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Climate Change and Forest Trees in the Pacific Northwest:

A Vulnerability Assessment and Recommended Actions for National Forests

Executive Summary

ABSTRACT

Climate change predictions for the U.S. Pacific Northwest include overall warming and potentially increased winter precipitation and decreased summer precipitation. Information on the potential impacts of these changes is essential to manage National Forest System lands for the future. The objective of this study is to assess the vulnerability of forest trees of Washington and Oregon to climate change and to propose practical management actions that will work under a variety of future climate scenarios and will conserve biodiversity and increase resiliency in Pacific Northwest national forests.

KEYWORDS

Climate change, forest trees, vulnerability assessment, adaptation strategies, Pacific Northwest, Oregon, Washington, Forest Service

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FULL REPORT AND ASSOCIATED DOCUMENTS AVAILABLE ONLINE

http://ecoshare.info/projects/ccft/

Climate Change and Forest Trees in the Pacific Northwest:

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Executive Summary

June 2012

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PREFACE

"Determining which *resources are most vulnerable enables managers to better set priorities for conservation action, while understanding* why *they are vulnerable provides a basis for developing appropriate management and conservation responses."* —Glick and Stein (2010)

Climate change presents new challenges to forest managers. We ask ourselves how climate change might impact forest resources and what we can do about it. We need new information and insights. At stake is our ability to make thoughtful, science-based decisions and to add climate change considerations to our projects and management plans. We also must prioritize among the opportunities that can be included in adaptation strategies because funding and time are limited, now more than ever.

This report provides information that can help in the effort to determine the potential implications of climate change on the management, restoration, and conservation of forest tree species of the Pacific Northwest. Designed and conducted with National Forest System professionals in mind, the project addresses several elements of the *USDA National Roadmap for Responding to Climate Change* (USDA Forest Service 2011b): integrate science and management, develop partnerships, assess vulnerability, develop action items, and monitor change.

The core of this report is a vulnerability assessment of forest tree species, and recommended actions based on the results of that assessment that will sharpen the focus of activities on the most vulnerable species while simultaneously conserving biodiversity and building resiliency. In this analysis, we divided the region into six subregions with two to three forests in each subregion; this allowed us to focus on more localized tree species and populations, and geographical and climate attributes. Analyzing one forest at a time would have obscured broader trends; analyzing all forests at one time would have blurred important differences across the region.

Our analytical approach does *not* include spatially explicit predictions of future tree species habitats. Rather, it uses life history traits, distribution, and pest and pathogen data for individual tree species—combined with consensus regional climate projections—to rate each species' relative vulnerability to a changing climate. We chose an analytical method that is transparent, flexible, and simple to apply. It can easily be adjusted and the analysis rerun to see how the vulnerability ranking of species might be affected by weighting or changing certain risk factors, or by changing the variables within the risk factors. The model and data are available at: http://ecoshare.info/projects/ccft/.

It became evident during this effort that gathering information on individual tree species and learning about their life histories and distributions can be invaluable in evaluating which species might be vulnerable to climate change, why they might be vulnerable, and where data gaps exist. We encourage readers to look beyond the relative species rankings to see the particular factors that were critical in making a species more at-risk.

The subregional recommendations are not meant to be all-inclusive. We intentionally did not include details on implementation, which will vary by forest; local expertise will determine the best local path. We hope that this report will instead serve as a springboard to develop individualized national forest climate change action plans that address a goal we all share: healthy, diverse national forests that are resilient far into the future, whatever that future might reveal itself to be.

Executive Summary: Regional Report

Introduction

Climate change projections for the Pacific Northwest include year-round warming and potentially increased winter precipitation and decreased summer precipitation (Mote and Salathé 2009). The extent and duration of the regional snowpack is projected to decrease, particularly at lower elevations (Elsner et al. 2010, 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). However, 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 goal of this analysis was to conduct an assessment of the vulnerability of individual forest tree species to climate change. An understanding of which tree species are most vulnerable will assist managers in efficiently allocating limited resources to the management of these species.

> *How can the national forests of the Pacific Northwest Region conserve biodiversity and increase resiliency given the predicted changes in temperature and precipitation?*

Objectives

The specific objectives of this analysis were to:

1. Assess the relative vulnerability of forest trees of the Pacific Northwest to potential impacts of projected climate change.
2. Recommend actions that will:
   - Improve understanding of changes taking place among tree species,
   - Maintain and increase forest biodiversity and increase resiliency, and
   - Prepare for an uncertain future.
3. Collaborate in the implementation of these actions with the other land management agencies of Washington and Oregon.

Forests of the Pacific Northwest

The study area was the Forest Service Pacific Northwest Region (Washington and Oregon) which encompasses over 25 million acres of land. Because forests of this region vary widely in composition and management issues, we divided the region into six subregional study areas to assess the various forest types in greater detail (see map at top of next page). After performing the six subregional analyses of climate change vulnerability, we combined these results into an overall, regional assessment, which is presented in this report; the subregional analyses are presented in appendices 1 through 6.

The two primary ways through which vegetation managers can increase tree species diversity and alter species distribution are thinning and planting.

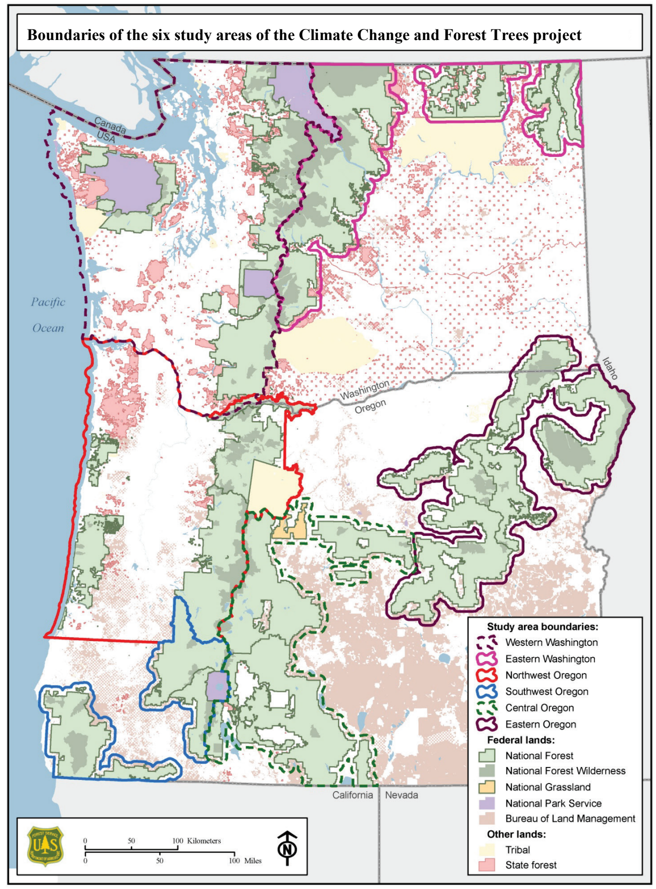
During 2008 through 2010, the total area planted on the national forests of the Pacific Northwest Region averaged approximately 20,000 acres per year. Planting ranged from fewer than 100 acres per year on the Olympic and Mt. Baker-Snoqualmie National

Forests to more than 4,000 acres per year on the Deschutes and Umatilla National Forests.

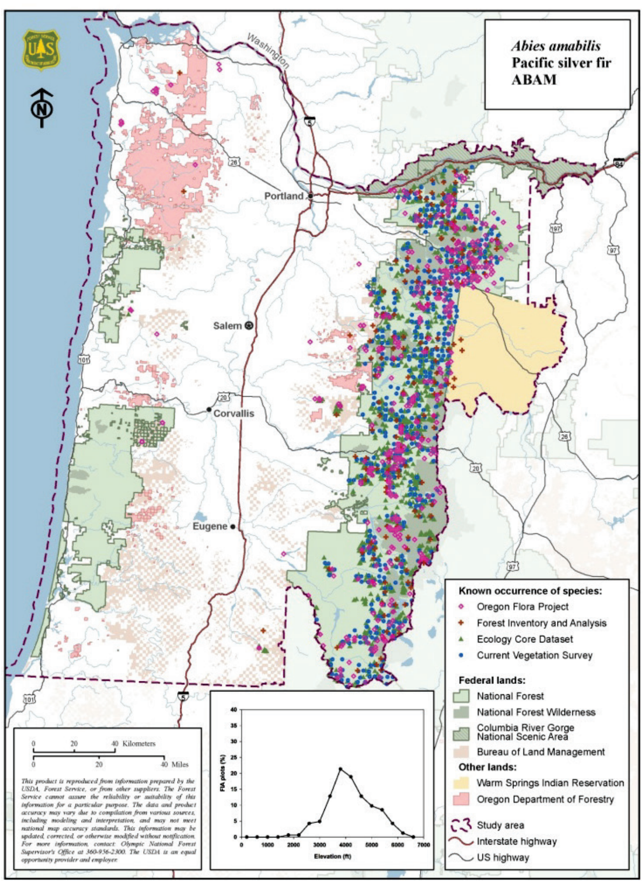
Regionally, thinning averaged approximately 123,000 acres per year from 2008 through 2010; 48,000 of these acres were thinned commercially and 75,000 acres were thinned precommercially.

Forest Tree Species

Our analysis includes the 57 native tree species of Washington and Oregon. Within each of our subregional analyses, we organized the tree species into three groups (see table on next page). Group 1 consists of overstory tree species that are common in major portions of the subregion 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; these species may occur infrequently across broad areas or may be common within a limited habitat. Group 3 consists of trees that are rare within the study area.



Boundaries of the six study areas of the Climate Change and Forest Trees project



We created distribution maps for all tree species in each subregion to show documented occurrences using the latest available data (appendix 7; available online at: http://ecoshare.info/projects/ccft/). An example for the northwestern Oregon subregion is shown to the left.

Drawing on information from a variety of published sources, we compiled profiles of the tree species (appendix 8; http://ecoshare.info/projects/ccft/). These profiles emphasize biological and ecological characteristics that were deemed relevant to the trees' potential adaptation to predicted changes in climate.

