopy forests south of Mount Rainier

Genetics

Genetic diversity	Average genetic diversity
Heterozygosity (H_e)	0.15
Geographic differentiation	Moderate population differentiation
F_{st} or G_{st}	0.14
Genetic analysis research results	Seedlings from higher elevations generally had higher cold hardiness than seedlings from lower elevations

Threats and Management Considerations

Insects and disease	Insects and diseases are not a serious problem; wood is resistant to most fungal damage
Harvest	A valuable timber species; harvested in the northern portion of its range
Fragmentation	Distribution is sparse south of Mount Rainier and in parts of the Olympic Range
Fire	Fire is infrequent in its cool, wet habitat; susceptible to fire damage owing to thin bark

Other damaging agents	Dieback has been occurring in southeastern Alaska for more than a century; cause may be a climate-related decrease in snowpack depth leading to root frost damage
NatureServe conservation status ranking	G4 Apparently Secure—Uncommon but not rare; some cause for long-term concern due to declines or other factors
Silvicultural considerations	Vegetative reproduction of seedling stock is preferred method of regeneration owing to poor seed crops and germination

References

Arno and Hammerly 2007, Berube et al. 2003, Griffith 1992a, Harrington 2010, Harris 1990a, Hawkins et al. 1994, Klinka et al. 2000, Ritland et al. 2001, USDA NRCS 2010

Cascara (*Frangula purshiana*)

Ecology

Taxonomy and nomenclature		Also known as *Rhamnus purshiana*
Description		A deciduous, broadleaf, tall shrub or small tree, sometimes reaching 30 to 40 ft (9 to 12 m) in height; a broad, bushy crown composed of ascending branches; broad-leaved and deciduous; thin, grayish brown bark
Distribution		Southern British Columbia to northern California; primarily west of the Cascade Range but also occurs east to Idaho and western Montana
Successional stage		Occurs as an understory species in early to mid-seral stages of conifer or hardwood forests; sometimes occurs in late seral stages on wet sites
Associated forest cover		An understory species in a wide range of forest types in the coastal and interior Pacific Northwest; associates include Douglas-fir, western hemlock, western redcedar, Sitka spruce, red alder, Pacific silver fir, Pacific madrone, and Oregon white oak
Habitat	**Sites**	Moist, fertile coastal sites; lower mountain slopes; moist bottomlands; canyons east of the Cascade crest
	Soils	Prefers soils of moderate to high fertility, particularly nitrogen-rich soils
	Moisture	Tolerant of wet soils, flooding, and a highly fluctuating water table; tolerant of dry soils
	Temperature	Low frost tolerance; tolerant of heat
	Shade tolerance	Very shade-tolerant when young; moderately shade-tolerant at maturity
Interspecific interactions	**Animal damage**	Browsed by deer in winter despite low palatability; fruits consumed by a variety of bird species; bears may break branches to reach fruit
	Mycorrhizal fungi	Unpublished reports of mycorrhizal associates

Reproduction and Growth

Mode of reproduction		Reproduces sexually and vegetatively through layering and sprouting; monoecious; vegetative reproduction less common
Reproductive phenology		In Idaho, flowers from late May to early June, with fruit growth beginning in June; fruit mature by September; in California, flowers from April to July, with fruit maturing from July through September
Pollination		Insect pollination has been observed in some locations
Seed	**Seed type**	Purplish-black drupe about 0.3 in (8 mm) in diameter; drupe contains approximately three seeds
	Seed-bearing age	Unknown
	Seed size/ weight	Seed comprises approximate 20 percent of fruit by weight; cleaned averages 12,300 seeds per lb (27,100 seeds per kg) with a range of 5,000 to 19,000

		seeds per lb (11,000 to 41,850 seeds per kg)
	Seed longevity/ survivability	Unknown
	Seed crop and frequency	A prolific seed producer, although seed production is lower when growing in an understory position
Seed dissemination	**Time of year**	Fruits mature by September
	Method and dispersal agents	Birds are the primary dispersal agent
	Distance	Unknown
Germination requirements		Germination is relatively low; cold stratification required; germination increased by exposed mineral soil; germination greater in sunlight than in the understory
Vegetative phenology		In Idaho, budswell occurred in late April, leafout occurred in May, and stem growth occurred from early May through July

Threats and Management Considerations

Insects and disease	Low risk of serious damage
Harvest	Some populations have been heavily harvested or extirpated for the medicinal value of cascara’s bark; larger trees were preferentially harvested
Fragmentation	Widespread in western Washington, although its current distribution is likely influenced by historical harvesting practices
Fire	Usually top-killed by fire; sprouts from root crown
NatureServe conservation status ranking	G4/G5: G4 Apparently Secure—Uncommon but not rare; some cause for long-term concern due to declines or other factors/G5 Secure—Common; widespread and abundant; range indicates some uncertainty about the exact status; concerns over rather intensive exploitation in considerable portions of the species’ range
Silvicultural considerations	Usually regarded as a weed species in conifer plantations

References

Arno and Hammerly 2007, Habeck 1992b, USDA NRCS 2010

Oregon Ash (*Fraxinus latifolia*)

Ecology

Description		A medium-sized, deciduous, broadleaf tree typically reaching 60 to 80 ft (18 to 24 m) in height; a narrow crown in dense stands and a broad, spreading crown where open-grown; opposite branchlets; self prunes rapidly; dark gray-brown bark has deep, patterned fissures
Distribution		From western Washington south through western Oregon to central California; in Washington, occurs from the Puget Sound region south, in lowland valleys west of the Cascade Range but not in the Olympic Range
Successional stage		A pioneer and early seral species that regenerates after floods, windstorms, fire, or other disturbances create open habitat; replaced by more shade-tolerant species such as bigleaf maple and conifers
Associated forest cover		Occurs with red alder, bigleaf maple, black cottonwood, Oregon white oak, and willows (*Salix* spp.); occasionally occurs in small, pure stands in western Washington
Habitat	**Sites**	Found in lowlands and river valleys, most often in riparian habitats; occurs frequently in bottomlands, swamps, wet meadows and swales
	Soils	May occur on a wide range of soils, but most often found on deep, rich alluvial soils including those that are poorly drained or seasonally flooded
	Moisture	Tolerant of flooding and seasonally saturated soils; occurs in Oregon and California where annual precipitation is as low as 20 in (510 mm)
	Temperature	Temperatures are generally mild within its range; tolerates temperatures to -8 °F (-22 °C)
	Shade tolerance	Shade tolerance is low to intermediate
Interspecific interactions	**Animal damage**	Browsed by deer and elk; seeds consumed by birds and squirrels
	Mycorrhizal fungi	Other species in the same genus are associated with arbuscular mycorrhizae

Reproduction and Growth

Mode of reproduction		Reproduction is sexual (dioecious) and vegetative; stumps sprout vigorously
Reproductive phenology		Flowers appear at the same time as leaves in April or May
Pollination		Wind-pollinated
Seed	**Seed type**	Oblong to elliptical, single, winged samaras, 1 to 2 in (2.5 to 5 cm) long, including the wing; ripens in August or September, turning light brown
	Seed-bearing age	Seed production begins around age 30 years
	Seed size/ weight	Approximately 10,000 to 14,000 cleaned seeds per lb (22,000 to 31,000 per kg)

	Seed longevity/ survivability	Unknown; reported to have persistent viability
	Seed crop and frequency	An abundant annual seed producer where open-grown; produces heavy seed crops at 3- to 5-year intervals in forest stands
Seed dissemination	**Time of year**	Seed dispersed in September and October
	Method and dispersal agents	Winged samaras are dispersed by wind and are eaten by birds and squirrels
	Distance	Unknown
Germination requirements		Cool, moist stratification required; germination medium to high; germination highest on moist or wet soils with significant organic matter; germination epigeal
Seedling survival		Seedlings tolerant of drought; seedling growth rapid on rich soils; seedlings moderately shade-tolerant
Vegetative phenology		Leaves appear in April or May

Threats and Management Considerations

Insects and disease	A variety of insects and fungal pathogens have been reported on Oregon ash, although the extent and severity of resulting damage is not well-documented; the heart rot *Perenniporia fraxinophilus* is found in older trees; small weevils (*Thysanocnemis* spp.) may damage seed crops throughout the range of Oregon ash
Fire	Typically occurs on wet sites where fire is less common; sprouts vigorously after trees are top-killed by fire
Other damaging agents	Very wind-firm
NatureServe conservation status ranking	G5 Secure—Common; widespread and abundant
Silvicultural considerations	Often planted as an ornamental

References

Arno and Hammerly 2007, Owston 1990, USDA NRCS 2010, Wallander 2008

Rocky Mountain juniper (*Juniperus scopulorum*)

Ecology

Taxonomy and nomenclature		Based on a recent genetic analysis, Adams (2007, 2010) identified the *Juniperus scopulorum* populations in the Puget Sound region and Olympic Range as a separate species, *Juniperus maritima,* found only in this area; because the descriptions presented here follow nomenclature of the USDA Plants Database, we treat *J. scopulorum* and *J. maritima* as a single species
Description		An evergreen, coniferous shrub or small tree, occasionally reaching a height of 35 ft (10 m) or more; scale-like leaves and a ragged, bushy crown; a tapered stem with long branches; thin, reddish brown or grayish, fibrous bark
Distribution		Throughout the mountains and foothills of interior British Columbia southward to Arizona and New Mexico; occurs from sea level to 9,000 ft (2,740 m); occurs on Vancouver Island and other Puget Sound islands and on the surrounding mainland
Successional stage		Typically part of long-term seral or near-climax communities
Associated forest cover		Often in isolated clumps or with Pacific madrone, Oregon white oak, red alder, western white pine, whitebark pine, trembling aspen, or Douglas-fir
Habitat	**Sites**	Wide ecological amplitude; occurs on a variety of sites and landforms including rocky bluffs and southern exposures, ravines, and valleys; in western Washington, Rocky Mountain juniper occurs close to the shore of Puget Sound on rocky sites characterized by granite and sand; in eastern Washington, it occurs on dry, rocky, mountainous sites
	Soils	Although it occurs on a wide range of soil types, it is often found on shallow, poorly developed, stony, alkaline soils; in the Puget Sound region it occurs on droughty soils derived from granite
	Moisture	Tolerant of extremely dry sites
	Temperature	Tolerant of growing-season frost; tolerant of heat
	Shade tolerance	Tolerates shade when young; shade-intolerant at maturity
Interspecific interactions	**Animal damage**	Although palatability is poor, damage occurs when other sources of browse are limited; animals use trees as “rubbing posts”
	Mycorrhizal fungi	No mycorrhizal associates have been reported for this species

Reproduction and Growth

Mode of reproduction	Reproduction is sexual; dioecious; may be cultivated from cuttings
Reproductive phenology	Pistillate flowers appear in late summer; pollination occurs the following April; seed cones reach maturity by November or December of the second year after pollination and remain on the tree until approximately 24 months post-pollination; among Puget Sound populations of Rocky Mountain juniper, this period is only 14 to 16 months
Pollination	Wind-pollinated

Seed	**Seed type**	Globose to reniform berries 0.2 to 0.3 in (4 to 8 mm) in diameter; berries contain one to three seeds
	Seed-bearing age	Seed production begins as early as age 10 to 20; peak seed production occurs between ages 50 and 200
	Seed size/ weight	Averages 27,100 seeds per lb (59,700 seeds per kg); ranges from 18,000 to 42,000 seeds per lb (39,700 to 92,600 seeds per kg)
	Seed longevity/ survivability	Seeds may remain dormant for several years or longer
	Seed crop and frequency	Prolific seed producer; seed crops every year; heavy crops every 2 to 5 years; production greatest for open-grown trees
Seed dissemination	**Time of year**	Berries mature and fall from the tree in spring
	Method and dispersal agents	Seeds are dispersed primarily by birds and less frequently by mammals; some seeds dispersed by gravity and surface runoff
	Distance	Dispersal is primarily by birds and is therefore influenced by their daily and migratory movements
Germination requirements		Germination averages 22 to 45 percent; germination epigeal; seeds have both a seed-coat and a chemical dormancy; germination does not occur until 14 to 16 months after seeds reach maturity
Seedling survival		Seedling distribution is usually sparse; survival requires moisture often found in rock crevices or pockets; partial shade may assist establishment

Threats and Management Considerations

Insects and disease	Insects and fungal pathogens not a serious problem; blight caused by *Cercospora sequoiae* is the most serious disease
Harvest	Not a commercial timber species
Fragmentation	Puget Sound populations are small and scattered; because populations apparently originate from seed dispersed by birds, Rocky Mountain juniper has a scattered distribution
Fire	Vulnerable to damage from fire; seedlings, saplings, and small trees easily killed; larger trees survive surface fires
Other damaging agents	Very resistant to windthrow
NatureServe conservation status ranking	G5 Secure—Common; widespread and abundant
Silvicultural considerations	Difficult to grow from seed owing to prolonged dormancy; may be propagated from cuttings; often planted for restoration and reclamation purposes, windbreaks, and as an ornamental

References

Adams 2007, Adams et al. 2010, Arno and Hammerly 2007, Klinka et al. 2000, Noble 1990, Scher 2002, USDA NRCS 2010

Western crab apple (*Malus fusca*)

Ecology

Taxonomy and nomenclature		Also known as *Pyrus fusca* and *Malus diversifolia*
Description		A small, scraggly, deciduous, broadleaf tree, sometimes reaching 40 ft (12 m) in height; spreading branches with a rounded crown
Distribution		Coastal Pacific Northwest from Alaska to northern California; elevations from sea level to 1,000 ft (300 m); occurs throughout western Washington but only as a minor component of vegetation communities
Successional stage		An early seral species
Associated forest cover		Occurs with a variety of species; commonly found on sites also occupied by red alder, bigleaf maple, cascara, Oregon ash (*Fraxinus latifolia*), and Sitka willow (*Salix sitchensis*)
Habitat	**Sites**	Moist woods, swamps, edges of rivers, streams, estuaries, and lakes; brackish-water marshes; sites affected by ocean spray
	Soils	Moist soils; sandy to clayey in texture; prefers nutrient-rich wetland soils
	Moisture	Tolerant of prolonged soil saturation; intolerant of drought
	Temperature	Intolerant of extremely cold temperatures
	Shade tolerance	Moderately shade tolerant; best growth occurs in full sunlight
Interspecific interactions	**Animal damage**	Attracts wildlife, providing food and cover; wildlife damage not reported
	Mycorrhizal fungi	Other species in the genus *Malus* are associated with arbuscular mycorrhizae

Reproduction and Growth

Mode of reproduction		Reproduces sexually and vegetatively; monoecious
Reproductive phenology		Flowers in late spring, around May
Pollination		Insect-pollinated
Seed	**Seed type**	Egg-shaped, yellow-green to red pomes about 0.4 to 0.6 in (10 to 15 mm) in diameter, formed in dense clusters
	Seed-bearing age	Unknown
	Seed size/ weight	24,500 cleaned seeds per lb (54,000 seeds per kg)
	Seed longevity/ survivability	Unknown
	Seed crop and frequency	Abundant seed producer

Seed dissemination	**Time of year**	Fruit ripens in October to November and is disseminated through the winter
	Method and dispersal agents	Fruits consumed by birds, deer, elk, and bears
	Distance	Dependent upon animal vectors
Germination requirements		Usually germinates in late winter; requires cold stratification

Genetics

Genetic diversity	Above-average genetic diversity
Heterozygosity (H_e)	0.27

Threats and Management Considerations

Insects and disease	Unknown
Harvest	Not a commercial species
Fragmentation	Widespread in western Washington
Fire	Unknown
NatureServe conservation status ranking	G5 Secure—Common; widespread and abundant
Silvicultural considerations	Planted for restoration and wildlife purposes; tolerates wet and saline soils better than many associated species

References

Arno and Hammerly 2007, Dickson et al. 1991, Lyons 1999, USDA NRCS 2010

Engelmann spruce (*Picea engelmannii*)

Ecology

Description		A large, evergreen conifer sometimes reaching 130 ft (40 m) in height; a narrow, conical crown that extends to the ground; dense limbs with hanging branchlets; thin, purplish or reddish bark with flaking scales
Distribution		From British Columbia and Alberta south to Arizona and New Mexico, including all states from the Pacific Coast to the Rocky Mountains; occurs in Washington along the crest and eastern slope of the Cascade Range and in eastern parts of the state; most commonly found at elevations from 4,000 to 6,000 ft (1,220 to 1,830 m); small populations occur in the northeastern Olympic Range
Successional stage		A long-lived seral species found at all successional stages; sometimes occurs as a climax species
Associated forest cover		Common associates at high elevations are subalpine fir, Pacific silver fir, mountain hemlock, and whitebark pine; common associates at low to mid-elevations are western white pine, Douglas-fir, grand fir, and lodgepole pine; sometimes occurs in pure stands
Habitat	**Sites**	Occurs on moist and cool sites, at all aspects at higher elevations and at northern and eastern aspects at lower elevations within its range
	Soils	Occurs on a variety of soils formed in residuum, glacial and lacustrine deposits, and volcanic materials; water availability is more important than soil physical properties
	Moisture	Tolerant of wet soils; shallow root system; low drought tolerance; requires a relatively large amount of soil water; transpiration rate is much higher than that of subalpine fir or lodgepole pine
	Temperature	High tolerance of growing-season frost; relatively intolerant of heat
	Shade tolerance	Moderately shade-tolerant; less shade-tolerant than its true fir (*Abies*) associates or mountain hemlock
Interspecific interactions	**Animal damage**	Occasionally browsed; not a preferred species
	Mycorrhizal fungi	Associated with both ectomycorrhizae and arbuscular mycorrhizae

Reproduction and Growth

Mode of reproduction	Reproduction is sexual and vegetative; monoecious, with ovulate cones in the upper crown and staminate cones in the lower crown; vegetative reproduction occurs through layering
Reproductive phenology	Strobili formed in late April to early May; pollination occurs from late May at lower elevations to early July at higher elevations; cones mature in one season, ripening from August to early September
Pollination	Wind-pollinated

Seed	**Seed type**	Cones 1 to 1.25 in (2.5 to 6.3 cm) long; small, winged seeds
	Seed-bearing age	May begin seed production by age 15 to 40; production peaks between ages 150 and 250
	Seed size/ weight	135,000 seeds per lb (297,000 seeds per kg)
	Seed longevity/ survivability	Seed viability is persistent
	Seed crop and frequency	A moderate to good seed producer; large inter-annual and geographic variations in crop size; large seed crops occur every 2 to 5 years; some seed produced nearly every year
Seed dissemination	**Time of year**	Most seedfall occurs during September and October; some seed continues to fall through winter
	Method and dispersal agents	Seed primarily dispersed by wind
	Distance	Seed typically dispersed to 300 ft (90 m) or to 600 ft (180 m) when heavy seed crops occur
Germination requirements		Seed viability relatively high compared to associated species; seeds germinate after snowmelt when seedbeds are moist and air temperature warms above 45 °F (7 °C); seeds germinate on many types of mineral and organic substrates; germination occurs at all light intensities although 40 to 60 percent of full sunlight is optimal at high elevations
Seedling survival		Seedlings germinating on exposed mineral soil or humus seedbeds are most likely to become established; seedlings are very vulnerable to drought and heat girdling in their first year owing in part to slow initial root penetration and heat sensitivity; drought mortality often remains significant through the first 5 years

Genetics

Mating system	High outcrossing rate
Outcrossing % (t_m)	0.93
Genetic diversity	Average genetic diversity
Heterozygosity (H_e)	0.16
Geographic differentiation	Weak differentiation based on molecular markers
F_{st} or G_{st}	0.02
Patterns of variation	Engelmann spruce is considered intermediate with regard to adaptive strategy; both individuals and populations are suited to a broad range of environments, but populations still show habitat specificity

Genetic analysis research results	Intermountain west populations are differentiated for seedling characters with clines related to elevation and latitude; however, the clines are gentle, indicating low levels of genetic differentiation

Threats and Management Considerations

Insects and disease	Moderately susceptible to damage from insects and disease; vulnerable to insects including spruce beetle (*Dendroctonus rufipennis*), western spruce budworm, white pine weevil, and the ragged sprucegall adelgid; susceptible to rots including *Schweinitzii* butt rot, tomentosus root rot, and red ring rot
Harvest	A commercial timber species with wood qualities yielding quality pulp; a minor timber species in Washington
Fragmentation	Widespread in the Cascade Range of Washington; small, disjunct populations in the northeastern Olympic Range
Fire	Very susceptible to damage from surface and crown fires
Other damaging agents	Relatively susceptible to windthrow
NatureServe conservation status ranking	G5 Secure—Common; widespread and abundant
Silvicultural considerations	Planting of nursery stock preferred over direct seedling for regeneration

References

Alexander and Shepperd 1990; Arno and Hammerly 2007; Klinka et al. 2000; Rajora and Dancik 2000; Rehfeldt 1994a; Shea 1987, 1990; Uchytil 1991c; USDA NRCS 2010

Sitka spruce (*Picea sitchensis*)

Ecology

Description		A very large, evergreen conifer; the largest spruce species in the world, reaching 300 ft (90 m) in height on some sites; a wide, dense crown with hanging branchlets; thin, reddish-brown bark with large, loose scales
Distribution		Occupies a narrow coastal zone from south-central Alaska to northern California; in Washington, this zone also includes the shores of Puget Sound, the lower portions of major rivers, and the broad coastal plain on the west side of the Olympic Peninsula; elevations from sea level to 2,000 ft (600 m)
Successional stage		Both a pioneer and a climax species; a pioneer following disturbances on coastal sites; its presence is maintained in these forests owing to its longevity, its size, and its ability to regenerate in gaps
Associated forest cover		Occurs with western hemlock and western redcedar, also with bigleaf maple, red alder, and black cottonwood; less frequently found in pure stands
Habitat	**Sites**	Moist, well-drained coastal sites with a heavy maritime influence; riparian zones; does not grow well in swampy areas; high tolerance of ocean spray and brackish water compared to associated species
	Soils	Deep, well-aerated soils; often found on alluvial soils of medium to coarse texture; best growth occurs on soils high in calcium, magnesium, and phosphorus
	Moisture	Restricted to a zone of high annual precipitation, fog, and cool, moist summers; drought-intolerant; requires abundant moisture year-round
	Temperature	Low heat and frost tolerances; occurs in a mild, maritime climate
	Shade tolerance	Shade-tolerant; less shade-tolerant than hemlock but more shade-tolerant than Douglas-fir
Interspecific interactions	**Animal damage**	Incurs less animal damage than associated species; beaver dam flooding may cause mortality
	Mycorrhizal fungi	Ectomycorrhizal inoculation increased seedling growth

Reproduction and Growth

Mode of reproduction		Sexual and vegetative reproduction; monoecious; vegetative reproduction occurs through layering
Reproductive phenology		Reproductive cycle spans two growing seasons; reproductive buds appear in early summer of first year; pollination occurs around May of the second year, 7 to 8 weeks after dormancy is broken; timing depends on temperature; fruit ripens around August
Pollination		Wind-pollinated
Seed	**Seed type**	Cones 2.5 to 4 in (6 to 10 cm) long contain small, winged seeds; a British Columbia study found an average of 7.2 seeds per cone; only 29 percent were viable

	Seed-bearing age	Seed production begins between ages 20 and 40
	Seed size/ weight	210,000 seeds per lb (463,000 seeds per kg)
	Seed longevity/ survivability	Seed viability was maintained in a trial in which cones were stored for 5 months
	Seed crop and frequency	Good seed crops occur every 3 to 5 years; growing-season moisture may affect seed crop in subsequent year
Seed dissemination	**Time of year**	Seed dispersal begins around October and continues through spring; majority of seed released within first 6 weeks
	Method and dispersal agents	Wind-dispersed
	Distance	Wind carries seed 100 ft (30 m) to 0.5 mi (0.8 km) depending on topography and other factors
Germination requirements		Germination occurs on mineral and organic soils and on rotting logs; germination greatest in sunlight resulting from canopy gaps or disturbances such as windstorms
Seedling survival		Survival greatest in open areas, on mineral soil seedbeds where soil drainage is adequate; survival often greater on rotting logs than on the forest floor

Genetics

Mating system	High outcrossing rate
Outcrossing % (t_m)	0.98
Genetic diversity	Average genetic diversity
Heterozygosity (H_e)	0.165
Geographic differentiation	Weak differentiation based on molecular markers
F_{st} or G_{st}	0.08
Patterns of variation	Strong patterns of differentiation for height, growth period, bud set, and cold injury (Q_{ST} = 0.80), but not for growth rate and budburst (Q_{ST} = 0.29)
Genetic analysis research results	Southern populations (California) have higher growth and frost damage than northern (British Columbia) populations; clinal patterns related to climate, especially temperature variables; families within a single watershed in Alaska differed significantly in growth and phenology traits, genetic gradients were related to elevation, slope and aspect

Threats and Management Considerations

Insects and disease	Highly susceptible to insect damage when young, particularly white pine weevil (*Pissodes strobe*) and spruce beetle (*Dendroctonus rufipennis*); low susceptibility to fungal pathogens

Harvest	Historically heavily logged, particularly during World Wars I and II
Fragmentation	Widespread within its habitat
Fire	Fires are infrequent in its hypermaritime habitat; stem is damaged by low- or high-intensity surface fires
Other damaging agents	Windthrow
NatureServe conservation status ranking	G5 Secure—Common; widespread and abundant
Silvicultural considerations	Planted in the northwestern United States and in British Columbia

