

Rise and Shine!

How Temperature Affects the Timing of Terminal Shoot and Diameter Growth of Pacific Northwest Tree Species

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Many people have contributed including:

Brad St. Clair

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Chris Poklemba

Sheel Bansal

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Andy Bower

Yianna Bekris

**Many organization have contributed data
or allowed access to their land**

**Special thanks to George McFadden,
OR BLM for financial support**



Phenology

- **A branch of science dealing with the relations between climate and periodic biological phenomena**
- **derived from the Greek word phaino meaning **to show** or to **appear****
 - **principally concerned with the dates of first occurrence of biological events in their annual cycle**

Phenological Events

- Emergence of leaves and flowers
- First flight of butterflies or appearance of migratory birds
- Leaf coloring and fall in deciduous trees
- Timing of egg-laying of birds and amphibians
- Developmental cycles of insects



Wikipedia

Royal Meteorological Society

- Craze in England to record phenology
- Annual reports from 1891-1948
- Flowering dates could be as many as 21 days early and as many as 34 days late, (Jeffree 1960)



More from Britain

- **First Flowering Date (FFD) of 557 plants recorded between 1954 and 1990**
- **FFD is sensitive to temperature**
- **150 to 200 species are flowering 15 days earlier in Britain now than in recent past**
- **Earlier FFDs will have "profound ecosystem and evolutionary consequences"**

Fitter and Fitter 2002



Biology Responses Differ?

- **Timing of biological events may become independent as novel climates dev.**
 - **Male and female flowering synchronized in past for all/most species**
 - **Black pine in Greece, ♂♀ flowers not well synchronized in hot/dry year (Alizoti et al. 2010)**
 - **Bird migration or egg hatching may not be responding to same environmental signals as plant or insect development**

Phenology is Deceptively Simple but Powerful Measure

- **Timing of growth initiation**
 - Influenced by winter and spring temperature
 - One determinant of growing season length

North America has very few long-term records



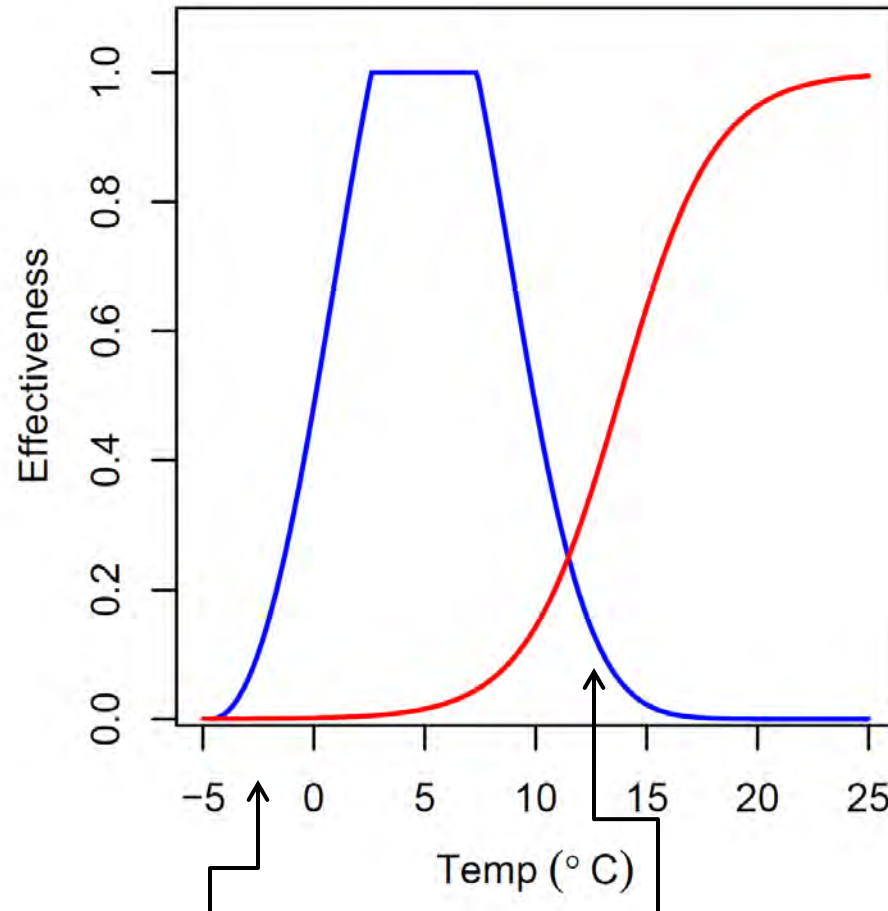
Timing is everything!



If we don't have long-term records, we can use models to predict phenological events

- **For spring budburst, we need to know:**
 - **Chilling and forcing effectiveness with temperature (I believe it does not differ for most woody species)**
 - **Need to know shape of possibility line by species and genotype (more later on this)**

Chilling and Forcing Requirements

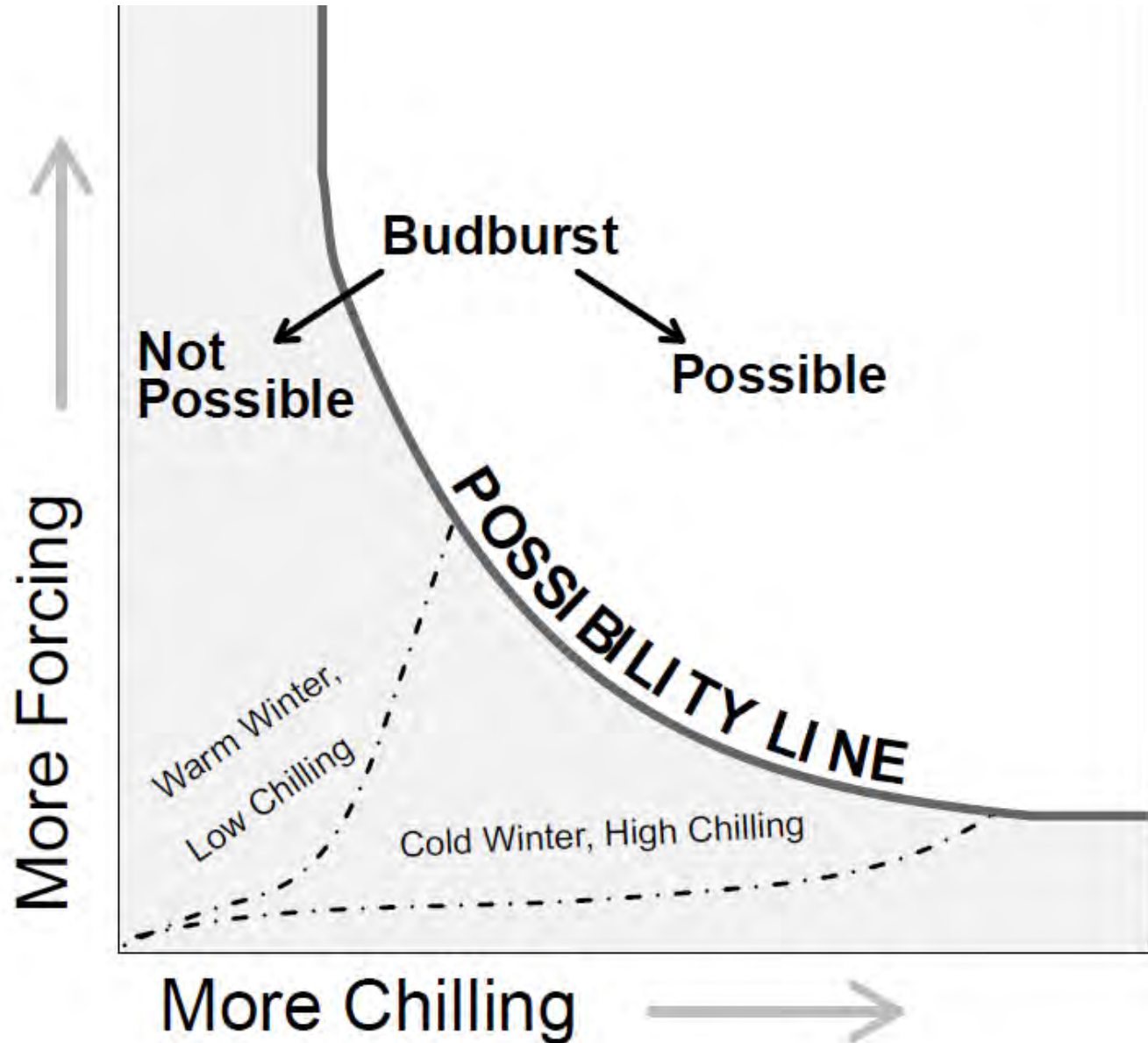


°C	°F
0	32
5	41
10	50
15	59
20	68

Freezing temps

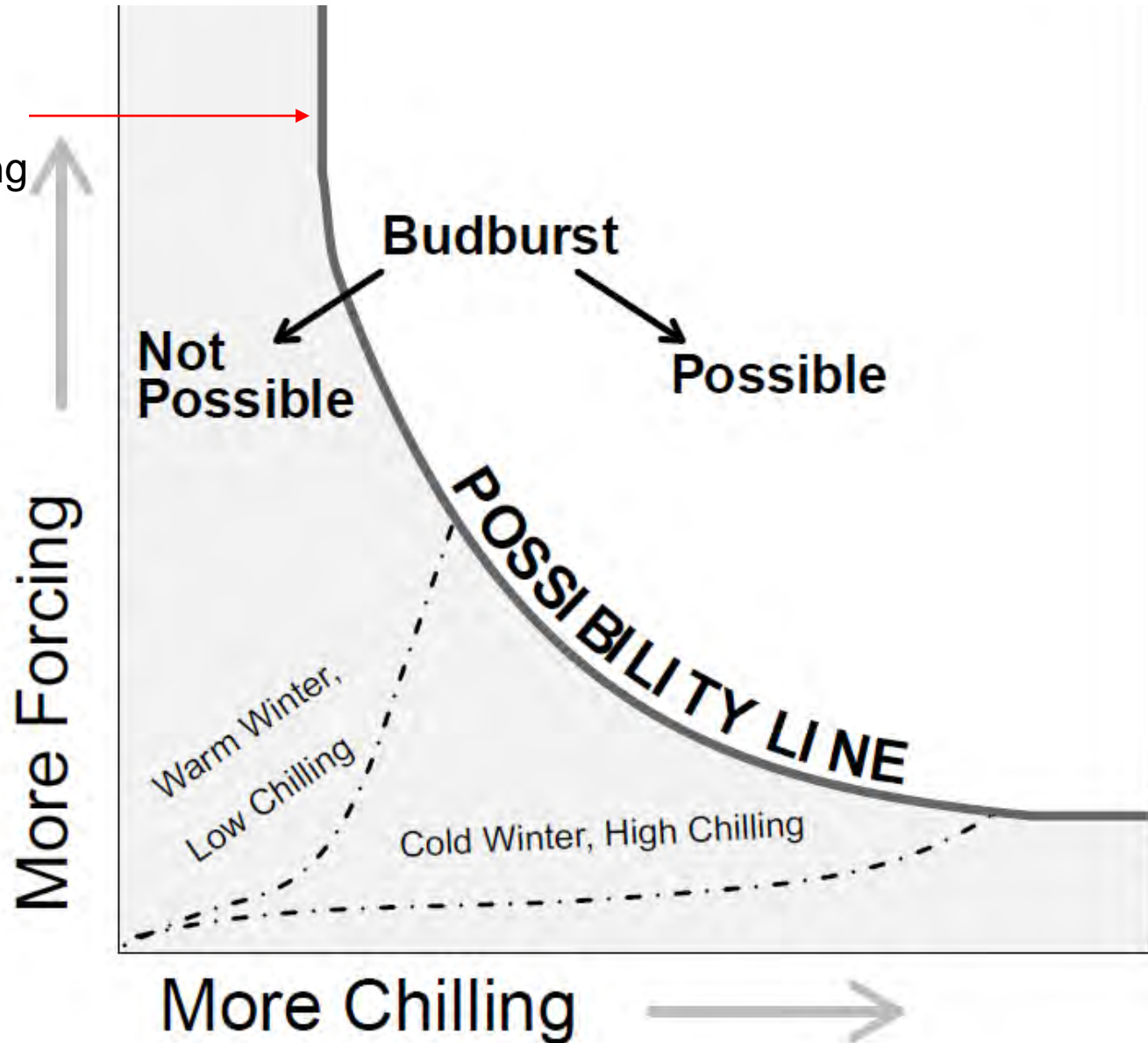
Warmer temps not very effective

Many combinations can result in spring budburst

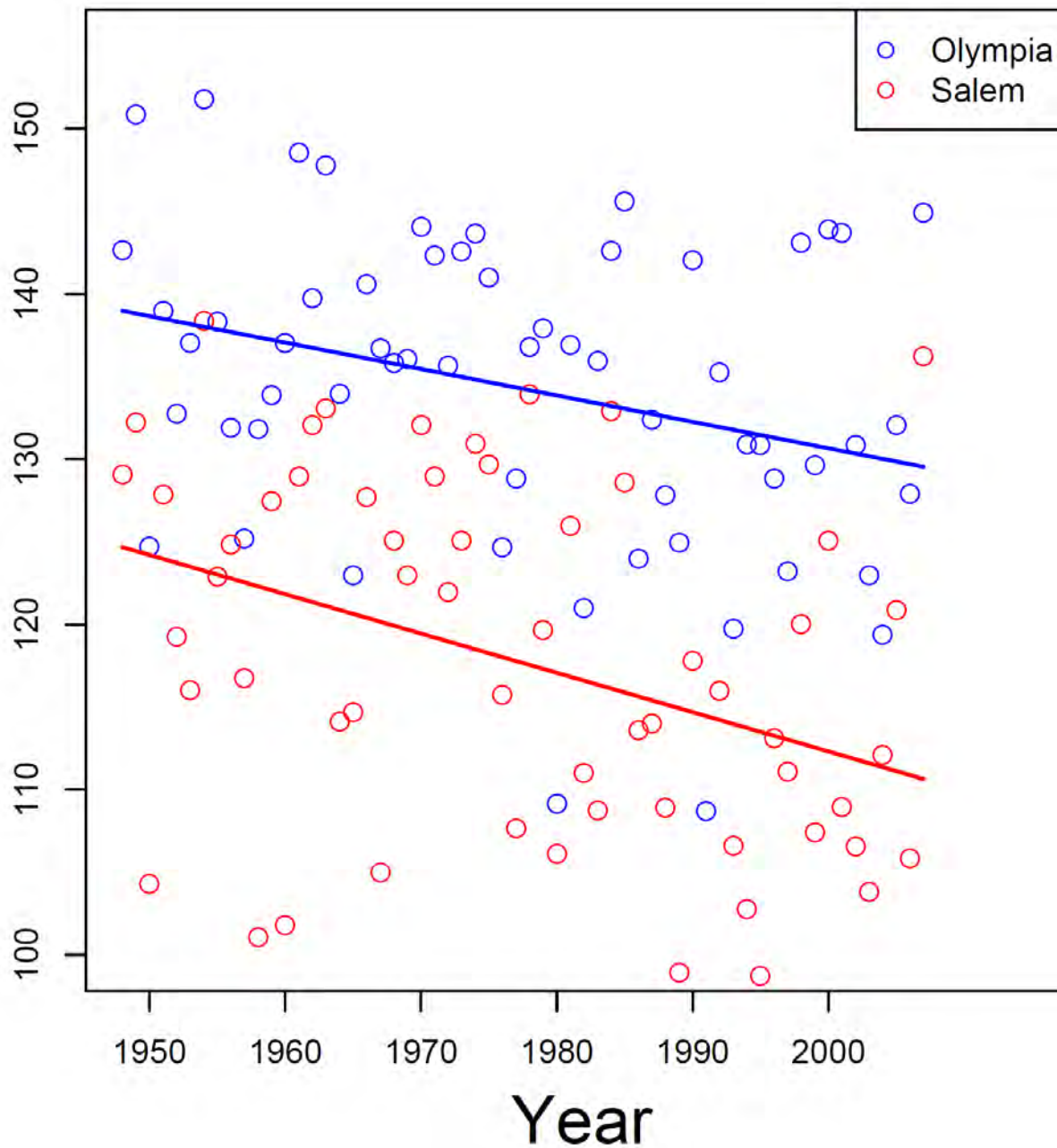


Many combinations can result in spring budburst

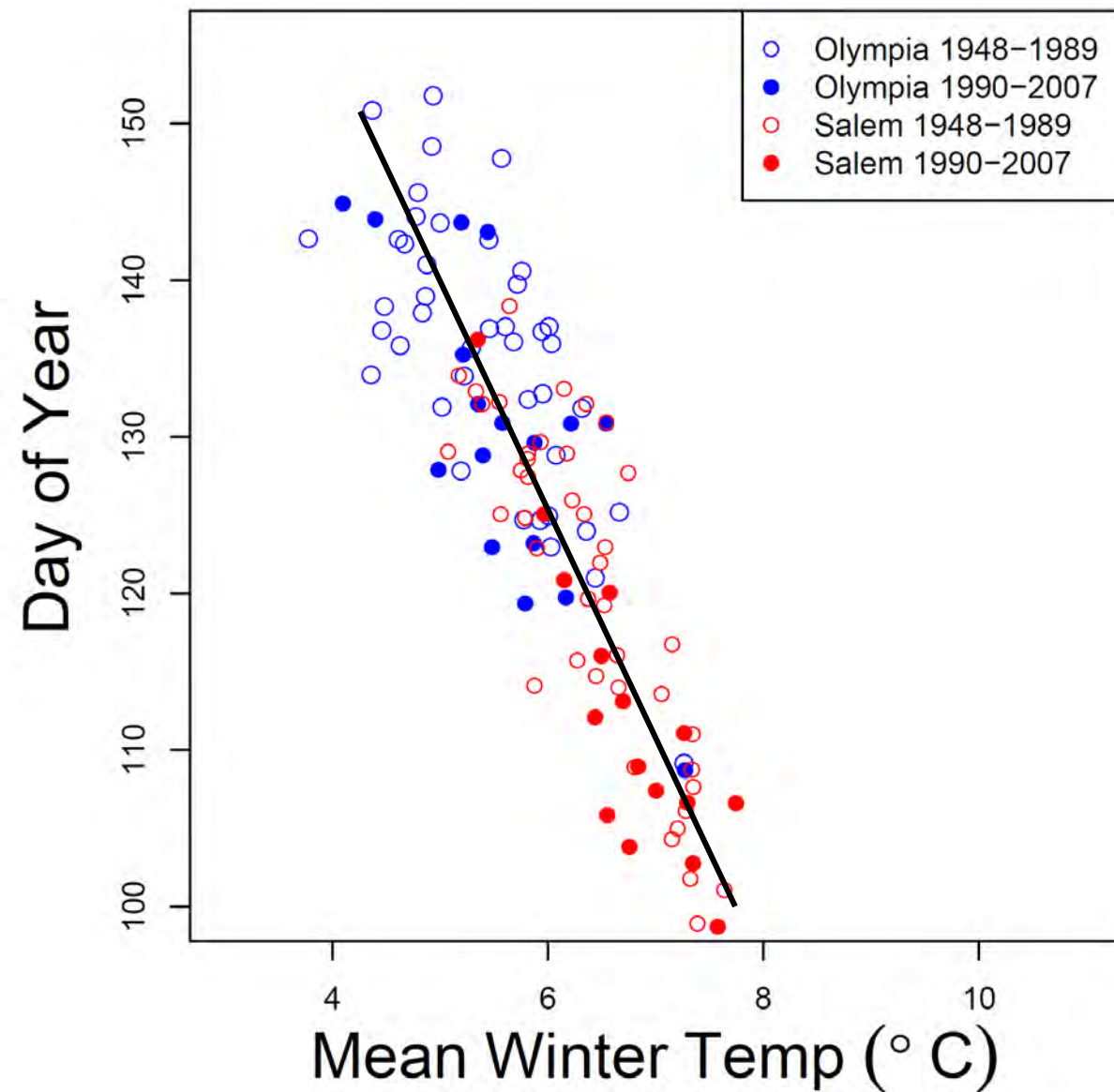
Asymptote
indicates
absolute chilling
requirement