List of native tree species and analysis groups for the six subregional study areas in Washington and Oregon[1]

	Subregional study area					
Common name	**Western Washington**	**Northwestern Oregon**	**Eastern Washington**	**Eastern Oregon**	**Central Oregon**	**Southwestern Oregon**
Alaska yellow-cedar	1	1	1	3		3
Baker cypress						3
Bigleaf maple	1	1	1			1
Bitter cherry	2	2	2	2	2	2
Black cottonwood	1	1	1	1	2	2
Black hawthorn	2					
Brewer spruce						3
California black oak						1
Canyon live oak						1
Cascara	2	2	2	2	2	2
Coast redwood						3
Douglas-fir	1	1	1	1	1	1
Engelmann spruce	1	1	1	1	1	1
Golden chinquapin	3	2			2	2
Grand fir	1		1			
Grand fir-white fir complex		1		1	1	1
Incense-cedar		2			1	1
Jeffrey pine						1
Knobcone pine						1
Limber pine				3		
Lodgepole pine, Sierra lodgepole pine	2	1	1	1	1	1
Mountain hemlock	1	1	1	3	1	1
Netleaf hackberry			2	2		
Noble fir	1	1	1			
Noble fir-Shasta red fir complex					1	1
Oregon ash	2	2				2
Oregon crab apple	2	2				
Oregon myrtle						2
Oregon white oak	2	1	1			1
Pacific dogwood	2	2				2
Pacific madrone	2	2				1
Pacific silver fir	1	1	1		1	1
Pacific willow	2	2	2	2	2	2
Pacific yew	2	2	2	2		2
Paper birch	2		1	2		
Peachleaf willow				2		
Ponderosa pine	3	1	1	1	1	1
Port-Orford-cedar						1
Quaking aspen	2		1	1	2	2
Red alder	1	1	2	2	2	1
Rocky Mountain juniper	3		2	3		
Rocky Mountain maple	2	2	2	2	2	2
Scouler’s willow	2	2	2	2	2	2
Shore pine	2	1				1
Sitka spruce	1	1				3
Subalpine fir	1	1	1	1	1	1
Subalpine larch			1			
Sugar pine		1			1	1
Tanoak						1
Water birch			2	2		
Western hemlock	1	1	1		1	1
Western juniper				1	1	
Western larch		1	1	1	1	
Western redcedar	1	1	1			1
Western white pine	1	1	1	1	1	1
White alder		2		2		2
Whitebark pine	3	1	1	1	1	1

[1] *Analysis group numbers are: group 1 (major canopy species), 2 (subcanopy or minor canopy species), or 3 (rare species).*

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 to right) according to their vulnerability to climate change impacts.

After testing several methods, we chose 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 rated 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 diseases. Each risk factor contained multiple variables quantifying each tree species' vulnerability to climate change.

We calculated an overall regional 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.

Results: Group 1 species (widespread forest canopy trees), ranked by regional climate change vulnerability score

Tree species	Regional vulnerability score
Whitebark pine	72
Subalpine fir	70
Pacific silver fir	65
Engelmann spruce	62
Subalpine larch	60
Noble fir	58
Grand fir	58
Port-Orford-cedar	56
Oregon white oak	55
Alaska yellow-cedar	53
Grand fir-white fir complex	51
Quaking aspen	51
Mountain hemlock	50
Sugar pine	50
Noble fir-Shasta red fir complex	48
Pacific madrone	46
Tanoak	46
Lodgepole pine	46
California black oak	45
Western hemlock	42
Douglas-fir	42
Bigleaf maple	41
Western larch	41
Canyon live oak	40
Jeffrey pine	39
Western white pine	38
Ponderosa pine	37
Incense-cedar	36
Western redcedar	36
Paper birch	35
Sitka spruce	33
Red alder	30
Knobcone pine	30
Black cottonwood	29
Western juniper	28
Shore pine	17

A higher score indicates greater vulnerability

Group 1 Tree Species

Several trends were evident in the regional vulnerability scores:

- Five species had regional vulnerability scores of 60 or higher: whitebark pine, subalpine fir, Pacific silver fir, Engelmann spruce, and subalpine larch. All these species occur in high- or mid-to-high-elevation habitat.
- Nine species had regional vulnerability scores of 50 to 59: noble fir, grand fir, Port-Orford-cedar, Oregon white oak, Alaska yellow-cedar, the grand fir-white fir complex, quaking aspen, mountain hemlock, and sugar pine. These species represent a wide range in habitats.
- Five species had regional vulnerability scores of 30 or lower: shore pine, western juniper, black cottonwood, knobcone pine, and red alder. All these species occupy low- or low-to-mid-elevation habitats.
- Most of the major commercial tree species of the region occurred toward the middle of the vulnerability rankings, although some true firs (*Abies* spp.) had high vulnerability.
- Broadleaf species were scattered throughout the vulnerability rankings, although there were only two species ranked among the higher-vulnerability trees (i.e., scores of 50 or higher): Oregon white oak (55) and quaking aspen (51).

Group 2 and Group 3 Tree Species

Group 2 tree species were predominantly non-commercial; 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. Implications for these species under a warming climate include:

- Based on projections of increased summer moisture deficit, the group 2 tree species that are highly drought-tolerant (e.g., Pacific madrone, golden chinquapin, and Rocky Mountain juniper) may become more competitive in areas presently dominated by less drought-tolerant tree species.
- The group 2 species that often colonize disturbed sites near streams and rivers (e.g., willow species, black cottonwood, and Oregon ash) may have increased opportunity for establishment under climate scenarios in which snowmelt and precipitation patterns increase major flood events, which create new habitat for them.
- Many group 2 tree species are insect-pollinated or produce seed that is dispersed by animals; thus, these species are vulnerable to changes in animal behavior associated with climate. However, vulnerability is likely to differ among these tree species based on number of animal associates and the specificity of the relationships.

Group 3 consists of a variety of tree species that are rare within at least one of the six subregional study areas. Often these species are represented by disjunct populations that may be genetically distinct from the species' contiguous distribution. Owing to their limited distributions, all of these species are already deemed vulnerable to the effects of climate change. The report includes specific recommendations for conserving and monitoring these species.

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. 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. 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.

> *"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."*

Action Items Based on the Results of the Climate Change Vulnerability Assessment

1. **Assess stand health and regeneration of subalpine fir, mountain hemlock, and Alaska yellow-cedar in western Washington and northwestern Oregon.**
   These three high-elevation tree species were found to be most at risk based on our 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.

2. **Establish permanent plots in high-elevation stands in eastern Washington, eastern Oregon, and southwestern Oregon to monitor changes in tree growth, survival, and distribution.**
   The most vulnerable tree species in these three subregions occur in specific areas that are described in table 30 in the report. It would be most efficient to establish permanent plots where most of the at-risk species co-occur.

3. **Develop conservation and monitoring plans for species limited to small or disjunct populations (table 31 in report).**
   Each species' plan should include surveys to verify location data, seed sampling for gene conservation, and needle collection for genetic studies. Where distributions span multiple ownerships, plans should include partnerships with other land managers. Genetic analysis, when appropriate, can be done in partnership with the National Forest Genetics Laboratory. Assessments of genetic variation and population structure will determine whether these small or disjunct populations are genetically distinct from populations within the contiguous part of the species' distribution. This information is important because disjunct populations could become 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.

4. **Continue and expand the survey and mapping program for whitebark pine, with participation by all land management agencies with whitebark pine habitat.**
   This should include a refinement of the existing regional GIS layer of whitebark pine occurrences. Readily accessible data on whitebark pine's present distribution are essential for monitoring and managing the species under climate change and pathogen threats.

5. **Maintain an inventory of high-quality seed for tree species for which seed is likely to be needed during 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 and Bend Seed Extractory;
   - Retest viability as needed;
   - Discard non-viable seed;
   - Update Seed Procurement Plans to include new and replacement collections; and
   - Maintain area seed orchards, which serve as gene conservation areas and are the national forests' most efficient source of high-quality tree seed.

Action Items Based on the Results of the Climate Change Vulnerability Assessment

6. **Continue the national forests' thinning and planting programs.**
   - Thinning promotes: (1) greater biodiversity by increasing the proportion of less abundant conifer and hardwood tree species; (2) development of understory vegetation; (3) enhancement of the habitat value provided by forest stands; and (4) increased stand resistance and resiliency to disturbance and environmental stressors. Forest density management through thinning in combination with prescribed fire may be key in producing resilient stands in many dry forest types.
   - Continue to include, and increase when feasible, a variety of local, native tree species in planting prescriptions, with an emphasis on under-represented species.

7. **Partner with other land managers to create virtual cooperative tree seed banks.** 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.

8. **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.

9. **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 whether there are trends in how trees are responding to annual climate variation. A pilot program was established in 2011 in the Dennie Ahl Seed Orchard (Olympic National Forest) to develop protocols to monitor phenology of conifers in seed orchards in the Pacific Northwest. This pilot program was initiated in partnership with Dr. Constance Harrington of Pacific Northwest Research Station and the Washington State Department of Natural Resources.

10. **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.

Note: Action items specific to the six subregional study areas appear in the subregional executive summaries.

EXECUTIVE SUMMARY:
WESTERN WASHINGTON SUBREGION

Introduction

Climate change projections for the Pacific Northwest include year-round warming and potentially increased winter precipitation and decreased summer precipitation (Mote and Salathé 2009). The extent and duration of the regional snowpack is projected to decrease, particularly at lower elevations (Elsner et al. 2010, 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). However, 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 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 relative vulnerability of forest tree species to projected climate changes.
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, maintain and increase biodiversity and increase resiliency, 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.

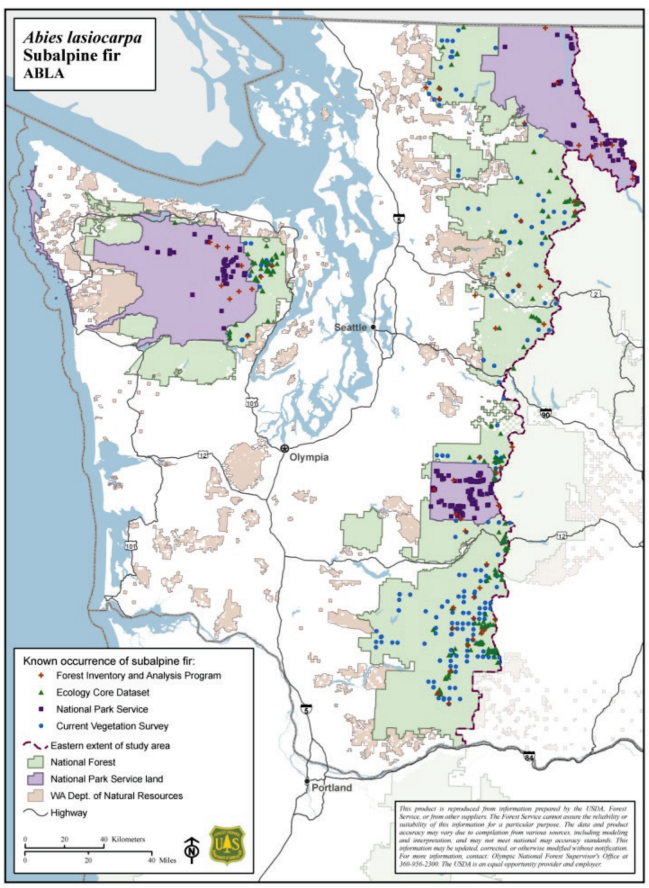
Forests of Western Washington

The study area consists of the forests of western Washington, defined here as the portion of the state west of the Cascade Range crest. It 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) (map on next page). 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 ac (1.6 million ha) are protected either as national parks or congressionally designated wilderness areas on national 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, pre-commercial or commercial thinning was conducted on a combined total of approximately 7,000 ac (2,800 ha) each year during 2008-2010, most often with the objective of improving wildlife habitat. Tree planting was infrequent; a combined total of fewer than 300 ac (120 ha) was reforested each year (2008-2010).