References

Arno and Hammerly 2007; Campbell et al. 1989; Chaisurisri and El-Kassaby 1994; Chaisurisri et al. 1994; Gapare and Aitken 2005; Gapare et al. 2005; Griffith 1992b; Harris 1990b; Klinka et al. 2000; Mimura and Aitken 2007a, 2007b; USDA NRCS 2010; Yeh and El-Kassaby 1980

Whitebark pine (*Pinus albicaulis*)

Ecology

Description		A small or medium-sized evergreen conifer reaching 80 ft (25 m) or more in height on some sites; slow-growing and long-lived; often multi-stemmed; long branches form an irregular, upswept crown; occurs as a low shrub or krummholz form near timberline; grayish-brown, scaly bark
Distribution		Two longitudinally oriented distributions; the coastal distribution reaches from the Coast Ranges of British Columbia through the Cascade Range and the Sierra Nevada; the interior distribution occupies the Rocky Mountains of British Columbia and Alberta southward through Idaho and Wyoming; in Washington, whitebark pine occurs in the Cascade and northeastern Olympic Ranges, primarily at elevations above 5,250 ft (1,600 m)
Successional stage		A pioneer species at all elevations within its range; an early seral species at its lower elevations; a climax species around timberline; in the upper timberline zone it may be the sole climax species
Associated forest cover		Occurs with subalpine fir, Engelmann spruce, lodgepole pine, mountain hemlock, and western white pine; pure whitebark pine stands occur at its highest elevations and on dry sites
Habitat	**Sites**	Exposed ridgetops and dry, rocky sites
	Soils	Found on a variety of soils types, although soils are generally rocky and poorly developed
	Moisture	Tolerates cool, droughty summer conditions; majority of precipitation occurs as snow; heavy snowpack is common
	Temperature	Tolerant of severe winter conditions; highly tolerant of frost; moderately tolerant of heat, although seedling may suffer heat damage
	Shade tolerance	Low to intermediate shade tolerance; less shade-tolerant than subalpine fir, Engelmann spruce, and mountain hemlock; more shade-tolerant than lodgepole pine but similar tolerance to western white pine
Interspecific interactions	**Animal damage**	High level of predation by species that disperse seed including Clark's nutcracker, pine squirrel (*Tamiasciurus* spp.), chipmunk (*Tamias* spp.), and deer mice (*Peromyscus* spp.)
	Mycorrhizal fungi	Associated with endomycorrhizae and ectomycorrhizae including *Cenococcum graniforme*

Reproduction and Growth

Mode of reproduction	Reproduces sexually and vegetatively; monoecious; vegetative reproduction is through layering, usually in its krummholz growth form
Reproductive phenology	Reproductive cycles spans two growing seasons; pollination occurs from May to August of the first year depending on elevation, latitude, and temperature; fertilization occurs 13 months after pollination and female cones ripen in August or September of the second year
Pollination	Wind-pollinated

Seed	**Seed type**	Egg-shaped cones 2 to 3.5 in (5 to 9 cm) long with large, wingless seeds
	Seed-bearing age	Seed production begins about age 20 to 30 years; full production reached at age 60 to 100 years
	Seed size/ weight	2,200 to 4,500 seeds per lb (4,850 to 9,900 seeds per kg)
	Seed longevity/ survivability	Apparently the only North American pine (*Pinus*) with a seed bank; seed has been stored successfully at sub-freezing temperatures for 8 years
	Seed crop and frequency	Individual trees produce large seed crops every 3 to 5 years; some seed produced every year at the stand level
Seed dissemination	**Time of year**	Seeds are dispersed by Clark's nutcracker when they ripen in the fall
	Method and dispersal agents	Clark's nutcracker is the primary dispersal agent; nutcrackers break open indehiscent cones using their beaks and then bury the seeds in shallow caches
	Distance	Many seeds cached within 1,640 ft (500 m) of source tree; emigrant nutcrackers cache seeds within 1.2 mi (2 km) of source trees; resident nutcrackers transport seeds an average of 6 mi (9.8 km) from source tree; some seeds have been transported as far as 18 mi (29 km)
Germination requirements		Seed must complete embryonic development, which often occurs after it is cached by Clark's nutcracker; stratification and seedcoat weathering required for germination; moist seedbed required; germination rate often low owing to these factors; germination epigeal
Seedling survival		Seedlings consumed by many animals including pocket gophers, elk, Clark's nutcracker and other bird species, and chipmunks; heat damage to unshaded seedlings may cause mortality
Vegetative phenology		Most growth occurs in mid-summer; growth rate is generally slow, and very slow on cold sites

Genetics

Mating system	Predominantly outcrossing but with moderate level of inbreeding present in some areas
Outcrossing % (t_m)	0.73-0.88
Genetic diversity	Genetic diversity average in Cascades; Olympic populations have somewhat lower diversity
Heterozygosity (H_e)	0.19 in Cascades, H_e = 0.16 in Olympics
Geographic differentiation	Weak differentiation based on molecular markers but strong differentiation based on quantitative traits
F_{st} or G_{st}	0.04
Patterns of variation	Q_{ST} = 0.36-0.47 for cold adaptation traits, 0.07-0.14 for growth traits

Genetic analysis research results	Significant population variation found in most traits; cold adaptation traits correlated with winter temperature while growth traits correlated with growing season length; predominantly outcrossing but some individuals highly inbreeding, although inbreeding depression detected only in biomass; northern and interior populations have highest cold hardiness in fall but lowest in spring and vice versa in the south

Threats and Management Considerations

Insects and disease	White pine blister rust, caused by *Cronartium ribicola*, is the most damaging pathogen; white pine blister rust increases susceptibility to mountain pine beetle, the most damaging insect; whitebark pine is affected to a much lesser extent by a number of other insects and fungal pathogens
Harvest	Rarely harvested
Fragmentation	Populations scattered owing to discontinuous distribution of habitat in high-elevation terrain
Fire	Fire benefits whitebark pine by reducing competition and creating new habitat in which it may establish; whitebark pine is more resistant to fire than its later-seral associates
Other damaging agents	Potential damaging agents include landslides and dwarf mistletoe
NatureServe conservation status ranking	G3/G4: G3 Vulnerable—At moderate risk of extinction or elimination due to a restricted range, relatively few populations, recent and widespread declines, or other factors/G4 Apparently Secure—Uncommon but not rare; some cause for long-term concern due to declines or other factors; range indicates some uncertainty about the exact status; populations of whitebark pine are affected by white pine blister rust, mountain pine beetle, and succession resulting from decades of fire suppression
Silvicultural considerations	Fire suppression has reduced regeneration of whitebark pine and increased the prevalence of shade-tolerant associates that overtop and shade whitebark pine; whitebark pine habitat is relatively inaccessible

References

Arno and Hammerly 2007; Arno and Hoff 1990; Aubry et al. 2008; Bonner and Karrfalt 2008; Bower and Aitken 2006, 2007, 2008; Bower et al., n.d.; Bruederle et al. 1998; Howard 2002; Jorgensen and Hamrick 1997; Klinka et al. 2000; Krakowski et al. 2003; Lorenz et al. 2008; Lorenz and Sullivan 2009; Rehfeldt 2004; Richardson et al. 2002a, 2002b, 2010; Rogers et al. 1999; Shoal and Aubry 2004; Shoal and Aubry 2006; USDA NRCS 2010; Ward et al. 2006; Warwell et al. 2006

Shore pine (*Pinus contorta* var. *contorta*)

Ecology

Taxonomy and nomenclature		Two of the four varieties of lodgepole pine (*Pinus contorta*) are native to western Washington; *Pinus contorta* var. *contorta* (shore pine) grows in the coastal region, and *Pinus contorta* var. *latifolia* (lodgepole pine) is typically found on interior mountains; these two varieties overlap and intergrade from the Puget Sound region northward
Description		A small, evergreen conifer reaching 20 to 50 ft (6 to 15 m) in height; stunted, frequently irregular crown with many branches often occurring to the ground; twisted stem with thick, grooved bark
Distribution		Along the Pacific Coast from southeastern Alaska to northern California; usually occurs at elevations lower than 2,000 ft (600 m)
Successional stage		An early seral species where it is replaced by Douglas-fir or other species; a climax species on many extreme sites where other species cannot grow
Associated forest cover		Extensive pure stands in the northern part of its range; a component of mixed stands in the southern part of its range including Washington; forms thickets or groves in mixed stands with a number of species including Douglas-fir, western redcedar, Sitka spruce, western hemlock, and Oregon white oak
Habitat	**Sites**	Occurs in a maritime climate throughout its range; bogs and lowlands; poorly drained sites; poor-quality, disturbed sites; coastal dunes and seaside bluffs
	Soils	Poorly drained, deep organic soils; swamps; sandy or rocky coastal soils; glacial gravel; bedrock; hardpan; disturbed soils; frequent on very nutrient-poor sites
	Moisture	Tolerates very dry to very wet, seasonally flooded sites
	Temperature	Tolerant of heat; frost-tolerant
	Shade tolerance	Intolerant of shade
Interspecific interactions	**Animal damage**	Seeds may be consumed by rodents
	Mycorrhizal fungi	Associated with ectomycorrhizae and arbuscular mycorrhizae

Reproduction and Growth

Mode of reproduction		Reproduction is sexual; monoecious
Reproductive phenology		Reproductive cycle lasts approximately 26 months; male and female strobili initiated in late summer; pollination occurs in May or June of the following growing season; fertilization occurs around June of the third year and seed development is completed by late summer
Pollination		Wind-pollinated
Seed	**Seed type**	Cones 1.5 to 2 in (4 to 5 cm) long; small, winged seeds; cones usually nonserotinous

	Seed-bearing age	Seed production usually begins by 10 years of age
	Seed size/ weight	135,000 seeds per lb (298,000 seeds per kg)
	Seed longevity/ survivability	Cones are persistent, remaining on trees for years open or closed; seeds have remained viable for 17 years at sub-freezing temperatures
	Seed crop and frequency	A prolific seed producer; large seed crops produced at 1- to 3-year intervals; some seed produced every year; seedfall in Oregon was measured at 14,000 to 500,000 seeds per ac (35,000 to 1,2000,000 seeds per ha)
Seed dissemination	**Time of year**	Seed from nonserotinous cones usually dispersed in late summer and fall and to a lesser extent in winter
	Method and dispersal agents	Seed primarily dispersed by wind; intense sunlight or fire opens serotinous cones; some seed dispersed by Douglas squirrels (*Tamiasciurus douglasi*), other rodents, or birds
	Distance	Seeds are usually dispersed less than 200 ft (60 m), although strong winds may carry them much farther
Germination requirements		Germination greatest in full sunlight on bare mineral soil or disturbed duff layer, assuming sufficient moisture; germination epigeal; stratification usually not necessary; germination rates high under favorable conditions
Seedling survival		Germinants very sensitive to dry conditions during first few weeks; seedlings shallow-rooted in first year and prone to drought mortality; young seedlings are prone to frost-heaving; seedlings are poor competitors relative to other herbaceous and woody vegetation
Vegetative phenology		Buds containing all the structures of the new shoots are formed throughout the previous growing season; these buds then begin to elongate around May; trees in coastal or mild climates often exhibit polycyclic shoot growth, with multiple periods of elongation during the growing season

Genetics

Genetic diversity	Average genetic diversity
Heterozygosity (H_e)	0.148
Geographic differentiation	Weak genetic differentiation based on molecular markers
F_{st} or G_{st}	0.054
Patterns of variation	Strong differentiation among varieties and populations within varieties based on morphometric traits
Genetic analysis research results	Cone serotiny is absent or infrequent in this subspecies. Levels of gene flow among coastal populations are lower and therefore differentiation is high than var. *latifolia*. This variety likely persisted in multiple coastal refugia during glaciation

Threats and Management Considerations

Insects and disease	Susceptible to insect and fungal damage; damaging agents include mountain pine beetle (*Dendroctonus ponderosae*), blister rust, gall rusts, stem rots, and stem cankers
Harvest	Shore pine is small and forms many branches, making it a poor species for timber production
Fragmentation	Widespread throughout its range
Fire	Low resistance to damage from fire; regenerates well following fire, but fire is infrequent in its maritime habitat
Other damaging agents	Dwarf mistletoe (*Arceuthobium* spp.) causes damage on a local scale
NatureServe conservation status ranking	G5 Secure—Common; widespread and abundant
Silvicultural considerations	Survives in saline coastal environments; used to stabilize soil and sand dunes

References

Anderson 2003; Arno and Hammerly 2007; Bonner and Karrfalt 2008; Cope 1993b; Despain 2001; Fazekas and Yeh 2006; Godbout et al. 2008; Klinka et al. 2000; Kurz et al. 2008; Lotan and Critchfield 1990; Owens 2006; Perry 1978; Perry and Dancik 1986; Rehfeldt et al. 2001; Rehfeldt et al. 1999; Rweyongeza et al. 2007; USDA NRCS 2010; Van Den Berg and Lanner 1971; Wagg et al. 2008; Wheeler and Guries 1982a, 1982b; Yang and Yeh 1993; Yeh et al. 1985; Yeh and Layton 1979; Ying 1991; Ying and Liang 1994

Lodgepole pine (*Pinus contorta* var. *latifolia*)

Ecology

Taxonomy and nomenclature		Two of the four varieties of lodgepole pine (*Pinus contorta*) are native to western Washington; *Pinus contorta* var. *contorta* (shore pine) grows in the coastal region, and *Pinus contorta* var. *latifolia* (lodgepole pine) is typically found on interior mountains; these two varieties overlap and intergrade from the Puget Sound region northward
Description		A small-to-medium, short-lived, evergreen conifer reaching 45 to 150 ft (13 to 45 m) in height, depending on the site; a straight, slender stem and a narrow, thin crown; self prunes lower branches; thin, gray-brown, scaly bark
Distribution		One of the most widely distributed conifers in western North America; from southeastern Alaska to northwestern Mexico; from the Pacific Coast eastward to South Dakota; in Washington, most common on the eastern slope of the Cascade Range, although also present on the western slope; found at elevations from 1,500 to 11,500 ft (450 to 3,500 m) throughout its range
Successional stage		An aggressive pioneer species frequently regenerating in single-aged stands after fire; replaced in less than 100 years by other conifer species on productive sites; a subclimax species on sites with periodic stand-replacing fire; a climax species on harsh sites where other conifers grow poorly or not at all
Associated forest cover		Often found in pure stands, but also occurs in mixed stands with a wide variety of other conifers including Douglas-fir, grand fir, western white pine, ponderosa pine, mountain hemlock, Engelmann spruce, subalpine fir, and Pacific silver fir
Habitat	**Sites**	Occurs in western Washington at mid- to high elevations; tolerant of nearly all sites but most prevalent on sites where periodic stand-replacing fire occurs or where extreme conditions limit establishment of other species; occurs on rocky soils and steep slopes and ridges
	Soils	Grows on nearly all soil types within its range; tolerates extreme conditions where other tree species cannot survive; often found on poorly developed, shallow, and nutrient-poor soils
	Moisture	Tolerates very dry to very wet, seasonally flooded sites
	Temperature	Tolerant of heat; frost-tolerant
	Shade tolerance	Intolerant of shade
Interspecific interactions	**Animal damage**	Not a preferred browse species; damaged by porcupines feeding on bark
	Mycorrhizal fungi	Associated with ectomycorrhizae and arbuscular mycorrhizae

Reproduction and Growth

Mode of reproduction	Reproduction is sexual; monoecious

Reproductive phenology		Reproductive cycle lasts approximately 26 months; male and female strobili initiated in late summer; pollination occurs in May or June of the following growing season; fertilization occurs around June of the third year and seed development is completed by late summer
Pollination		Wind-pollinated
Seed	**Seed type**	Cones 1.5 to 2 in (4 to 5 cm) long; small, winged seeds; cone serotiny is a function of disturbance type; percentage of serotinous cones is greatest where stand-replacing fire is most frequent
	Seed-bearing age	Seed production usually begins between 5 and 15 years of age
	Seed size/ weight	83,000 seeds per lb (183,000 seeds per kg)
	Seed longevity/ survivability	Cones are persistent, remaining on trees for many years open or closed; seeds in closed cones in the tree canopy may remain viable for 80 years; seeds have remained viable for 20 years in storage at sub-freezing temperatures
	Seed crop and frequency	A prolific seed producer; large seed crops produced at 1- to 3-year intervals; some seed produced every year; annual seed production in a nonserotinous stand was greater than 600,000 seeds per ac (1,500,000 seeds per ha)
Seed dissemination	**Time of year**	Seed from nonserotinous cones usually dispersed in late summer and fall and to a lesser extent in winter
	Method and dispersal agents	Seed primarily dispersed by wind; intense sunlight or fire opens serotinous cones; some seed dispersed by Douglas squirrels (*Tamiasciurus douglasi*), other rodents, or birds
	Distance	Seeds are usually dispersed less than 200 ft (60 m), although strong winds may carry seeds much further
Germination requirements		Germination greatest in full sunlight on bare mineral soil or disturbed duff layer, assuming sufficient moisture; germination epigeal; stratification usually not necessary; germination rates high under favorable conditions; laboratory germination was 65 to 90 percent
Seedling survival		Germinants very sensitive to dry conditions during first few weeks; seedlings shallow-rooted in first year and prone to drought mortality; young seedlings are prone to frost-heaving; seedlings are poor competitors relative to other herbaceous and woody vegetation
Vegetative phenology		Buds containing all the structures of the new shoots are formed throughout the previous growing season; these buds then begin to elongate around May; trees in coastal or mild climates often exhibit polycyclic shoot growth, with multiple periods of elongation during the growing season

Genetics

Mating system	Predominantly outcrossing with high outcrossing rate
Outcrossing % (t_m)	0.95

Genetic diversity	Average genetic diversity
Heterozygosity (H_e)	0.156
Geographic differentiation	Weak genetic differentiation based on molecular markers
F_{st} or G_{st}	0.036
Patterns of variation	Strong differentiation among varieties and populations within varieties based on morphometric traits
Genetic analysis research results	There is a relationship between geographic and genetic distance for this variety; recent interpretations of genetic and paleobotanical evidence seems to indicate a single glacial refugium south of the ice sheet and subsequent northward migration

Threats and Management Considerations

Insects and disease	Suffers extensive damage from insects and fungi, particularly mountain pine beetle(*Dendroctonus ponderosae*); also damaged by pine engraver, northern lodgepole pine needleminer, blister rust, gall rusts, stem rots, and stem cankers
Harvest	An important commercial species in the Pacific Northwest, especially in British Columbia
Fragmentation	Widespread throughout its range in western Washington
Fire	Low resistance to damage from fire; regenerates rapidly following fire
Other damaging agents	Dwarf mistletoe (*Arceuthobium* spp.) causes damage
NatureServe conservation status ranking	G5 Secure—Common; widespread and abundant
Silvicultural considerations	Natural regeneration following fire is sometimes too dense, and growth subsequently stagnates

References

Anderson 2003; Arno and Hammerly 2007; Bonner and Karrfalt 2008; Cope 1993b; Despain 2001; Fazekas and Yeh 2006; Godbout et al. 2008; Klinka et al. 2000; Kurz et al. 2008; Lotan and Critchfield 1990; Owens 2006; Perry 1978; Perry and Dancik 1986; Rehfeldt et al. 2001; Rehfeldt et al. 1999; Rweyongeza et al. 2007; USDA NRCS 2010; Van Den Berg and Lanner 1971; Wagg et al. 2008; Wheeler and Guries 1982a, 1982b; Yang and Yeh 1993; Yeh et al. 1985; Yeh and Layton 1979; Ying 1991; Ying and Liang 1994

Western white pine (*Pinus monticola*)

Ecology

Description		A medium-to-large, evergreen conifer, occasionally surpassing 200 ft (60 m) in height, but usually less than 120 ft (37 m) tall; crown is sparse with branches in distinct whorls; smooth grayish bark forming rectangular plates by maturity
Distribution		Coastal and interior distributions in the Pacific Northwest; coastal distribution extends from southwestern British Columbia to Tulare County, California; interior distribution extends from southeastern British Columbia to northern Idaho; in Washington, occurs from the coast to the Cascade Range and in the eastern part of the state; occurs in the Olympic Range from sea level to 1,800 ft (550 m) elevation; occurs in the Cascade Range at elevations below 3,000 ft (900 m)
Successional stage		Establishes after major disturbances including stand-replacing fires; may persist through all stages of secondary succession
Associated forest cover		Associated with numerous species including Pacific silver fir, grand fir, subalpine fir, noble fir, western hemlock, western redcedar, whitebark pine, and Engelmann spruce
Habitat	**Sites**	Most often occurs on moist sites on mountain slopes
	Soils	Occurs on a wide range of soil parent materials and textures; most abundant on poor sites where it is a strong competitor
	Moisture	Tolerant of wet soils and periodic flooding; tolerant of heavy snowpack; low drought tolerance
	Temperature	Moderate to high frost tolerance; relatively tolerant of heat
	Shade tolerance	Intermediate in shade tolerance relative to associated species
Interspecific interactions	**Animal damage**	Low palatability as browse; seeds consumed by squirrels and mice
	Mycorrhizal fungi	Associated with ectomycorrhizae and arbuscular mycorrhizae

Reproduction and Growth

Mode of reproduction		Reproduction sexual; monoecious
Reproductive phenology		Reproductive cycle lasts approximately 26 months; 15 months from pollination to seed maturity; pollen-cone buds differentiate around August; seed-cone buds differentiate around April of the year 2; flowering occurs around June, 8 weeks after dormancy is broken; fertilization occurs in year 3, approximately 12 months after pollination; seeds mature within 3 months of fertilization
Pollination		Wind-pollinated
Seed	**Seed type**	Cones 6 to 11 in (15 to 28 cm) long, containing single-winged seeds
	Seed-bearing age	Production of seed cones begins around age 10 to 15 years, and pollen cones are produced a few years later;

	Seed size/ weight	Seed weight ranges from 14,000 to 32,000 seeds per lb (30,900 to 70,500 seeds per kg) and averages 27,000 seeds per lb (59,000 seeds per kg)
	Seed longevity/ survivability	Seed viability 40 percent after one winter, 25 percent after the second winter, and less than 1 percent after 3 and 4 years; stored under sub-freezing conditions, seed remains viable for at least 20 years
	Seed crop and frequency	Heavy crops every 3 to 4 years; some cones produced nearly every year
Seed dissemination	**Time of year**	Seeds mature from mid-August to September depending on site and summer temperatures
	Method and dispersal agents	Seeds dispersed by wind, and to a lesser extent, by squirrels, mice, and birds
	Distance	Most seeds fall within 390 ft (120 m) of source tree; some seeds travel more than 2,600 ft (800 m)
Germination requirements		Requires a stratification period of 30 to 120 days under cold, moist conditions; dormancy likely controlled by seed coat, seed membrane, and embryo physiology; mineral soil increases germination; germination often occurs while surface soils are wet following snowmelt; strong genetic component to germination rate, with high family heritability; germination epigeal
Seedling survival		High mortality during first growing season owing to fungal pathogens, drought, heat, insects, birds, and rodents; on harsh sites, partial shade increases establishment; once established, growth best in full sunlight
Vegetative phenology		Height and radial growth begins in May or June depending on latitude, elevation, and aspect; shoot buds formed during previous spring and summer

Genetics

Mating system	Predominantly outcrossing with high outcrossing rate
Outcrossing % (t_m)	0.98
Genetic diversity	Average genetic diversity
Heterozygosity (H_e)	0.147
Geographic differentiation	Moderate genetic differentiation based on molecular markers
F_{st} or G_{st}	0.124
Patterns of variation	Population variation in quantitative traits within the northern and southern regions is weak or non-existent; western white pine is considered a “generalist” species with broad climate and environmental tolerances

Genetic analysis research results	Research has indicated two wide-ranging “populations” of western white pine; a broad “northern” population (Rocky Mountains, northern Cascades, and northern coastal areas) that have generally high growth potential and low cold hardiness, and a “southern” population in the Sierra Nevada with low growth potential and high cold hardiness; populations in the central and southern Cascades are arranged along a steep latitudinal gradient that connects the northern and southern population

Threats and Management Considerations

Insects and disease	Moderately susceptible to insect damage, primarily from mountain pine beetle and pine engraver; highly susceptible to fungal pathogens, of which the non-native white pine blister rust is the most devastating; seedlings with increased resistance to white pine blister rust have been planted since 1970
Harvest	A valuable timber species prized for the quality of its wood; heavily logged since the late 1800s
Fragmentation	In its coastal distribution, western white pine often occurs scattered throughout forests dominated by other species
Fire	A fire-dependent species, its extent decreased by fire suppression; high level of natural regeneration following stand-replacing fire; young trees often killed by fire; mature trees moderately resistant to fire damage
Other damaging agents	Pole blight led to extensive damage during the 1900s, caused in part by extreme weather conditions; pole blight is not currently a major cause of mortality
NatureServe conservation status ranking	G4/G5: G4 Apparently Secure—Uncommon but not rare; some cause for long-term concern due to declines or other factors/ G5 Secure—Common; widespread and abundant; range indicates some uncertainty about the exact status; populations of western white pine are affected by white pine blister rust and several species of bark beetles
Silvicultural considerations	West of the Cascade Range, the lack of stand-replacing disturbance is leading to a decline of western white pine; the prevalence of western white pine was greatly diminished during the 1900s by heavy logging, extensive wildfires, fungal diseases, and bark beetles

References

Arno and Hammerly 2007, Bishaw et al. 2003, Bonner and Karrfalt 2008, El-Kassaby et al. 1993, El-Kassaby et al. 1987, Graham 1990, Griffith 1992c, Kim et al. 2003, Kinloch et al. 1999, Klinka et al. 2000, Mehes et al. 2009, Owens 2004, Rehfeldt et al. 1984, Richardson et al. 2009, Steinhoff et al. 1983, USDA NRCS 2010