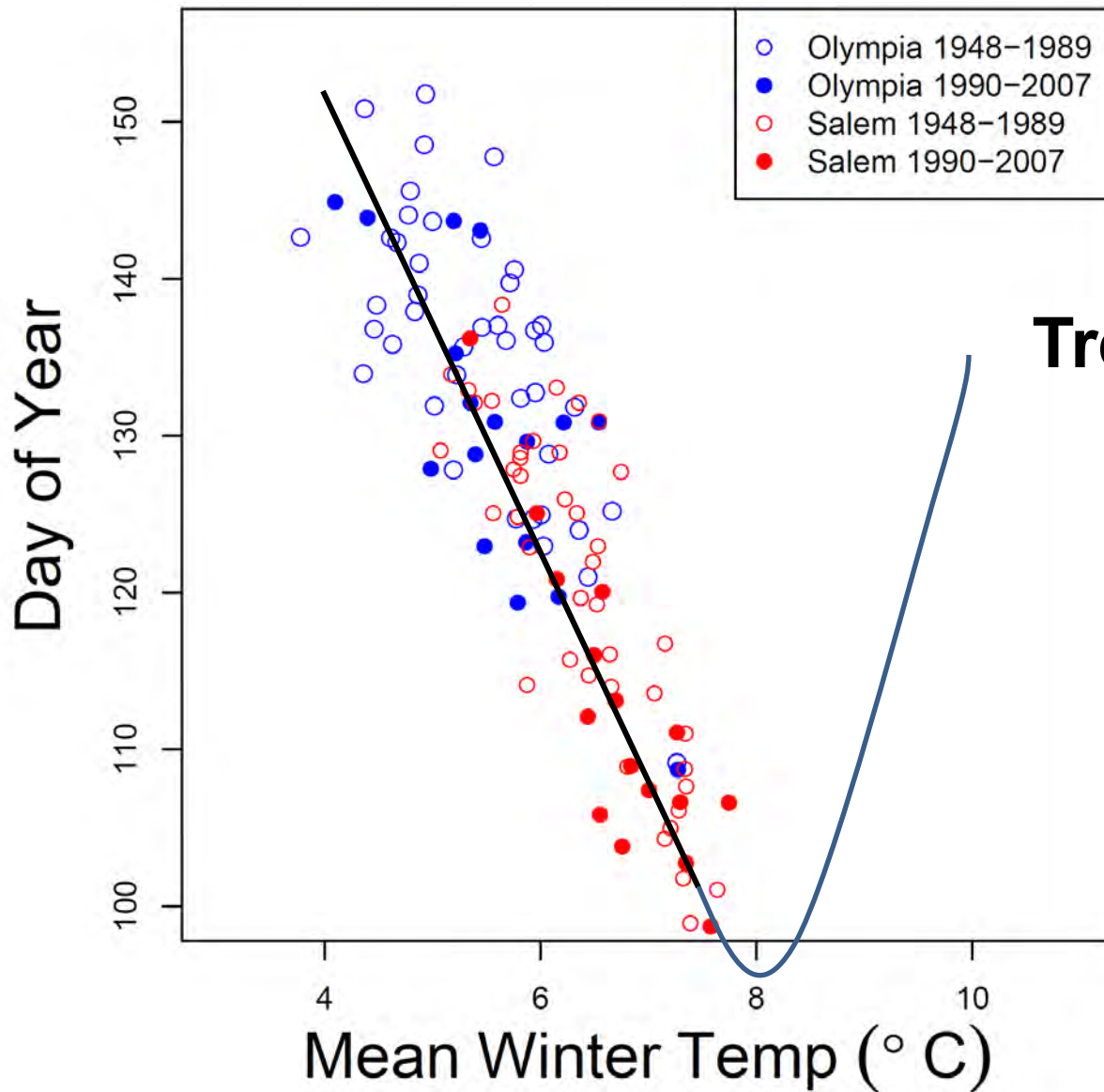
Day of Year



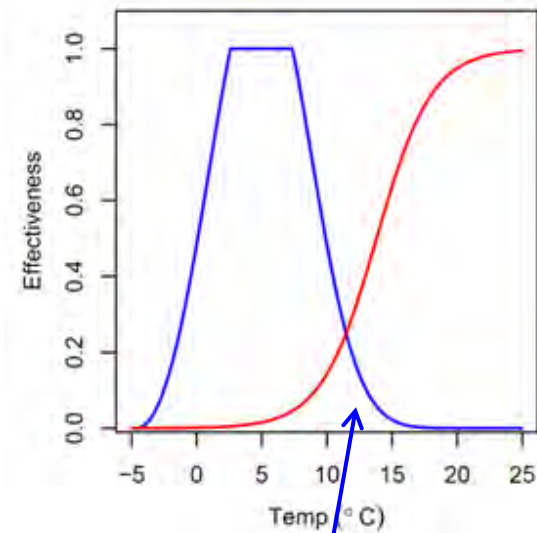
**Predicted
historical
dates of
budburst for
Douglas-fir**



**Predicted date
of historical
budburst is
earlier after
warmer winters**

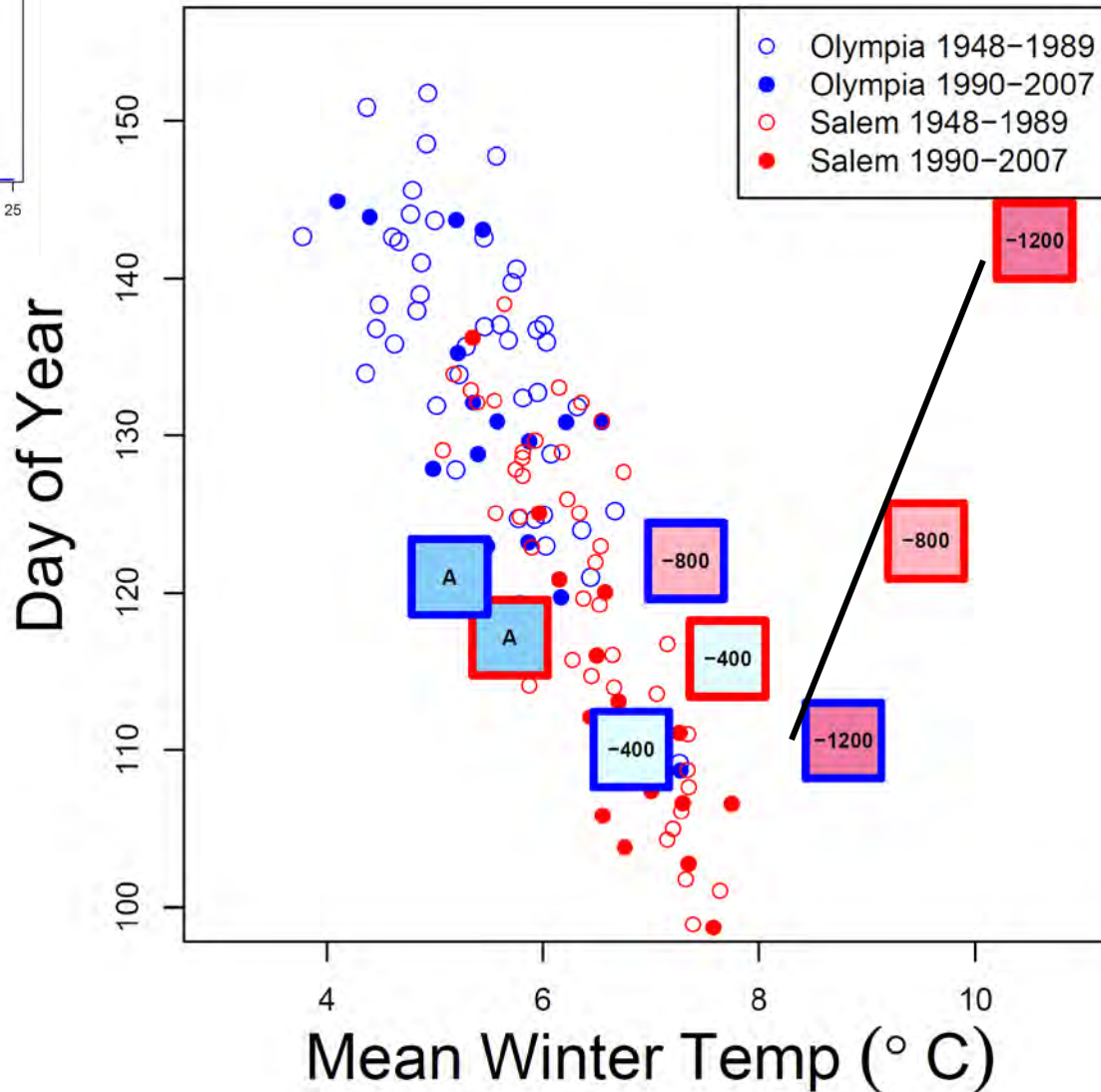
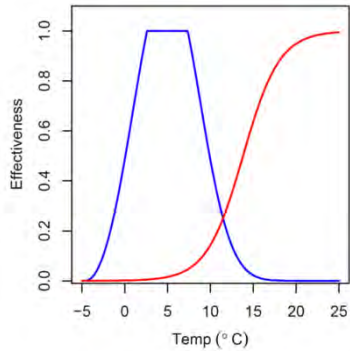


Trend will reverse!!



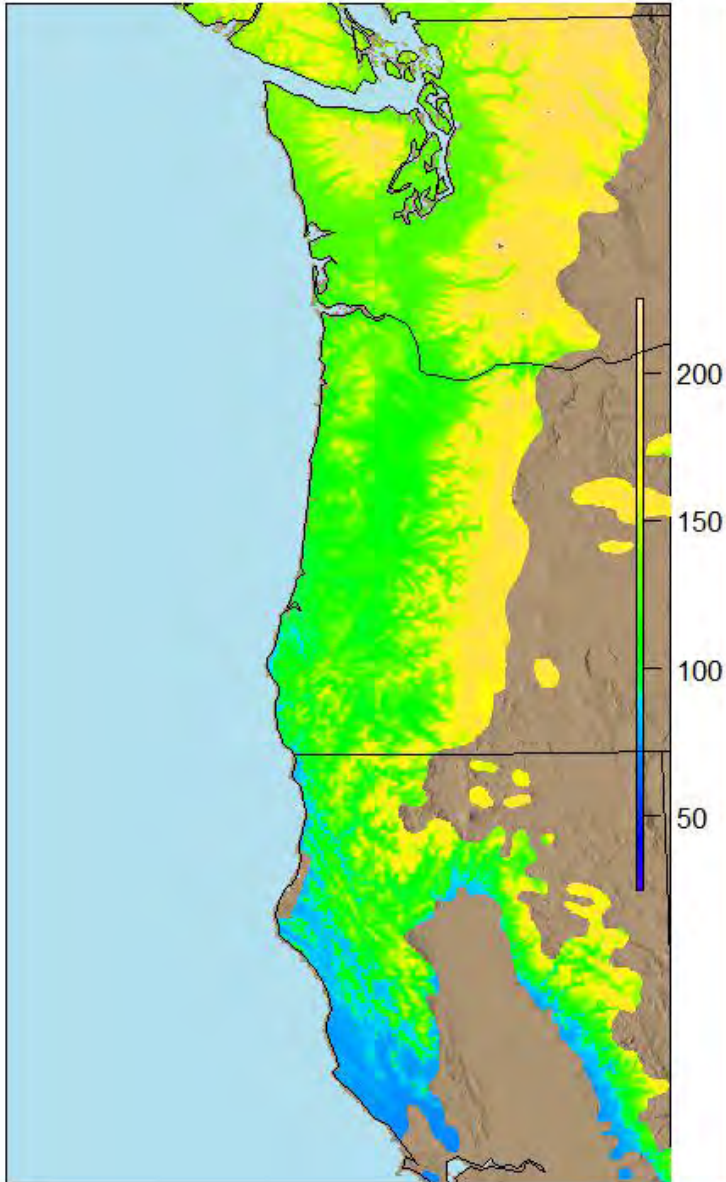
**Warm temps = low
chilling effectiveness**

Extra warming will change trend

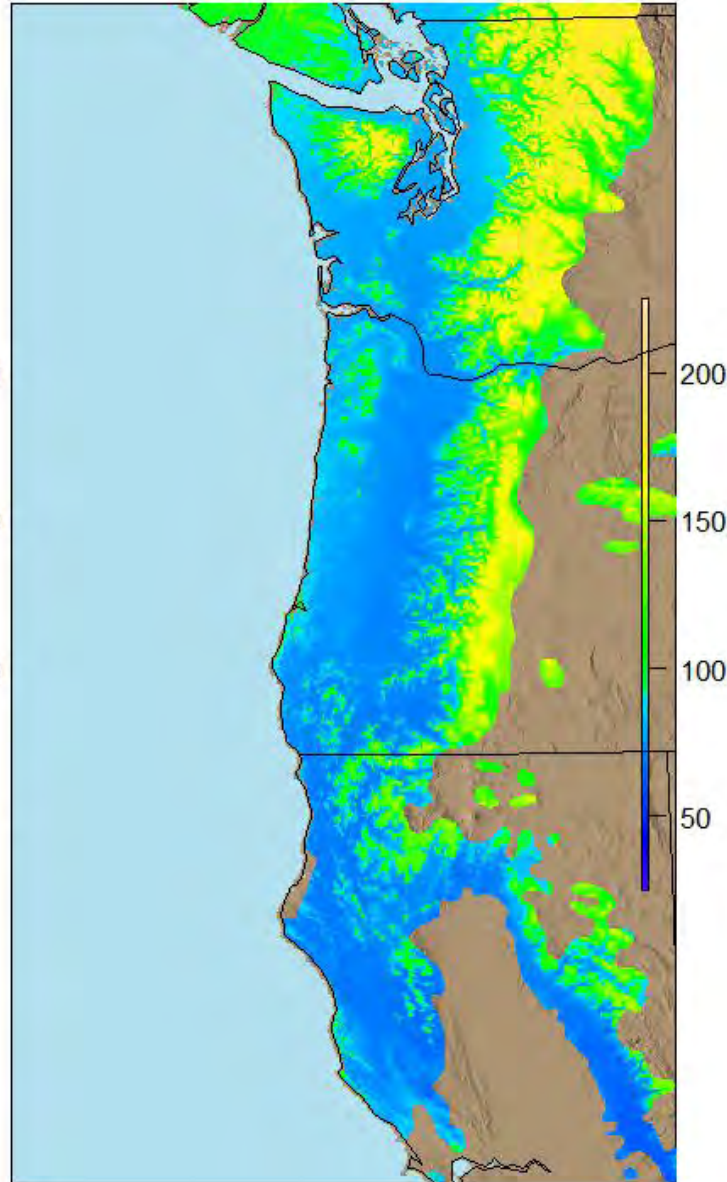


Douglas-fir – Date of Spring Budburst

Historic Climate



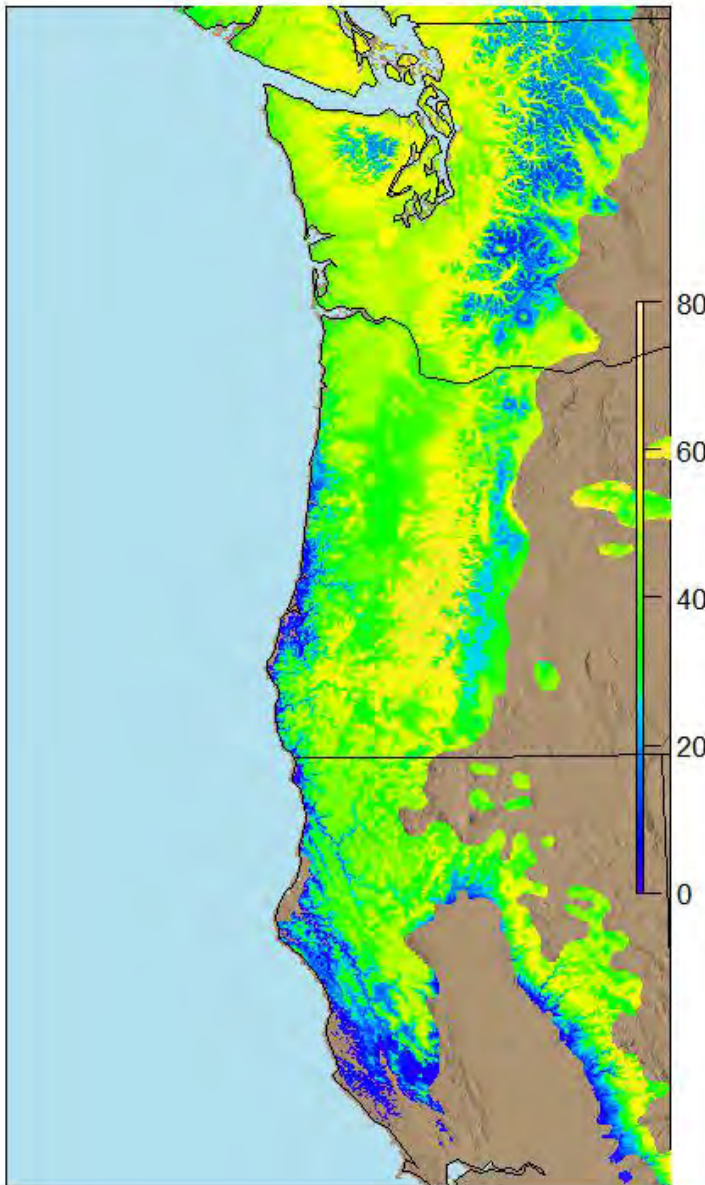
2080 Climate (A2 Scenario)



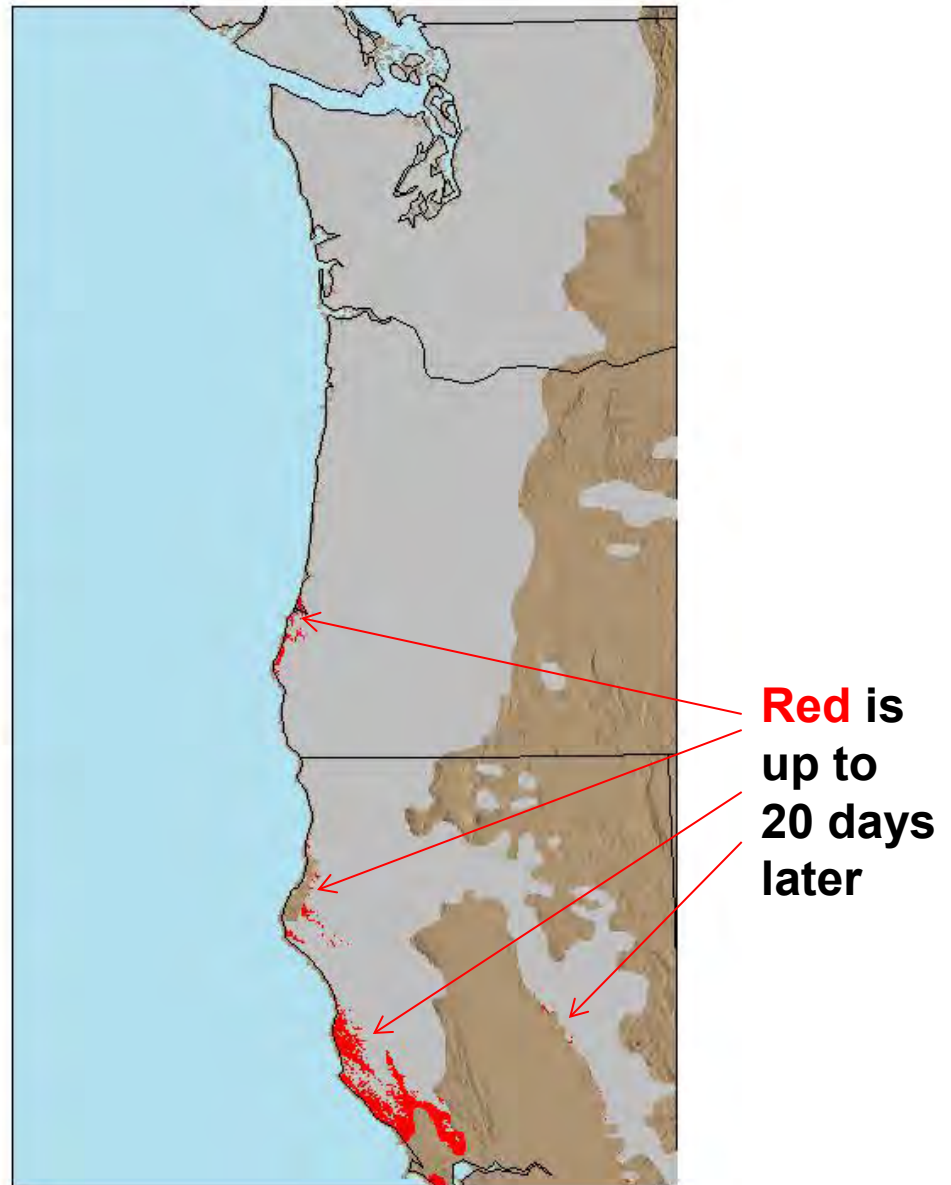
Based on
predictions from
ClimateWNA
(Forest Genetics,
Univ. British
Columbia)

