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

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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

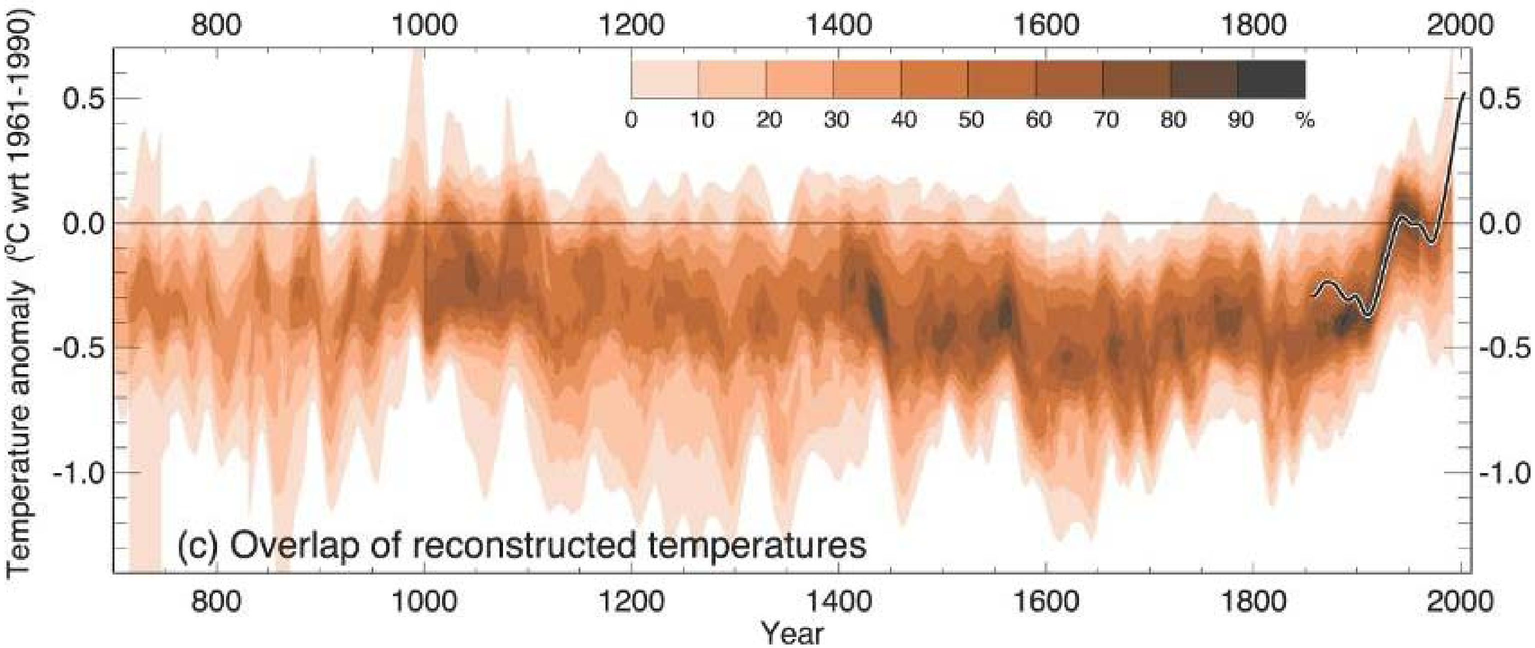

Piñon pine mortality from drought

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

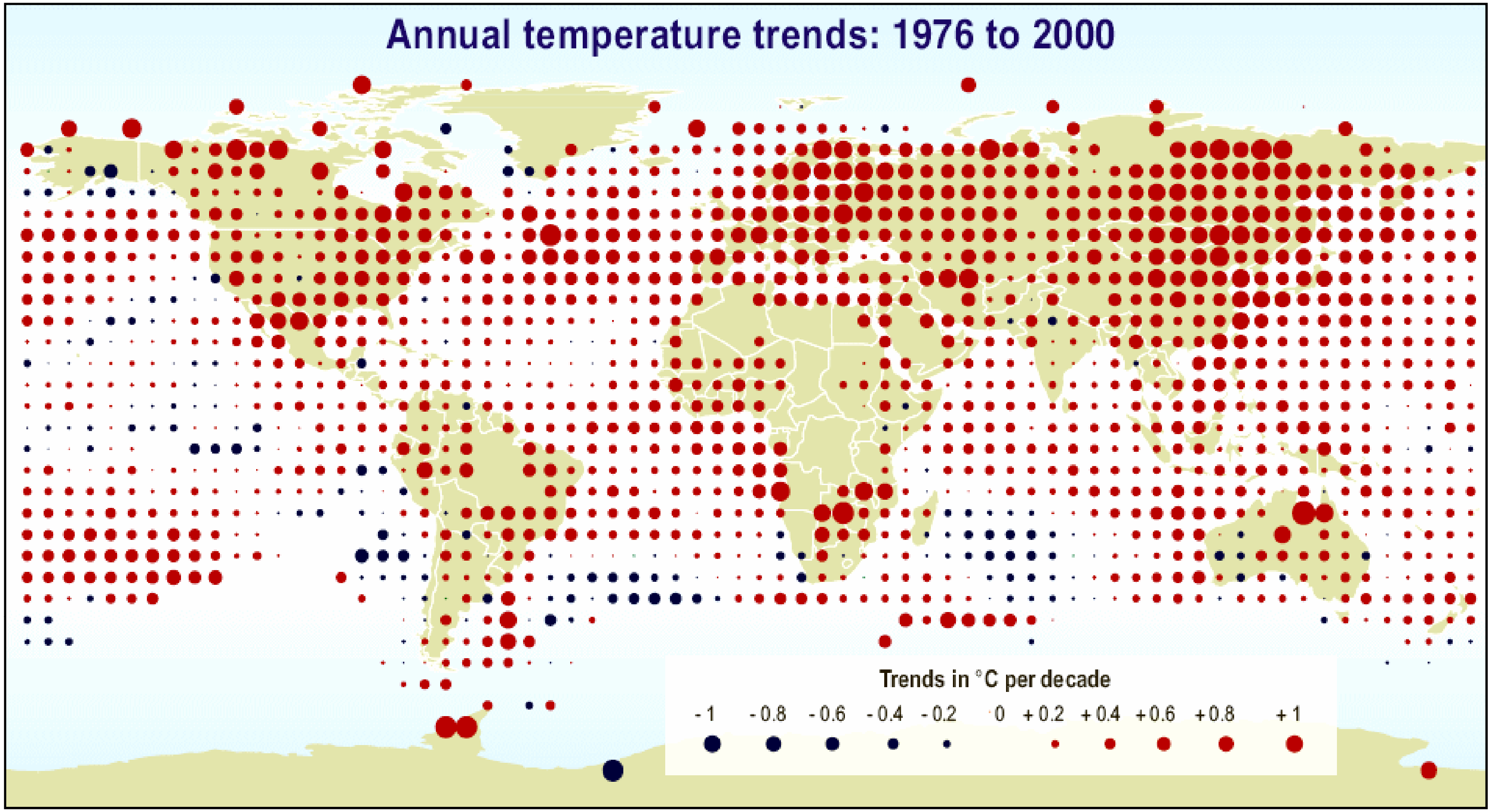
Evidence for Global Warming

- 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)

