

Strategies for Conservation of Forest Genetic Resources in the Face of Climate Change



Brad St.Clair
*US Forest Service, Pacific Northwest Research Station
Corvallis, Oregon, U.S.A.*



BIORARE-2010, Fethiye, Turkey, May 28, 2010

Outline

- I. Background on gene conservation and climate change
- II. Adaptation of plant populations to climates and climate change
- III. Strategies for gene conservation in the face of changing climates

Main points

1. Many threats to biodiversity. Although not immediate, climate change is a serious threat that needs to be addressed.
2. Trees are highly vulnerable to climate change owing to long generation intervals, particularly small, disjunct populations at the trailing edge of the species margin.
3. Rare and endemic plants require special attention because of their special value and issues of population size, lack of knowledge, and policy.
4. The conservation of genetic diversity in native habitats will require a shift in thinking from static to dynamic conservation.
5. *Ex situ* conservation will become more important.
6. We will need to consider moving plant populations to locations that they may be expected to be adapted (assisted colonization)

I. Background

Why conserve genetic diversity?

- Economic: to ensure long-term sustainable access to variation for economic and social values
- Ecological: maintenance of ecological processes and life support systems; continued evolution
- Ethical: ethical, moral or aesthetic reasons

Threats to Genetic Diversity

- Habitat loss, deforestation, and land use change
 - Net loss in global forest area 2000-2005 = 7.3 million ha
- Habitat fragmentation
- Management practices
 - dysgenic selection
 - replacement with other genotypes
 - reduced genetic variation
- Fire, disease, insects
- Climate change



Habitat loss



Fires



Disease



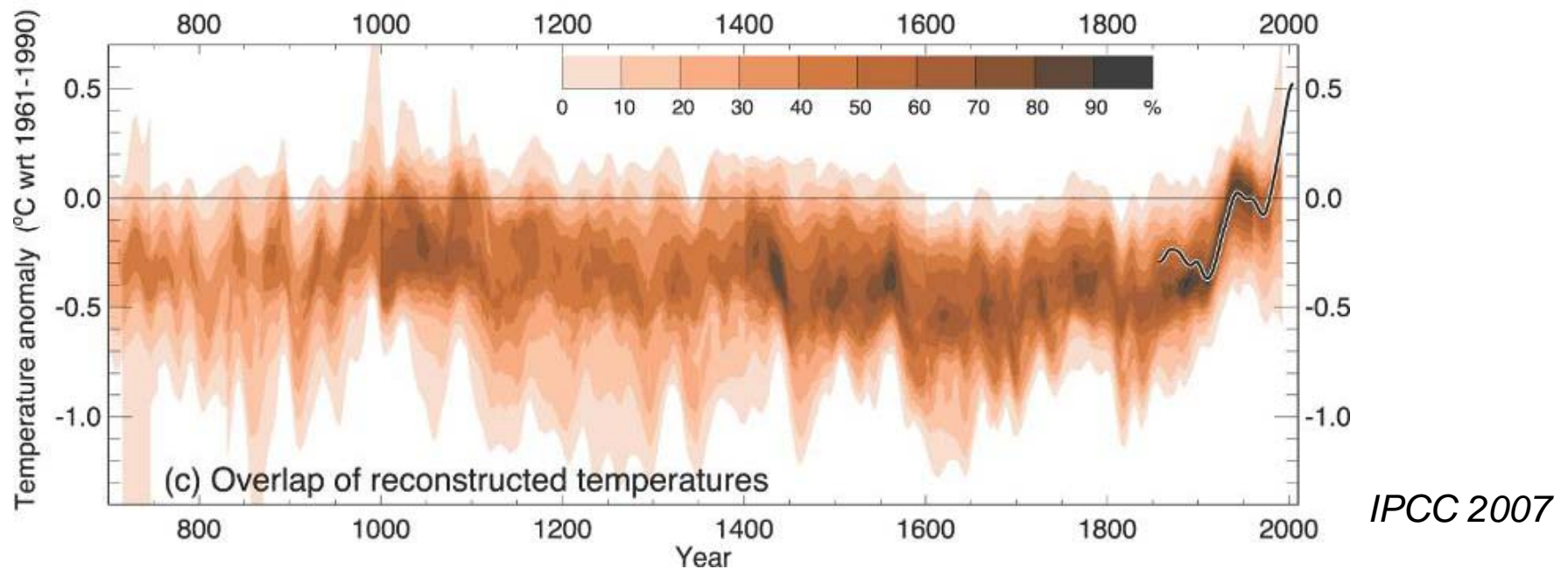
Piñon pine mortality from drought

IPCC Fourth Assessment Report (2007)

1. Considerable evidence for global warming
2. Increases in global average temperatures are very likely due to the observed increase in anthropogenic greenhouse gases
3. Temperatures are projected to continue to increase and will have important impacts
4. Calls for increased efforts for mitigation and adaptation

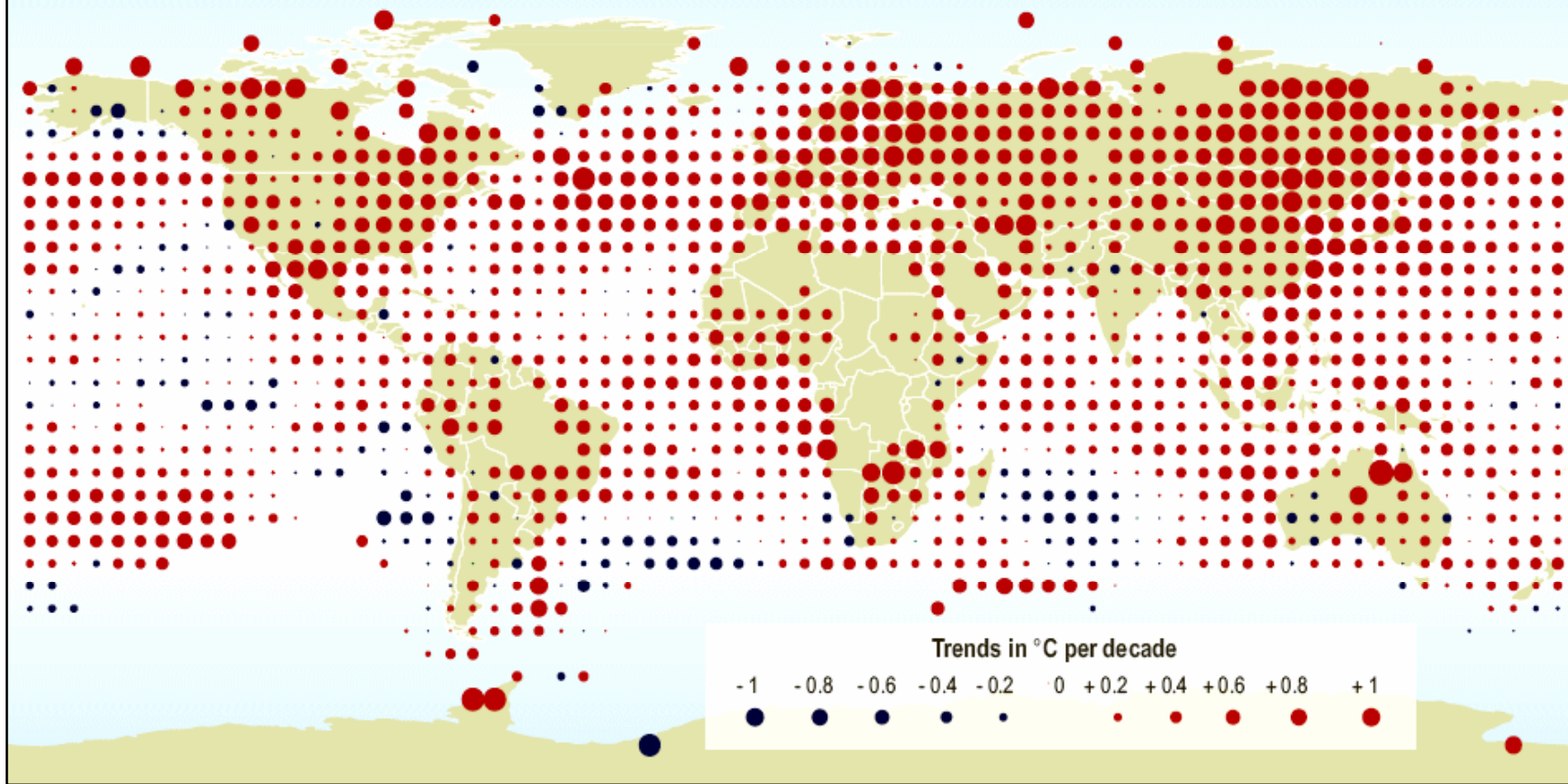
Evidence for Global Warming

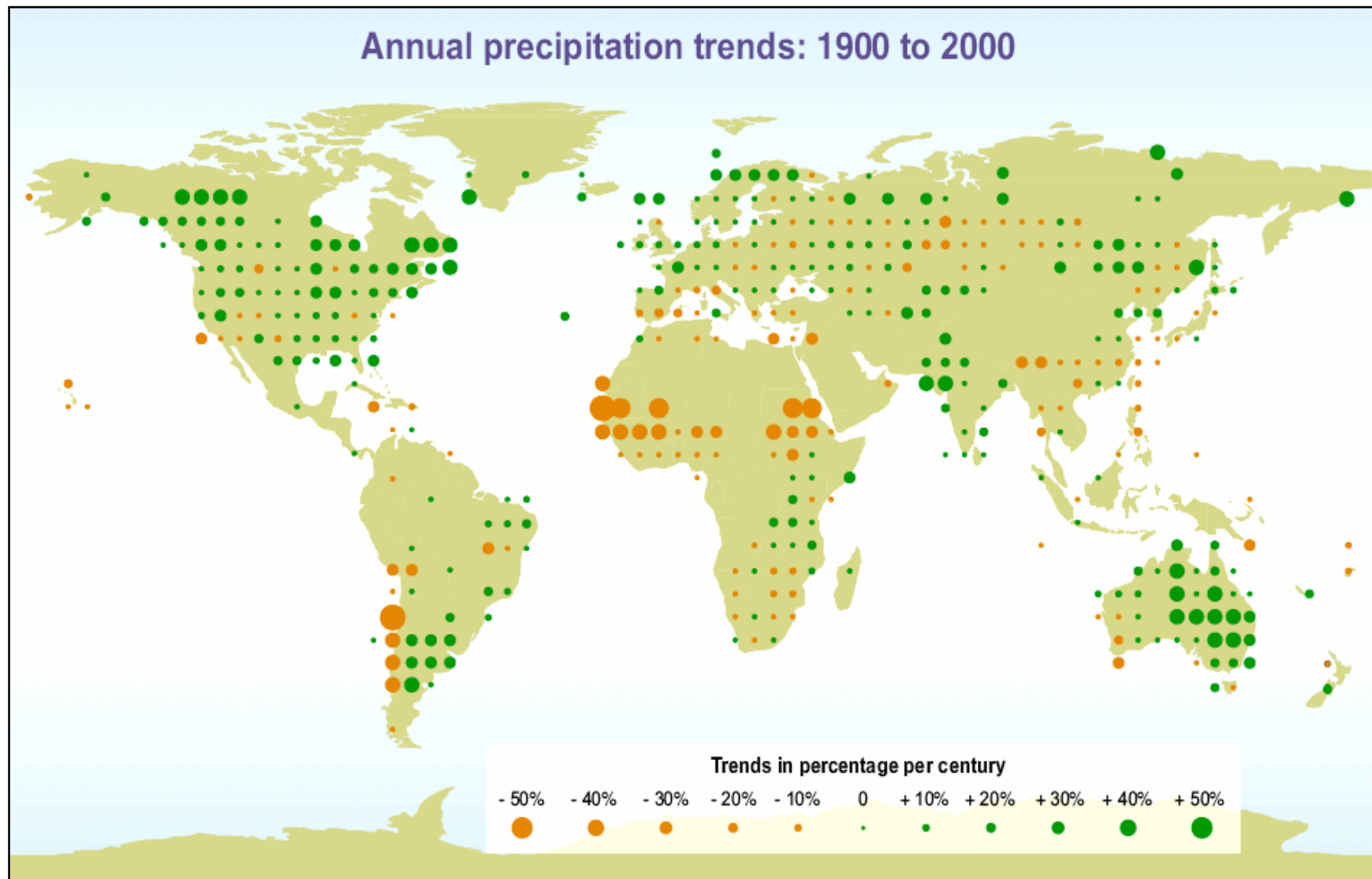
- Climates are naturally variable.
- Climates have changed - it was warmer in the last two decades than at any period during the last 1,300 years.
- The 100-year (1905-2005) linear warming trend is **0.74 °C**.
- *"If warming continues unabated, the resulting climate change within this century would be extremely unusual in geological terms"* (IPCC 2007)



