Genetic Options for Adapting Forests to Climate Change

Glenn Howe
Department of Forest Ecosystems and Society
Oregon State University

Brad St.Clair
Pacific Northwest Research Station
U.S. Forest Service

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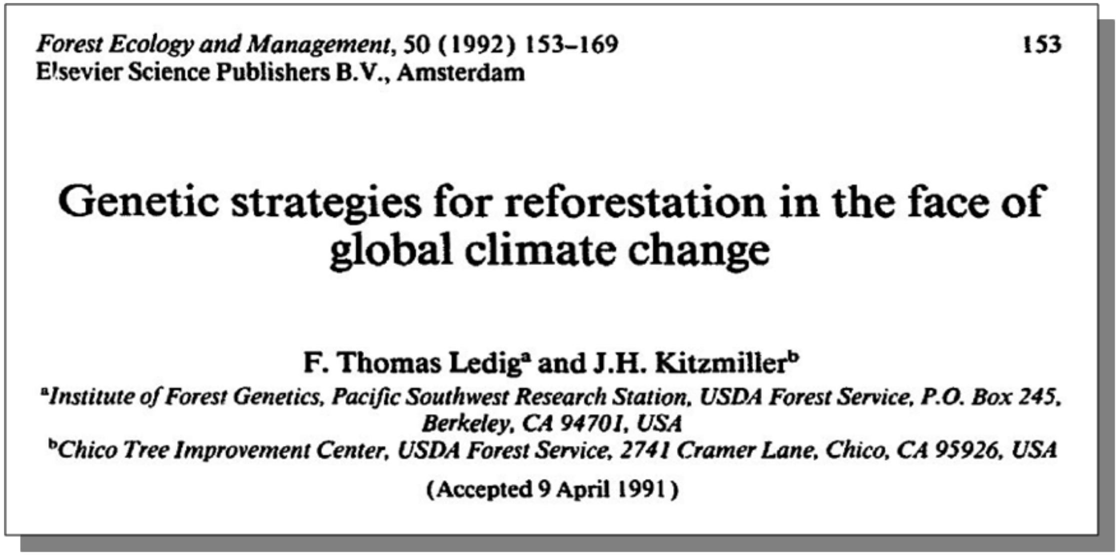
Taskforce on Adapting Forests to Climate Change

Recent focus on an old topic



Forest Ecology and Management, 50 (1992) 153–169 153
Elsevier Science Publishers B.V., Amsterdam

Genetic strategies for reforestation in the face of global climate change

F. Thomas Ledig[a] and J.H. Kitzmiller[b]
[a]*Institute of Forest Genetics, Pacific Southwest Research Station, USDA Forest Service, P.O. Box 245, Berkeley, CA 94701, USA*
[b]*Chico Tree Improvement Center, USDA Forest Service, 2741 Cramer Lane, Chico, CA 95926, USA*

(Accepted 9 April 1991)

“Uncertainty must be the guiding factor for planning reforestation efforts over the next several decades”

- Uncertainty about future climates
- Uncertainty about the future health of forests

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Concerns and opportunities

Trees – major concern in relation to climate change

- Key components of ecosystems
- Economically important and provide multiple ecosystem services
- Can mitigate or increase CO_2 emissions
- Long generation intervals means slow adaptation via natural selection and migration
- Many of today’s trees will be exposed to the climates of 2090

Concerns and opportunities

Specific concerns are…

- Poor sexual reproduction and regeneration
- Poor survival, particularly at the seedling stage
- Poor growth
- Catastrophic losses from fire, insects, and disease

Potential opportunities are…

- Increased growth in the short-run in some areas?
- Increased water use efficiency?

Specific concerns

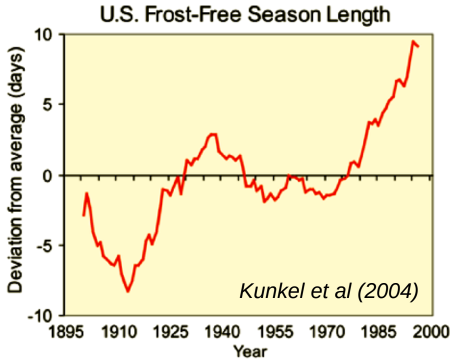
Primary abiotic stressors

- Fire
- Summer drought
- Summer heat
- Warm winters
- Spring and fall frosts
- Long frost-free seasons
- Elevated CO_2

Primary biotic stressors

- Insects and pathogens
- Competition

Westerling et al. (2006) Science 313:940-943.



Kunkel et al (2004)

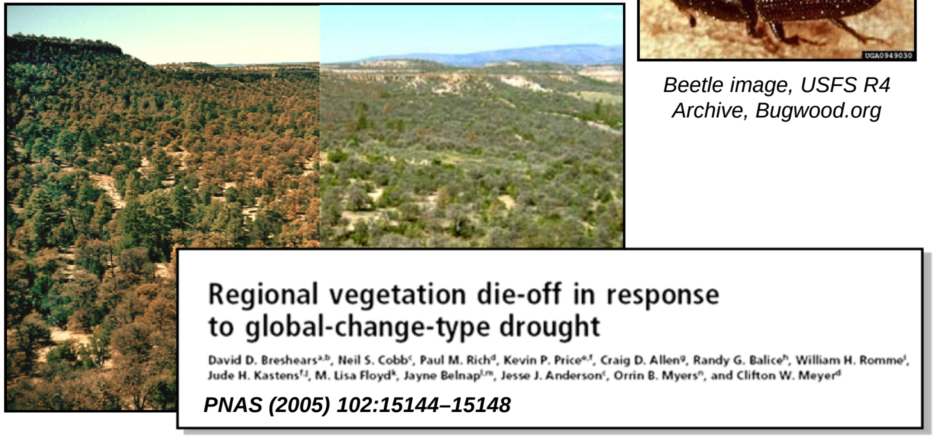
Lorraine Maclauchlan BC Ministry of Forests

Beetle image, USFS R4 Archive, Bugwood.org

Is an Unprecedented Dothistroma Needle Blight Epidemic Related to Climate Change? *BioScience (2005) 55:761-769*

ALEX WOODS, K. DAVID COATES, AND ANDREAS HAMANN

Robert L. James, USFS, Bugwood.org



Regional vegetation die-off in response to global-change-type drought

David D. Breshears[a,b], Neil S. Cobb[c], Paul M. Rich[d], Kevin P. Price[e,f], Craig D. Allen[g], Randy G. Balice[h], William H. Romme[i], Jude H. Kastens[f,j], M. Lisa Floyd[k], Jayne Belnap[l,m], Jesse J. Anderson[c], Orrin B. Myers[n], and Clifton W. Meyer[d]

PNAS (2005) 102:15144–15148

How does genetics impact forest management?

How does genetics impact forest management?