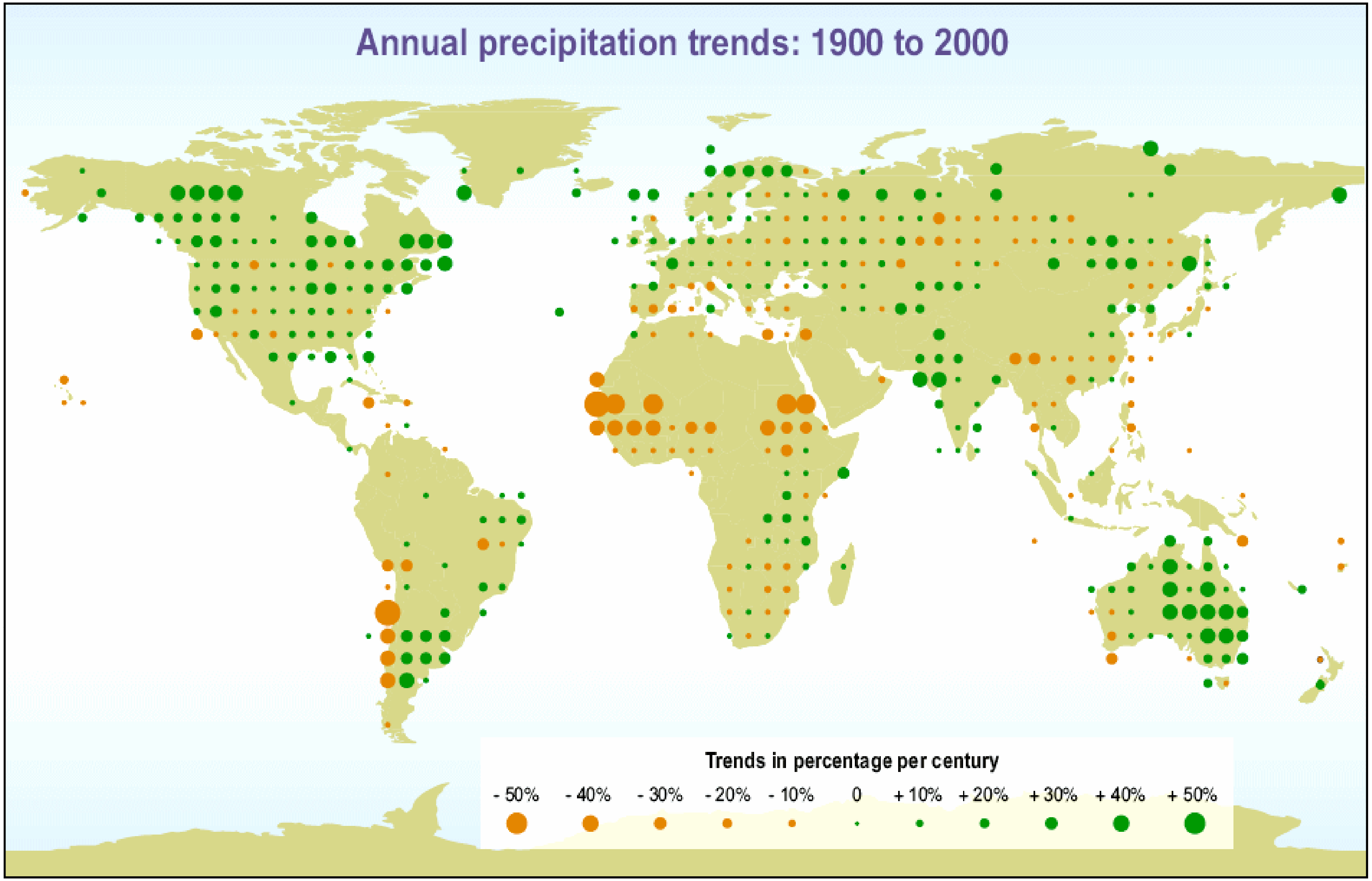


IPCC 2007

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

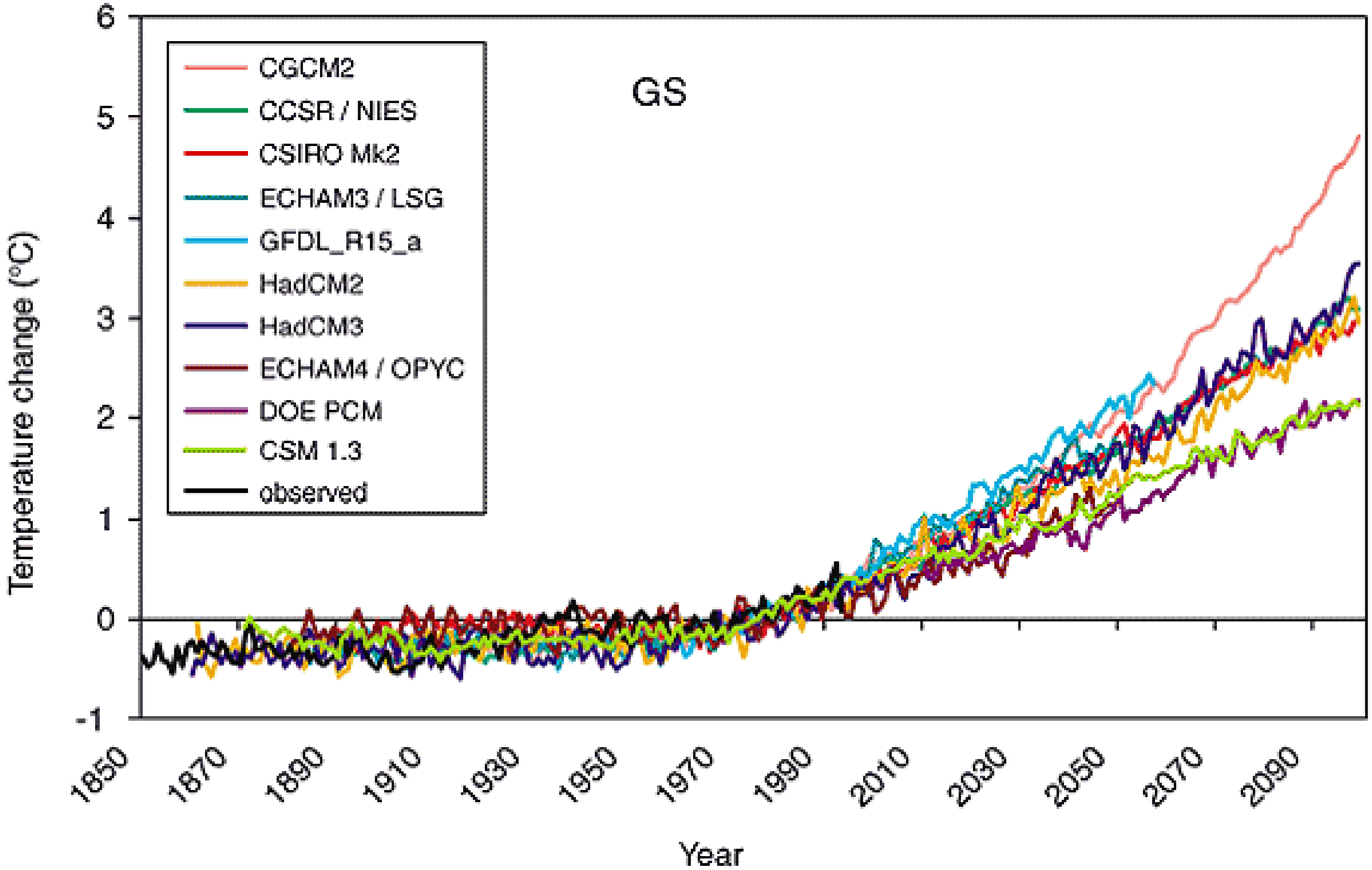


Annual temperature trends: 1976 to 2000
Trends in °C per decade
- 1
- 0.8
- 0.6
- 0.4
- 0.2
0
+ 0.2
+ 0.4
+ 0.6
+ 0.8
+ 1



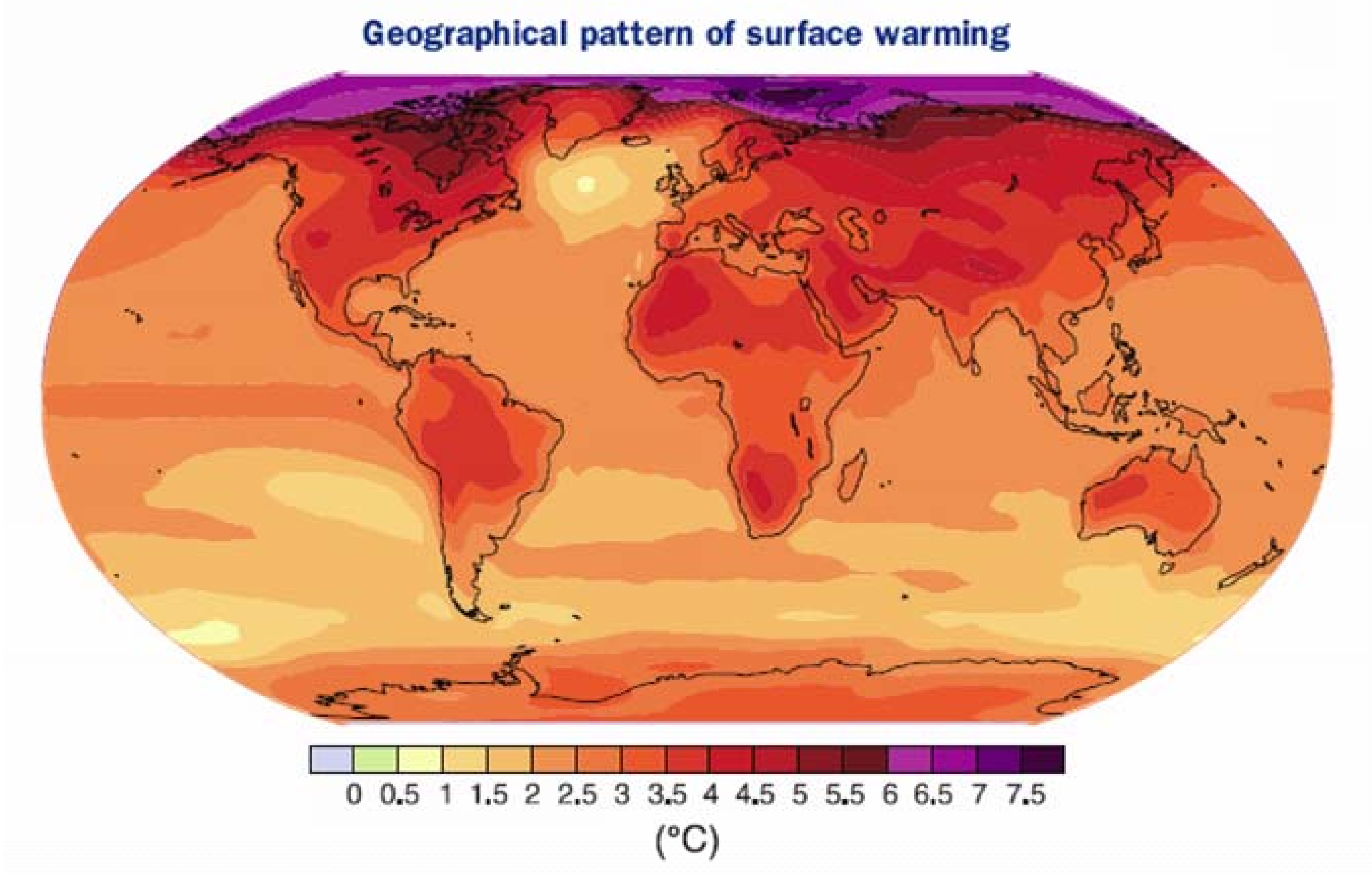
Precipitation trends highly variable spatially and temporally

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

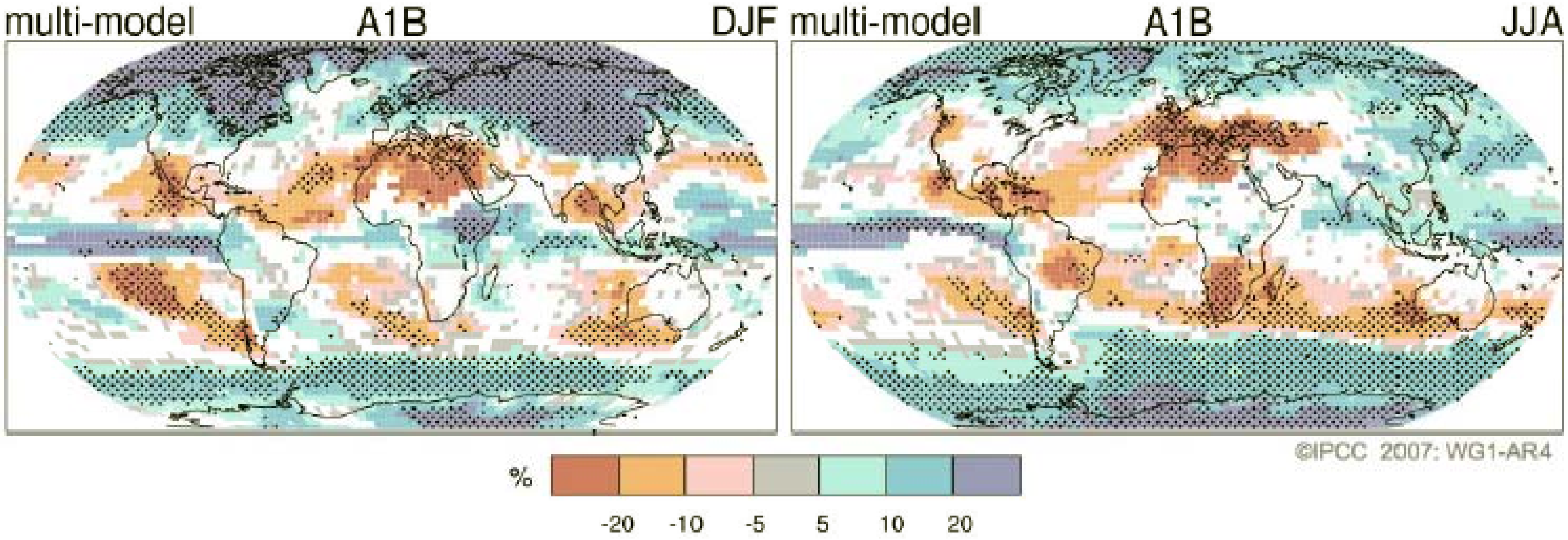
Projections of Surface Temperatures



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

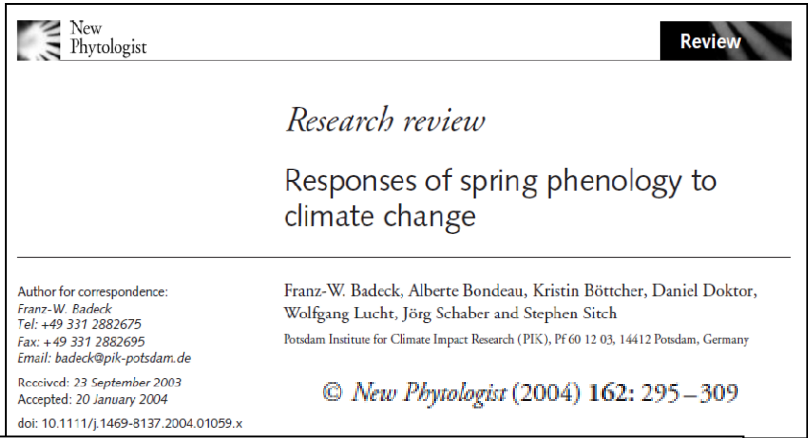
Phenological events are occurring earlier

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

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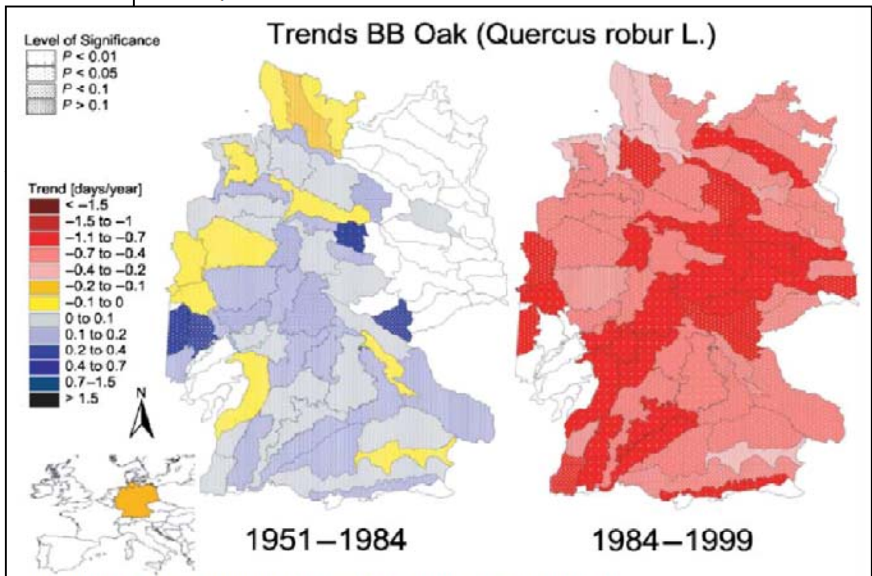
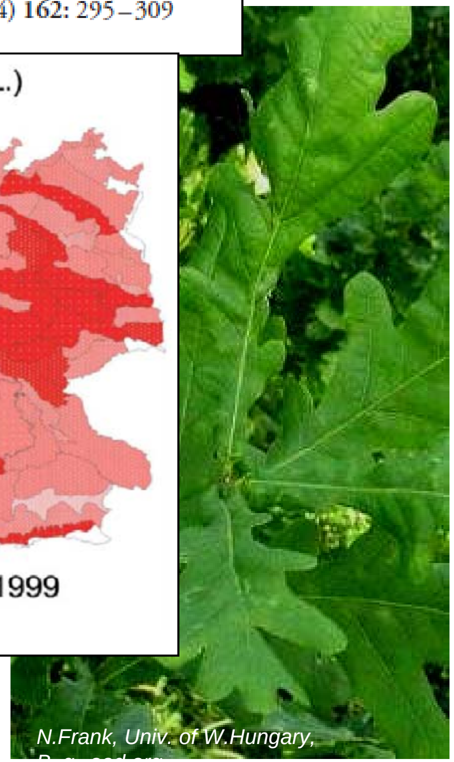


Fig. 1 Trends in bud burst of birch and oak in Germany in the periods 1951–84 and 1984–98.



