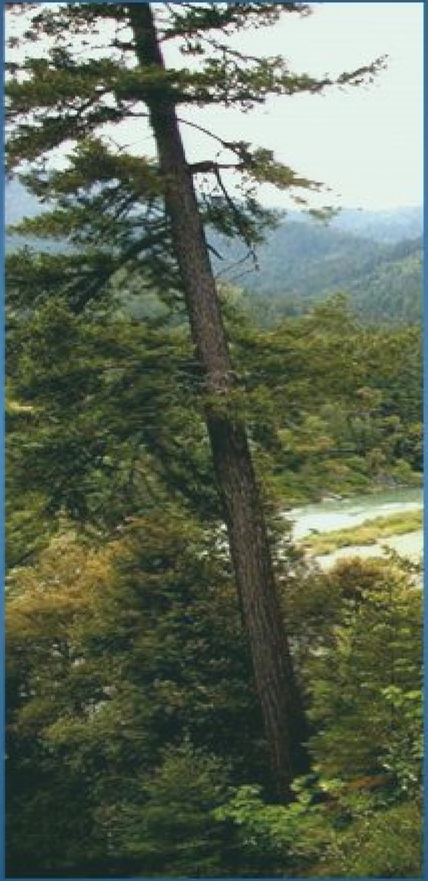
Landscape Variation in Adaptation and Implications for Managing for Future Climates

Brad St.Clair

USFS Pacific Northwest Research Station

Corvallis, OR



WFCA Assisted Migration Workshop, February 21, 2013

Adaptation - Definitions

- The evolutionary process whereby a population becomes better suited to its environment
- A feature which is especially important for an organism's survival and reproduction; a product of natural selection in a given environment (adaptive trait)
  - Heritable
  - Functional
  - A result of natural selection
- Adaptedness is the state of being adapted: the degree to which an organism is able to survive, grow and reproduce in a given environment

Other definitions of adaptation

More broadly in biology: the capacity for an organism to adjust to varying environmental conditions

- More properly termed flexibility, acclimatization, or phenotypic plasticity

"Societal" adaptation: the adjustment of natural or human systems to new environments, which moderates harm or exploits opportunities (IPCC 2001)

Why do we care about adaptation?

- Plant populations are genetically adapted to their local climates
  - A result of natural selection in a given environment
  - The climatic tolerances of populations are lower than the tolerances of the species as a whole
- Climates change, which affects adaptedness
  - Movement of populations for reforestation
  - Global climate change
- Choice of species and populations matters for survival, growth, and reproduction, and therefore the health and productivity of forest stands in the short- and long-term

How do scientists study adaptation?

Evidence for adaptation comes from:

1. Correlation between a character and environmental factors – the same form occurs in similar environments (genecology studies)
2. Comparisons of naturally-occurring variants in environments where they are hypothesized to function as adaptation (reciprocal transplant studies)
3. Direct evidence from altering a character to see how it affects function in a given environment
4. In population genetics, deviation of genetic differences from what would be expected from neutrality (F_{ST} outliers, Tajima's D)

Genecology Studies

- The study of intraspecific genetic variation of plants in relation to source environments (Turresson 1923)
- Seeks correlations between "plant type" and "habitat type"
- Consistent correlations are taken to indicate adaptation as determined by natural selection

Studying Genetic Variation

Common-garden experiments are used to separate genetic from environmental effects

$$P = G + E$$

Studying Genetic Variation

Common-garden experiments are used to separate genetic from environmental effects

Advantages of common garden studies:

Environment is more uniform

- "E" is smaller
- Phenotype (P) more closely reflects the genotype (G)

$$P = G + E$$

Studying Genetic Variation

Common-garden experiments are used to separate genetic from environmental effects

Advantages of common garden studies:

Environment is more uniform

- "E" is smaller
- Phenotype (P) more closely reflects the genotype (G)

$$P = G + E$$

Studying Genetic Variation

Common-garden experiments are used to separate genetic from environmental effects

Advantages of common garden studies:

Environment is more uniform

- "E" is smaller
- Phenotype (P) more closely reflects the genotype (G)

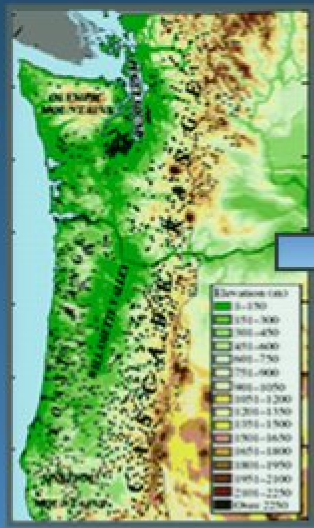
P = G + ~~E~~

Genotypes are replicated

- Parent tree's genotype is well estimated based on growing many offspring on many microsites

Douglas-Fir Genecology Study

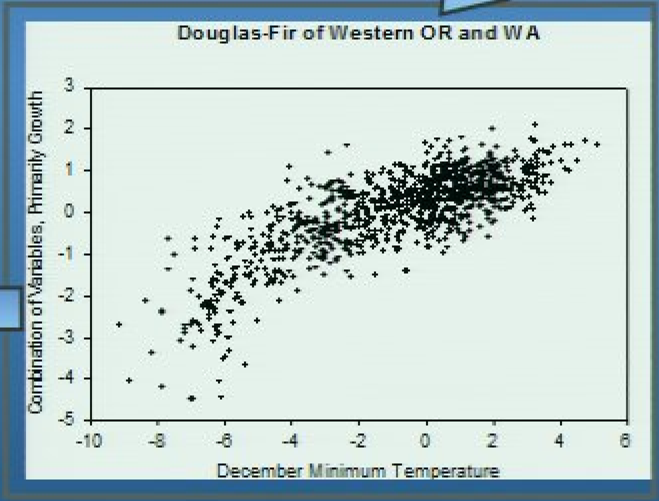
Collect seed from many trees



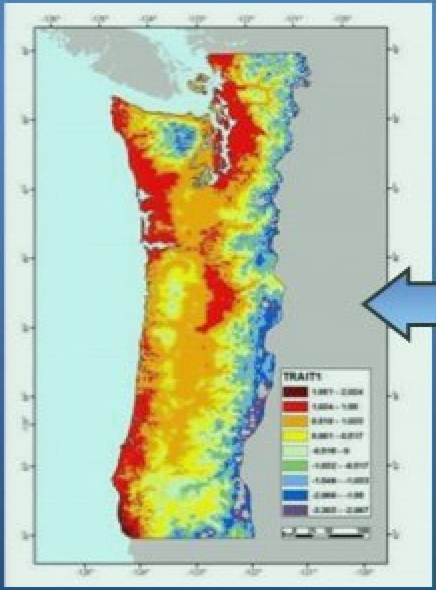
Grow families in a common environment

Measure many adaptive traits

Traits vs source environment

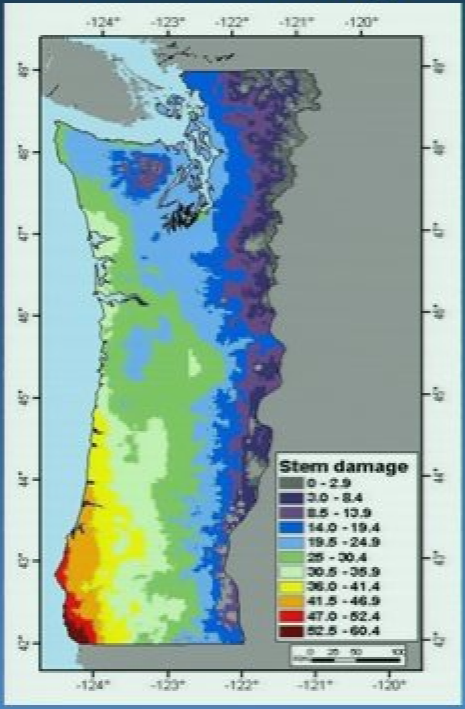


GIS



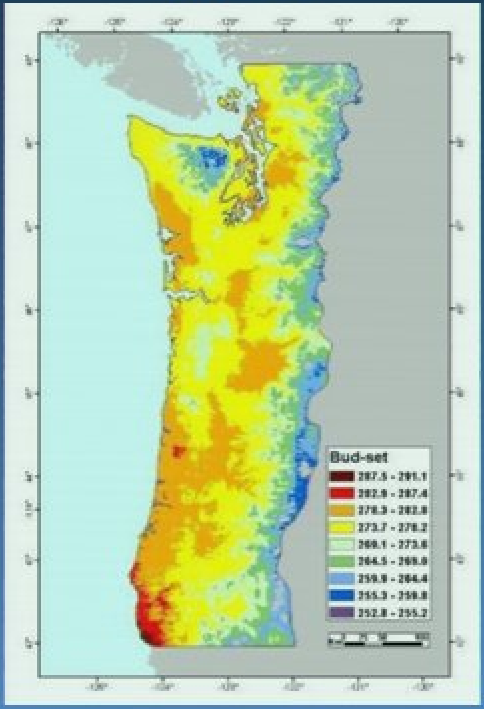
St.Clair et al. 2005. Genecology of Douglas-fir in western Oregon and Washington. Annals of Botany 96: 1199-1214.

Fall cold damage



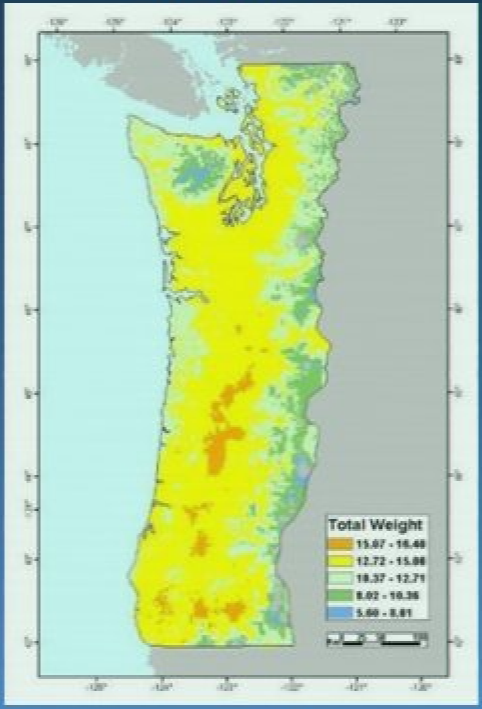
r = 0.79
Qst = 0.68

Bud-set



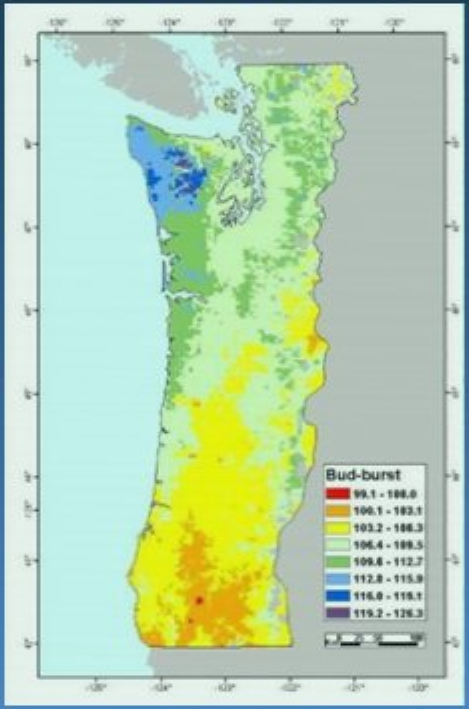
r = 0.76
Qst = 0.29

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. Relationships make sense

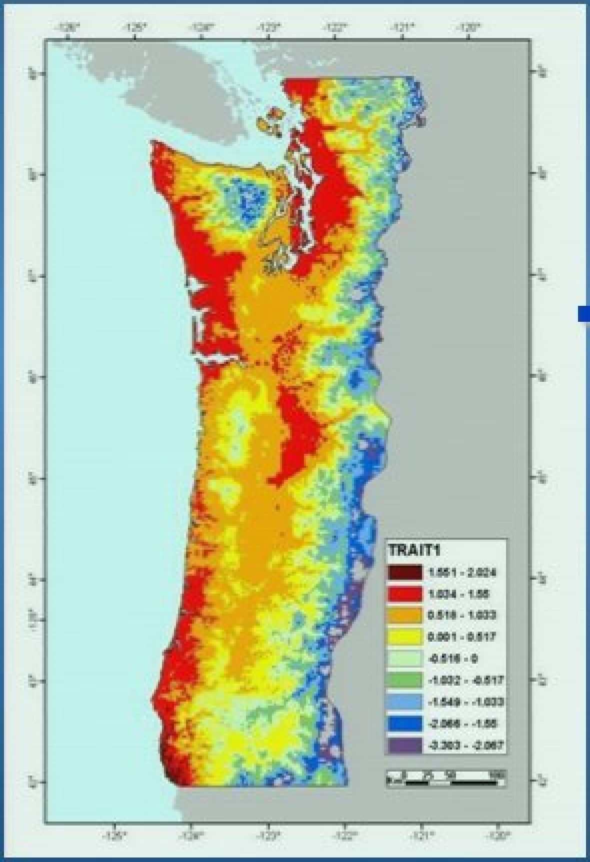
Different traits show different patterns and scales of adaptation

Maps are of both traits and environments.