Ponderosa pine (*Pinus ponderosa*)

Ecology

Taxonomy and nomenclature		The variety of ponderosa pine occurring in Washington is *Pinus ponderosa* var. *ponderosa*; the other recognized variety is interior ponderosa pine (*Pinus ponderosa* var. *scopulorum*)
Description		A medium-to-large, evergreen conifer, often reaching 130 ft (40 m) in height; an open, conical crown with long branches bearing tufts of long needles; bark composed of large, scaly, orange-brown plates
Distribution		Occurs in the Pacific Northwest from southern British Columbia through California; other varieties of the species occur throughout the western United States; occurs in Washington from 330 to 4,950 ft (100 to 1510 m), primarily east of the Cascade crest; occurs to a limited extent in south Puget Sound lowlands and on Mount Rainier; stands on the Olympic Peninsula were planted; although not formally described, ponderosa pine west of the Cascade Range in the Pacific Northwest, and throughout nearly all of California, is also known as *Pinus ponderosa* var. *benthamiana*
Successional stage		An early seral species on higher-elevation or relatively moist sites, replaced by more shade-tolerant species; a climax species on harsh sites where other tree species cannot establish; on intermediate sites, ponderosa pine depends on recurring fire to maintain its dominance
Associated forest cover		Occurs in pure and mixed stands; succeeds to Douglas-fir, true firs, and lodgepole pine on moist sites; in climax stands, may occur with Rocky Mountain juniper, quaking aspen, lodgepole pine, or Oregon white oak; pure climax stands consist of a mosaic of small, even-aged groups
Habitat	**Sites**	Occurrence heavily influenced by its regeneration after fire, its fire tolerance at maturity, and its tolerance of sites too dry for other trees
	Soils	Occurs on a wide range of soil types; where moisture limits the presence of trees, its occurrence depends on soil moisture availability; in Washington, coarse-textured, sandy soils are more likely sites than clayey soils because grass and shrubs dominate the latter sites
	Moisture	High tolerance of seasonal drought and very dry sites; tolerant of flooding
	Temperature	Highly tolerant of heat; moderately tolerant of frost
	Shade tolerance	Intolerant of shade; often regenerates in even-aged groups or stands after fire
Interspecific interactions	**Animal damage**	Seeds consumed by small mammals and birds; a high proportion of seeds may be consumed in years of small crops; seedlings browsed by deer; seedlings may be damaged by rabbits or gophers
	Mycorrhizal fungi	Ectomycorrhizal fungi have been reported on ponderosa pine

Reproduction and Growth

Mode of reproduction	Reproduction is sexual; monoecious
Reproductive phenology	Reproductive cycle spans three growing seasons; reproductive buds initiated

		in year 1; pollination occurs between April and June of year 2; seeds ripen in late August or September of year 3
Pollination		Wind-pollinated
Seed	**Seed type**	Cones 3 to 6 in (8 to 15 cm) long; average number of seeds per cone varies by region, with 31 in Arizona and 70 in California
	Seed-bearing age	Cone production begins as early as age 7 years; seed production reaches its maximum level around age 60 years
	Seed size/ weight	Cleaned seeds vary from 6,900 to 23,000 seeds per lb (15,200 to 50,700 seeds per kg) and average 12,000 seeds per lb (26,500 seeds per kg)
	Seed longevity/ survivability	Seed stored at sub-freezing temperatures remained viable for 17 years
	Seed crop and frequency	Heavy cone crops produced every 4 to 5 years in the Pacific Northwest; in a heavy seed year 345,000 seeds per ac (850,000 seeds per ha) may be dropped
Seed dissemination	**Time of year**	Cones open in August or September and most seed is dropped by November
	Method and dispersal agents	Seeds dispersed by wind and, to a lesser extent, animals including Clark’s nutcracker
	Distance	Most seed falls within 100 ft (30 m) of the source tree; a small amount of seed falls beyond 400 ft (120 m) of the source
Germination requirements		Greatest regeneration results from a heavy seed crop, exposed mineral soil, and favorable growing-season weather; germination reduced by moisture stress; insects such as the ponderosa pine cone beetle (*Conophthorus ponderosae*) and the pine seed chalcid (*Megastigmus albifrons*) may destroy seed before germination; germination epigeal
Seedling survival		Survival reduced by moisture stress and competing vegetation; frost and high soil temperatures may cause mortality; seedlings may be destroyed by gophers or rabbits; seedlings can survive very dry conditions by reducing transpiration rates and vigorously extending root systems, including the taproot
Vegetative phenology		With increasing elevation, height growth begins later in the year and growing-season length is shorter; growth rate during the growing season does not change with elevation; radial growth begins about one month before height growth

Genetics

Mating system	Predominantly outcrossing with high outcrossing rate
Outcrossing % (t_m)	0.95
Genetic diversity	Above-average genetic variation
Heterozygosity (H_e)	0.23
Geographic differentiation	Weak genetic differentiation based on molecular markers

F_{st} or G_{st}	0.75
Patterns of variation	Strong population differentiation based on quantitative traits; ponderosa pine is considered intermediate with regard to adaptive strategy; both individuals and populations are suited to a broad range of environments, but populations still show habitat specificity
Genetic analysis research results	Inland Northwest populations differed for seedling growth and shoot elongation traits; differences followed relatively steep clines in elevation and gentle clines in latitude and longitude

Threats and Management Considerations

Insects and disease	Moderately susceptible to damage from insects and fungal pathogens; mountain pine beetles (*Dendroctonus* spp.), including *(D. brevicomis),* are the most damaging insects; beetles are a vector for blue stain fungus; pine engraver beetles (*Ips* spp.) also cause extensive damage; ponderosa pine is susceptible to numerous fungal pathogens, including western gall rust (*Endocronartium harknessii*) and root and butt rots
Harvest	Ponderosa pine is planted and harvested east of the Cascade crest
Fragmentation	Widespread east of the Cascade crest; isolated populations occur on Mount Rainier and in the southeastern part of the Puget Sound region
Fire	Ponderosa pine evolved under a regime of frequent fire that favored it over other species such as Douglas-fir and true firs that are less tolerant of fire; ponderosa pine seedlings are killed by fire, but large trees survive surface fires owing to thick bark and self-pruning of low branches; severe fires may kill trees via crown scorch
Other damaging agents	Dwarf mistletoes (*Arceuthobium* spp.) cause a significant amount of damage; heavy, wet snow may damage young trees; high ozone levels may cause foliar damage
NatureServe conservation status ranking	G5 Secure—Common; widespread and abundant
Silvicultural considerations	The structure of most ponderosa pine stands has been dramatically changed by fire suppression over the past century; formerly open, park-like stands now contain numerous small trees of ponderosa pine and other species; harvest of large trees has contributed to younger, denser stands; dense stands are less vigorous and more prone to disease and crown fire

References

Agee 1993; Arno and Hammerly 2007; Bonner and Karrfalt 2008; Carey et al. 1997; DeLucia et al. 1994; Gooding 1998; Habeck 1992a; Klinka et al. 2000; Mitton et al. 1981; Niebling and Conkle 1990; Oliver and Ryker 1990; Owens and Blake 1985; Rehfeldt 1991; Rotach 1997; Rygiewicz et al. 1997; Sorensen 1994a, 1994b; USDA NRCS 2010

Black cottonwood (*Populus balsamifera* ssp. *trichocarpa*)

Ecology

Taxonomy and nomenclature		Also known as *Populus trichocarpa*; one of two subspecies of *Populus balsamifera*
Description		A large, deciduous, broadleaf tree reaching heights of 160 to 200 ft (50 to 60 m); crown is broad and spreading when open-grown, but narrow in a closed canopy; few low branches; deeply furrowed, gray bark
Distribution		From Alaska's Kenai Peninsula to Baja, California; from the Pacific Coast east to Montana, Wyoming, and Utah; occurs from sea level to 5,000 ft (1,500 m) elevation in the Pacific Northwest; found at lower elevations throughout western Washington and on moist sites in eastern Washington
Successional stage		A fast-growing pioneer and early seral species found on disturbed sites
Associated forest cover		Often found on alluvial sites with willows (*Salix* spp.), red alder, Sitka spruce, and bigleaf maple; may form pure stands as a pioneer but associates with conifers and other hardwoods in subsequent seral stages; found with Douglas-fir, western hemlock, western redcedar, grand fir, black hawthorn, cherry (*Prunus* spp.), and Oregon ash; east of the Cascade Range, associated with western white pine, ponderosa pine, Douglas-fir, quaking aspen, and Douglas maple
Habitat	**Sites**	Most prevalent on low-elevation, alluvial sites and in disturbed areas in western Washington; occurs in valleys and canyon bottoms, riparian zones, and other moist sites in central and eastern Washington
	Soils	Most often occurs on the deep alluvial silts and sands of floodplains, but also found on upland sites where moisture is sufficient; occurs on soils of moderate to high fertility; best growth occurs on well-drained soils
	Moisture	Tolerant of flooding and sediment deposition; tolerant of a fluctuating water table; intolerant of drought; intolerant of brackish water
	Temperature	Moderate frost tolerance; moderately tolerant of heat
	Shade tolerance	Very intolerant of shade
Interspecific interactions	**Animal damage**	Voles, mice, and rabbits may damage seedlings; occasional browse damage from ungulates
	Mycorrhizal fungi	Recently established or flooded trees may be associated with arbuscular mycorrhizae, although black cottonwood is more typically associated with ectomycorrhizae

Reproduction and Growth

Mode of reproduction	Reproduction is sexual and vegetative; typically dioecious; regenerates vegetatively from stump sprouts, from fragments of branches, and occasionally from root sprouts
Reproductive phenology	Flowers between early March and late May; prior to flowering, the next year's inflorescences begin to develop at leaf nodes

Pollination		Wind-pollinated
Seed	**Seed type**	Catkins 3 to 8 in (8 to 20 cm) long contain capsules with 30 to 50 seeds in each; seeds have long, white hairs
	Seed-bearing age	Seed production begins by age 10
	Seed size/ weight	95,000 to 190,000 seeds per oz (3,300 to 6,700 seeds per g)
	Seed longevity/ survivability	Initial viability high; under natural conditions, seed remains viable for less than 1 month; remains viable for at least 1 year in storage; storage temperatures should be between -11 and 23 °F (-24 and -5 °C)
	Seed crop and frequency	Abundant seed crop produced every year
Seed dissemination	**Time of year**	By late May to late June
	Method and dispersal agents	Seed is dispersed by wind and water
	Distance	Seed may be transported miles (kilometers) by wind or water
Germination requirements		Best seedbed is exposed mineral soil or new alluvium; seedbed moisture is vital to establishment; germination epigeal
Seedling survival		Major causes of mortality and damage are overtopping vegetation, insufficient moisture during the first month after germination, late or early frosts, and damage from rodents
Vegetative phenology		Leaf growth initiated after spring flowering; shoot elongation and leaf growth continues through the growing season

Genetics

Genetic diversity	Low genetic diversity
Heterozygosity (H_e)	0.06
Geographic differentiation	Weak genetic differentiation
F_{st} or G_{st}	0.063
Patterns of variation	Morphological traits exhibit abundant genetic diversity
Genetic analysis research results	Seedling common garden studies showed significant variation among populations for numerous traits such as survival, growth, leaf morphology, crown morphology, phenology, and rust incidence; differences were related to moisture conditions (mesic vs. xeric) and temperature (upper vs. lower canyon positions)

Threats and Management Considerations

Insects and disease	Low susceptibility to insect damage and fungal pathogens; a variety of fungal

	diseases including leaf rust (*Melampsora* spp.) have been observed in plantations
Harvest	Not a major timber species in natural stands; hybrids established in plantations
Fire	Highly susceptible to damage and top-kill from fire; sprouts following top-kill; establishes from seed after fire
Other damaging agents	Ice storms and heavy snowfall may cause significant damage; top damage from wind is common
NatureServe conservation status ranking	G5 Secure—Common; widespread and abundant
Silvicultural considerations	Clones of hybrid *Populus* grown for pulp, veneer, and lumber production; planted as a windbreak; often planted from cuttings

References

Arno and Hammerly 2007; Bergha et al. 2003; Boes and Strauss 1994; Bonner and Karrfalt 2008; DeBell 1990; Dunlap et al. 1994, 1995; Dunlap and Stettler 1996; Gornall and Guy 2007; Klinka et al. 2000; Steinberg 2001; Taylor and Boss 1975; USDA NRCS 2010; Weber and Stettler 1981

Quaking aspen (*Populus tremuloides*)

Ecology

Description		A small- to medium-sized, deciduous, broadleaf tree reaching 50 to 60 ft (15 to 18 m) in height; a narrow, domed crown with slender, bent limbs; smooth, thin, whitish bark
Distribution		Widest distribution of any native tree species in North America, from western Alaska across Canada to the Atlantic coast; occurs in the northern hardwood forests of the United States and throughout the Rocky Mountains south to Mexico, at increasing elevations at lower latitudes; less prevalent in the Pacific Northwest and California; in Washington, occurs in scattered locations west of the Cascade, as low as sea level in the Puget Sound region; much more common in Washington east of the Cascade crest
Successional stage		An aggressive pioneer species; maintains dominance where wildfire regularly occurs; a fire climax species in some locations; in the absence of fire, succeeds to shade-tolerant conifers
Associated forest cover		Associated with numerous species throughout its range; also occurs in pure stands and groves; east of the Cascade crest in Washington, quaking aspen occurs with scattered ponderosa pine and Douglas-fir
Habitat	**Sites**	Found on a variety of sites, where soil moisture is not limiting; east of Washington's Cascades, occurs in moist meadows, canyons, avalanche chutes, and riparian zones
	Soils	Found on numerous soil types; requires sufficient drainage and soil moisture, typically with a water table between 2 and 8 ft (0.6 and 2.5 m) below the surface
	Moisture	Occurrence is limited to sites with adequate drainage; does not tolerate long-term flooding; low tolerance of drought; drought stress lowers resistance to insects and disease
	Temperature	High frost tolerance; moderately tolerant of high temperatures
	Shade tolerance	Very intolerant of shade
Interspecific interactions	**Animal damage**	Occasional browse damage and girdling by ungulates and small mammals
	Mycorrhizal fungi	Roots are ectomycorrhizal

Reproduction and Growth

Mode of reproduction	Sexual and vegetative reproduction; primarily dioecious; commonly regenerates by sprouting from its vigorous, spreading root system; this sprouting results in large colonies of genetically identical stems
Reproductive phenology	Flowers in April or May; fruiting catkins reach maturity in May or June, 4 to 6 weeks after flowering; timing of flowering is influenced by air temperature
Pollination	Wind-pollinated

Seed	**Seed type**	Catkins approximately 4 in (10 cm) long; catkins contain several dozen capsules, each containing approximately 10 seeds; seeds surrounded by tufts of silky hairs
	Seed-bearing age	Flowers at age 2 to 3 years; large seed crops begin between ages 10 to 20 years; seed production reaches a maximum at 50 years of age
	Seed size/ weight	Cleaned seeds average 156,000 to 250,000 seeds per oz (5,500 to 8,000 seeds per g)
	Seed longevity/ survivability	Under favorable conditions, seeds remain viable for 2 to 4 weeks after reaching maturity; storage tests have produced varied results, but seed should be stored between -11 and 23 °F (-24 and -5 °C)
	Seed crop and frequency	Heavy seed crops every 4 to 5 years; light seed crops in other years
Seed dissemination	**Time of year**	Seeds dispersed beginning a few days after they ripen in May or June; dispersal continues for 3 to 5 weeks
	Method and dispersal agents	Seeds dispersed by wind and water
	Distance	Seeds carried by wind for distances of 1,600 ft (500 m) to several miles (kilometers)
Germination requirements		Seeds germinate within days of dispersal; germination requires a water-saturated substrate; bare mineral soil is best seedbed; seeds may germinate underwater or in the dark; seed viability 80 to 95 percent; germination epigeal
Seedling survival		Seedling mortality is high; survival reduced by insufficient moisture, high soil temperatures, the brief period of seed viability, and fungal pathogens; natural thinning of dense, young stands is rapid, whether stems are of seed or sprout origin
Vegetative phenology		Leaf growth initiated after spring flowering; shoot elongation and leaf growth continues through the growing season

Genetics

Genetic diversity	Above-average genetic diversity
Heterozygosity (H_e)	0.32
Geographic differentiation	Weak genetic differentiation based on molecular markers
F_{st} or G_{st}	0.03
Patterns of variation	Strong population differentiation in phenotypic traits
Genetic analysis research results	Substantial phenotypic variation has been found in both field and common garden studies; populations throughout the range in the western United States varied in leaf size and shape, a trail that was strongly correlated with latitude; while high levels of genetic diversity have been observed in quaking aspen, it also commonly grows as large clonal stands, some of which are thought to be tens of thousands of years old and potentially the largest living organisms on

	earth, covering dozens of hectares

Threats and Management Considerations

Insects and disease	Low susceptibility to insect damage; although many defoliating insects attack quaking aspen, damage is usually not serious; quaking aspen is moderately susceptible to damage from a wide variety of fungal pathogens including butt and root rots, cankers, shoot and leaf blight, leaf spot, and leaf rust
Harvest	A fast-growing species capable of producing timber under even-aged silvicultural systems in the inland West; not an important timber species in Washington
Fragmentation	Populations are scattered and infrequent in western Washington
Fire	Highly susceptible to fire damage; fires kill trees or damage them to an extent that fungal pathogens can exacerbate the injury; fires may kill or damage shallow roots; quaking aspen regenerates vigorously following stand-replacing fire
NatureServe conservation status ranking	G5 Secure—Common; widespread and abundant
Silvicultural considerations	The combination of fire suppression and grazing has reduced the extent of aspen in the western United States

References

Arno and Hammerly 2007, Barnes 1975, Bonner and Karrfalt 2008, De Woody et al. 2009, Howard 1996, Jelinski and Cheliak 1992, Kanaga et al. 2008, Klinka et al. 2000, Namroud et al. 2005, Ostry and Anderson 2009, Perala 1990, Rehfeldt et al. 2009, St. Clair et al. 2009, USDA NRCS 2010, Yeh et al. 1995

Bitter cherry (*Prunus emarginata*)

Ecology

Taxonomy and nomenclature		There are two recognized varieties of bitter cherry: *Prunus emarginata* var. *mollis*, the variety described here, is a small tree occurring west of the Cascade crest, and *Prunus emarginata* var. *emarginata* is a shrub found east of the Cascade crest
Description		A small, short-lived, deciduous, broadleaf tree reaching 50 ft (15 m) or more in height; spreading and ascending branches; smooth, reddish-brown bark
Distribution		From British Columbia to southern California; in Washington, widespread west of the Cascade Range from sea level to 3,000 ft (900 m) elevation; found most often in ponderosa pine ecosystems east of the Cascades
Successional stage		An early seral species; declines in frequency as the canopy closes; scattered in young hardwood and conifer forests
Associated forest cover		A minor component of numerous early seral cover types; colonizes open areas; in eastern Washington, associates include Douglas maple, Scouler's willow, and chokecherry; may occur in dense, pure stands
Habitat	**Sites**	Typically occurs on moist, low- to mid-elevation sites; often found near water; requires at least partial shade on dry, exposed slopes
	Soils	Occurs on loamy, sandy, and gravelly soils; often found on nutrient-poor and acidic soils
	Moisture	Most often occurs on moist soils; tolerant of flooding and a fluctuating water table; infrequent on dry sites
	Temperature	Moderately tolerant of heat; frost damage typically not a problem
	Shade tolerance	Tolerant of partial shade; grows best in full sunlight
Interspecific interactions	**Animal damage**	Commonly browsed by deer and elk
	Mycorrhizal fungi	Other species in the genus *Prunus* are associated with arbuscular mycorrhizae and ectomycorrhizae

Reproduction and Growth

Mode of reproduction		Reproduction is sexual and vegetative; monoecious; vegetative reproduction by root collar and root sprouts
Reproductive phenology		Flowers between April and June; fruit ripens from July through September
Pollination		Insect-pollinated
Seed	**Seed type**	Red drupe-like ovoid fruit 0.25 to 0.55 in (6 to 14 mm) in diameter containing one seed; seed surrounded by a stony endocarp
	Seed-bearing age	Unknown; other North American *Prunus* species flower by age 4 and bear fruit by age 10
	Seed size/	Ranges from 4,120 to 8,790 cleaned seeds per lb (9,060 to 19,340 seeds per

	weight	kg); averages 7,020 seeds per lb (15,440 seeds per kg); 1 pound seed extracted from 4 pounds fruit
	Seed longevity/ survivability	Seeds remain viable in soil and duff for many years
	Seed crop and frequency	Prolific producer of seed
Seed dissemination	**Time of year**	August through September
	Method and dispersal agents	Birds, bears, and small mammals
	Distance	Unknown; dependent on movement of birds and mammals
Germination requirements		Undergoes embryo dormancy; after-ripening period necessary for germination; requires exposure to moisture and oxygen during after-ripening; cold stratification for 90 to 160 days increases germination
Seedling survival		Regeneration abundant where adequate sunlight and exposed mineral soil occur

Threats and Management Considerations

Insects and disease	Numerous insects and fungal pathogens are associated with the genus *Prunus*; susceptible to stem- and root-rot fungi
Harvest	Not a commercial timber species
Fragmentation	Widespread throughout its range in Washington
Fire	Top-killed by fire; sprouts vigorously after top-kill; high-severity fire favors bitter cherry over associated species
NatureServe conservation status ranking	G5 Secure—Common; widespread and abundant
Silvicultural considerations	Propagated from seed and cuttings; planted for land reclamation and slope stabilization

References

Arno and Hammerly 2007, Esser 1995, Klinka et al. 2000, USDA NRCS 2010

Douglas-fir (*Pseudotsuga menziesii*)

Ecology

Taxonomy and nomenclature		There are two varieties of Douglas-fir: *Pseudotsuga menziesii* var. *menziesii*, the variety described here, occurs along the Pacific Coast, and *Pseudotsuga menziesii* var. *glauca* occurs predominantly in the Rocky Mountains
Description		A large, evergreen conifer reaching heights over 250 ft (75 m), with a dense conical to columnar crown of long branches; lower branches are self-pruned except for open-grown trees; deeply furrowed, reddish brown bark
Distribution		From west-central British Columbia to central California; var. *menziesii* occurs from the coast through the Cascade Range, from sea level to around 5,000 ft (1,520 m) elevation in Washington; var. *glauca* occurs from central British Columbia throughout the Rocky Mountains and into central Mexico
Successional stage		A long-lived species occurring in all stages of secondary succession; west of the Cascade crest it typically regenerates in nearly pure stands following large-scale, stand-replacing disturbances including wildfire, logging, and windthrow; a pioneer, but owing to its longevity, it often remains a major component of such stands for well over 300 years; also a major or minor component of old-growth stands; east of the Cascade crest, Douglas-fir is often a late-successional species
Associated forest cover		The most dominant tree species in the region; in western Washington, Douglas-fir typically regenerates after disturbance as a pure stand or as the dominant species; associates include western hemlock, western redcedar, Pacific silver fir, Sitka spruce, grand fir, red alder, bigleaf maple, and shore pine; east of the Cascade crest, common associates are ponderosa pine, grand fir, lodgepole pine, and western larch (*Larix occidentalis*)
Habitat	**Sites**	Competes well on a wide range of sites, at all slopes, aspects, and on most soils
	Soils	Shallow to deep soils derived from a broad range of parent materials; texture ranges from clay to sand; fertility ranges from low to very high
	Moisture	Intolerant of flooding and shallow water tables; tolerant of very dry soils
	Temperature	Low frost tolerance; intolerant of temperatures below 14 °F (-10 °C) for more than 1 week; moderate heat tolerance
	Shade tolerance	Intermediate shade tolerance; shade tolerance decreases with age
Interspecific interactions	**Animal damage**	New growth of young trees is highly palatable and often browsed by deer and elk; small mammals, birds, and insects destroy seeds; impact is greatest in years of low seed production
	Mycorrhizal fungi	Associated with arbuscular mycorrhizae and ectomycorrhizae

Reproduction and Growth

Mode of reproduction	Reproduction is sexual; monoecious

Reproductive phenology		The reproductive cycle last approximately 17 months; reproductive primordia develop throughout the growing season prior to the cone crop; flowering and pollination occur between March and May of the following year, 7 to 8 weeks after dormancy is broken; cones ripen between mid-August and mid-September; phenology strongly influenced by elevation and latitude; pollen shedding is delayed by 1 day for each 77-ft (23-m) increase in elevation
Pollination		Wind-pollinated
Seed	**Seed type**	Cones 2 to 4 in (5 to 10 cm) long, primarily in the upper crown; cones usually contain 26 to 50 seeds; seeds have a large, single wing
	Seed-bearing age	Cones may be produced by age 10 years or younger; significant seed production does not begin until age 20 to 30 years
	Seed size/ weight	Seed weight is highly variable but averages 39,300 cleaned seeds per lb (86,600 seeds per kg)
	Seed longevity/ survivability	Under natural conditions, seed remains viable for 1 or occasionally 2 years; seed has been successfully stored at 0 °F (-18 °C) for 27 years
	Seed crop and frequency	Seed production is irregular; heavy crops occur every 5 to 7 years, and crop failures occur at the same frequency; in heavy crop years, most of the seed is produced by only about 25 percent of trees
Seed dissemination	**Time of year**	Seedfall begins in August or September; the majority of seeds are often dropped by the end of October, but some seedfall continues throughout winter
	Method and dispersal agents	Seeds are primarily dispersed by wind; small amounts of seed are dispersed by small mammals and birds including Clark’s nutcracker
	Distance	Most seed falls within 330 ft (100 m) of the source tree; a small portion of seed may be dispersed as far as 0.6 to 1.2 mi (1 to 2 km)
Germination requirements		Germination occurs between March and May, depending on climate; seed viability typically only 40 to 50 percent, sometimes less; germination best on moist mineral soil
Seedling survival		Seedling survival highest on bare mineral soil or mineral soil with light litter layer; excessive heat and drying results in mortality; first-year growth limited by moisture availability; onset of dormancy occurs in mid-summer of first year; first-year survival increased by shade; growth in subsequent years greater under full sunlight
Vegetative phenology		Budburst occurs from May to early June; vegetative shoots elongate for approximately 6 weeks; most shoot growth occurs as part of this initial flush, although young trees also exhibit lammas growth if sufficient soil water is available; diameter growth begins in April and continues through October, given adequate moisture; diameter growth ceases in mid-summer on droughty sites; lateral bud primordia enlarge in June and July