Can we see a warming signal? – Yes

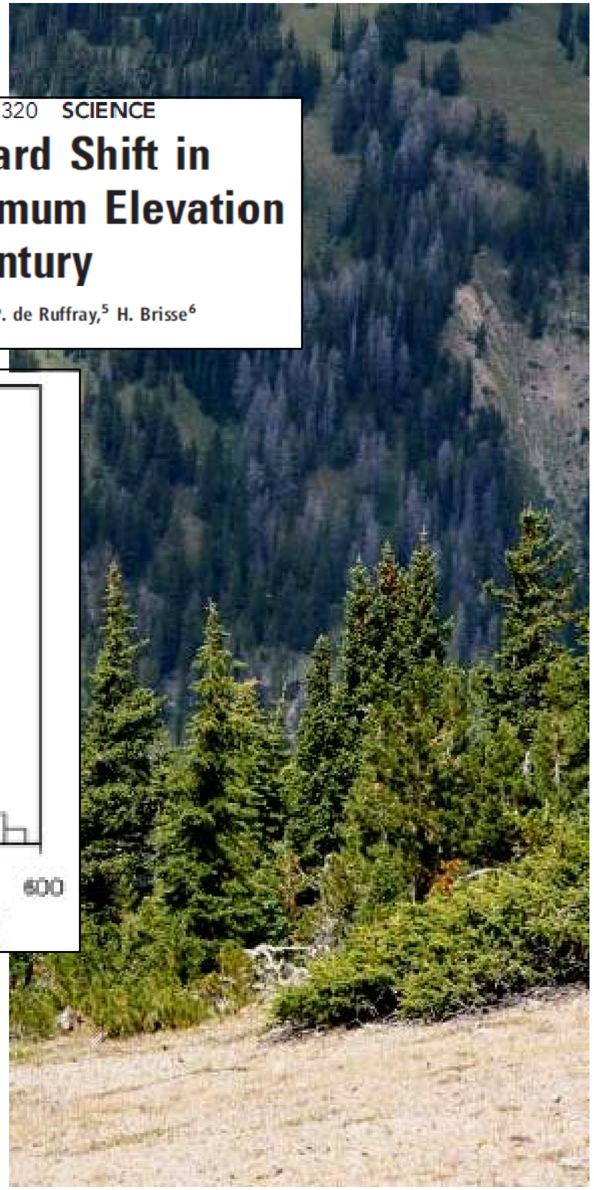
Species distributions have moved up in elevation

Concerns

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

Potential opportunities

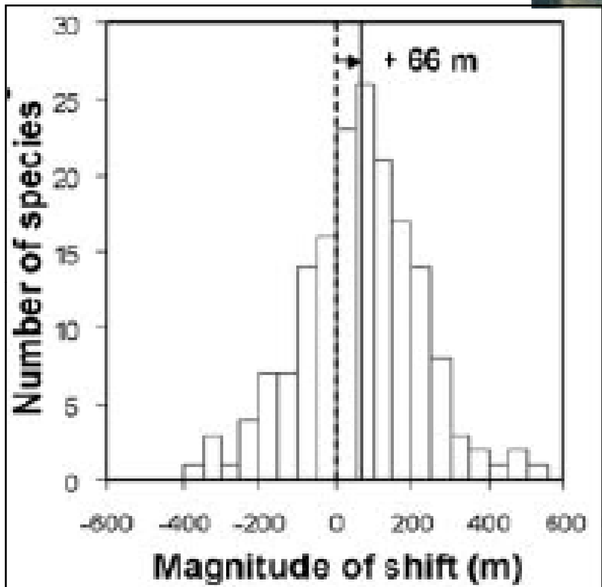
- Improved growth and productivity in high-elevation forests



27 JUNE 2008 VOL 320 SCIENCE

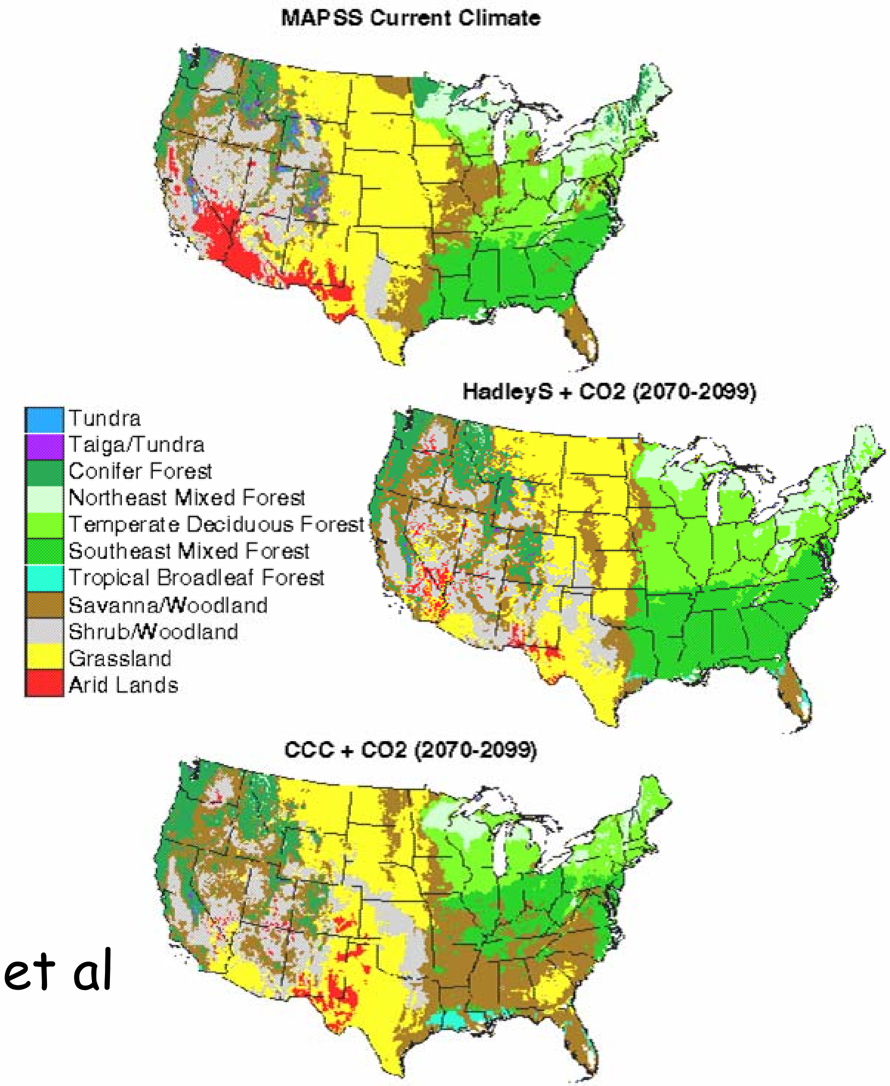
A Significant Upward Shift in Plant Species Optimum Elevation During the 20th Century

J. Lenoir,[1*] J. C. Gégout,[1] P. A. Marquet,[2,3,4] P. de Ruffray,[5] H. Brisse[6]



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

November 2006 CLIMATE CHANGE BC ECOSYSTEMS 2781

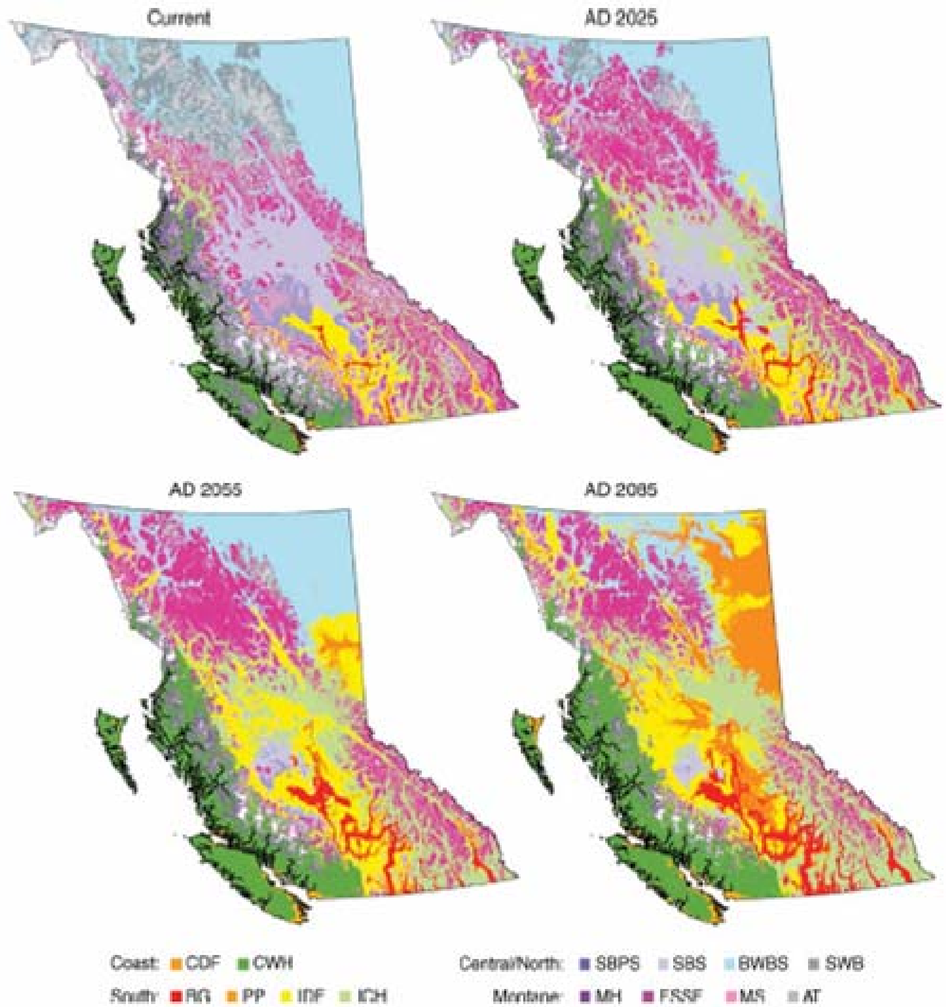


FIG. 2. Shift of the climatic envelope of ecological zones based on the ensemble simulation CGCM1gax for the normal periods 2011–2040 (2025), 2041–2070 (2055), and 2071–2100 (2085). The ecological zones are: CDF, Coastal Douglas-fir; CWH, Coastal Western Hemlock; BG, Bunchgrass; PP, Ponderosa Pine; IDF,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

Hamann and Wang
2006 Ecology

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:

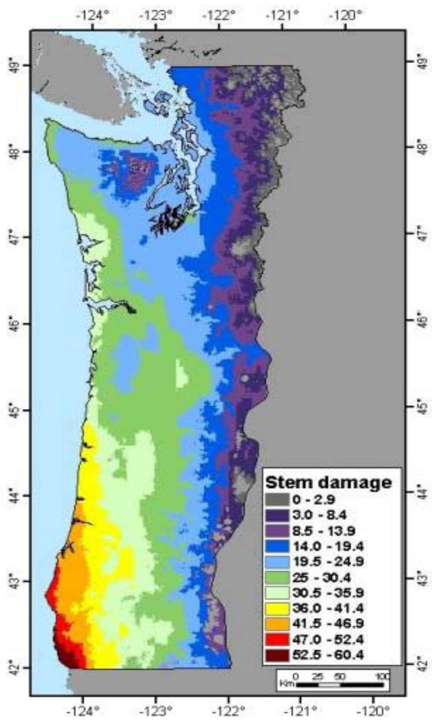
1. Correlation between a character and environmental factors - the same form occurs in similar environments
2. Comparisons of naturally-occurring variants in environments where they are hypothesized to function as adaptations
3. Direct evidence from altering a character to see how it affects function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

from West-Eberhard 1992

Evidence for adaptation comes from common garden (provenance) studies

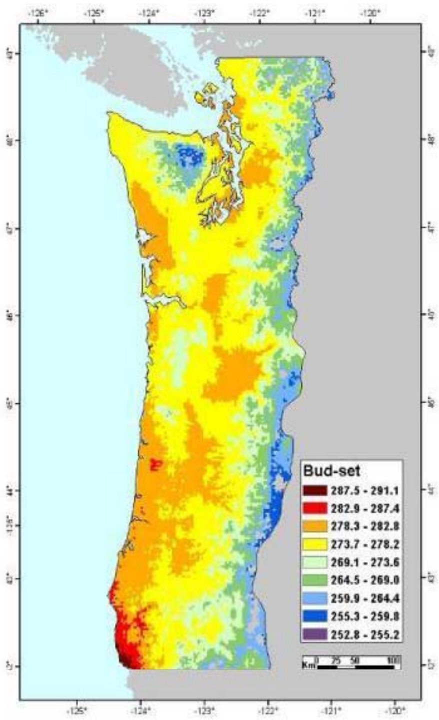
Evidence for adaptation: Douglas-Fir Genecology Study