Forest Tree Species

We organized the tree species of western Washington into three groups (see box 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.



We created distribution maps for all tree species of western Washington to show documented occurrences using the latest available data (appendix 7; available online at: http://ecoshare.info/projects/ccft/). An example is shown to the left.

Drawing on information from a variety of published sources, we compiled profiles of the western Washington tree species (appendix 8; available online at: http://ecoshare.info/projects/ccft/). These profiles emphasize biological and ecological characteristics that were deemed relevant to the trees' potential adaptation to predicted changes in climate.

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 according to their vulnerability to climate change impacts.

After testing several methods, we chose 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.

Native tree species of western Washington

Group 1: Widespread forest canopy species

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

Group 2: Less common or non-canopy species

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

Group 3: Species rare in western Washington

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

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 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, the 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.

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.

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

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 distributions, 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.

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. 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. 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.

> *"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, the predominant species in areas under active management, have a lower vulnerability to a changing climate."*

Action Items Based on the Results of the Climate Change Vulnerability Assessment

Western Washington

1. **Learn about and track changes in plant communities as the climate changes**

   - **Continue and expand the heath and condition surveys and mapping program for whitebark pine, with participation by all land management agencies with whitebark pine habitat in Washington State.**
     Readily accessible data on whitebark pine's present distribution is essential for monitoring and managing the species under climate change and pathogen threats.

   - **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.**

   - **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.

   - **Monitor vegetative and reproductive phenology 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.

2. **Maintain and enhance biodiversity and increase resiliency**

   - **Continue the national forests' thinning programs.**
     These programs achieve: (1) the 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 disturbances, including fire and insect outbreaks, and environmental stressors.

   - **Continue to include a variety of tree species in planting prescriptions, with an emphasis on under-represented tree species.**

Action Items Based on the Results of the Climate Change Vulnerability Assessment

Western Washington

2. Maintain and enhance biodiversity and increase resiliency (continued)

- **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.

- **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.

- **Develop a partnership between the Forest Service, WDNR, and private landowners to map, conserve, and restore the ISSSSP-listed[1] species, golden chinquapin, on the Olympic Peninsula. Continue to actively manage golden chinquapin sites on the Gifford Pinchot National Forest to promote growth and survival of the species.**
  These disjunct populations represent the northernmost occurrences of this species.

3. Prepare for the future

- **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.

- **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.

- **Maintain forest tree seed orchards.**
  These serve as gene conservation areas and are the national forests' most efficient source of high quality tree seed.

- **Assess seed viability of individual selected tree lots in storage.**
  The three national forests in western Washington have more than 5,000 single tree seedlots from selected trees in storage at the Dorena Genetic Resources Center. Many of these seedlots have been in storage for one or more decades and their viability is unknown.

[1] *Interagency Special Status / Sensitive Species Program (USDA 2010c)*

EXECUTIVE SUMMARY:
NORTHWESTERN OREGON SUBREGION

INTRODUCTION

Climate change projections for the Pacific Northwest include year-round warming and potentially increased winter precipitation and decreased summer precipitation (Mote and Salathé 2009). The extent and duration of the regional snowpack is projected to decrease, particularly at lower elevations (Elsner et al. 2010, 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). However, 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 and propose practical management actions that will work under a variety of future climate scenarios and can be implemented by the national forests in northwestern Oregon in cooperation with other land managers.

How can the national forests in northwestern Oregon conserve biodiversity and increase resiliency given the predicted changes in temperature and precipitation?

OBJECTIVES

The specific objectives of this analysis are to:

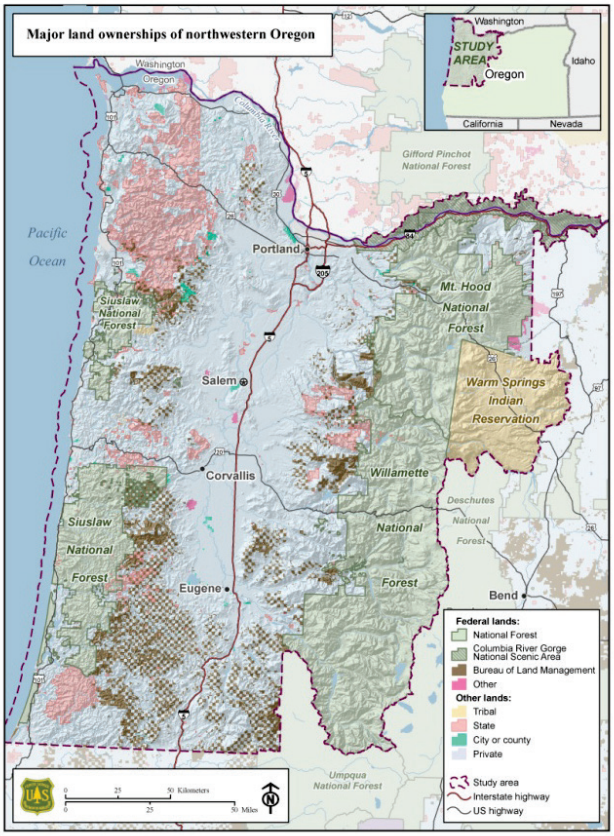
1. Assess the relative vulnerability of forest tree species to projected climate changes.
2. Recommend actions that will improve understanding of changes taking place among tree species, maintain and increase biodiversity and increase resiliency, and prepare for an uncertain future.
3. Collaborate in the implementation of these actions with other land managers in northwestern Oregon.

FORESTS OF NORTHWESTERN OREGON

The study area consists of the forests and woodlands of northwestern Oregon. The eastern boundary of the study area is based on the eastern edges of the Mt. Hood and Willamette National Forests but also includes the Columbia River Gorge National Scenic Area and Warm Springs Indian Reservation (map at top of next page). The southern boundary of the study area was based on the southernmost latitude of the Willamette National Forest. The western and northern study area boundaries follow the state line, with the exception of the Columbia River Gorge National Scenic Area, which includes a portion of Washington.

The northwestern Oregon study area includes a total of 13.7 million acres (5.5 million ha). The Mt. Hood, Siuslaw, and Willamette National Forests comprise 1.1, 0.6, and 1.7 million acres (0.4, 0.3, and 0.7 million ha), respectively, for a total of 3.3 million acres (1.3 million ha). On these three national forests are approximately 715,000 acres (290,000 ha) of designated wilderness, most of which are on the Mt. Hood and Willamette National Forests.

Vegetation management on northwestern Oregon's national forests is conducted to meet a wide variety of objectives designed to diversify and improve forest structure. On the Mt. Hood, Siuslaw, and Willamette National Forests, respectively, averages of 2,600;



4,500; and 3,040 ac (1,050; 1,820; and 1,230 ha) of forest land were thinned annually during 2008-2010.

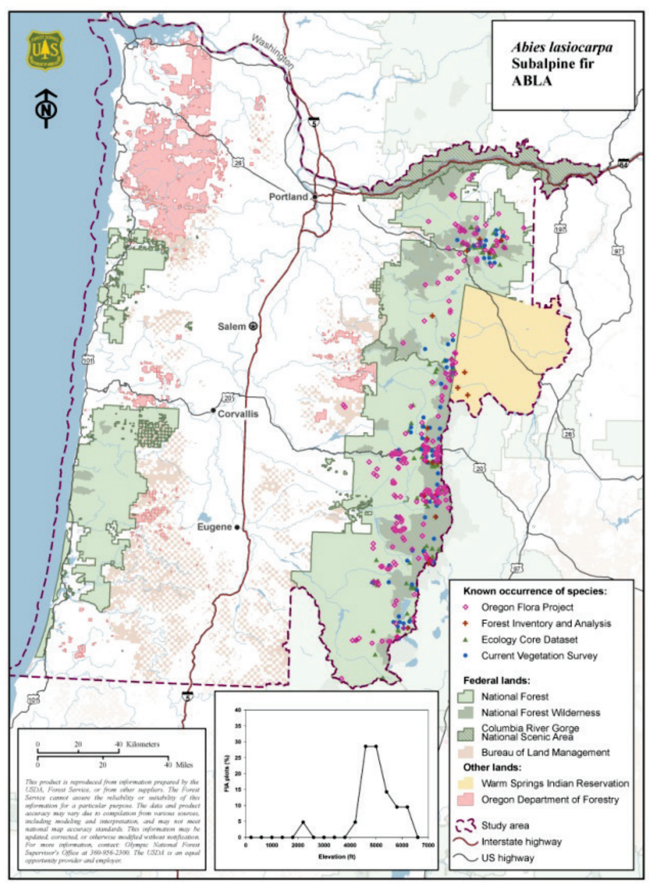
On the Mt. Hood, Siuslaw, and Willamette National Forests, respectively, averages of 280, 375, and 920 ac (115, 150, and 370 ha) of forest land were planted annually during 2008-2010. Species planted on the Mt. Hood National Forest include Douglas-fir, noble fir, ponderosa pine, and western larch; most planting prescriptions also include approximately 20 percent western white pine. On the Siuslaw National Forest, planting of western redcedar and western hemlock, as well as a smaller amount of Douglas-fir, is typically conducted in coordination with stand thinning for the purpose of meeting late successional reserve structural objectives. The Willamette National Forest plants Douglas-fir, western white pine, and western redcedar, usually in created gaps or riparian restoration projects.

Forest Tree Species

We organized the tree species of northwestern Oregon into two groups (see box on next page). Group 1 consists of 22 overstory tree species that are common in major portions of northwestern Oregon 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 northwestern Oregon; these species may occur infrequently across broad areas or may be common within a limited habitat.

We created distribution maps for all tree species of northwestern Oregon to show documented occurrences using the latest available data (appendix 7; example below).