Seed zones derived from genecology studies

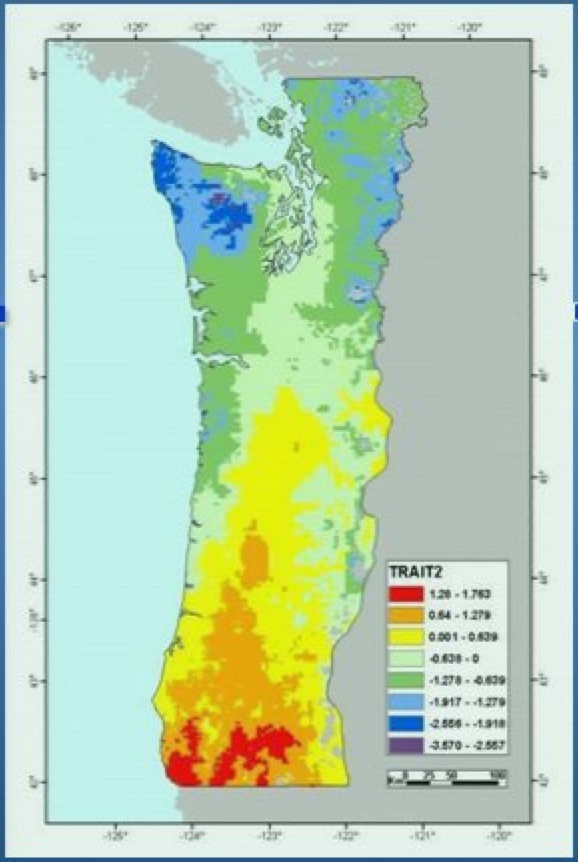
Overlay two component traits

Canonical variate 1
"vigor"

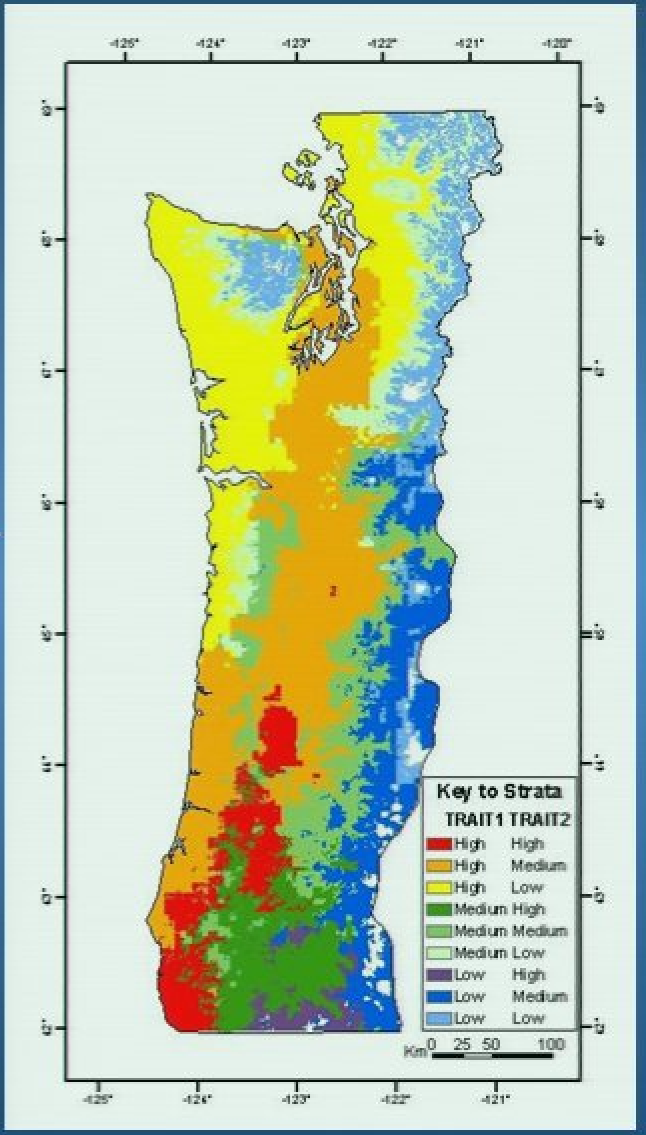


+

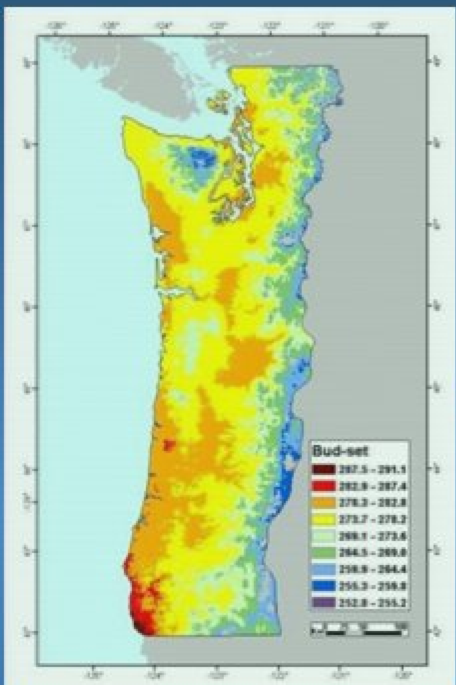
Canonical variate 2
bud-burst, ht:diam



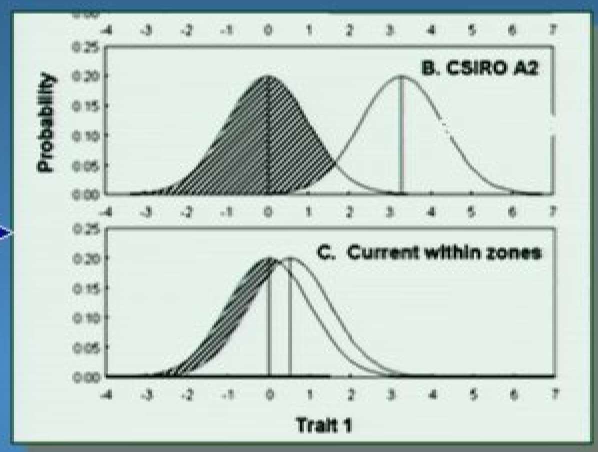
→



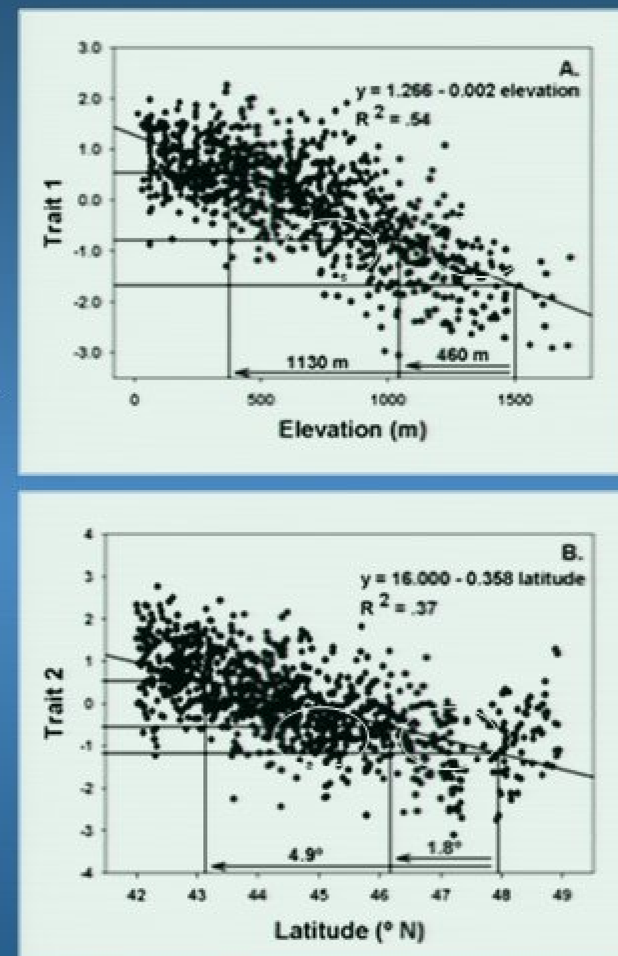
Will current populations be adapted to future climates?



Genetic variation in bud-set



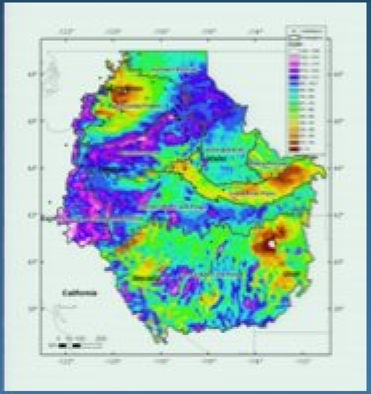
Risk of maladaptation from climate change



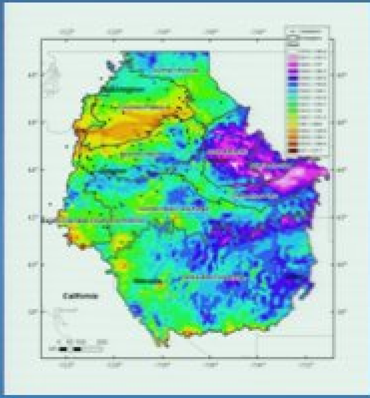
Seed movement guidelines for climate change

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

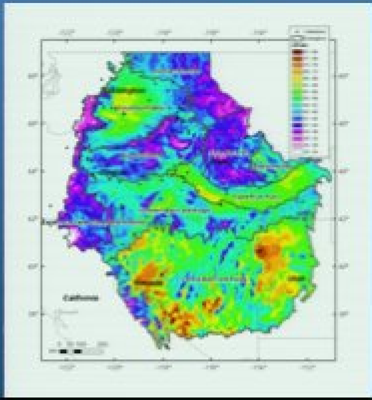
Genecology and seed zones for bluebunch wheatgrass



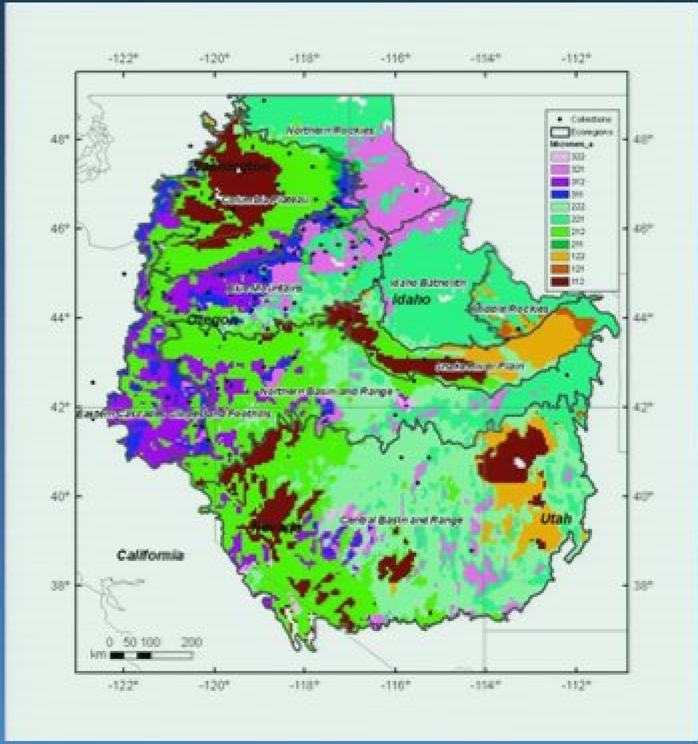
Dry weight



Flowering date



Leaf width



Seed zones for bluebunch wheatgrass

Advantages/disadvantages of genecology approach (Campbell method)