Fall cold damage



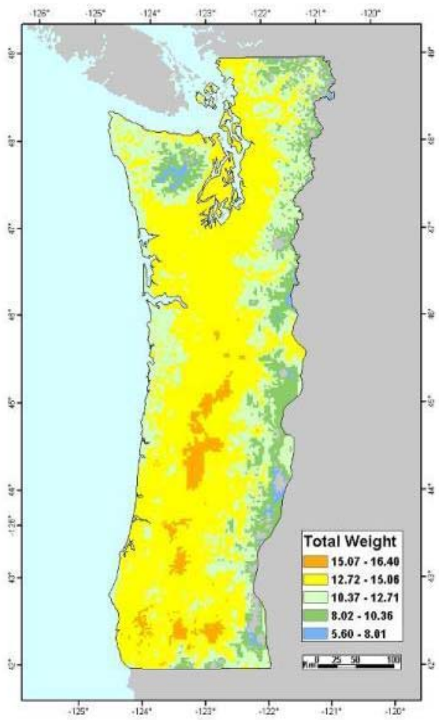
r = 0.79
Qst = 0.68

Bud-set



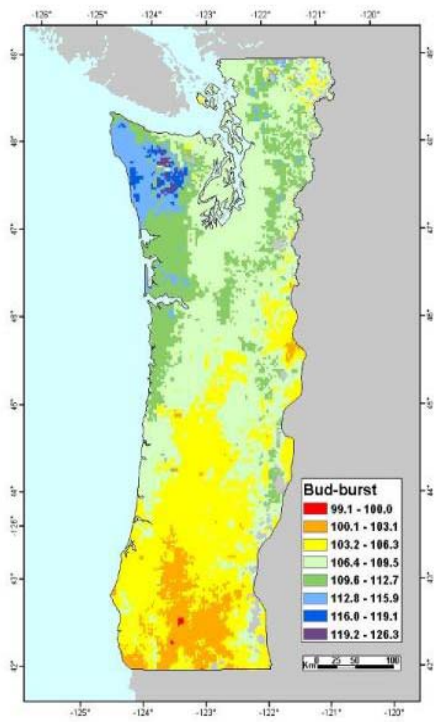
r = 0.76
Qst = 0.29

Biomass



r = 0.52
Qst = 0.13

Bud-burst



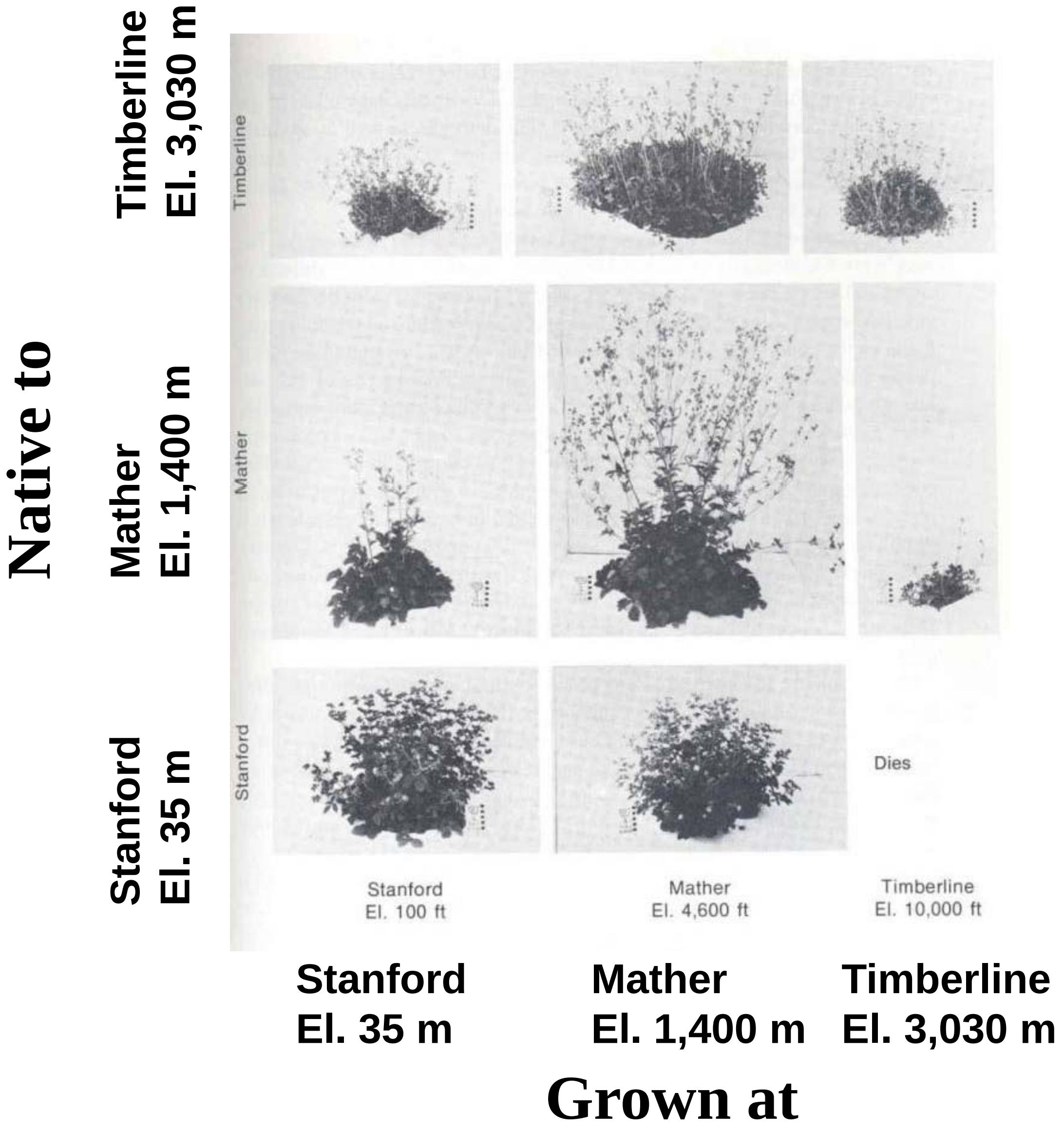
r = 0.60
Qst = 0.21

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



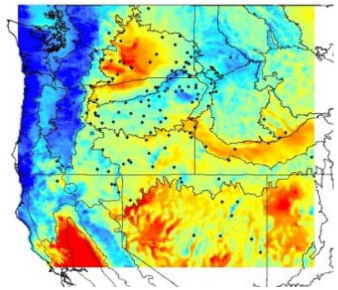
Potentilla glandulosa from three different elevations planted at three different elevations (Clausen, Keck & Hiesey 1940)

Adaptation in other forest species?

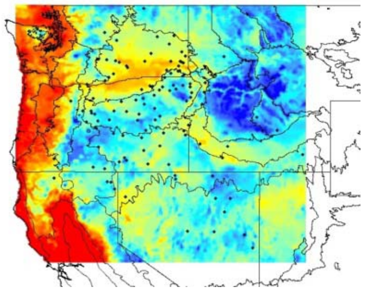
- Growing evidence for local adaptation
- Different species show different patterns and scales of adaptation
- Moderate degree of adaptation (generalists)

Bluebunch wheatgrass

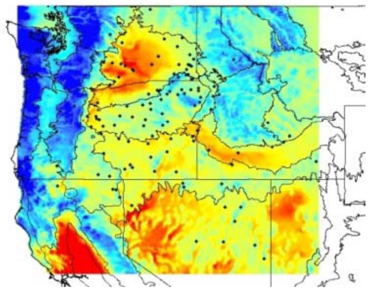
Dry weight



Flowering date

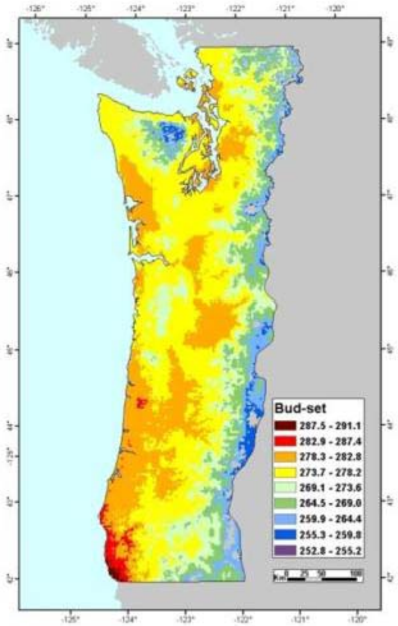


Leaf width

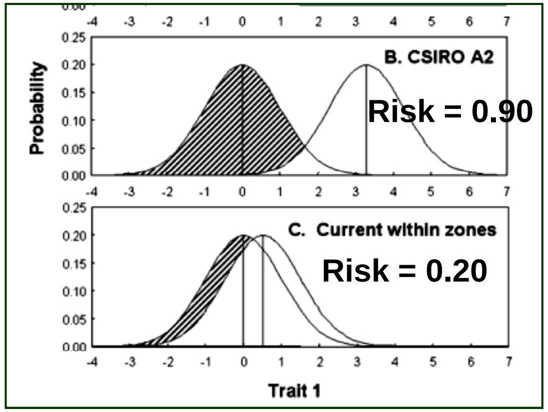


Are current populations adapted to future climates?

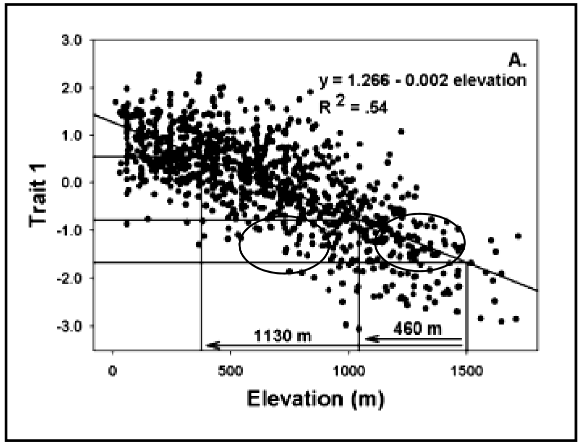
Risk of maladaptation from climate change and location of adapted populations

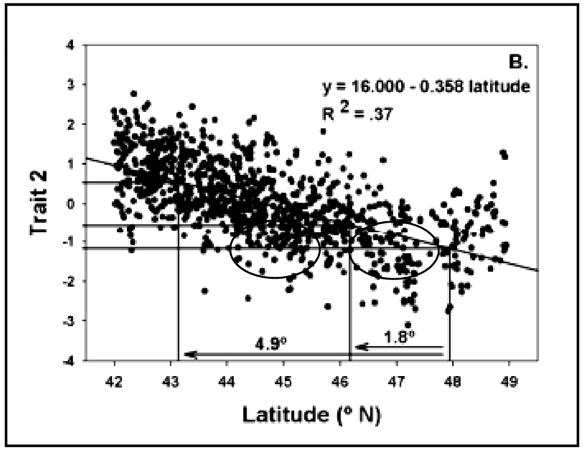


Genetic variation in bud-set



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

Aitken et al. 2008. Evolutionary Applications 1: 95-111.