- Deployment of seed sources and breeding populations
- Development of improved genotypes via breeding or genetic engineering
- Gene conservation and maintenance of genetic diversity

Genetic and silvicultural options are complementary

- Breeding and genetic engineering require very long lead times
- Genetic fixes may be more persistent than silvicultural fixes

Genetic and silvicultural options are often complementary

		Options readily available?	
Stressors	*Possible actions*	*Genetic*	*Silvicultural*
Primary abiotic stressors			
Fire	Increase fire resistance/tolerance or reduce fires	N	Y
Summer drought	Increase drought hardiness or increase soil moisture	Y	Y
Summer heat	Increase heat tolerance or decrease heat load	N	Y
Warm winters	Lower chilling and seed stratification requirements	Y	N
Spring and fall frosts	Delay growth initiation and advance growth cessation or decrease cold by retaining canopies	Y	Y
Long frost-free seasons	Advance growth initiation and delay growth cessation	Y	N
Elevated CO_2	None	N	N
Primary biotic stressors			
Insects and pathogens	Increase pest resistance/tolerance or reduce pests	Maybe	Y
Competition	Increase growth or reduce competitors	Y	Y

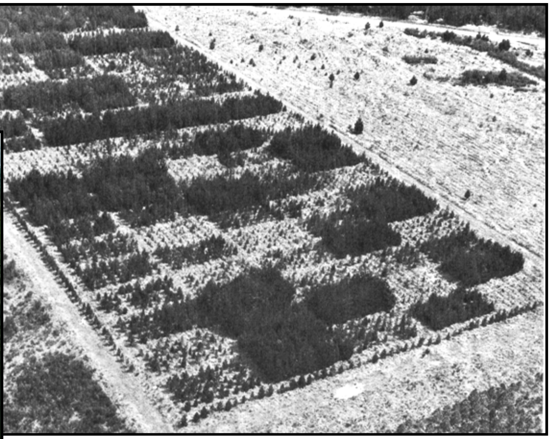
Genetic options include modification of traits for which sufficient genetic variation and heritability is known to exist.
Silvicultural options include alterations to the site or stand, but excludes site selection.

Why is genetics important?

Superior adaptability of a Douglas-fir seed source from California growing in Spain (Hernandez et al 1993)

Finnish Forest Research Institute

Lodgepole pine provenances from maritime areas are not adapted to the winters of eastern Finland



Lodgepole pine provenance test in New Zealand (Wright 1976)

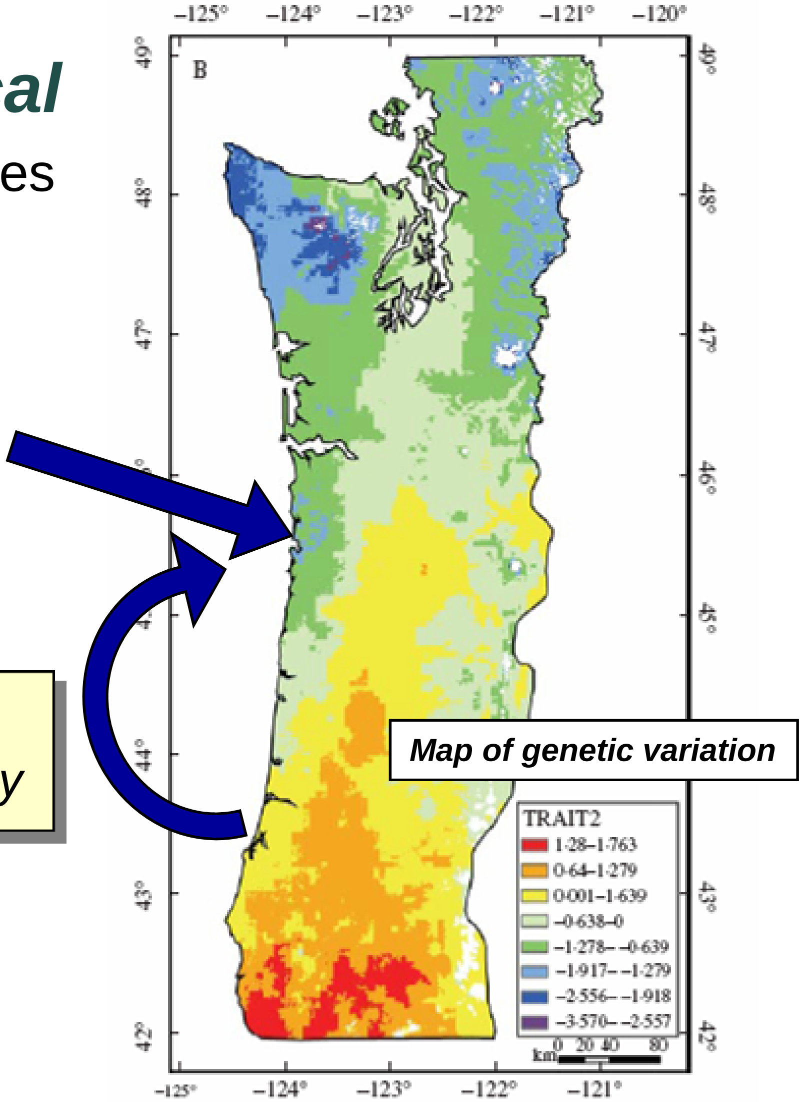
- Provenance variation is often large — associated with adaptation to cold and drought (e.g., growth phenology, cold hardiness, winter desiccation)
- Provenances moved northward are often damaged by cold
- Provenances moved southward often grow slower than local provenances

Why is genetics important?

Trees are adapted to their local climates – if the climate changes, trees may become maladapted

Current climate, Tillamook Forest

In 2090, the climate of the Tillamook Forest may be like it now is in Coos Bay



Map of genetic variation

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Why is genetics important?

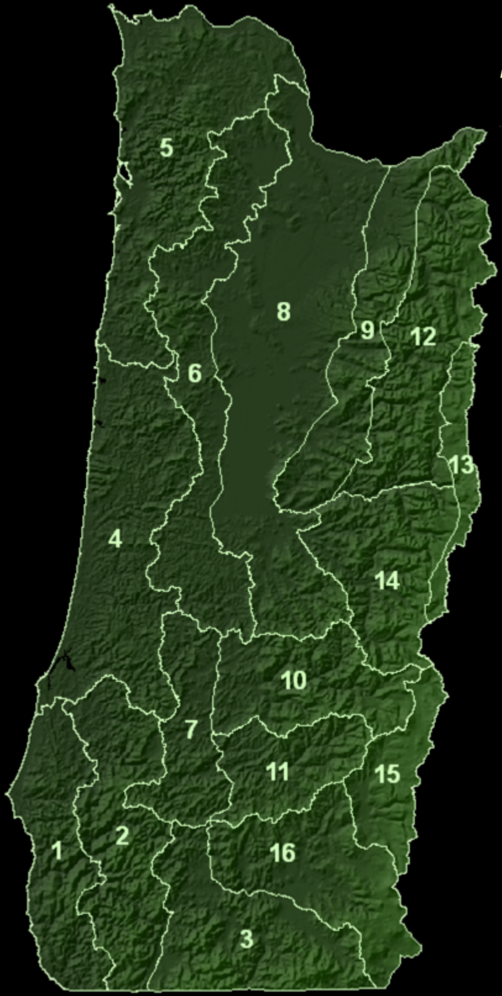
Projections of forest productivity in future climates may be inaccurate if adaptive genetic variation is ignored.

Analyses of the potential for carbon sequestration often assume that forest health will be maintained, and ignore adaptive genetic variation.