Genetics

Mating system	Predominantly outcrossing with high outcrossing rate

Outcrossing % (t_m)	0.925
Genetic diversity	Average genetic diversity
Heterozygosity (H_e)	0.17
Geographic differentiation	Weak population differentiation based on molecular markers but strong for quantitative traits
F_{st} or G_{st}	0.043
Patterns of variation	Q_{ST} = 0.62, 0.34, 0.51 for fall cold injury, growth, and phenology traits, respectively; Douglas-fir is considered a specialist species, with fairly narrow climatic tolerances within populations
Genetic analysis research results	Probably the most studied Pacific Northwest conifer; substantial genetic variation has been found in many traits including spring and fall cold hardiness, drought hardiness, growth, phenology, and wood quality

Threats and Management Considerations

Insects and disease	Susceptible to numerous insects and fungal pathogens; significant damage results from shoestring root rot (*Armillaria mellea*), laminated root rot (*Phillinus weirii*), and red ring rot (*Phillinus pini*); Douglas-fir beetle is the most damaging insect
Harvest	The most important timber species in the region and one of the most important timber species in the world
Fragmentation	Old-growth forests are fragmented and infrequent; younger forests, both natural and planted, are ubiquitous
Fire	At maturity, more resistant to surface fire than many of its associates; older trees have thick bark and few low branches; historically, the moist Douglas-fir forests of western Washington burned in large, stand-replacing wildfires at intervals of approximately 300 to 500 years
Other damaging agents	High winds may cause significant windthrow when soils are wet; heavy snow and ice may cause top breakage
NatureServe conservation status ranking	G5 Secure—Common; widespread and abundant
Silvicultural considerations	By far the most frequently planted species in the region; regenerated in single-age silvicultural systems, rarely in multi-age systems

References

Aagaard et al. 1998, Aitken and Adams 1996, Anekonda et al. 2002, Arno and Hammerly 2007, Balduman et al. 1999, Bonner and Karrfalt 2008; El-Kassaby and Ritland 1996, El-Kassaby et al. 1981, Hawkins 2007, Hawkins and Stoehr 2009, Hermann and Lavender 1990, Hoffmann and Geburek 1995, Klinka et al. 2000, Krakowski and Stoehr 2009, Krutovsky et al. 2009, Li and Adams 1989, Shaw and Allard 1982, Silen 1963, St. Clair 2006, St. Clair et al. 2005, Uchytil 1991d, USDA NRCS 2010, Viard et al. 2001

Oregon white oak (*Quercus garryana*)

Ecology

Taxonomy and nomenclature		Known regionally as *Quercus garryana*, this is actually *Quercus garryana* var. *garryana*, one of three varieties of *Quercus garryana*; var. *fruticosa* (also known as var. *breweri*) and var. *semota* are shrub varieties occurring in California and Oregon
Description		A small-to-medium, deciduous, broadleaf tree reaching 80 ft (25 m) in height; long, crooked, ascending limbs form a spreading crown, except in dense stands where crowns are narrow; gray to grayish-brown, furrowed, scaly bark
Distribution		From Vancouver Island, British Columbia, to southern California; in Washington, occurs in the lowlands surrounding Puget Sound and south to the Columbia River; follows the Columbia River Gorge, and to a lesser extent, occurs in the foothills east of the Cascade Range; occurs from sea level to 3,800 ft (1,160 m) elevation in Washington
Successional stage		A pioneer species; a climax species where fire occurs frequently and on very dry sites where other trees cannot survive
Associated forest cover		Occasionally occurs as the sole tree species in oak woodlands and savannas; more frequently occurs with conifers and other hardwoods; often present as a mid-story species beneath Douglas-fir, although it cannot survive in that condition due to shade intolerance; also occurs with Oregon ash (*Fraxinus latifolia*), bigleaf maple, lodgepole pine, and grand fir
Habitat	**Sites**	Found on sites where other trees have historically been excluded by fire and on harsh sites where other species cannot survive or compete; occurs on a wide range of sites from seasonally flooded riparian zones to dry rock outcrops; in the Puget Sound region, typically occurs on plains and terraces of glacial origin
	Soils	Soil texture ranges from heavy clay to sandy glacial outwash; soil fertility ranges from poor to rich
	Moisture	High drought tolerance; tolerates flooding and a fluctuating water table
	Temperature	High tolerance of heat; frost damage is infrequent
	Shade tolerance	Shade-intolerant to moderately shade-tolerant; shade tolerance decreases with age; regenerates beneath a partial canopy but cannot survive at maturity if overtopped
Interspecific interactions	**Animal damage**	Seedlings browsed by deer and elk; seedling roots may be damaged by rodents
	Mycorrhizal fungi	Associated with numerous species of mycorrhizae

Reproduction and Growth

Mode of reproduction	Reproduces sexually and vegetatively; monoecious; vegetative reproduction typically occurs through root crown sprouts; sprouts prolifically after stem damage, harvest, or fire

Reproductive phenology		Reproductive primordia initiated in June, approximately 11 months before pollination; pollination occurs between April and June; flowering lasts approximately 1 week; acorns reach maturity from late August to September, 4 to 5 months after pollination
Pollination		Wind-pollinated
Seed	**Seed type**	Acorn usually 0.75 to 1.25 in (2 to 3 cm) in length with a shallow cup
	Seed-bearing age	Seed production begins between 20 and 40 years of age; production continues beyond age 180 years
	Seed size/ weight	Approximately 90 acorns per lb (200 per kg)
	Seed longevity/ survivability	Under natural conditions, acorns do not remain viable longer than the growing season after they are formed; acorns may be stored at near-freezing temperatures for two years, although they frequently germinate during storage
	Seed crop and frequency	In western Washington, crop size varies substantially by year, although some acorns are produced every year; heavy crops occur every 2 to 4 years; there is synchrony in crop size within a region (e.g., the Puget Sound region), but synchrony among regions occurs only in years of very high or very low production; production (dry weight) has been measured at 500 to 1,550 pounds per ac (560 to 1,740 kg per ha)
Seed dissemination	**Time of year**	Most acorns are dispersed from late August through September
	Method and dispersal agents	Gravity, small mammals, and birds, including Steller's Jays
	Distance	Squirrels and birds were observed transporting acorns from 30 ft (8 m) to 1,300 ft (400 m) from the source before burying, dropping, or consuming them
Germination requirements		Acorns begin to germinate in fall, when conditions are sufficiently warm and moist; germination hypogeal; acorn viability high; acorn moisture content must remain above 30 percent to maintain viability; predation is high as acorns are eaten by animals or damaged by insect larvae
Seedling survival		After germination, seedlings form a vigorous taproot; taproot enables survival on dry sites and where vegetative competition is severe; top dieback is common but seedlings frequently sprout from the root crown following dieback
Vegetative phenology		Leaves expand around the time of flowering; radial growth also is initiated at this time and continues through July; shoot elongation occurs primarily during May and June; leaf and flower primordia occupy the same overwintered bud

Genetics

Mating system	Predominantly outcrossing with high outcrossing rate
Outcrossing % (t_m)	0.962
Genetic diversity	Average genetic diversity
Heterozygosity (H_e)	0.17

Geographic differentiation	Strong population differentiation based on chloroplast microsatellites but weak differentiation based on nuclear microsatellites; relatively weak population differentiation for seedling traits
F_{st} or G_{st}	0.86 for chloroplast and 0.05 for nuclear microsatellites
Patterns of variation	Q_{ST} = 0.1 for growth and phenology, 0.3 for cold hardiness
Genetic analysis research results	High pollen flow among populations likely the reason for the low population differentiation in nuclear microsatellites; significant genetic clines exist for height, germinant emergence date, and cold hardiness. Height and germinant emergence were strongly correlated with environmental variables associated with summer aridity, while cold hardiness was strongly correlated with temperature differential and mean warmest month temperature

Threats and Management Considerations

Insects and disease	Host to numerous insects and fungal pathogens, although none are serious threats to survival; as a member of the white oak group, it is not susceptible to sudden oak death (*Phytophthera ramorum*)
Harvest	Not a major timber species; sometimes used for firewood; recognized as an important wildlife species on public lands
Fragmentation	Current range in Washington may have been influenced by Native Americans' transportation of acorns; since European settlement, distribution in western Washington has been heavily fragmented by agriculture, development, and expansion of conifer forests; most existing oak woodlands established after European settlement
Fire	Oregon white oak has evolved to tolerate fire; competing tree species are less tolerant of fire; seedlings and saplings may be top-killed by surface fire; larger trees have thick bark and are resistant to fire damage, particularly that of surface fires burning herbaceous fuels; Oregon white oak may sometimes recover from a growing-season crown fire
Other damaging agents	Invasive understory species such as Scotch broom (*Cytisus scoparius*) suppress oak regeneration; most Oregon white oak woodlands and savannas in western Washington have been invaded by conifers; in these invaded stands, oak trees become shaded and eventually die, although individual oak trees may survive for decades; this mortality can be prevented by removing invading conifers
NatureServe conservation status ranking	G5 Secure—Common; widespread and abundant
Silvicultural considerations	Some state-listed, threatened herbaceous species occur in the vicinity of Oregon white oak trees, but they are not dependent on the trees; some Oregon white oak plant associations are listed as imperiled or critically imperiled according to NatureServe (G2 or G1)

References

Agee 1993; Arno and Hammerly 2007; Devine et al. 2010; Gucker 2007; Hubert and Aitken, n.d.; Klinka et al. 2000; Marsico et al. 2009; Peter and Harrington 2002, 2009; Ritland et al. 2005; Stein 1990; USDA NRCS 2010

Pacific willow (*Salix lucida* ssp. *lasiandra*)

Ecology

Taxonomy and nomenclature		One of three subspecies of *Salix lucida*
Description		A deciduous, broadleaf, tall shrub or small tree reaching 50 ft (15 m) in height; stout, crooked limbs form a tall, shaggy crown; bark gray to black
Distribution		From interior Alaska south along the Pacific Coast to southern California; also occurs through the Rocky Mountains to New Mexico; in Washington, most prevalent west of the Cascade Range
Successional stage		A pioneering early seral species; rapidly colonizes disturbed sites, typically fresh alluvium; persists as a result of repeated flooding
Associated forest cover		Black cottonwood, red alder, other willows (*Salix* spp.), Oregon ash, bigleaf maple
Habitat	**Sites**	Along streams and rivers; in wetlands; low to middle elevations
	Soils	Typically occurs on alluvial deposits; soils may be of any texture, but are most often coarse-textured
	Moisture	Very tolerant of flooding and a fluctuating water table; occurs primarily near water
	Temperature	Unknown
	Shade tolerance	Shade-intolerant; will not regenerate in the shade of tall grasses
Interspecific interactions	**Animal damage**	Browsed by deer and elk; consumed by beaver in winter
	Mycorrhizal fungi	Species of the genus *Salix* are associated with both arbuscular mycorrhizae and ectomycorrhizae

Reproduction and Growth

Mode of reproduction		Reproduction is sexual and vegetative; dioecious; sexual reproduction more common; vegetative reproduction usually occurs through pieces of broken stem or branches; no root sprouting
Reproductive phenology		Flowers appear in the spring at the same time as the leaves; in Idaho, flowers from April to May, and fruit ripens and is dispersed from June to August
Pollination		Other *Salix* species are known to be pollinated by wind, insects, or both
Seed	**Seed type**	Fruits are capsules containing numerous, very small seeds with hairs
	Seed-bearing age	Unknown; other willows produce seed by age 10 years
	Seed size/ weight	11,500,000 cleaned seeds per lb (25,300,000 seeds per kg)

	Seed longevity/ survivability	Unknown; for other *Salix* spp. germination declines rapidly after 10 days; seed of *Salix* spp. has been successfully stored for 36 months at 14 °F (-10 °C) and for 44 months at -4 °F (-20 °C)
	Seed crop and frequency	A prolific seed producer
Seed dissemination	**Time of year**	Spring through early summer
	Method and dispersal agents	Seeds dispersed by wind and water
	Distance	Unknown; other willows disperse seeds very long distances (i.e., several miles (kilometers))
Germination requirements		Moist seedbed and sunlight required for germination; seeds landing on a moist seedbed germinate within 12 to 24 hours of dispersal; no seed dormancy; seeds begin photosynthesis as soon as they are moistened; germination rate is positively correlated with the amount of light seeds receive

Threats and Management Considerations

Insects and disease	Unknown; associated willow species are attacked by insects and fungal diseases although the extent of damage is not quantified
Harvest	Not a commercial timber species
Fragmentation	Widespread within its range and habitat
Fire	Fires infrequent in moist habitats where Pacific willow is often found; colonizes burned sites rapidly via prolific seed production; potential for sprouting following top-kill is unknown
Other damaging agents	May be heavily browsed; occurs on sites prone to disturbance by flooding
NatureServe Conservation Status Ranking	G5T5 Secure—Common; widespread and abundant
Silvicultural considerations	Well-suited for use in streambank stabilization

References

Arno and Hammerly 2007, Bonner and Karrfalt 2008, Lyons 1999, Uchytil 1989c, USDA NRCS 2010

Scouler’s willow (*Salix scouleriana*)

Ecology

Description		A deciduous, broadleaf, tall shrub or small tree reaching 40 ft (12 m) in height; often multi-stemmed; sprawling, twisted, stout limbs form a rounded crown; smooth to flaky bark
Distribution		From interior Alaska east to Manitoba and south through the western United States into Mexico; occurs at higher elevations (up to 10,000 ft; 3,050 m) with decreasing latitude; occurs in eastern and western Washington on upland sites and riparian areas
Successional stage		A persistent, early to mid-seral species; rapidly colonizes disturbed sites, including burned areas; sometimes persists into late seral stages east of the Cascade Range
Associated forest cover		Occurs in many different vegetation types but is rarely a dominant species; found in disturbed areas and gaps; semi-arid ponderosa pine-Douglas-fir forests
Habitat	**Sites**	Found on a wide range of sites, from moist floodplain sites and gravel bars to dry uplands east of the Cascade Range; most often found on upland sites and in transitional upland-riparian zones; capable of growing on drier sites than most other willow species; found on drier, low-elevation sites in the Pacific Northwest; common on depositional land forms including colluvial soils and glacial deposits
	Soils	Shallow to deep soils of a wide variety of parent materials; moderately well-drained to well-drained soils
	Moisture	Tolerant of a wide range of moisture conditions; often occurs on moist but well-drained sites as well as dry, shallow soils
	Temperature	Occurs in a mild, maritime climate in the Pacific Northwest but also tolerates greater temperature extremes in the Rocky Mountains
	Shade tolerance	Slight tolerance of shade; may persist beneath a thin canopy
Interspecific interactions	**Animal damage**	A preferred browse species, but very tolerant of browse damage
	Mycorrhizal fungi	Species of the genus *Salix* are associated with both arbuscular mycorrhizae and ectomycorrhizae

Reproduction and Growth

Mode of reproduction		Reproduction is sexual and vegetative; dioecious; sprouts vigorously from the root crown beneath the soil surface
Reproductive phenology		Flowering occurs between April and June; catkins appear before leaves; fruit ripens and is dispersed from May to July
Pollination		Insects are important pollinators
Seed	**Seed type**	Catkins bear capsules 0.2 to 0.3 in (5 to 8 mm) long that contain numerous, tiny seeds with hairs

	Seed-bearing age	Likely begins to produce by age 10 years
	Seed size/ weight	6,500,000 seeds per lb (14,300,000 seeds per kg)
	Seed longevity/ survivability	Seeds do not undergo dormancy; seeds remain viable for only a few days unless exposed to moisture; seed of *Salix* spp. has been successfully stored for 36 months at 14 °F (-10 °C) and for 44 months at -4 °F (-20 °C)
	Seed crop and frequency	Abundant seed crop
Seed dissemination	**Time of year**	Late spring
	Method and dispersal agents	Wind and water
	Distance	Seeds may be carried several miles (kilometers) by wind
Germination requirements		Seeds are short-lived and germinate within 12 to 24 hours of dispersal; moist mineral soil and sunlight required for germination; seed viability very high under laboratory conditions
Seedling survival		Survival is high where seedlings establish following a stand-replacing fire
Vegetative phenology		Buds develop in April and leaves appear in April or May; stem elongates from May through July; leaves are dropped between July and November, depending on moisture availability

Threats and Management Considerations

Insects and disease	Unknown; associated willow species are attacked by insects and fungal diseases although the extent of damage is not quantified
Harvest	Not a commercial timber species
Fragmentation	Widespread in Washington
Fire	Favored by fire owing to vigorous sprouting and rapid colonization of burned sites; moderately susceptible to fire damage; sprouts from belowground buds near the root crown following top-kill or damage; sprouts grow vigorously and increase overall crown size
NatureServe conservation status ranking	G5 Secure—Common; widespread and abundant
Silvicultural considerations	Competes vigorously with conifer seedlings

References

Anderson 2001b, Arno and Hammerly 2007, Bonner and Karrfalt 2008, Royle and Ostry 1995, USDA NRCS 2010

Pacific yew (*Taxus brevifolia*)

Ecology

Description		A long-lived, coniferous, evergreen, tall shrub or small tree rarely reaching 60 ft (18 m) in height; an often contorted, malformed stem; long branches form an irregular crown; thin, purplish, scaly bark
Distribution		Along the Pacific Coast from southeastern Alaska to central California; an inland distribution occurs from southeastern British Columbia into northern Idaho and adjacent states; occurs throughout western Washington, from the coast to the Cascade Range, although it is rare in the Coast Range south of the Olympic Peninsula; occurs at low to moderate elevations in the Cascade Range
Successional stage		Present in all stages of secondary succession, but uncommon in young stands; typically increases in cover with stand age; present in many climax communities and most prevalent in old-growth forests
Associated forest cover		Most often occurs beneath canopies of western hemlock, Douglas-fir, western redcedar, and Pacific silver fir; also found beneath Sitka spruce, ponderosa pine, and grand fir; sometimes occurs in moist microsites beneath Oregon white oak and Oregon ash
Habitat	**Sites**	Capable of growing on a wide range of sites; typically found in cool, moist, shaded locations in lowlands and mountains; also occurs on warm, dry, sites
	Soils	Occurs most often on deep, moist, well-drained soils; soil fertility ranges from poor to very high
	Moisture	Tolerant of flooding; moderately tolerant of drought; more abundant on moist sites
	Temperature	Moderately frost tolerant; moderately tolerant of heat
	Shade tolerance	The most shade-tolerant tree in the Pacific Northwest; may require shade on hot, dry sites; may establish and grow in deep shade but also can survive after canopy removal
Interspecific interactions	**Animal damage**	A preferred browse species of ungulates; may suffer damage from rabbits; may be heavily browsed in open areas, although delayed germination may reduce exposure to browsing
	Mycorrhizal fungi	Associated with arbuscular mycorrhizae; some observations of ectomycorrhizal associations in old-growth forests

Reproduction and Growth

Mode of reproduction		Reproduction is sexual and vegetative; dioecious; vegetative reproduction is through layering and stump sprouts
Reproductive phenology		In Washington, flowering occurs in June and fruit ripens between August and October; fruit is dropped around October
Pollination		Wind-pollinated
Seed	**Seed type**	Ovoid-oblong seed approximately 0.3 in (8 mm) long; seed is partially

		encased in a fleshy, cup-shaped aril; the seed has a bony inner seedcoat and a membranous outer seedcoat
	Seed-bearing age	Unknown; English yew (*Taxus baccata*) begins to bear seed at age 80
	Seed size/ weight	Cleaned seeds average 15,000 seeds per lb (33,100 seeds per kg)
	Seed longevity/ survivability	Some seeds germinate the first year and some germinate the second year; it is possible that a potion of seeds remain in the soil for many years before germinating; seed can likely be stored for many years at -4 to 0 °F (-20 to -18 °C)
	Seed crop and frequency	A prolific seeder; frequency of heavy crops is unknown
Seed dissemination	**Time of year**	Seeds ripen and are dispersed from August to October
	Method and dispersal agents	Seed falls to the ground or is taken from the tree by birds and rodents; rodents and some birds cache seed
	Distance	Some seed transported long distances by birds
Germination requirements		Seed germinates slowly over a period of at least 2 years; stratification required; germination epigeal; germination typically occurs in heavy organic matter
Seedling survival		Seedling establishment generally greater in the understory than in openings

Genetics

Genetic diversity	Average genetic diversity
Heterozygosity (H_e)	0.145
Geographic differentiation	Weak population differentiation based on molecular markers
F_{st} or G_{st}	0.096
Genetic analysis research results	Populations and individuals within populations differ significantly in taxane content

Threats and Management Considerations

Insects and disease	Insects and fungal pathogens are not a major concern
Harvest	Once harvested to produce the medication Taxol, which is now created synthetically or harvested from other *Taxus* spp. that are planted for that purpose
Fragmentation	Widespread, although sometimes infrequent throughout its range in Washington; rare in forests with a history of logging or recent fire
Fire	Very susceptible to fire; killed by light surface fires; most prevalent in stands with long fire-free intervals

NatureServe conservation status ranking	G4/G5: G4 Apparently Secure—Uncommon but not rare; some cause for long-term concern due to declines or other factors/ G5 Secure—Common; widespread and abundant; range indicates some uncertainty about the exact status; concerns are slow growth, the fact that it does not reproduce rapidly, its somewhat narrow ecological range, and loss of habitat as a result of logging activity
Silvicultural considerations	Pacific yew typically becomes most prevalent after centuries of stand development; it grows and reproduces slowly in the understory; Pacific yew released through complete overstory removal apparently undergoes stress but often adapts to the new conditions

References

Arno and Hammerly 2007, Bolsinger and Jaramillo 1990, Bonner and Karrfalt 2008; Busing et al. 1995, Daoust 1992, Doede et al. 1993, DiFazio et al. 1997, El-Kassaby and Yanchuk 1994, Griffiths et al. 1995, Klinka et al. 2000, Scher and Jimerson 1989, Tirmenstein 1990, USDA NRCS 2010, Wheeler et al. 1995

Western redcedar (*Thuja plicata*)

Ecology

Description		A long-lived, medium-to-large, evergreen conifer occasionally reaching 200 ft (60 m) in height; a pointed, conical crown of drooping branches; hanging sprays of scale leaves; thin, reddish, fibrous bark; a frequently tapered, fluted base
Distribution		Occupies coastal and interior ranges; coastal range extends from southeastern Alaska to northern California, including western Washington from the coast to the Cascade Range; less frequent on eastern slopes of the Cascades; interior range reaches from southeastern British Columbia into northern Idaho and includes northeastern Washington; common below 4,100 ft (1,250 m) in Washington
Successional stage		Occurs in all stages of succession; often considered a climax species because of its shade tolerance
Associated forest cover		Typically in mixed-species stands, often with Douglas-fir and western hemlock; also occurs with Sitka spruce, red alder, and black cottonwood
Habitat	**Sites**	Found on most low- and mid-elevation sites in western Washington, from forested swamps to shallow, rocky soils on slopes
	Soils	Occurs on a wide variety of soils and parent materials; soils range from very nutrient-poor to very nutrient-rich
	Moisture	Tolerant of wet soils and seasonal flooding; moderate drought tolerance
	Temperature	Low frost tolerance; moderately tolerant of heat; requires protection on hot, dry sites
	Shade tolerance	Very shade tolerant; nearly as tolerant as Pacific silver fir and western hemlock
Interspecific interactions	**Animal damage**	Preferred browse species for deer and elk; seedlings and saplings heavily browsed; bears occasionally strip bark to feed from sapwood
	Mycorrhizal fungi	Associated with arbuscular mycorrhizae; seedlings responsive to mycorrhizal inoculation

Reproduction and Growth

Mode of reproduction	Reproduces sexually and vegetatively; monoecious; vegetative reproduction occurs through layering, from fallen limbs, or from the branches of fallen trees; vegetative reproduction is most common in moist, closed-canopy stands; reproduction from seed is most common after disturbance
Reproductive phenology	Reproductive cycle lasts approximately 16 months, beginning in early June of year 1 with the initiation of cone primordia; 6 to 7 weeks after breaking dormancy in year 2, pollination occurs over a period of 1 to 2 weeks from mid-February (mild climates) to early April (higher elevations); fertilization occurs around late May; west of the Cascades, redcedar cones mature approximately 5 months after pollination
Pollination	Wind-pollinated