- May be done in a short timeframe
- Greatly minimizes environmental variation
- Can sample many source locations from a wide range of environments
- Can produce maps of adaptive traits/climates for easy visualization and manipulation

Advantages/disadvantages of genecology approach (Campbell method)

- May be done in a short timeframe
- Greatly minimizes environmental variation
- Can sample many source locations from a wide range of environments
- Can produce maps of adaptive traits/climates for easy visualization and manipulation

But,

- Assumes we have measured all the most important adaptive traits
- May be difficult to synthesize results of many traits
- Comparisons between sites or years assume local is best
- Not a direct test of adaptation

Reciprocal Transplant Studies

- Populations from a range of source environments are evaluated in the same or similar range of test environments
- Provenance tests may be considered to be a type of reciprocal transplant study
- Can generate models to predict adaptedness as function of:
  - Planting environments (response function)
  - Source environments (genecology function)
  - Difference between planting and source environments (transfer function)
  - Both the planting environment and source environment together (universal response function)

Advantages/disadvantages of reciprocal transplant studies

- Direct test of adaptation
- Can test hypothesis of local adaptation
- Can better model variables of direct interest such as stand productivity

Advantages/disadvantages of reciprocal transplant studies

- Direct test of adaptation
- Can test hypothesis of local adaptation
- Can better model variables of direct interest such as stand productivity

But,

- Takes a long time for results
- Expensive to test over many planting sites and seed sources
- Few samples make it difficult to interpolate between locations to adequately model response or transfer functions, or draw maps
- Often components of adaptation are not considered, traits that might be useful for selection of populations or individuals

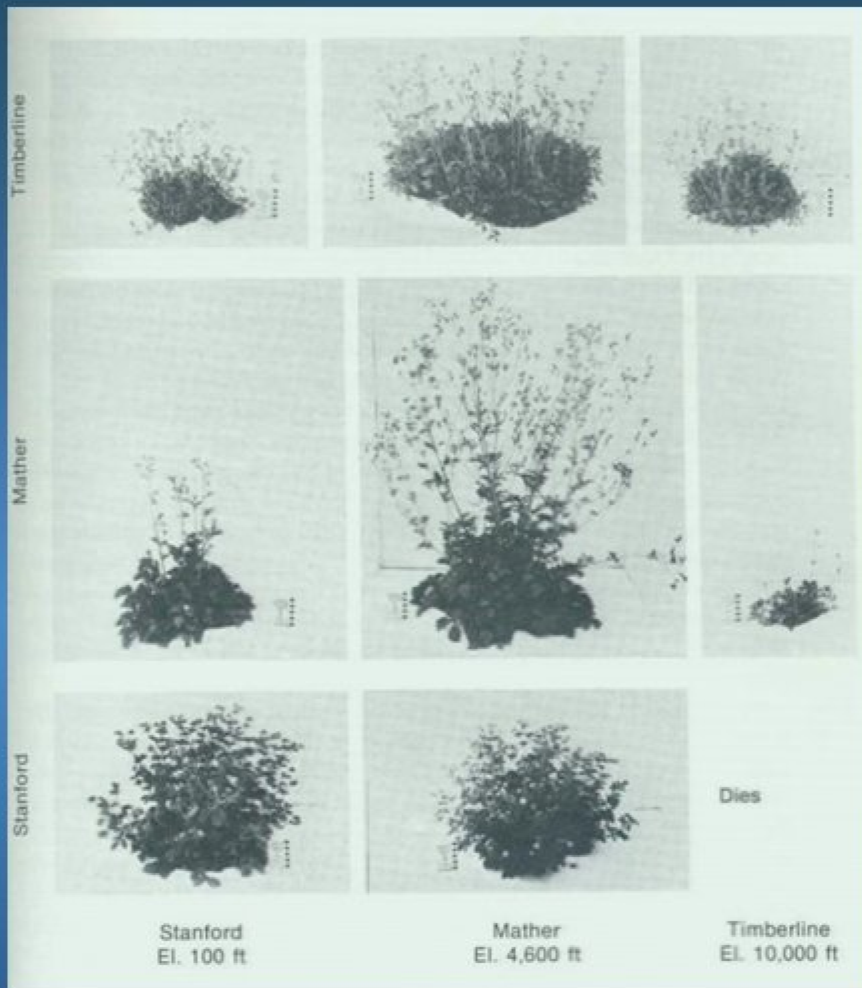
Classical studies of Clausen, Keck & Hiesey

Native to

Timberline
El. 3,030 m

Mather
El. 1,400 m

Stanford
El. 35 m



Stanford
El. 35 m

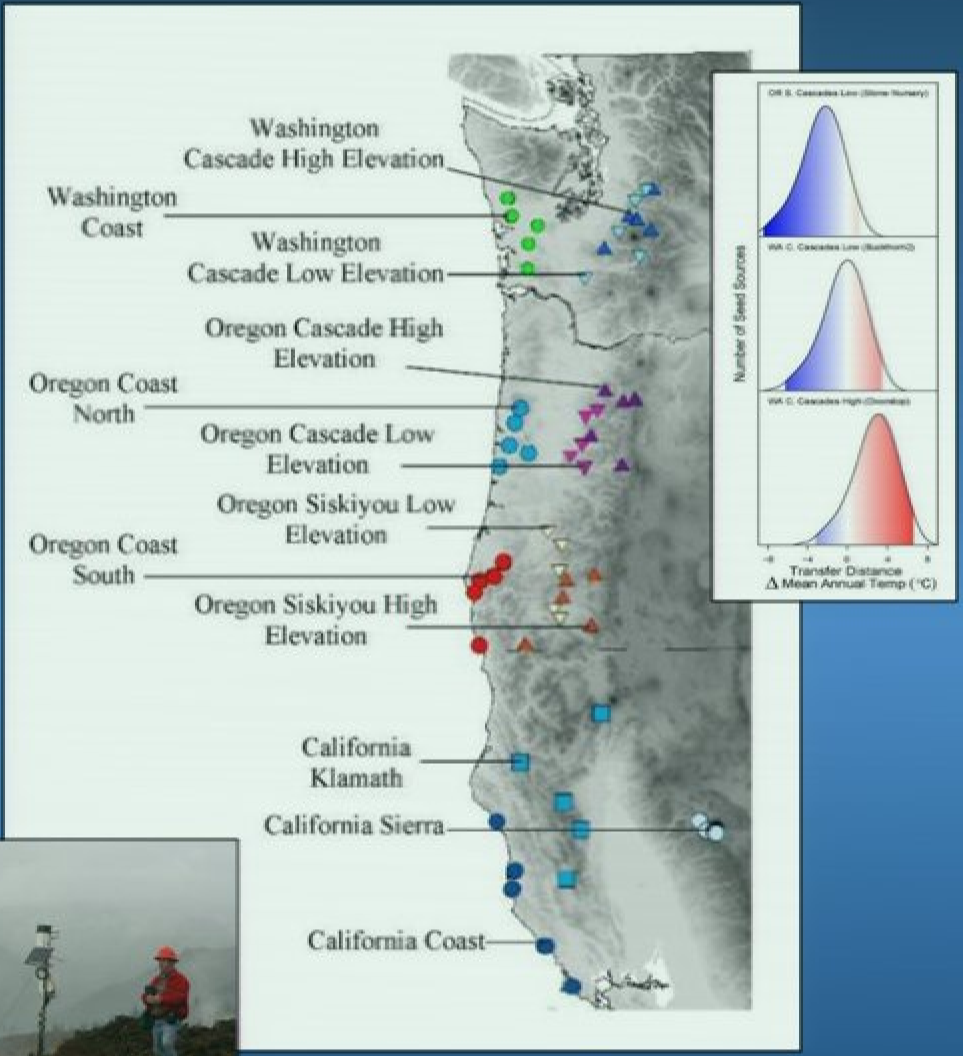
Mather
El. 1,400 m

Timberline
El. 3,030 m

Grown at

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

Reciprocal Transplant Study: Douglas-Fir Seed Source Movement Trials



Objective

- To develop a model to predict the adaptation (survival, growth, reproduction) and productivity of Douglas-fir populations given information about the climates of source locations and planting sites

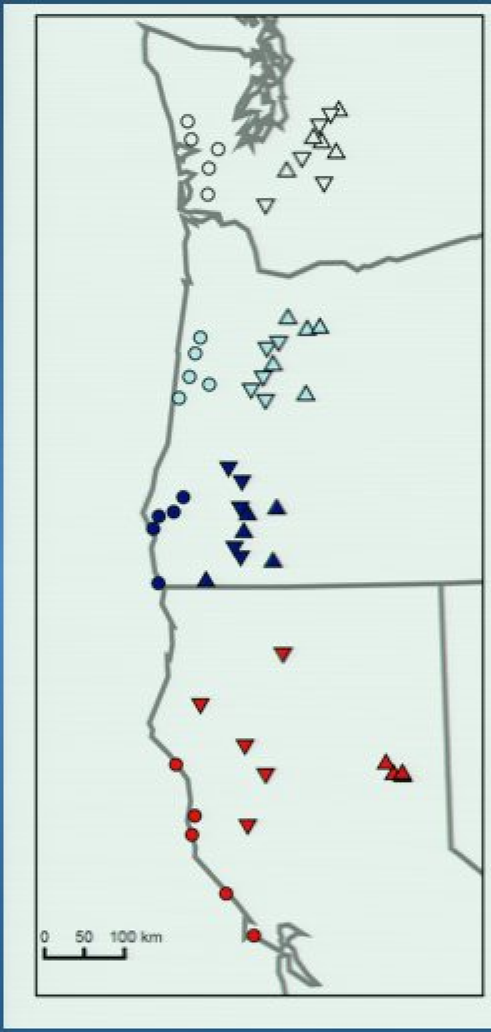
Objective

- To develop a model to predict the adaptation (survival, growth, reproduction) and productivity of Douglas-fir populations given information about the climates of source locations and planting sites
- Secondary objectives:
  - To identify key traits, genes, and aspects of the environment that determine adaptation and productivity
  - To develop and refine models of climate effects on key adaptive traits
  - To determine the climatic niches of populations (=seed zones, breeding zones)
  - To explore effects of climate change on Douglas-fir and evaluate management options for responding to climate change

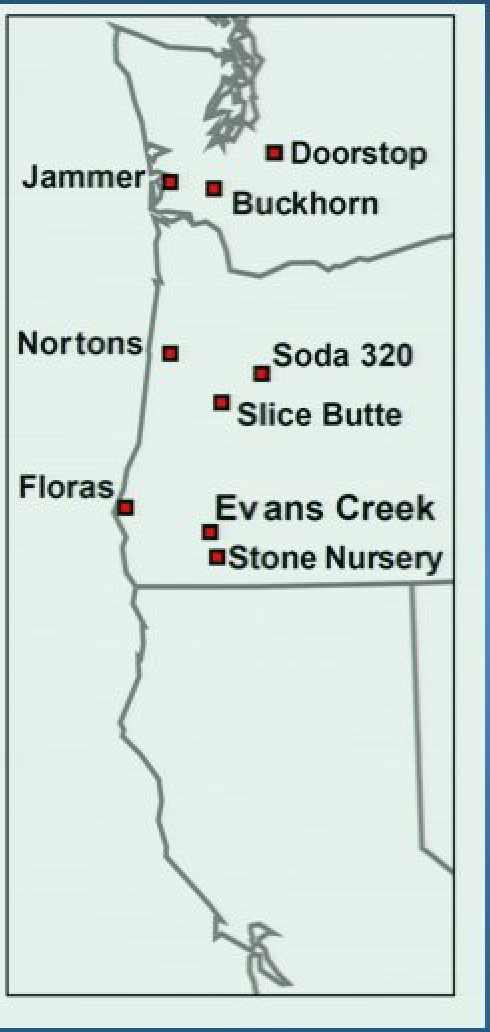
Study Design

- Reciprocal transplant study
- 120 families from 60 populations from 12 diverse regions planted at sites chosen to represent 9 of those regions