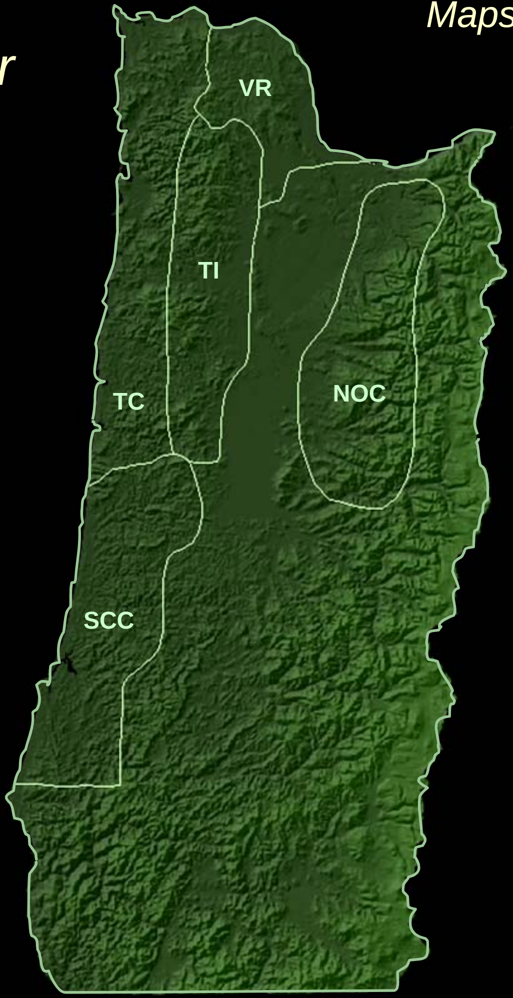
Seed zones and breeding zones are used to ensure adaptability in tree improvement programs

Data from N. Crookston
Maps by L. Magalska

Douglas-fir

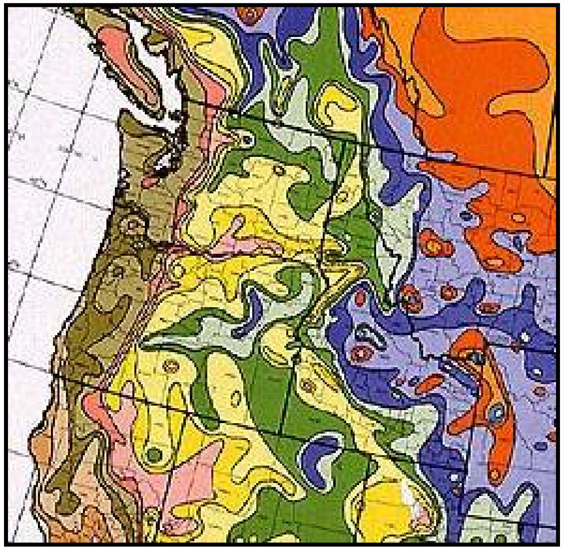


Seed zones

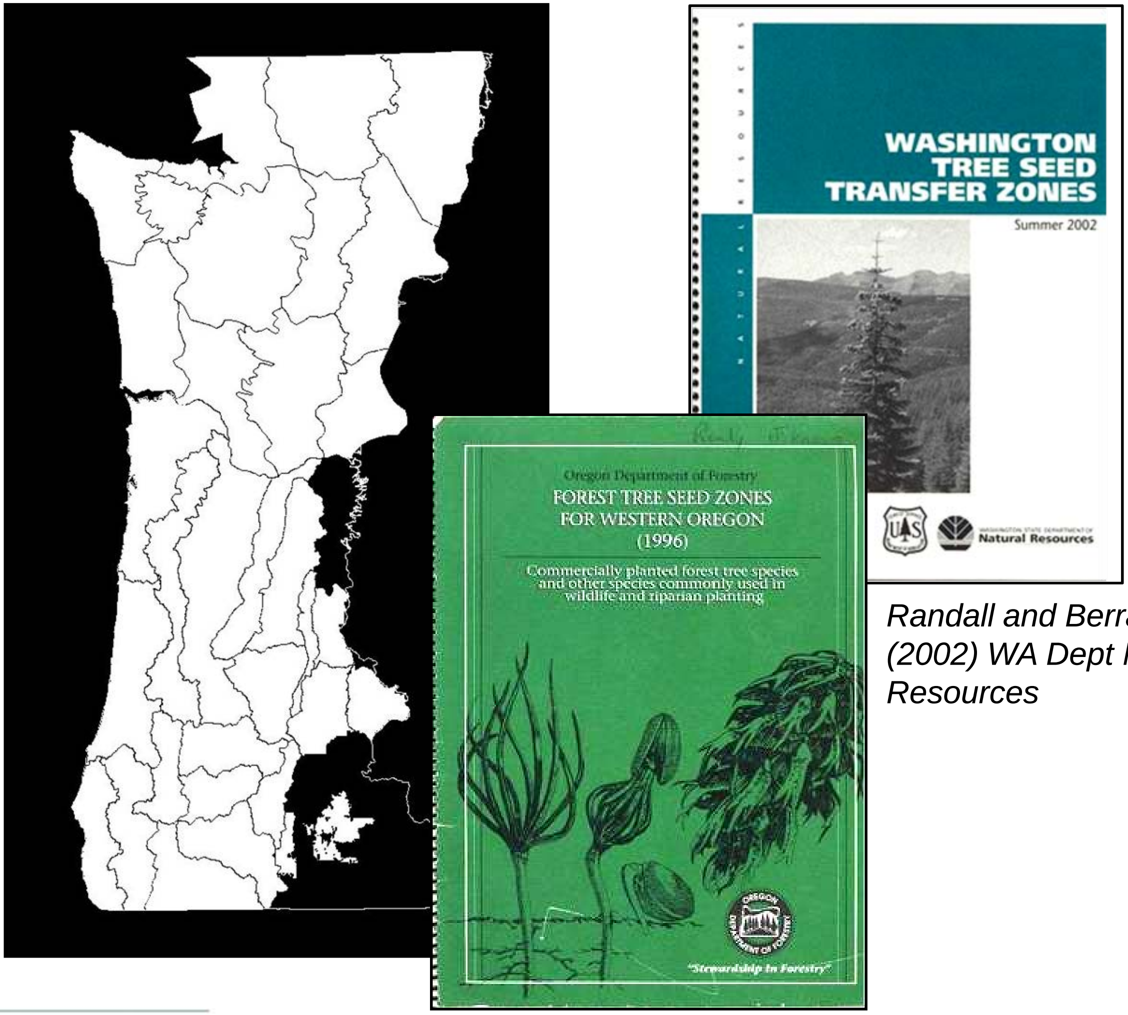


NWTIC breeding zones

Climate change impacts seed zones



Seed zones and breeding zones are largely delineated based on climate



WASHINGTON TREE SEED TRANSFER ZONES

Summer 2002

NATURAL RESOURCES

Washington State Department of Natural Resources

Oregon Department of Forestry

FOREST TREE SEED ZONES FOR WESTERN OREGON (1996)

Commercially planted forest tree species and other species commonly used in wildlife and riparian planting

"Stewardship in Forestry"