Douglas-fir – Predicted Δ in Date of BB by 2080

Budburst Early

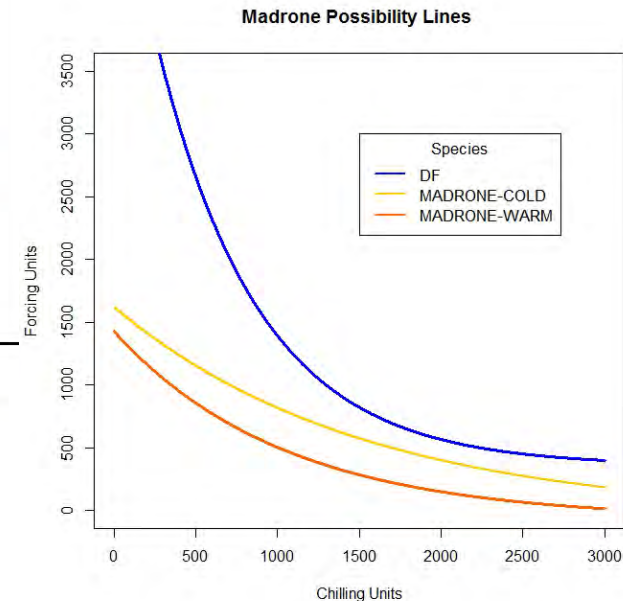
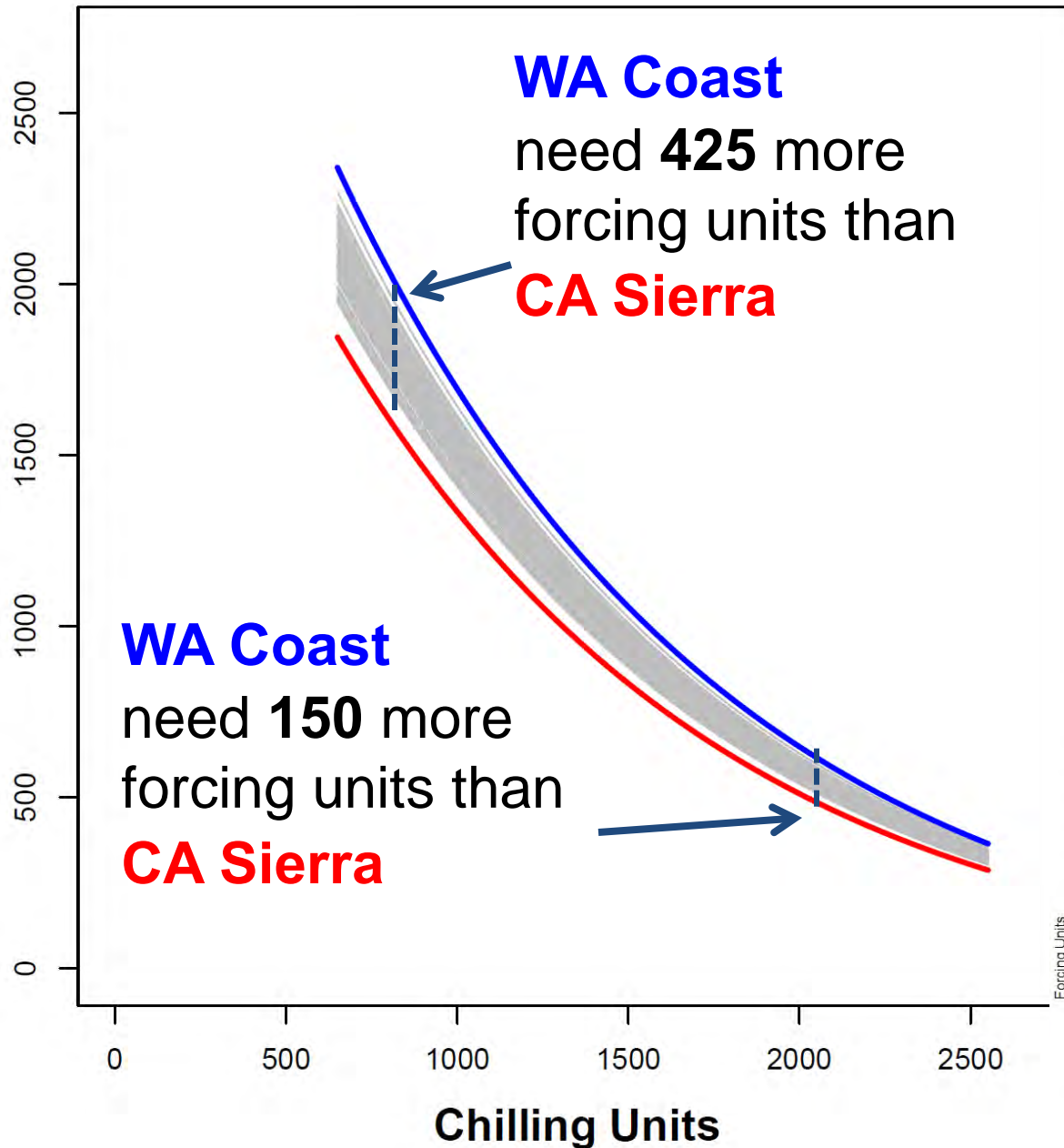


Budburst Later



**Seed sources
respond
differently,
especially
when chilling
is low**

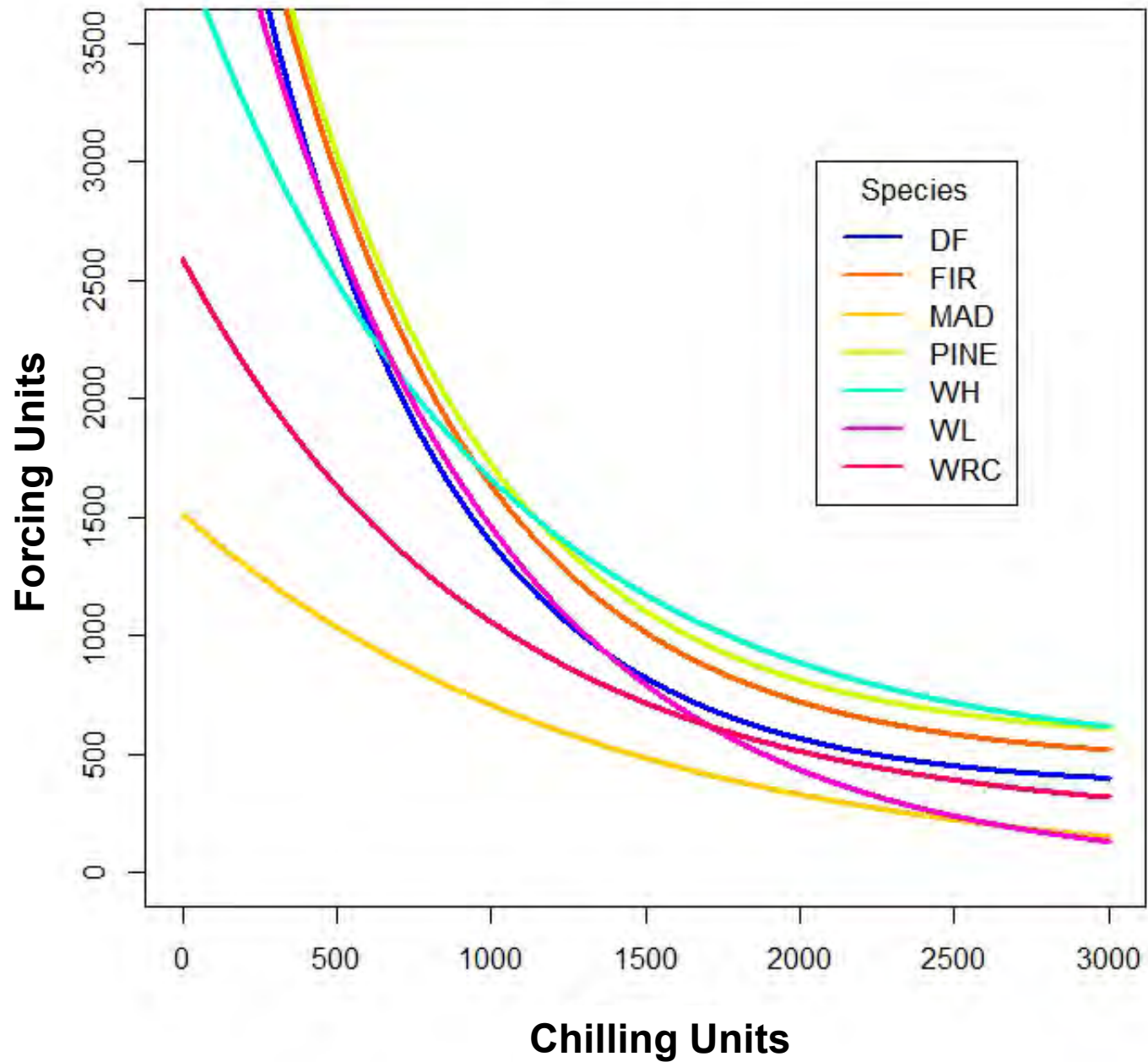
Forcing Units



2012-05-01 06:00

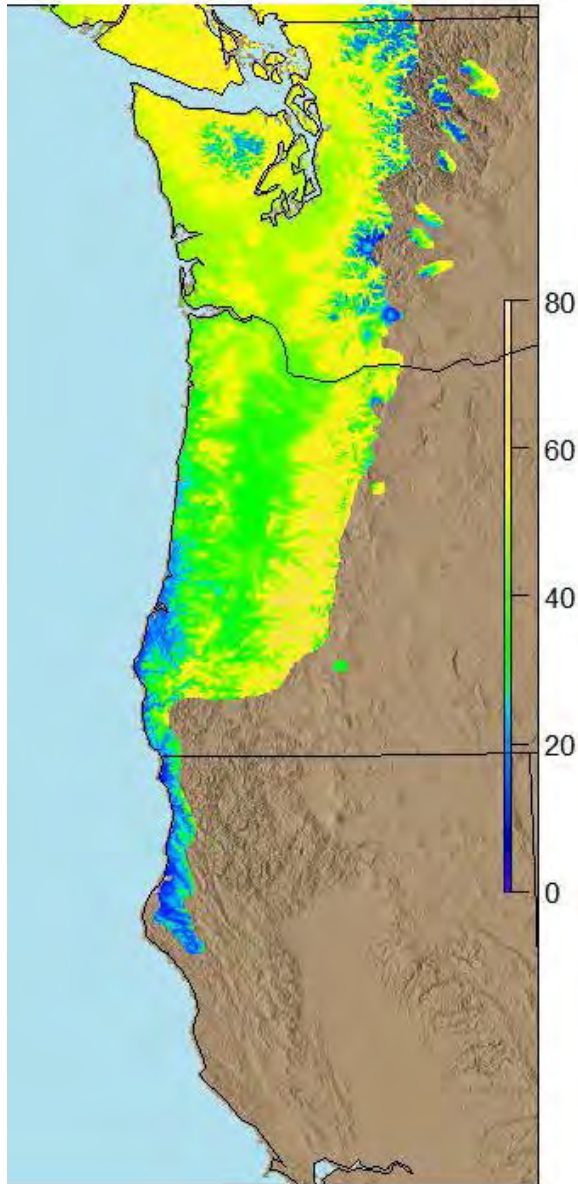


Possibility Lines

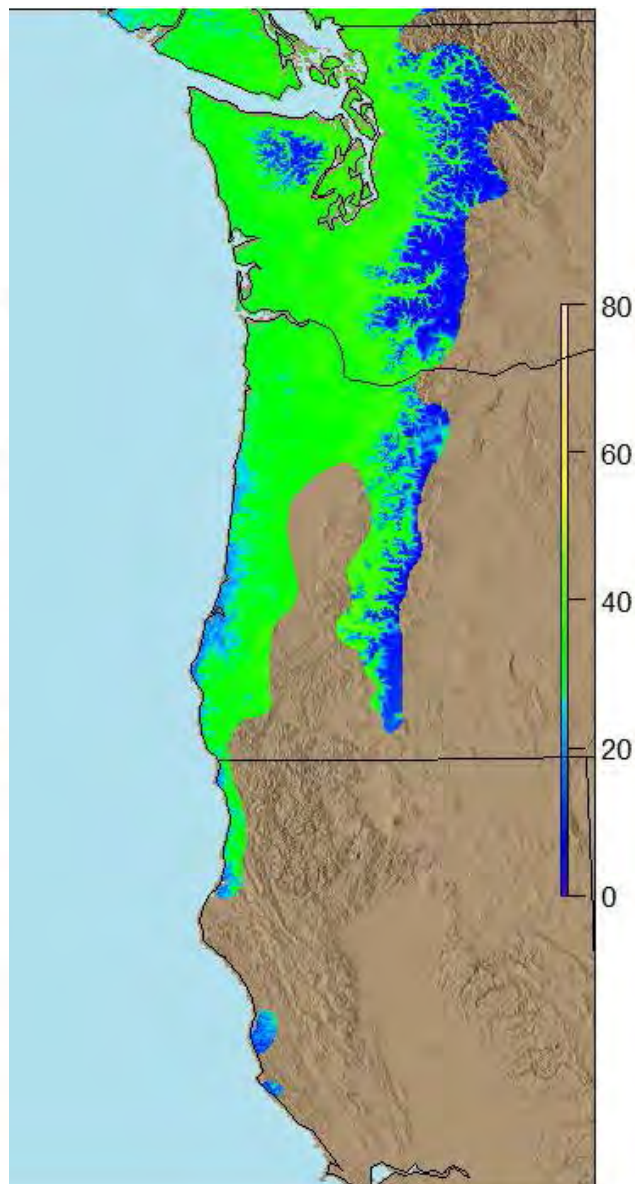


Change in Date of BB by 2080

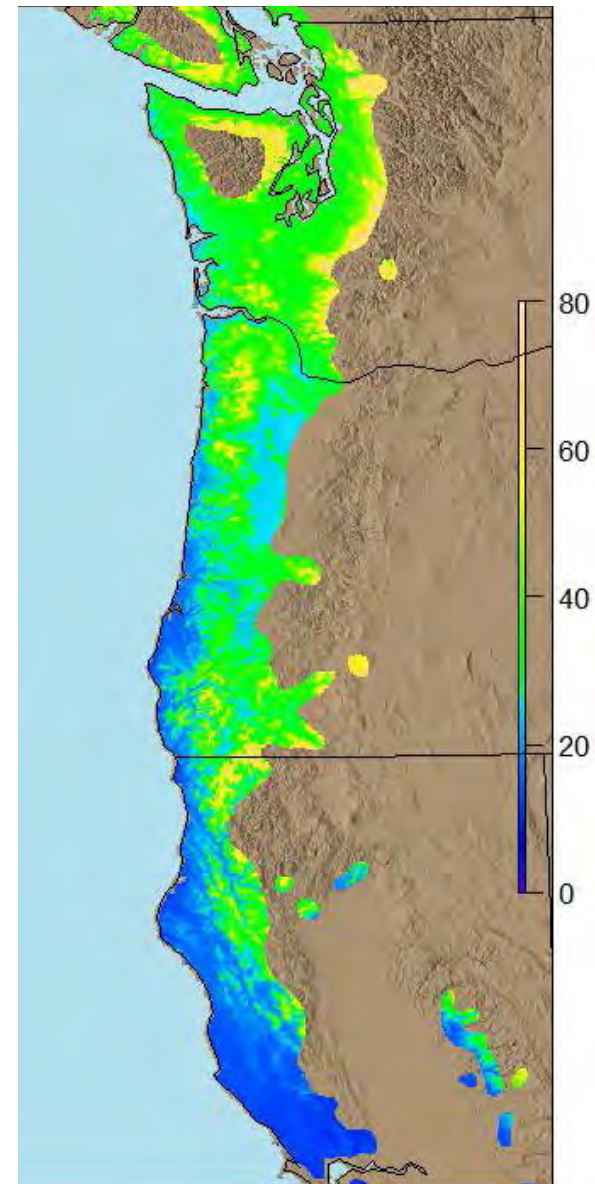
Western Redcedar

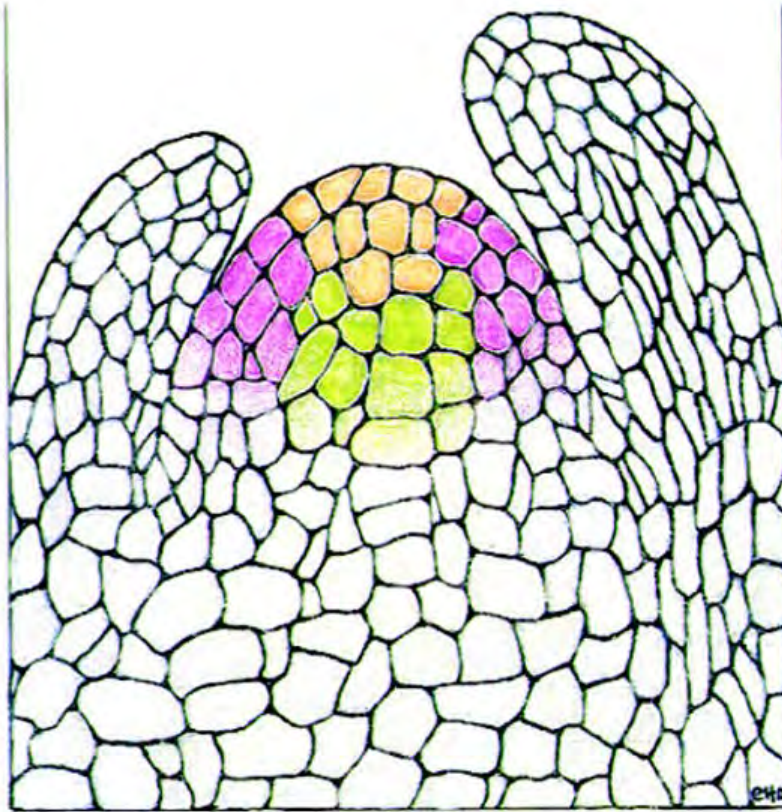


Western Hemlock



Pacific Madrone





- Central zone
- Peripheral zone
- Rib zone

SAM - Shoot Apical Meristem

**Peripheral zone
creates leaves,
cones, flowers**

**Rib zone creates pith
and stem**

**Central zone
replenishes Per. and
Rib zones**

**Zones can respond
differently**

Sharma and Fletcher 2002



2027-03-25 13:30:00

Genetics and Silviculture Team, PNW Research Station



Plant Growth (cont'd)

Sub-apical buds may respond differently than terminal buds

Plant form may be impacted

Douglas-fir -- very low chilling

**Branches from last year
have burst bud and are out-
growing former terminal**

Terminal bud previous year



Big Buds/Little Buds/No Buds!