Past temperature reconstructions in **Northern Hemisphere** based on proxy data (tree rings, ice cores, etc.) and instrumental records (black line)

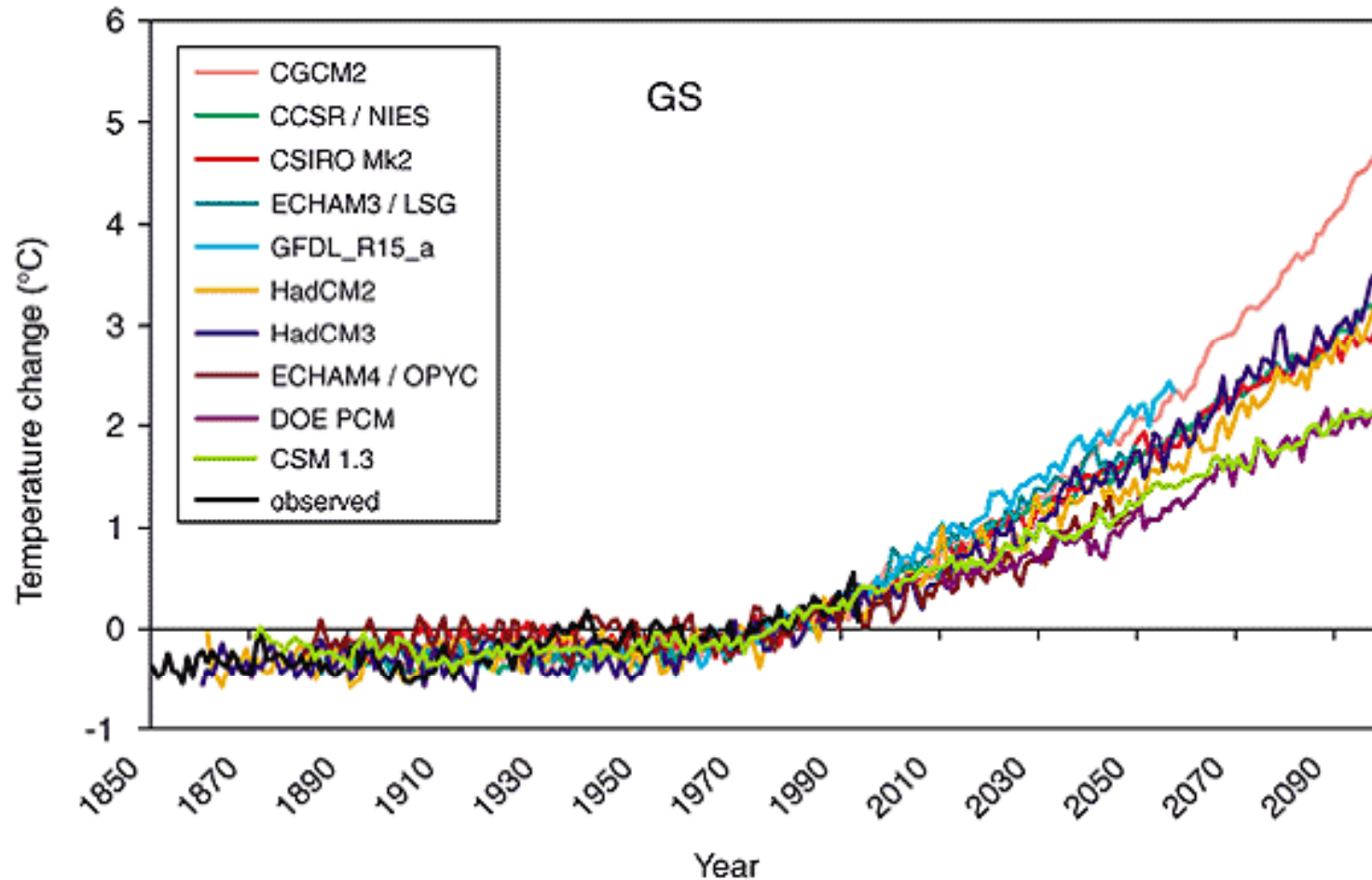
Annual temperature trends: 1976 to 2000





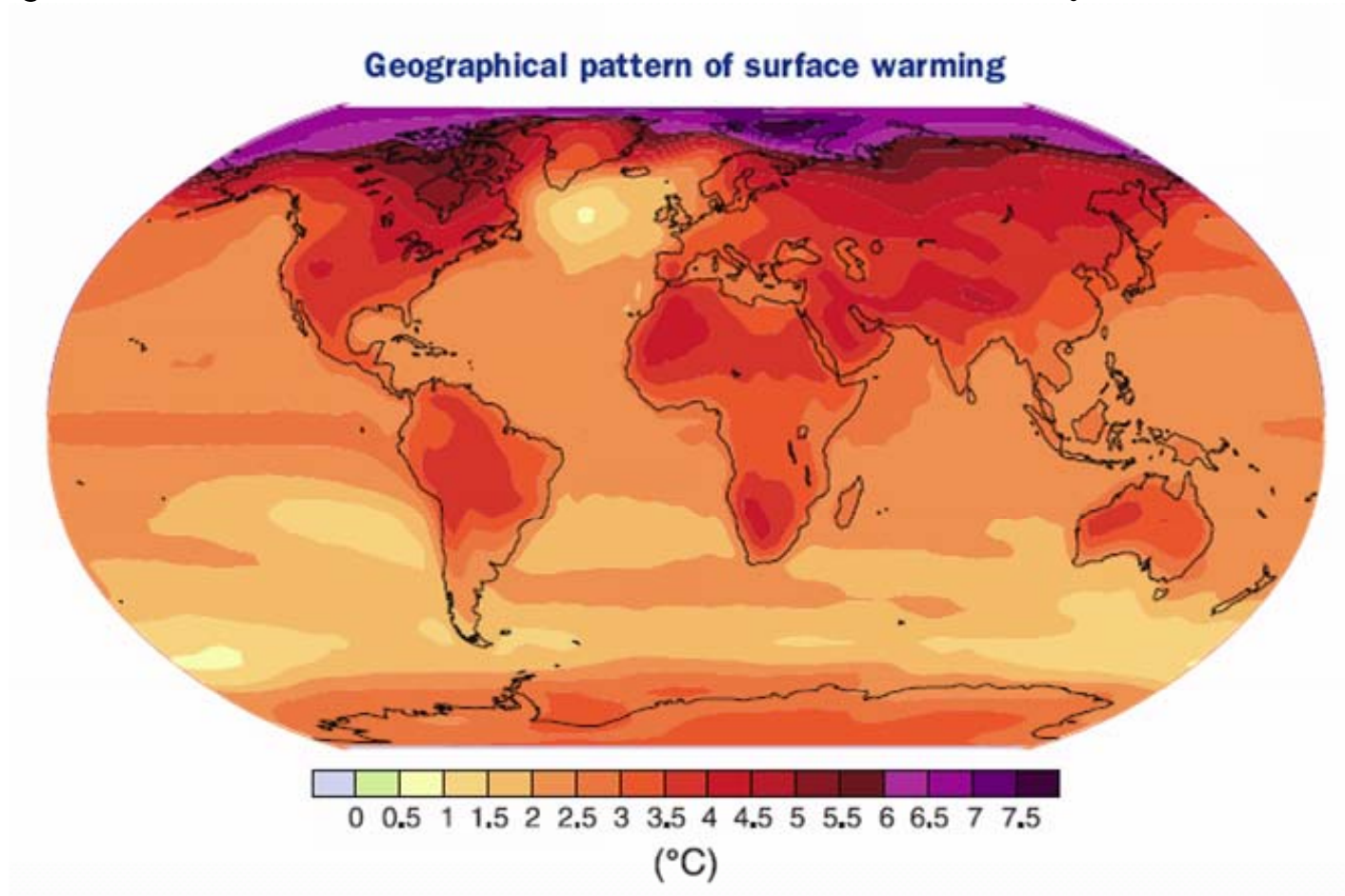
Precipitation trends highly variable spatially and temporally

Temperature Projections



1. Continued warming: 1.8 to 4.0 °C increase in global average temperature (2090-2099 from 1980-1999)
2. Considerable uncertainty: due to climate models and emission scenarios

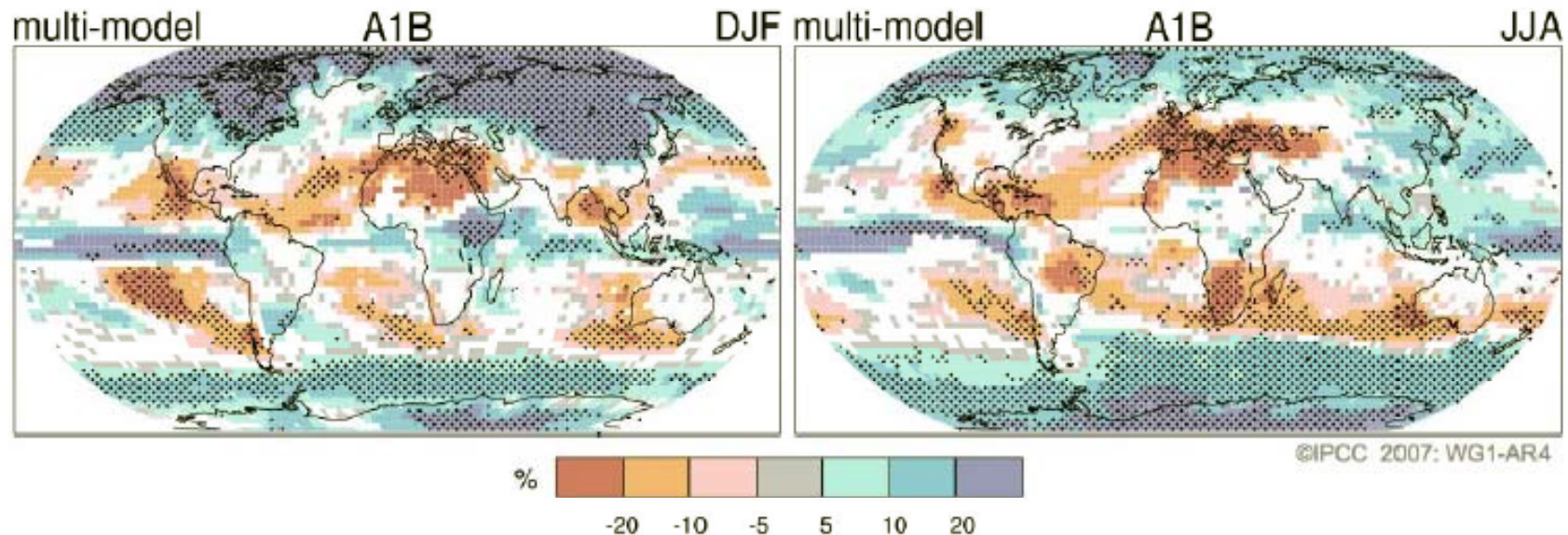
Projections of Surface Temperatures



Changes greatest at northern latitudes and over land, and least over the Southern Ocean and parts of North Atlantic

Projected Patterns of Precipitation Changes

1980-1999 average vs 2090-2099 average



white <66% of models agree in sign of change

stippled, >90% agree

Increases at high latitudes; decreases in most subtropical lands

Increased extreme events and tropical cyclones

Can we see a warming signal? - Yes

Phenological events are occurring earlier

Concerns

- Possible frost injury
- Disruption of relationships within communities

Potential opportunities

- Longer growing season
- Greater growth

New Phytologist Review

Research review

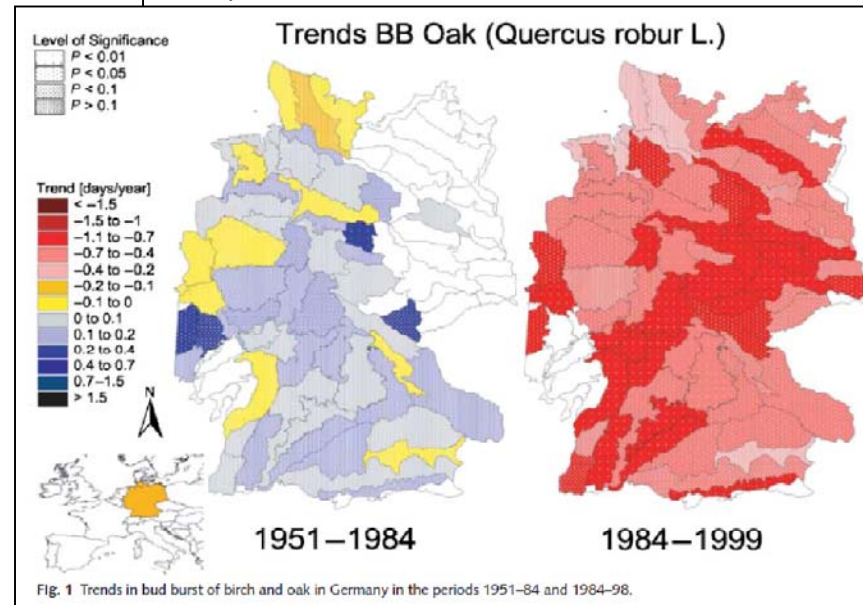
Responses of spring phenology to climate change