Drawing on information from a variety of published sources, we compiled profiles of the northwestern Oregon tree species (appendix 8). 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 Northwestern Oregon

Group 1: Widespread forest canopy species

- Alaska yellow-cedar
- Bigleaf maple
- Black cottonwood
- Douglas-fir
- Engelmann spruce
- Grand fir
- Lodgepole pine
- Mountain hemlock
- Noble fir
- Oregon white oak
- Pacific silver fir
- Ponderosa pine
- Red alder
- Shore pine
- Sitka spruce
- Subalpine fir
- Sugar pine
- Western hemlock
- Western larch
- Western redcedar
- Western white pine
- Whitebark pine

Group 2: Less common or non-canopy species

- Bitter cherry
- Cascara
- Douglas maple
- Golden chinquapin
- Incense-cedar
- Oregon ash
- Pacific dogwood
- Pacific madrone
- Pacific willow
- Pacific yew
- Scouler's willow
- Western crab apple
- White alder

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 according to their vulnerability to climate change impacts.

After testing several methods, we chose 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:

- Among the 22 group 1 tree species, overall vulnerability scores ranged from 17 to 77 (lowest and highest scores possible were 0 and 100, respectively). When species were ranked by score, the scores were distributed relatively evenly, with the largest gaps between scores occurring among species ranked near both ends of the scale.
- The most common low- to mid-elevation conifers, Douglas-fir, western hemlock, and western redcedar, all were in the lower half of the vulnerability ranking.
- Three of the four broadleaf species occurred low in the ranking. The fourth, Oregon white oak, ranked near the middle.
- For the species that shared a common genus, the four true firs were generally ranked near the top, whereas the six pines showed no pattern in ranking.
- Vulnerability of tree species generally increased with mean elevation of their occurrences. With the exception of western white pine, all species with mean elevations of 3,800 ft (1,160 m) or higher had overall vulnerability scores greater than 50.

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

Tree species	Overall vulnerability score
Subalpine fir	77
Whitebark pine	67
Pacific silver fir	66
Mountain hemlock	60
Noble fir	60
Alaska yellow-cedar	59
Sugar pine	59
Grand fir	59
Lodgepole pine	56
Engelmann spruce	55
Oregon white oak	54
Western larch	52
Western hemlock	52
Bigleaf maple	50
Ponderosa pine	46
Douglas-fir	41
Western white pine	39
Sitka spruce	39
Red alder	38
Western redcedar	36
Black cottonwood	27
Shore pine	17

Group 2 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. Implications for these species under a warming climate include:

- Based on projections of increased summer moisture deficit, the group 2 tree species that are highly drought-tolerant may become more competitive in areas presently dominated by less drought-tolerant tree species.
- The group 2 species that often colonize disturbed sites near streams and rivers (i.e., the willow species, white alder, and Oregon ash) may have increased opportunity for establishment under climate scenarios in which snowmelt and precipitation patterns increase major flood events, which create new habitat for them.
- Many group 2 tree species are insect-pollinated or produce seed that is dispersed by animals; thus, these species are vulnerable to changes in animal behavior associated with climate. However, vulnerability is likely to differ among these tree species based on number of animal associates and the specificity of the relationships.

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. 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. 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.

Action Items Based on the Results of the Climate Change Vulnerability Assessment

Northwestern Oregon

1. **Learn about and track changes in plant communities as the climate changes**

- **Continue and expand the survey and mapping program for whitebark pine, with participation by all land management agencies with whitebark pine habitat in Oregon.**
  Readily accessible data on whitebark pine's present distribution is essential for monitoring and managing the species under climate change and pathogen threats. (Item refers only to Mt. Hood and Willamette National Forests.)

- **Develop a conservation and monitoring plan for the 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.**

- **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.

- **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.

- **Assess genetic variation and population structure in two species with disjunct populations in the Coast Range: Pacific silver fir and noble fir.**
  This information is important because these disjunct populations may act 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.

Action Items Based on the Results of the Climate Change Vulnerability Assessment

Northwestern Oregon

2. Maintain and enhance biodiversity and increase resiliency

- **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 resiliency to disturbance and environmental stressors.

- **Continue to include a variety of tree species in planting prescriptions, with an emphasis on under-represented tree species.**

- **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 Agricultural Research Service National Center for Germplasm Preservation in Ft. Collins, CO, for Coast Range populations of Pacific silver fir and noble fir. This project would include a partnership with ODF.

3. Prepare for the future

- **Partner with other land managers in northwestern Oregon 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.

- **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.

- **Maintain forest tree seed orchards.**
  These serve as gene conservation areas and are the national forests' most efficient source of high quality tree seed.

- **Assess seed viability of individual selected tree lots in storage.**
  The three national forests in northwestern Oregon have at least 11,344 single tree seedlots from selected trees in storage at the Dorena Genetic Resources Center. Many of these seedlots have been in storage for one or more decades and their viability is unknown.

EXECUTIVE SUMMARY:
EASTERN WASHINGTON SUBREGION

Introduction

Climate change projections for the Pacific Northwest include year-round warming and potentially increased winter precipitation and decreased summer precipitation (Mote and Salathé 2009). The extent and duration of the regional snowpack is projected to decrease, particularly at lower elevations (Elsner et al. 2010, 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). However, 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 and propose practical management actions that will work under a variety of future climate scenarios and can be implemented by the national forests in eastern Washington in cooperation with other land managers.

How can the national forests in eastern 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 relative vulnerability of forest tree species to projected climate changes.
2. Recommend actions that will improve understanding of changes taking place among tree species, maintain and increase biodiversity and increase resiliency, and prepare for an uncertain future.
3. Collaborate in the implementation of these actions with other land managers in eastern Washington.

Forests of Eastern Washington

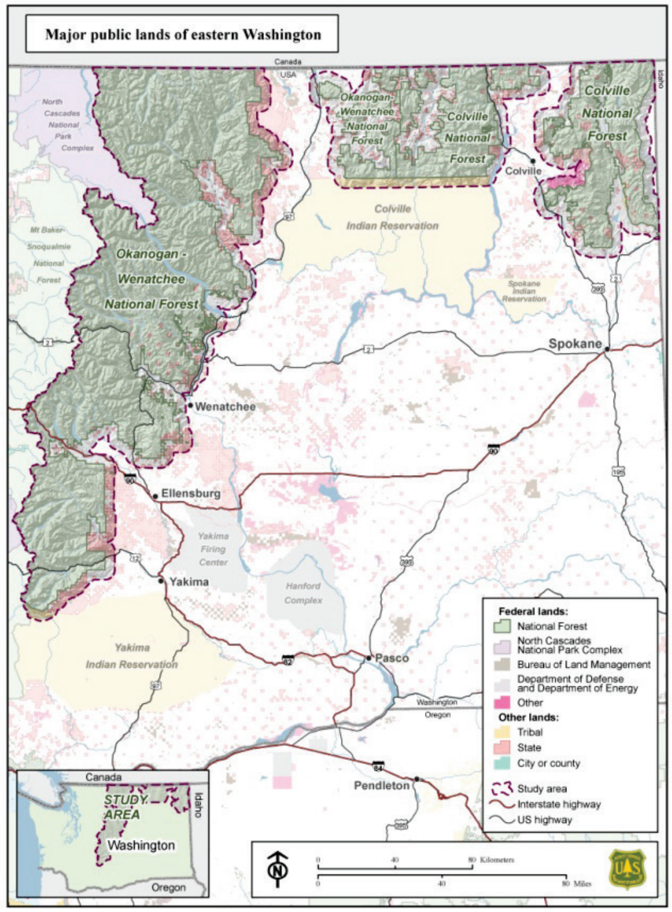
The eastern Washington study area includes a total of 7.7 million ac (3.1 million ha), encompassing the Colville and Okanogan-Wenatchee National Forests and an associated buffer area (see map at top of next page). The Colville and Okanogan-Wenatchee National Forests comprise 1.1 million ac (0.4 million ha) and 4.3 million ac (1.7 million ha), respectively. Approximately 3 and 35 percent of these forests, respectively, are designated wilderness areas.

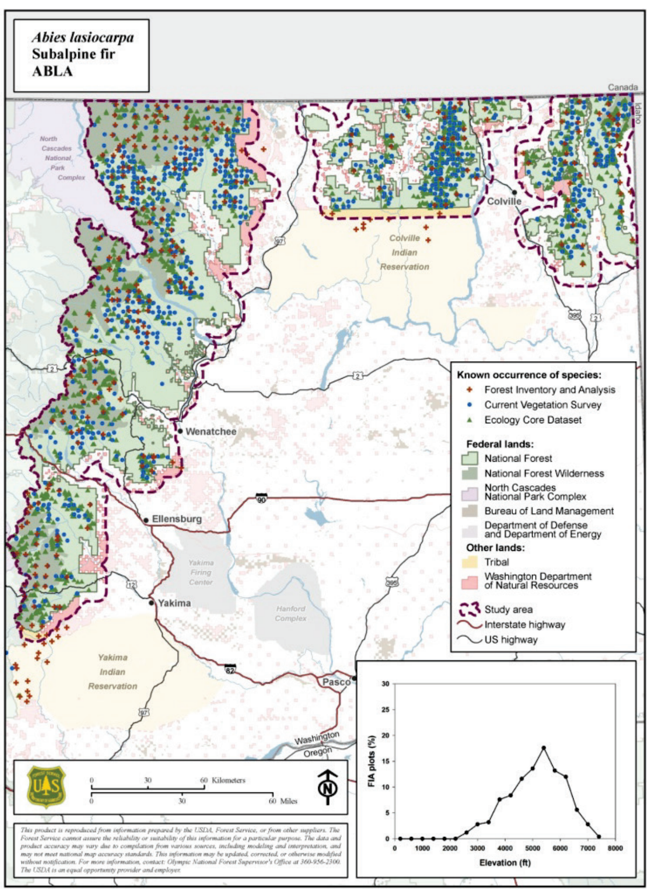
Vegetation management on eastern Washington's national forests is conducted to meet a wide variety of objectives designed to diversify and improve forest structure. During 2008 through 2010, the Colville and Okanogan-Wenatchee National Forests commercially thinned averages of 3,190 and 2,830 ac (1,290 and 1,150 ha) of forest land, respectively, each year. Averages of 2,230 and 7,230 ac (900 and 2,930 ha) per year were precommercially thinned on these two forests during the same period.

On the Colville and Okanogan-Wenatchee National Forests, respectively, averages of 450 and 1,990 ac (180 and 810 ha) of forest land were planted annually during 2008-2010. The Colville National Forest planted ponderosa pine, western larch, western white pine, and Douglas-fir. The Okanogan-Wenatchee National Forest planted primarily ponderosa pine, Douglas-fir, and western larch. A small amount of Engelmann spruce, western white pine, western redcedar, and whitebark pine also was planted.