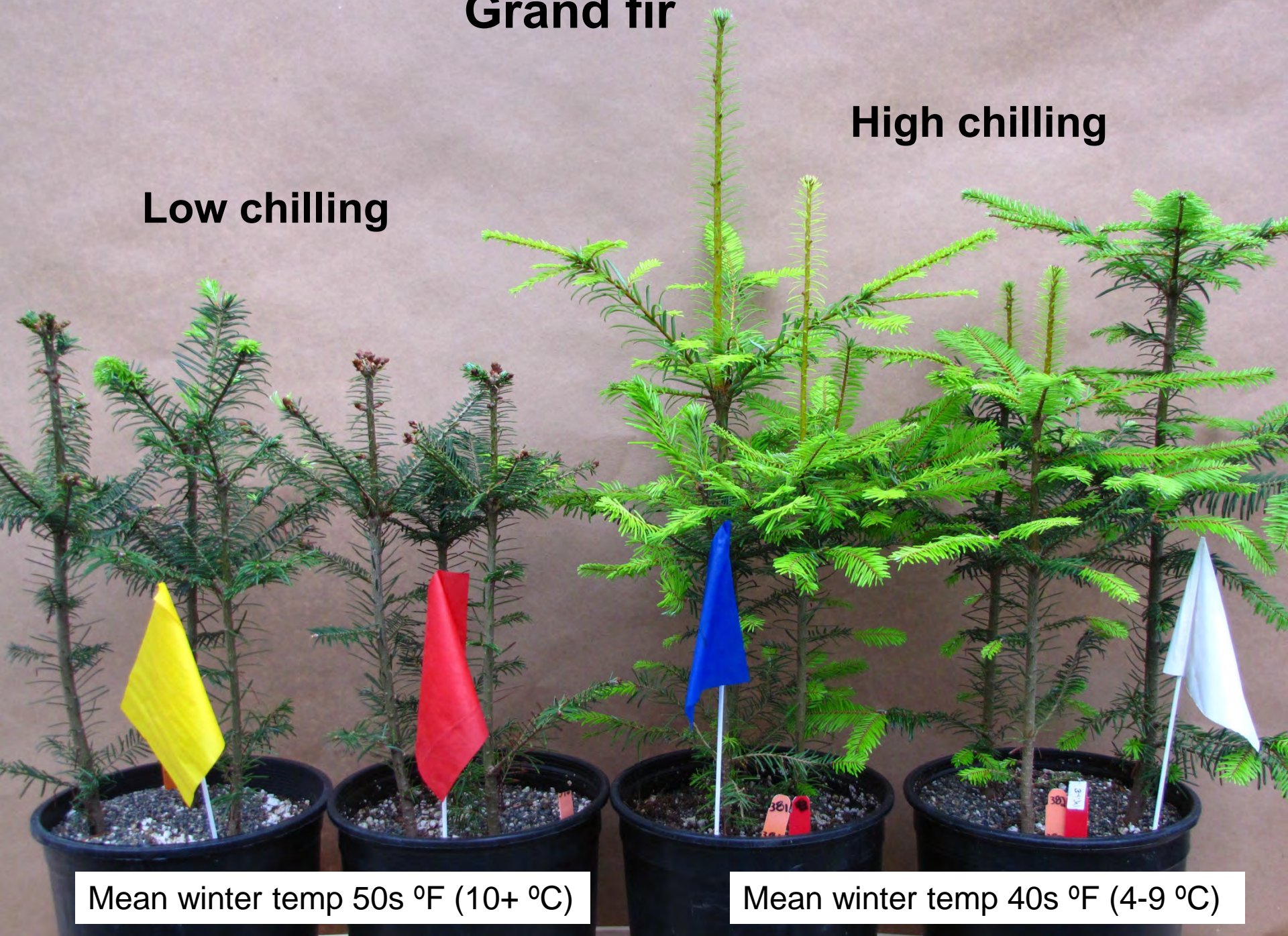
Species differ in many aspects of their responses



Grand fir

High chilling

Low chilling



Mean winter temp 50s °F (10+ °C)

Mean winter temp 40s °F (4-9 °C)

Lodgepole pine

Low chilling

High chilling



Pacific madrone

Low chilling

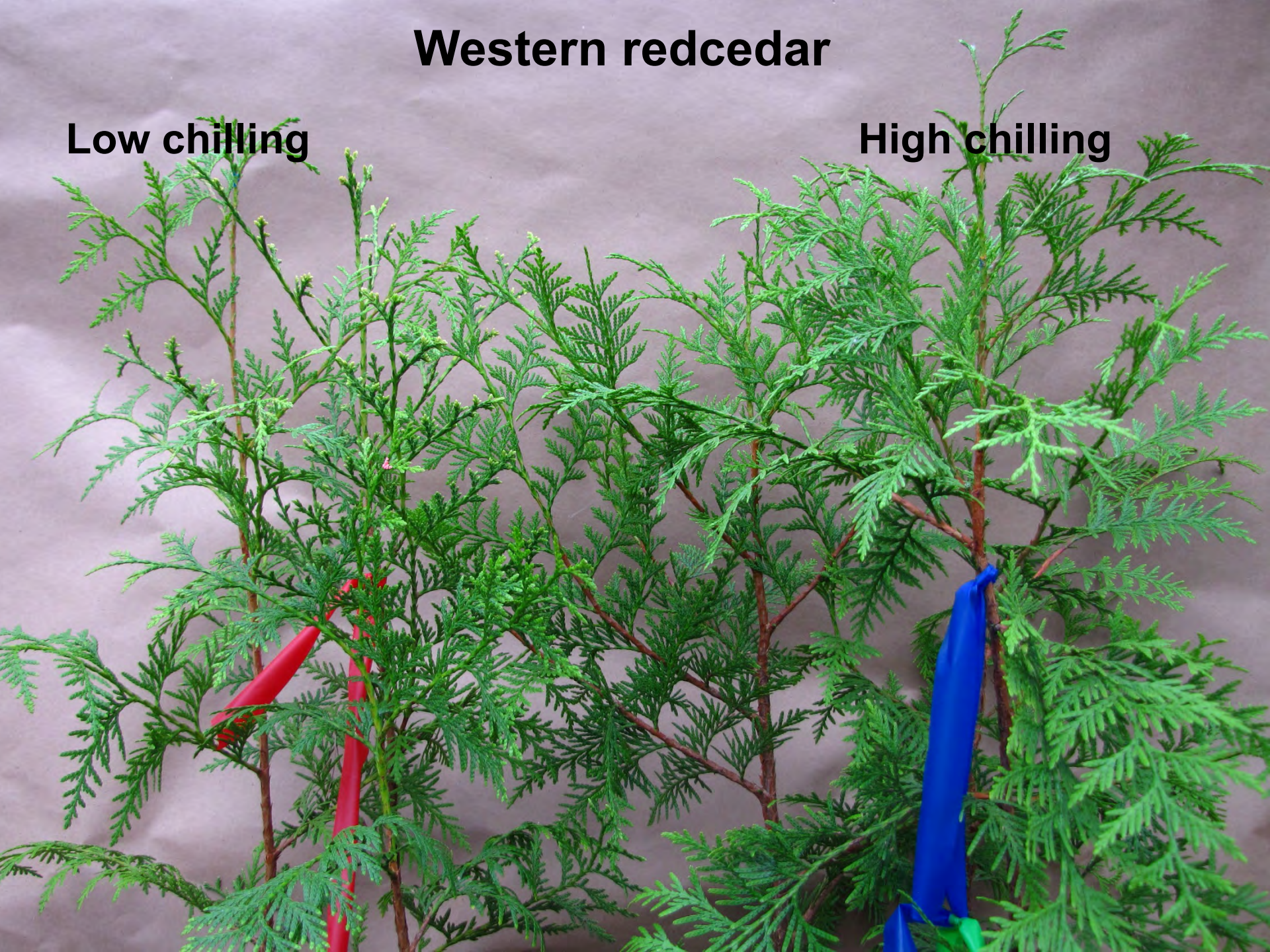
High chilling



Western redcedar

Low chilling

High chilling



Simplified Growth of Plants

Height growth:

Shoot apical meristem

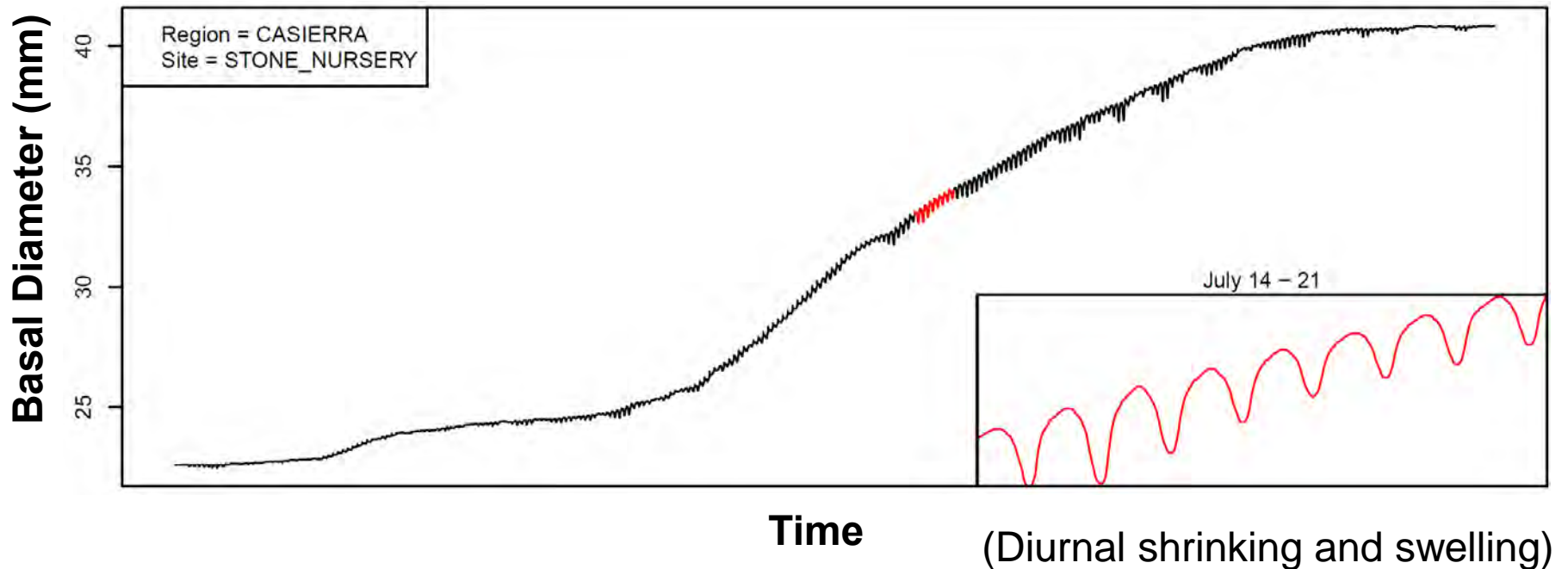
(creates needles, cones, stem)

Diameter growth:

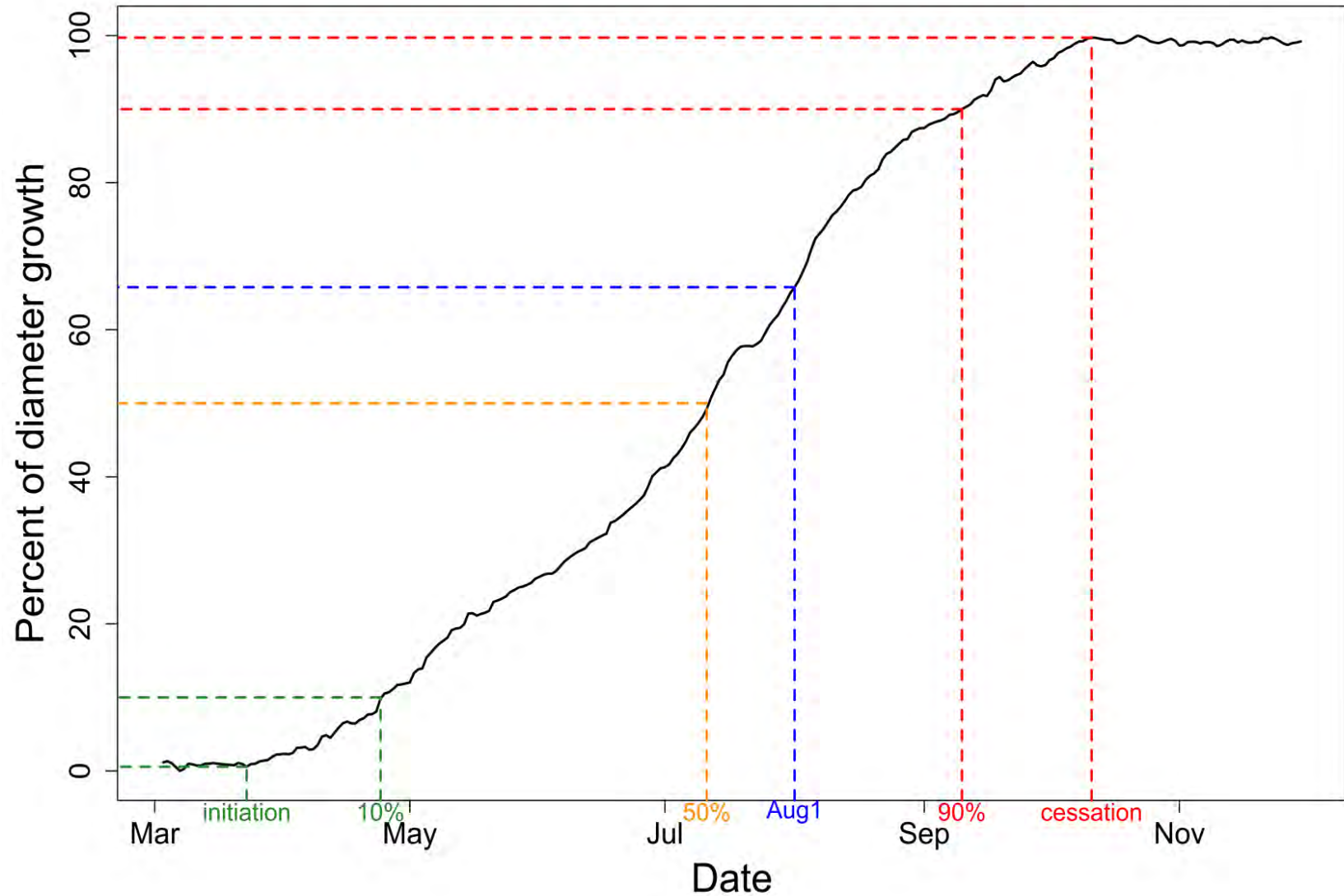
**Vascular cambium creates phloem &
xylem**

Phellogen creates bark

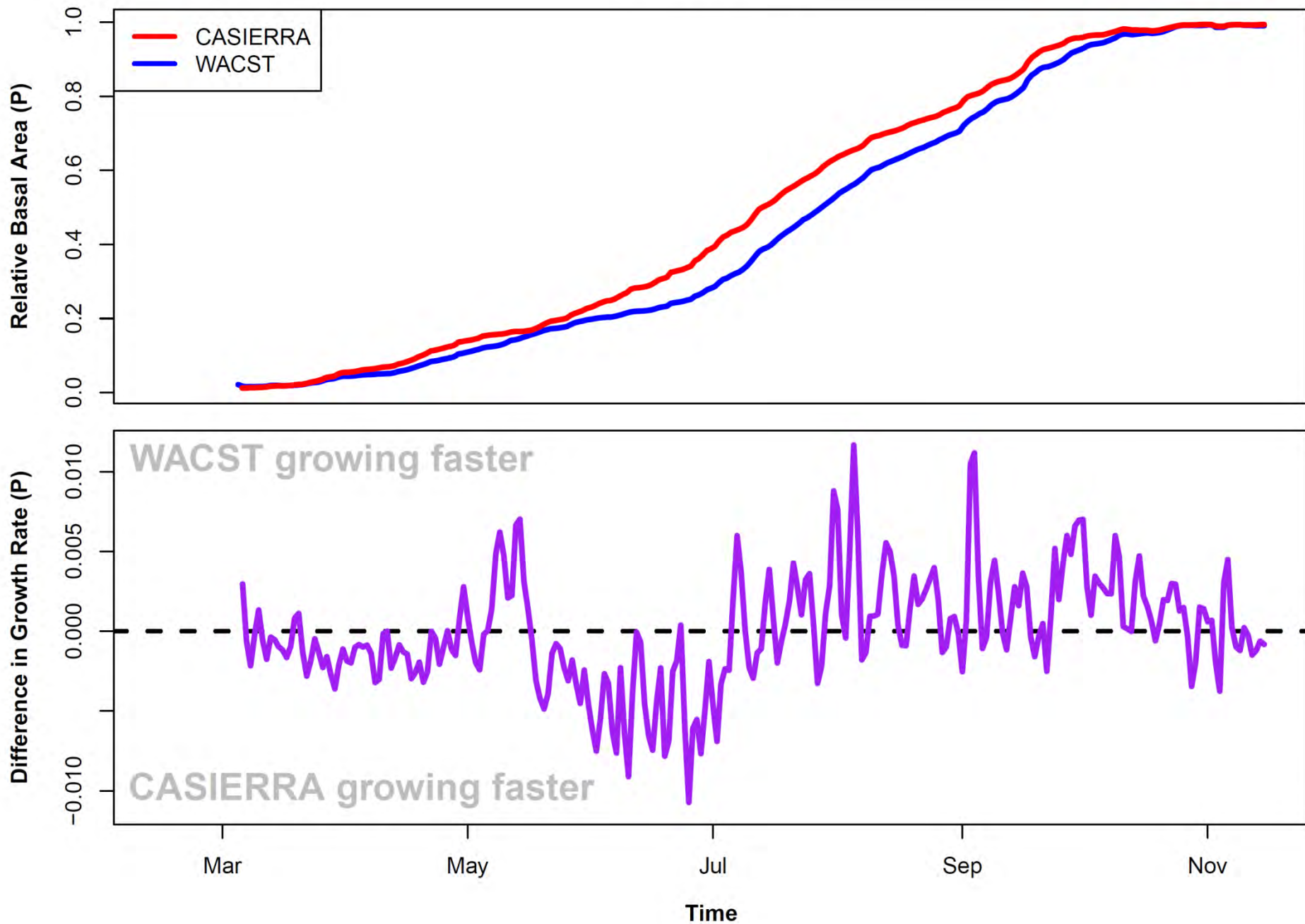
- Dendrometers can be used to look at timing of diameter growth (VC + phellogen)



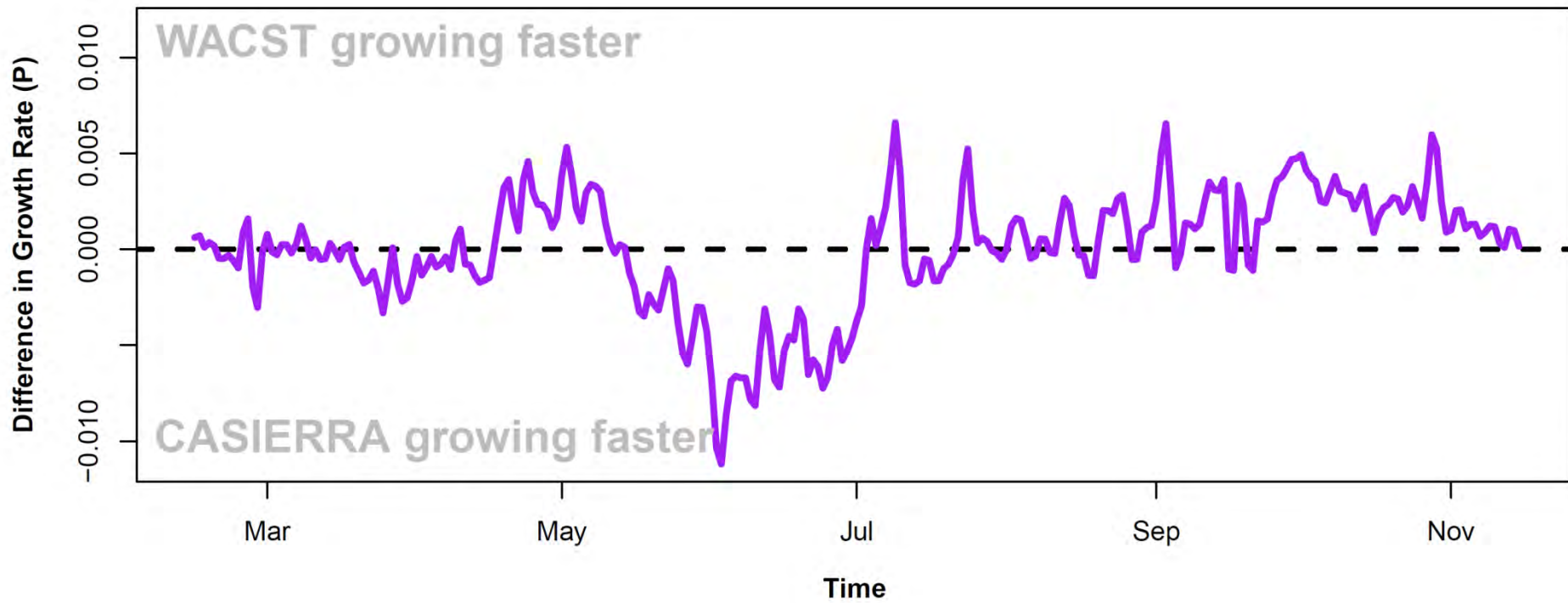
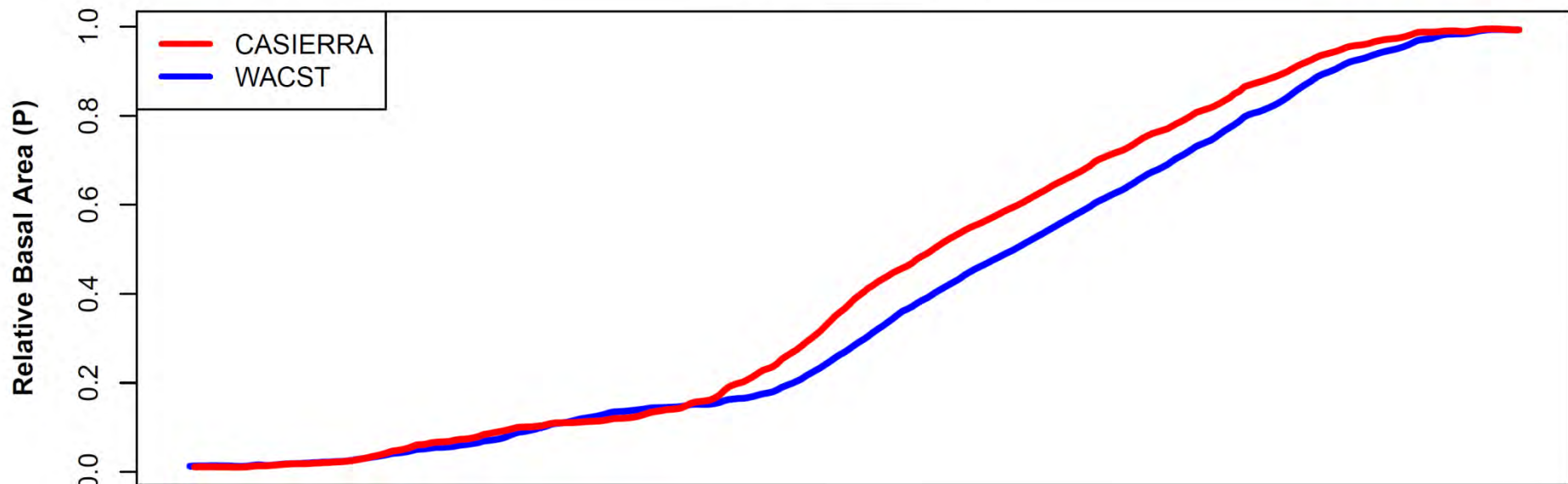
Dendrometer data