Author for correspondence:
Franz-W. Badeck
Tel: +49 331 2882675
Fax: +49 331 2882695
Email: badeck@pik-potsdam.de

Received: 23 September 2003
Accepted: 20 January 2004
doi: 10.1111/j.1469-8137.2004.01059.x

Franz-W. Badeck, Alberte Bondeau, Kristin Böttcher, Daniel Doktor, Wolfgang Lucht, Jörg Schaber and Stephen Siech
Potsdam Institute for Climate Impact Research (PIK), Pf 60 12 03, 14412 Potsdam, Germany

© New Phytologist (2004) 162: 295–309



Can we see a warming signal? - Yes

Species distributions
have moved up in
elevation

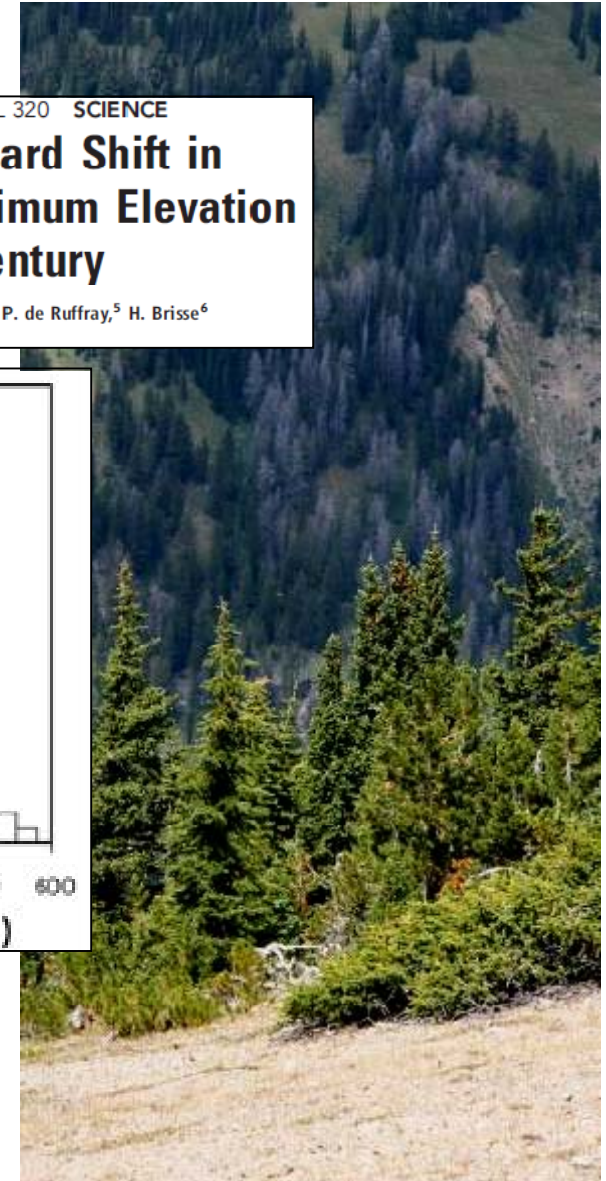
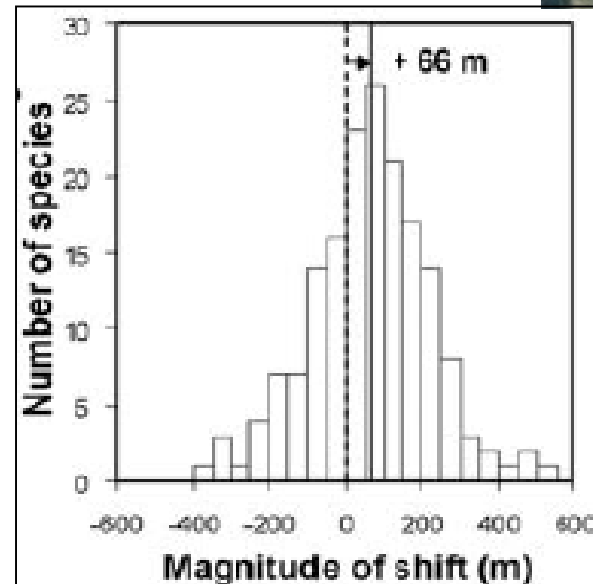
Concerns

- Habitat loss for alpine species
- Disruption of relationships within communities

Potential opportunities

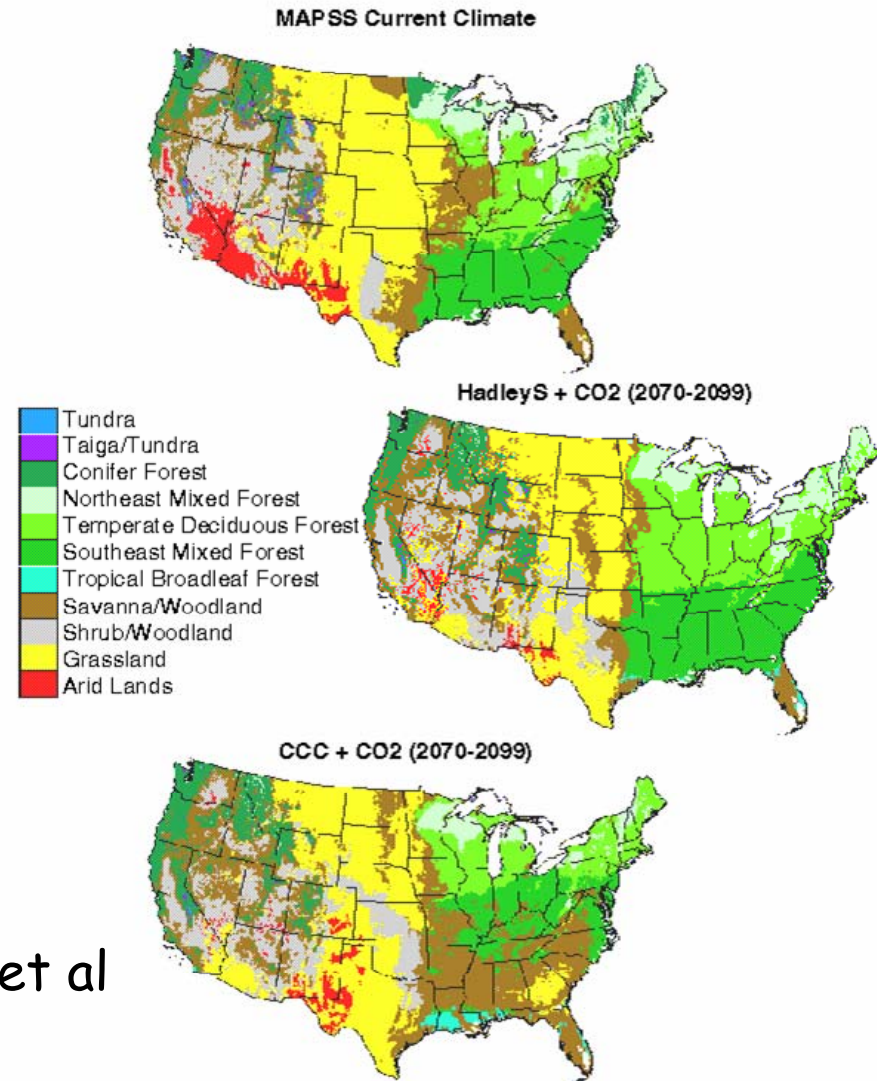
- Improved growth and productivity in high-elevation forests

27 JUNE 2008 VOL 320 SCIENCE
**A Significant Upward Shift in
Plant Species Optimum Elevation
During the 20th Century**
J. Lenoir,^{1*} J. C. Gégout,¹ P. A. Marquet,^{2,3,4} P. de Ruffray,⁵ H. Brisse⁶



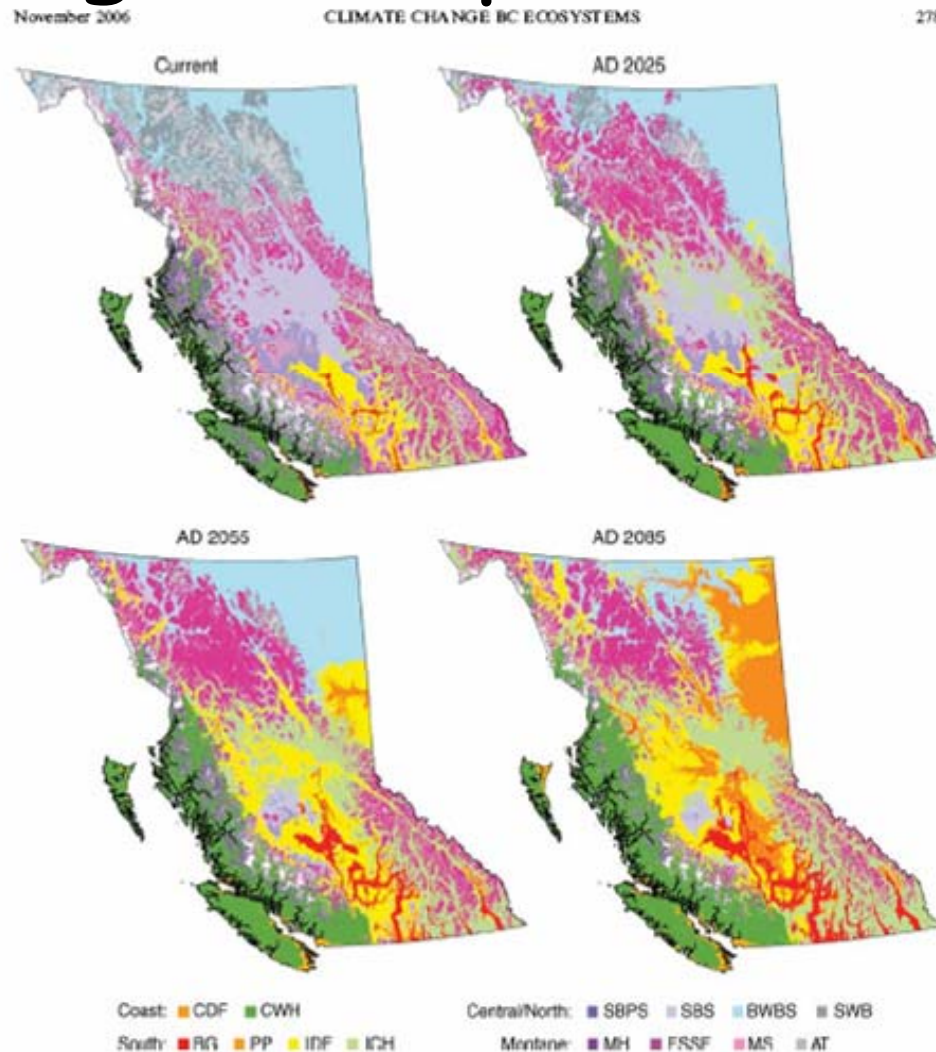
Vegetation Change

- Shifting to the north
- Some dieback of boreal forests
- Conversion of eastern forests
- Early increases in productivity and density
- But later drought-induced stress and dieback, increased wildfires



from Neilson et al

Changes in Species Ranges



Hamann and Wang
2006 Ecology

FIG. 2. Shift of the climatic envelope of ecological zones based on the ensemble simulation on CGCM1gax for the normal periods 2011–2040 (2025), 2041–2070 (2055), and 2071–2100 (2085). The ecological zones are: CDF, Coastal Douglas-fir; CWH, Coastal Western Hemlock; BG, Branchgrass; PP, Ponderosa Pine; IDF, Interior Douglas-fir; ICH, Interior Cedar-Hemlock; SBPS, Sub-boreal Pine and Spruce; SBS, Sub-boreal Spruce; BWBS, Boreal White and Bark Spruce; MH, Mountain Hemlock; ESSF, Engelmann Spruce-Subalpine Fir; MS, Montane Spruce; SWB, Spruce-Willow-Birch; AT, Alpine Tundra.