Seed	**Seed type**	Ellipsoid cones 0.4 to 0.6 in (10 to 14 mm) long; 8 to 14 seeds per cone; winged seeds
	Seed-bearing age	Seed production usually begins between ages 15 and 25 years; peak production occurs after age 70 to 80 years
	Seed size/ weight	Averages 414,000 seeds per lb (912,700 seeds per kg) ranges from 203,000 to 592,000 seeds per lb (448,000 to 1,305,000 seeds per kg); seeds 0.16 to 0.30 in (4 to 7.5 mm) in diameter including wings
	Seed longevity/ survivability	High initial viability; under natural conditions viability declines rapidly; viability remains high for 7 to 20 years stored at -4 °F (-20 °C)
	Seed crop and frequency	Relatively high capacity for regeneration; ranges from 100,000 to 1,000,000 seeds per ac (247,000 to 2,470,000 per ha); seed crops usually every other year for individual trees; heavy seed crops every 3 to 4 years
Seed dissemination	**Time of year**	Begins in September, peaks in October and November, and continues through February or March; warm, dry conditions may lead to earlier seedfall
	Method & dispersal agents	Seeds dispersed by wind; seeds have small wings; birds eat seeds but not a confirmed vector
	Distance	Adequate dispersal to 330 ft (100 m); seeds rarely found beyond 400 ft (122 m) from source
Germination requirements		Germinates well without stratification in fall, winter, or spring; germination minimal after first year; shaded mineral soil best for germination; mortality high during germination period and thereafter
Seedling survival		Seedling survival generally low; seedlings in exposed areas less tolerant of high soil temperatures, drought, and frost than associated species; high resistance to flooding; a preferred browse species
Vegetative phenology		Shoot elongation begins as early as mid-March, peaks in May, and ends between August and November; radial growth occurs from May to September

Genetics

Mating system	Outcrossing with widely varying but often substantial inbreeding
Outcrossing % (t_m)	0.72 (range 0.173–1.257)
Genetic diversity	Very low genetic diversity
Heterozygosity (H_e)	0.039
Geographic differentiation	Weak population differentiation
F_{st} or G_{st}	0.033
Patterns of variation	Generally low levels of population differentiation in quantitative traits have led to western redcedar being considered a “generalist” species with relatively wide climatic and environmental tolerances

Genetic analysis research results	Early isozyme studies found zero genetic diversity in seed from trees in Oregon and Washington; families with lower terpene content are more palatable to deer; interior populations (northern Idaho area) differ significantly in some growth and cold hardiness traits, but the clines are gentle and populations need to be >600 m apart in elevation or >2^{o} in latitude to be genetically differentiated

Threats and Management Considerations

Insects and disease	Insect damage infrequently a problem; often damaged by a variety of fungal pathogens; trunk decay more common than in associated species; *Phellinus weirii* most common rot fungus
Harvest	A valuable timber species harvested from second-growth stands and occasionally from old-growth stands
Fragmentation	Occurs in mixed-species forests throughout its range in Washington
Fire	More susceptible to fire damage than associated species; thin bark, low branches, flammable foliage; large trees less susceptible to fire; in western Washington, fire-return interval is long (50 to 350 years) in most stands containing western redcedar
Other damaging agents	Susceptible to windthrow on wet sites
NatureServe conservation status ranking	G5 Secure—Common; widespread and abundant
Silvicultural considerations	Increasingly planted although browse damage to planted seedlings is a concern; research is ongoing to develop browse-resistant trees; often relegated to sub-canopy positions by faster-growing conifers in mixed-species stands

References

Arno and Hammerly 2007; El-Kassaby et al. 1994; Glaubitz et al. 2000; Harrington 2010; Klinka et al. 2000; Minore 1983, 1990; O'Connell et al. 2001, 2004, 2008; Tesky 1992a; USDA NRCS 2010; Yeh 1988

Western hemlock (*Tsuga heterophylla*)

Ecology

Description		A medium-to-large evergreen conifer, occasionally reaching 200 ft (60 m) in height; a slender stem and a dense, narrow crown with a drooping leader; thin, reddish-brown bark becoming furrowed with age
Distribution		Coastal and inland ranges; coastal range extends from Alaska's Kenai Peninsula to central California; inland range extends through southeastern British Columbia into northern Idaho, northeastern Washington, and northwestern Montana; occurs from Washington's coast to the eastern slopes of the Cascade Range; less frequent east of the Cascade crest; occurs to an elevation of 3,500 ft (1,070 m) in western Washington and to 5,000 ft (1,500 m) in eastern Washington
Successional stage		A climax species; present in all stages of secondary succession; frequent in old-growth stands
Associated forest cover		Occurs in pure and mixed-species stands; in western Washington, most frequently occurs with Douglas-fir, Pacific silver fir, Sitka spruce, and western redcedar
Habitat	**Sites**	Grows best in mild, humid climates with growing-season fog and precipitation
	Soils	Tolerates soils of very low fertility including acidic, organic soils; tolerates soils of most textures, although growth rate is reduced on compacted or clayey soils
	Moisture	Low drought tolerance; intolerant of very shallow water tables; prefers well-drained soils
	Temperature	Low heat tolerance; intolerant of frozen soil; shallow-rooted and requires snowpack to insulate soil
	Shade tolerance	Very shade-tolerant; shade tolerance similar to Pacific silver fir and western redcedar
Interspecific interactions	**Animal damage**	Sometimes browsed by deer and elk, though not a preferred species; small stems may be clipped by rodents
	Mycorrhizal fungi	Associated with arbuscular mycorrhizae and ectomycorrhizae

Reproduction and Growth

Mode of reproduction	Reproduction is sexual and vegetative; monoecious; vegetative reproduction occurs through layering; seedlings may sprout from the root crown
Reproductive phenology	Pollen and seed cones differentiate in June and July, respectively, of the year prior to pollination; pollination occurs from mid to late April in Oregon and from late May to June in Alaska; seed cones mature 120 to 160 days after pollination, although time of maturation is variable within a tree
Pollination	Wind-pollinated

Seed	**Seed type**	Cones 0.75 to 1.25 in (19 to 32 mm) long containing 30 to 40 seeds with large wings
	Seed-bearing age	Regular cone production begins around age 25 to 30 years
	Seed size/ weight	Weight ranges from 189,000 to 508,000 seeds per lb (417,000 to 1,120,000 seeds per kg), with an average of 260,000 seeds per lb (573,000 seeds per kg)
	Seed longevity/ survivability	Seeds viable only during the first growing season after seedfall; seed can be stored at 0 °F (-18 °C) for 5 years or longer
	Seed crop and frequency	Mature trees produce abundant seed; some cones produced every year; heavy crops every 3 to 4 years; a 100-year-old stand produced 8,000,000 seeds per ac (19,800,000 seeds per ha) in good seed years
Seed dissemination	**Time of year**	Cone scales open and seeds drop in late October; most seeds shed in fall; cone scales open and close in response to atmospheric moisture
	Method and dispersal agents	Seed dispersed by wind
	Distance	In open stands, most seeds fall within 2,000 ft (600 m) of the parent tree, although some travel as far as 3,800 ft (1,150 m); distances are much less in dense stands
Germination requirements		Cold stratification increases germination; following stratification, germination rate increased by warmer temperatures; seeds germinate on mineral soil and a wide range of organic substrates, given sufficient moisture; decaying logs and rotten wood are favorable seedbeds; germination epigeal
Seedling survival		Mortality results when organic seedbeds become dry in direct sunlight; seedling survival is highest on mineral soil and other materials that provide adequate moisture; early growth is slow
Vegetative phenology		Vegetative phenology varies substantially by latitude; buds begin to swell in late March and burst around May; shoots elongate rapidly until early July; shoot elongation then slows and ends around August

Genetics

Mating system	Predominantly outcrossing with high outcrossing rate
Outcrossing % (t_m)	0.93
Genetic diversity	Average genetic diversity
Heterozygosity (H_e)	0.12

Genetic analysis research results	Differences in 5-year height among four populations in Washington and Oregon were significant, but variation among families within sites was not; in 5-year old seedlings, fall and spring cold hardiness and date of budburst increased and height growth decreased with latitude; significant variation was found in seed weight, number of cotyledons, and seedling growth rate, growth rate was related to soil and air temperature; seedlings in southern latitudes, middle elevations, and coastal provenances grew fastest, although a strong north-south cline exists in coastal provenances

Threats and Management Considerations

Insects and disease	Although many different insects attack western hemlock, damage is not a serious concern in coastal populations; fungal pathogens are more often a problem; common pathogens include Indian paint fungus, annosus root and butt rot, red ring rot, laminated root rot, *Armillaria* root disease, Schweinitzii butt rot, Douglas-fir needlecast, and black stain root disease; dwarf mistletoe (*Arceuthobium campylopodum*) is a common parasite
Harvest	An important commercial species harvested for timber and pulp
Fragmentation	While old-growth stands are fragmented, younger stands containing western hemlock are common throughout its range in western Washington
Fire	Very susceptible to fire damage owing to thin bark, shallow roots, low branches, and highly flammable foliage; fire-return interval is low (150 to 400 or more years) in the moist maritime stands where western hemlock is prevalent
Other damaging agents	Low resistance to windthrow
NatureServe Conservation Status Ranking	G5 Secure—Common; widespread and abundant
Silvicultural considerations	An extremely productive species; more productive than Douglas-fir on some sites; can be regenerated under many different silvicultural systems; responds well to release from suppression

References

Arno and Hammerly 2007; Bonner and Karrfalt 2008; El-Kassaby et al. 2003; Foster and Lester 1983; Hannerz et al. 1999; Klinka et al. 2000; Kuser and Ching 1980, 1981; Owens and Molder 1984; Packee 1990; Tesky 1992b; USDA NRCS 2010; Wellman et al. 2003, 2004

Mountain hemlock (*Tsuga mertensiana*)

Ecology

Description		A small-to-medium, evergreen conifer reaching 75 to 150 ft (23 to 45 m) in height depending on the site; a narrow conical crown of drooping and spreading branches; dark, thick bark becomes deeply furrowed and plated with age
Distribution		Along the Pacific Coast from the Kenai Peninsula of Alaska to central California, increasing in elevation southward; occurs in Washington in the Olympic Range and on the western slopes and relatively moist, upper eastern slopes of the Cascade Range; reported at elevations of 4,200 to 5,600 ft (1,300 to 1,700 m) in Washington's North Cascades
Successional stage		Occurs in all stages of succession; a long-lived climax species in most of its habitat
Associated forest cover		Occurs in mixed stands, less often in pure stands; near treeline occurs as scattered individuals or in clumps; occurs in mixed stands with Pacific silver fir, subalpine fir, and Alaska yellow-cedar; occurs less frequently with whitebark pine, Engelmann spruce, western white pine, lodgepole pine, western hemlock, western redcedar, and Douglas-fir
Habitat	**Sites**	Present in the highest forested zones; occurs on most landforms, but often in mixed stands on sheltered slopes, in draws, and on north-facing slopes
	Soils	Present on a wide range of soil types; fertility ranges from very poor to moderate; tolerant of organic soils, very acidic soils, and low nutrient availability
	Moisture	Low drought tolerance; usually found on moist soils; tolerates soils ranging from slightly dry to very moist; mean annual precipitation in its range is 107 in (272 cm), mostly as snow
	Temperature	Low tolerance of heat; moderate to high frost tolerance; low tolerance of frozen soil; requires snowpack to insulate soil in winter
	Shade tolerance	Shade-tolerant; exceeded in shade tolerance only by Pacific silver fir, western hemlock, and Alaska yellow-cedar
Interspecific interactions	**Animal damage**	Not reported
	Mycorrhizal fungi	Associated with arbuscular mycorrhizae with ectomycorrhizae

Reproduction and Growth

Mode of reproduction	Reproduction is predominantly sexual; monoecious; occasionally reproduces vegetatively through layering

Reproductive phenology		Reproductive cycle spans two growing seasons; pollen and seed cone differentiate in late July of year 1; cones develop until dormancy in October; ovules initiated after winter dormancy; post-dormancy development is strongly affected by temperature; flowering occurs in June or July, approximately 12 weeks after the end of dormancy, depending on elevation; seed cones receptive for 1 to 2 weeks; fertilization occurs around early August; seeds mature around mid-September; seedfall begins between late September and November, 90 to 120 days after pollination
Pollination		Wind-pollinated; pollen released on warm, dry days
Seed	**Seed type**	Cones are 0.75 to 3.5 in (2 to 9 cm) long; bear winged seeds
	Seed-bearing age	Seed production begins around age 20 years; mature trees (175 to 250 years) produce moderate to heavy cone crops
	Seed size/ weight	Averages 114,000 seeds per lb (251,300 seeds per kg); ranges from 102,000 to 207,000 seeds per lb (225,000 to 456,000 seeds per kg)
	Seed longevity/ survivability	Unknown under natural conditions; seed is stored at 0 °F (-18 °C), although success of long-term storage is likely variable and influenced by genetics
	Seed crop and frequency	Large seed crops occur about every 3 years; seed crops may be very low in other years; very heavy seedfall estimated at 87,000 to 1,677,000 seeds per ac (215,000 to 4,144,000 seeds per ha); warm summer in the previous year yields heaviest crops
Seed dissemination	**Time of year**	Majority of seedfall occurs when cones initially open between late September and November; warm, dry weather causes earlier seed release; wet, cool weather may delay release
	Method and dispersal agents	Seed predominantly wind-dispersed; occasionally consumed by birds
	Distance	Seed dispersed to approximately 500 ft (150 m) from source tree
Germination requirements		Moist organic soil, mineral soil, and snow are suitable substrates; cold stratification may increase germination; germination epigeal; germination ranges from 47 to 75 percent
Seedling survival		Young seedling growth best in partial shade; early growth slow; seedlings have relatively low drought tolerance; slow to regenerate in disturbed areas
Vegetative phenology		Late snowpack shortens the growing season; growth positively related to summer temperature, length of growing season, and depth of snowpack

Genetics

Genetic diversity	Average genetic diversity
Heterozygosity (H_e)	0.087
Geographic differentiation	Weak genetic differentiation based on molecular markers
F_{st} or G_{st}	0.077

Patterns of variation	Moderate population differentiation based on quantitative traits
Genetic analysis research results	Populations and families within populations in southern coastal British Columbia differed in height growth, fall cold hardiness, gas exchange, and biomass allocation, but most of the genetic variation was within populations (77 to 87 percent); populations from higher latitudes or elevations had higher growth rates and the variation was related to climate coldness

Threats and Management Considerations

Insects and disease	Susceptibility to insect and fungal damage generally low; prone to damage by *Phellinus weiri*; moderately susceptible to dwarf mistletoe
Harvest	Occasionally harvested in mixed stands; high-elevation stands have very limited access
Fragmentation	More susceptible to fragmentation as a result of climate change than as a result of direct human impacts (owing to high elevation sites); upward migration could lead to fragmentation
Fire	More susceptible to fire damage than its associates, owing to retention of low branches, flammable foliage, and occurrence in dense clusters; wildfire return interval is typically very long
Other damaging agents	Susceptible to windthrow owing to shallow root system
NatureServe conservation status ranking	G5 Secure—Common; widespread and abundant
Silvicultural considerations	Natural regeneration is slow after disturbance; early growth is slow; planting often ineffective at high elevations

References

Ally and Ritland 2007, Ally et al. 2000, Arno and Hammerly 2007, Benowicz and El-Kassaby 1999, Benowicz et al. 2001b, Bonner and Karrfalt 2008; Franklin and Krueger 1968, Klinka et al. 2000, Means 1990, Owens and Molder 1984, Tesky 1992c, USDA NRCS 2010, Woodward et al. 1994

APPENDIX C:
EVALUATION OF THE NATURESERVE CLIMATE CHANGE VULNERABILITY INDEX

BACKGROUND

The NatureServe Climate Change Vulnerability Index (NSVI) is a management tool designed to identify the vulnerability of plant and animal species to climate change (NatureServe 2010a). The NSVI also organizes user-collected information in a format that enables the user to identify underlying causes of vulnerability across multiple species.

From user-collected information on exposure and sensitivity to climate change, the NSVI calculates a score for each species' vulnerability within a specified geographic area. *Exposure* is defined as the magnitude of the predicted changes in temperature and precipitation across the species' range within the assessment area. *Sensitivity* relates to characteristics that increase a species' ability to adapt to significant changes in temperature and precipitation. Vulnerability scores consist of six categories ranging from *extremely vulnerable* to *not vulnerable*.

The NSVI vulnerability score for a single species is based on three categories of factors:

1. The combination of exposure and sensitivity to climate conditions projected for the year 2050. A species' sensitivity to climate change is calculated from up to 17 parameters including predicted sensitivity to temperature and precipitation changes, physical habitat specificity, dispersal ability, and interspecific interactions. Exposure to climate change is based on year-2050 temperature and precipitation predictions acquired online, calculated from provided GIS data, or derived from other climate models. The NSVI integrates sensitivity and exposure: the sensitivity of a species to climate change intensifies as its level of exposure increases.

2. Indirect exposure to this projected climate change. Indirect exposure to climate change includes exposure to rising sea level and a species' distribution relative to natural or anthropogenic barriers that potentially interfere with migration.

3. The species' documented response to climate change. Documented response to climate change is applied to species for which a documented or modeled response to climate variation already exists.

First released in 2009, the NSVI is a Microsoft Excel spreadsheet model that requires no computer modeling experience. However, basic familiarity with the ecological characteristics of the subject species facilitates collection of the required input data. Intended for use by management programs working with numerous species, the NSVI is most applicable to areas ranging from the size of a national park or wildlife refuge to the average size of a western U.S. state. The NSVI works independently of and complements the existing NatureServe conservation status ranking system (NatureServe 2010b). A detailed guide to applying of the NSVI is provided on the NatureServe website (NatureServe 2010a).

APPLYING THE NATURESERVE VULNERABILITY INDEX TO TREE SPECIES ON THE OLYMPIC PENINSULA

We tested the NSVI (release 2.0) as a potential tool for assessing the vulnerability of tree species in western Washington. Ideally, such a tool would assist managers in prioritizing species according to vulnerability and would reveal fundamental causes of vulnerability. Possible advantages of using the NSVI for this purpose are: (1) it is a relatively well-known index produced by a nationally recognized organization, (2) it provides a standardized approach that can be applied to both plants and animals in any ecosystem, and (3) it is readily available and relatively easy to use.

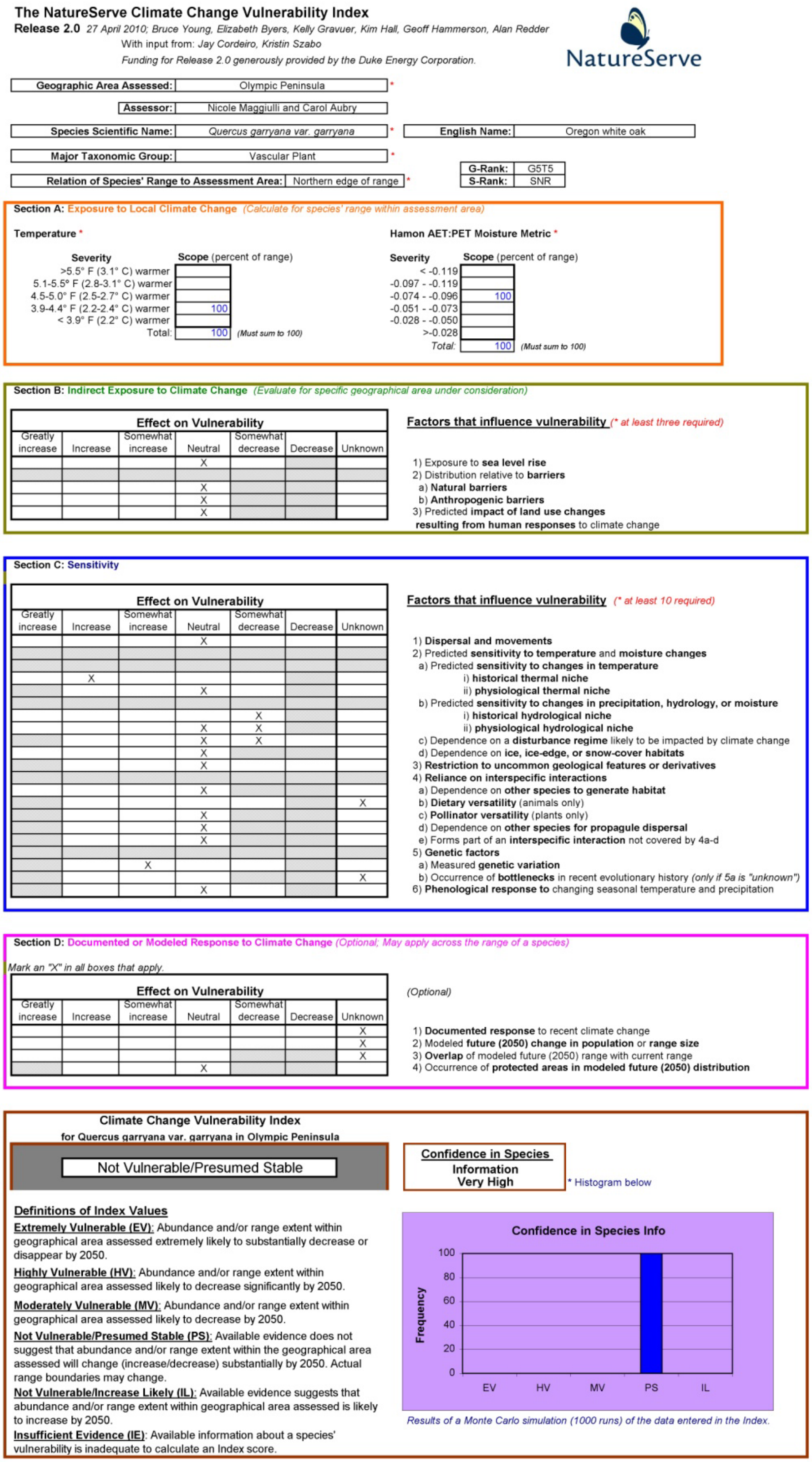
To evaluate the applicability of the NSVI to trees of western Washington, we tested the index on six tree species on the Olympic Peninsula: whitebark pine, golden chinquapin, Pacific yew, western white pine, Oregon white oak, and quaking aspen (table C-1). These six species vary in their distribution, life history, vulnerability to insects and disease, and represent a range of management challenges.

In the process of applying the NSVI, we collected information from several sources. For predicted local climate change exposure in the year 2050, we used temperature forecasts developed by the Climate Impacts Group at University of Washington (Littell at al. 2009c) and the Hamon AET:PET moisture metric predictions from data provided by NatureServe (Hamon 1961, NatureServe 2010a). We obtained historical climate data, which are used to determine species' sensitivity to changes in temperature and precipitation, from the online Climate Wizard tool (Girvetz at al. 2009), one of the NSVI's recommended sources for climate data. For each tree species, we gathered additional required information on sensitivity to climate change from a number of sources including *Silvics of North America* (Burns and Honkala 1990), the Fire Effects Information System (Fischer 2010), journal publications, and Forest Service reports. In cases where published information was not available, we consulted Forest Service personnel with knowledge of the species. An example of the completed worksheet for Oregon white oak is given in fig. C-1.

Table C-1. Six tree species from the Olympic Peninsula selected for evaluation with the NatureServe Climate Change Vulnerability Index

		NatureServe conservation status[1]		
Species	**Group**	**Washington state rank**	**Global rank**	**NatureServe vulnerability index score**
Chrysolepis chrysophylla Golden chinquapin	Evergreen, broadleaf	S2	G5	Highly vulnerable
Pinus albicaulis Whitebark pine	Evergreen conifer	SNR	G3/G4	Moderately vulnerable
Pinus monticola Western white pine	Evergreen conifer	SNR	G4/G5	Moderately vulnerable
Populus tremuloides Quaking aspen	Deciduous, broadleaf	SNR	G5	Not vulnerable, presumed stable
Quercus garryana Oregon white oak	Deciduous, broadleaf	SNR	G5	Not vulnerable, presumed stable
Taxus brevifolia Pacific yew	Evergreen conifer	SNR	G4/G5	Not vulnerable, presumed stable

[1] *S2 Imperiled*
SNR Not ranked at the state level
G5 Secure
G3/G4 Vulnerable/Apparently Secure Range indicates some uncertainty about the exact status.
G4/G5 Apparently Secure/Secure Range indicates some uncertainty about the exact status.



The NatureServe Climate Change Vulnerability Index
Release 2.0 *27 April 2010; Bruce Young, Elizabeth Byers, Kelly Gravuer, Kim Hall, Geoff Hammerson, Alan Redder*
With input from: *Jay Cordeiro, Kristin Szabo*
Funding for Release 2.0 generously provided by the Duke Energy Corporation.