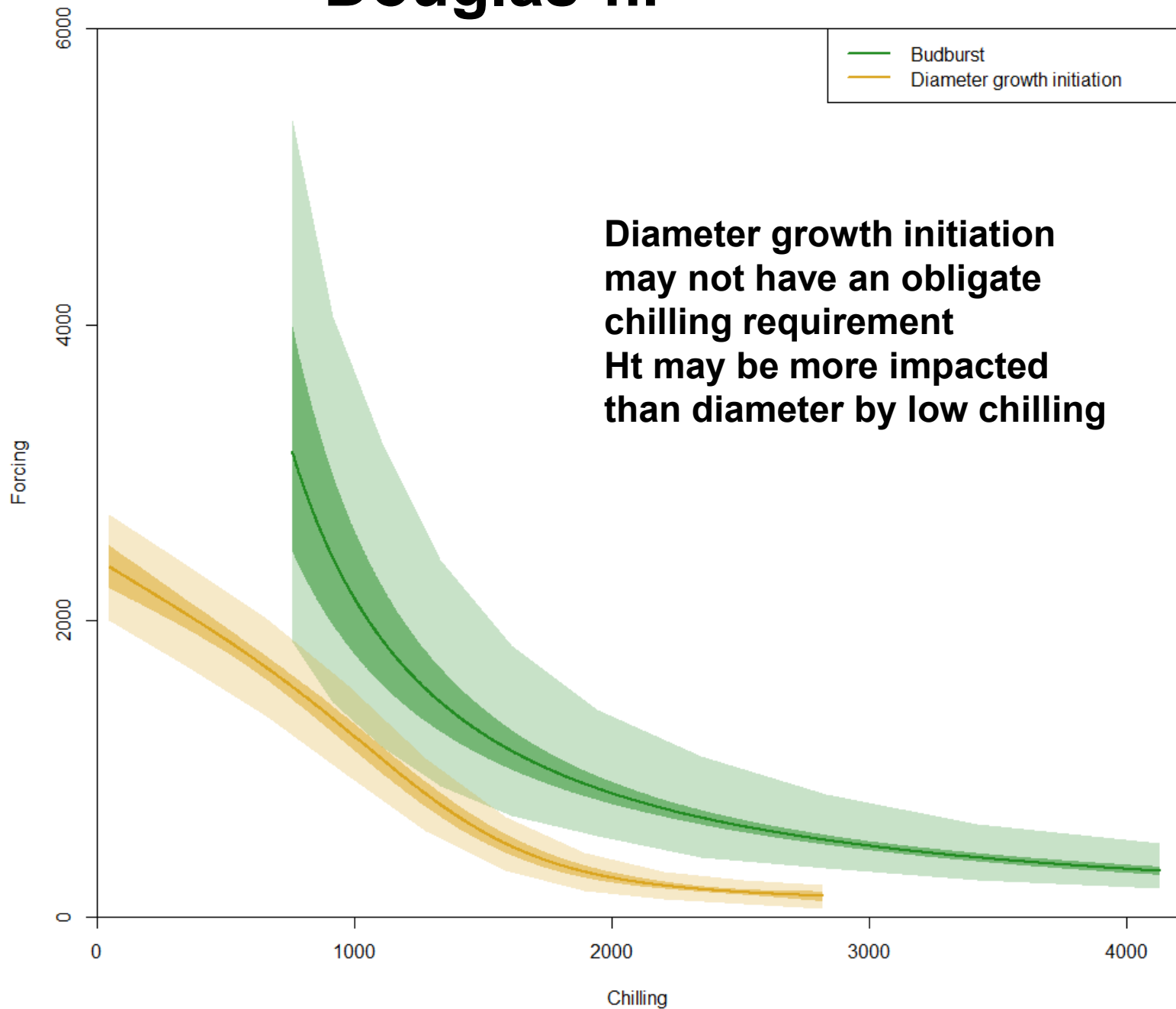
Buckhorn



Stone Nursery



Douglas-fir



How About **Reproductive** Buds?

Relatively little known in terms of predictive models

Value in older data to develop models

Start monitoring



WINGSCAPES

15 MINUTES

WP EARLY

APR.11,14

12:45 PM

**Western White Pine, Denny Ahl Seed Orchard
From Andy Bower, Olympic NF**



WINGSCAPES

15 MINUTES

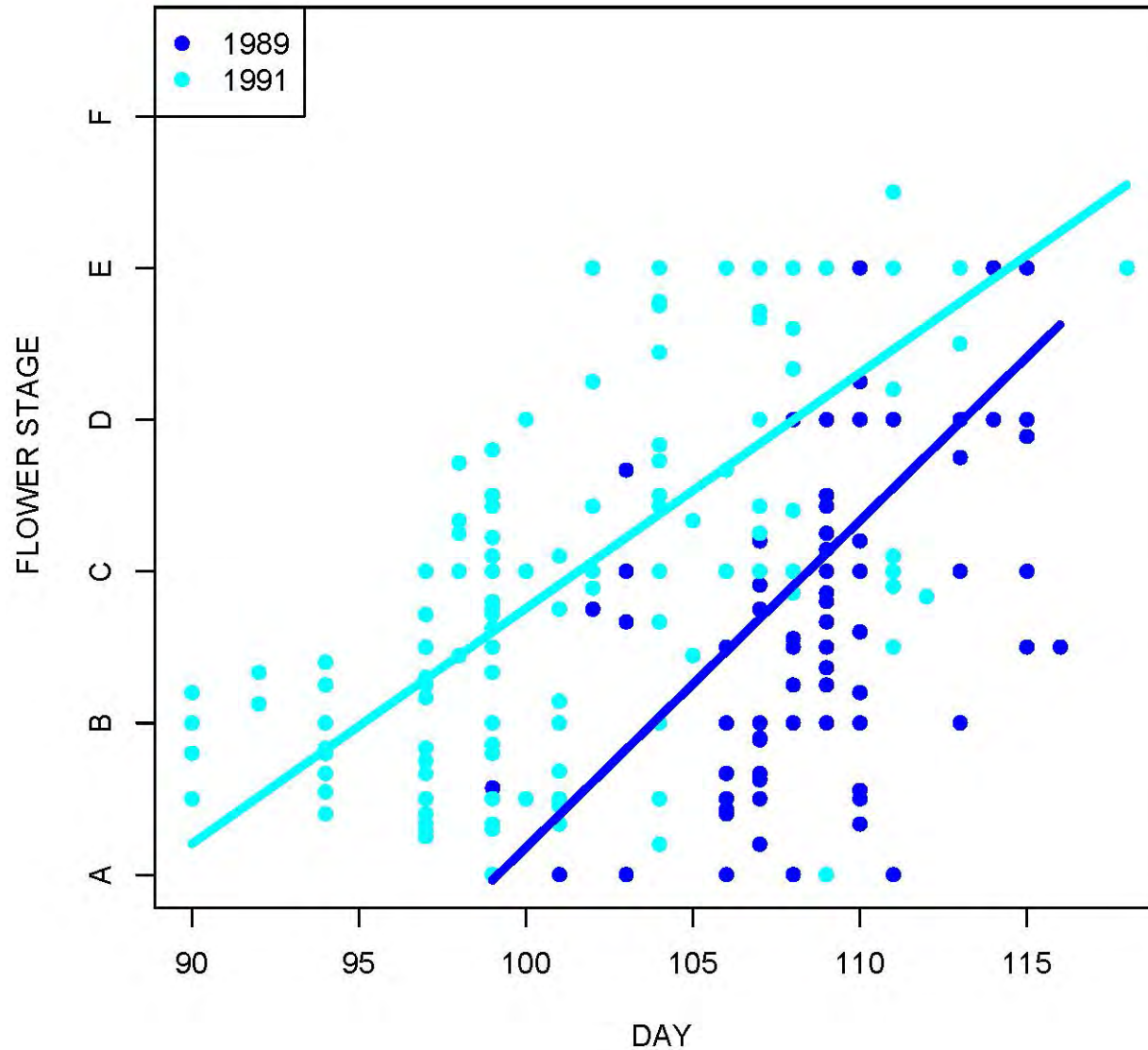
SF EARLY

APR.11,14

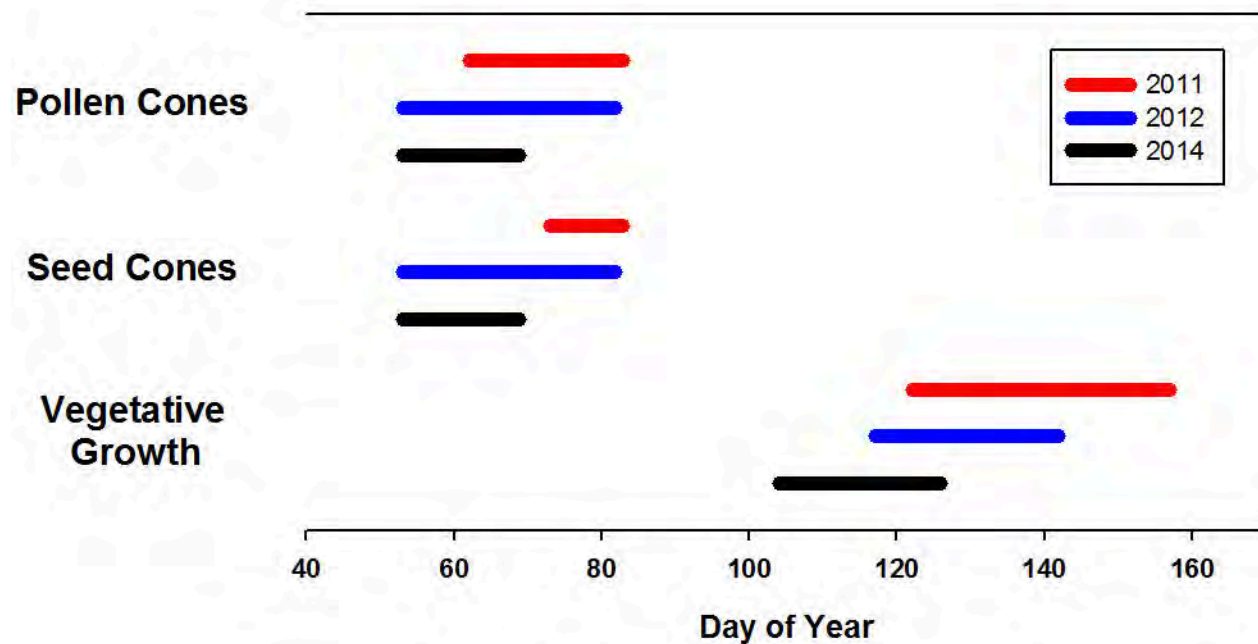
12:00 PM

**Pacific Silver Fir, Denny Ahl Seed Orchard
From Andy Bower, Olympic NF**

DF Cone Stages at DNR Meridian Seed Orchard



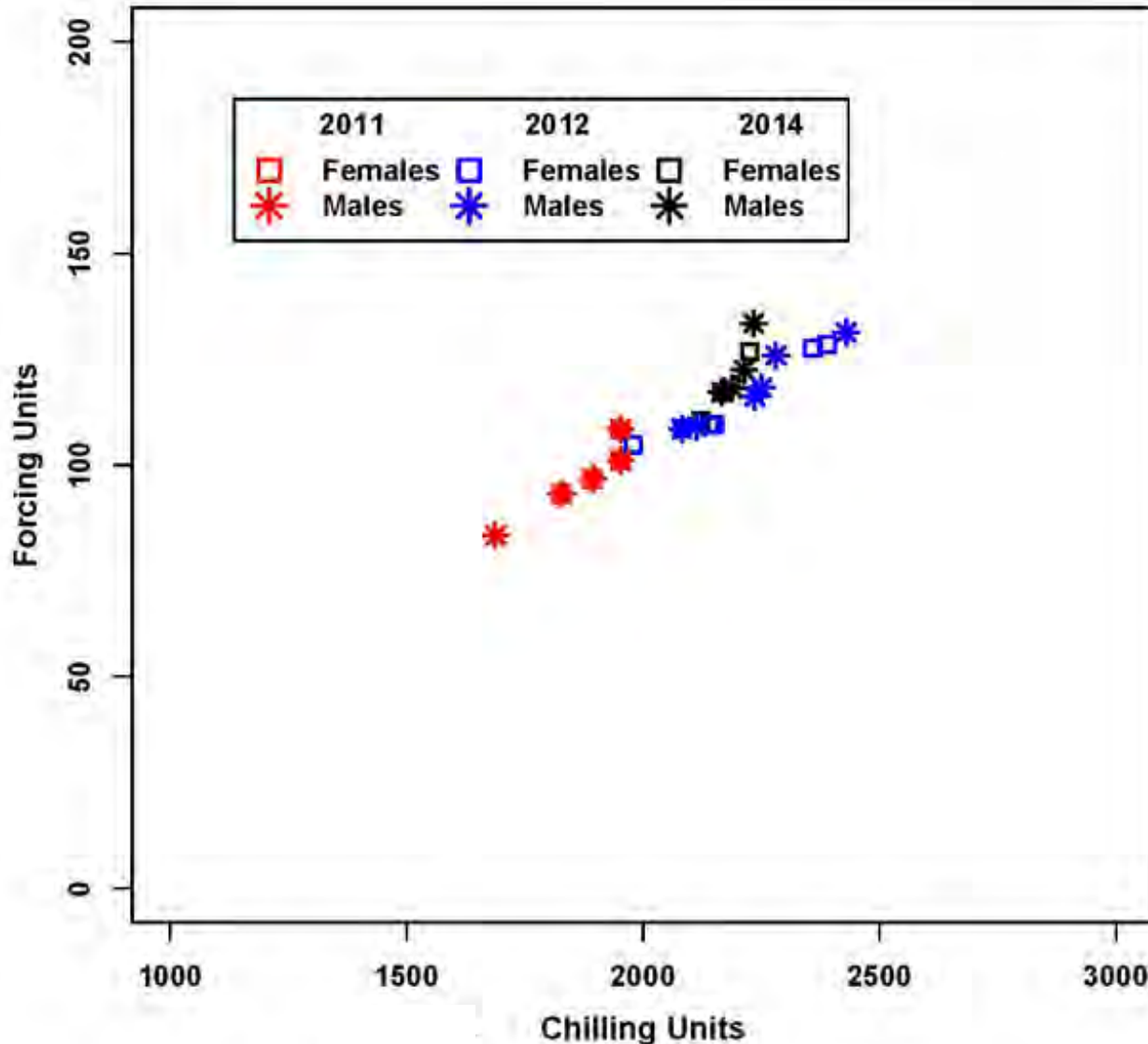
WRC Phenology at Meridian Seed Orchard



Length of horizontal lines indicates beginning and ending dates of event

WA DNR Meridian Seed Orchard

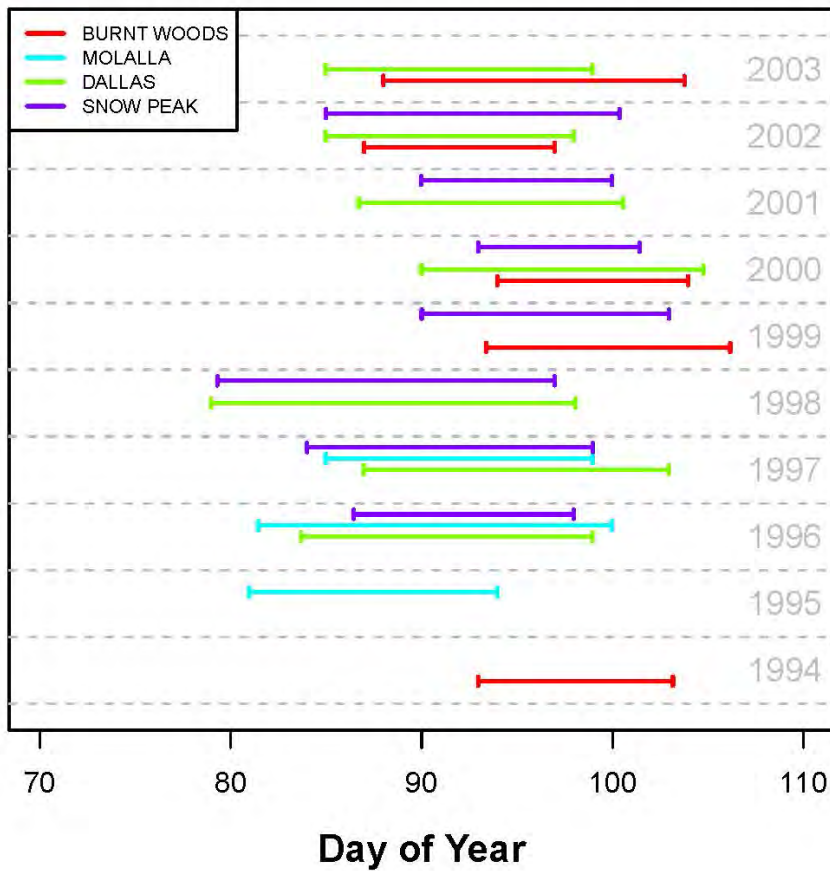
Western Redcedar



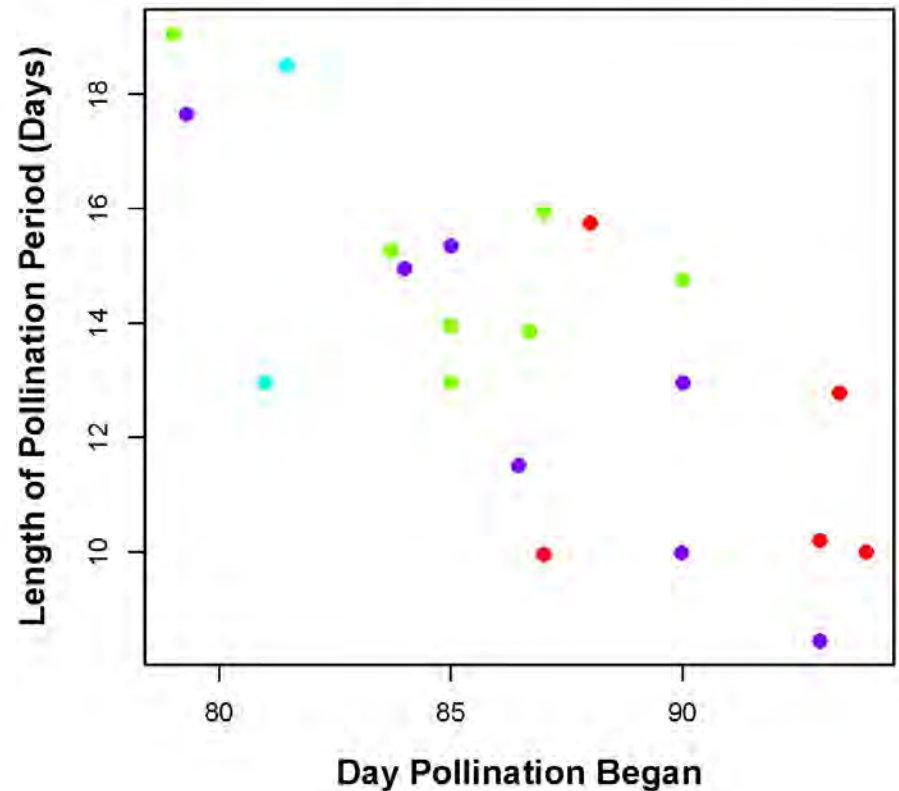
Combinations of chilling and forcing which are associated with pollen shed or receptiveness