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

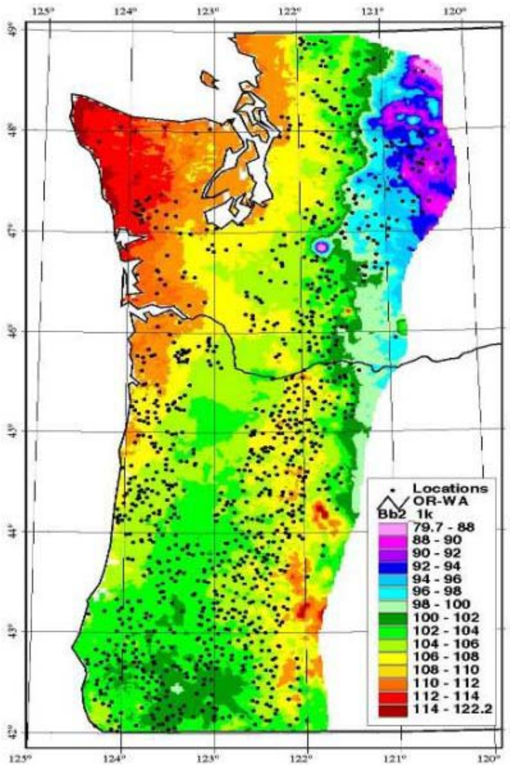
What about phenotypic plasticity?

- 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

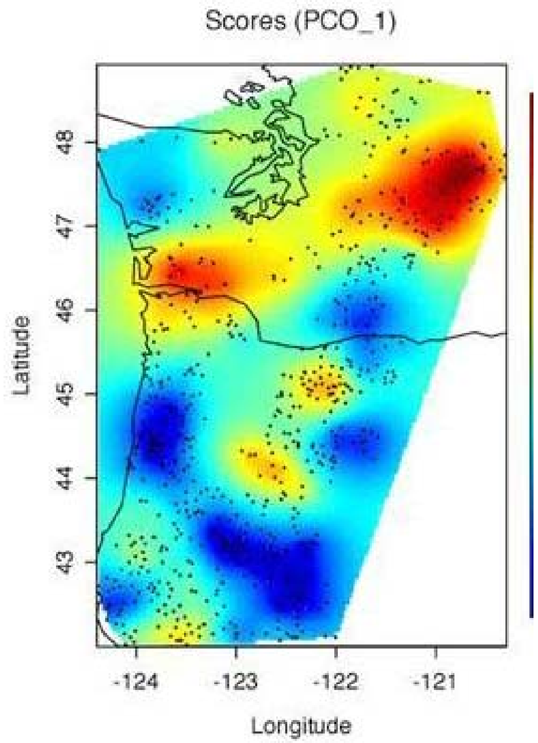
What about genetic variation at the level of DNA?

Patterns of Adaptive Molecular Genetic Diversity

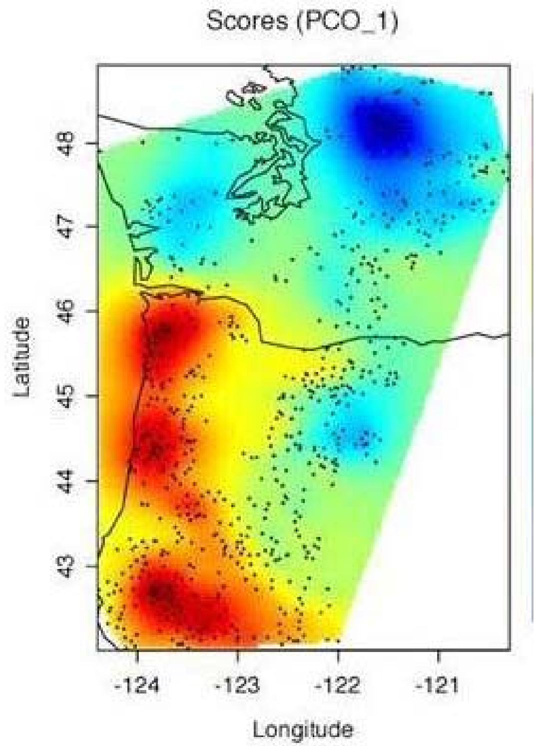
From Eckhart, Neale, et al. 2009



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"

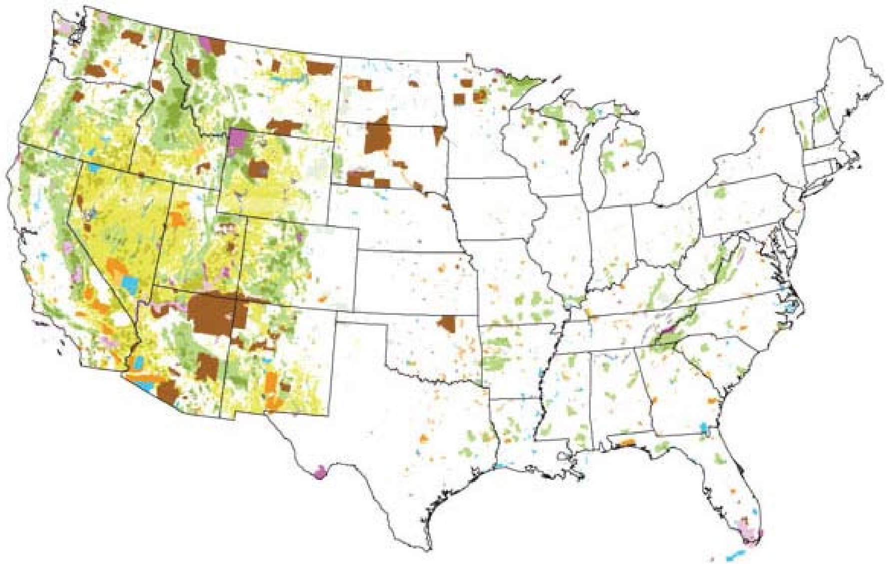
Strategies for Conserving Genetic Diversity

- *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

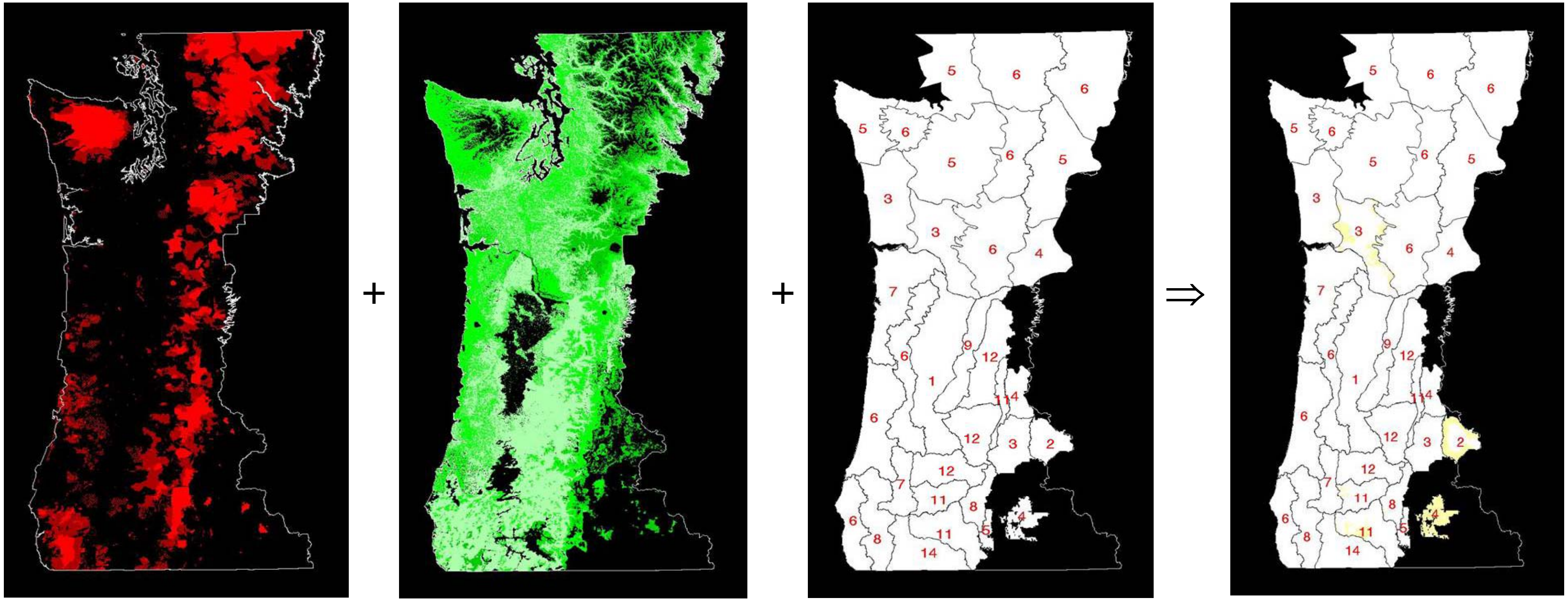


Public lands in the United States

***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?

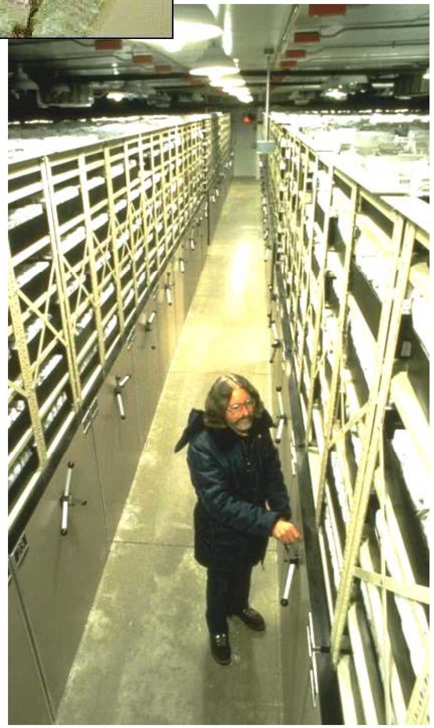
Potential gaps are defined as stratifications with <5,000 trees.

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

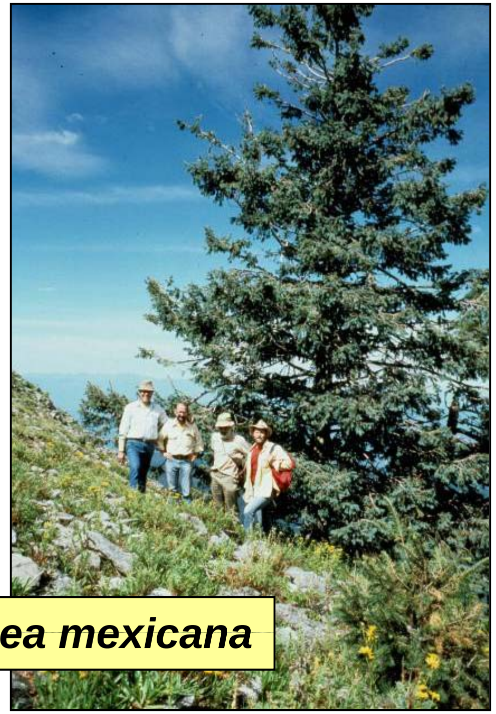
Ex Situ Conservation



- 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

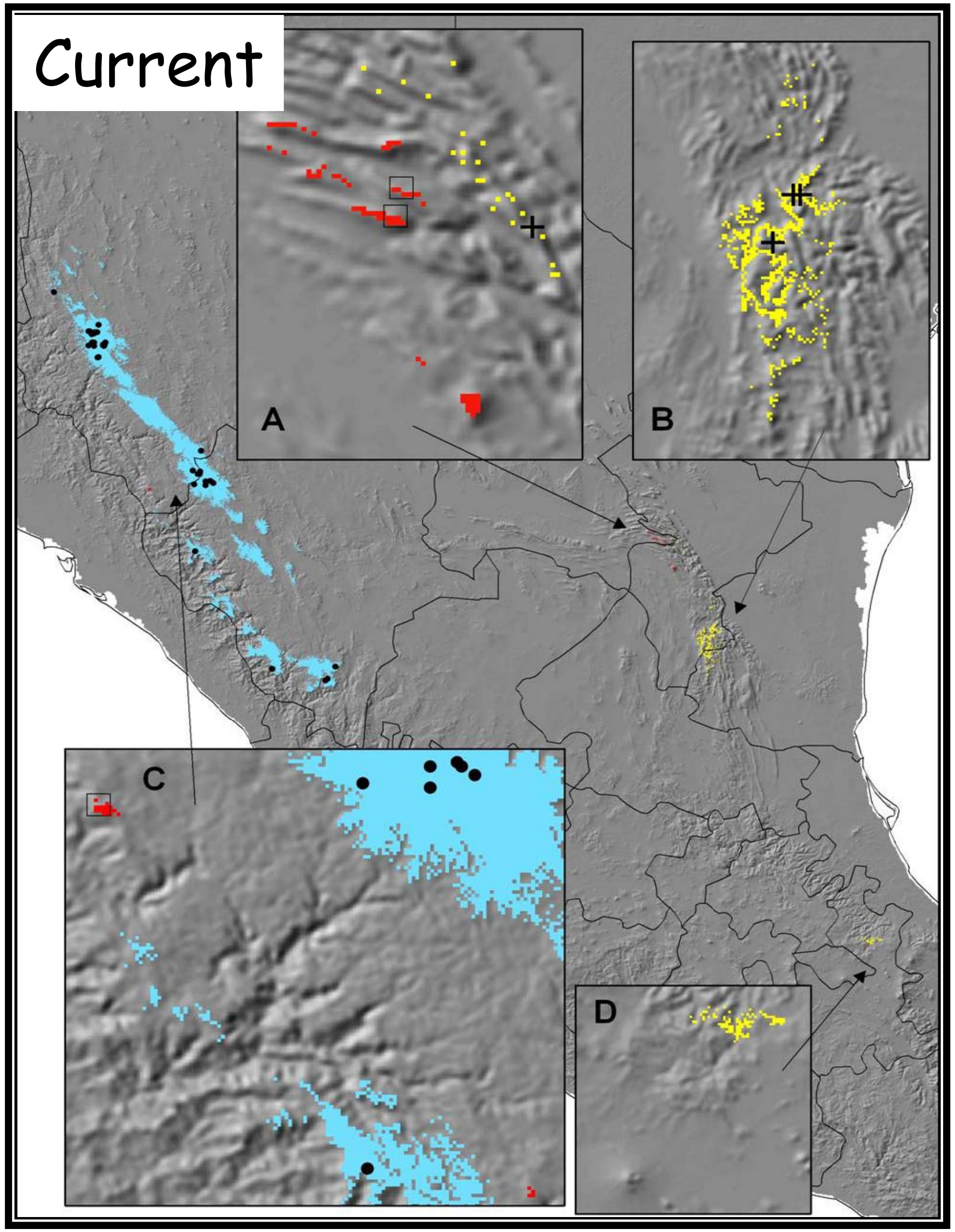
Blister rust

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.