Forest Tree Species

We organized the tree species of eastern Washington into two groups (see box on next page). Group 1 consists of 21 overstory tree species that are common in major portions of eastern 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 eastern Washington; these species may occur infrequently across broad areas or may be common within a limited habitat.





We created distribution maps for all tree species of eastern Washington to show documented occurrences using the latest available data (appendix 7; example shown to left).

Drawing on information from a variety of published sources, we compiled profiles of the eastern Washington tree species (appendix 8). These profiles emphasize biological and ecological characteristics that were deemed relevant to the trees' potential adaptation to predicted changes in climate.

FOREST TREE VULNERABILITY ASSESSMENT

NATIVE TREE SPECIES OF EASTERN WASHINGTON

Group 1: Widespread forest canopy species

Pacific silver fir
Grand fir
Subalpine fir
Noble fir
Bigleaf maple
Paper birch
Alaska yellow-cedar
Subalpine larch
Western larch
Engelmann spruce
Whitebark pine
Lodgepole pine
Western white pine
Ponderosa pine
Black cottonwood
Quaking aspen
Douglas-fir
Oregon white oak
Western redcedar
Western hemlock
Mountain hemlock

Group 2: Less common or non-canopy species

Rocky Mountain maple
Red alder
Water birch
Netleaf hackberry
Cascara
Rocky Mountain juniper
Bitter cherry
Pacific willow
Scouler's willow
Pacific yew

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 according to their vulnerability to climate change impacts.

After testing several methods, we chose 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:

- Among the 21 group 1 tree species, overall vulnerability scores ranged from 28 to 74 (lowest and highest scores possible were 0 and 100, respectively). When species were ranked by score, the scores were distributed relatively evenly, with the largest gap between scores occurring between the highest ranked species, whitebark pine (74), and the second-ranked species, subalpine fir (64).

- The most common low- to mid-elevation conifers, Douglas-fir, ponderosa pine, western larch, western hemlock, and western redcedar, all were in the lower half of the vulnerability ranking.

- Many of the important commercial species including Douglas-fir, ponderosa pine, and western larch had relatively low vulnerability scores. All four of the true firs, however, had relatively high scores.

- With the exception of Oregon white oak, which ranked in the top group, the other broadleaf species occurred in the lower half of the ranking.

- Vulnerability of tree species generally increased with increasing mean elevation of occurrences.

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

Tree species	Overall vulnerability score
Whitebark pine	74
Subalpine fir	64
Pacific silver fir	62
Oregon white oak	62
Subalpine larch	60
Grand fir	60
Engelmann spruce	57
Noble fir	54
Lodgepole pine	51
Alaska yellow-cedar	50
Mountain hemlock	50
Bigleaf maple	47
Douglas-fir	45
Western redcedar	45
Western hemlock	44
Quaking aspen	44
Ponderosa pine	39
Western larch	38
Paper birch	35
Western white pine	28
Black cottonwood	28

Group 2 Tree Species

Group 2 tree species were not significant components of the forest canopy, owing to small size or because they typically occur as scattered individuals or components of the mid-story rather than the forest overstory. 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.

Implications for these species under a changing climate include:

- Most of the group 2 tree species occur on sites with extreme moisture regimes (i.e., flooding or drought) or as understory components of multiple forest types.
- The group 2 tree species that are highly drought-tolerant may become more competitive in areas presently dominated by less drought-tolerant tree species.

- The group 2 species that often colonize disturbed sites near streams and rivers (Pacific willow, Scouler's willow, red alder, and water birch) may have increased opportunity for establishment under projected climate scenarios in which snowmelt and precipitation patterns increase major flood events (Elsner et al. 2010), which create new habitat for them.
- Many group 2 tree species are insect-pollinated or produce seed that is dispersed by animals; thus, these species are vulnerable to changes in animal behavior associated with climate. However, vulnerability is likely to differ among these tree species based on number of animal associates and the specificity of the relationships.

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. 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. 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.

"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."

Action Items Based on the Results of the Climate Change Vulnerability Assessment

Eastern Washington

1. **Learn about and track changes in plant communities as the climate changes**

   - **Continue and expand the survey and mapping program for whitebark pine, with participation by all land management agencies that manage whitebark pine habitat in Washington.**
     Readily accessible data on whitebark pine's present distribution are essential for monitoring and managing the species under climate change and pathogen threats.

   - **Develop a conservation and monitoring plan for subalpine larch, a high-elevation tree species that ranked high in vulnerability to climate change and has not been managed in the past.**
     A cooperative program would be most beneficial because the range of subalpine larch is limited to the Mt. Baker-Snoqualmie and Okanogan-Wenatchee National Forests and the North Cascades National Park Complex (NCNPC) on lands between 5,500 and 7,500 ft elevation.

   - **Establish permanent plots at high elevations (above 4,500 ft) in the eastern Cascades of the Okanogan-Wenatchee National Forest and the NCNPC to monitor changes in tree growth, survival, and reproduction.**
     Most of the higher-vulnerability tree species of eastern Washington are either limited to the east side of the Cascade Range (Pacific silver fir, subalpine larch, noble fir, mountain hemlock, Alaska yellow-cedar) or are relatively prevalent there (whitebark pine, subalpine fir, Engelmann spruce).

   - **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.

Action Items Based on the Results of the Climate Change Vulnerability Assessment

Eastern Washington

2. Maintain and enhance biodiversity and increase resiliency

- **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 resiliency to disturbances, including fire and insect outbreaks, and environmental stressors, such as drought.

- **Continue to include a variety of tree species in planting prescriptions, with an emphasis on under-represented tree species.**

- **Expand thinning and planting programs to include areas other than fuels reduction in the wildland-urban interface.**
  A variety of elevations and species across the forests need to be treated to make a real difference in enhancing biodiversity and increasing resiliency.

- **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 underway for whitebark pine, but to date no collections have been made for other species.

3. Prepare for the future

- **Partner with other land managers in eastern 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.

- **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.

- **Maintain forest tree seed orchards.**
  These serve as gene conservation areas and are the national forests' most efficient source of high quality tree seed.

- **Assess seed viability of individual selected tree lots in storage.**
  The two national forests in eastern Washington have 16,300 single-tree seedlots from selected trees in storage at the Dorena Genetic Resources Center. Many of these seedlots have been in storage for one or more decades and their viability is unknown.

EXECUTIVE SUMMARY:
EASTERN OREGON SUBREGION

Introduction

Climate change projections for the Pacific Northwest include year-round warming and potentially increased winter precipitation and decreased summer precipitation (Mote and Salathé 2009). The extent and duration of the regional snowpack is projected to decrease, particularly at lower elevations (Elsner et al. 2010, 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). However, 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 and propose practical management actions that will work under a variety of future climate scenarios and can be implemented by the national forests in eastern Oregon in cooperation with other land managers.

How can the national forests in eastern Oregon conserve biodiversity and increase resiliency given the predicted changes in temperature and precipitation?

Objectives

The specific objectives of this analysis are to:

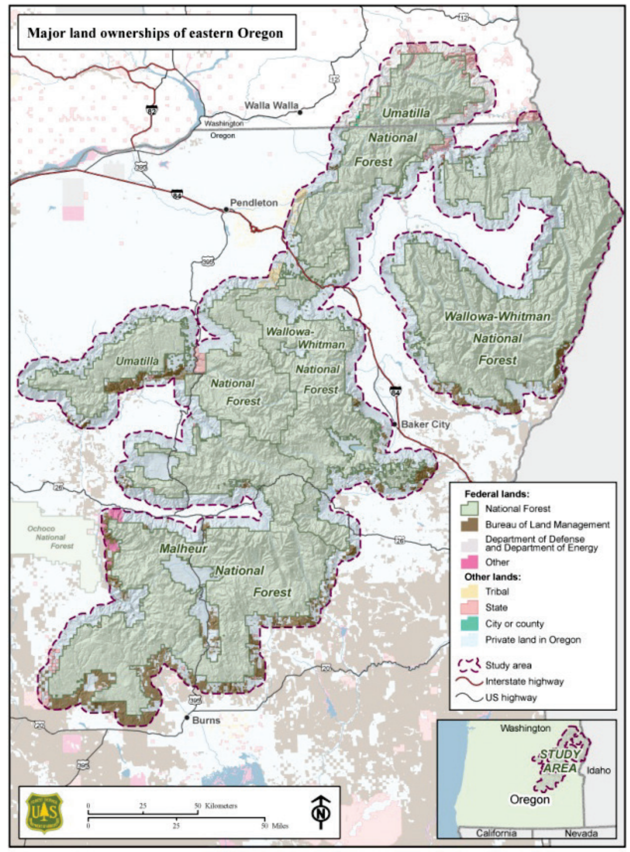
1. Assess the relative vulnerability of forest tree species to projected climate changes.
2. Recommend actions that will improve understanding of changes taking place among tree species, maintain and increase biodiversity and increase resiliency, and prepare for an uncertain future.
3. Collaborate in the implementation of these actions with other land managers in eastern Oregon.

Forests of Eastern Oregon

The study area is based on the three national forests of eastern Oregon (the Malheur, Umatilla, and Wallowa-Whitman), including the portion of the Umatilla National Forest that is located in Washington (map at top of next page). The eastern Oregon study area includes a total of 8.6 million ac (3.5 million ha), encompassing the national forests and associated buffer areas. The Malheur National Forest includes 1.7 million ac (0.7 million ha), the Umatilla National Forest includes 1.4 million ac (0.6 million ha), and the Wallowa-Whitman National Forest includes 2.4 million ac (1.0 million ha).

Vegetation management on eastern Oregon's national forests is conducted to meet a wide variety of objectives designed to diversify and improve forest structure. During 2008 through 2010, an average of more than 10,000 ac (4,000 ha) per year were commercially thinned on these three forests, combined. Precommercial thinning averaged approximately 19,000 ac (7,700 ha) per year in the same period.

On the Malheur, Umatilla, and Wallowa-Whitman National Forests, averages of 3,400, 4,200, and 300 ac (1,400, 1,700, and 120 ha) were planted annually during 2008 through 2010. On the Malheur National Forest, most seedlings planted were ponderosa pine, with the remainder consisting of western larch and western white pine. On the Umatilla National Forest, the most commonly planted species included ponderosa pine, western larch, Douglas-fir, western white pine, and Engelmann spruce. On the Wallowa-Whitman National Forest, planted seedlings included western larch, ponderosa pine, western white pine, and Douglas-fir.