ODF Schroeder Seed Orchard Records for DF

Periods when Pollination Took Place

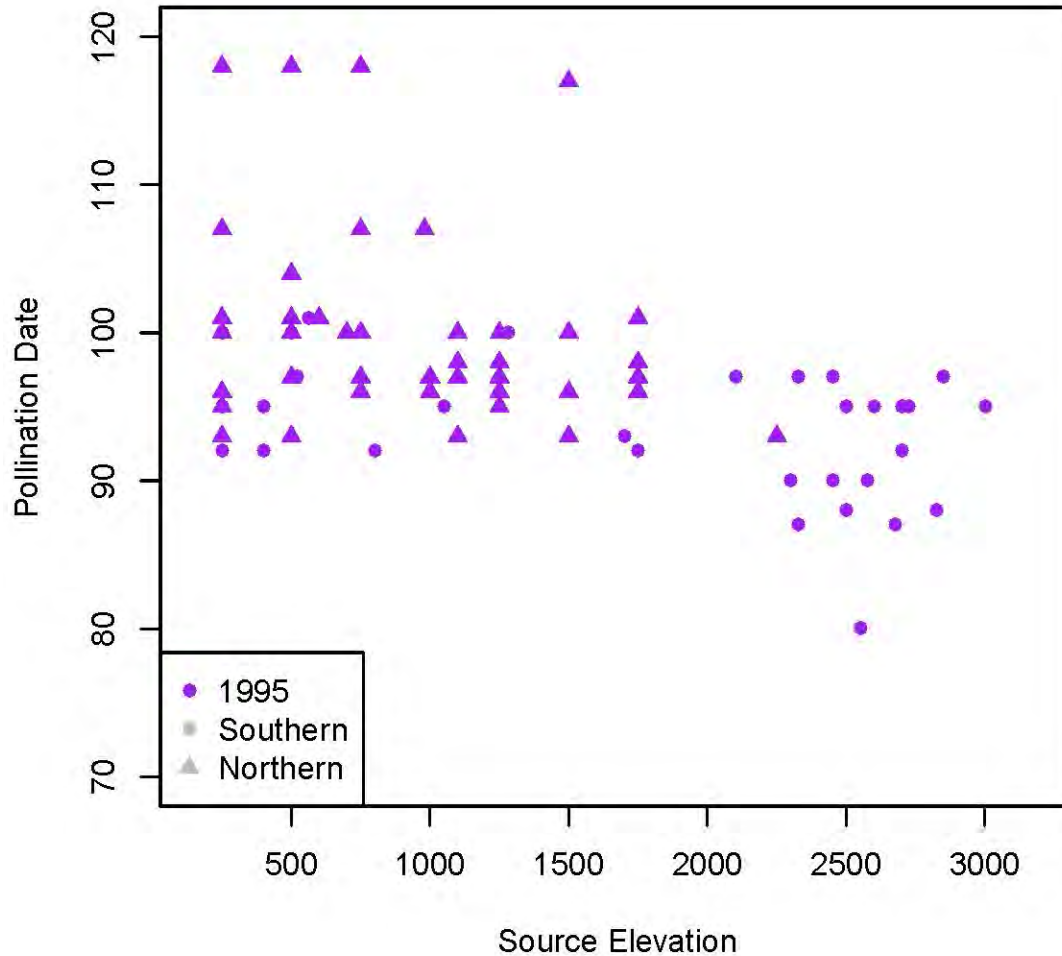


Is the pollination period shorter when it starts late?



Plum Creek Cottage Grove Orchard

(assume pollination date = receptive females)



Phenology matters!

**Winter/spring temperatures affect tree
“futures”**

Timing of growth, form, amount

Trees have “memories”

Ht vs Diam chilling requirements

**Species and genotypes differ in
responses**

We need **more pheno-studies!**

- **How different genotypes respond**
- **Veg. budburst plus flowering, budset, cambial and shoot growth, and how phenology affects cold hardiness, drought responses, I&D interactions etc**

Have I Convinced You?

Consider collecting data on phenology and temperature (PNW temp recorders?)

Time-lapse cameras (Andy Bower or me)

Share data you already have collected for other purposes (like timing of pollination)

Think carefully about potential use of historical data before discarding (scan it?)

The image features a warm, orange-hued sky, likely during a sunset or sunrise. Silhouetted evergreen trees are visible along the bottom edge, and a large, dark evergreen tree is on the right side. The word "Thanks!" is centered in the sky.

Thanks!



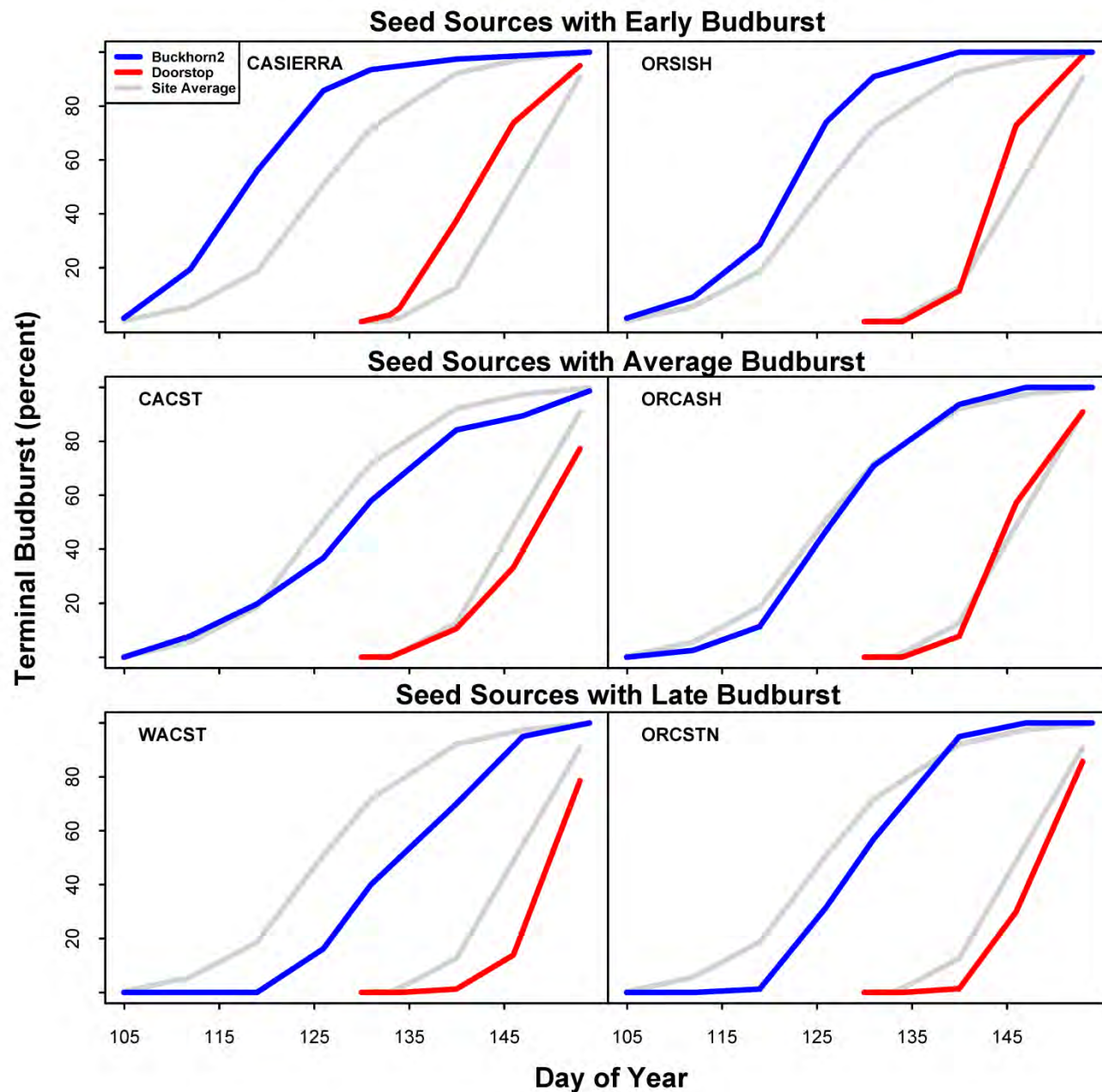
2012-04-18 13:30:00

Genetics and Silviculture Team, PNW Research Station



Low elevation site

High elevation site



**Spring
budburst of DF
in 2009 on 2
sites in WA**

Which families/regions had EARLIEST budburst in 2010?

Early Budburst: Top Row = Earliest Budburst

Rank	Doorstop	Buckhorn	Norton	Stone Nursery	Slice Butte	Evans Creek	Soda 320	Floras	Jammer
1	7042 CASIERRA	7802 CACST	7801 CACST	7038 CASIERRA	7802 CACST	7802 CACST	7038 CASIERRA	7802 CACST	7802 CACST
2	7047 CASIERRA	7801 CACST	7802 CACST	7802 CACST	7801 CACST	7038 CASIERRA	7039 CASIERRA	7807 CACST	7038 CASIERRA
3	7040 CASIERRA	7807 CACST	6005 ORSISH	1166 ORSISH	7806 CACST	7042 CASIERRA	7044 CASIERRA	7039 CASIERRA	3083 ORSISL
4	7045 CASIERRA	7038 CASIERRA	7038 CASIERRA	1199 ORCASL	7807 CACST	7039 CASIERRA	3077 ORSISL	3083 ORSISL	7806 CACST
5	1170 ORSISH	7042 CASIERRA	7043 CASIERRA	1026 ORCASL	7034 CAKLA	7801 CACST	3082 ORSISL	7038 CASIERRA	3306 ORSISL
6	3083 ORSISL	7043 CASIERRA	3083 ORSISL	6005 ORSISH	7038 CASIERRA	7810 CACST	3083 ORSISL	7042 CASIERRA	7040 CASIERRA
7	7038 CASIERRA	6005 ORSISH	3082 ORSISL	7801 CACST	7039 CASIERRA	7807 CACST	3285 ORSISL	7806 CACST	7047 CASIERRA
8	3028 ORCASL	3082 ORSISL	7806 CACST	7046 CASIERRA	7040 CASIERRA	7040 CASIERRA	1146 WACASH	7810 CACST	7807 CACST
9	3077 ORSISL	3083 ORSISL	7010 CAKLA	3077 ORSISL	7044 CASIERRA	3285 ORSISL	7043 CASIERRA	7047 CASIERRA	7034 CAKLA
10	7039 CASIERRA	1163 WACASH	7040 CASIERRA	3082 ORSISL	7047 CASIERRA	1163 WACASH	7802 CACST	3077 ORSISL	7039 CASIERRA
11	7044 CASIERRA	7047 CASIERRA	7045 CASIERRA	3306 ORSISL	6059 ORCSTS	7043 CASIERRA	7807 CACST	3095 ORSISL	7042 CASIERRA
12	1026 ORCASL	7046 CASIERRA	7047 CASIERRA	1146 WACASH	6005 ORSISH	3082 ORSISL	7810 CACST	1163 WACASH	7043 CASIERRA
13	6058 ORCSTS	3077 ORSISL	1167 ORSISH	7039 CASIERRA	3076 ORSISL	3083 ORSISL	7042 CASIERRA	7010 CAKLA	1026 ORCASL
14	6005 ORSISH	1146 WACASH	6004 ORSISH	6004 ORSISH	3077 ORSISL	7046 CASIERRA	6059 ORCSTS	3028 ORCASL	1198 ORCASL
15	3082 ORSISL	7039 CASIERRA	7039 CASIERRA	3083 ORSISL	3082 ORSISL	7806 CACST	7806 CACST	8528 ORCSTS	1199 ORCASL
16	3306 ORSISL	7040 CASIERRA	7007 CAKLA	1163 WACASH	3083 ORSISL	7034 CAKLA	7040 CASIERRA	8552 ORCSTS	3028 ORCASL
17	7802 CACST	7045 CASIERRA	7042 CASIERRA	7045 CASIERRA	3306 ORSISL	6020 ORCSTN	7801 CACST	3082 ORSISL	6059 ORCSTS
18	7034 CAKLA	1224 ORCASH	7046 CASIERRA	1198 ORCASL	1199 ORCASL	3180 ORCSTS	7034 CAKLA	3306 ORSISL	8528 ORCSTS
19	7036 CAKLA	6020 ORCSTN	1199 ORCASL	6020 ORCSTN	3095 ORSISL	7044 CASIERRA	7046 CASIERRA	7040 CASIERRA	1166 ORSISH
20	3076 ORSISL	3180 ORCSTS	5122 WACASH	7037 CAKLA	1163 WACASH	1198 ORCASL	3095 ORSISL	7045 CASIERRA	6005 ORSISH

Which families/regions set terminal bud FIRST in 2010?

Early Budset: Top Row = Earliest Budset

Rank	Doorstop	Buckhorn	Norton	Stone Nursery	Slice Butte	Evans Creek	Soda 320	Floras	Jammer
1	1146 WACASH	7034 CAKLA	7811 CACST	2028 ORCASH	7004 CAKLA	1162 WACASH	1029 ORCASH	5041 WACASH	1162 WACASH
2	1162 WACASH	2028 ORCASH	5202 WACASH	5130 WACASH	7809 CACST	5202 WACASH	1130 WACASL	8537 WACASL	1029 ORCASH
3	3134 ORSISH	4053 ORCASH	1162 WACASH	7034 CAKLA	5129 WACASH	4052 ORCASH	3029 ORCASH	1162 WACASH	1147 WACASH
4	1199 ORCASL	5202 WACASH	1163 WACASH	1147 WACASH	7010 CAKLA	5122 WACASH	3133 ORSISH	5202 WACASH	2028 ORCASH
5	4064 ORCASH	1162 WACASH	3134 ORSISH	1163 WACASH	7202 WACST	5129 WACASH	4053 ORCASH	5122 WACASH	5202 WACASH
6	3285 ORSISL	3134 ORSISH	5129 WACASH	4052 ORCASH	1162 WACASH	7808 CACST	5129 WACASH	1163 WACASH	1030 ORCASH
7	7044 CASIERRA	1030 ORCASH	7818 CACST	5122 WACASH	1030 ORCASH	2028 ORCASH	8547 WACASL	2028 ORCASH	7201 WACST
8	1166 ORSISH	5129 WACASH	2028 ORCASH	5129 WACASH	1199 ORCASL	7009 CAKLA	1026 ORCASL	3134 ORSISH	7202 WACST
9	3053 ORCASL	3094 ORSISL	7045 CASIERRA	5202 WACASH	1224 ORCASH	7035 CAKLA	1224 ORCASH	5130 WACASH	8026 WACST
10	4052 ORCASH	7004 CAKLA	1146 WACASH	8524 ORCSTN	8026 WACST	7201 WACST	2028 ORCASH	1152 WACASL	8028 WACST
11	5130 WACASH	7206 WACST	1030 ORCASH	8547 WACASL	1163 WACASH	8026 WACST	4052 ORCASH	5116 WACASL	5122 WACASH
12	5202 WACASH	7201 WACST	5130 WACASH	1166 ORSISH	3083 ORSISL	3053 ORCASL	4064 ORCASH	7035 CAKLA	1163 WACASH
13	7004 CAKLA	7009 CAKLA	7039 CASIERRA	1167 ORSISH	3134 ORSISH	3013 ORCASH	5041 WACASH	7036 CAKLA	3134 ORSISH
14	7034 CAKLA	7202 WACST	7044 CASIERRA	1171 ORSISH	3285 ORSISL	1029 ORCASH	5122 WACASH	7206 WACST	7007 CAKLA
15	7035 CAKLA	7811 CACST	7040 CASIERRA	1027 ORCASL	5122 WACASH	1030 ORCASH	5130 WACASH	8541 WACST	7034 CAKLA
16	7037 CAKLA	7039 CASIERRA	7038 CASIERRA	1162 WACASH	7036 CAKLA	5130 WACASH	8046 ORCSTN	3133 ORSISH	4052 ORCASH
17	7043 CASIERRA	1039 ORCASL	6005 ORSISH	3013 ORCASH	7808 CACST	6016 ORCSTN	8525 ORCSTN	1030 ORCASH	1151 WACASL
18	3013 ORCASH	1163 WACASH	1130 WACASL	3134 ORSISH	6004 ORSISH	7034 CAKLA	1162 WACASH	1039 ORCASL	5115 WACASL
19	7045 CASIERRA	5116 WACASL	3285 ORSISL	7035 CAKLA	3076 ORSISL	7037 CAKLA	7005 CAKLA	5115 WACASL	7205 WACST
20	8045 ORCSTN	7008 CAKLA	1170 ORSISH	8028 WACST	1198 ORCASL	7045 CASIERRA	3053 ORCASL	5129 WACASH	4064 ORCASH

Which families/regions had LATEST budburst in 2010?

Late Budburst: Top Row = Latest Budburst

Rank	Doorstop	Buckhorn	Norton	Stone Nursery	Slice Butte	Evans Creek	Soda 320	Floras	Jammer
1	7202 WACST	7206 WACST	7817 CACST	7206 WACST	3147 ORCSTN	7202 WACST	5042 WACASH	8027 WACST	7201 WACST
2	7817 CACST	8046 ORCSTN	1030 ORCASH	8045 ORCSTN	7201 WACST	7009 CAKLA	1152 WACASL	8028 WACST	7202 WACST
3	8046 ORCSTN	5115 WACASL	5042 WACASH	8542 WACST	7206 WACST	1029 ORCASH	5116 WACASL	1147 WACASH	7818 CACST
4	7201 WACST	7201 WACST	1152 WACASL	1029 ORCASH	8026 WACST	1030 ORCASH	7201 WACST	1151 WACASL	8045 ORCSTN
5	1147 WACASH	7202 WACST	7201 WACST	7811 CACST	1030 ORCASH	2028 ORCASH	7206 WACST	7205 WACST	8046 ORCSTN
6	5115 WACASL	8025 WACST	8026 WACST	7817 CACST	8548 WACASL	3014 ORCASH	7202 WACST	8542 WACST	1147 WACASH
7	7206 WACST	8027 WACST	8028 WACST	7035 CAKLA	8028 WACST	1147 WACASH	7205 WACST	7202 WACST	1152 WACASL
8	7808 CACST	1030 ORCASH	5041 WACASH	7044 CASIERRA	1029 ORCASH	5042 WACASH	8026 WACST	1027 ORCASH	7206 WACST
9	7810 CACST	3014 ORCASH	8046 ORCSTN	3147 ORCSTN	7004 CAKLA	1151 WACASL	8028 WACST	8045 ORCSTN	5041 WACASH
10	7010 CAKLA	7205 WACST	7202 WACST	7004 CAKLA	7035 CAKLA	1152 WACASL	7808 CACST	5041 WACASH	5042 WACASH
11	7035 CAKLA	1147 WACASH	5115 WACASL	6016 ORCSTN	3014 ORCASH	8538 WACASL	7035 CAKLA	1152 WACASL	1151 WACASL
12	7037 CAKLA	5041 WACASH	1147 WACASH	6021 ORCSTN	6016 ORCSTN	7201 WACST	1029 ORCASH	8538 WACASL	8538 WACASL
13	3014 ORCASH	1152 WACASL	7206 WACST	5116 WACASL	8524 ORCSTN	7205 WACST	8045 ORCSTN	5042 WACASH	8025 WACST
14	3147 ORCSTN	8045 ORCSTN	8538 WACASL	7202 WACST	3133 ORSISH	7206 WACST	8547 WACASL	3147 ORCSTN	8027 WACST
15	8525 ORCSTN	8538 WACASL	8025 WACST	7205 WACST	5042 WACASH	8025 WACST	8548 WACASL	3148 ORCSTN	8028 WACST
16	3133 ORSISH	8026 WACST	8027 WACST	1223 ORCASH	5129 WACASH	8026 WACST	8025 WACST	6016 ORCSTN	1030 ORCASH
17	5042 WACASH	8028 WACST	7811 CACST	4053 ORCASH	5130 WACASH	8027 WACST	8027 WACST	8046 ORCSTN	5116 WACASL
18	5130 WACASH	5116 WACASL	1039 ORCASH	3148 ORCSTN	1151 WACASL	4052 ORCASH	1030 ORCASH	8524 ORCSTN	7205 WACST
19	1131 WACASL	1027 ORCASH	6016 ORCSTN	8046 ORCSTN	1152 WACASL	8046 ORCSTN	8046 ORCSTN	5116 WACASL	8026 WACST
20	1151 WACASL	1038 ORCASH	6021 ORCSTN	8524 ORCSTN	5115 WACASL	5130 WACASH	1147 WACASH	8537 WACASL	7817 CACST

Which families/regions set terminal bud LAST in 2010?