Randall and Berrang (2002) WA Dept Nat Resources

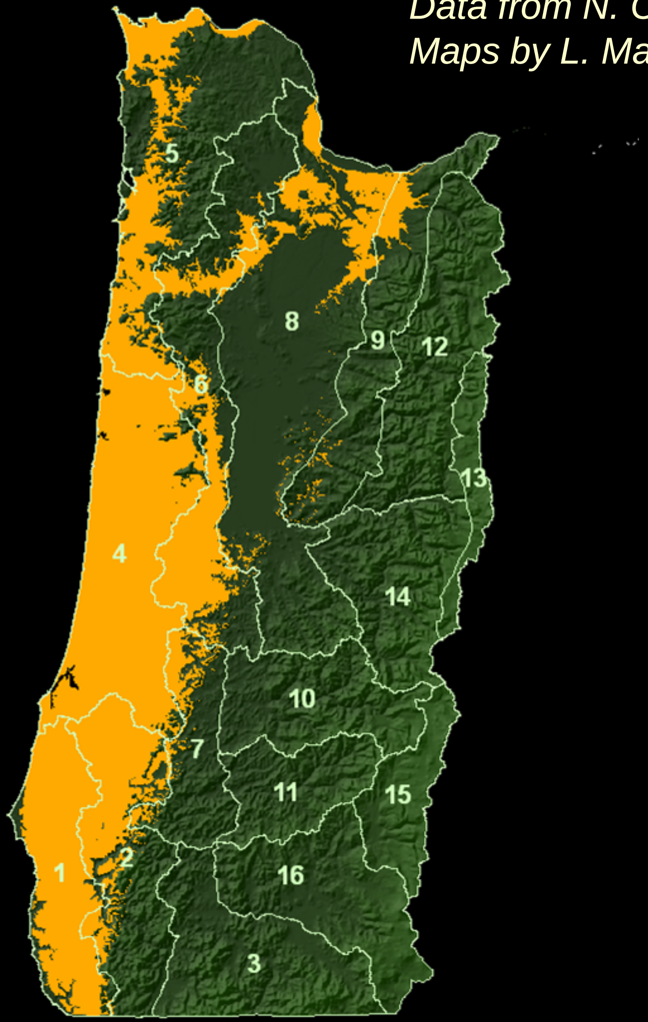
Randall (1996) OR Dept of Forestry

Present 2030 2060 2090

Data from N. Crookston
Maps by L. Magalska

Douglas-fir
Seed zone #4
0-1000 ft

Seed zone



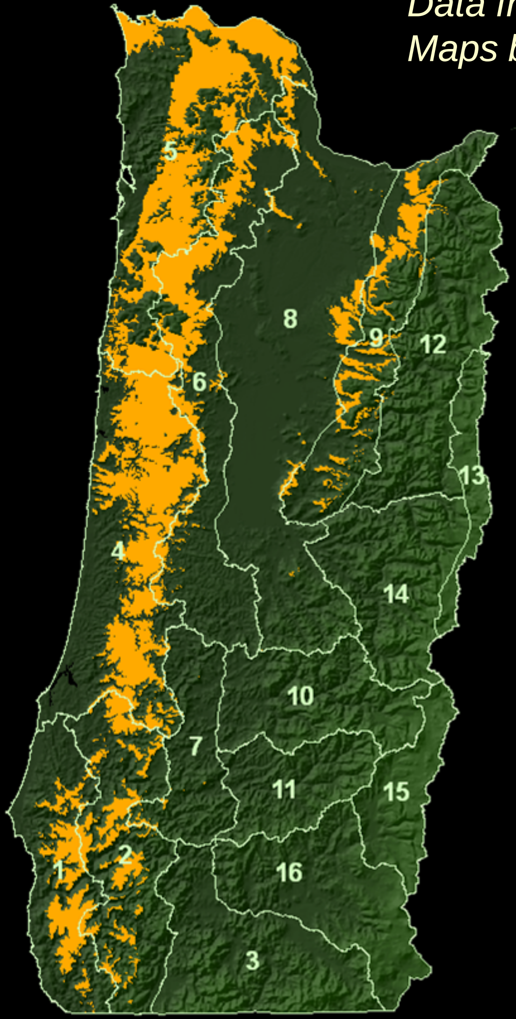
Climate

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

Douglas-fir
Seed zone #4
0-1000 ft

Seed zone

Data from N. Crookston
Maps by L. Magalska



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

Douglas-fir
Seed zone #4
0-1000 ft

Seed zone

Data from N. Crookston
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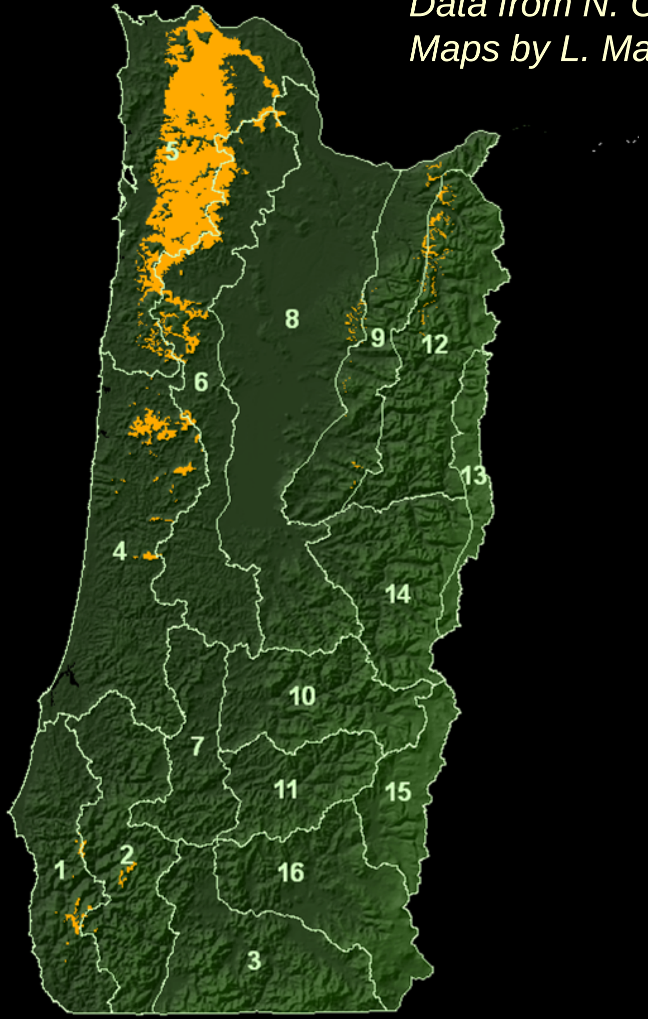