Populations

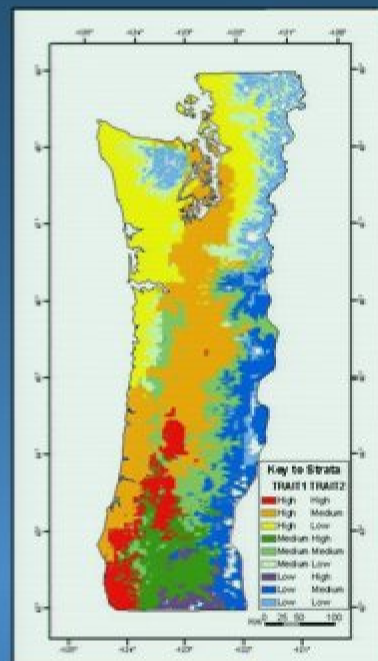


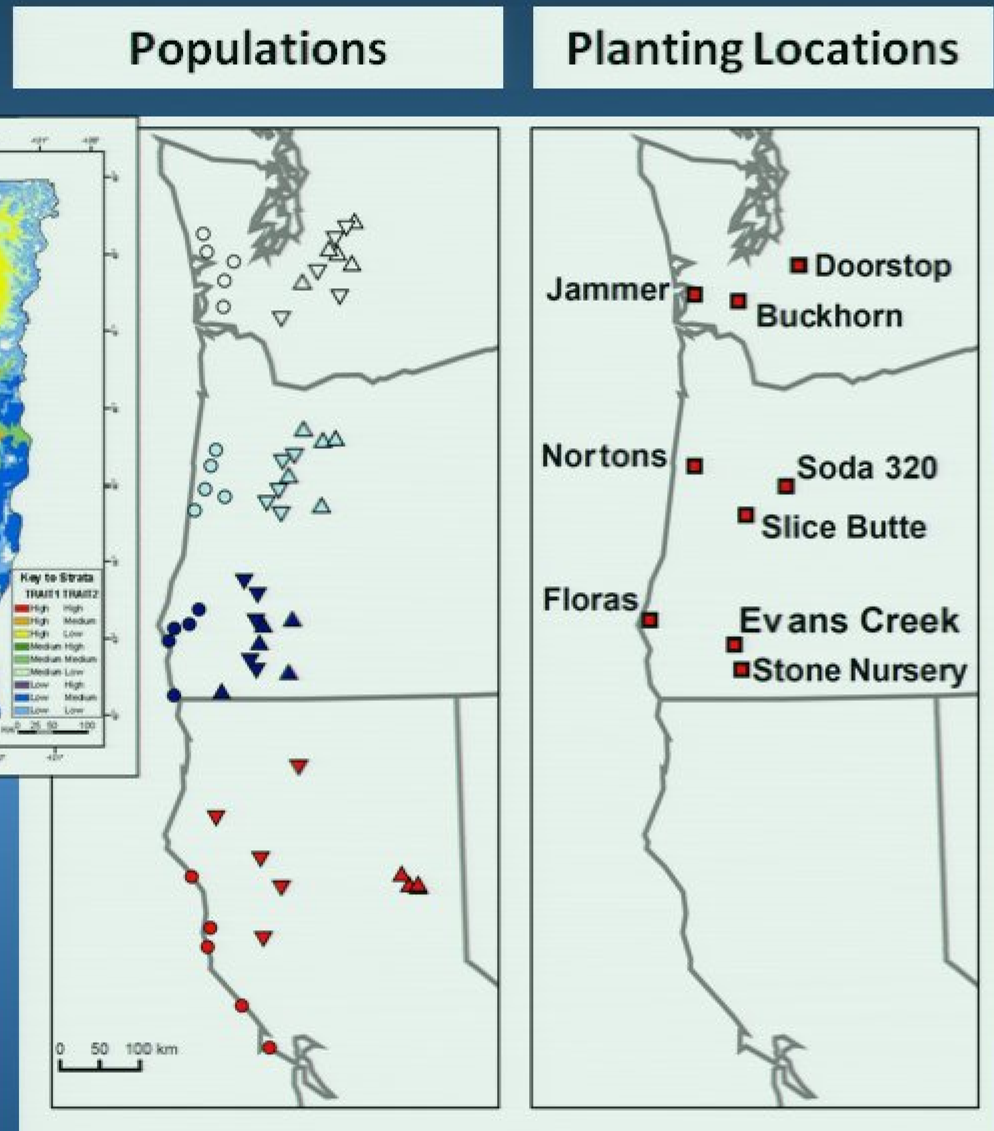
Planting Locations



Study Design

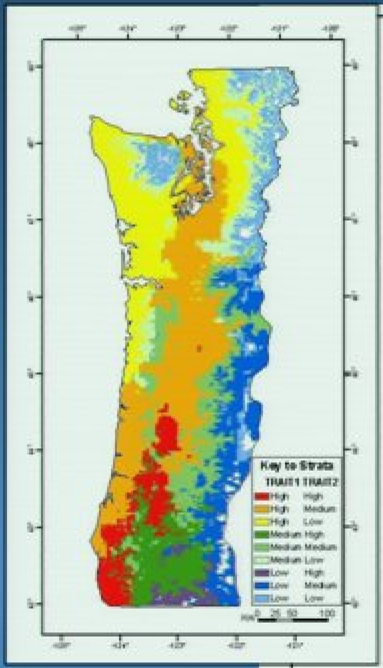
- Reciprocal transplant study
- 120 families from 60 populations from 12 diverse regions planted at sites chosen to represent 9 of those regions



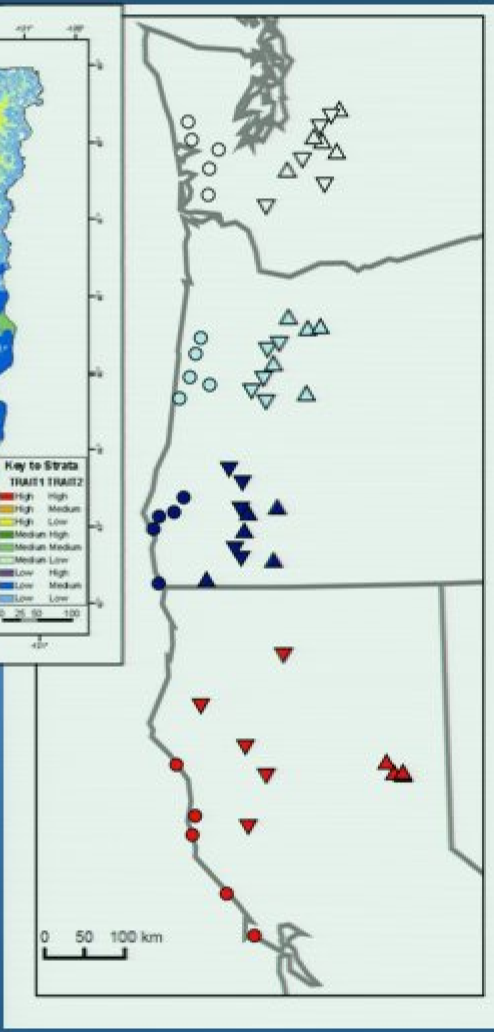


Study Design

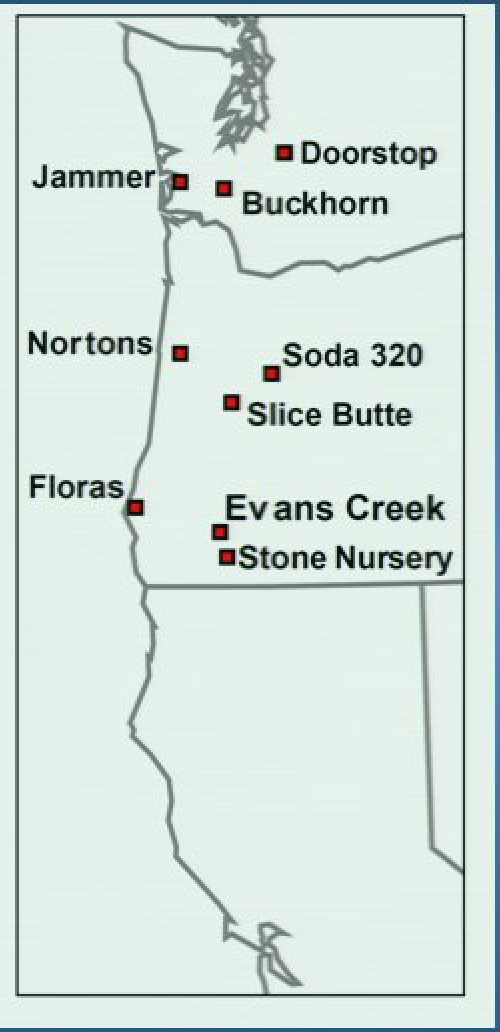
- Reciprocal transplant study
- 120 families from 60 populations from 12 diverse regions planted at sites chosen to represent 9 of those regions
- Populations chosen based on previous genecology study



Populations

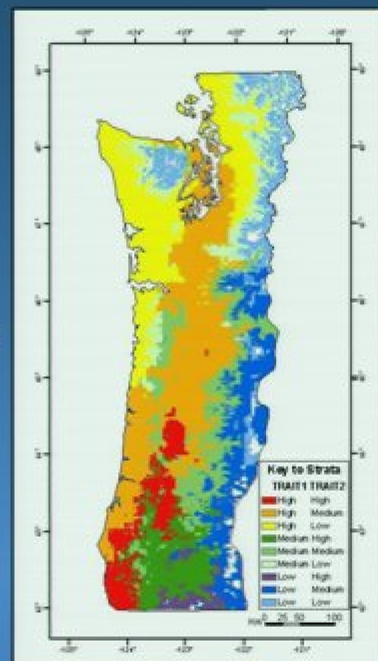


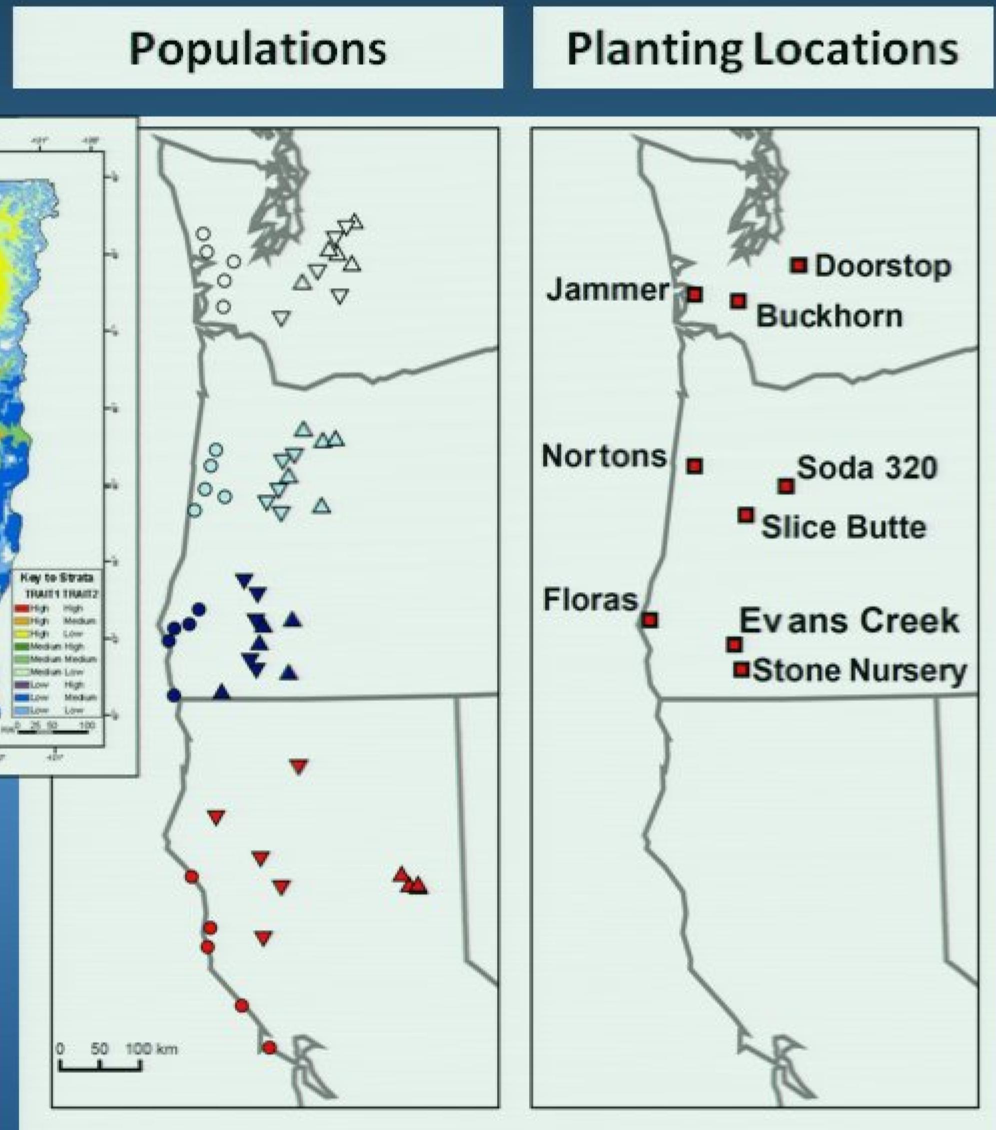
Planting Locations



Study Design

- Reciprocal transplant study
- 120 families from 60 populations from 12 diverse regions planted at sites chosen to represent 9 of those regions
- Populations chosen based on previous genecology study
- Subset of populations and sites chosen for more intensive measurements