II. Adaptation of plant populations to climate and climate change

1. Studies of within-species variation indicate that the climatic tolerances of populations are considerably lower than that of the species as a whole
2. Evolutionary adaptation will determine what happens to plant populations given climate change
3. Management of genetic variation may positively influence how plants respond and adapt to climate change

Evidence for adaptation:

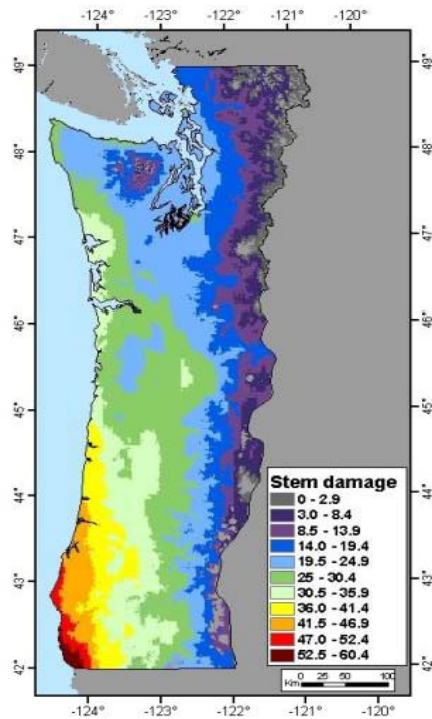
1. Correlation between a character and environmental factors - the same form occurs in similar environments
2. Comparisons of naturally-occurring variants in environments where they are hypothesized to function as adaptations
3. Direct evidence from altering a character to see how it affects function in a given environment

from West-Eberhard 1992

Evidence for adaptation comes from common garden (provenance) studies

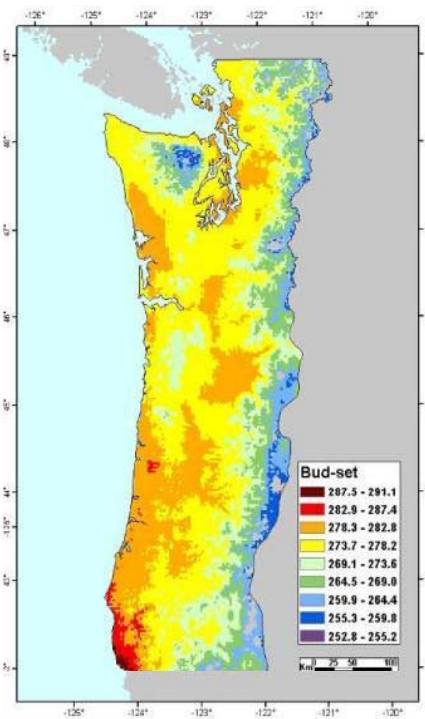
Evidence for adaptation: Douglas-Fir Genecology Study

Fall cold damage



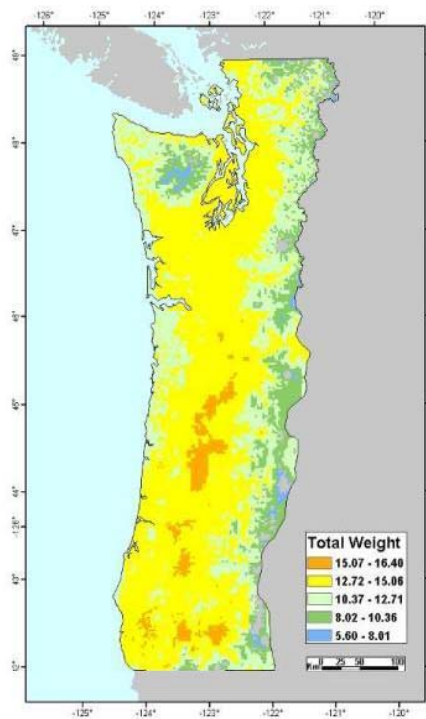
$r = 0.79$
 $Qst = 0.68$

Bud-set



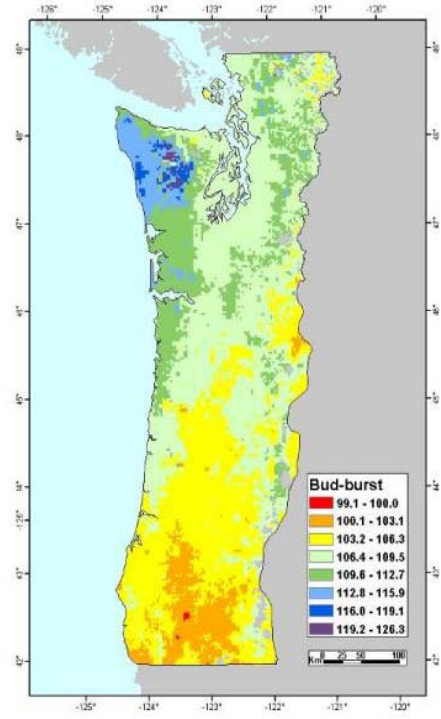
$r = 0.76$
 $Qst = 0.29$

Biomass



$r = 0.52$
 $Qst = 0.13$

Bud-burst



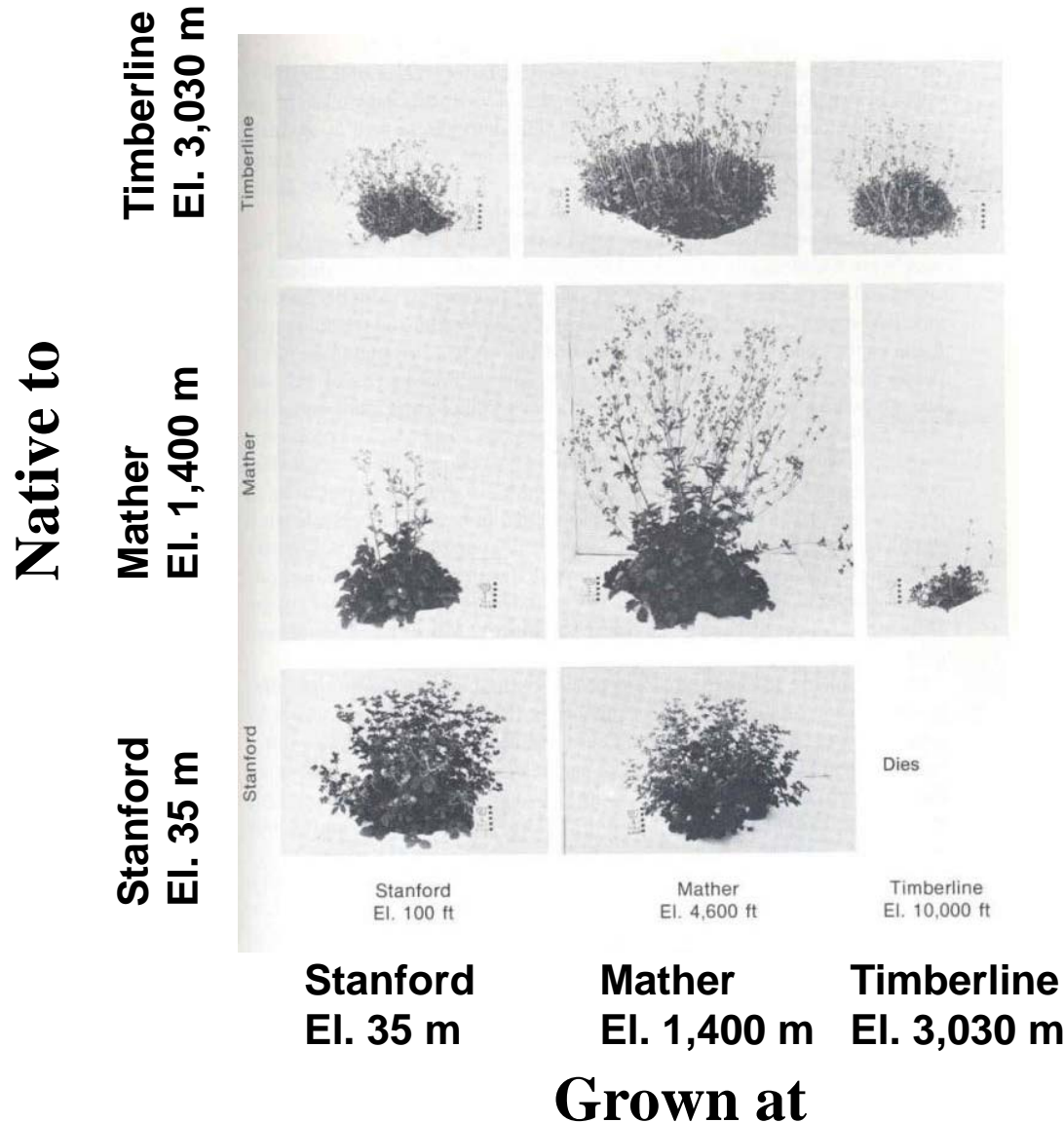
$r = 0.60$
 $Qst = 0.21$

1. Populations differ
2. Traits are correlated with source environments
3. Different traits show different patterns and scales of adaptation
 - Ultimately interested in survival, growth and reproduction

Differences among species:
distance needed to detect genetic differences in
Northern Rockies (Rehfeldt 1994)

Species	Elev. (m)	Frost- free days	Evolutionary mode
Douglas-fir	200	18	Specialist
Lodgepole pine	220	20	Specialist
Engelmann spruce	370	33	Intermediate
Ponderosa pine	420	38	Intermediate
Western larch	450	40	Intermediate
Western redcedar	600	54	Generalist
Western white pine	none	90	Generalist

Evidence for adaptation: Comparisons of naturally-occurring variants in native environments - reciprocal transplant studies



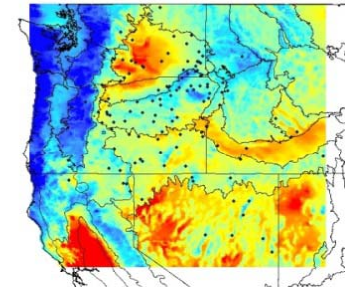
Potentilla glandulosa from three different elevations planted at three different elevations (Clausen, Keck & Hiesey 1940)

Adaptation in other forest species?

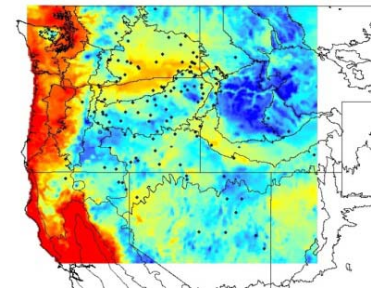
- Growing evidence for local adaptation
- Different species show different patterns and scales of adaptation
- Moderate degree of adaptation (generalists)

Bluebunch wheatgrass

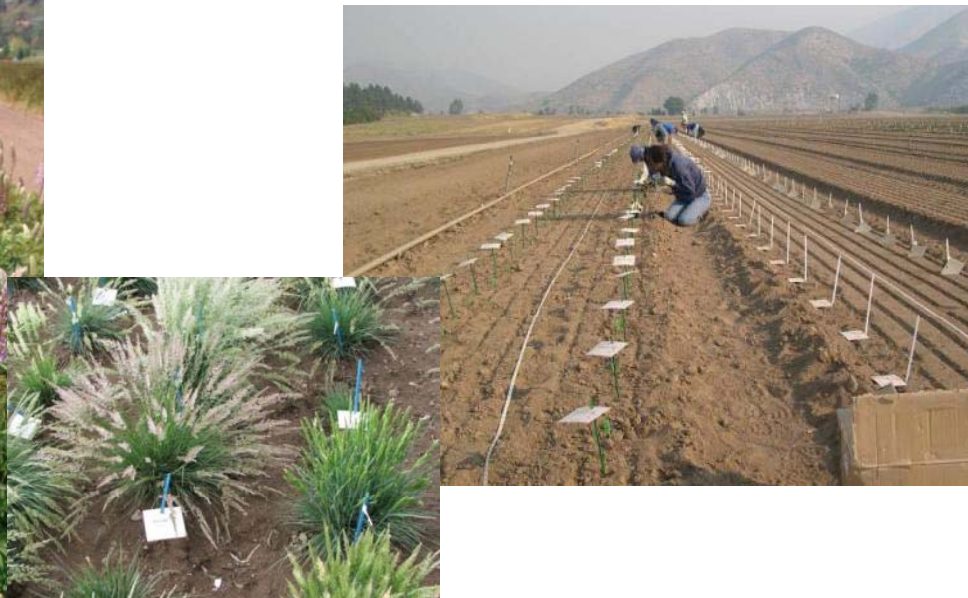
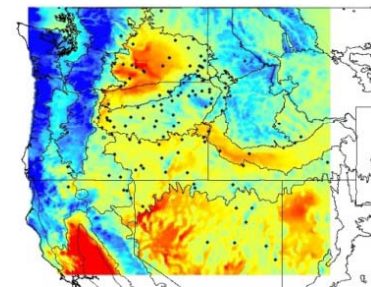
Dry weight



Flowering date

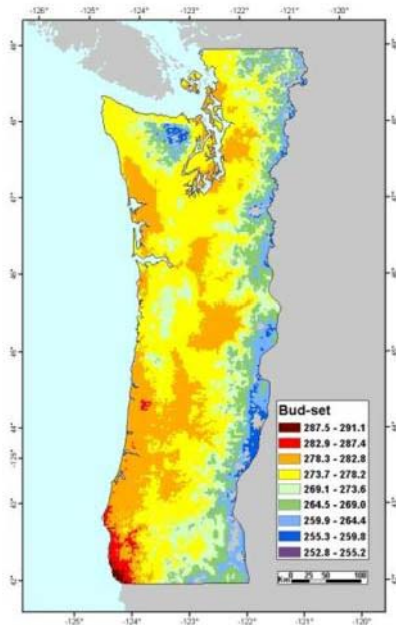


Leaf width

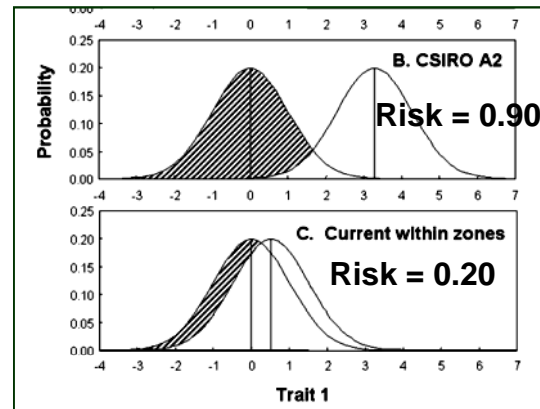


Are current populations adapted to future climates?