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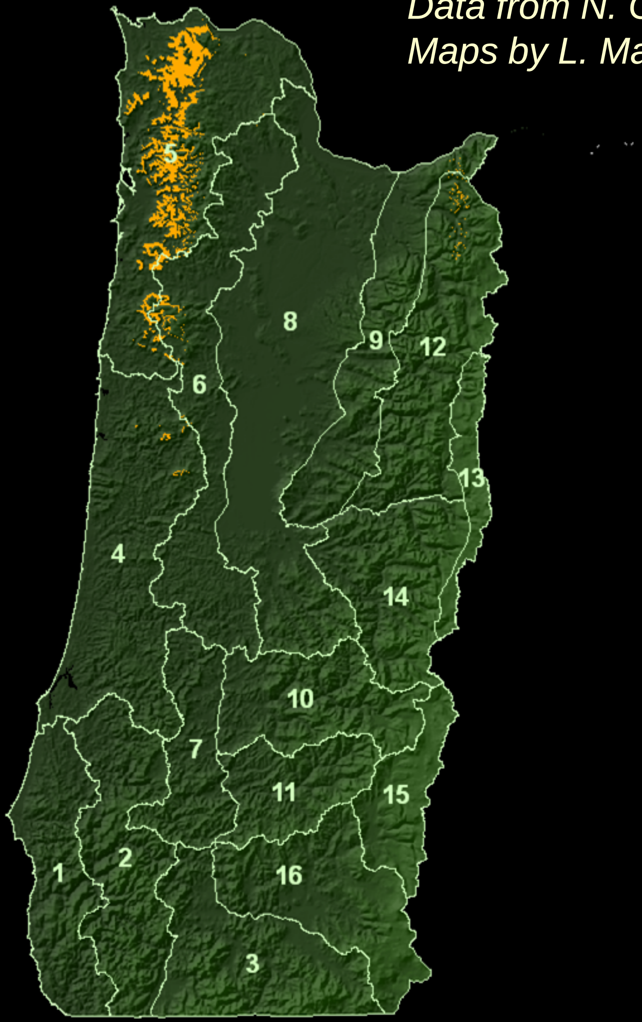


Climate

How do species adapt?

Phenotypic plasticity – the ability of an individual to change its characteristics (phenotype) in response to changes in environment

*Environmental patterns of genetic variation suggest that **phenotypic plasticity is insufficient** (but what about epigenetic effects?)*

Natural selection – the differential survival and reproductive success of individuals that differ in hereditary characteristics

*Ability of tree populations to evolve in place is **unclear***

Migration – the movement of genes from one population into another via seeds, pollen, or vegetative propagules

***Assisted migration** may be the **most effective approach** for ensuring genetically adapted populations, but is not without risk*

How do we infer the effects of climate change?

Common-garden tests – *different individuals are grown in a common environment so that environmental differences among individuals are minimized and genetic differences are more readily observed*

Controlled environment experiments

Impose a few relatively simple regimes that mimic future climates.

Difficult to do on a large scale, but useful for studying causes of maladaptation.

Short-term nursery tests (genecological tests)

Important adaptive traits show large differences among populations and strong correlations with climate.

Long-term field tests (provenance tests)

Empirical tests of complex climatic regimes in the field over many years.

Short-term nursery tests

Assumptions…

Sensitive traits have the strongest correlations with temperature and precipitation.
‘Relative risk’ can be used to judge the relative potential of maladaptation.

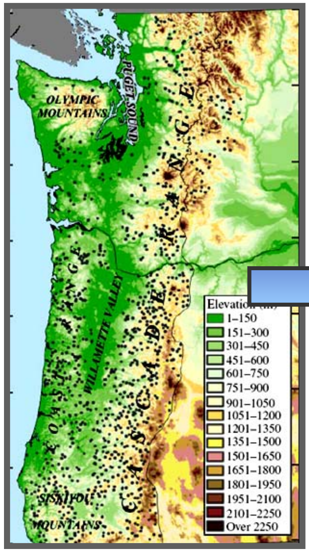
Advantages…

Can provide information on new species cheaply and quickly.
Can examine genetic variation in seed germination and establishment.

Disadvantages…

Absolute responses to climate change are unknown.

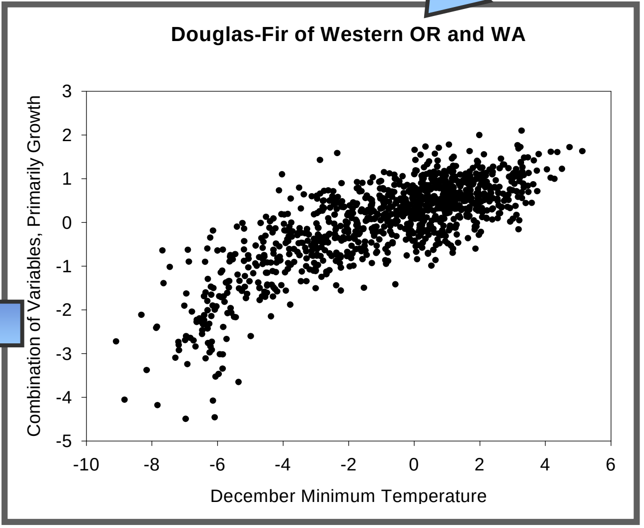
Collect seed from many trees



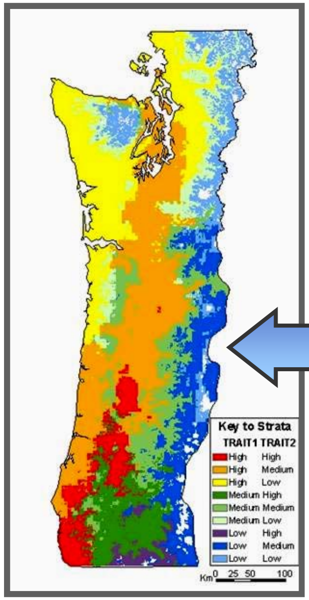
Grow families in a common environment

Measure many adaptive traits

Traits vs source environ.



GIS



St.Clair et al (2005), Anal. Bot. 96:1199

Genetic maladaptation of Douglas-fir seedlings to future climates

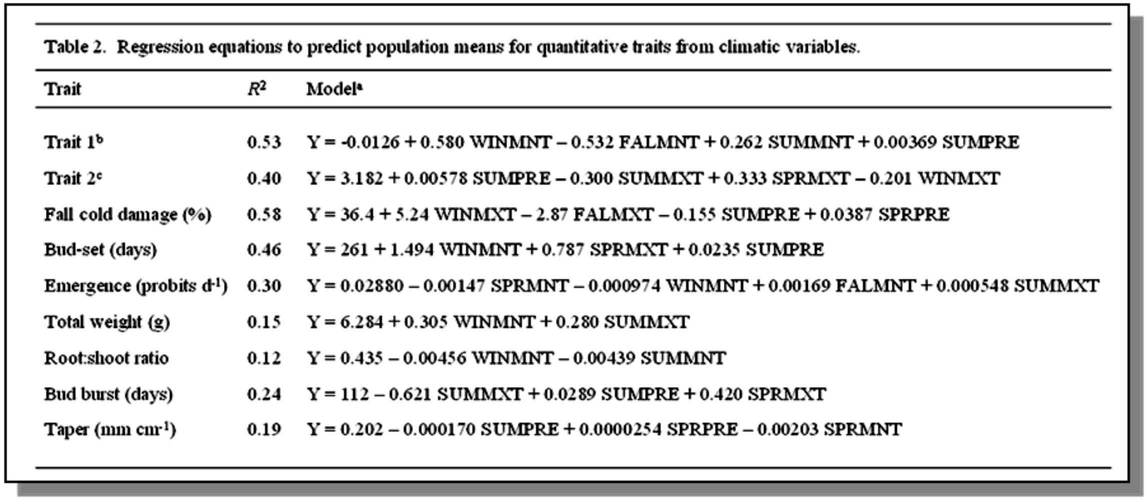
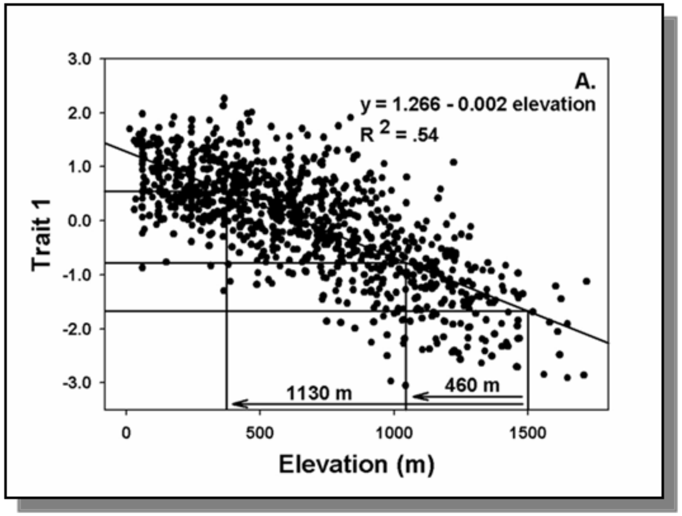