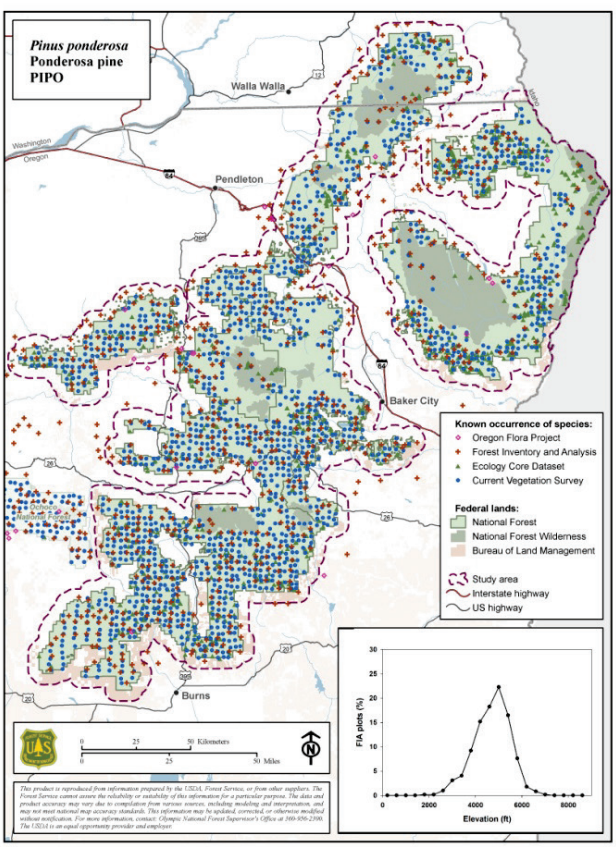


Forest Tree Species

We organized the tree species of eastern Oregon into three groups (see box on next page). Group 1 consists of 12 overstory tree species that are common in major portions of eastern Oregon 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 eastern Oregon; 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 eastern Oregon or are represented by disjunct populations.

We created distribution maps for all tree species of eastern Oregon to show documented occurrences using the latest available data (appendix 7; see example to left).

Drawing on information from a variety of published sources, we compiled profiles of the eastern Oregon tree species (appendix 8). These profiles emphasize biological and ecological characteristics that were deemed relevant to the trees' potential adaptation to predicted changes in climate.



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 according to their vulnerability to climate change impacts.

After testing several methods, we chose 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.

Native Tree Species of Eastern Oregon

Group 1: Widespread forest canopy species

Black cottonwood
Douglas-fir
Engelmann spruce
Grand fir - white fir complex
Lodgepole pine
Mountain hemlock
Ponderosa pine
Quaking aspen
Subalpine fir
Western hemlock
Western juniper
Western larch
Western redcedar
Western white pine
Whitebark pine

Group 2: Less common or non-canopy species

Bitter cherry
Cascara
Netleaf hackberry
Pacific willow
Pacific yew
Paper birch
Peachleaf willow
Red alder
Rocky Mountain maple
Scouler's willow
Water birch
White alder

Group 3: Species rare in eastern Oregon

Alaska yellow-cedar
Limber pine
Mountain hemlock
Rocky Mountain juniper

Group 1 Tree Species

Several trends were evident in the vulnerability scores:

- The three species with the highest vulnerability scores (greater than 60), were all high-elevation species: whitebark pine, subalpine fir, and Engelmann spruce (see table to right).
- The conifers characteristic of low-elevation, dry forests (ponderosa pine and western juniper) ranked lowest in overall vulnerability.
- Many of the important commercial species including ponderosa pine, Douglas-fir, and western larch had vulnerability scores ranked in the lower half of species.
- Vulnerability of tree species generally increased with mean elevation of occurrences. The four species with the highest overall vulnerability scores had mean elevations greater than 5,400 ft (1,650 m).
- For most species, scores were quite variable across the five risk factors. Four species with the greatest variability were western white pine, western juniper, Douglas-fir, and the grand fir-white fir complex.

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

Tree species	Overall vulnerability score
Whitebark pine	74
Subalpine fir	70
Engelmann spruce	61
Western white pine	57
Grand fir - white fir complex	51
Quaking aspen	45
Lodgepole pine	43
Douglas-fir	42
Western larch	32
Black cottonwood	32
Western juniper	30
Ponderosa pine	22

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. Implications for these species under a changing climate include:

- Most of the group 2 tree species occur on sites with extreme moisture regimes (i.e., flooding or drought) or as understory components of multiple forest types. Given conditions of increased summer moisture deficit, the group 2 tree species that are highly drought-tolerant may become more competitive in areas presently dominated by less drought-tolerant tree species.
- Many of the species are insect-pollinated and thus vulnerable to climate-induced changes in insect behavior.

Group 3 consists of four tree species determined to be rare within the eastern Oregon study area: Alaska yellow-cedar, Rocky Mountain juniper, limber pine, and mountain hemlock. These four species are each represented in eastern Oregon by populations that are separated from the main parts of the species' distributions. The report includes specific recommendations for conserving and restoring these species.

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. 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. 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.

> *"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."*

Action Items Based on the Results of the Climate Change Vulnerability Assessment

Eastern Oregon

1. Learn about and track changes in plant communities as the climate changes

- **Continue and expand the survey and mapping program for whitebark pine, with participation by all land management agencies with whitebark pine habitat in Oregon.**
  Readily accessible data on whitebark pine's present distribution are essential for monitoring and managing the species under climate change and pathogen threats.

- **Continue and expand health and condition surveys and a mapping program for quaking aspen. Reach out to collaborators and interested stakeholders to develop partnerships in this effort.**

- **Develop a conservation and monitoring plan for Alaska yellow-cedar, which is limited to a single population in the Cedar Grove Botanic Area on the Malheur National Forest, and limber pine, which is found on at least three sites on the Wallowa-Whitman National Forest.**

- **Establish permanents plots in the Eagle Cap Wilderness on the Wallowa-Whitman National Forest to record and evaluate the impacts of climate change both on high-elevation species and on species with limited distributions.**
  The higher vulnerability tree species of eastern Oregon—whitebark pine, subalpine fir, Engelmann spruce, and western white pine—all had mean elevations greater than 5,400 ft. Three of the four rare species, limber pine, Rocky Mountain juniper, and mountain hemlock, are limited to the area in and around the Eagle Cap Wilderness.

- **Monitor vegetative and reproductive phenology for one or more of the species established in seed orchards in eastern Oregon: ponderosa pine, Douglas-fir, and western larch.**
  Timing of phenology is closely linked to climate, and collecting data on annual phenology and microclimate will allow us to determine how trees are responding to annual climate variation.

Unless noted otherwise, action items apply to all national forests.

Action Items Based on the Results of the Climate Change Vulnerability Assessment

Eastern Oregon

2. Maintain and enhance biodiversity and increase resiliency

- **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 resiliency to disturbance and environmental stressors.
- **Continue to include a variety of tree species in planting prescriptions, with an emphasis on under-represented tree species.**
- **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 underway for whitebark pine, but to date no collections have been made for other species.
- **Establish a seed orchard for the production of rust resistant western white pine seed.**
  Although trees have been tested for resistance, seed is still being collected from tested parent trees in forest stands. A seed orchard would provide the highest level of rust resistance, be the most efficient means of producing seed, and act as an *ex situ* gene conservation area.

3. Prepare for the future

- **Form partnerships with other land managers in eastern Oregon 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.
- **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.
- **Maintain forest tree seed orchards. Establish additional seed orchards, seed collection stands, or seed production areas for species and elevations likely to be needed in the future.**
  Seed orchards serve as gene conservation areas and are the national forests' most efficient source of high quality tree seed.
- **Assess seed viability of individual selected-tree seed lots in storage.**
  The three national forests in eastern Oregon have 15,098 single-tree seedlots from selected trees in storage at the Dorena Genetic Resources Center. Many of these seedlots have been in storage for one or more decades and their viability is unknown.

EXECUTIVE SUMMARY: CENTRAL OREGON SUBREGION

Introduction

Climate change projections for the Pacific Northwest include year-round warming and potentially increased winter precipitation and decreased summer precipitation (Mote and Salathé 2009). The extent and duration of the regional snowpack is projected to decrease, particularly at lower elevations (Elsner et al. 2010, 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). However, 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 and propose practical management actions that will work under a variety of future climate scenarios and can be implemented by the national forests in central Oregon in cooperation with other land managers.

How can the national forests of central Oregon 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 relative vulnerability of forest tree species to projected climate changes.
2. Recommend actions that will improve understanding of changes taking place among tree species, maintain and increase biodiversity and increase resiliency, and prepare for an uncertain future.
3. Collaborate in the implementation of these actions with other land managers in central Oregon.