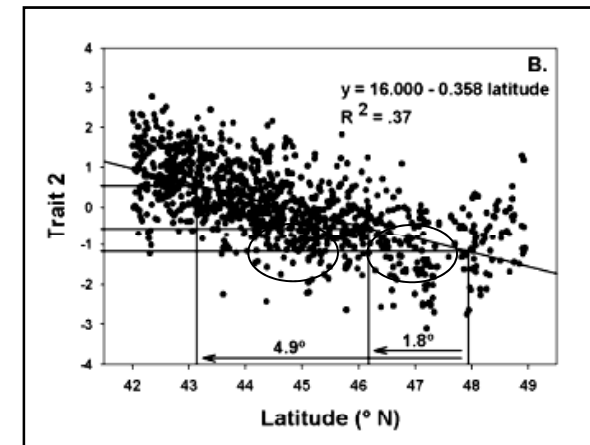
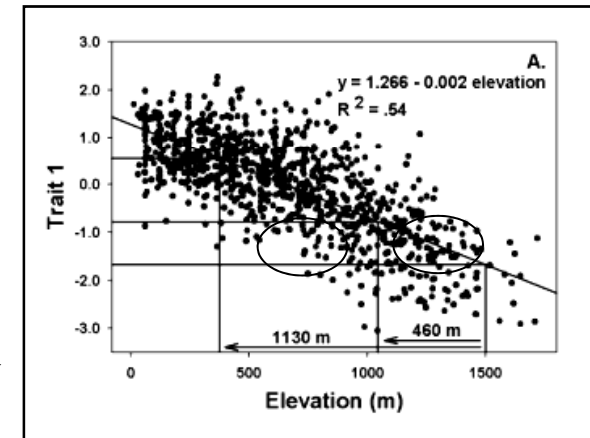
Risk of maladaptation from climate change and location of adapted populations



Genetic variation in bud-set



Risk of maladaptation from climate change



Seed movement guidelines for climate change

St.Clair and Howe. 2007. Genetic maladaptation of coastal Douglas-fir seedlings to future climates. *Global Change Biology* 13: 1441-1454.

Will forests naturally adapt to future climates?

Three possibilities when environments change:

1. Move

- Migrate to new habitats

2. Stay

- Acclimate by modifying individuals to new environment (phenotypic plasticity)
- Evolve through natural selection

3. Disappear

- Extinction of local population

What is the potential for migration?

- Estimates of past migration rates vary
 - Davis and Shaw 2001: 200-400 m per yr
 - Aitken et al 2007: 100- 200 m per yr
- But current rates of climate change might require 3000-5000 m per yr
 - Seed migration may not be sufficient
 - Pollen flow may be ineffective due to non-synchronous flowering phenology

What is the potential for adaptation via natural selection?

Important factors include:

- Phenotypic variation
- Heritabilities / additive genetic variation
- Intensity of selection
- Fecundity



- Generation turnover
- Population size
- Levels of gene flow
- Structure of genetic variation/ steepness of clines
- Central vs peripheral populations
- Trailing edge vs leading edge

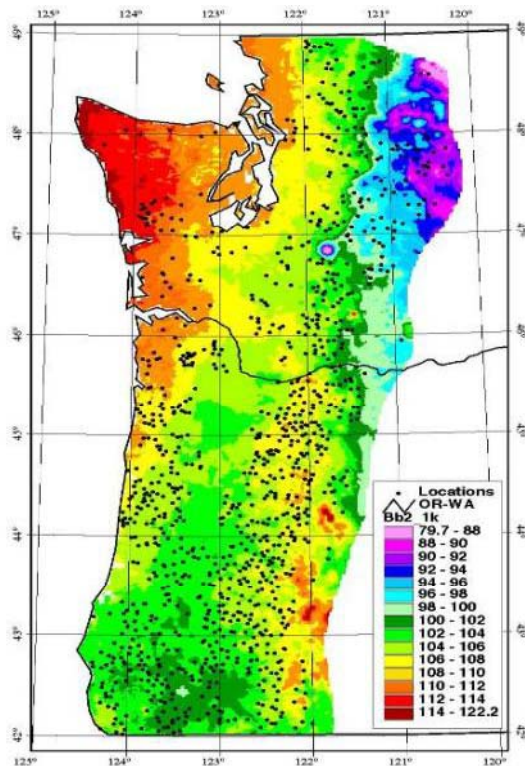
What about phenotypic plasticity?

- Phenotypic plasticity = the ability of an individual to change its characteristics (phenotype) in response to changes in the environment
- Phenotypic plasticity is common in plants
 - Plants modify their phenology, physiology and growth in response to changes in environments
 - Bud-set
 - Bud-burst
 - Flowering
 - Acclimation to drought
- However, patterns of genetic variation in adaptive characteristics associated with environmental variation suggest that phenotypic plasticity is insufficient
 - No single phenotypically plastic genotype is optimal in all environments

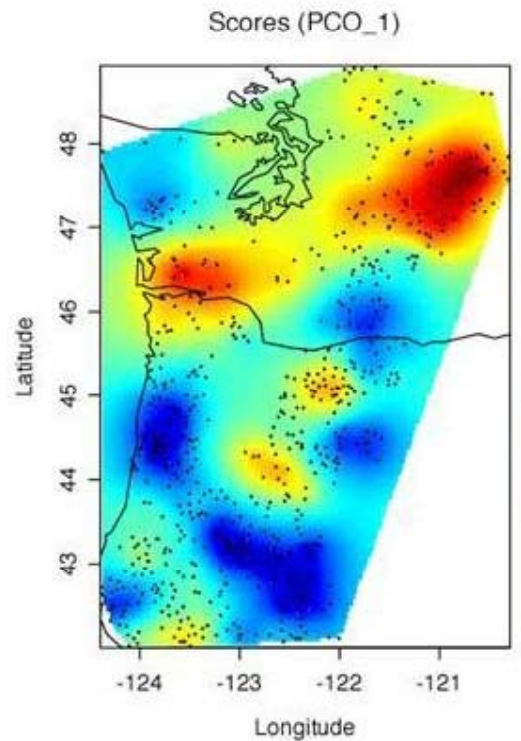
What about genetic variation at the level of DNA?

Patterns of Adaptive Molecular Genetic Diversity

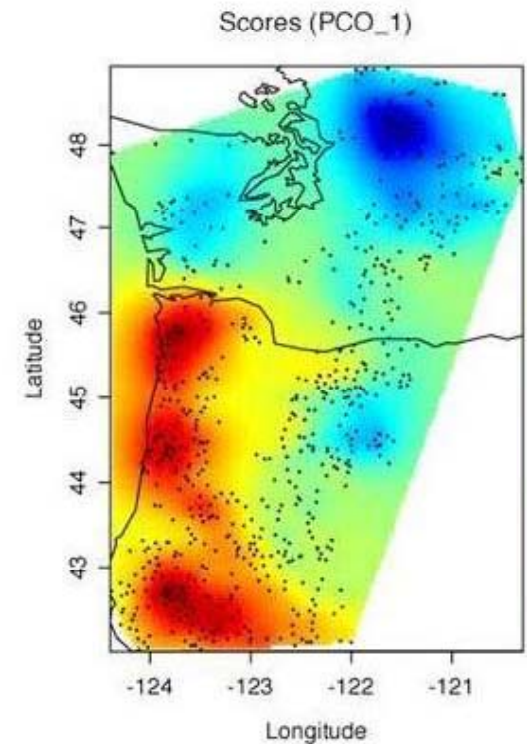
From Eckhart, Neale, et al. 2009



Phenotype



Neutral Genotype



Genotype - Non-neutral and associated with phenotype

III. Strategies for gene conservation: Prioritizing species and populations

Risk = impact of loss x probability of loss

- Impact = value to environment or society
 - economic
 - keystone species
 - rare, threatened or endangered species
 - unique variants
- Probability of loss
 - human factors
 - probability of occurrence of habitat loss, deforestation, management change, etc.
 - natural processes
 - migration
 - natural selection

Priorities for conservation considering risk from climate change

- Species of high value to environment or society
- Rare species
- Long-lived species
- Genetic specialists
- Populations with rare, valuable variants
- Species or populations with low genetic variation
 - Small populations
 - Inbreeding species
- Species or populations with low dispersal potential
- Fragmented, disjunct populations
- Populations at the trailing edge of climate change (southern, low elevation)
- Species or populations with "nowhere to go"
- Populations threatened from habitat loss, fire, disease, insects

Rare and endemic species represent unique challenges

- Limited genetic diversity
- Narrow realized niches
- Not as much room for mistakes because of limited seed and propagules
- Limited knowledge of genetic structure, niche requirements, regeneration requirements
- Ex situ may be important
- Policy limitations, e.g., endangered species laws
- High priority because "extinction is forever"

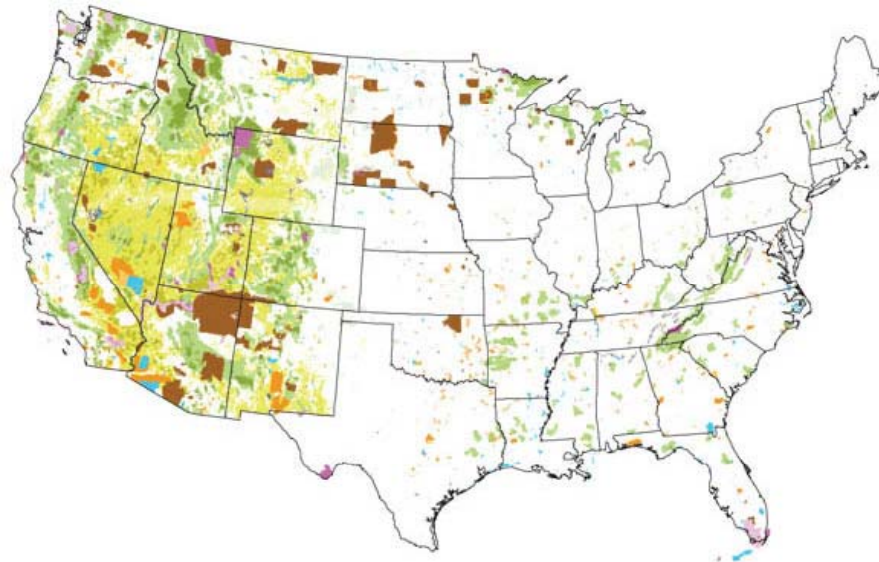
Strategies for Conserving Genetic Diversity

- *In situ* = conserved in place
- *Ex situ* = conserved at another place
- Assisted colonization or migration = moving populations to new places where they are adapted but subject to natural processes given climate change

In Situ Conservation

- Includes:
 - strict reserves (wilderness areas, national parks, other set asides)
 - gene resource management units
 - other lands that perpetuate native populations, preferably natural regeneration
- Advantages:
 - Allows for natural evolutionary processes
 - May conserve several species of interest
 - May serve other purposes; may already be established for other purposes
 - May conserve large numbers of individuals
 - Little management required
- Disadvantages:
 - Subject to loss from climate change, disease, fire, land use change
 - Succession may eliminate species
 - May be difficult to observe and find unique variation
 - Unlikely to be created for purposes of gene conservation alone

In situ conservation is largely by default

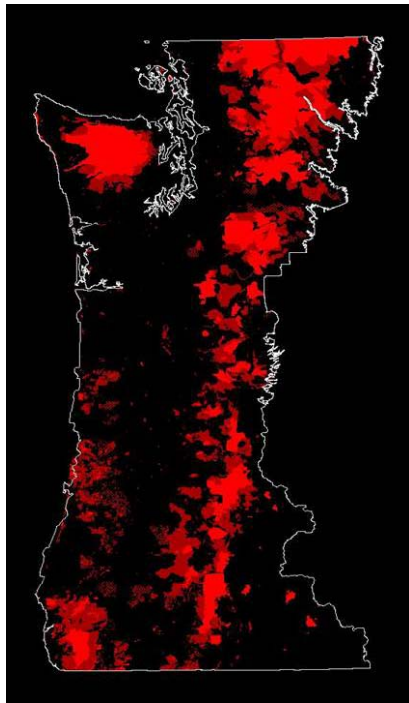


Public lands in the United States

In Situ Reserves:

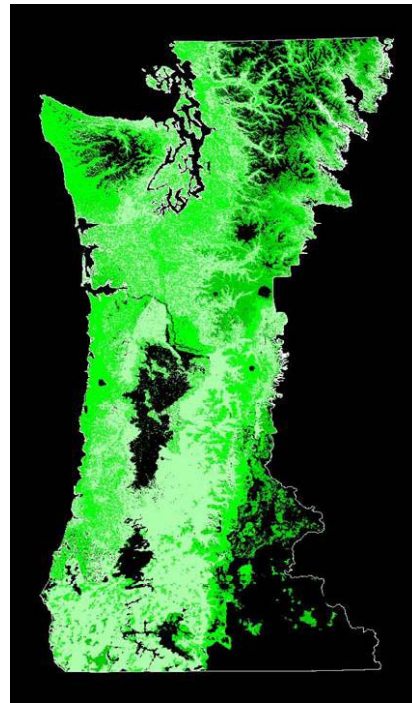
- **USFS Wilderness Areas**
- **National Parks**
- **Research Natural Areas**
- **State and county parks**
- **Wildlife Refuges**
- **Other reserves (e.g., The Nature Conservancy)**
- **Lands managed with natural regeneration**
- **Gene resource management areas (rarely)**

Gap Analysis for Douglas-Fir (*Pseudotsuga menziesii*)



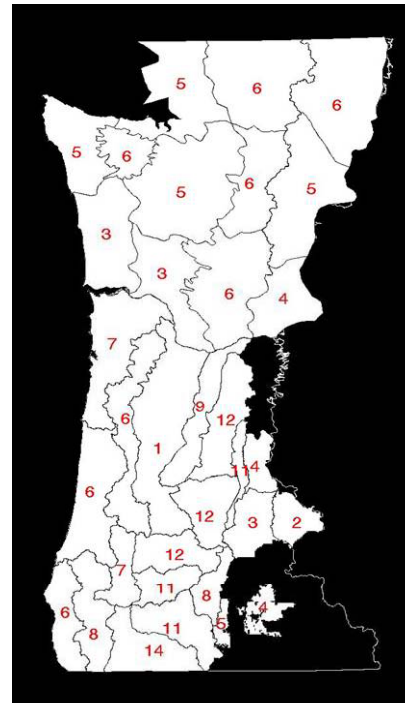
Protected areas

+



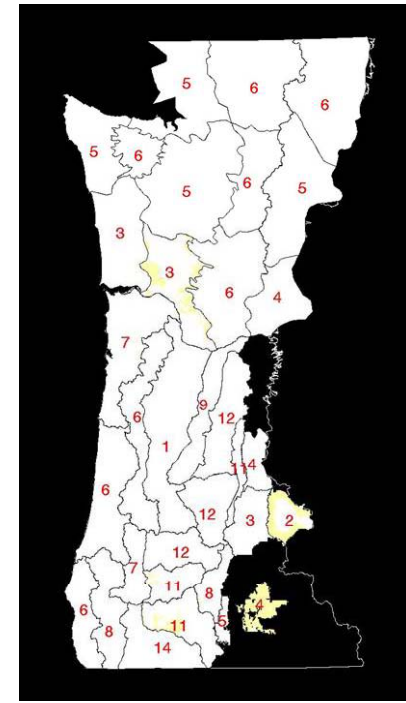
Distribution map

+



Genetic stratification

⇒



Potential gaps

How much area at each density does each species occupy in each ecoregion/seed zone?

Potential gaps are defined as stratifications with <5,000 trees.

Rethinking *In Situ* Conservation

Static vs dynamic conservation: maintaining existing genetic variation vs promoting adaptation to new climates with potential loss of genetic variation

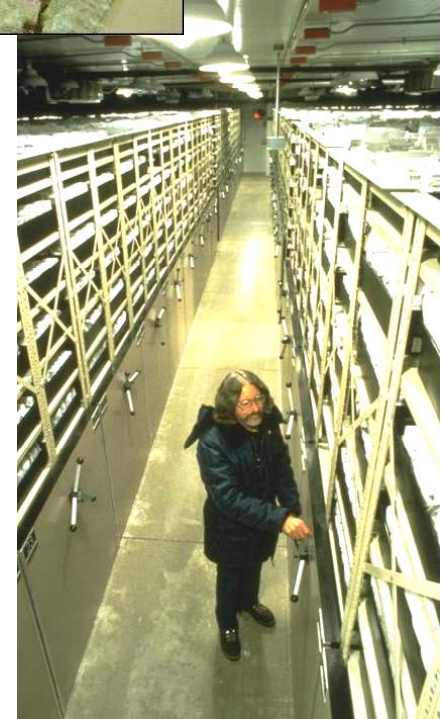
- Reduce disturbance probability and intensity
 - thinning, prescribed fire, fuels reduction, insect traps
- Locate reserves in areas of high environmental heterogeneity and high genetic diversity
- Avoid fragmentation of reserves
- Supplement existing variation by planting populations expected to be adapted to future climates within or adjacent to reserves
- Greater emphasis on ex situ collections



Ex Situ Conservation

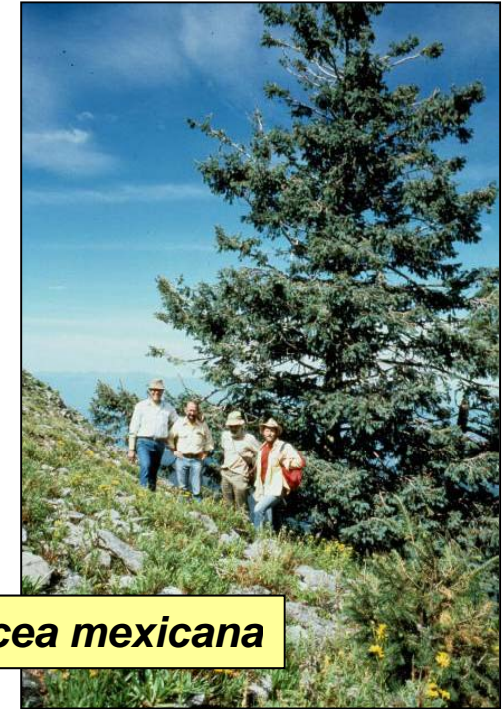


- Includes seed stores, genetic tests, seed orchards, clone banks, other specific plantings
- Advantages:
 - Removed from threats such as climate change, disease, fire, land use change
 - More likely to observe unique variation in genetic tests than in the wild due to common environment and repeated visits and measurements
- Disadvantages:
 - May be costly to collect and maintain
 - Population sizes are smaller than in *in situ* reserves
 - Seeds need to be grown into plants to observe variation (more of a problem with long-lived trees)



Priorities for *Ex Situ* Conservation

- At immediate threat from fire, disease, or insects
- Rare, small, disjunct populations
- Marginal populations at the trailing edge of climate change
- High elevation populations



Picea mexicana



Fire



Blister rust

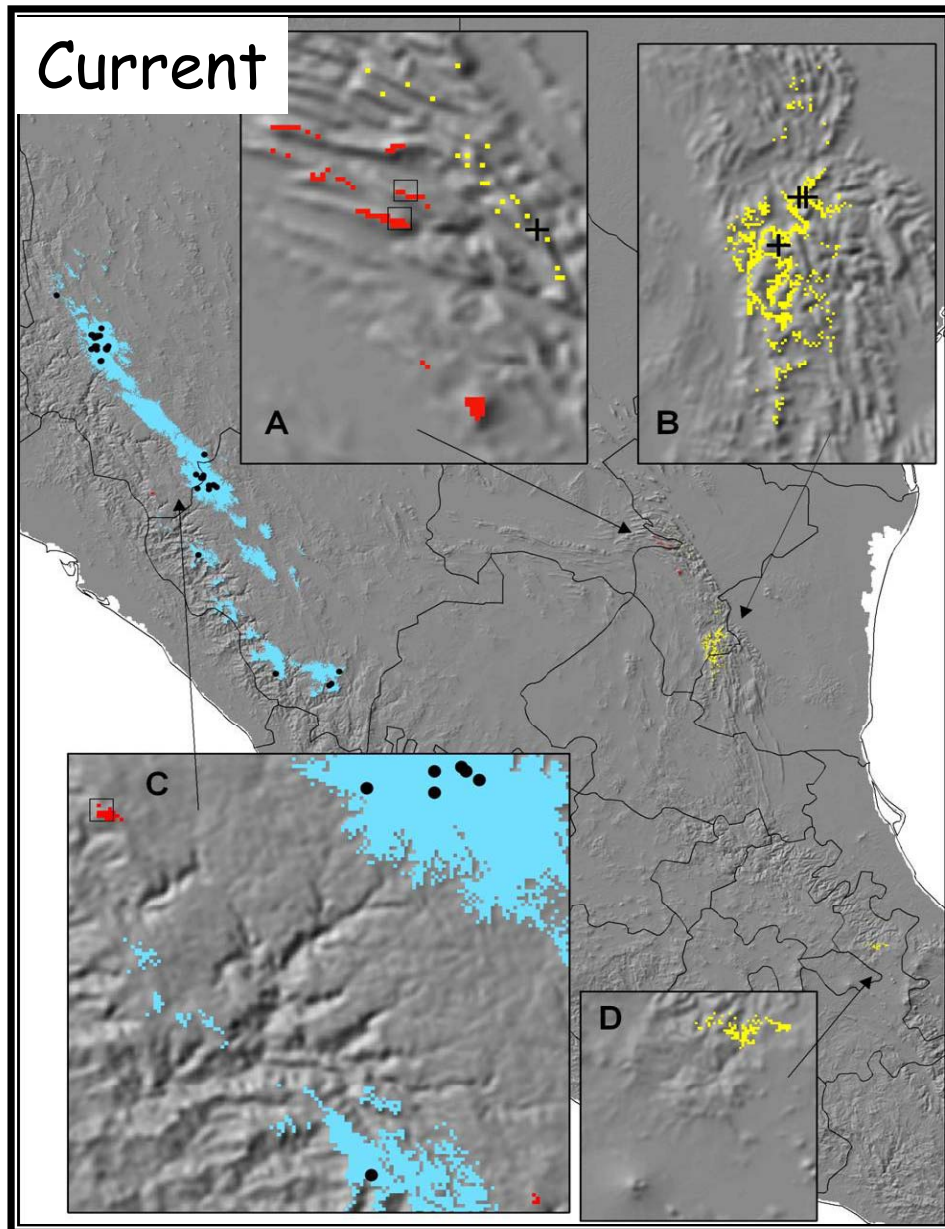


Emerald Ash Borer

Assisted colonization

- A form of *ex situ* conservation
- But may also be considered a form of *in situ* conservation if populations are subject to natural evolutionary processes.
- Requires knowledge of species distribution, population variation in adaptive traits, climatic variation, and predicted future climates.