NatureServe

Geographic Area Assessed: Olympic Peninsula *
Assessor: Nicole Maggiulli and Carol Aubry
Species Scientific Name: *Quercus garryana var. garryana* *
English Name: Oregon white oak
Major Taxonomic Group: Vascular Plant *
Relation of Species' Range to Assessment Area: Northern edge of range *
G-Rank: G5T5
S-Rank: SNR

Section A: Exposure to Local Climate Change *(Calculate for species' range within assessment area)*

Temperature *

Severity	**Scope** (percent of range)
>5.5° F (3.1° C) warmer	
5.1-5.5° F (2.8-3.1° C) warmer	
4.5-5.0° F (2.5-2.7° C) warmer	
3.9-4.4° F (2.2-2.4° C) warmer	100
< 3.9° F (2.2° C) warmer	
Total:	100 *(Must sum to 100)*

Hamon AET:PET Moisture Metric *

Severity	**Scope** (percent of range)
< -0.119	
-0.097 - -0.119	
-0.074 - -0.096	100
-0.051 - -0.073	
-0.028 - -0.050	
>-0.028	
Total:	100 *(Must sum to 100)*

Section B: Indirect Exposure to Climate Change *(Evaluate for specific geographical area under consideration)*

Effect on Vulnerability							
Greatly increase	Increase	Somewhat increase	Neutral	Somewhat decrease	Decrease	Unknown	**Factors that influence vulnerability** *(* at least three required)*
			X				1) Exposure to **sea level rise**
							2) Distribution relative to **barriers**
			X				a) **Natural barriers**
			X				b) **Anthropogenic barriers**
			X				3) Predicted **impact of land use changes resulting from human responses** to climate change

Section C: Sensitivity

Effect on Vulnerability							
Greatly increase	Increase	Somewhat increase	Neutral	Somewhat decrease	Decrease	Unknown	**Factors that influence vulnerability** *(* at least 10 required)*
			X				1) **Dispersal and movements**
							2) Predicted **sensitivity to temperature** and **moisture changes**
							a) Predicted **sensitivity to changes in temperature**
	X						i) **historical thermal niche**
			X				ii) **physiological thermal niche**
							b) Predicted **sensitivity to changes in precipitation, hydrology, or moisture**
				X			i) **historical hydrological niche**
			X	X			ii) **physiological hydrological niche**
			X	X			c) Dependence on a **disturbance regime** likely to be impacted by climate change
			X				d) Dependence on **ice, ice-edge, or snow-cover habitats**
			X				3) **Restriction to uncommon geological features or derivatives**
							4) **Reliance on interspecific interactions**
			X				a) Dependence on **other species to generate habitat**
						X	b) **Dietary versatility** (animals only)
			X				c) **Pollinator versatility** (plants only)
			X				d) Dependence on **other species for propagule dispersal**
			X				e) Forms part of an **interspecific interaction** not covered by 4a-d
							5) **Genetic factors**
		X					a) Measured **genetic variation**
						X	b) Occurrence of **bottlenecks** in recent evolutionary history *(only if 5a is "unknown")*
			X				6) **Phenological response to** changing seasonal temperature and precipitation

Section D: Documented or Modeled Response to Climate Change *(Optional; May apply across the range of a species)*

Mark an "X" in all boxes that apply.

Effect on Vulnerability							
Greatly increase	Increase	Somewhat increase	Neutral	Somewhat decrease	Decrease	Unknown	*(Optional)*
						X	1) **Documented response** to recent climate change
						X	2) Modeled **future (2050) change in population** or **range size**
						X	3) **Overlap** of modeled future (2050) range with current range
			X				4) Occurrence of **protected areas in modeled future (2050) distribution**

Climate Change Vulnerability Index
for Quercus garryana var. garryana in Olympic Peninsula

Not Vulnerable/Presumed Stable

Confidence in Species Information
Very High
* Histogram below

Definitions of Index Values

Extremely Vulnerable (EV): Abundance and/or range extent within geographical area assessed extremely likely to substantially decrease or disappear by 2050.

Highly Vulnerable (HV): Abundance and/or range extent within geographical area assessed likely to decrease significantly by 2050.

Moderately Vulnerable (MV): Abundance and/or range extent within geographical area assessed likely to decrease by 2050.

Not Vulnerable/Presumed Stable (PS): Available evidence does not suggest that abundance and/or range extent within the geographical area assessed will change (increase/decrease) substantially by 2050. Actual range boundaries may change.

Not Vulnerable/Increase Likely (IL): Available evidence suggests that abundance and/or range extent within geographical area assessed is likely to increase by 2050.

Insufficient Evidence (IE): Available information about a species' vulnerability is inadequate to calculate an Index score.

Results of a Monte Carlo simulation (1000 runs) of the data entered in the Index.

Figure C-1. NatureServe Climate Change Vulnerability Index (release 2.0) calculator, using Oregon white oak as an example. Species data are entered in sections A, B, C, and D, and the Index score appears in the final section

Vulnerability Index Scores

Table C-2 summarizes the input data, and, in the final two columns, the output of the NSVI. Each column represents an exposure or sensitivity factor with a rating (e.g., greatly increased, somewhat decreased) that indicates how that factor is expected to affect the species' overall vulnerability to climate change. We assigned these ratings based on the information collected for each species and the model's published guidelines that define the rating categories for each factor.

When applying the NSVI:

- Exposure to local climate change (predicted changes in temperature and Hamon AET:PET) was based on climate predictions made at the scale of the full assessment area (i.e., the Olympic Peninsula), rather than at the scale of individual species' ranges, because the full assessment area provided the most meaningful downscaled estimates (Halofsky 2010). Therefore, exposure ratings are the same for all six species.
- Most of the factors describing indirect exposure to climate change were rated neutral and did not affect the index scores.
- Factors describing sensitivity to climate change often received ratings that spanned multiple levels (e.g., neutral to somewhat increase) owing to a lack of specific data in the scientific literature. Rating specificity was lowest for the least-studied species.

In the following sections, we discuss the scores calculated for each species, with special attention to the factors that had the greatest impact on each species' vulnerability score.

Whitebark Pine

Whitebark pine is a slow-growing species adapted to survival in high mountains; it often occurs in climax communities around timberline (Arno and Hammerly 2007). Across its range it is threatened by one or more of the following: white pine blister rust, mountain pine beetle, fire (too much or too little) and climate change (Aubry et al. 2008). The NSVI scored whitebark pine as *highly vulnerable* to climate change. Of the 17 vulnerability and sensitivity factors, 1 factor greatly increased the species' vulnerability score, 4 factors increased its vulnerability score, and 3 factors somewhat increased its vulnerability score (table C-2).

The NSVI elevated whitebark pine's vulnerability score from *moderately vulnerable* to *highly vulnerable* based on the species' indirect exposure to climate change, specifically its distribution relative to natural topographic or geographic barriers. On the Olympic Peninsula, whitebark pine occurs only on peaks in the northeastern rainshadow (appendix B), and predicted increases in temperature by 2050 could substantially reduce its habitat there. The barrier to a potential shift in its range lies in the fact that the Olympic whitebark pine already occurs at the highest elevations in its range, and it therefore cannot track an upward-moving climate envelope.

Whitebark pine's modeled response to climate change also increased its overall vulnerability score. Multivariate spatio-temporal clustering (MSTC) models (Hargrove and Hoffman 2005, Hargrove et al. 2010) and tree climate viability maps (TCVM) (Rehfeldt et al. 2006, 2009) indicate that whitebark pine's habitat range is likely to be reduced under predicted climate scenarios. While the species cannot shift to higher elevations in the Olympic Range, shifts in habitat may occur within its current range, from south-facing slopes where it is presently most common, to cooler, north-facing slopes (Millar at al. 2004).

The NSVI increased whitebark pine's vulnerability score as a result of its historical thermal niche. This factor is based on mean seasonal temperature variation during the past 50 years; it is calculated as the difference between the highest annual mean monthly maximum temperature and the lowest annual mean monthly minimum temperature. This value is used as an indication of a species' broad-scale tolerance of temperature variation. For the range of whitebark pine in the Olympics, we estimated seasonal temperature variation to be 45 °F (25 °C). This relatively small value contributed to an increase in the overall vulnerability score of whitebark pine, according to the rating levels for the historical thermal niche factor. However, the rating for this factor is based on the range of annual temperature variation across the continental United States. The coastal Pacific Northwest has the least annual variation in temperature, comparable to that of southern Florida. Therefore, all species in this region receive a rating that increases vulnerability.

Whitebark pine's vulnerability score also was increased by its historical hydrological niche. Unlike historical thermal niche, which is calculated from mean seasonal variation, historical hydrological niche is calculated from the spatial variation in mean annual precipitation within a species' range in the management area. The lowest 50-year mean annual precipitation value in the species' range is subtracted from the highest 50-year value. Whitebark pine's vulnerability score was increased as a result of a difference in annual precipitation between 4 and 10 in (10 and 25 cm) within its range on the Olympic Peninsula.

Whitebark pine's near-complete dependence on a single species for propagule dispersal also increased its vulnerability score. Seed of whitebark pine is dispersed primarily by Clark's nutcracker (*Nucifraga columbiana*) (Lorenz at al. 2008); thus, changes in the distribution or density of Clark's nutcracker would have a substantial impact on dispersal of whitebark pine seed.

The somewhat low genetic variation of whitebark pine in the Olympic Range (Bower et al., n.d.) further increased its vulnerability score. The NSVI associates low genetic variation with increased vulnerability to climate change based on the assumption that low genetic variation reduces a species' ability to evolve in response to environmental changes. Genetic variation of whitebark pine both within and among populations of the Olympic Peninsula is lower than in the rest of the range of the species, possibly due to lower gene flow resulting from the geographic isolation of these populations.

Anticipated change in disturbance regime also increased whitebark pine's NSVI score, albeit to a lesser extent than the aforementioned factors. Examples of disturbance regimes include periodic fires, floods, severe winds, pathogen outbreaks, and similar events. Given the predicted stress of climate change, whitebark pine is expected to become more susceptible to damage from white pine blister rust. White pine blister rust is caused by *Cronartium ribicola*, an injurious, non-native fungi already present on whitebark pine throughout its limited range in the Olympics.

Golden Chinquapin

Golden chinquapin is an medium-sized, evergreen, broadleaf tree occurring to a very limited extent on the Olympic Peninsula (Arno and Hammerly 2007) (appendix B). The NSVI assigned golden chinquapin a score of *moderately vulnerable*. Four factors had the greatest influence on this vulnerability score: historical thermal and hydrological niches, limited dispersal ability, and low genetic variation.

Historical thermal niche increased the vulnerability score of golden chinquapin as a result of relatively low historical seasonal variation of temperature within its limited range on the Olympic Peninsula. Because historical hydrological niche is calculated from spatial variation in mean annual precipitation, and because golden chinquapin occurs only in a very small area on the Olympic Peninsula, the small amount of precipitation variation within that area increased its vulnerability score.

It appears that golden chinquapin on the Olympic Peninsula frequently reproduces via vegetative shoots, and its dispersal ability is therefore very limited. Limited dispersal ability increased golden chinquapin's NSVI score because it lacks the capacity to migrate and follow a shifting climate envelope. The fourth major factor that contributed to the *moderately vulnerable* score for golden chinquapin was low genetic variation. Because the Olympic Peninsula population of golden chinquapin is a disjunct population and frequently reproduces vegetatively, it might have arisen from a single individual or a small number of individuals. Therefore, we made the assumption that genetic variation in this population was relatively low, although quantitative data do not exist at this time.

Pacific Yew

Pacific yew is a small coniferous tree adapted to shady conditions in the understory of conifer forests; it is most prevalent in the older forests of the coastal Pacific Northwest Arno and Hammerly 2007. The NSVI scored Pacific yew *not vulnerable* to climate change. Given that most factors were neutral or unknown, only one factor, historical thermal niche, clearly increased Pacific yew's vulnerability score. Physiological thermal niche, which quantifies a species' tendency to occupy relatively cool microsites, had a neutral to somewhat increasing effect on its vulnerability score. Although Pacific yew tolerates a wide temperature range, it is sensitive to excessive heat and sometimes requires the protection of larger trees. Alternatively, historical hydrological niche somewhat decreased Pacific yew's vulnerability score; this rating resulted from the wide variation in mean annual precipitation across Pacific yew's range on the Olympic Peninsula.

Pacific yew's disturbance regime specificity and interspecific dependence factors had a neutral to somewhat increasing effect on its vulnerability score. Owing to the combination of its susceptibility to fire damage and its increased prevalence in late-successional forests, greater fire frequency (which is one outcome predicted by some climate models) could adversely affect Pacific yew on the Olympic Peninsula. Pacific yew also could be affected by the loss of habitat provided by late-successional trees if disturbances associated with climate change, including insects and pathogens, caused mortality among the late-successional trees.

Modeled response to climate change had a somewhat increasing effect on Pacific yew's vulnerability score, based on MSTC and TCVM models which predicted moderately small decreases in Olympic Peninsula habitat (Hargrove and Hoffman 2005, Hargrove et al. 2010, Rehfeldt et al. 2006, 2009).

Western White Pine

Scattered through low- and middle-elevation forests, western white pine is a large tree that regenerates best following major disturbances Arno and Hammerly 2007. The NSVI scored western white pine *not vulnerable* to climate change. As in the case of Pacific yew, because most exposure and sensitivity factors were neutral or unknown, only historical thermal niche and modeled response to climate change had increasing effects on its vulnerability score.

Western white pine's disturbance regime specificity had a neutral to somewhat decreasing effect on its vulnerability score, because stand-replacing disturbances conducive to western white pine regeneration are projected to occur with greater frequency as a result of climate change in some climate change models. A major source of disturbance, and the greatest threat to western white pine in Washington, is white pine blister rust. However, it is unclear how projected climate changes will influence the effects of this pathogen in low- and middle-elevations forests. Given that western white pine already has experienced high levels of mortality as a result of white pine blister rust, planting rust-resistant seedlings is crucial to its survival. This management imperative is not considered by the NSVI, nor does its rating of *not vulnerable* account for the differing effects of multiple disturbance regimes.

Oregon White Oak

Oregon white oak is a stout, deciduous tree, capable of surviving on a wide range of sites; it is found most frequently in lowland areas that were historically burned by Native Americans (appendix A). The NSVI scored Oregon white oak *not vulnerable* to climate change. Beyond historical thermal niche, genetic variation was the only factor that increased Oregon white oak's vulnerability score.

Oregon white oak's level of genetic variation somewhat increased its vulnerability score based on the fact that the species' genetic variation was rated low compared to related taxa (Ritland at al. 2005). Oregon white oak's genetic variation is approximately half that of other white oak (*Quercus* subgenus *Leucobalanus*) species. Within the state of Washington, genetic differences among Oregon white oak populations are not significant (Taylor and Boss 1975).

Ratings for many of Oregon white oak's sensitivity and vulnerability factors were neutral or included the neutral rating. In the NSVI, a neutral rating affects the vulnerability score differently than a rating of unknown. While a rating of unknown indicates a lack of information and does not affect a species' vulnerability score, a neutral rating is often based on specific information indicating that the species' level of sensitivity or exposure has no anticipated impact on its vulnerability score. For example, the neutral impact of Oregon white oak's dispersal ability on its overall vulnerability score was based on evidence that dispersal of acorns by Steller's jays (*Cyanocitta stelleri*) and small mammals often exceeds a distance of 328 ft (100 m) but rarely exceeds 3,280 ft (1,000 m); the NSVI assigns this dispersal range a rating of neutral.

Quaking Aspen

Quaking aspen is a small- to medium-sized deciduous tree that often regenerates by sprouting; it occurs in widely scattered groves in western Washington Arno and Hammerly 2007 (appendix B). The NSVI scored quaking aspen *moderately vulnerable* to climate change. Factors increasing its vulnerability score included historical thermal niche, historical hydrological niche, and dispersal ability. As with golden chinquapin, historical hydrological niche increased its vulnerability score solely owing to the species' limited range on the Olympic Peninsula.

The clumped distribution and the limited extent of individual quaking aspen populations on the Olympic Peninsula suggest that they are reproducing primarily through vegetative mechanisms. This limited propagule dispersal ability had an increasing to greatly increasing effect on quaking aspen's vulnerability score. Quaking aspen's vegetative reproduction also influenced its genetic variation factor, which somewhat increased the vulnerability score.

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Availability and Quality of Data

The validity of the NSVI score depends on the availability of information on a wide range of exposure and sensitivity and vulnerability factors. For less-studied species, much of this information remains unknown. The creators of the NSVI recognized this issue and designed the index so that it would function with a partial dataset. A vulnerability score is obtained with a minimum of 10 of the 17 sensitivity factors and three of the four indirect climate change exposure factors. All four exposure factors describing documented or modeled climate change response are optional. However, a vulnerability score that is based on the minimum number of factors is likely less reliable than one that is based on a well-studied species for which all factors are rated. This is further complicated by the fact that it is unclear how the model weights the various factors. If some factors are weighted more heavily, it may be appropriate for the user to devote more time to accurately rating those factors.

In addition to the overall vulnerability score for each species, the model includes a measure of confidence in the score (table C-2). This confidence level ranges from *low* to *very high* and is based, in part, on the specificity of the user-provided information. The NSVI allows the user to select up to three ratings for a single factor (e.g., increased – somewhat increased – neutral) to accommodate uncertainty in the data or to account for variation in sensitivity or vulnerability within the species' range. Confidence generally increases when fewer ratings are selected within each factor (i.e., greater specificity) and when the selected ratings are relatively consistent among factors. In the case of whitebark pine, the model returned a confidence level of *very high* for its score of *highly vulnerable*. This high degree of confidence resulted from the fact that a relatively large number of factors had specific ratings of somewhat increased vulnerability, increased vulnerability, or greatly increased vulnerability.

Climate Sensitivity Calculations

The NSVI predicts sensitivity of each species to temperature and precipitation changes based on historical climate exposure and other species information. However, several aspects of the sensitivity rating system are difficult to interpret and not well-suited to the climate of western Washington.

The NSVI's approach to calculating sensitivity to climate at multiple scales is not intuitive. Historical thermal niche is based on seasonal temperature variation, while historical hydrological niche is based on spatial precipitation variation. Conversely, physiological thermal niche is based on spatial temperature patterns (i.e., a species' preference for cool microsites), while physiological hydrological niche is based, in part, on the extent to which seasonal precipitation patterns affect habitat. Historical thermal and hydrological niches are defined quantitatively, but sensitivity to seasonal precipitation patterns, which may be more susceptible to climate change and more relevant in the Pacific Northwest, is assessed qualitatively as physiological hydrological niche.

Historical thermal and hydrological niches have substantial influences on a species' vulnerability score, as the NSVI equates the breadth of a species' thermal and hydrological niches with its ability to adapt to changes in temperature and precipitation. However, the vulnerability rating system for all geographic regions is based on a single set of predefined temperature and precipitation levels. These predefined levels have questionable value in locations where temperature or precipitation differs significantly from those of a typical temperate ecosystem. For example, a species' historical hydrological niche is rated as increasing its overall vulnerability score if the variation in mean annual precipitation across its range

Table C-2. Summary of NatureServe Climate Change Vulnerability Index sensitivity and exposure factor ratings[1] (indicating the effect that each factor had on each species' overall vulnerability index score) and index results for six selected tree species on the Olympic Peninsula

	Exposure to local climate change		Indirect exposure to climate change				Sensitivity to climate change												Documented response to climate change				Index results	
Species	**Temperature (°F)**	**Hamon AET:PET Moisture Metric**	**Sea level rise**	**Natural barriers**	**Anthropogenic barriers**	**Climate change mitigation**	**Dispersal ability**	**Historical thermal niche**	**Physiological thermal niche**	**Historical hydrological niche**	**Physiological hydrological niche**	**Disturbance regime specificity**	**Dependence on ice/snow**	**Physical habitat specificity**	**Dependence on other spp for habitat**	**Dependence on other spp for dispersal**	**Other interspecific interactions**	**Genetic variation**	**Documented response to recent climate change**	**Modeled future change in range or population size**	**Modeled overlap of current and future range**	**Occurrence in protected areas**	**Index vulnerability score**	**Confidence in score, based on provided data**
Whitebark pine	<3.9	-0.074 to -0.096	N	GI	N	N	SD-Dec	Inc	N	Inc	N	SI	U	N	N	Inc	U	Inc	U	SI	SI	N	HV	Very high
Golden chinquapin	<3.9	-0.074 to -0.096	N	N	N	N	GI-Inc-SI	Inc	N-SD	Inc	SI-N	N	N	U	N	SI-N	U	Inc	U	N	N	SI-N	MV	Very high
Quaking aspen	<3.9	-0.074 to -0.096	N	N	N	N	GI-Inc	Inc	N-SD	Inc	N	N-SD	N	N-SD	N	N	U	SI	U	U	U	N	MV	Very high
Pacific yew	<3.9	-0.074 to -0.096	N	N	N	N	N	Inc	SI-N	SD	N	SI-N	N	N	SI-N	N	U	N	U	SI	U	N	NV	Very high
Western white pine	<3.9	-0.074 to -0.096	N	N	N	N	N	Inc	N	N-SD	N	N-SD	N	N	N	N	N	N	U	SI	U	N	NV	Very high
Oregon white oak	<3.9	-0.074 to -0.096	N	N	N	N	N	Inc	N	SD	N-SD	N-SD	N	N	N	N	N	SI	U	SD	U	N	NV	Very high

[1] *Some factors are not shown because no data were available for these six species. Factor abbreviations are: GI, greatly increase; Inc, increase; SI, somewhat increase; N, neutral; SD, somewhat decrease; Dec, decrease; U, unknown. Index score abbreviations are: HV, highly vulnerable; MV, moderately vulnerable; NV, not vulnerable/presumed stable*

in the management area is between 4 and 10 in (10 and 25 cm). This relatively narrow range is probably not appropriate on the Olympic Peninsula, where mean annual precipitation can vary dramatically over short distances. Alternatively, some species such as golden chinquapin occupy a very limited range on the Olympic Peninsula and, because precipitation varies little within their range, receive an increased sensitivity rating. This is rating approach is based on the assumption that climate limits a species' range, rather than competition from other species or other types of barriers. For golden chinquapin and Oregon white oak, for example, competition from conifers may be the most important factor limiting their ranges on the Olympic Peninsula.

Effects of Disturbance

The NSVI includes disturbance effects to the extent that a species may be dependent on a specific disturbance regime that could be affected by climate change. Examples of this are regular occurrences of wildfire or flooding. The NSVI does not, however, address the potential initiation of new types of disturbance, including introductions of non-native insects and diseases. Furthermore, native insects and diseases are likely to expand their range in response to climate change, significantly affecting areas where they did not exist historically. One dramatic example of this is the northward expansion of mountain pine beetle's (*Dendroctonus ponderosae*) range (Logan and Powell 2001). These new disturbance regimes may occur cyclically once they are initiated, but they are not necessarily part of current or historical disturbance cycles and thus are not addressed by the NSVI disturbance specificity factor.

Genetics

Genetic vulnerability to climate change is addressed by only one factor, genetic variation relative to similar taxa, which is measured by selecting one of four qualitative levels ranging from very low to high. The NSVI guidelines state that genetic variation should be measured over a substantial portion of a species' range. However, the genetic variation factor does not assess whether the population in the management area is contiguous with the broader range of the species. For whitebark pine, golden chinquapin, and quaking aspen, the genetic variation of the disjunct populations on the Olympic Peninsula and their ability to adapt is affected by the lack of opportunity for gene flow with populations beyond the management area. For forest trees it would also improve the index to include a factor reflecting the patterns of genetic variation across the landscape. These patterns vary widely among the tree species of the Olympic Peninsula (Randall and Berrang 2002) and will affect each species' ability to adapt to future changes in climate.

Age-Dependent Sensitivities

A problematic aspect of the NSVI is its handling of species with temperature or precipitation sensitivities that change with age. This was a recurrent issue for us when assigning sensitivity and vulnerability ratings to tree species. For example, some drought-tolerant tree species, such as Oregon white oak, require moist soils to germinate and survive as seedlings. Because summer precipitation levels are projected to decline in predicted climate change scenarios, this requirement increases the sensitivity rating for Oregon white oak's physiological hydrological niche. However, Oregon white oak's drought tolerance at maturity favors its competitive ability in forest stands where it occurs among tree species that are less drought-tolerant, thus decreasing its sensitivity rating. Although this apparent discrepancy in sensitivity is understood by managers, the NSVI is not designed to include this level of detail. In this situation, the best compromise is for the user to select multiple sensitivity ratings. However, such compromises reduce the NSVI's confidence score and also likely reduce the user's confidence in the NSVI.

Practical Applications for the Index

The NSVI score for each species indicates its overall level of vulnerability; however, management actions to alleviate vulnerabilities to climate change must be based on specific types of vulnerabilities, such as shifting climate envelopes and altered disturbance regimes. The NSVI results summary table (table C-2) is useful in that respect, as it shows patterns in sensitivity and vulnerability factors across multiple species. For example, the two species with increased vulnerability associated with dispersal ability, golden chinquapin and quaking aspen, are the only two species that are reproducing primarily through vegetative mechanisms. Also evident in the table is a pattern indicating that low genetic variation within five of the six modeled species contributes to their vulnerability. Grouping species by vulnerability factors would likely be most useful to managers if a large number of species were modeled. For example, if all tree species within a forest were modeled, the resulting groupings would assist in understanding potential changes in composition of each forest cover type.

The process of compiling and critically evaluating species-level data on exposure, sensitivity, and documented response to climate change may, for some applications, be a more important product of the Index than the vulnerability score itself. To understand the potential effects of a changing climate on biodiversity, this information must be collected regardless of whether it is used in the NSVI or interpreted through a different approach. However, the NSVI provides a template for a logical method of organizing this information, facilitating comparisons of sensitivity and vulnerability factors within species and across multiple species. To further improve its applicability, a user could simplify the NSVI’s rating system and customize the results table based on the species and management area of interest, incorporating only the sensitivity and vulnerability factors deemed relevant or adding factors not included in the original NSVI. This approach would bypass the calculation of an overall vulnerability score for each species, but it would enable the user to interpret the species data directly from a table similar to table C-2.

Conclusions

In its present form, the NSVI has limited utility for assessing the vulnerability of plant species on Washington’s national forests.