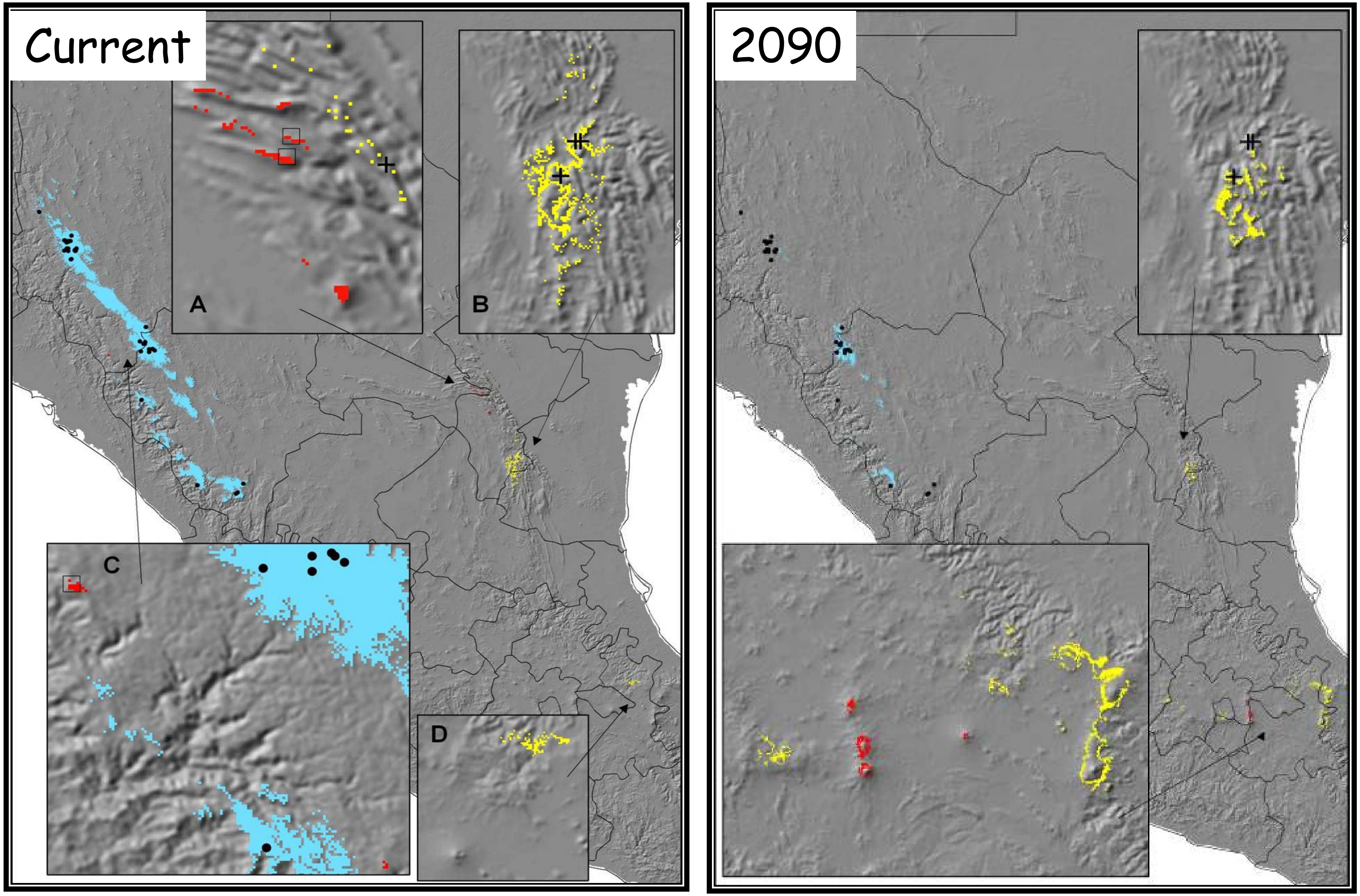
Actual and Modeled Distributions of Mexican Spruces



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

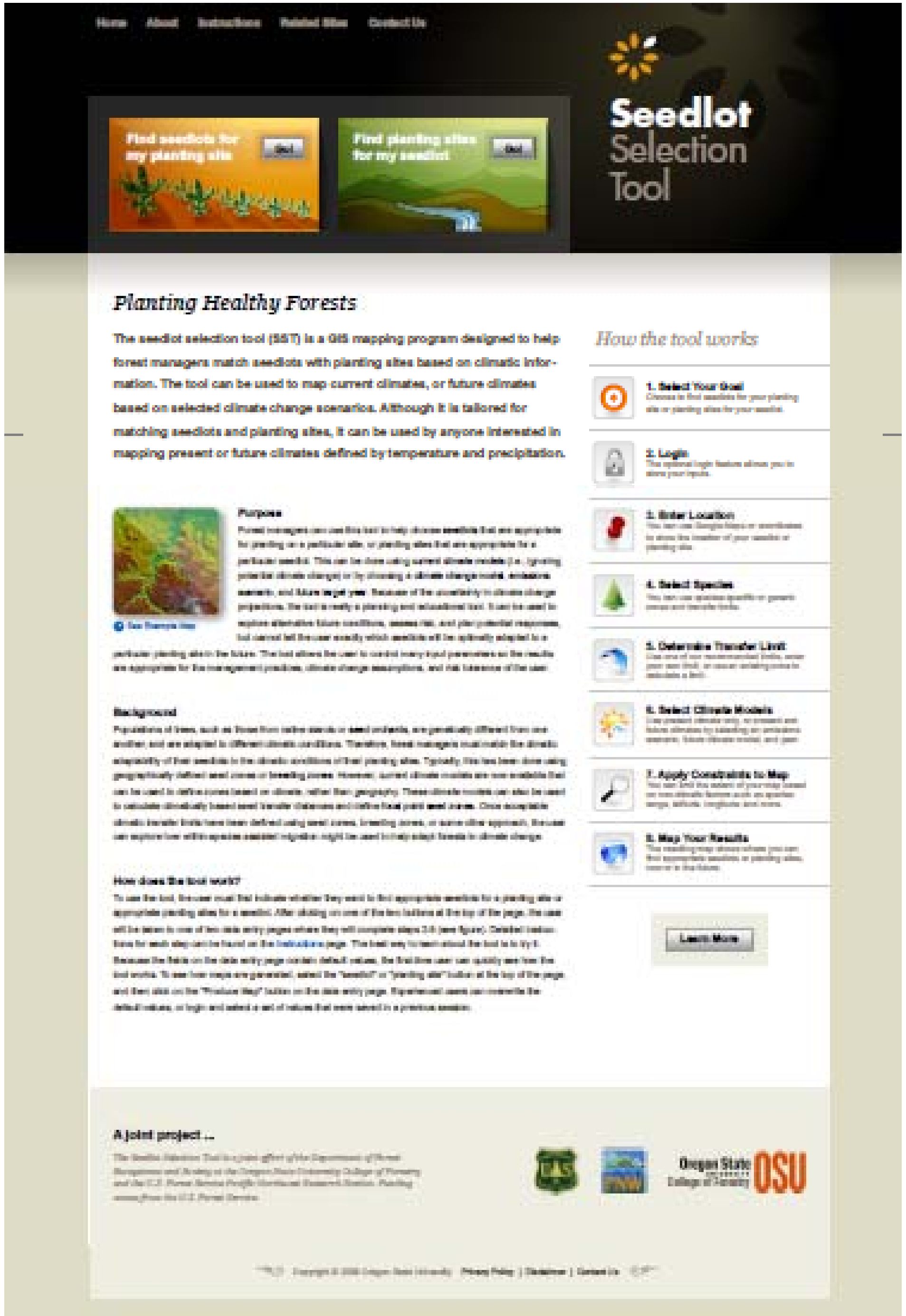
From: Jerry Rehfeldt, Tom Ledig, Cuauhtémoc Sáenz Romero

Actual and Modeled Distributions of Mexican Spruces



What to plant for future climates?