Table 2. Regression equations to predict population means for quantitative traits from climatic variables.

Trait	R^2	Model[a]
Trait 1[b]	0.53	Y = -0.0126 + 0.580 WINMNT – 0.532 FALMNT + 0.262 SUMMNT + 0.00369 SUMPRE
Trait 2[c]	0.40	Y = 3.182 + 0.00578 SUMPRE – 0.300 SUMMXT + 0.333 SPRMXT – 0.201 WINMXT
Fall cold damage (%)	0.58	Y = 36.4 + 5.24 WINMXT – 2.87 FALMXT – 0.155 SUMPRE + 0.0387 SPRPRE
Bud-set (days)	0.46	Y = 261 + 1.494 WINMNT + 0.787 SPRMXT + 0.0235 SUMPRE
Emergence (probits d^{-1})	0.30	Y = 0.02880 – 0.00147 SPRMNT – 0.000974 WINMNT + 0.00169 FALMNT + 0.000548 SUMMXT
Total weight (g)	0.15	Y = 6.284 + 0.305 WINMNT + 0.280 SUMMXT
Root:shoot ratio	0.12	Y = 0.435 – 0.00456 WINMNT – 0.00439 SUMMNT
Bud burst (days)	0.24	Y = 112 – 0.621 SUMMXT + 0.0289 SUMPRE + 0.420 SPRMXT
Taper (mm cm^{-1})	0.19	Y = 0.202 – 0.000170 SUMPRE + 0.0000254 SPRPRE – 0.00203 SPRMNT



Higher values for ***Trait 1*** *are associated with later bud-set, faster emergence, larger size, greater partitioning to shoot versus roots.*

St.Clair and Howe (2007) Global Change Biol.13:1441-1454.

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Long-term provenance tests

Assumptions…

Climatic variation across the landscape mimics climate change.

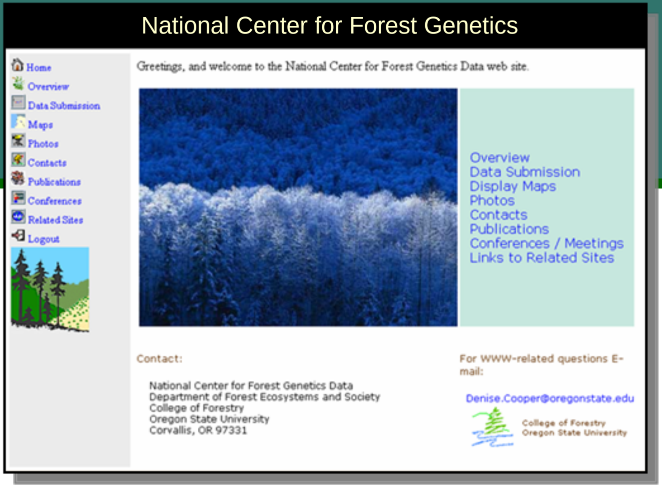
Advantages…

Tests complex climatic regimes over a long time in the field.
Traits measured are usually relevant to production forestry.
Provides some information on the absolute effects of climate change.

Disadvantages…

Mostly relevant to plantation forestry because seed germination and establishment phases are bypassed.
Expensive and slow to produce results.
May confound climate and photoperiod.

Genetic tests - Needs



Greetings, and welcome to the National Center for Forest Genetics Data web site.

Contact:

National Center for Forest Genetics Data
Department of Forest Ecosystems and Society
College of Forestry
Oregon State University
Corvallis, OR 97331

For WWW-related questions E-mail:

Denise.Cooper@oregonstate.edu

Forest genetics database…

USFS Climate Change Research Program

Analyses of existing provenance test data…

Response surfaces for new species using existing provenance test data.

Meta-analysis to develop general response surfaces.

Provenance tests that examine wider climatic ranges…

Provenance tests that examine flowering, seed production, seed germination, and establishment…

More relevant to native, naturally regenerated forests.