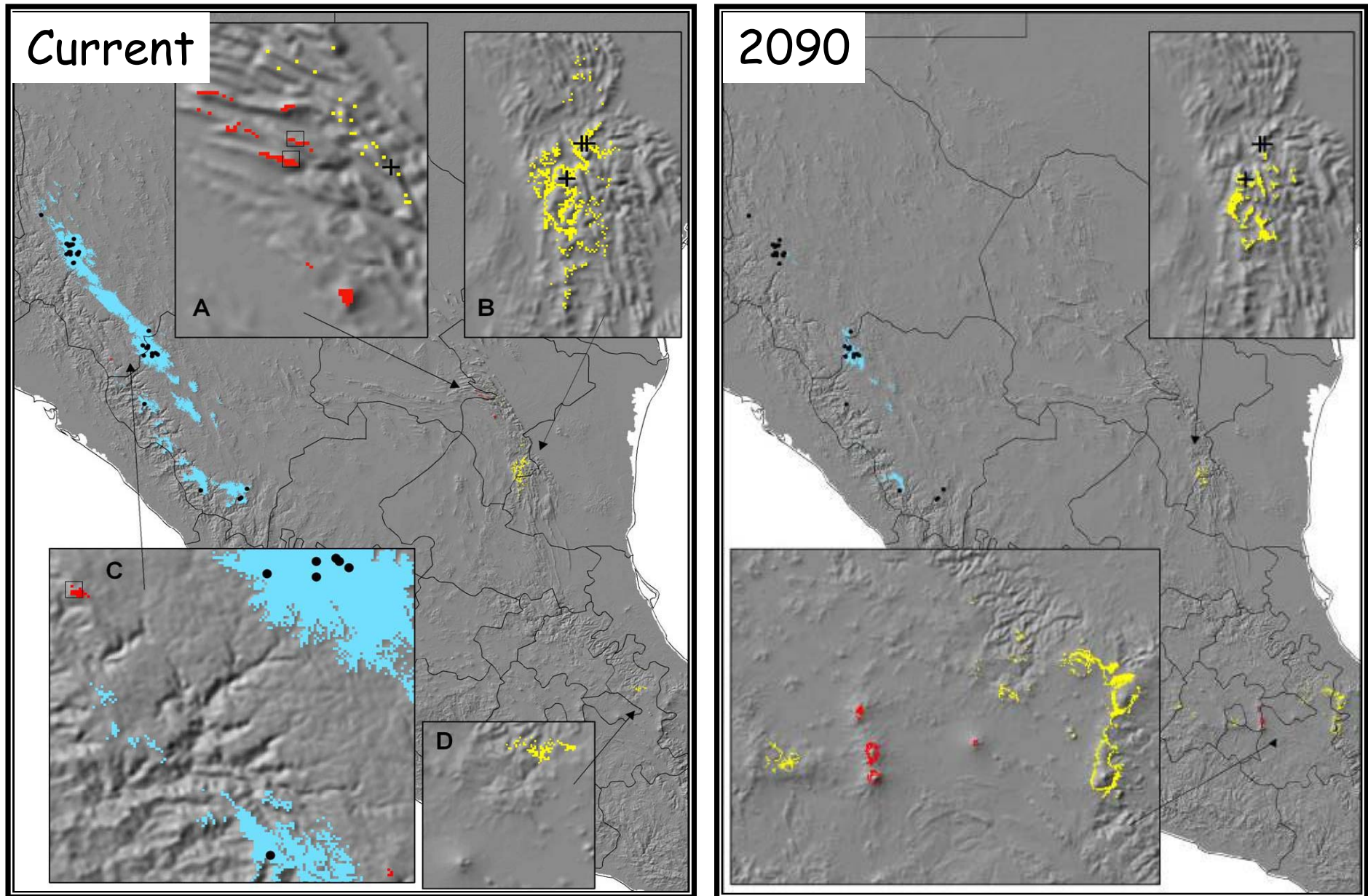
Actual and Modeled Distributions of Mexican Spruces



Blue = *Picea chihuahuana*
Red = *Picea mexicana*
Yellow = *Picea martinezii*

From: Jerry Rehfeldt, Tom Ledig,
Cuauhtémoc Sáenz Romero

Actual and Modeled Distributions of Mexican Spruces



What to plant for future climates?

Seedlot Selection Tool

Ron Beloin, Glenn Howe, Brad St.Clair,
Lauren Magalska, Greg Deveer
Funded by the USFS Climate Change
Research Program

Home About Instructions Related Sites Contact Us

Find seedlots for my planting site

Find planting sites for my seedlot

Seedlot Selection Tool

Planting Healthy Forests

The seedlot selection tool (SST) is a GIS mapping program designed to help forest managers match seedlots with planting sites based on climatic information. The tool can be used to map current climates, or future climates based on selected climate change scenarios. Although it is tailored for matching seedlots and planting sites, it can be used by anyone interested in mapping present or future climates defined by temperature and precipitation.

Purpose

Forest managers can use this tool to help choose seedlots that are appropriate for planting on a particular site, or planting sites that are appropriate for a particular seedlot. This can be done using current climate models (i.e., ignoring potential climate change) or by choosing a climate change model, emissions scenario, and future target year. Because of the uncertainty in climate change projections, the tool is really a planning and educational tool. It can be used to explore alternative future conditions, assess risk, and plan potential responses, but cannot tell the user exactly which seedlots will be optimally adapted to a particular planting site in the future. The tool allows the user to control many input parameters so the results are appropriate for the management problem, climate change assumptions, and risk tolerance of the user.

Background

Populations of trees, such as those from native stands or seed orchards, are genetically adapted from one another and are adapted to different climatic conditions. Therefore, forest managers must match the climatic adaptability of their seedlots to the climatic conditions of their planting sites. Typically, this has been done using geographically defined seed zones or breeding zones. However, current climate models are now available that can be used to define zones based on climate, rather than geography. These climate models can also be used to calculate climatically based seed transfer distances and define final post- and pre- zones. Once acceptable climatic transfer limits have been defined using seed zones, breeding zones, or some other approach, the user can explore how well the species selected originally might be used to help adapt forests to climate change.

How does the tool work?

To use the tool, the user must first indicate whether they want to find appropriate seedlots for a planting site or appropriate planting sites for a seedlot. After clicking on one of the two buttons at the top of the page, the user will be taken to one of two data entry pages where they will complete steps 1-3 (see figure). Detailed instructions for each step can be found on the [Instructions](#) page. The best way to learn about the tool is to try it. Because the fields on the data entry page contain default values, the first time user can quickly see how the tool works. To see how maps are generated, select the "Seedlot" or "Planting site" button at the top of the page, and then click on the "Produce Map" button on the data entry page. Experimental users can override the default values, or login and select a set of values that were saved in a previous session.




How the tool works

- 1. Select Your Goal**
Choose to find seedlots for your planting site or planting sites for your seedlot.
- 2. Login**
The optional login feature allows you to store your inputs.
- 3. Enter Location**
Use the Google Maps or coordinates to show the location of your seedlot or planting site.
- 4. Select Species**
This tool uses species specific or general climate and transfer limits.
- 5. Determine Transfer Limit**
Use one of our recommended limits, enter your own limit, or create a new transfer limit.
- 6. Select Climate Models**
Use present climate only, or present and future climates by selecting an emissions scenario, future climate model, and year.
- 7. Apply Constraints to Map**
Use our tool to select all your map layers or use climate transfer such as transfer range, altitude, longitude and more.
- 8. Map Your Results**
The resulting map shows where you can find appropriate seedlots or planting sites, based on the data.

[Learn More](#)

A joint project ...

The Seedlot Selection Tool is a joint effort of the Department of Forest Management and Silviculture at the Oregon State University College of Forestry and the U.S. Forest Service through the National Systematic Planning Program from the U.S. Forest Service.