Late Budset: Top Row = Latest Budset

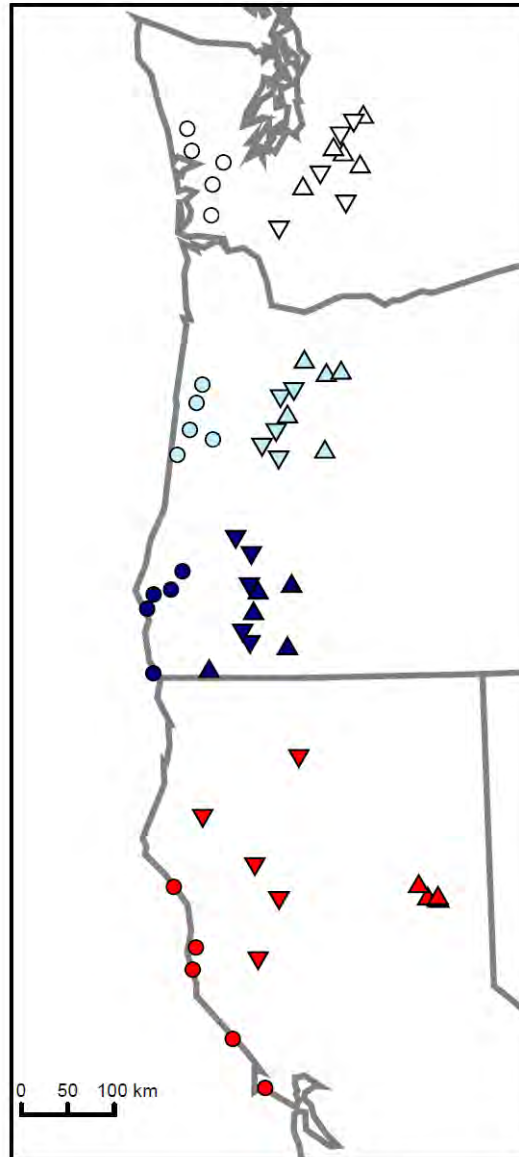
Rank	Doorstop	Buckhorn	Norton	Stone Nursery	Slice Butte	Evans Creek	Soda 320	Floras	Jammer
1	1151 WACASL	7818 CACST	8046 ORCSTN	7811 CACST	7818 CACST	3209 ORCSTS	6019 ORCSTN	7806 CACST	7206 WACST
2	7042 CASIERRA	1029 ORCASH	7817 CACST	1026 ORCASH	7206 WACST	7807 CACST	1131 WACASL	8524 ORCSTN	5041 WACASH
3	3296 ORSISH	6021 ORCSTN	7206 WACST	3029 ORCASH	8027 WACST	6048 ORCSTS	6048 ORCSTS	8551 ORCSTS	7817 CACST
4	3094 ORSISL	7007 CAKLA	8026 WACST	7802 CACST	7009 CAKLA	7817 CACST	8045 ORCSTN	3094 ORSISL	8542 WACST
5	8541 WACST	7808 CACST	8542 WACST	8046 ORCSTN	3147 ORCSTN	6058 ORCSTS	7802 CACST	3028 ORCASH	7810 CACST
6	7807 CACST	8046 ORCSTN	1026 ORCASH	8538 WACASL	6016 ORCSTN	3028 ORCASH	3083 ORSISL	3077 ORSISL	7005 CAKLA
7	6005 ORSISH	8538 WACASL	5116 WACASL	7810 CACST	6020 ORCSTN	3054 ORCASH	1151 WACASL	6021 ORCSTN	8525 ORCSTN
8	7810 CACST	8551 ORCSTS	6016 ORCSTN	7808 CACST	1151 WACASL	6004 ORSISH	3094 ORSISL	7047 CASIERRA	3133 ORSISH
9	1170 ORSISH	3028 ORCASH	6021 ORCSTN	3147 ORCSTN	6021 ORCSTN	6050 ORCSTS	7008 CAKLA	7040 CASIERRA	3054 ORCASH
10	3076 ORSISL	7810 CACST	6058 ORCSTS	1030 ORCASH	6059 ORCSTS	7806 CACST	7801 CACST	3054 ORCASH	7801 CACST
11	3077 ORSISL	7817 CACST	6059 ORCSTS	3209 ORCSTS	7041 CASIERRA	7811 CACST	3082 ORSISL	3082 ORSISL	7809 CACST
12	6016 ORCSTN	1151 WACASL	7202 WACST	6021 ORCSTN	3094 ORSISL	8548 WACASL	7810 CACST	3147 ORCSTN	7818 CACST
13	7801 CACST	3180 ORCSTS	7801 CACST	6019 ORCSTN	6058 ORCSTS	1223 ORCASH	3095 ORSISL	3180 ORCSTS	8524 ORCSTN
14	3028 ORCASH	7801 CACST	7802 CACST	7801 CACST	7005 CAKLA	7802 CACST	1163 WACASH	3209 ORCSTS	6021 ORCSTN
15	5116 WACASL	8542 WACST	8025 WACST	7806 CACST	1131 WACASL	6005 ORSISH	3077 ORSISL	8045 ORCSTN	7041 CASIERRA
16	6019 ORCSTN	5041 WACASH	8028 WACST	6058 ORCSTS	1167 ORSISH	7038 CASIERRA	7807 CACST	1027 ORCASH	3180 ORCSTS
17	6050 ORCSTS	1199 ORCASH	8045 ORCSTN	7817 CACST	3180 ORCSTS	1038 ORCASH	3014 ORCASH	1198 ORCASH	5116 WACASL
18	3082 ORSISL	6016 ORCSTN	8525 ORCSTN	3094 ORSISL	4064 ORCASH	5116 WACASL	3076 ORSISL	6058 ORCSTS	8046 ORCSTN
19	7009 CAKLA	7046 CASIERRA	8552 ORCSTS	1223 ORCASH	7807 CACST	7042 CASIERRA	3296 ORSISH	7044 CASIERRA	3147 ORCSTN
20	8542 WACST	7807 CACST	3028 ORCASH	6005 ORSISH	8025 WACST	8552 ORCSTS	7047 CASIERRA	8028 WACST	7045 CASIERRA

Douglas-Fir Seed Source Movement Trial

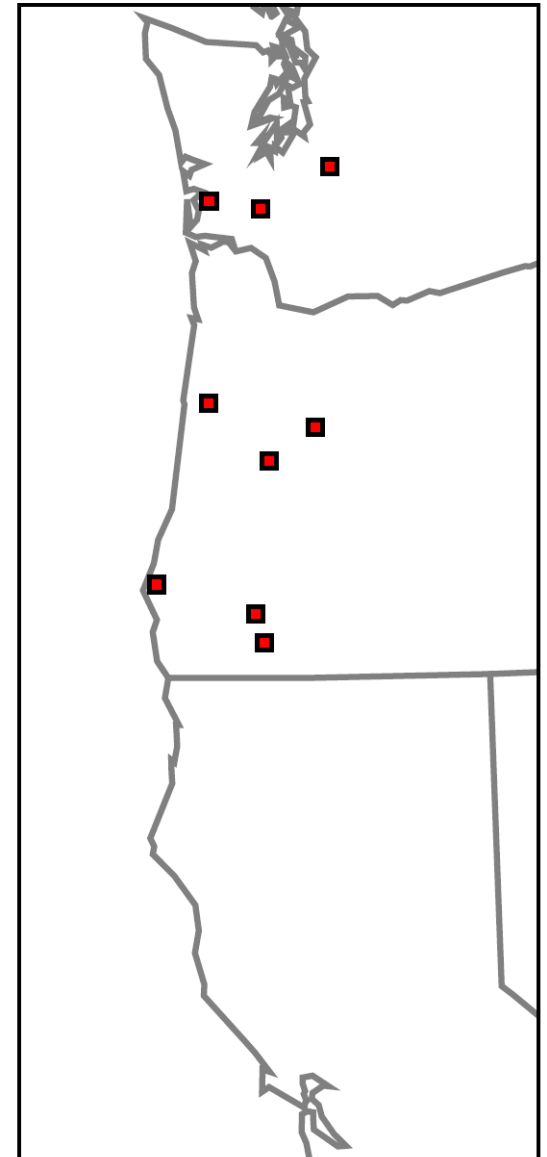
- Established 2009
- 60 populations
- 9 planting locations in diverse environment

Each location has
different landowner

Populations



**Planting
Locations**



Douglas-fir

Historic Climate



2080 Climate (A2 Scenario)



March 17

Pacific Madrone

Historic Climate

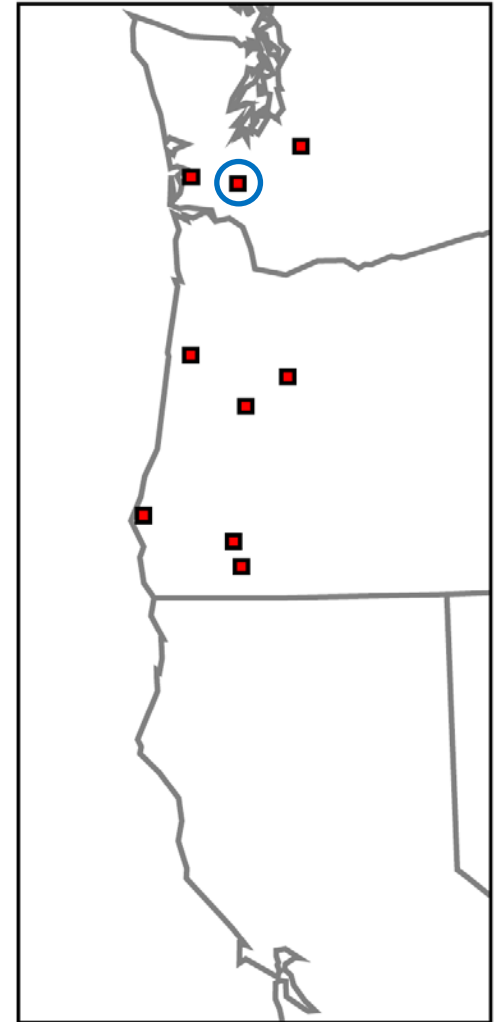
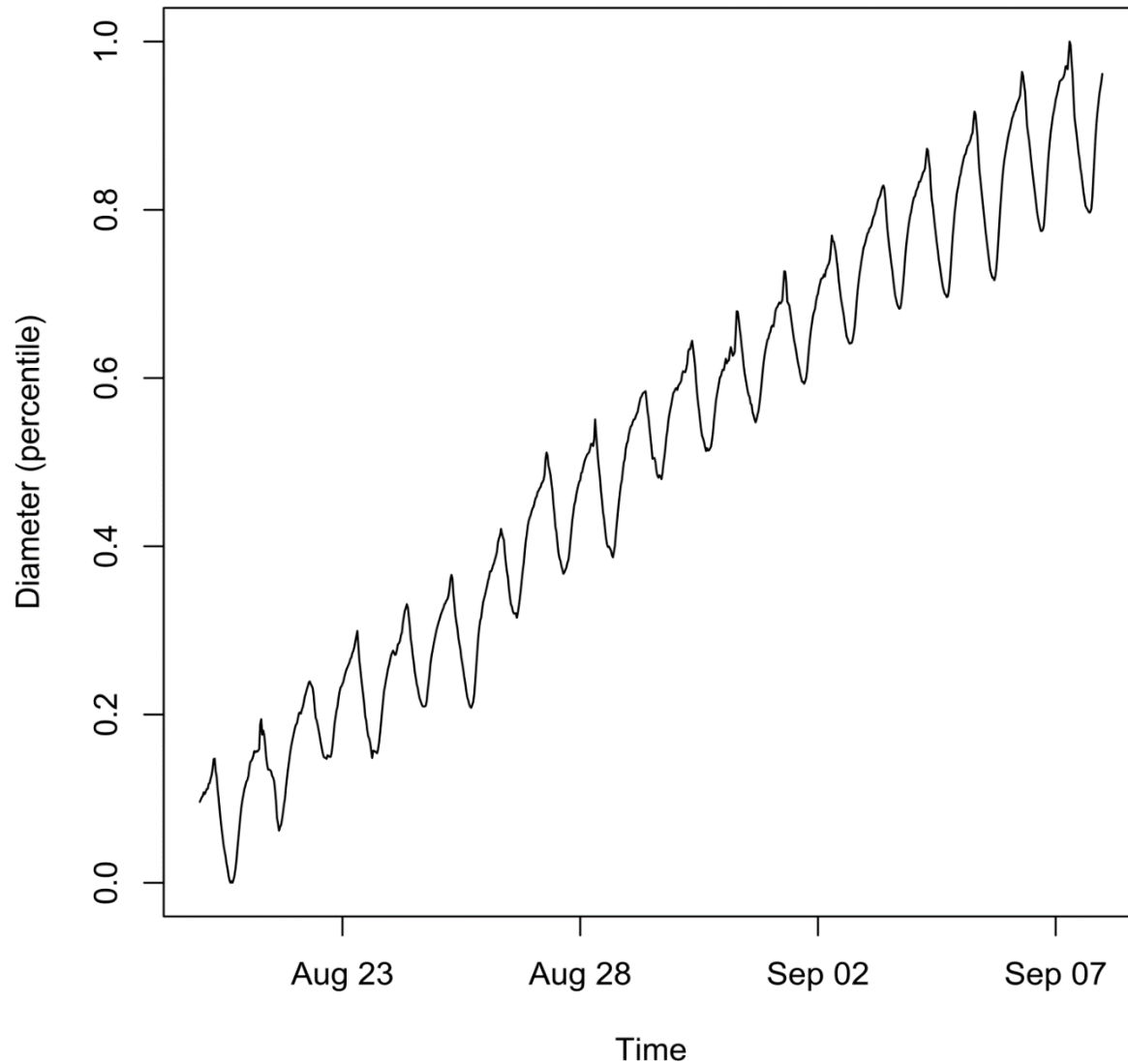


2080 Climate (A2 Scenario)

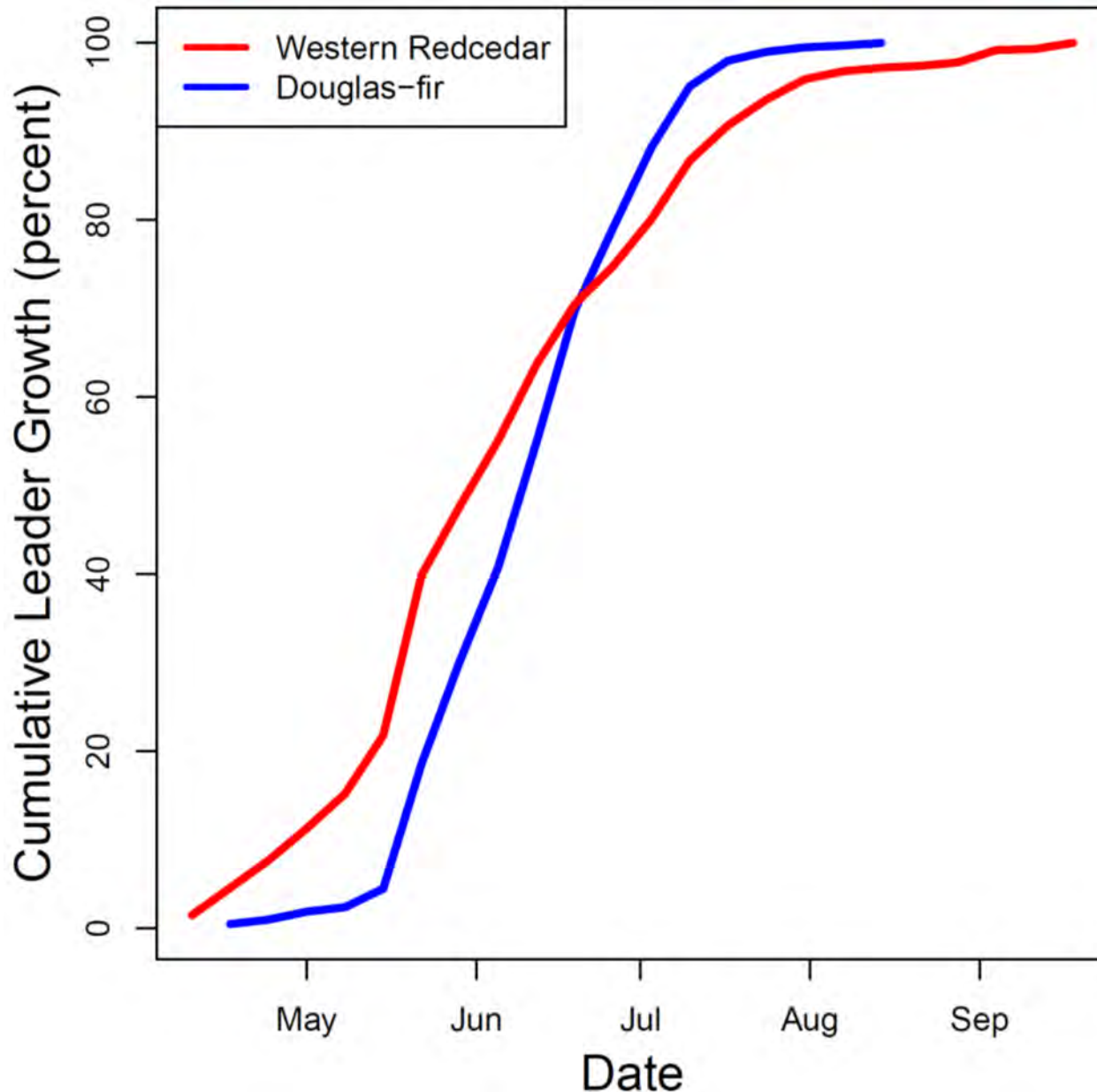


February 18

Daily dendrometer fluctuations



Seasonal Leader Growth



**12 -13 trees
per species,
1961, near
Haney, BC**

**Growth of
WRC started
sooner and
lasted longer
than growth
of DF**

**From
Walters and Soos 1963**

Stem Cells

Will differentiate into various tissue types depending on chemical signal

Former forestry terminology -- mother cells and daughter cells

Growth of plants

- Occurs via **cell division** and **cell elongation**
- **Cell division** occurs in **meristems**
- **Meristems** include **stem cells** that produce other cells that can turn into various types of cells through a process called **differentiation**
- **Primary meristems** – found in the embryo of the seed. Primary tissues are formed from primary meristems.