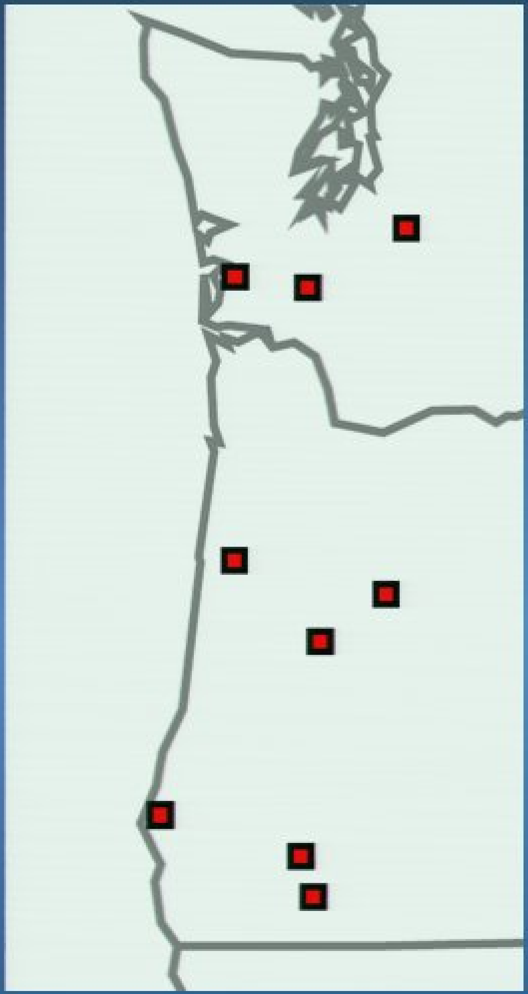




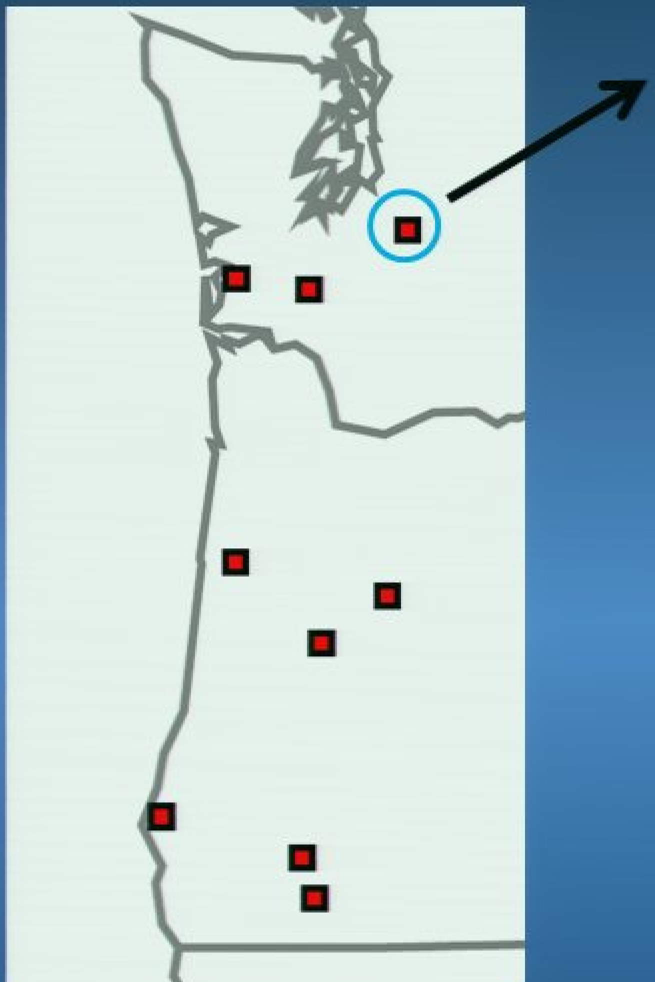
Study Design

- Families from same region planted in plots
- 4 replications at a site
- Sites planted in fall/winter of 2008-2009
- Each site is fenced

A diverse set of test environments



A diverse set of test environments

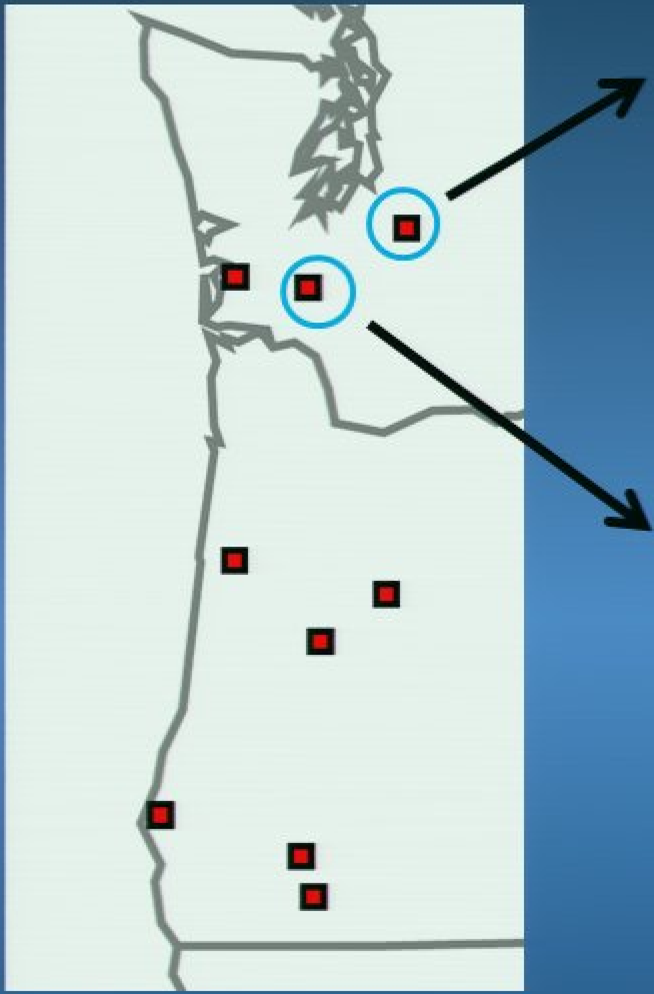


Doorstop (WA high elevation):
coldest, wettest site

Mean max T = 16.1° C

Growing season precip = 671 mm

A diverse set of test environments



Doorstop (WA high elevation): coldest, wettest site

Mean max T = 16.1° C

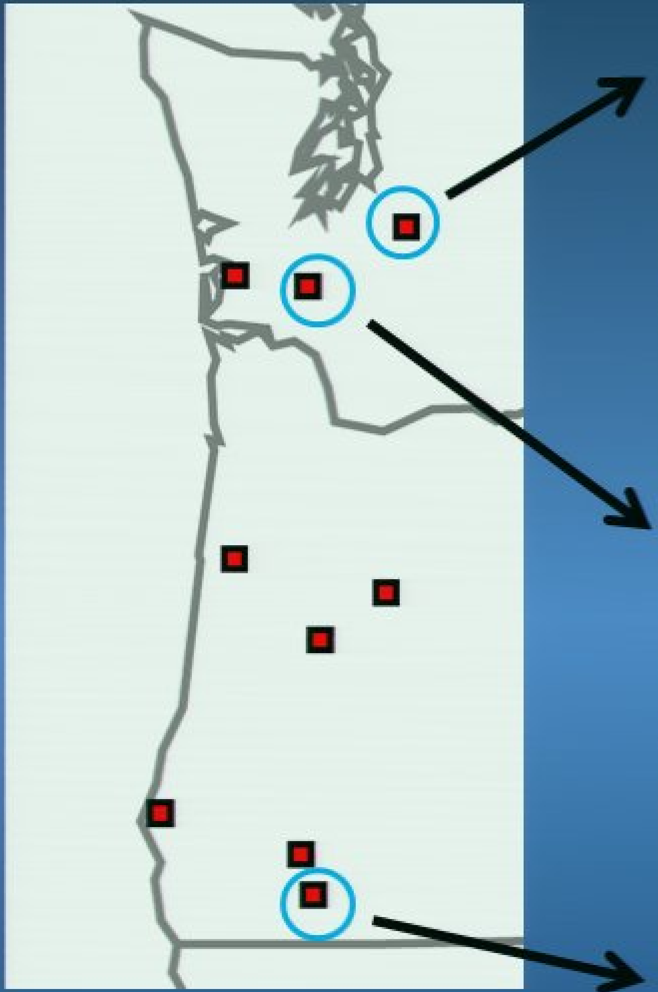
Growing season precip = 671 mm

Buckhorn (WA low elevation): intermediate site

Mean max T = 18.7° C

Growing season precip = 420 mm

A diverse set of test environments



Doorstop (WA high elevation):
coldest, wettest site
Mean max T = 16.1° C
Growing season precip = 671 mm

Buckhorn (WA low elevation):
intermediate site
Mean max T = 18.7° C
Growing season precip = 420 mm

Stone (OR low elevation):
warmest, driest site
Mean max T = 24.9° C
Growing season precip = 184 mm

Measurements

- Adaptation and productivity
  - Survival, height and diameter growth
- Adaptive traits
  - Phenology
    - Bud phenology – budburst, budset and height growth during growing season
    - Cambial phenology - initiation, cessation, and diameter growth during growing season
  - Drought hardiness
  - Cold hardiness
- Gene expression (Cronn et al.)

Monitoring the Environment

- Each site has a weather station (installed 2007- 2008)
- Additional equipment is installed throughout the sites
  - Air temperature (5 to 200 cm)
  - Humidity
  - Precipitation
  - Soil moisture
  - Soil temperature

Monitoring the Environment

- Each site has a weather station (installed 2007- 2008)
- Additional equipment is installed throughout the sites
  - Air temperature (5 to 200 cm)
  - Humidity
  - Precipitation
  - Soil moisture
  - Soil temperature

Climate data for the source locations comes from ClimateWNA (Wang et al 2012)

Collaborators and Funding

Collaborators:

- Cascade Timber Consulting
- Giustina Land and Timber
- Hancock Forest Resources (& Washington Cascade Tree Improvement Cooperative)
- Lone Rock Timber Company
- Port Blakely Tree Farms (& Puget Sound Tree Improvement Cooperative)
- Roseburg Resources
- Starker Forests
- Washington Department of Natural Resources
- USFS National Forests Region 6
- Bureau of Land Management

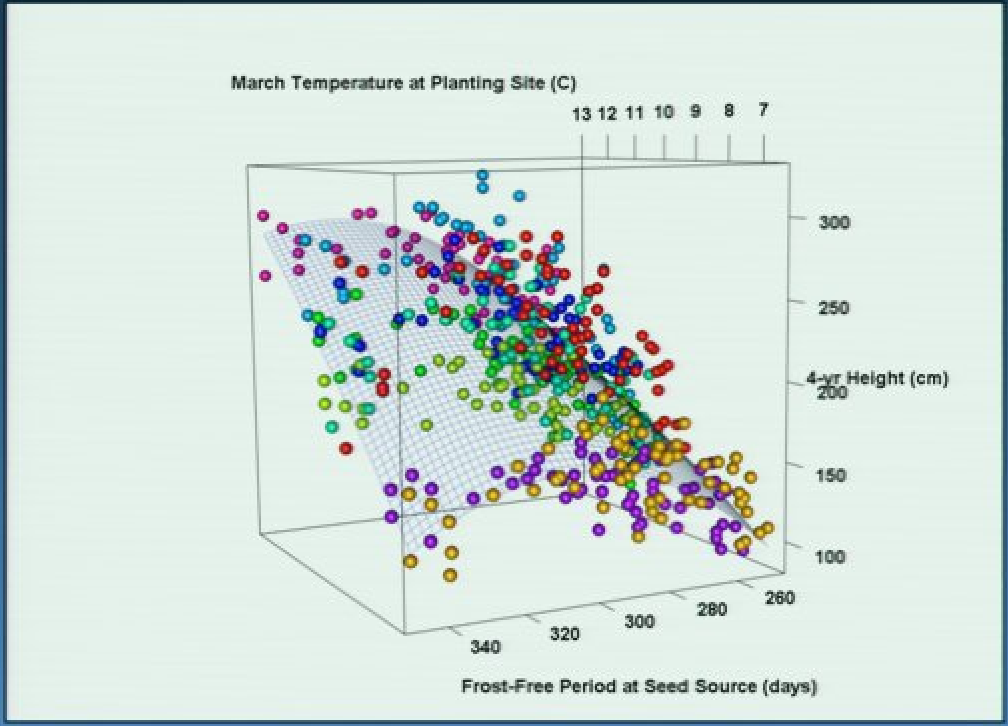
Funding (in addition to test sites and in-kind support):