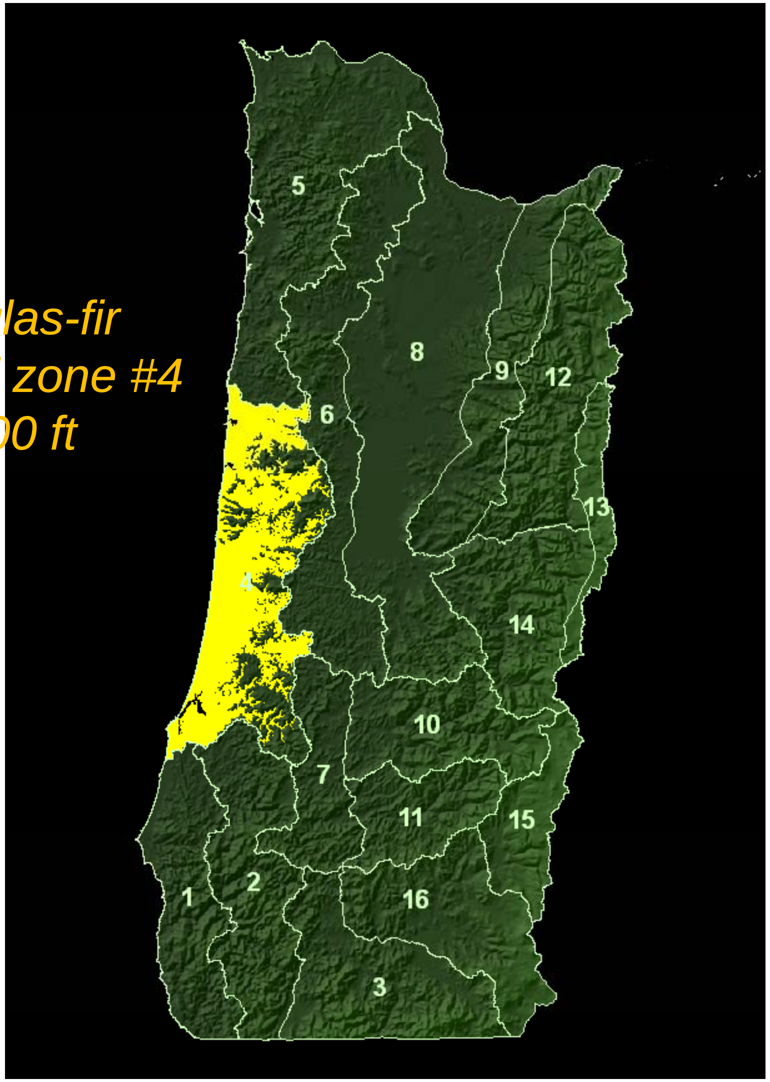
Seedlot Selection Tool



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

Present 2030 2060 2090

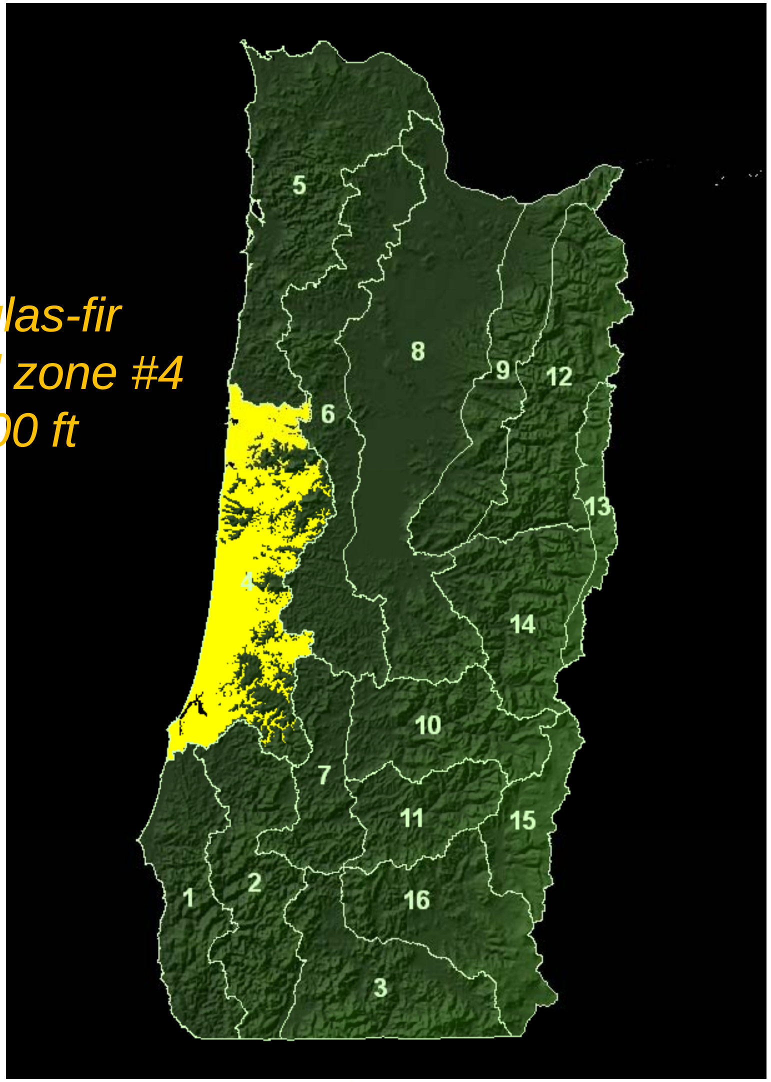
Douglas-fir
Seed zone #4
0-1000 ft



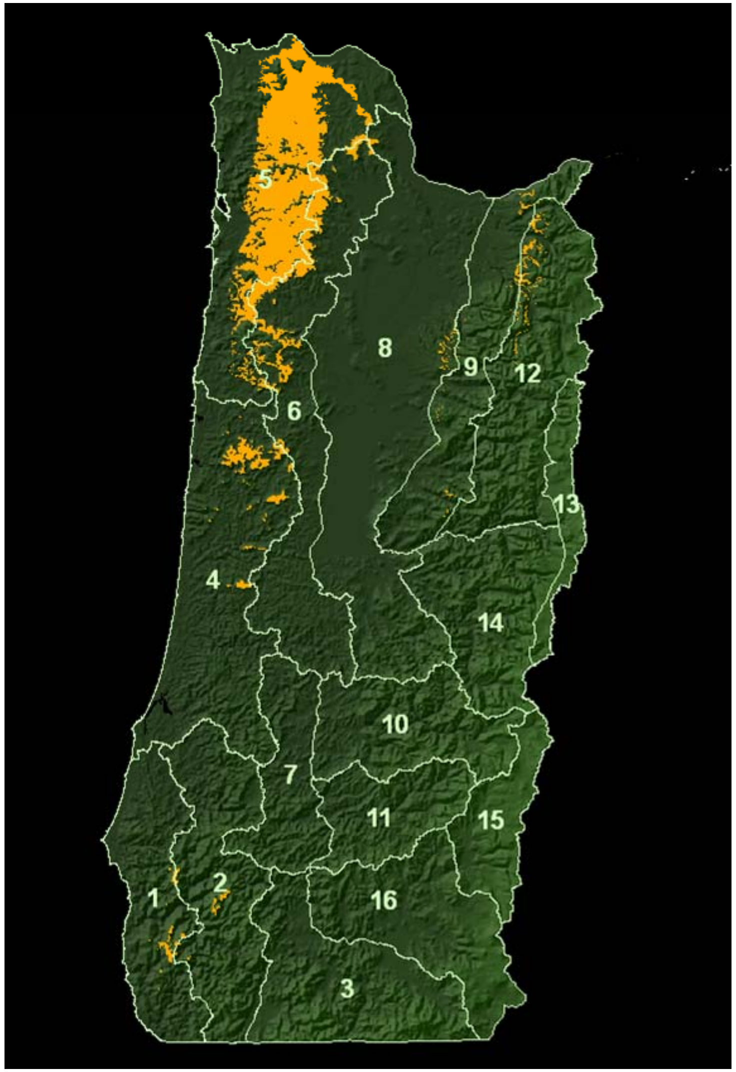
Seed zone

Present **2030** **2060** **2090**

Douglas-fir
Seed zone #4
0-1000 ft



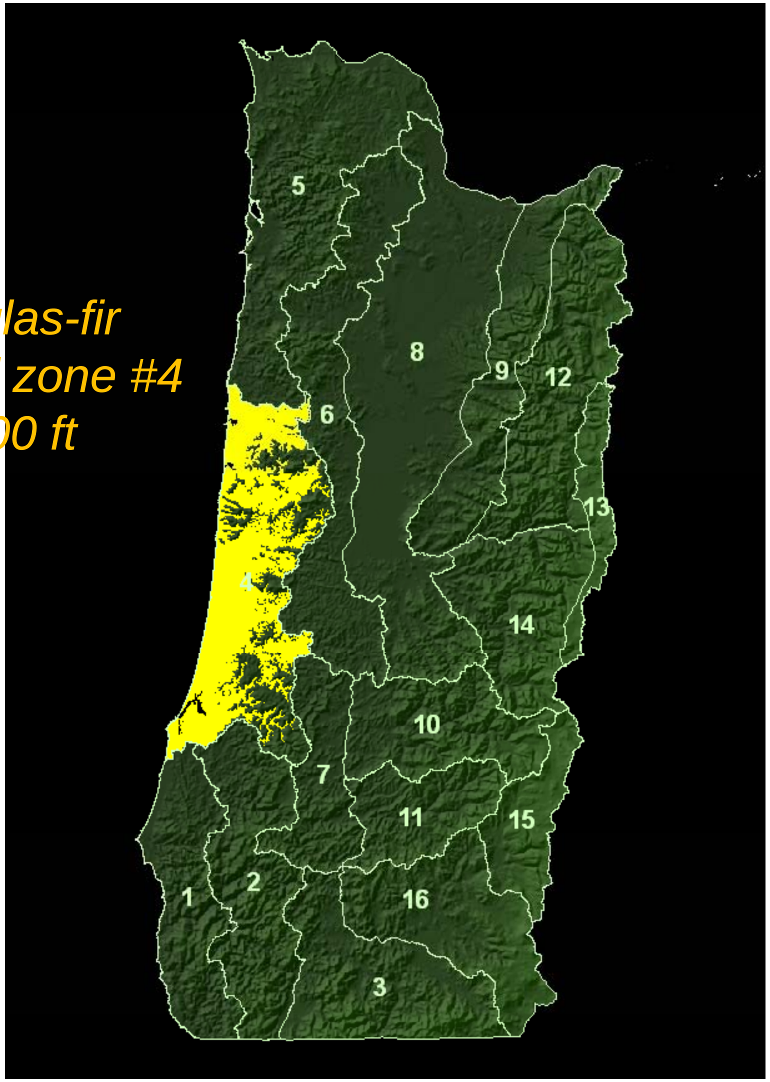
Seed zone



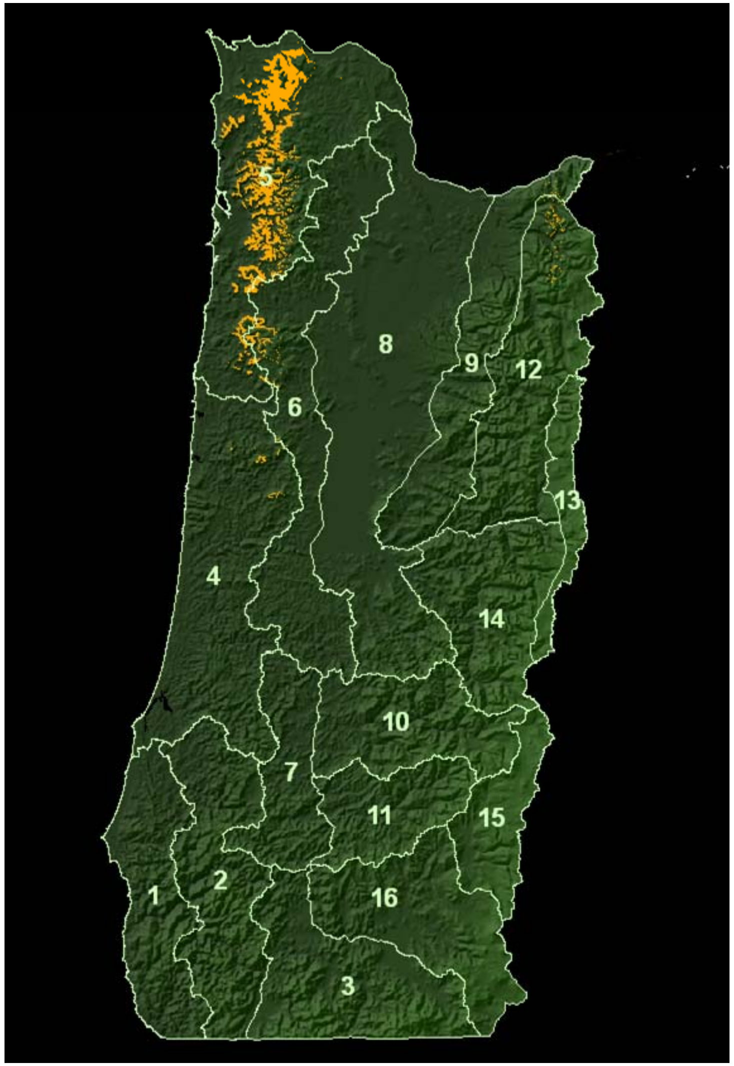
Climate
(Canadian GCM, A1B)