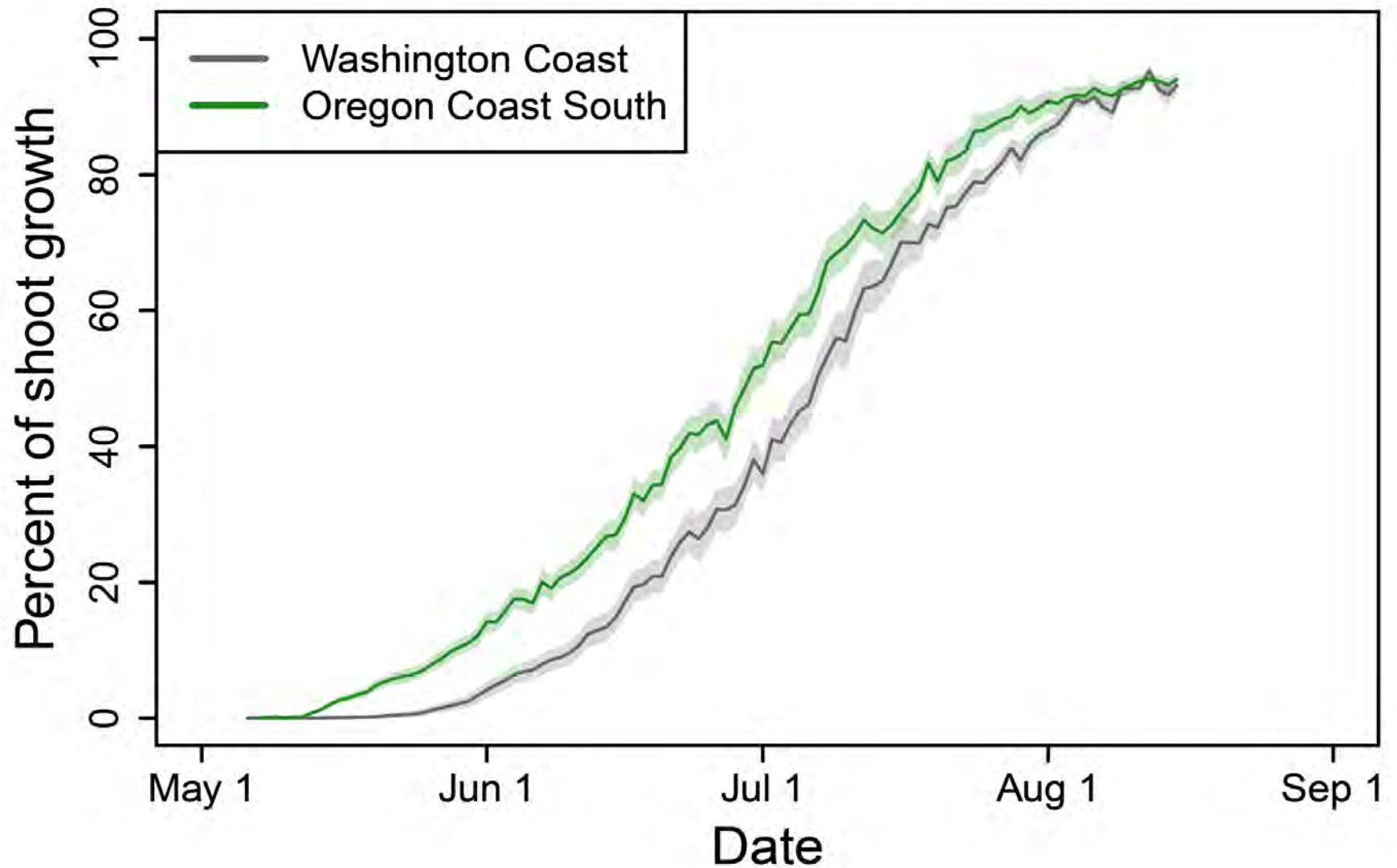
How Do Trees Grow?

- **Shoot Growth (Height Growth)**
- **Dormancy (models, predictions, seedling trials)**

Ongoing Research (SSMT)

Collaboration - Past and Future

Shoot growth with SE

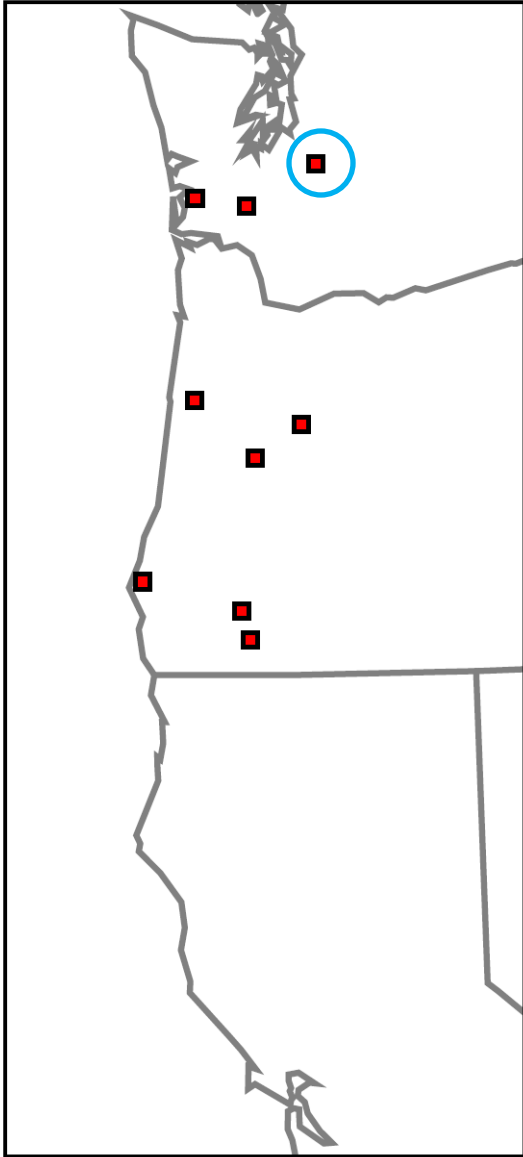


Range of test environments

WA High Elevation: coldest site, wet.

2010 Growing Season

mean max T = 16.1°C, Precip = 671 mm

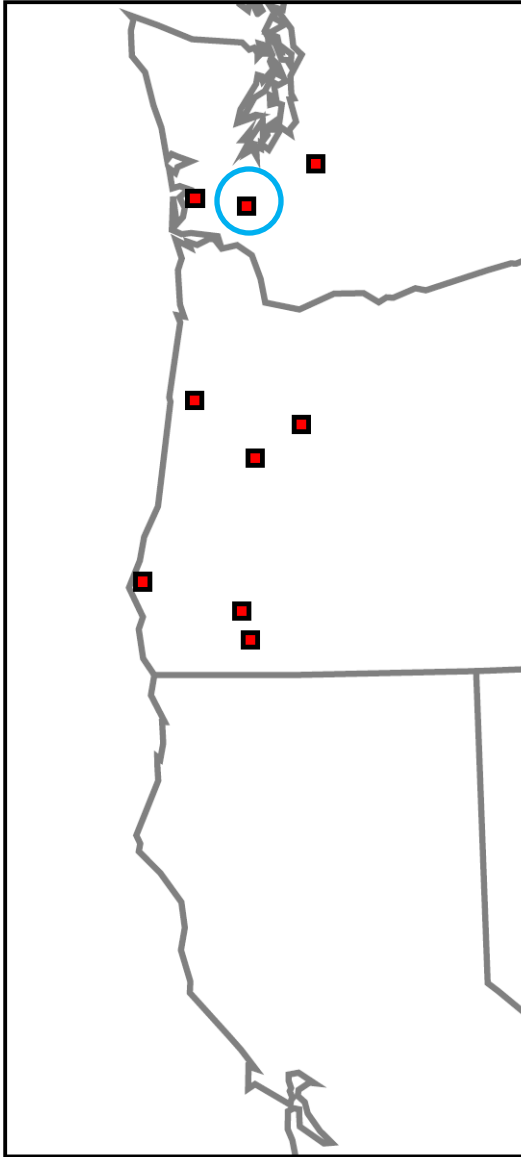


Range of test environments

WA Low Elevation: warmer, drier.

2010 Growing Season

mean max T = 18.7°C , Precip = 420 mm

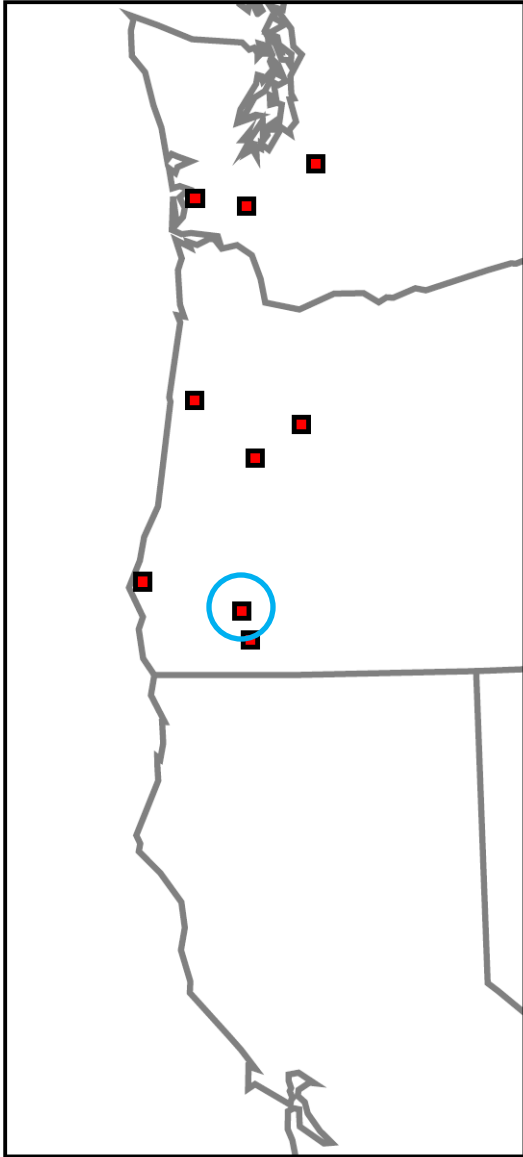


Range of test environments

OR Low Elevation: warmest, driest site.

2010 Growing Season

mean max T = 24.9°C, Precip = 184 mm



Determinant Growth Options

2nd Yr

1st Year

Chilling &/or Photoperiod Requirement Met

Chilling &/or Photoperiod Requirement Met

Spring

Summer

Fall

Winter

Spring

1st

Flush →

Overwin-
tered
buds

Fixed Growth

Overwintered leaf primordia
elongate

**Continuous
growth**

(outgrowth of
new buds)

Rapid return
to forming
leaf primordia

**Bud Scale
Formation**

Bud forms

**Endo-
dormancy**

Reproductive
structures form

1st
Flush

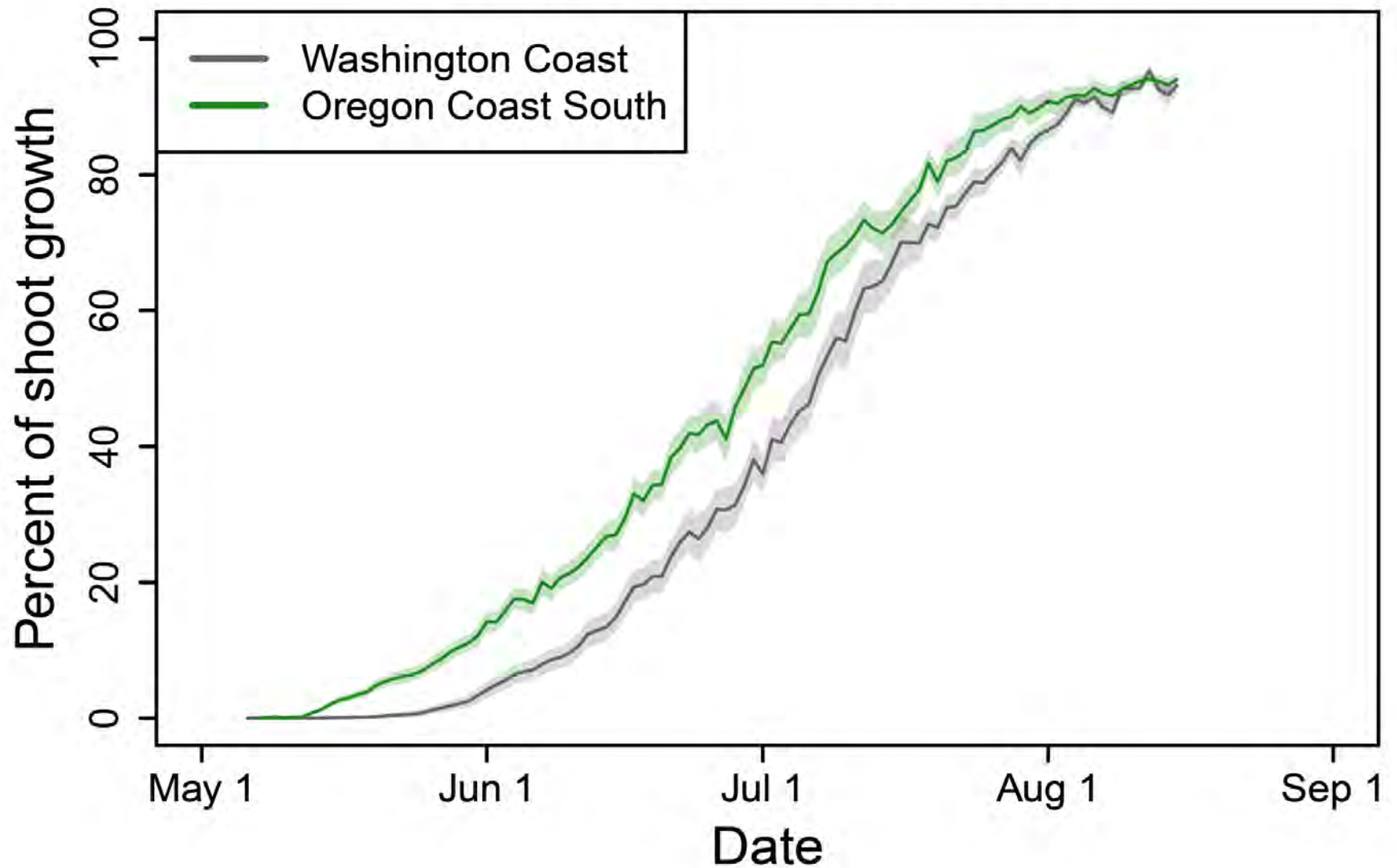
Free Growth

Pause, then return to
forming leaf primordia

Second flushing

So, second flushing indicates conditions
became **less** favorable, then improved

Shoot growth with SE



Bud development and response to chilling

Plants set bud in response to external stimuli:

- Drought
- Nutrient stress
- Shortening photoperiod
- High night respiration rates

Bud development cont'd

Once set, buds develop a primordia shoot under the bud scales:

- This process starts 2-3 weeks after bud scales cover the apex (visible by leaf primordia starting to form below the shoot apical meristem)
- Once the primordial shoot is formed, dormancy occurs. Period of very little cell division
- Douglas-fir and others have an obligate (aka absolute) chilling requirement for bud break

Shoot Growth

Types

Timing

Implications

No Buds = Indeterminant Growth

(Free growth)

No “leaf bank”

No protection of new tissues

Has less woody stem for long time

Can grow when conditions are favorable

Likely “increasers” under climate change

Examples – cedars and junipers

**Few leaves in the bud =
indeterminant growth**

**Shoot apex must produce new leaf
primordia rapidly**

**Length of shoot almost completely
dependent on current season
conditions**

Examples – cottonwood, hemlock

Many Leaves in Buds = Determinant Growth (Fixed growth)

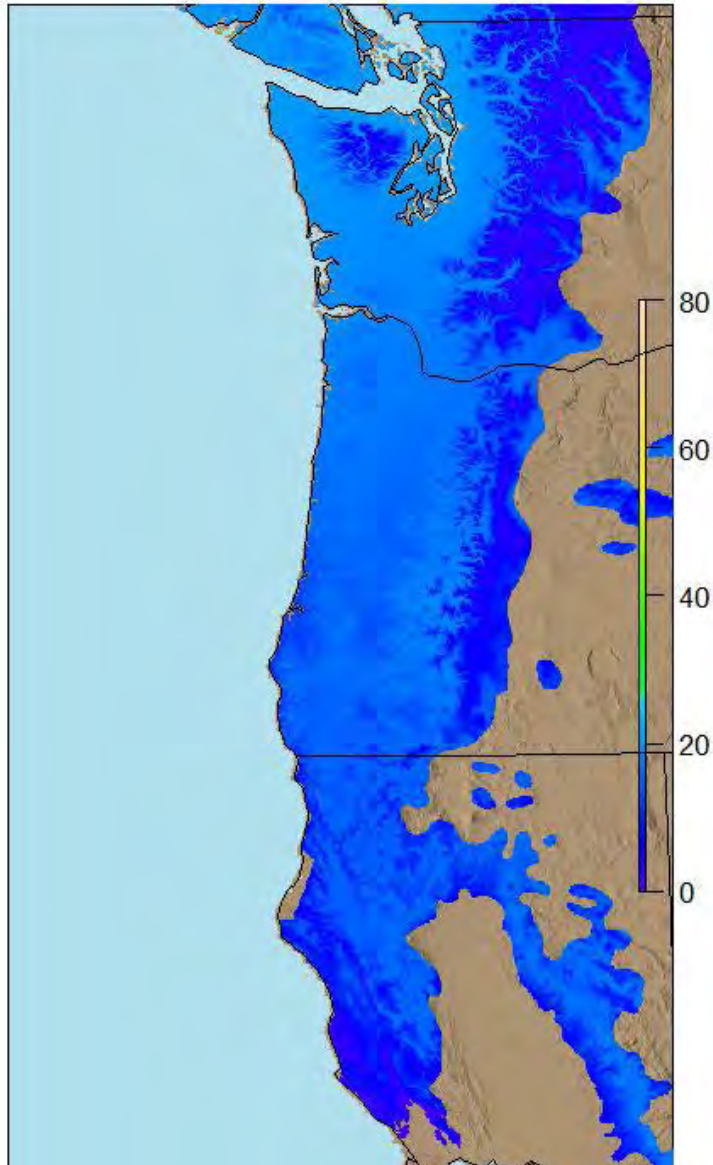
**Common shoot growth type –
Douglas-fir, pines, true firs, oak**

**Most species with large buds ALSO
have a long indeterminate growth
phase under favorable conditions**

**Bud bank might account for 1 ft of
growth**

Predicted Δ in date of budburst for Douglas-fir by 2020

Budburst Early

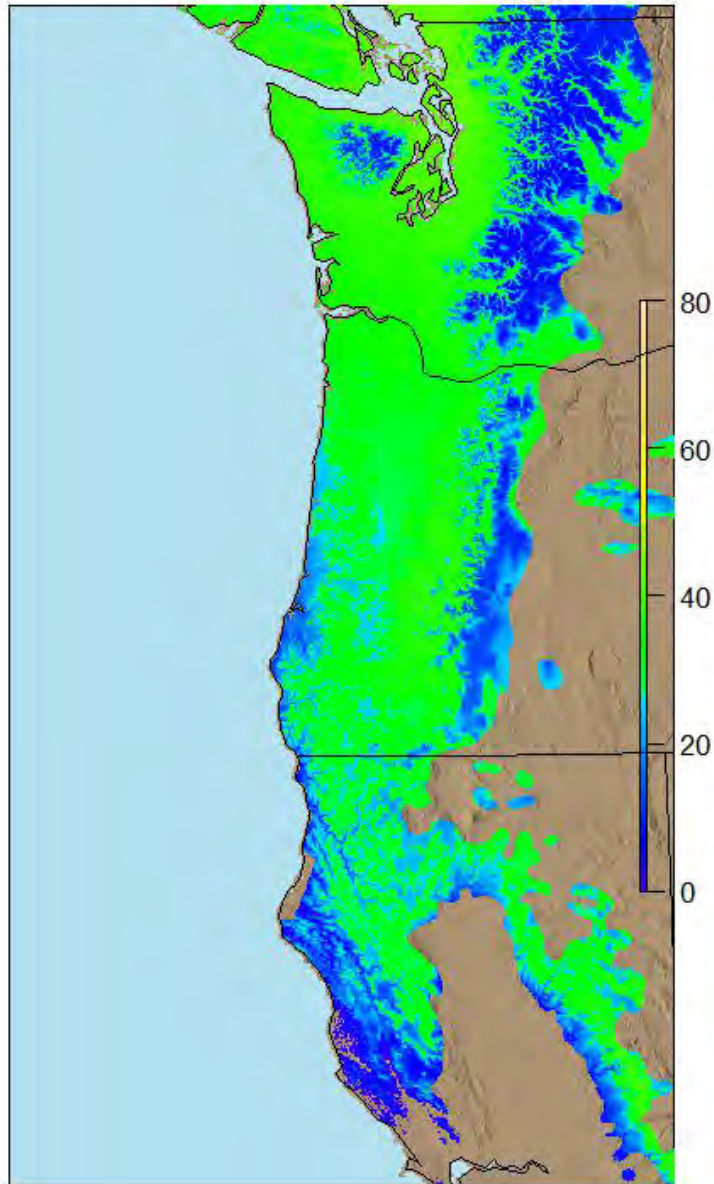


Budburst Later



Predicted Δ in date of budburst for Douglas-fir by 2050

Budburst Early



Budburst Later