- Bureau of Land Management
- USFS Pacific Northwest Research Station (including initial funding from Agenda 2020 Program)

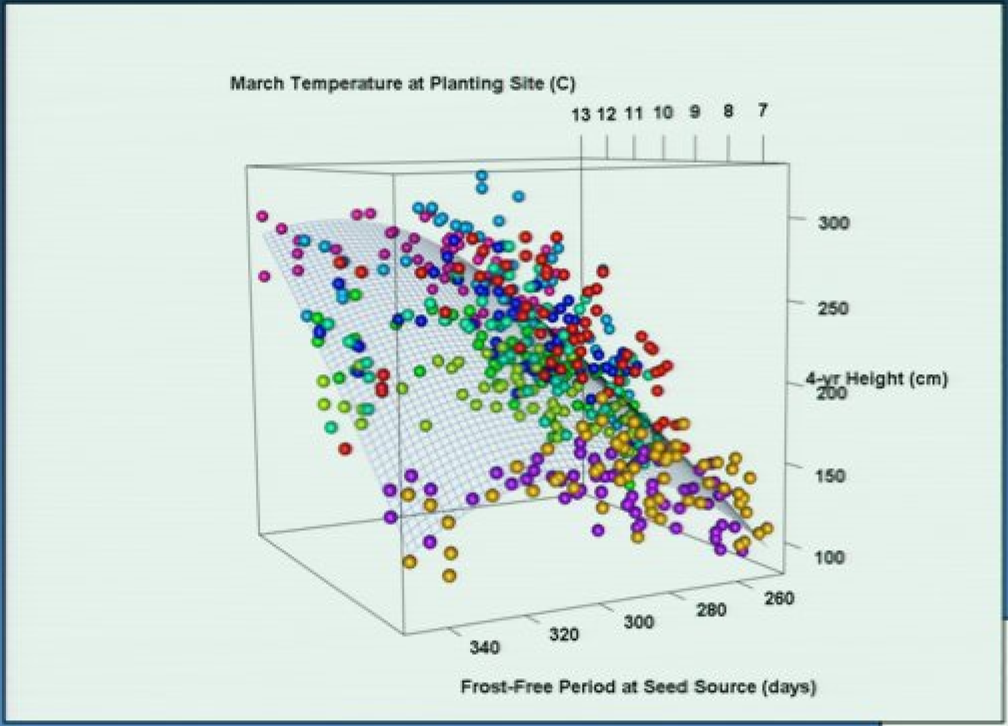
Adaptedness: Survival and Growth

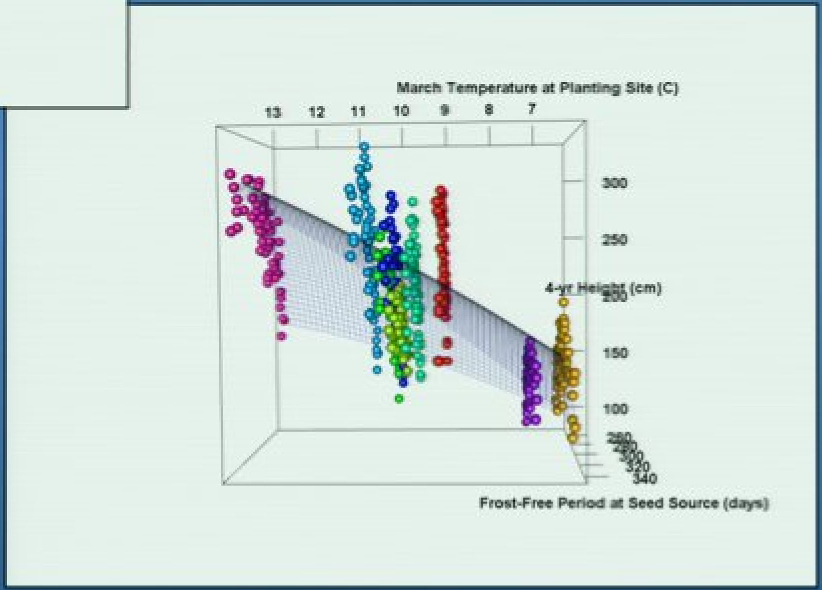
- Adaptation/productivity: survival
  - Overall excellent survival (97%)
  - Exception is trees from the CA Coast planted at higher latitude test sites
    - 91% overall
    - 71% at WA Coast site
    - 87% at two coldest sites
- Adaptation/productivity: growth
  - Evaluated using Universal Response Function approach developed by Wang et al. (2010)

Response Surface for 4-Yr Height

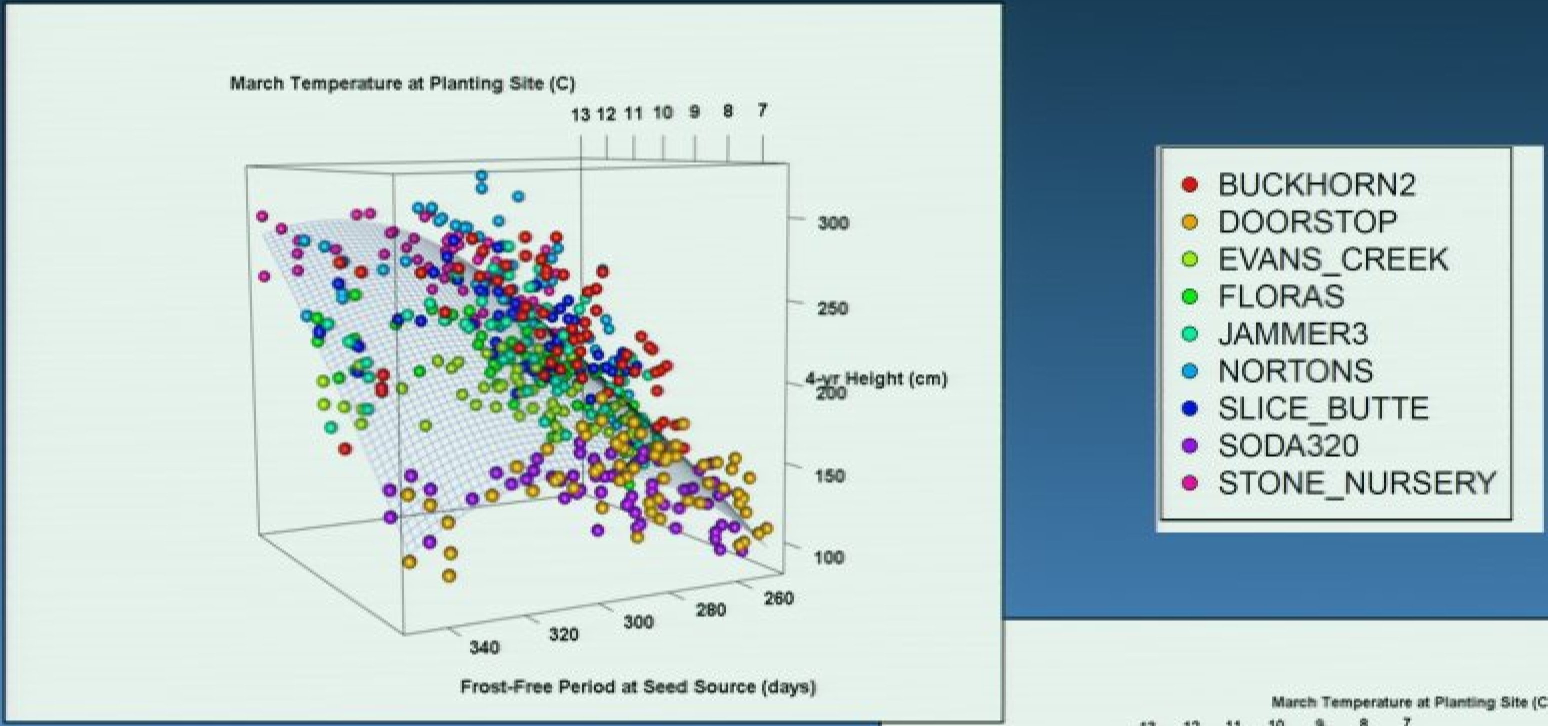


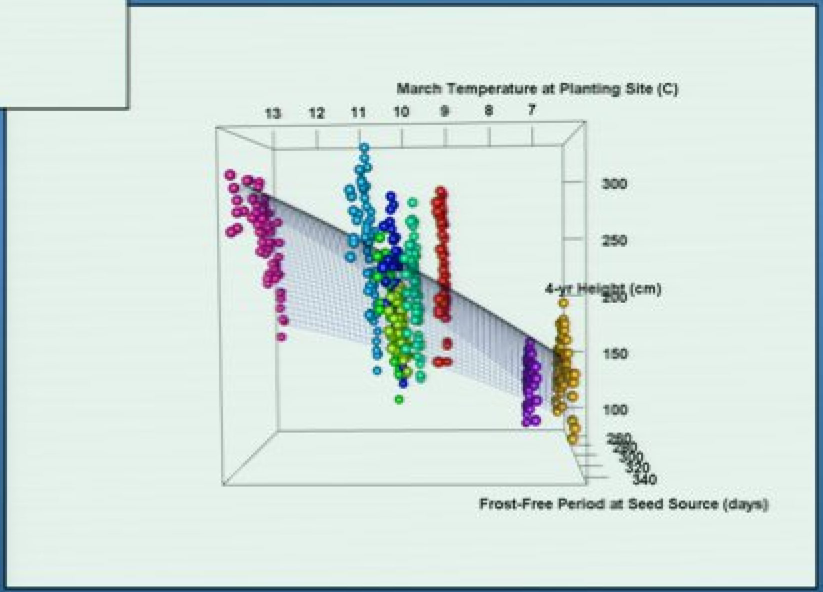
Response Surface for 4-Yr Height





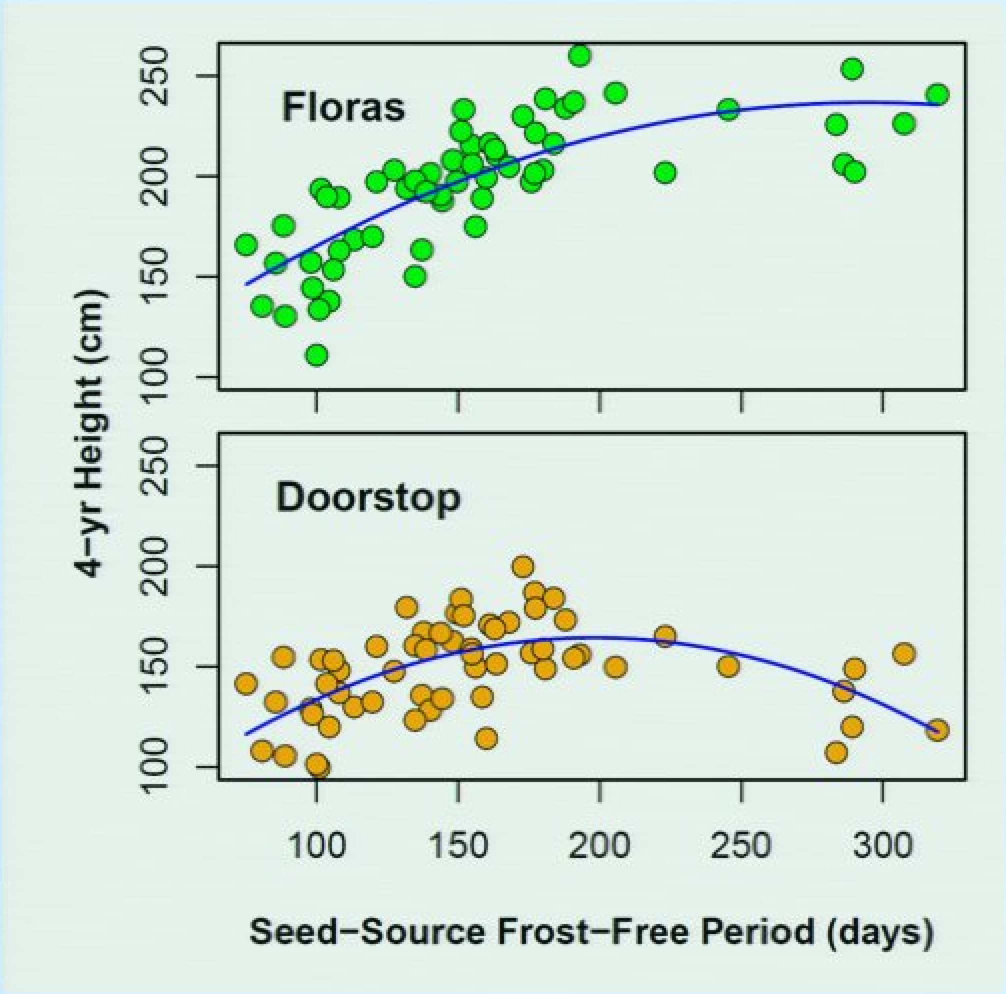
Response Surface for 4-Yr Height





- Significant differences among test sites, regions, populations within regions
- Larger differences among test sites than among populations
- Warmer sites have greater growth
- Significant test site x region interaction
- Warmer populations have greater growth at warmer sites but not at cooler sites
- Temperature is more important than aridity