- The NSVI is designed to work with a wide range of plant and animal species; as a result, the sensitivity and vulnerability factors on which it is based are too general and, in some instances, not directly applicable to plant species of Washington’s national forests.
- The NSVI is useful in that it provides a template for collecting the wide range of information that is needed to understand each species’ vulnerabilities to projected changes in climate. We found that this template should be viewed as a starting point, as it would have to be modified to become a more effective tool for our management area.
- Ranking of species by vulnerability score must be followed by addressing the types of management actions that might be necessary to mitigate the potential effects of climate change. It would be useful to use vulnerability data to identify common themes in vulnerability that could then be managed more efficiently.

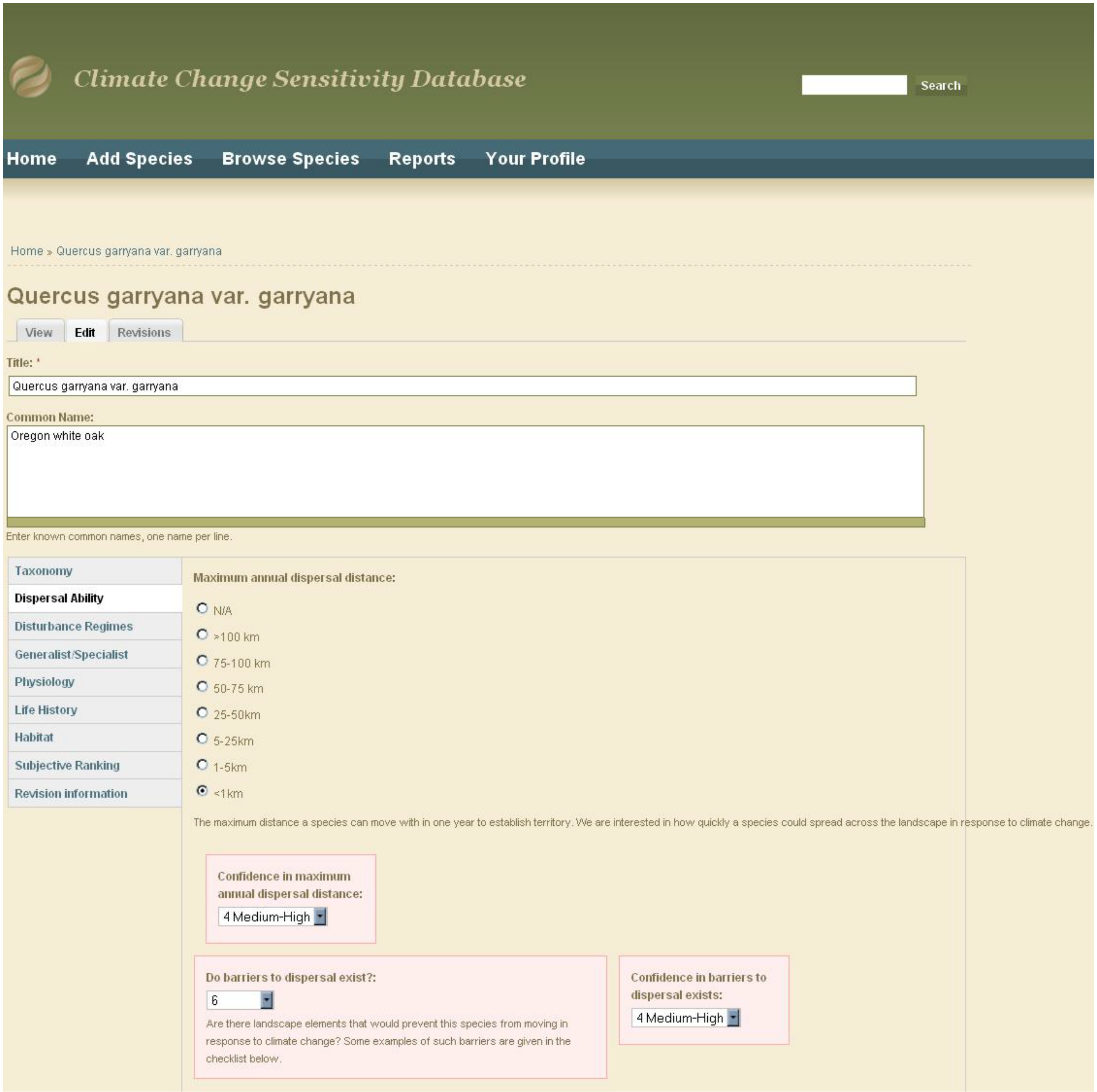
APPENDIX D:
EVALUATION OF THE CLIMATE CHANGE SENSITIVITY DATABASE

BACKGROUND

The Climate Change Sensitivity Database (CCSD) is part of the Pacific Northwest Climate Change Vulnerability Assessment, a project designed to evaluate the relative climate change vulnerability of the species and ecological systems of the Pacific Northwest. The Pacific Northwest Climate Change Vulnerability Assessment is a collaborative effort of the University of Washington and numerous other agencies (Lawler and Case 2010a). It includes the CCSD, which is designed to evaluate the climate change sensitivity of individual species, and spatially explicit computer models that include downscaled climate projections, simulations of vegetation change, and assessments of climate change effects on habitat and distribution of focal wildlife species.

The CCSD is a web-based model for predicting the sensitivity of animal and plant species to climate change. The model user rates a species' sensitivity using eight biological and ecological variables, each of which is assigned a value between 0 and 7 (fig. D-1). Based on these ratings, the CCSD calculates a climate-change sensitivity index score between 0 and 100. The variables include a species' dispersal capability, its physiological ability to cope with changes in climate, and several ecological factors related to its habitat requirements. Unlike the NatureServe Climate Change Vulnerability Index (NSVI), the CCSD does not incorporate historical climate data or future climate projections. The CCSD allows the user to customize the weighting of each variable in the index score calculation, assigning greater influence to the variables that are deemed most important. In addition to rating sensitivity for each variable, users also must rate their level of confidence in their sensitivity rating, on a scale of 1 to 5 (1 being low confidence, 5 being high). This produces two scores for each species: an overall sensitivity score and a confidence score.

The CCSD is available online for public use; after creating a profile, users may then begin rating the sensitivity of animal or plant species of their choice or view the results of other users' species evaluations. The model includes a section in which the user may justify each rating by adding relevant text and listing references. All entered data are stored and visible to other users on the model's website. The model interface is straightforward, and the equations used to calculate index scores are shown on the website.



Quercus garryana var. garryana

Title: *
Quercus garryana var. garryana

Common Name:
Oregon white oak

Enter known common names, one name per line.

Maximum annual dispersal distance:

○ N/A
○ >100 km
○ 75-100 km
○ 50-75 km
○ 25-50km
○ 5-25km
○ 1-5km
● <1km

The maximum distance a species can move with in one year to establish territory. We are interested in how quickly a species could spread across the landscape in response to climate change.

Confidence in maximum annual dispersal distance: 4 Medium-High

Do barriers to dispersal exist?: 6

Are there landscape elements that would prevent this species from moving in response to climate change? Some examples of such barriers are given in the checklist below.

Confidence in barriers to dispersal exists: 4 Medium-High

Figure D-1. Editing the dispersal distance and dispersal barriers variables in the CCSD

APPLYING THE CLIMATE CHANGE SENSITIVITY DATABASE TO TREE SPECIES OF THE OLYMPIC PENINSULA

We applied the CCSD to the six tree species to which we also applied the NSVI: whitebark pine, golden chinquapin, Pacific yew, western white pine, Oregon white oak, and quaking aspen. As with the NSVI, we limited the scope of the evaluation to Washington's Olympic Peninsula. The species information required to run the CCSD was acquired from *Silvics of North America* (Burns and Honkala 1990) and the Fire Effects Information System (Fischer 2010). The goals of this evaluation were: (1) assess the CCSD's applicability to tree species representing a range of management challenges, and (2) compare both the process of applying the model and the model's results to the NSVI.

Sensitivity ratings for each variable, as well as the model's calculated sensitivity and confidence index scores, are shown in table D-1. Equal weighting was assigned to each variable (the model's default setting) for the purpose of this evaluation. One species, whitebark pine, had a relatively high sensitivity index score of 80. Scores for all other species fell within a narrow range: from 42 to 46. Confidence scores also fell within a narrow range of 67 to 77.

In the following sections, we discuss each of the eight variables used to calculate the index scores and describe the ratings for each species.

Table D-1. Summary of the Climate Change Sensitivity Database, including user-assigned ratings for eight variables and sensitivity and confidence index scores for six selected tree species on the Olympic Peninsula

	Sensitivity ratings, by variable								Index results	
Species	**Dispersal distance[1]**	**Dispersal barriers[2]**	**Disturbance regimes[3]**	**Generalist/specialist[4]**	**Physiology[5]**	**Life history[6]**	**Habitat[7]**	**Subjective ranking[8]**	**Sensitivity index score**	**Confidence index**
Pinus albicaulis Whitebark pine	7	7	2	6	6	5	7	6	80	75
Chrysolepis chrysophylla Golden chinquapin	7	6	5	2	2	4	0	1	42	73
Populus tremuloides Quaking aspen	7	5	5	3	4	1	0	2	45	68
Taxus brevifolia Pacific yew	7	4	0	5	4	5	0	4	44	68
Pinus monticola Western white pine	7	5	6	3	3	2	0	2	46	67
Quercus garryana Oregon white oak	7	6	6	2	2	5	0	1	45	77

[1] *1 = less than 1 km/yr ; 7 = greater than 100 km/yr*
[2] *0 = no barriers; 7 = many barriers*
[3] *0 = not associated with any disturbance regime; 7 = highly dependent on one or more disturbance regimes*
[4] *1 = generalist; 7 = specialist*
[5] *1 = low sensitivity; 7 = high sensitivity*
[6] *1 = r-selected species; 7 = K-selected species*
[7] *0 = does not occupy sensitive habitats; 7 = occupies a sensitive habitat*
[8] *0 = not sensitive; 7 = extremely sensitive*

Dispersal Distance

The dispersal distance variable quantifies "the maximum distance a species can move within one year to establish territory." A sensitivity rating of 7 is associated with a distance of less than 1 km per year, and, at the other end of the scale, a rating of 1 is associated with a distance of greater than 100 km per year. The tree species in this evaluation require multiple years to reach reproductive maturity, and after reaching maturity, most disperse seed distances of less than 1 km. Averaging their seed dispersal distance over the number of years until reproductive maturity is reached, the mean annual dispersal distance is clearly less than 1 km, and thus we assigned a rating of 7 to every species.

Dispersal Barriers

Dispersal barriers are defined as landscape elements that would prevent a species from migrating in response to a changing climate. The rating scale ranges from 0 (no barriers) to 7 (many barriers). Although the CCSD lists 11 examples of barriers (e.g., roads, clearcuts, dams) that may be selected by the user, these do not influence the rating. The model user must decide what barriers exist, how severe the barriers are, and how to quantify them on a scale of 0 to 7.

For the six tree species evaluated, applicable dispersal barriers included topography, land use (e.g., urbanization, agriculture), and vegetation. All the selected tree species, with the exception of Pacific yew, are most prevalent in pioneer or early seral stands. Mature conifer forests may hinder or prohibit migration of these species, and thus we assigned relatively high ratings of 5 or greater for the dispersal barrier variable. By contrast, Pacific yew, assigned a rating of 4, is most prevalent in mature conifer stands, although it can also regenerate post-disturbance. For whitebark pine, we assigned a rating of 7 owing to the fact that the species occurs only at high elevations in the Olympic Range and thus topography prevents migration to higher elevations under a warmer climate.

Disturbance Regimes

The disturbance regime variable is rated according to the dependence of the species on the nature of one or more specific disturbance regimes. The rating scale includes values of 0 (not associated with any disturbance regime) to 7 (highly dependent on one or more disturbance regimes). We assigned ratings ranging from 0 to 6 for the 6 tree species. For Pacific yew, a species that becomes more prevalent with increasing stand age and is most common in old-growth stands, we assigned a rating of "N/A" (a value of 0) because the species does not depend on the nature of a specific type of disturbance. We assigned western white pine and Oregon white oak ratings of 6. Both species thrive under disturbance: western white pine regenerates best following stand-replacing fire, while Oregon white oak is very tolerant of fire and depends on periodic fire to eliminate competition from other tree species.

Generalist/Specialist

For the generalist/specialist variable, the model user rates a species on a scale of 1 (generalist) to 7 (specialist) based on its ecological niche. The model user also may select, from a list, specific factors such as "seed dispersal dependency" and "pollinator dependency" that describe the nature of a species' specialist niche. However, selection of these factors does not affect the species' score.

We assigned relatively low values (i.e., 2 or 3) to the early seral, low- to mid-elevation species because they are capable of establishing and surviving on a relatively wide range of sites following disturbance. Alternatively, we assigned Pacific yew a generalist/specialist rating of 5 owing to the fact that it is found primarily in the understory of mature conifer forests. We assigned whitebark pine a rating of 6 based on its relatively narrow ecological niche on the Olympic Peninsula.

Physiology

For the physiology variable, species are rated based on their physiological sensitivity to environmental changes that are likely to occur under projected climate change, such as temperature, precipitation, pH, and carbon dioxide concentration. The rating scale ranges from 1 (low sensitivity) to 7 (high sensitivity). We assigned Oregon white oak and golden chinquapin ratings of 2 because both of these species can survive on hot, droughty sites, and the Olympic Peninsula populations are at or near the northern ends of their range. These species are likely to be least sensitive to increased summer temperature or drought. We assigned Pacific yew, western white pine, and quaking aspen physiological sensitivity ratings of 4, 3, and 4, respectively; as with Oregon white oak and golden chinquapin, these species' ranges encompass regions that are hotter and drier than the Olympic Peninsula. Owing to the fact that it occupies only cold, high-elevation habitat that is likely to shrink if air temperatures increase, we assigned whitebark pine a sensitivity rating of 6.

Life History

The life history variable represents the continuum between r-selected species (a rating of 1) and K-selected species (a rating of 7). Not all trees are easily classified on this scale; for example Pacific yew is a long-lived, slow-growing, shade-tolerant species, which are traits of a K-selection strategy; however, it also is a prolific producer of relatively small seed, indicating an r-selection strategy. We assigned Pacific yew a rating of 5. Whitebark pine is a long-lived, slow-growing species that produces relatively large seed, and thus, we assigned it a rating of 5 despite the fact that it is considered a pioneer or early seral species on many sites. Because Oregon white oak is long-lived, slow-growing, produces large seed, we also assigned it a rating of 5. Alternatively, we assigned quaking aspen a rating of 1 because it is a short-lived pioneer species and a prolific producer very small seed.

Habitat

The habitat variable assigns a rating based on whether the species depends on one of six listed sensitive habitats. Sensitive habitats include coastal marshes and estuaries, perennial streams, shallow pools, seasonal wetlands, ecotones, alpine/subalpine habitat, and an "other" category for sensitive habitats not on this list. Unlike the other variables, which are rated on a scale ranging from 0 to 7, habitat is assigned a score of either 0 or 7 based on whether the species occupies any of the sensitive habitats (7) or not (0). Whitebark pine occurs in subalpine habitat, which is one of the listed sensitive habitat types; therefore, we assigned it a rating of 7. The other species were not dependent on sensitive habitat types, and we assigned them each a rating of 0.

Subjective Ranking

The final variable in the model, called subjective ranking, is based on the user's answer to the question, "In your opinion, how would you rank the overall sensitivity of this species to climate change?" In response to this question the user selects a value from 0 (not sensitive) to 7 (extremely sensitive). This variable allows the model user to consider all ecological factors influencing climate change sensitivity, including factors that may not be quantified by the other variables.

We assigned whitebark pine a rating of 6 for its subjective ranking, owing to the limited and potentially decreasing extent of its habitat. We assigned Pacific yew a rating of 4, owing to the fact that it is primarily found in the understory and thus is somewhat dependent on the presence of mature conifer forests; shifts in the distributions of overstory conifers, or other canopy disturbances associated with climate change, could affect the habitat of Pacific yew. We assigned the four remaining species ratings of 1 or 2 owing to the fact that they are relatively tolerant of warmer conditions and of disturbance.

THE CLIMATE CHANGE SENSITIVITY DATABASE AS AN ASSESSMENT TOOL FOR TREE SPECIES OF WESTERN WASHINGTON

The CCSD is a flexible index that produces scores based on general information about a species. The generality of the CCSD makes it applicable to both animals and plants, although it might be better-suited to rating the sensitivity of animals. For example, dispersal distance ratings appear to be calibrated for animal species, rather than for plants. Likewise, the ecological concept of r- and K-selection is more applicable to differentiating the reproductive strategies animal species than it is to differentiating that of tree species.

With the exception of the dispersal distance and habitat variables, the scale on which the CCSD's sensitivity variables are rated is qualitative rather than quantitative. The model user assigns a value from 0 to 7, based on the user's assessment of a species' sensitivity. These values are presented as a continuum, rather than as a series of defined classes. As a result, it is unlikely that two equally knowledgeable users would assign the same values to the full set of sensitivity variables for a given species. Thus, ratings among multiple species are likely to be more consistent, and more comparable, if they are made by the same individual or by the same team. Similarly, it may not be appropriate to compare confidence ratings beyond the species assessed by a single individual or team.

The CCSD's simplified approach to assessing a species' sensitivity made it challenging to rate the physiology variable for tree species. The physiology variable is defined as "…a species' physiological ability to tolerate changes in temperature, precipitation, salinity, pH, and CO_2…" (Lawler and Case 2010b). However, this does not account for the fact that if several of these variables change, their effects may be both positive and negative. For example, increased temperature may have a negative effect on a tree species' survival and growth, while simultaneous increases in precipitation and CO_2 may have positive effects on the species' growth. Therefore, we interpreted the physiology variable as the species' ability to tolerate changes in the single environmental variable most likely to impede survival and growth. Conversely, the simplified approach of the CCSD bypassed one problem of the more detailed NSVI: the difficulty of rating age-dependent sensitivities exhibited by many tree species was not encountered when using the CCSD model.

The CCSD's disturbance regime variable also was difficult to interpret. The variable was defined as the dependence of a species on the nature of one or more specific disturbance regimes that may be affected by climate change. However, this definition refers only to the level of dependence on a disturbance regime rather than the frequency or intensity of the disturbance or the degree to which climate change is expected to affect that disturbance. Thus, a species strongly dependent on frequent disturbance may be assigned the same rating as a species strongly dependent on a very long interval between disturbances.

As result of its broad scope and simplicity of use, the strength of the CCSD is its capacity to make general evaluations of climate change sensitivity across a wide range of species and life forms. While the model identified sensitivity differences among the six tree species, the categories did not specify individual factors such as genetic variation or temperature and drought sensitivities. Some of the eight variables in the model, such as physiology and generalist/specialist, require the user to assign a single rating based on multiple factors. Using the generalist/specialist variable as an example, these factors include seed dispersal dependency, pollinator dependency, and phenological dependency. Given our objective of evaluating the climate change sensitivity of a relatively small number of tree species on the Olympic Peninsula, a more practical approach for managers would be to compare the individual factors contributing to each variable's rating. Based on the same data, this approach would result in a more mechanistic evaluation of sensitivity.

Conclusions

Our application of the CCSD to six tree species of the Olympic Peninsula revealed several key features of the index:

- The CCSD is simple and easy to use, assuming basic ecological information is available for each species. It does not require historical climate data, although a basic knowledge of projected future climate is required.
- The CCSD index is based primarily on broad ecological concepts (e.g., generalist/specialist, r/K selection) rather than on information on specific traits.
- Owing to the lack of quantitative guidelines in the rating process, the results of the CCSD are dependent on the user's interpretation of the rating scales. While scores are comparable within and among species assessed by the same user or team, ratings from different model users may not be comparable.

APPENDIX E:
CLIMATE DATA ANALYSIS

INTRODUCTION

In an earlier draft of the vulnerability assessment for forest tree species in Group 1 (Part 1), we developed a sixth risk factor, climate pressure, to quantify the relative risk of climate change to tree species in our analysis. This risk factor was based on the one described by Potter and Crane (2010). A number of reviewers enumerated the challenges in applying the models on which this risk factor is based. Upon further consideration we decided to drop this factor from the vulnerability assessment. Here we present both the process we used to develop the climate pressure factor and the characteristics of the models that made the results too uncertain to include in the analysis.

METHODS

Climate Pressure Factor

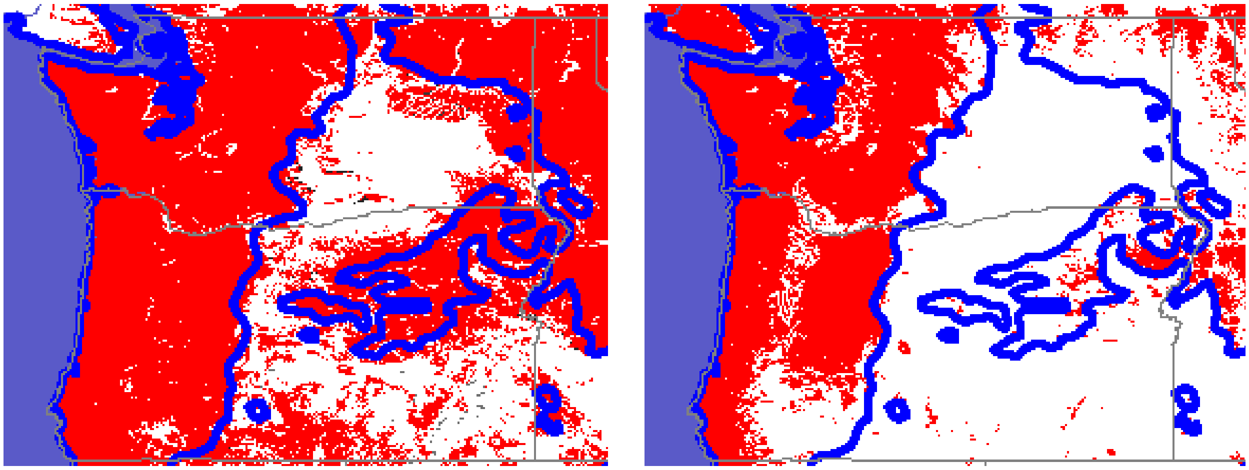
As designed by Potter and Crane (2010), this factor identifies the relative risk to each forest tree species due to the potential change in distribution or climate habitat as climate conditions change. Here we use the term climate habitat to indicate areas that are expected to be suitable in the future based on the climate of the current species distribution. Species distribution models (SDM) are used to map these potential range shifts.

A number of studies have analyzed impacts of projected climate change on forest type (Bachelet et al. 2001) and the distribution of individual tree species (Hamann and Wang 2006, Littell et al. 2009, Coops and Waring, in press, McKinney et al. 2007, Shafer et al. 2001, Thompson et al. 1998, Zolbred and Peterson 1999). However, some of these studies included only a small number of species or predicted changes in growth rather than in potential range extent. We selected two SDMs that analyzed most of the tree species in Group 1. Both these climate envelope models (CEM; also called statistical species distribution models) predict changes in climate habitat or in climatic conditions that presently are required by the species. It is easy to lapse into considering that these projections are predictions of species' future distributions (for example, "This species will disappear by 2100."), but this type of conclusion is beyond the power and scope of the models. The two SDMs selected were:

1. Tree Climate Viability Maps (TCVM) (Rehfeldt et al. 2006, Rehfeldt et al. 2009). For each species, current and predicted future distributions (years 2030, 2060, and 2090) are mapped using climate projections from one of three global climate models (GCM) (CGCM3 from the Canadian Climate Center, GFDLCM21 from Geophysical Fluid Dynamics Laboratory, or HADCM3 from the Hadley Center) and anthropogenic emission levels A1B (intermediate), A2 (hot and dry), and B1 (cooler and wetter) (fig. E-1). See Mote et al. (2008) for background information on GCMs and emission levels. On each map, the predicted range is displayed as two probability classes: 0.5 to 0.75 and 0.75 to 1.00 (Crookston et al. 2010). To facilitate our analysis, we combined probability classes equal to or greater than 0.5 and produced maps simply showing presence (≥0.5) and absence (<0.5). TCVMs are available for all Group 1 tree species in this assessment except black cottonwood.

2. Multivariate Spatio-Temporal Clustering (MSTC) (Hargrove and Hoffman 2005, Hoffman et al. 2005). For each species, current and future species distribution for 2050 and 2100 were mapped, using one of two GCMs (one from the Hadley Center or from NCAR, PCM) and anthropogenic emission levels A1 (warmer) and B1 (fig. E-2). Maps are available for all Group 1 species in this assessment.