Extensive provenance test data

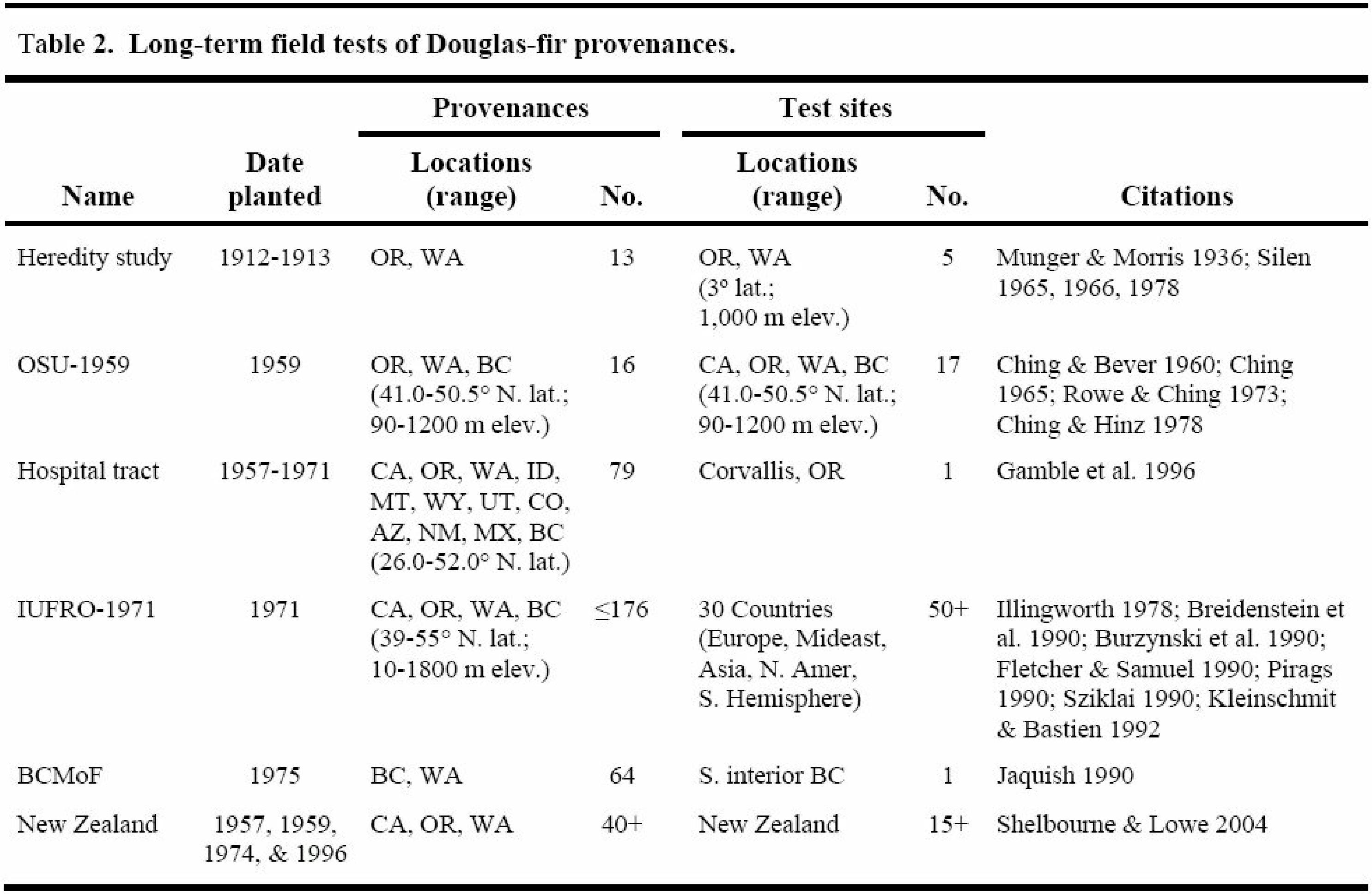


Table 2. Long-term field tests of Douglas-fir provenances.

Name	Date planted	Provenances Locations (range)	Provenances No.	Test sites Locations (range)	Test sites No.	Citations
Heredity study	1912-1913	OR, WA	13	OR, WA (3° lat.; 1,000 m elev.)	5	Munger & Morris 1936; Silen 1965, 1966, 1978
OSU-1959	1959	OR, WA, BC (41.0-50.5° N. lat.; 90-1200 m elev.)	16	CA, OR, WA, BC (41.0-50.5° N. lat.; 90-1200 m elev.)	17	Ching & Bever 1960; Ching 1965; Rowe & Ching 1973; Ching & Hinz 1978
Hospital tract	1957-1971	CA, OR, WA, ID, MT, WY, UT, CO, AZ, NM, MX, BC (26.0-52.0° N. lat.)	79	Corvallis, OR	1	Gamble et al. 1996
IUFRO-1971	1971	CA, OR, WA, BC (39-55° N. lat.; 10-1800 m elev.)	≤176	30 Countries (Europe, Mideast, Asia, N. Amer, S. Hemisphere)	50+	Illingworth 1978; Breidenstein et al. 1990; Burzynski et al. 1990; Fletcher & Samuel 1990; Pirags 1990; Sziklai 1990; Kleinschmit & Bastien 1992
BCMoF	1975	BC, WA	64	S. interior BC	1	Jaquish 1990
New Zealand	1957, 1959, 1974, & 1996	CA, OR, WA	40+	New Zealand	15+	Shelbourne & Lowe 2004

Genetic options – Planning

Develop your organization's perspective on risk and manage accordingly

Be prepared for climate change

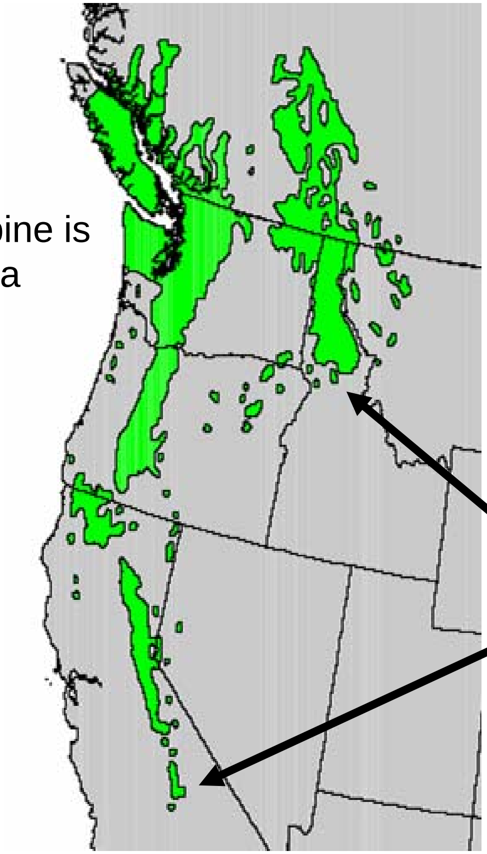
- Prioritize species, provenances, and sites for sensitivity to climate change
- Monitor sensitive systems for climate change impacts
- Know what to do <u>before</u> climate change impacts are observed
- In the future, you may need to get your seed from a different seed orchard (i.e., owned by someone else?)

Genetic options – Planning

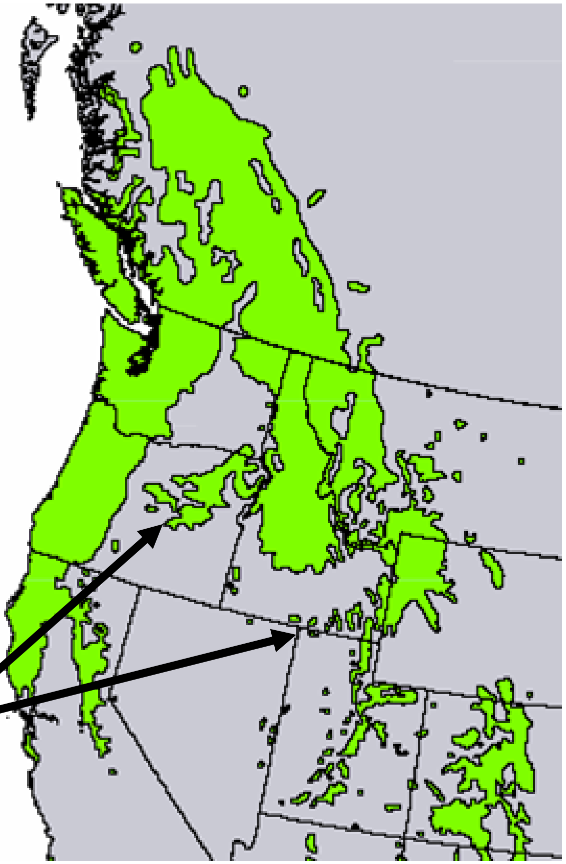
Species/populations differ in sensitivity to climate change

Mountainous areas may be <u>less sensitive</u> because genetically different populations are close to one another

Western white pine is
considered a
<u>generalist</u>



Douglas-fir is
considered a
<u>specialist</u>



Trailing edge
populations are
<u>more sensitive</u>

Other peripheral
and disjunct
populations may be
<u>more sensitive</u>

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Maps from USGS: http://esp.cr.usgs.gov/data/atlas/little/

Genetic options
Native, naturally regenerated forests

Maintain species and genetic diversity in situ…
Effectiveness may be limited if entire ecosystems become maladapted.