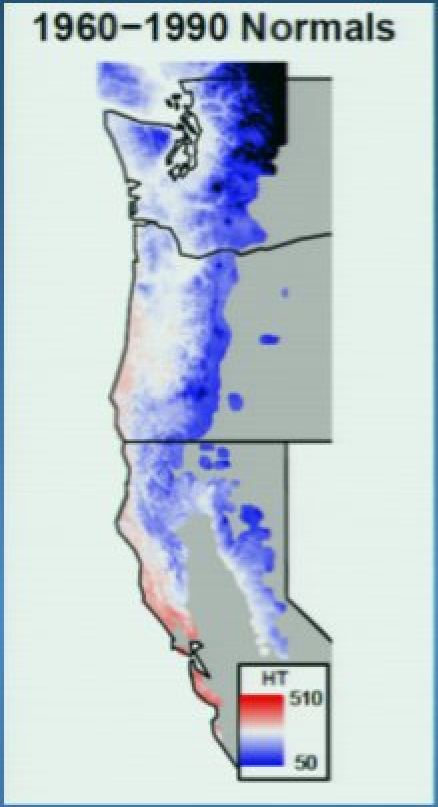
Looking more closely at two sites



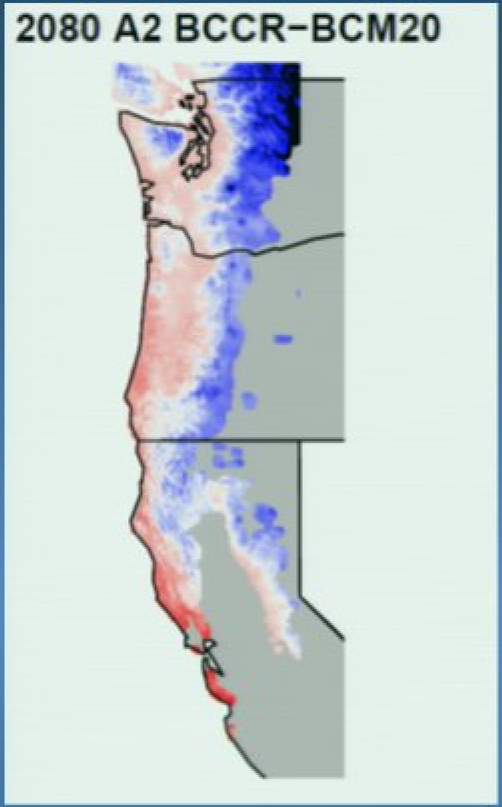
- Floras – warm site
  Frost free days = 308
- Doorstop – cool site
  Frost free days = 190
- Sources from similar climates are growing best at each site

Modeling Growth Given Climate Change

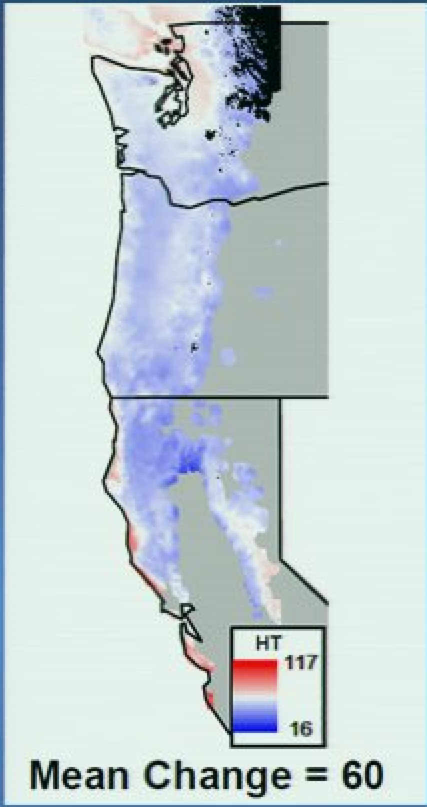
Present



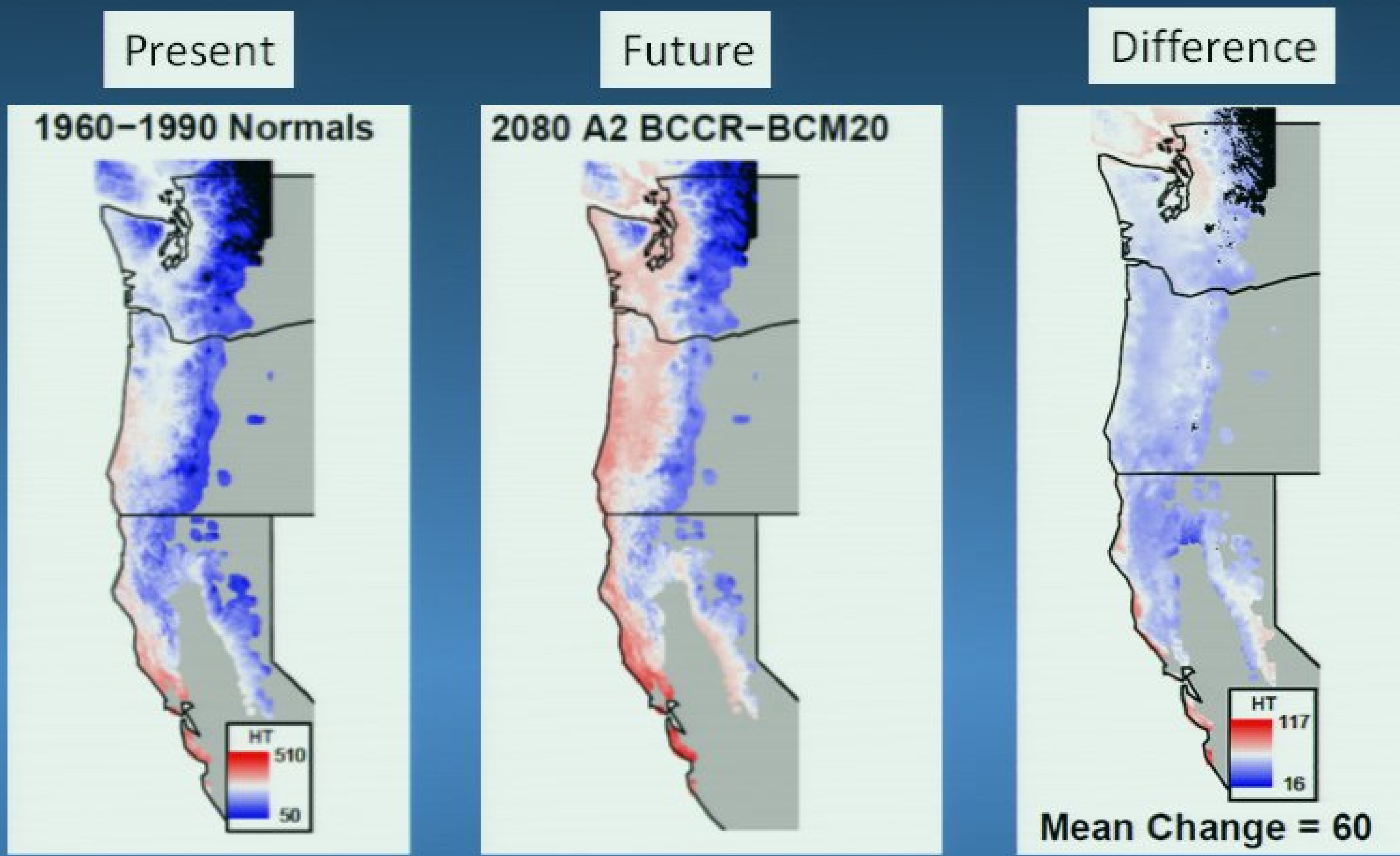
Future



Difference

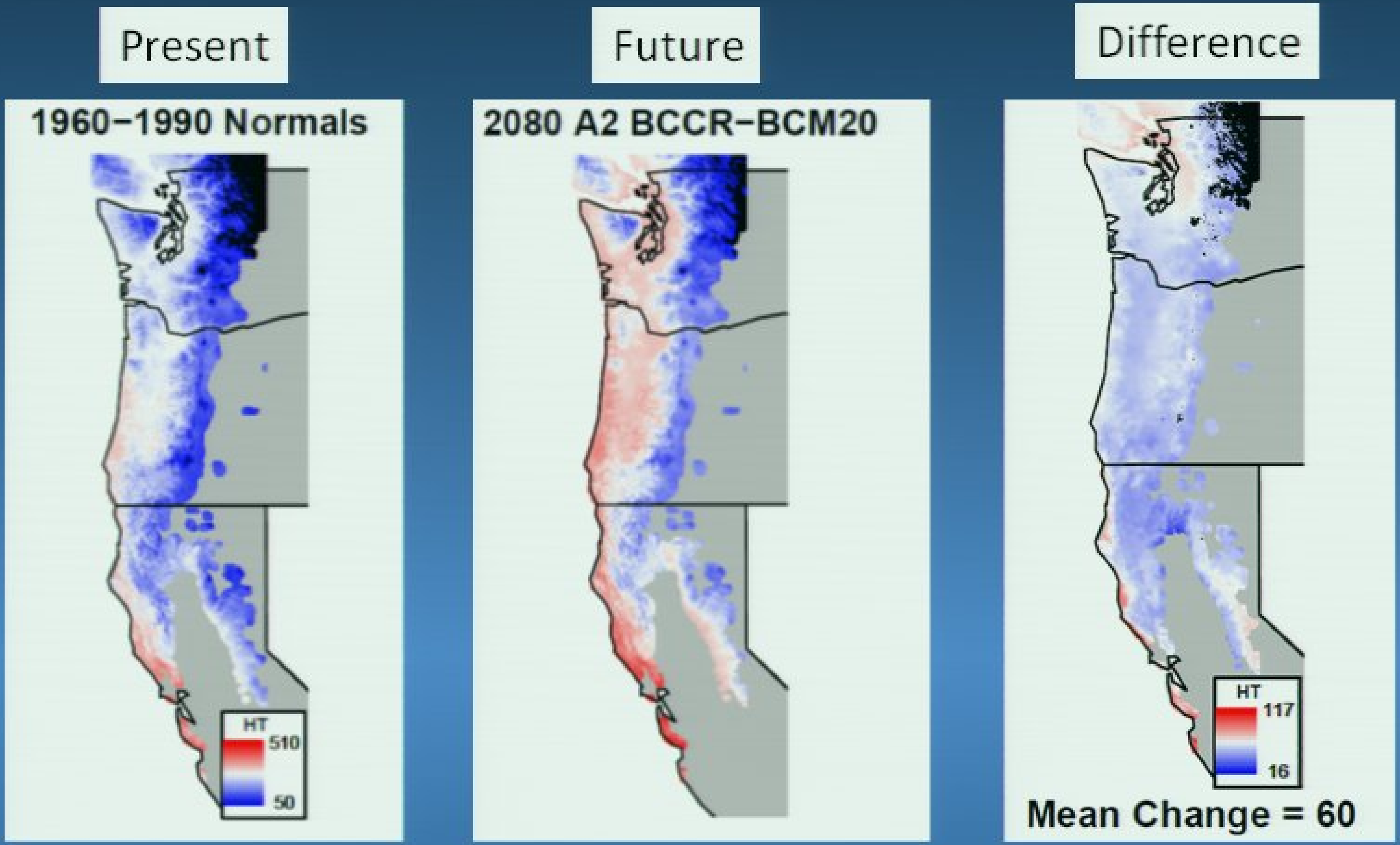


Modeling Growth Given Climate Change



- Results depend on climate variables in model and future scenario
  - Using minimum temperature in March = -47 cm