Present **2030** **2060** **2090**

Douglas-fir
Seed zone #4
0-1000 ft



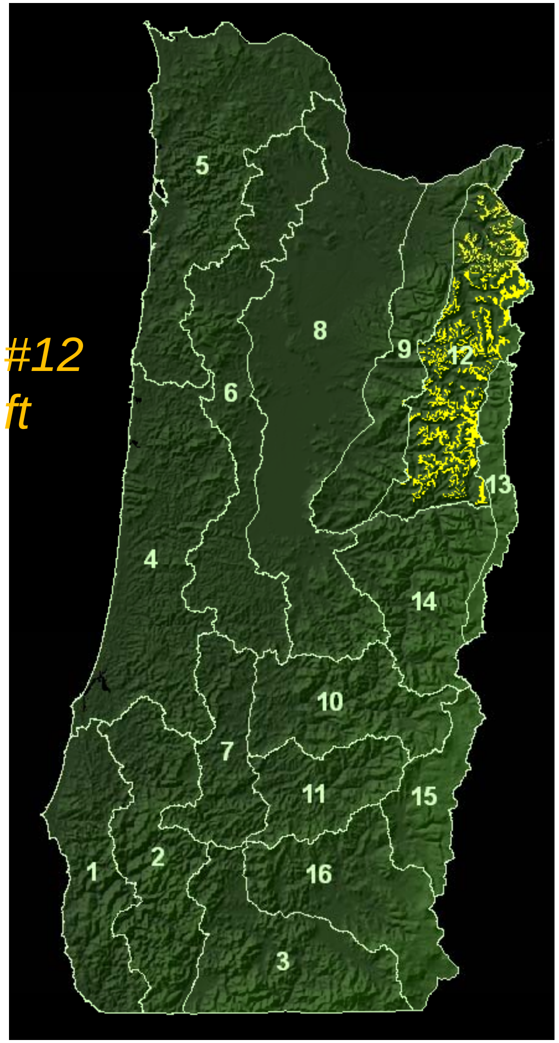
Seed zone



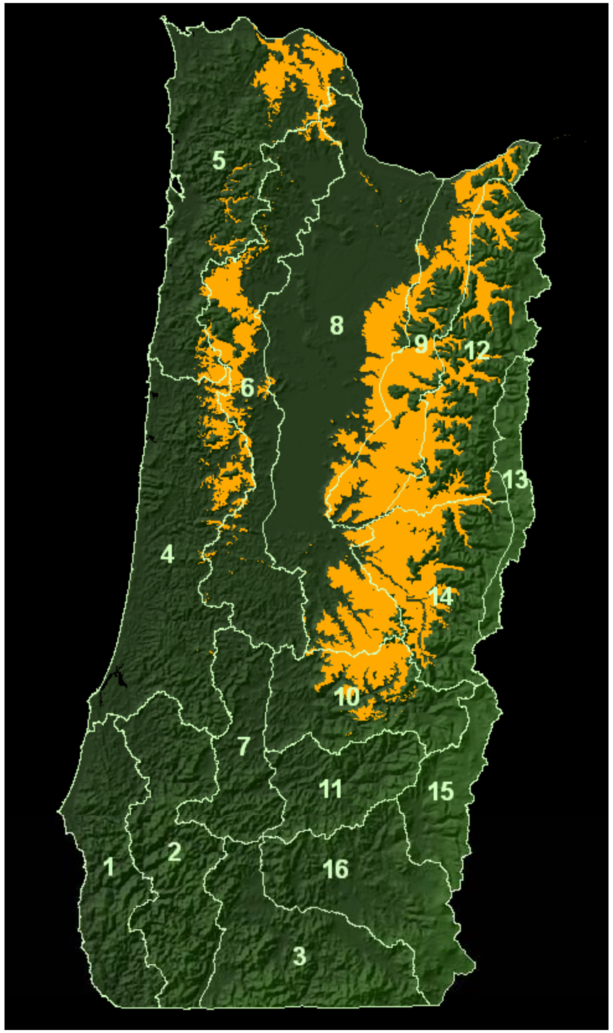
Climate

Present **2030** **2060** **2090**

Douglas-fir
Seed zone #12
3500-4000 ft



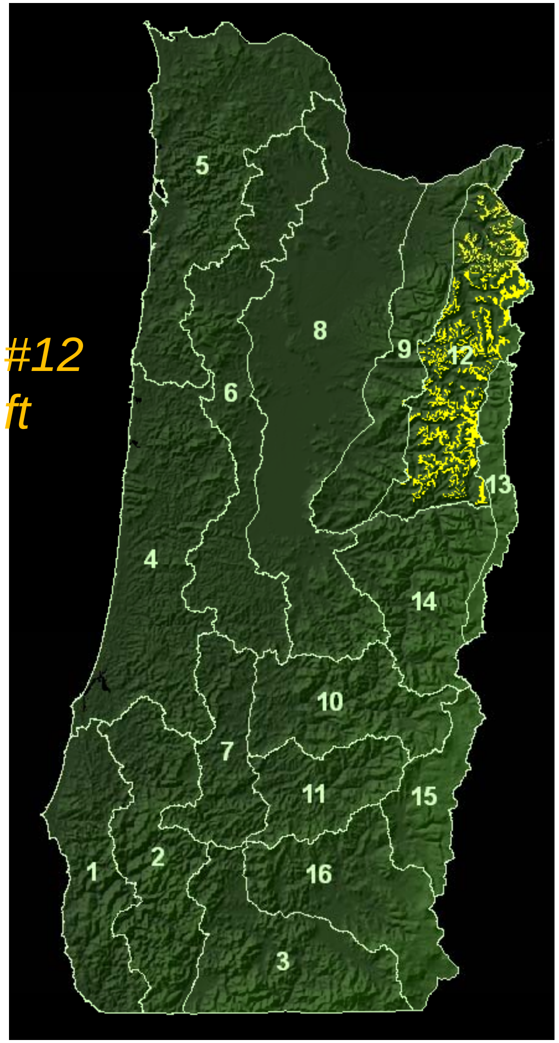
Seed zone



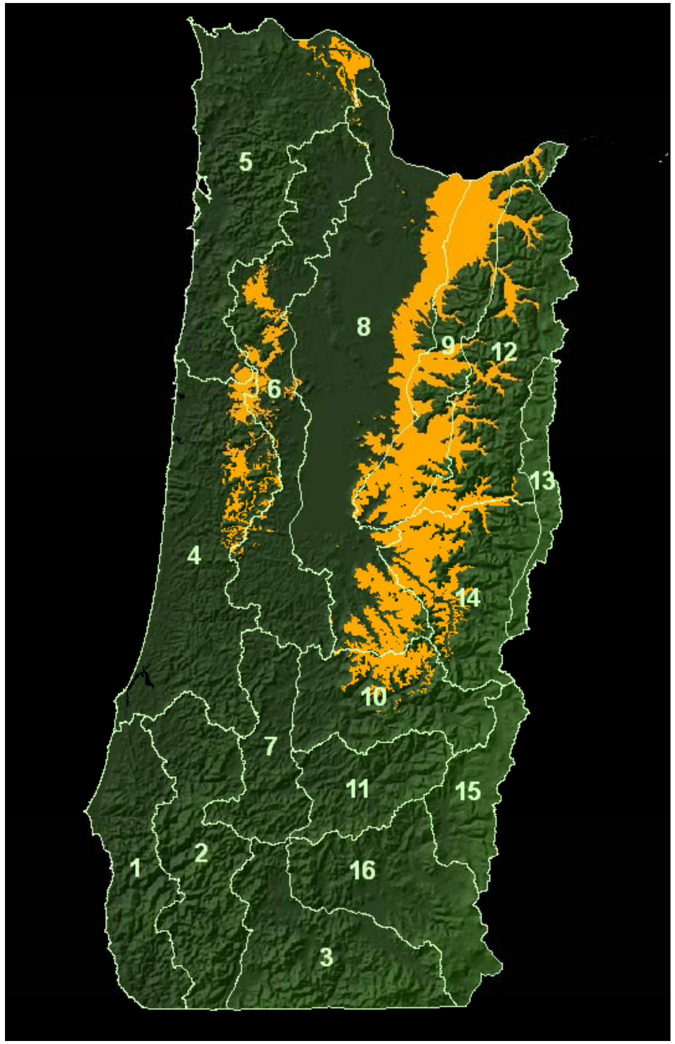
Climate

Present **2030** **2060** **2090**

Douglas-fir
Seed zone #12
3500-4000 ft



Seed zone



Climate

Research Needs

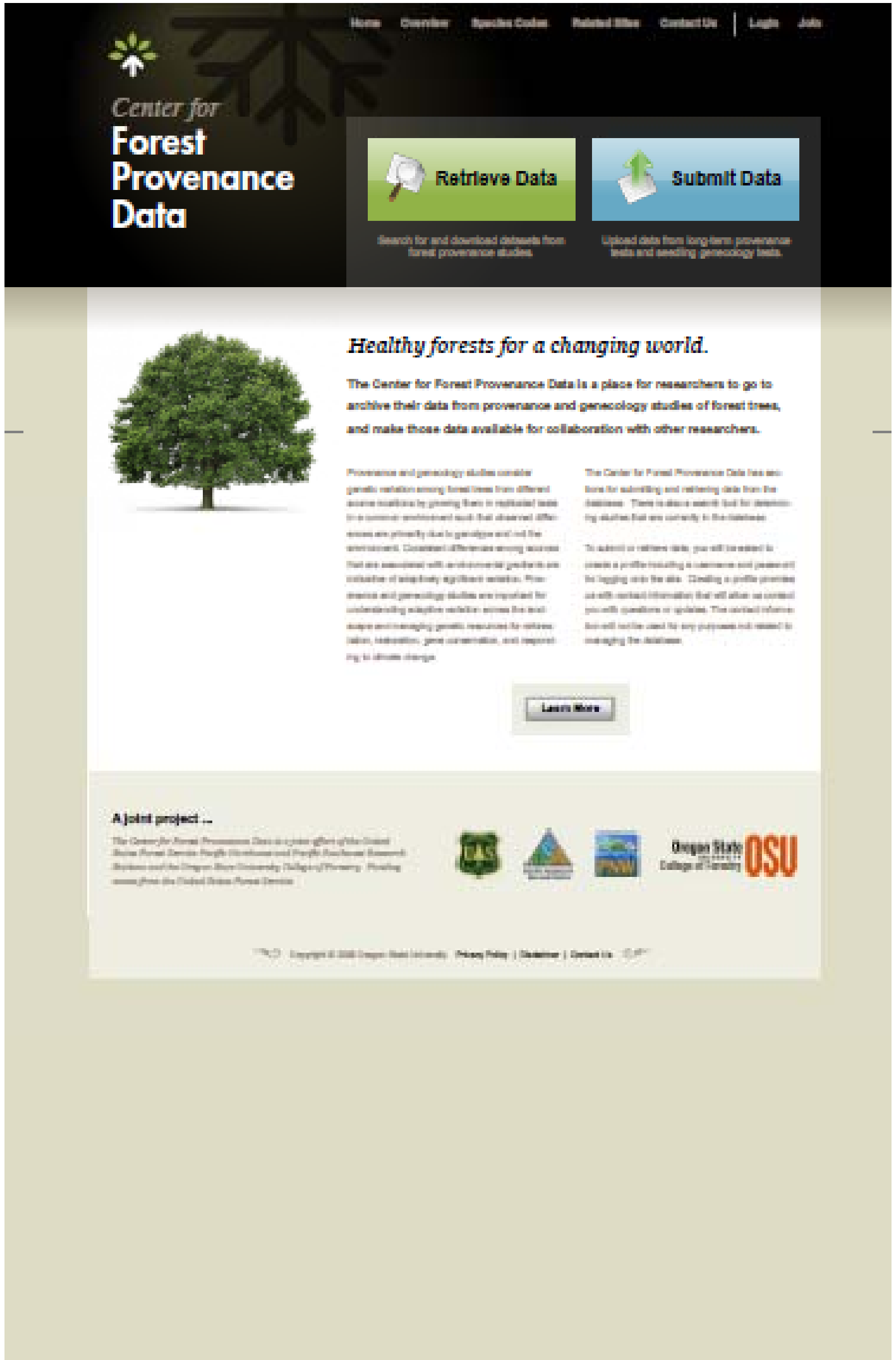
- Monitor health, phenology, regeneration, and productivity in natural populations and in plantations
- Revisit old species and genetic trials for knowledge to guide changes to restoration
- Establish new field experiments to evaluate species and population predictions from niche models and test assisted colonization
- Establish growth chamber experiments to study species and population responses to temperature and CO_2 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

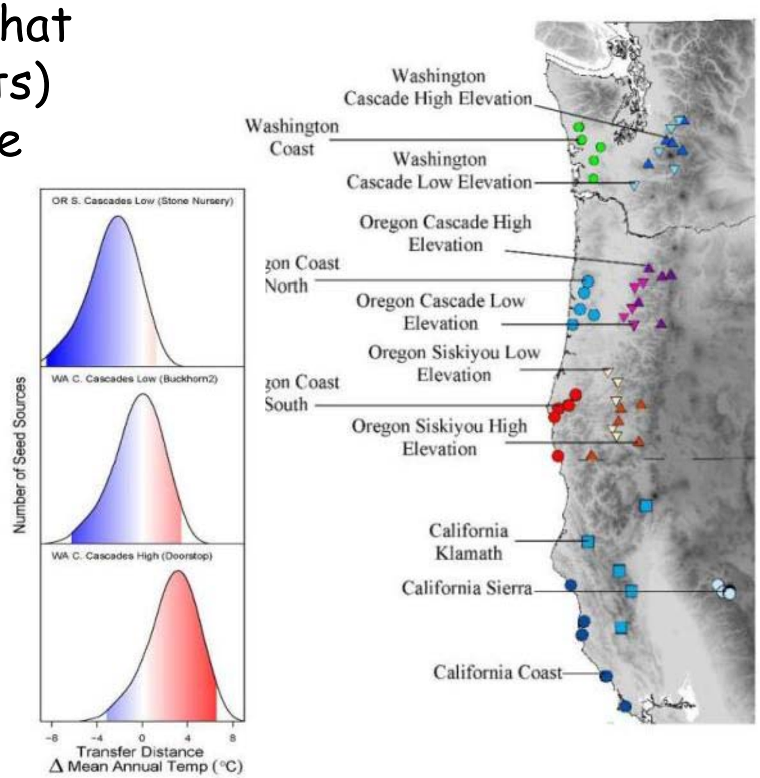


Denise Cooper, Brad St.Clair, Glenn Howe,
Jessica Wright, Greg DeVeer
Funded by USFS Climate Change
Research Program

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.


Thank you