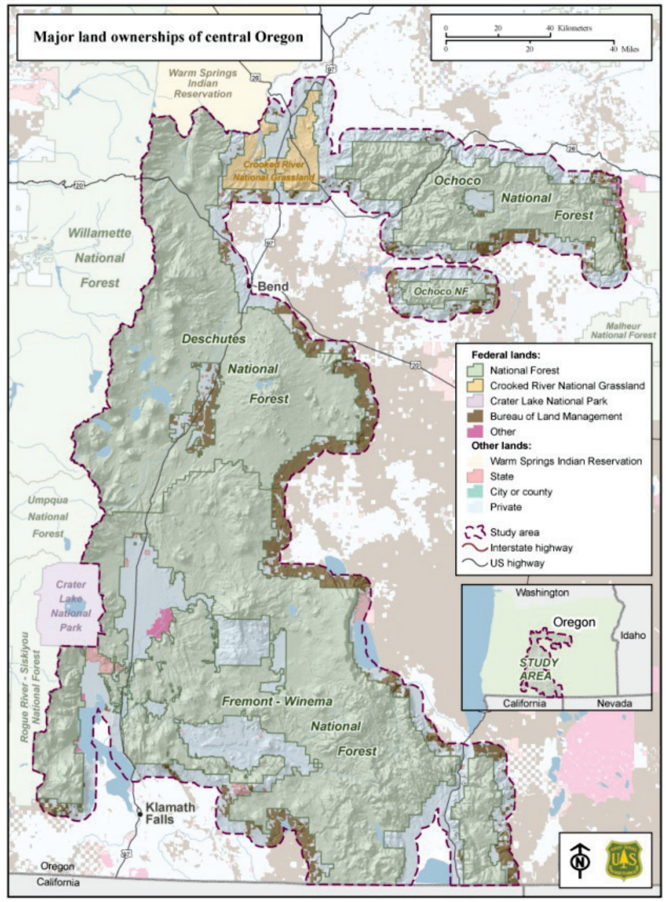
Forests of Central Oregon

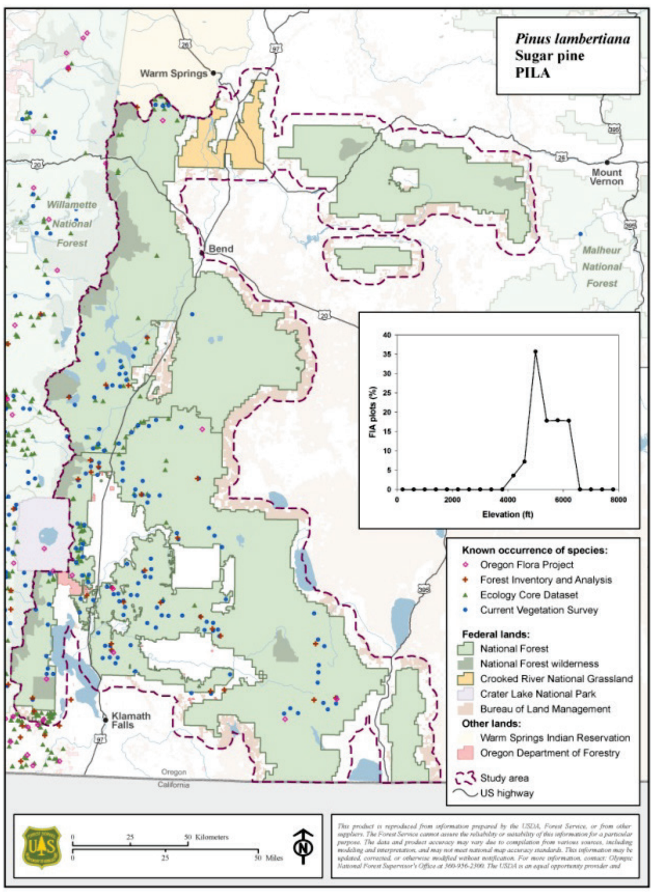
The central Oregon study area comprises a portion of the state east of the Cascade Range crest that includes the Deschutes and Ochoco and Fremont-Winema National Forests and a buffer surrounding these forests (map at top of next page). The study area comprises 8 million ac (3 million ha) and the national forests within it comprise a total of 5.6 million ac (2.2 million ha). Approximately 8 and 4 percent, respectively, of the Deschutes and Ochoco and the Fremont-Winema National Forests are designated wilderness areas.

Vegetation management on central Oregon's national forests is conducted to meet a wide variety of objectives designed to diversify and improve forest structure. During 2008 through 2010, more than 18,000 ac (7,300 ha) were commercially thinned annually on these forests, combined. Precommercial thinning averaged nearly 35,000 ac (14,100 ha) annually during this period. Approximately 5,900 ac (2,900 ha) were planted annually. On the Deschutes National Forest, the majority of seedlings planted were ponderosa pine, Douglas-fir, and western larch and the remaining species (2 percent or less) were western white pine, sugar pine, and lodgepole pine. On the Ochoco National Forest, ponderosa pine and western larch were planted. On the Fremont-Winema National Forest, over 99 percent of the acres planted were ponderosa pine.

Forest Tree Species

We organized the tree species of central Oregon into two groups (see box on next page). Group 1 consists of 16 overstory tree species that are common in major portions of central Oregon 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 central Oregon; these species may occur infrequently across broad areas or may be common within a limited habitat.





We created distribution maps for all tree species of central Oregon to show documented occurrences using the latest available data (appendix 7; example shown to left).

Drawing on information from a variety of published sources, we compiled profiles of the central Oregon tree species (appendix 8). These profiles emphasize biological and ecological characteristics that were deemed relevant to the trees' potential adaptation to predicted changes in climate.

Forest Tree Vulnerability Assessment

Native tree species of Central Oregon

Group 1: Widespread forest canopy species

- Douglas-fir
- Engelmann spruce
- Grand fir-white fir
- Incense-cedar
- Mountain hemlock
- Noble fir-Shasta red fir
- Pacific silver fir
- Ponderosa pine
- Sierra lodgepole pine
- Subalpine fir
- Sugar pine
- Western hemlock
- Western juniper
- Western larch
- Western white pine
- Whitebark pine

Group 2: Less common or non-canopy species

- Bitter cherry
- Black cottonwood
- Cascara
- Douglas maple
- Golden chinquapin
- Pacific yew
- Quaking aspen
- Red alder
- Scouler's willow

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 chose 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:

- Among the group 1 tree species, overall vulnerability scores ranged from 27 to 78 (lowest and highest scores possible were 0 and 100, respectively).
- There was not a strong relationship between tree species' mean elevation and overall vulnerability score. Two exceptions were the highest-ranked species, whitebark pine, which also had the highest mean elevation, and the lowest-ranked species, western juniper, which also had the lowest mean elevation. When these two species were excluded, there was no correlation between elevation and vulnerability for the remaining 14 species.

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

Tree species	Overall vulnerability score
Whitebark pine	78
Subalpine fir	69
Engelmann spruce	61
Douglas-fir	60
Pacific silver fir	59
Western hemlock	52
Sugar pine	51
Noble fir - Shasta red fir	48
Grand fir - white fir	47
Western larch	43
Mountain hemlock	41
Incense-cedar	38
Sierra lodgepole pine	36
Western white pine	33
Ponderosa pine	32
Western juniper	27

- The important commercial species varied widely in overall vulnerability score.
- For most tree species, scores were quite variable across the five risk factors. Western juniper exhibited the greatest range, with factor scores ranging from 0 to 100.

Group 2 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. Implications for these species under a changing climate include:

- Most of the group 2 tree species occur as understory components of multiple forest types or on sites with extreme moisture regimes (i.e., flooding or drought).
- The group 2 species that often colonize disturbed sites near streams and rivers (black cottonwood, red alder, Scouler's willow) may have increased opportunities for establishment under projected climate scenarios in which seasonal snowmelt and precipitation patterns increase major flood events, which would potentially create habitat.
- Many group 2 tree species are insect-pollinated or produce seed that is dispersed by animals; thus, these species are vulnerable to changes in animal behavior associated with climate. However, vulnerability is likely to differ among these tree species based on number of animal associates and the specificity of the relationships.

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. 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. 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.

Action Items Based on the Results of the Climate Change Vulnerability Assessment

Central Oregon

1. Learn about and track changes in plant communities as the climate changes

- **Continue and expand the survey and mapping program for whitebark pine, with participation by all land management agencies with whitebark pine habitat in Oregon.**
  Readily accessible data on whitebark pine's present distribution are essential for monitoring and managing the species under climate change and pathogen threats. (This item pertains only to the Deschutes and Fremont-Winema National Forests.)
- **Monitor vegetative and reproductive phenology in seed orchards, particularly that of ponderosa and lodgepole pine at the Kelsey Butte seed orchard in the Deschutes National Forest.**
  Timing of phenology is closely linked to climate, and collecting data on annual phenology and microclimate will allow us to determine how trees are responding to annual climate variation.

2. Maintain and enhance biodiversity and increase resiliency

- **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 resiliency to disturbance and environmental stressors.
- **Continue to include a variety of tree species in planting prescriptions, with an emphasis on under-represented tree species.**
- **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 underway for whitebark pine, but to date no collections have been made for other species.
- **Maintain and protect the vast *ex situ* collection of eastern Oregon native cottonwood and willow accessions.**
- **Continue to monitor and treat where possible the insects and diseases that pose the greatest threats to group 1 species: Douglas-fir beetle, mountain pine beetle, fir engraver, balsam woolly adelgid, and dwarf mistletoe.**
  These are causing moderate to significant mortality in mature trees; impacts of a number of these threats appear to be increasing owing to climate change.

Action Items Based on the Results of the Climate Change Vulnerability Assessment

Central Oregon

3. Prepare for the future

- **Partner with other land managers in central Oregon 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.

- **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; and
  - Update Seed Procurement Plans to include new and replacement collections.

- **Maintain and protect conifer seed orchards.**
  These serve as gene conservation areas and are essential in providing high quality and genetically diverse seed. They are the national forests' most efficient source of high quality tree seed for national forest reforestation and restoration programs.

- **Continue to provide a genetically diverse source of hardwood cuttings from the Clarno hardwood production beds (Deschutes and Ochoco National Forest).**
  Currently, this program provides material for many eastern Oregon public lands partners, and promotes the restoration of many extirpated hardwood populations.

- **Assess seed viability of individual selected tree seedlots in storage.**
  The national forests in central Oregon have more than 16,900 single tree seedlots from selected trees in storage at the Dorena Genetic Resources Center. Many of these seedlots have been in storage for one or more decades, and their viability is unknown.

EXECUTIVE SUMMARY: SOUTHWESTERN OREGON SUBREGION

Introduction

Climate change projections for the Pacific Northwest include year-round warming and potentially increased winter precipitation and decreased summer precipitation (Mote and Salathé 2009). The extent and duration of the regional snowpack is projected to decrease, particularly at lower elevations (Elsner et al. 2010, 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). However, 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 and propose practical management actions that will work under a variety of future climate scenarios and can be implemented by the national forests in southwestern Oregon in cooperation with other land managers.

How can the national forests in southwestern Oregon 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 relative vulnerability of forest tree species to projected climate changes.
2. Recommend actions that will improve understanding of changes taking place among tree species, maintain and increase biodiversity and increase resiliency, and prepare for an uncertain future.
3. Collaborate in the implementation of these actions with other land managers in southwestern Oregon.

Forests of Southwestern Oregon

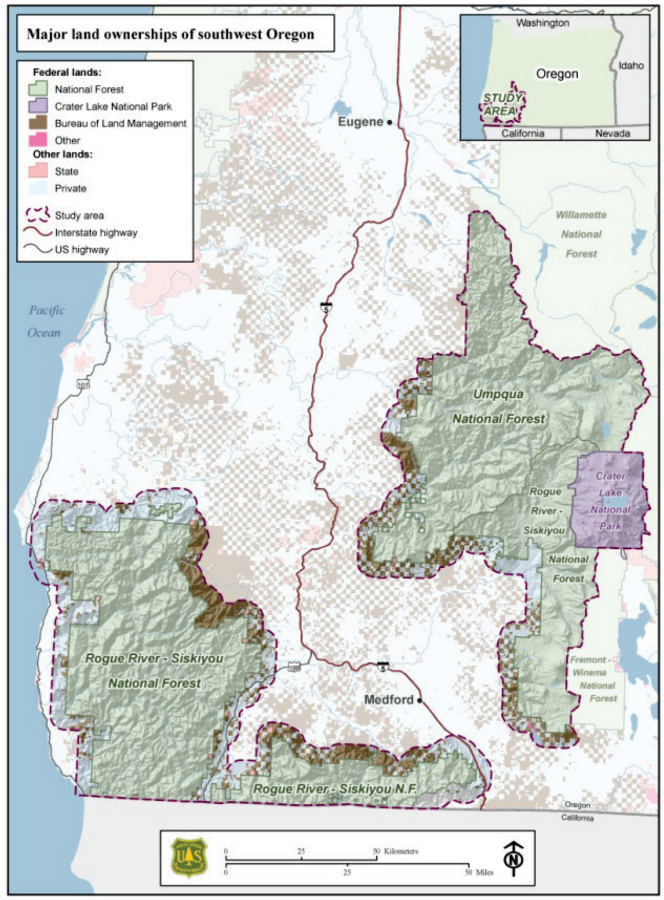
The study area is based on the national forests of southwestern Oregon: the Rogue River-Siskiyou and the Umpqua (see map at top of next page). The study area boundary follows the national forest boundaries within Oregon, and also includes a 3-mile-wide buffer, for a total of 3.9 million ac (1.6 million ha). The Rogue River-Siskiyou and the Umpqua National Forests contain 1.8 and 1.0 million ac (0.7 and 0.4 million ha), respectively. Approximately 19 and 7 percent, respectively, of these forests are designated wilderness areas.