Avoid fragmentation and maintain corridors that facilitate migration (gene flow)…
Seed migration may be insufficient.
Pollen migration is limited by temperature-associated flowering phenology.

.

Establish 'genetic outposts'…

Stands adapted to future climates planted near native forests.
Facilitates assisted migration at the pollen level and (maybe) seed level.
Small number should be effective.
Plantation forests will help serve this function.

Genetic options
In situ preservation may become inviable

Conserve ecosystem <u>functions</u>, not current ecosystems…
Ex situ conservation will become more important.
Without artificial regeneration, genetic options are limited.
Rely on silviculture instead? But policies may preclude active management.

Assisted migration via planting must be considered…
e.g., Reforestation after fires – make reforestation plans before fires occur.

Genetic options - Planted forests

Assisted migration…

Movement of species, provenances, or breeding populations to 'new' sites where they are expected to be better adapted in the future.

Considerations…

Should be highly effective, but requires artificial regeneration.
Which future climate is your target?
Deploy a mixture vs match genotypes to a specific future climate?
Plant at higher densities in anticipation of higher mortality due to mixing?

Recommendations…

Use species on sites well within their current range.
Move seed within zones, but not to warmer or drier sites.
Need good, readily accessible climate data to do this (e.g., web based tools).

Genetic options - Planted forests

Match genotypes to sites and future climate…

Lots of genetic variation in current breeding populations.
Families and clones differ in drought /cold hardiness and growth phenology.
Genotype-site matching may reduce risks of added mismatch from climate change.

Considerations…

Maybe effective, but requires artificial regeneration.
Same risk considerations as for assisted migration.

Recommendations…

Characterize genotypes for drought hardiness, cold hardiness, growth phenology.
Plant these materials on characterized sites and monitor performance.

Genetic options - Planted forests

Breed for resistance or tolerance to pests…

A long-term, expensive, difficult prospect.
Key pests are being addressed – Which others will become problematic?
Biotech approaches may be the most effective (e.g., Bt insect toxins).

Breed for drought hardiness and growth phenology…

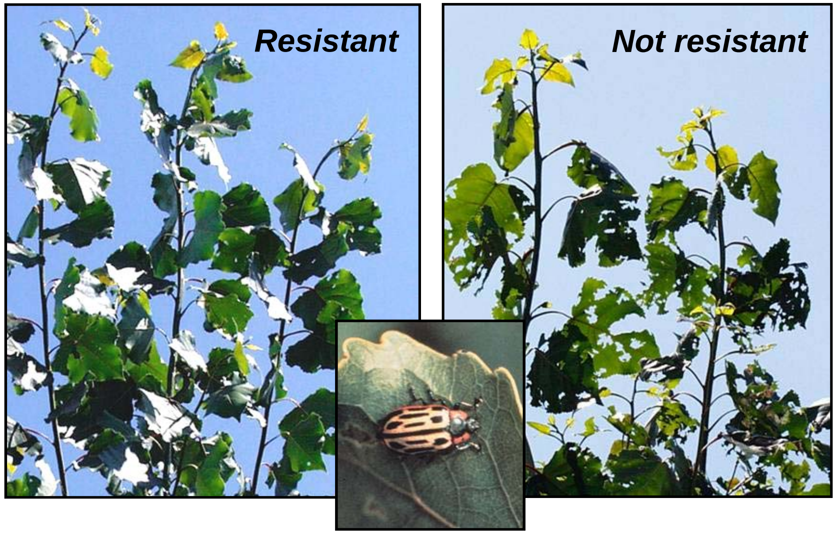
Tests have been developed to assess cold and drought hardiness.
Breeding per se is generally not needed – assisted migration already available.

Breed for broad adaptation…

Efficacy has not been tested.

Recommendations…

Research needed to develop these tools.

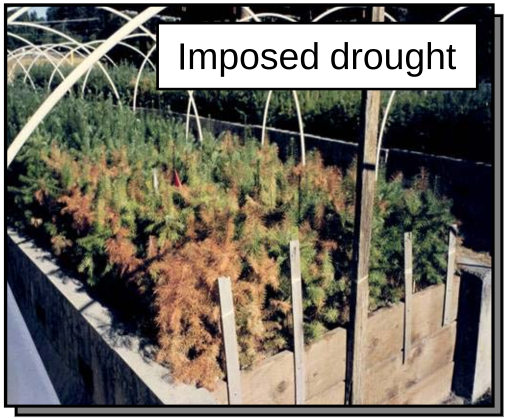


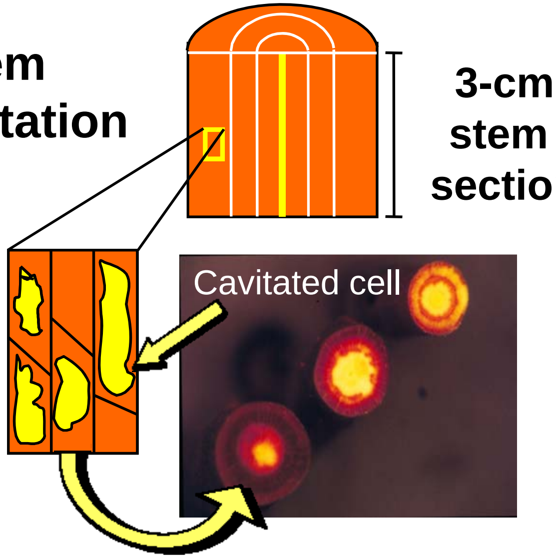
Poplar trees have been genetically engineered
to be resistant to the cottonwood leaf beetle.
Photos, Steve Strauss, OSU

Tests for genetic differences in cold and drought hardiness

Cold hardiness

Drought hardiness





Xylem cavitation

3-cm stem section

Genetic options - Planted forests

Clonal forestry…

May speed adaptation to future climates via traditional breeding.
Will speed deployment of genetically-engineered materials.
May provide incentive to reduce genetic diversity.
May be more risky if match between genotype and future climate is incorrect.

Genetic engineering (GE) and marker-aided selection

Maybe most effective for insects and pathogens.
Maybe the only realistic solution for some problems.

Considerations…

Public perceptions will be an issue for clonal forestry and GE.

Recommendations…

We need these options in our tool box – more research effort is needed.

Action items

Tools…

- Interactive web-based tool to generate seed zones and breeding zones for future climates (USFS Climate Change Research Program)
- National Forest Genetics Data Center of genecological and provenance test data (USFS Climate Change Research Program)
- Growth models that incorporate climate change, species range shifts, and provenance variation (e.g., FVS, Crookston)

Action items

Research and testing…

- Provenance tests

  Seed production and seedling establishment phases.
  Short-term seedling tests for unstudied species.
  Wide-ranging, long-term field tests for key species.

- Wide testing of breeding materials in locations that represent a full range of future climates
- Characterize breeding populations and genotypes for adaptive traits to allow genotype-site matching

Conclusions

- Prepare for climate change
- Complementary genetic and silvicultural options are available
- Maintain genetic diversity and flexibility
- Understand and evaluate assisted migration of species, seed sources, and breeding populations
- Plan for active management of native, naturally-regenerated forests, including protected areas to maintain healthy ecosystems
- Identify appropriate reforestation materials before large fires occur
- Foresters who know how to implement genetic and silvicultural options will be increasingly valuable in the future