© 2008 Oregon State University | Privacy Policy | Disclaimer | Contact Us

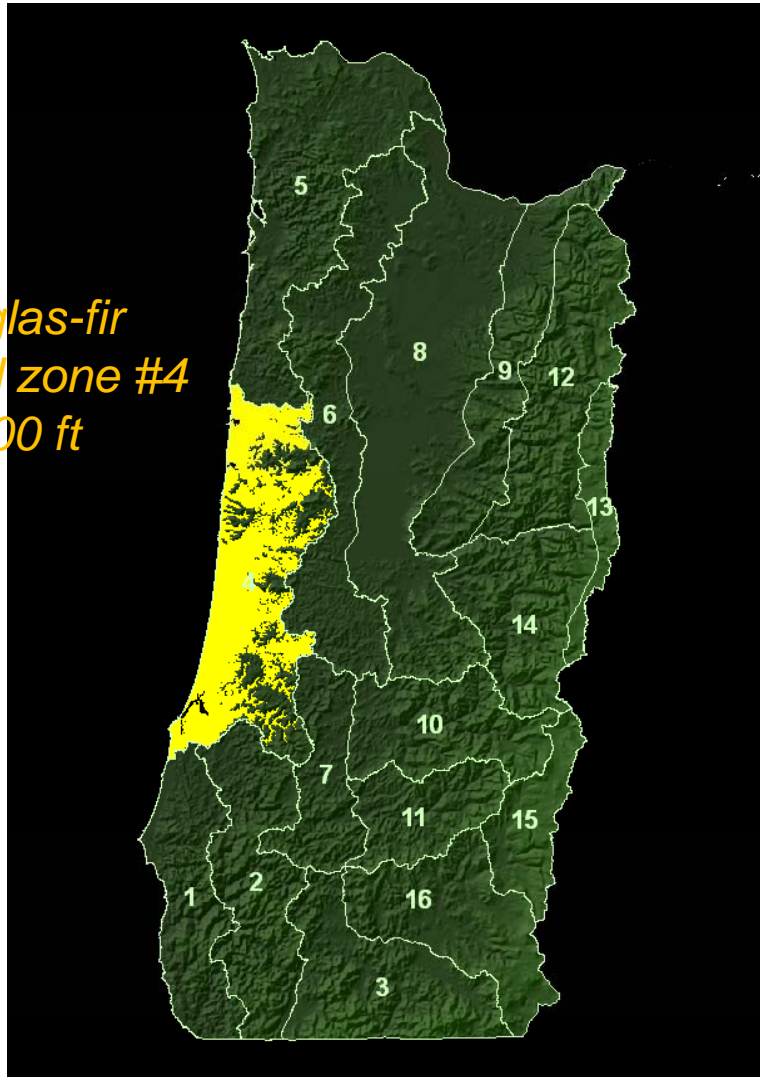
Present

2030

2060

2090

*Douglas-fir
Seed zone #4
0-1000 ft*



Seed zone

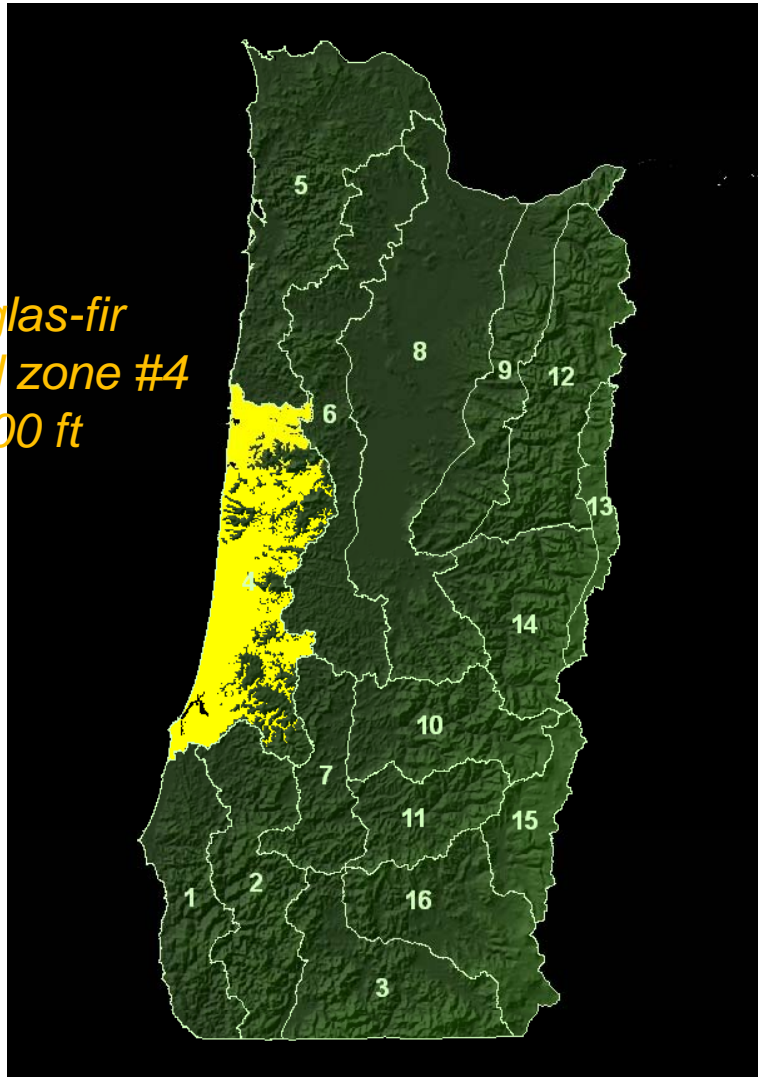
Present

2030

2060

2090

*Douglas-fir
Seed zone #4
0-1000 ft*



Seed zone



*Climate
(Canadian GCM, A1B)*

Present

2030

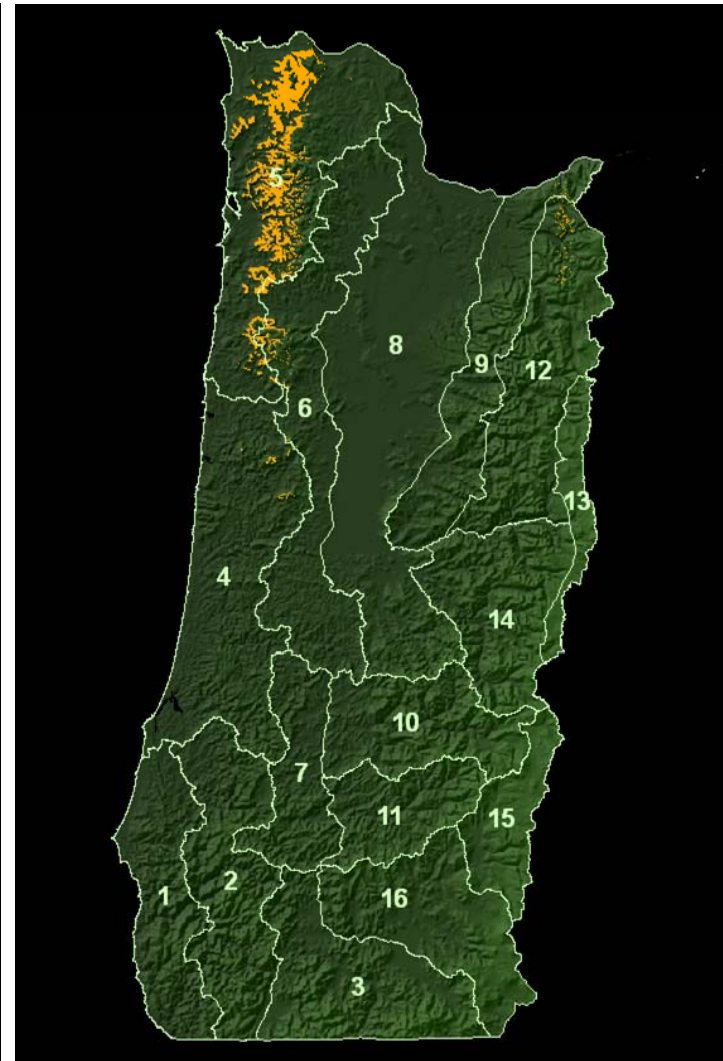
2060

2090

*Douglas-fir
Seed zone #4
0-1000 ft*



Seed zone



Climate

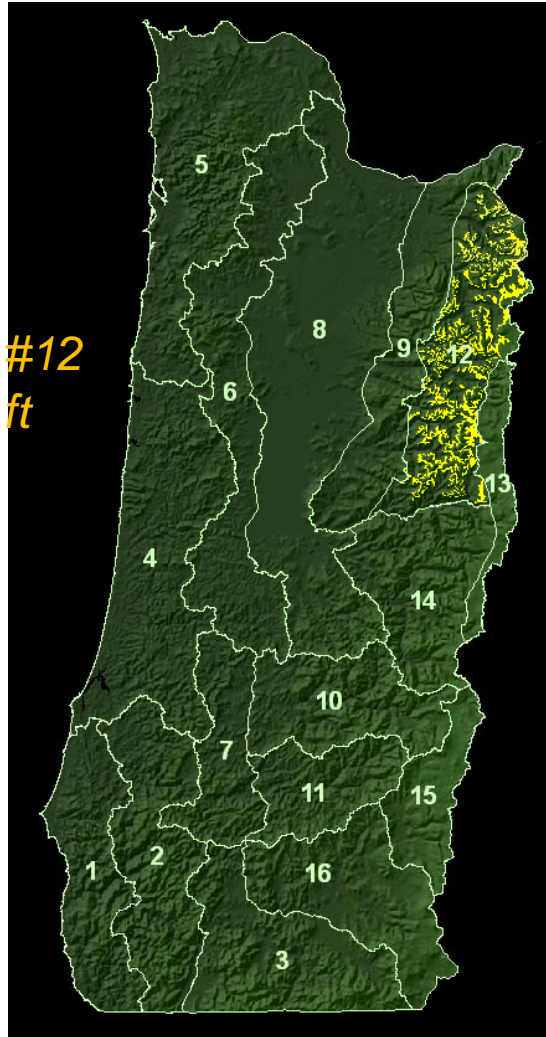
Present

2030

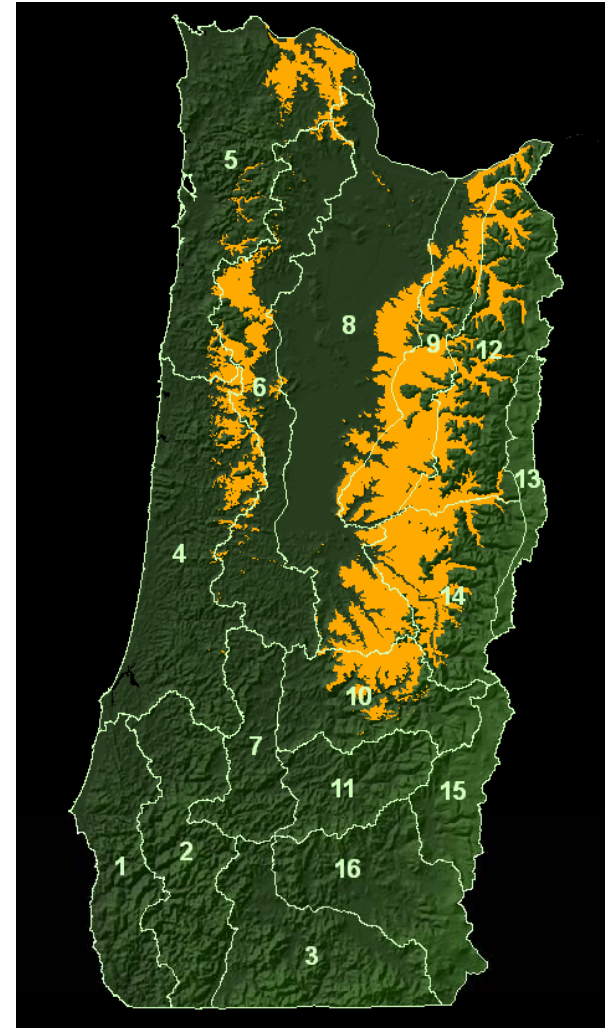
2060

2090

*Douglas-fir
Seed zone #12
3500-4000 ft*



Seed zone



Climate

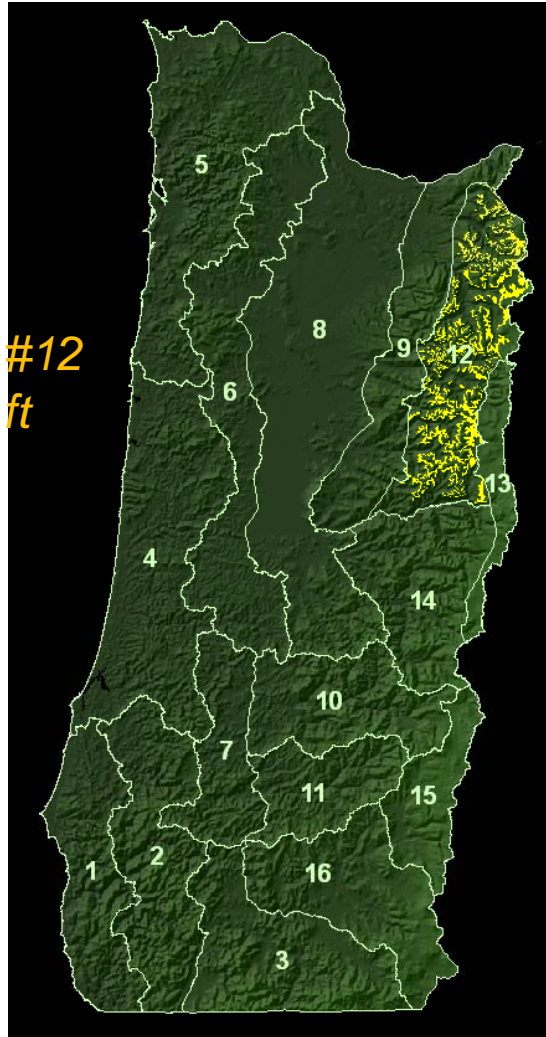
Present

2030

2060

2090

*Douglas-fir
Seed zone #12
3500-4000 ft*



Seed zone



Climate

Research Needs

- Monitor health, phenology, regeneration, and productivity in natural populations and in plantations
- Revisit old species and genetic trials for knowledge to guide changes to restoration
- Establish new field experiments to evaluate species and population predictions from niche models and test assisted colonization
- Establish growth chamber experiments to study species and population responses to temperature and CO₂ increases

Center for Forest Provenance Data

Objectives:

1. Archive data from long-term provenance tests and seedling genecology tests
2. Make datasets available to researchers through the web

*Denise Cooper, Brad St.Clair, Glenn Howe,
Jessica Wright, Greg DeVeer
Funded by USFS Climate Change
Research Program*

Center for Forest Provenance Data

Retrieve Data
Search for and download datasets from forest provenance studies.

Submit Data
Upload data from long-term provenance tests and seedling genecology tests.

Healthy forests for a changing world.

The Center for Forest Provenance Data is a place for researchers to go to archive their data from provenance and genecology studies of forest trees, and make those data available for collaboration with other researchers.

Provenance and genecology studies consider genetic variation among forest trees from different source locations by growing them in replicated tests in a common environment and then observing differences among them in the wild. Genetic differences among source trees are associated with environmental gradients and contribute to adaptive variation. Provenance and genecology studies are important for understanding adaptive variation across the landscape and identifying genetic resources for reforestation, restoration, gene conservation, and responding to climate change.

The Center for Forest Provenance Data has a secure site for submitting and retrieving data from the database. There is also a search tool for identifying studies that are currently in the database.

To submit or retrieve data, you will be asked to create a profile including a username and password to logging onto the site. Creating a profile provides us with contact information that will allow us contact you with questions or updates. The contact information will not be used for any purposes not related to managing the database.

[Learn More](#)

A joint project ...

The Center for Forest Provenance Data is a joint project of the United States Forest Service, Pacific Northwest and Pacific Southwest Research Stations and the Oregon State University College of Forestry. Funding comes from the United States Forest Service.

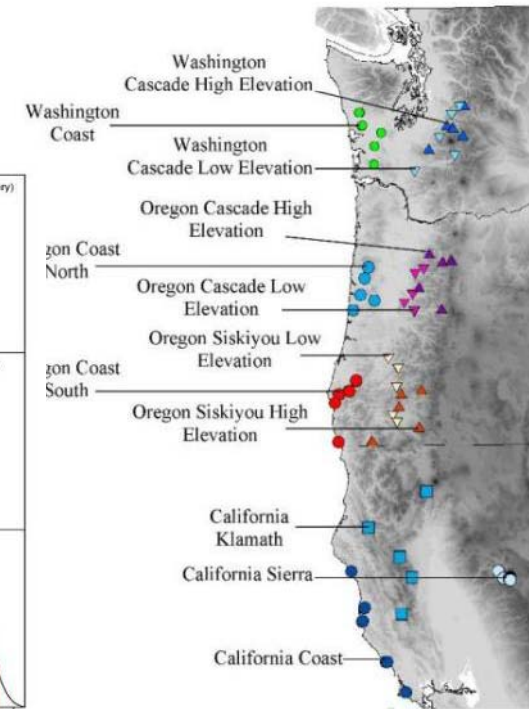
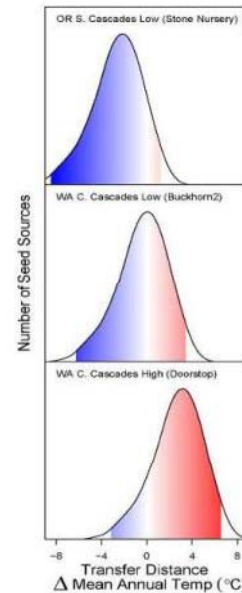
US Forest Service Oregon State University College of Forestry

Copyright © 2008 Oregon State University. [Privacy Policy](#) | [Disclaimer](#) | [Contact Us](#)

New provenance tests established for Douglas-fir in Oregon & Washington

Primary objective: to build transfer functions that look at tree growth and survival (and components) as a function of the differences between source and planting environments

Reciprocal transplant study:
120 Douglas-fir families (from previous study)
from 60 locations in 12 regions
planted back into 9 of the regions



Conclusions

1. Many threats to biodiversity. Although not immediate, climate change is a serious threat that needs to be addressed.
2. Trees are highly vulnerable to climate change owing to long generation intervals, particularly small, disjunct populations at the trailing edge of the species margin.
3. Rare and endemic plants should be given high priority because of their uniqueness, but present special challenges due to small population sizes, lack of knowledge, and policy issues that might preclude management options.
4. The conservation of genetic diversity in native habitats will require a shift in thinking from static to dynamic conservation.
 - Trade-offs between maintaining existing variation vs promoting natural selection and adaptation to new environments
 - *In situ* reserves should be located in areas of high environmental heterogeneity to maximize genetic diversity and gene flow.
 - Connectivity between reserves should be maintained.
 - Genetic variation may be enhanced by planting populations expected to be adapted to future climates within or adjacent to reserves.
5. *Ex situ* conservation will become more important.
6. Consider assisted colonization to move plant populations to locations where they may be expected to be adapted.

A photograph of a dense forest of tall evergreen trees, likely pines or firs, shrouded in a thick mist or fog. The trees are dark green and their forms are softened by the atmospheric haze. The overall mood is serene and quiet. The text "Thank you" is written in a bright yellow, italicized font, centered in the upper half of the image.

Thank you