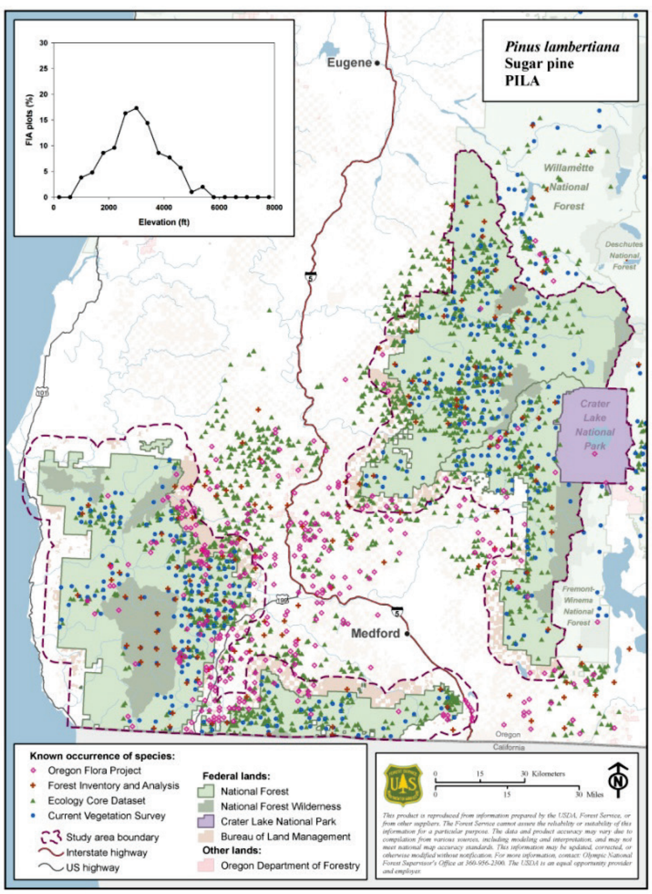
During 2008-2010, annual averages of approximately 2,700 and 4,200 ac (1,100 and 1,700 ha) were thinned (commercially or precommercially) on the Rogue River-Siskiyou and Umpqua National Forests, respectively. On the Rogue River-Siskiyou and Umpqua National Forests, averages of 270 and 890 ac (110 and 360 ha) were planted annually during 2008-2010. On the Rogue River-Siskiyou National Forest, sugar pine and Douglas-fir were most often planted, with fewer acres of ponderosa pine and Port-Orford-cedar. On the Umpqua National Forest, the most commonly planted species were Douglas-fir, ponderosa pine, sugar pine, incense-cedar, and western white pine, in descending order. Small amounts of

Shasta red fir, Pacific madrone, western redcedar, incense-cedar, western hemlock, and white fir also were planted.

Forest Tree Species

We organized the tree species of southwestern Oregon into three groups (see box on next page). Group 1 consists of 25 overstory tree species that are common in major portions of southwestern Oregon 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 southwestern Oregon; 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 southwestern Oregon or are represented by disjunct populations.





We created distribution maps for all tree species of southwestern Oregon to show documented occurrences using the latest available data (appendix 7; example to left).

Drawing on information from a variety of published sources, we compiled profiles of the southwestern Oregon tree species (appendix 8). These profiles emphasize biological and ecological characteristics that were deemed relevant to the trees' potential adaptation to predicted changes in climate.

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 according to their vulnerability to climate change impacts.

After testing several methods, we chose 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.

Native tree species of southwestern Oregon

Group 1: Widespread forest canopy species

- Bigleaf maple
- California black oak
- Canyon live oak
- Douglas-fir
- Engelmann spruce
- Grand fir - white fir
- Incense-cedar
- Jeffrey pine
- Knobcone pine
- Lodgepole pine
- Mountain hemlock
- Noble fir - Shasta red fir
- Oregon white oak
- Pacific madrone
- Pacific silver fir
- Ponderosa pine
- Port-Orford-cedar
- Red alder
- Subalpine fir
- Sugar pine
- Tanoak
- Western hemlock
- Western redcedar
- Western white pine
- Whitebark pine

Group 2: Less common or non-canopy species

- Bitter cherry
- Black cottonwood
- Cascara
- Douglas maple
- Golden chinquapin
- Oregon ash
- Oregon myrtle
- Pacific dogwood
- Pacific willow
- Pacific yew
- Quaking aspen
- Scouler's willow
- White alder

Group 3: Species rare in southwestern Oregon

- Alaska yellow-cedar
- Baker cypress
- Brewer spruce
- Coast redwood
- Sitka spruce

Group 1 Tree Species

Several trends were evident in the vulnerability scores:

- Among the group 1 tree species, overall vulnerability scores ranged from 33 to 72 (lowest and highest scores possible were 0 and 100, respectively).
- The three most vulnerable species were Engelmann spruce, subalpine fir, and whitebark pine. These three species generally had high vulnerability scores across all risk factors except for the insects and diseases risk factor.
- There was a general positive trend between mean elevation (assessed using FIA plots) and overall vulnerability score. With the exception of Port-Orford-cedar, all of the species below approximately 3,500 ft elevation had vulnerability scores of 50 of lower. The three species with the highest vulnerability scores had mean elevations above 4,500 ft.
- Among species present in lower elevation forests, those with the highest vulnerability scores were Port-Orford-cedar and the grand fir-white fir complex.
- For most tree species, scores were quite variable across the five risk factors. Pacific madrone exhibited the greatest range, with factor scores ranging from 0 to 100.
- The important commercial species varied widely in overall vulnerability score.

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

Tree species	Overall vulnerability score
Engelmann spruce	72
Subalpine fir	69
Whitebark pine	67
Pacific silver fir	56
Port-Orford-cedar	56
Grand fir - white fir	55
Mountain hemlock	49
Noble fir - Shasta red fir	48
Oregon white oak	48
Ponderosa pine	46
Pacific madrone	46
Tanoak	46
California black oak	45
Western hemlock	42
Lodgepole pine	42
Canyon live oak	40
Jeffrey pine	39
Bigleaf maple	39
Sugar pine	39
Knobcone pine	38
Western white pine	36
Douglas-fir	36
Western redcedar	35
Incense-cedar	33
Red alder	33

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. Implications for these species under a changing climate include:

- Most of the group 2 tree species occur on sites with extreme moisture regimes (i.e., flooding or drought) or as understory components of multiple forest types.
- The group 2 species that often colonize disturbed sites near streams and rivers (e.g., willows, cottonwood, white alder) may have increased opportunities for establishment under projected climate scenarios in which

seasonal snowmelt and precipitation patterns increase major flood events, which would potentially create habitat.

- Many group 2 tree species are insect-pollinated or produce seed that is dispersed by animals; thus, these species are vulnerable to changes in animal behavior associated with climate. However, vulnerability is likely to differ among these tree species based on number of animal associates and the specificity of the relationships.

Group 3 tree species are known to be rare within southwestern Oregon, and, owing to their limited distributions, all of these species are already deemed vulnerable to the effects of climate change. The report includes specific recommendations for conserving and monitoring these species.

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. 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. 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.

> *"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."*

Action Items Based on the Results of the Climate Change Vulnerability Assessment

Southwestern Oregon

1. Learn about and track changes in plant communities as the climate changes

- **Continue and expand the survey and mapping program for whitebark pine, with participation by all land management agencies with whitebark pine habitat in Oregon.**
  Readily accessible data on whitebark pine's present distribution are essential for monitoring and managing the species under climate change and pathogen threats.

- **Develop conservation and monitoring plans for Brewer spruce, Baker cypress, and Alaska yellow-cedar, which are limited to small or disjunct populations in southwestern Oregon.**
  Such information is important because disjunct populations may become refugia under predicted climate change scenarios or, conversely, might be more severely impacted because lack of gene flow would limit opportunities for immigration of more highly adapted genes from other populations.

- **Establish permanent plots at high elevations (5,000 to 7,000 ft) on the Diamond Lake Ranger District of the Umpqua National Forest north and northwest of Crater Lake National Park to monitor changes in tree growth, survival and distribution.**
  Six of the eight tree species that we determined were most at risk under a changing climate are found in this area (Engelmann spruce, subalpine fir, whitebark pine, Pacific silver fir, mountain hemlock, and the noble fir - Shasta red fir complex).

- **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 how trees are responding to annual climate variation.

Unless noted otherwise, action items apply to both national forests.

Action Items Based on the Results of the Climate Change Vulnerability Assessment

Southwestern Oregon

2. Maintain and enhance biodiversity and increase resiliency

- **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 resiliency to disturbance and environmental stressors.

- **Continue to include a variety of tree species in planting prescriptions, with an emphasis on under-represented tree species.**

- **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 underway for whitebark pine, but to date no collections have been made for other species.

3. Prepare for the future

- **Partner with other land managers in southwestern Oregon 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.

- **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.

- **Maintain forest tree seed orchards.**
  These serve as gene conservation areas and are the national forests' most efficient source of high quality tree seed.

- **Assess seed viability of individual selected tree seed lots in storage.**
  The two national forests in southwestern Oregon have at least 15,241 single tree seedlots from selected trees in storage at the Dorena Genetic Resources Center. Many of these seedlots have been in storage for one or more decades and their viability is unknown.

Climate Change and Forest Trees in the Pacific Northwest:

A Vulnerability Assessment and Recommended Actions for National Forests

Executive Summary

United States
Department of
Agriculture

Forest Service

Pacific Northwest
Region

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