Douglas-fir

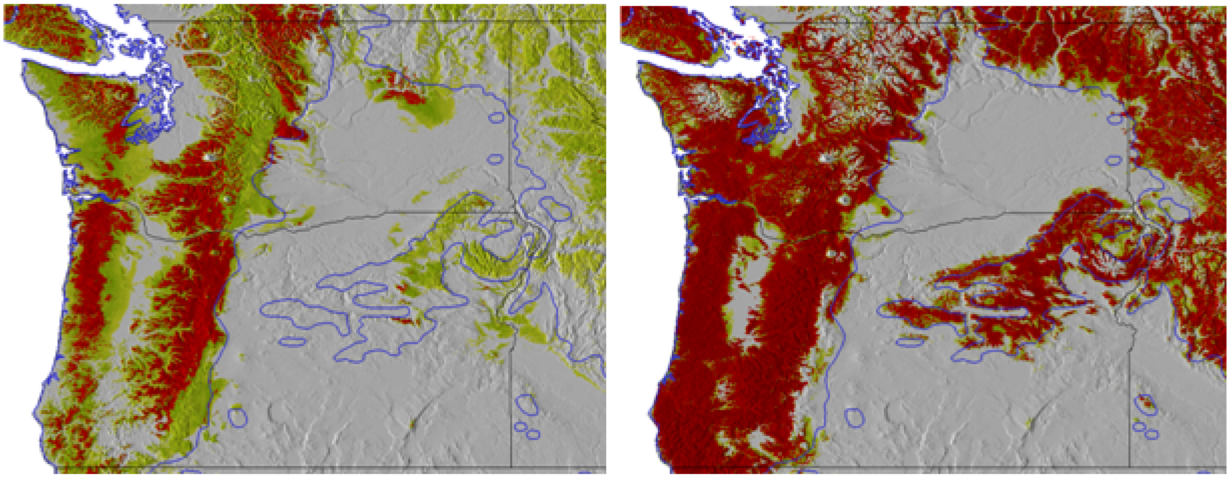


MSTC Current

MSTC 2050, Hadley A1

Figure E-1. Climate habitat projection for Douglas-fir, current and for the year 2050, based on the Multivariate Spatio-Temporal Clustering (MSTC) model (Hargrove et al. 2010, Hoffman et al. 2005), http://www.geobabble.org/~hnw/global/treeranges/climate_change/index.html. Blue line represents present distribution based on Little (1971); red solid color indicates projected species distribution.

Douglas-fir



TCVM Current

TCVM 2060, Hadley A2

Figure E-2. Climate habitat projection for Douglas-fir, current and the year 2060, based on the Tree Climate Viability Map (TCVM) model (Rehfeldt et al. 2006, Rehfeldt et al. 2009), http://forest.moscowfsl.wsu.edu/climate/species/index.php. The projected range is displayed as two probability classes: 0.5 to 0.75 (both shades of green) and 0.75 to 1.00 (red) (Crookston et al. 2010). The blue line represents present distribution based on Little (1971).

Both these SDMs use CEM to predict future suitable habitat based on climate variables. There are limitations to the usefulness of CEMs, and some have expressed concerns about their application (Davis et al. 1998, Pearson and Dawson 2003, Robinson et al. 2008). For example, spatial data produced by these models should only be interpreted in a very broad sense. In this case, we planned to use the SDMs to gauge vulnerability, not to pinpoint habitat changes on any particular site. But such concerns did influence our development of the scoring system for this risk factor. One scoring approach that we examined was ranking species based on the change in cover between current and predicted future distributions. The percentage change in cover has been used in at least one SDM (Thompson et al. 1998). But after considering the assumptions and uncertainties of these models, we did not feel that extracting numeric values representing distribution was appropriate. Furthermore, an overall change in percentage cover could mask spatial heterogeneity including increases in certain areas and decreases in others. For these reasons, we took a more conservative approach and decided to visually assess the change in distribution and then assign categorical values based on increases or decreases.

Selection of climate habitat projections

The combination of emission levels, target future year, and GCMs produced a large number of maps for each species. To determine if the analysis could be simplified, we compared the maps for both TCVM and MSCT across GCMs and anthropogenic emission levels for Douglas-fir and subalpine fir (figs. E-3 and E-4). We found that changes in anthropogenic emission levels resulted in small changes in climate habitat projections but not in the overall trend. The higher emission levels produced the greatest relative change and provided the most extreme outcome; therefore, we choose these for our analysis: A2 for TCMV and A1 for MSTC. It would have been ideal to have the same emission scenario for both SDMs, but that the two research groups did not use the same scenarios.

We compared the TCMV model results for 2030 and 2060. As with emission levels, different target years produced slight differences in species distribution, but these differences do not change the scoring results. Uncertainty can only increase with time to the target year, so TCMV 2090 and MSTC 2100 were not considered. Because it was desirable to use as close a target year as possible for the two SDM approaches, we selected 2060 for TCMV and 2050 for MSTC.

Comparison of the results using different GCMs revealed only slight changes in predicted suitable habitat. Therefore we limited our analysis to the Hadley GCM projections because they were used in both SDMs.

In some cases, the models were poor predictors of current distribution, consistently producing a more extensive range than observed. For example, the current range of noble fir was projected to extend into the northern Cascades and onto the Olympic Peninsula beyond its present distribution, as outlined in blue on fig. E-5. This issue has been recognized (Rehfeldt et al. 2006) and will be the subject of refinements in the future (Hargrove, pers. comm.). For this assessment, scores were based on comparisons only in areas where the species was known to occur.

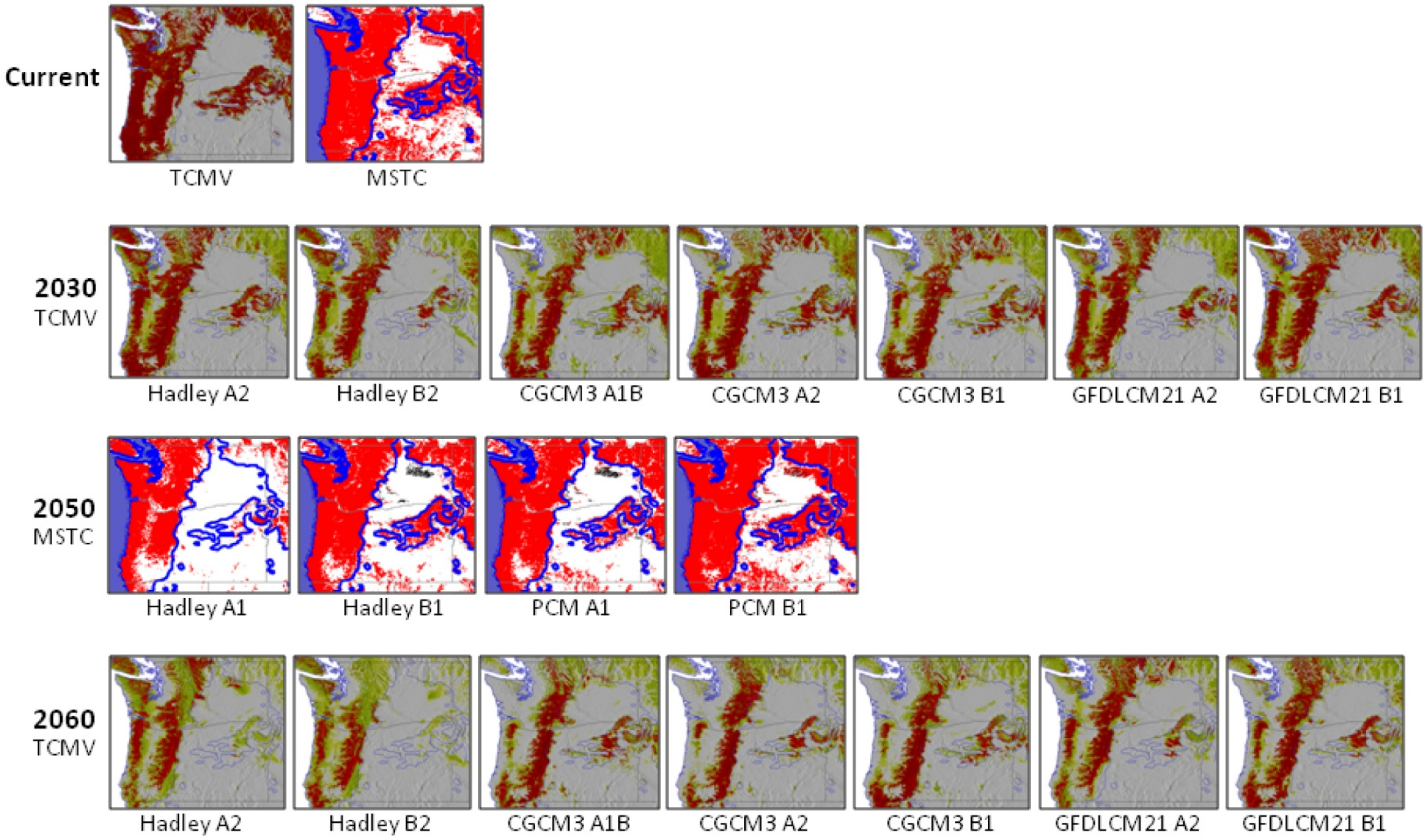


Figure E-3. Current and future predicted distribution of Douglas-fir in western Washington based on two species distribution models (MSTC[1] and TCVM[2]) for a series of general climate models and emission levels. The blue line on MSTC maps represents present distribution based on Little (1971); red solid color indicates projected species distribution. On TCMV maps, the projected range is displayed as two probability classes: 0.5 to 0.75 (two shades of green) and 0.75 to 1.00 (dark red).

[1] URL for MSTC species distribution maps: http://www.geobabble.org/~hnw/global/treeranges/climate_change/index.html

[2] URL for TCVM species distribution maps: http://forest.moscowfsl.wsu.edu/climate/species/index.php

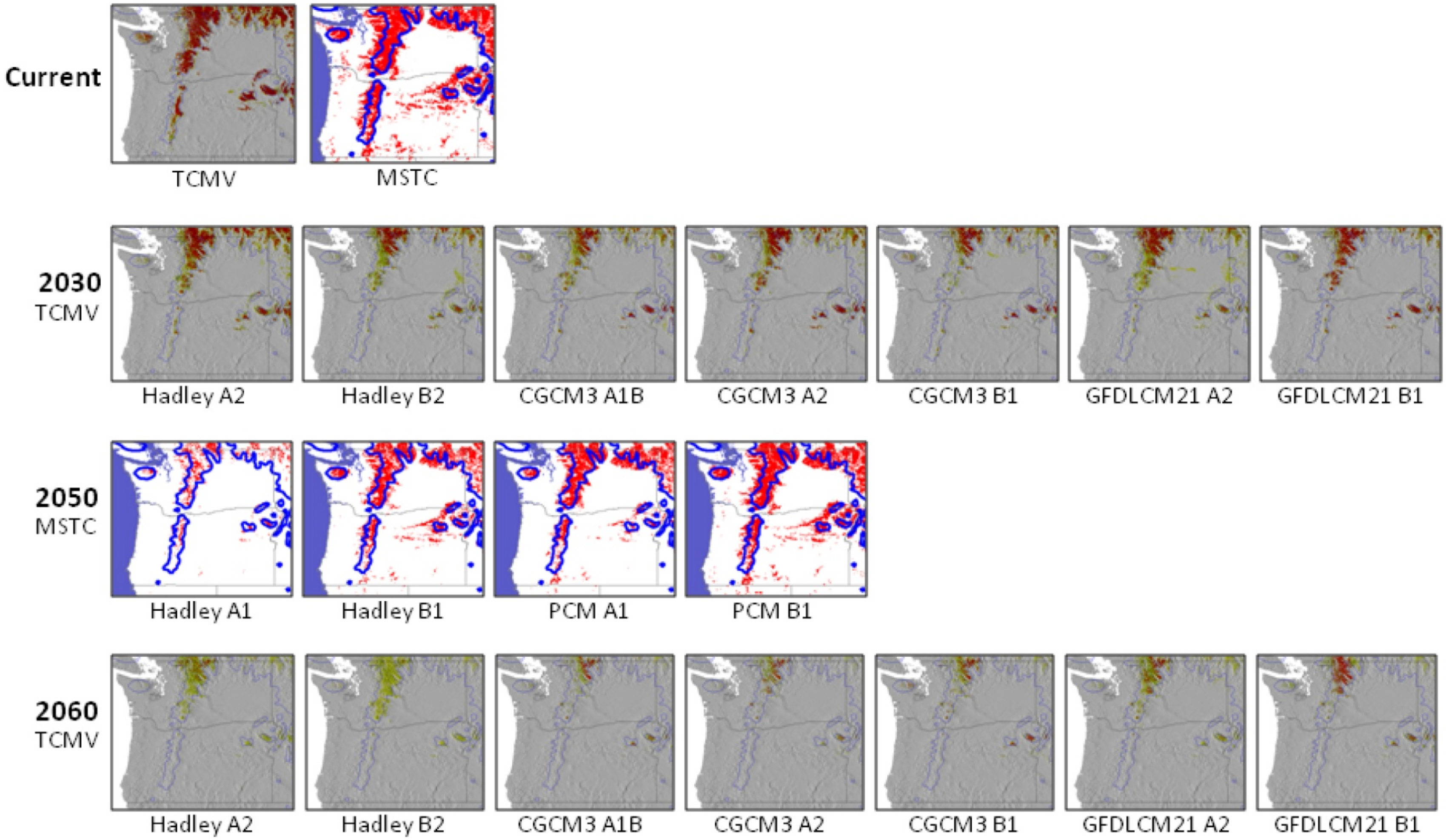


Figure E-4. Current and future predicted distribution of subalpine fir in western Washington based on two species distribution models (MSTC[1] and TCVM[2]) for a series of general climate models and emission levels. The blue line on MSTC maps represents present distribution based on Little (1971); red solid color indicates projected species distribution. On TCMV maps, the projected range is displayed as two probability classes: 0.5 to 0.75 (two shades of green) and 0.75 to 1.00 (dark red).

1 URL for MSTC species distribution maps: http://www.geobabble.org/~hnw/global/treeranges/climate_change/index.html

2 URL for TCVM species distribution map: http://forest.moscowfsl.wsu.edu/climate/species/index.php

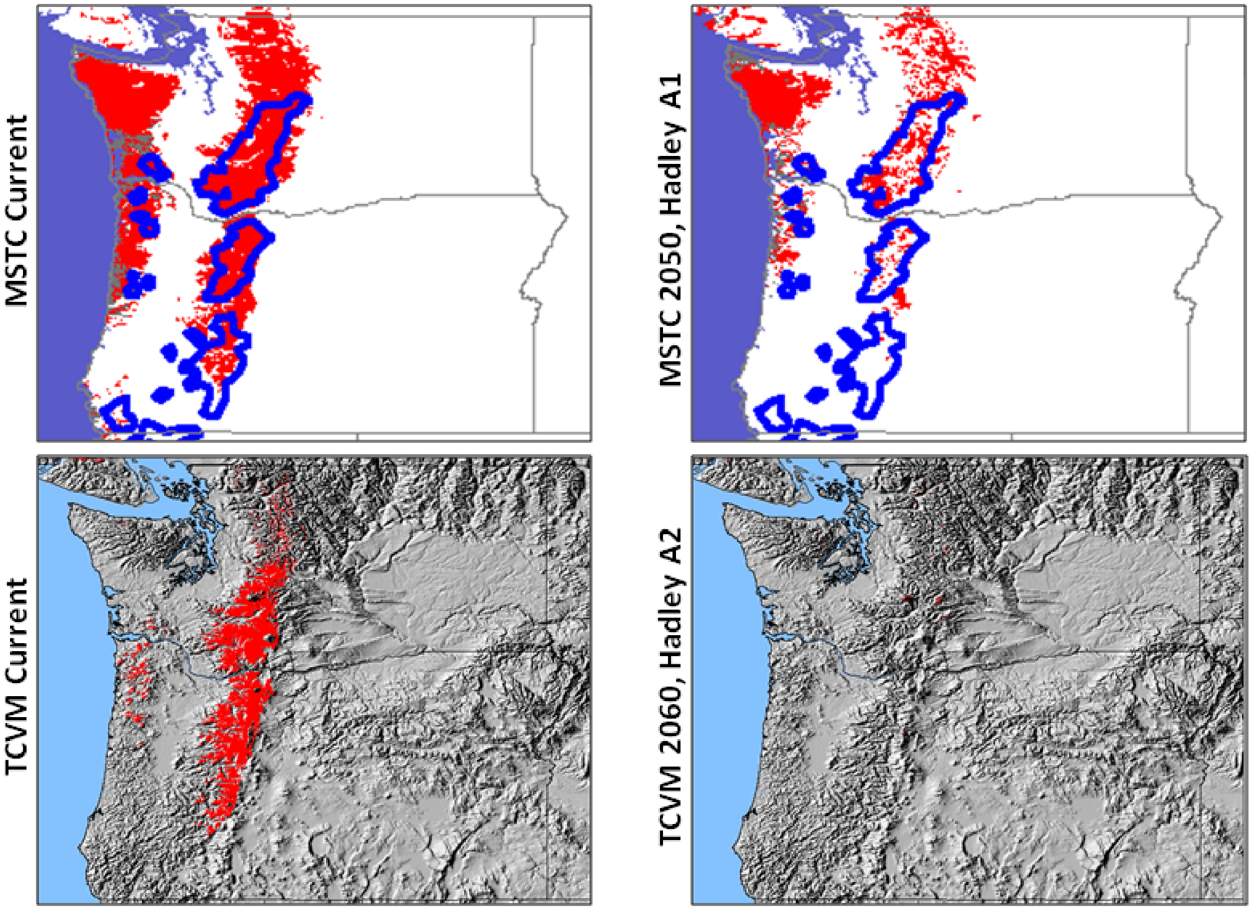


Figure E-5. Current and future predicted distribution (red color) of noble fir in western Washington based on two species distribution models (MSTC[1] and TCVM[2]) for the Hadley General Climate Model and A1 and A2 emission levels, respectively. Blue line on MSTC maps represents present distribution based on Little (1971).

1 URL for MSTC species distribution maps: http://www.geobabble.org/~hnw/global/treeranges/climate_change/index.html

2 URL for TCVM species distribution maps: http://forest.moscowfsl.wsu.edu/climate/species/index.php

SCORING AND RESULTS

We visually scored the projected change in tree species climate habitat in western Washington by comparing current to future maps for the Hadley GCM under two species distribution models, TCVM (A2, year 2060) and MSTC (A1, year 2050) (table E-1). Projections often differed between the Olympic Peninsula and the Cascade Range and Puget Sound Area. For this reason we scored the two areas separately. For each species, model (MSTV or TCMV), and area combination, the projected change was scored as follows:

- No change in projected habitat (NC)
- Small decrease in projected habitat, no reduction in projected species range (–)
- Medium decrease in projected habitat, no reduction in projected species range (– –)
- Large decrease in projected habitat and a reduction in projected species range (– – –).

Suitable climate habitat decreased for most species when considering their range across western Washington, but the magnitude of the decrease varied. A number of species showed no change at all. Predictions also varied by SDM. Although both modeling approaches predicted no change in suitable habitat for more species on the Olympic Peninsula than for the rest of western Washington, under TCMV more species were predicted to have a either a decrease in habitat or a complete loss of habitat in a portion of the range. The overall score used in the index was based on the area (Olympic Peninsula compared to Cascade Range and Puget Sound) with the greatest decrease in suitable habitat.

The species with the greatest predicted decreases in suitable habitat were noble fir, Alaska yellow-cedar, western hemlock, and mountain hemlock. The species with the least decrease in habitat were Douglas-fir, three fir species (Pacific silver fir, grand fir, and subalpine fir), bigleaf maple, and black cottonwood.

DISCUSSION

As stated earlier, we decided to eliminate the climate pressure risk factor from the vulnerability assessment based on peer review and an in-depth evaluation of the components and assumptions of the analysis. The challenges, limitations, and levels of uncertainty in the application of the two SDMs in the vulnerability assessment are outlined below. These elements produced a wide range of possible future scenarios, resulting in a level of uncertainty that was not compatible with our approach to the vulnerability assessment.

Climate envelope models are one type of model used to predict potential distribution of vegetation (See Halofsky et al. 2011 for summary). The climate habitat of individual species is projected based on statistical models with basic climate information as input (Robinson 2008). Limitations of CEMs include:

- Projections are based on current relationship between species in their realized niche and climate and cannot account for the opportunities brought about by future novel climate.
- These models do not account for competition, dispersal, local adaptation, or phenotypic plasticity, and they assume that the primary determinant of a species distribution is climate. Biotic interactions as new species assemblages develop may bring opportunities as well as challenges for species survival.
- CEMs cannot account for potential future changes in disturbance regimes, which are powerful drivers of current species distribution and can punctuate the trajectory between today and 2060.
- CEMs cannot account for the fact that plants respond to climate change individually (adaptation, acclimation dependent on genetic diversity) and that composition of vegetation assemblages will change as the climate changes as it has in the past (Leopold et al. 1982).

Of the more than 20 general circulation models (GCM) available for the climate information used in SDMs, only a few were used in the MSTC and TCVM models. We did not find much variation in the climate habitat projections across GCMs, but if the full range of models had been used, greater variation in predicted future change would be expected (Bachelet 2010a).

Climate input data from western Washington that was used in the CEM is another source of uncertainty. The maps for each tree species appear definitive, but confidence in the results must be based on the evaluation of number of aspects of climate and geography, which would be very difficult to quantify. At a recent workshop, Dominique Bachelet, Conservation Biology Institute, listed uncertainty criteria as a series of questions:

- How many **meteorological stations** are close to your site and have been used to create the climate information used by SDMs? How long are the **records** from the meteorological

Table E-1. Climate change vulnerability assessment for 15 major western Washington tree species, based on two species distribution models, MSTC and TCMV, projecting changes in each species' suitable habitat in the years 2050 and 2060, respectively

	MSTV Model (2050 projection)		TCMV Model (2060 projection)		Score	
Species	**Olympic Peninsula**	**Cascades and Puget Sound**	**Olympic Peninsula**	**Cascades and Puget Sound**	**Overall change in western Washington (both models)**	**Scaled index[2]**
Abies procera Noble fir	no data[1]	(− −)	no data	(− − −)	(− − −)	100
Cupressus nootkatensis Alaska yellow-cedar	(− −)	(− −)	(− − −)	(− − −)	(− − −)	100
Tsuga heterophylla Western hemlock	NC	(− −)	(− − −)	(− −)	(− − −)	100
Tsuga mertensiana Mountain hemlock	(− −)	(− −)	(− − −)	(− − −)	(− − −)	100
Alnus rubra Red alder	NC	(−)	(− −)	(− −)	(− −)	50
Picea engelmannii Engelmann spruce	NC	(− −)	NC	(− −)	(− −)	50
Picea sitchensis Sitka spruce	NC	NC	(− − −)	(− − −)	(− −)	50
Pinus monticola Western white pine	(−)	(− −)	(−)	(− −)	(− −)	50
Thuja plicata Western redcedar	NC	(− −)	(−)	(− −)	(− −)	50
Abies amabilis Pacific silver fir	NC	(−)	(−)	NC	(−)	0
Abies grandis Grand fir	(−)	(−)	NC	(−)	(−)	0
Abies lasiocarpa Subalpine fir	(−)	(−)	(−)	(−)	(−)	0
Acer macrophyllum Bigleaf maple	NC	(−)	NC	(−)	(−)	0
Populus balsamifera ssp. *trichocarpa* Black cottonwood	NC	(−)	no data	no data	(−)	0
Pseudotsuga menziesii Douglas-fir	NC	(−)	NC	(− −)	(−)	0

[1] *NC indicates no change in projected habitat; (–) indicates a small decrease in projected habitat, no reduction in predicted species range; (– –) indicates a medium decrease in projected habitat, no reduction in projected species range; (– – –) indicates a large decrease in projected habitat and a reduction in projected species range.*

stations near your site and how much infilling has occurred in the meteorological station records used to create the SDM climate inputs?

- How complex is the **terrain** at your site? Complex topography generates a local decoupling of local climate that will not be affected by changes in regional climate as simulated by coarse-scale GCMs.
- How far from a **relief feature** (mountain range - shadow or deep valley - inversion) is your site?
- How far away is your site from a **water body**? Proximity to the coast will affect local climate processes. Fog conditions may change for example and allow for greater moisture than projected by GCMs.
- How much is your site affected by **humans**?
  - How far is your site from urban areas? (urban heat island effect from the greater Seattle area)
  - Are there management impacts on vegetation structure or changes to stand composition due to harvest practices?
- How **stable** is the climate at your site? The Pacific Northwest has large seasonal variability with warm dry summers and cool wet winters and local species are already adapted to wide seasonal swings in temperatures and moisture levels.
  - How much change will affect organisms already adapted to such swings in weather patterns?
  - What are the thresholds or tipping points that may affect survival?

Many of these questions are meant to be addressed at the stand level; we would need to understand these complex processes across national forests to begin to understand the climate variability and the usefulness of the model results.

There also were challenges in applying the projections of the two different SDMs used in the risk factor. In order to create one score for each species, we combined the results of the two models. This was problematic because the changes in projected climate habitat varied by model or by model and area (i.e., Olympic Peninsula compared to Cascades and Puget Sound) for a number of species. This trend has been found in other studies (Hijmans and Graham 2006, Pearson 2006).

To summarize the challenges of the use of SDMs in the vulnerability assessment:

- The level of uncertainty for species envelope model results is high.
- Model uncertainty can come from a number of different sources, which are difficult to quantify but essential to evaluate SDM results.
- This uncertainty is inconsistent with the variables in the other risk factors of the vulnerability assessment, most of which are not open to interpretation because they are based on known life history traits and current distribution.
- Projected future climate habitat maps varied by model (MSTV compared to TCMV; table E-1).
- Projected future climate habitat maps varied by area within the region (Olympic Peninsula compared to Cascade Range and Puget Sound; table E-1).
- Combining results across models and areas to produce a score for each species masks these differences.
- Absence of a climate pressure factor in the vulnerability assessment does not preclude the use of model projections in vegetation management.
- Models will continue to improve; this is an additional reason to evaluate their usefulness outside of vulnerability assessment.

- There is a need for using an ensemble of climate projections (particularly regional climate models that give better local information) and multiple model approaches to test various hypotheses about species adaptability (beyond the scope of a simple assessment).

Climate Change and Forest Biodiversity:

A Vulnerability Assessment and Action Plan for National Forests in Western Washington

United States
Department of
Agriculture

Forest Service

Pacific Northwest
Region

April 2011