Modeling Growth Given Climate Change



- Results depend on climate variables in model and future scenario
  - Using minimum temperature in March = -47 cm
- Need to also evaluate results given assumptions about using the best populations for future climates (assisted migration)

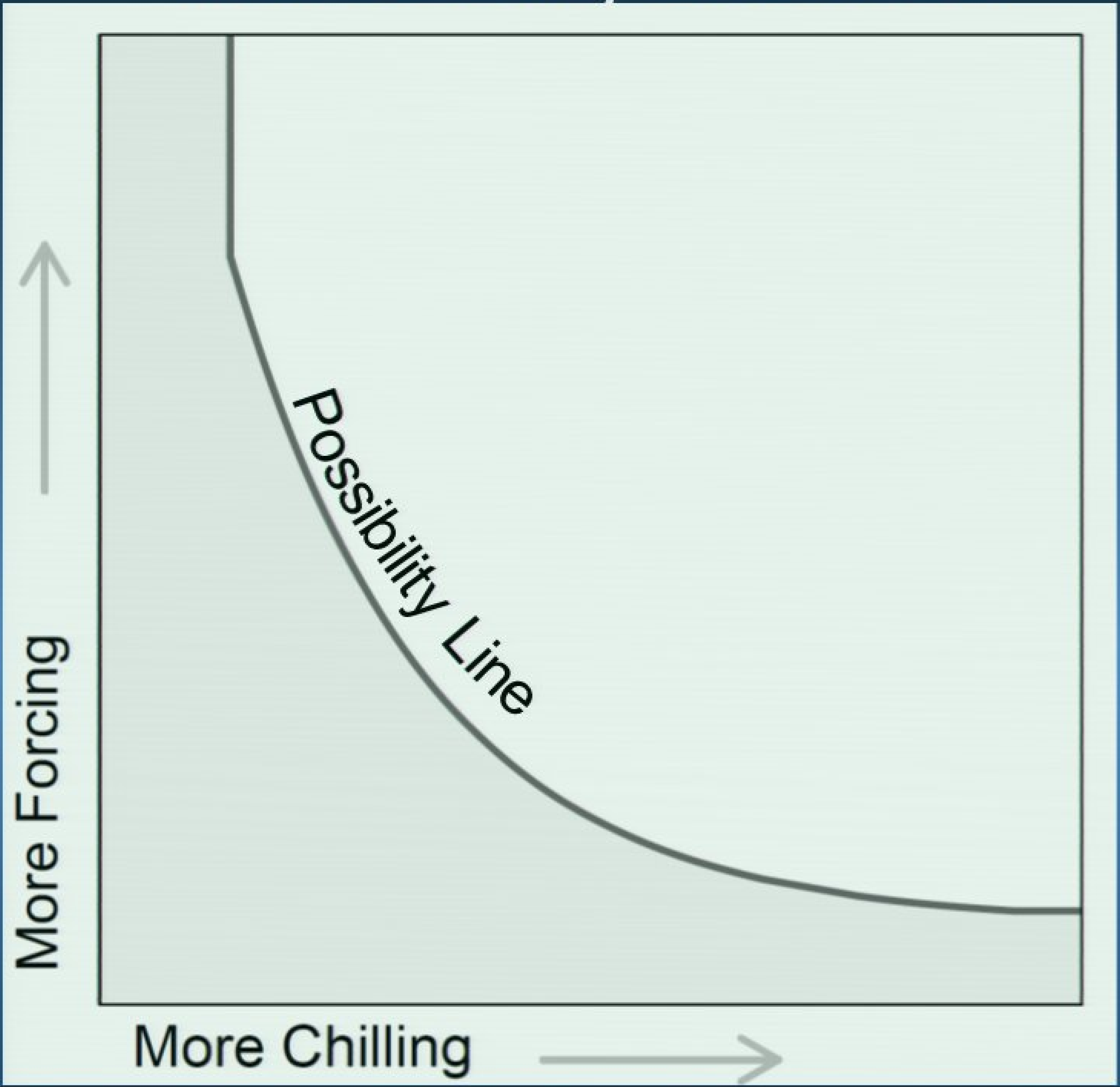
Adaptive Traits

- Bud phenology
  - Budburst
  - Budset
- Cambial phenology
- Drought hardiness
- Cold hardiness

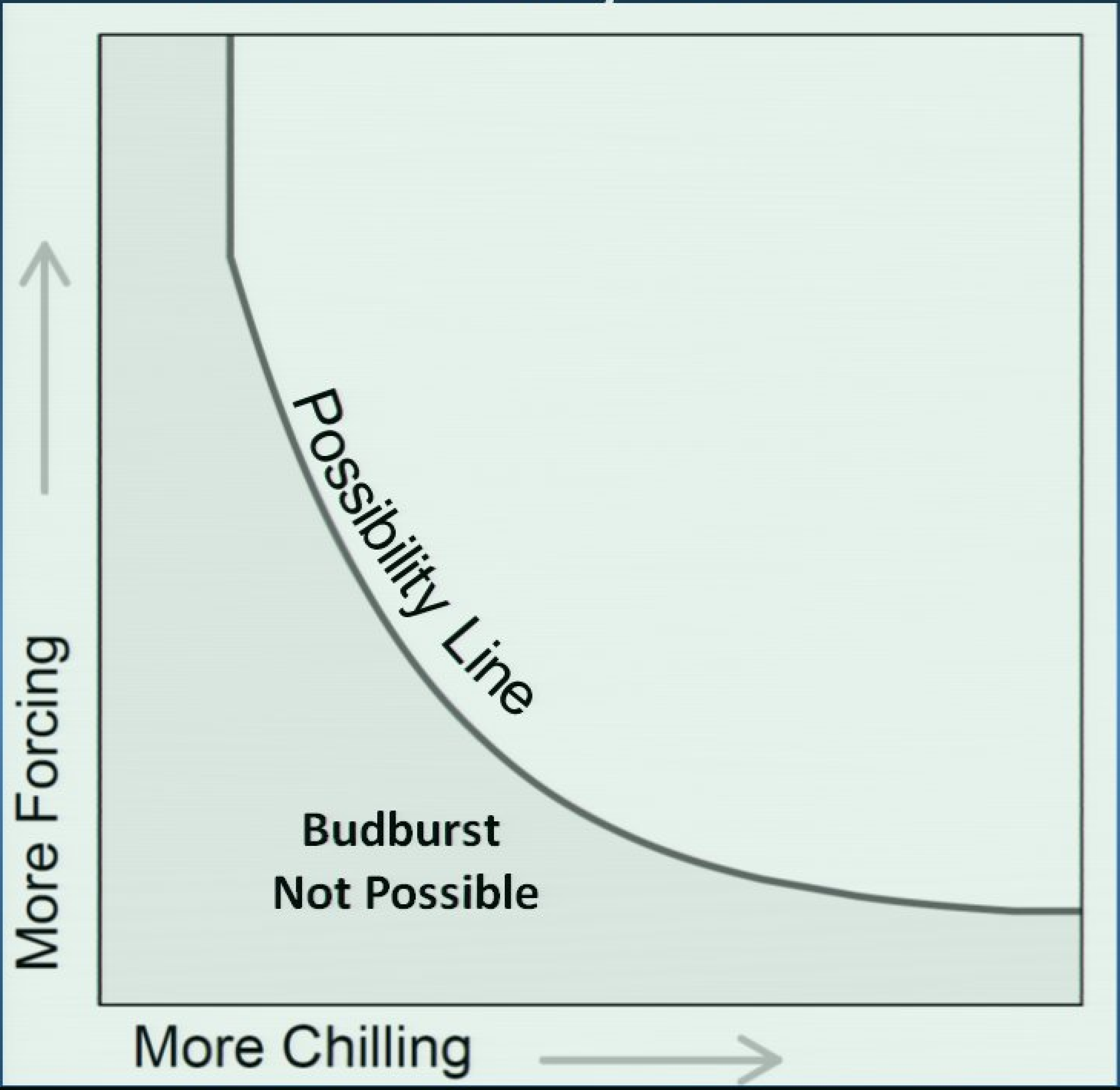
Budburst Study

- Objective: to develop a model to predict timing of budburst given winter temperature and genotype
- Same plant material as later used in the Seed Source Movement Study
  - 120 families from 60 populations in 12 regions
- Moved material in and out of greenhouses at Olympia and Corvallis to give eight different winter temperature environments
- Recorded budburst in the spring

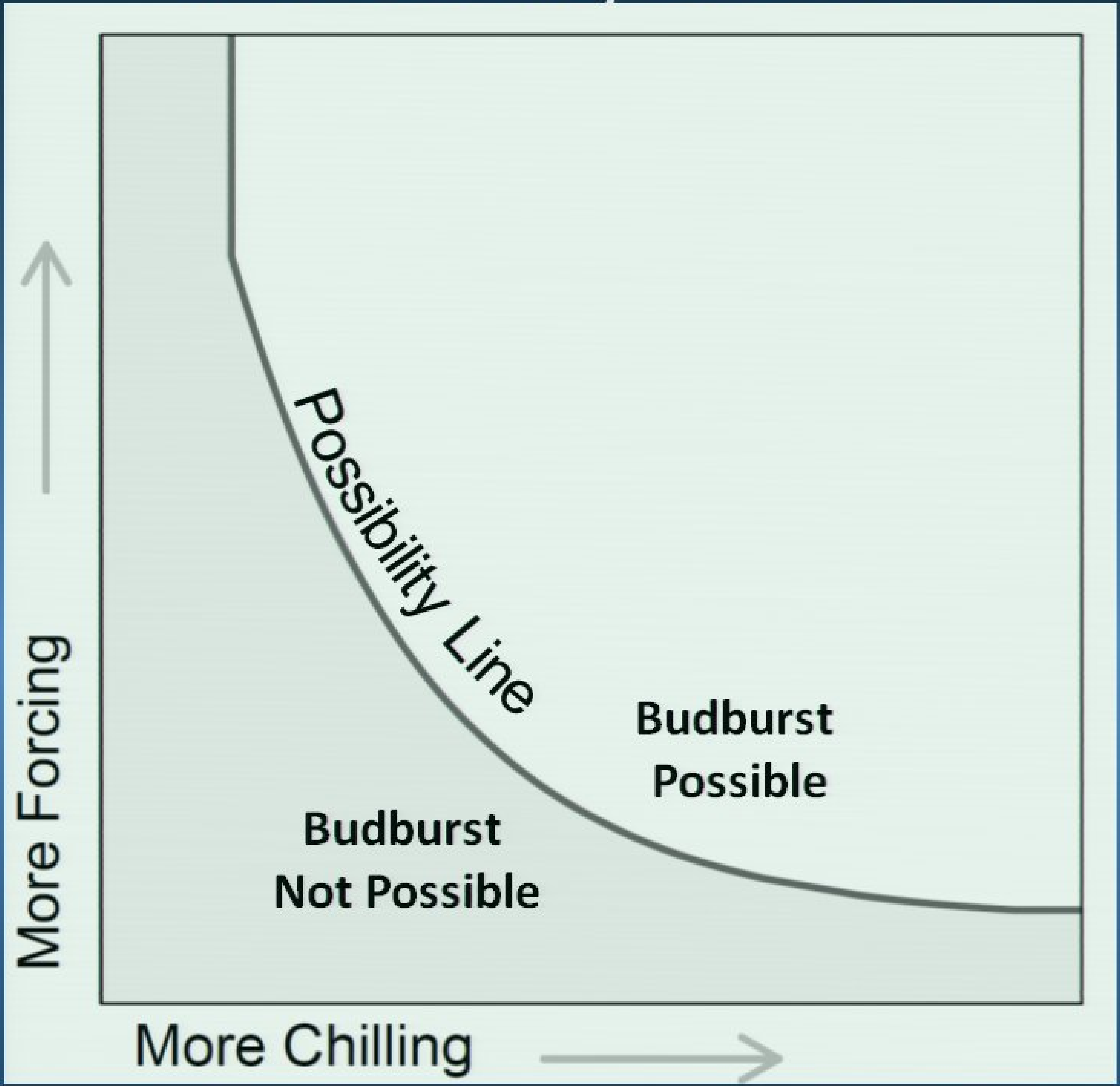
The Possibility-Line Model



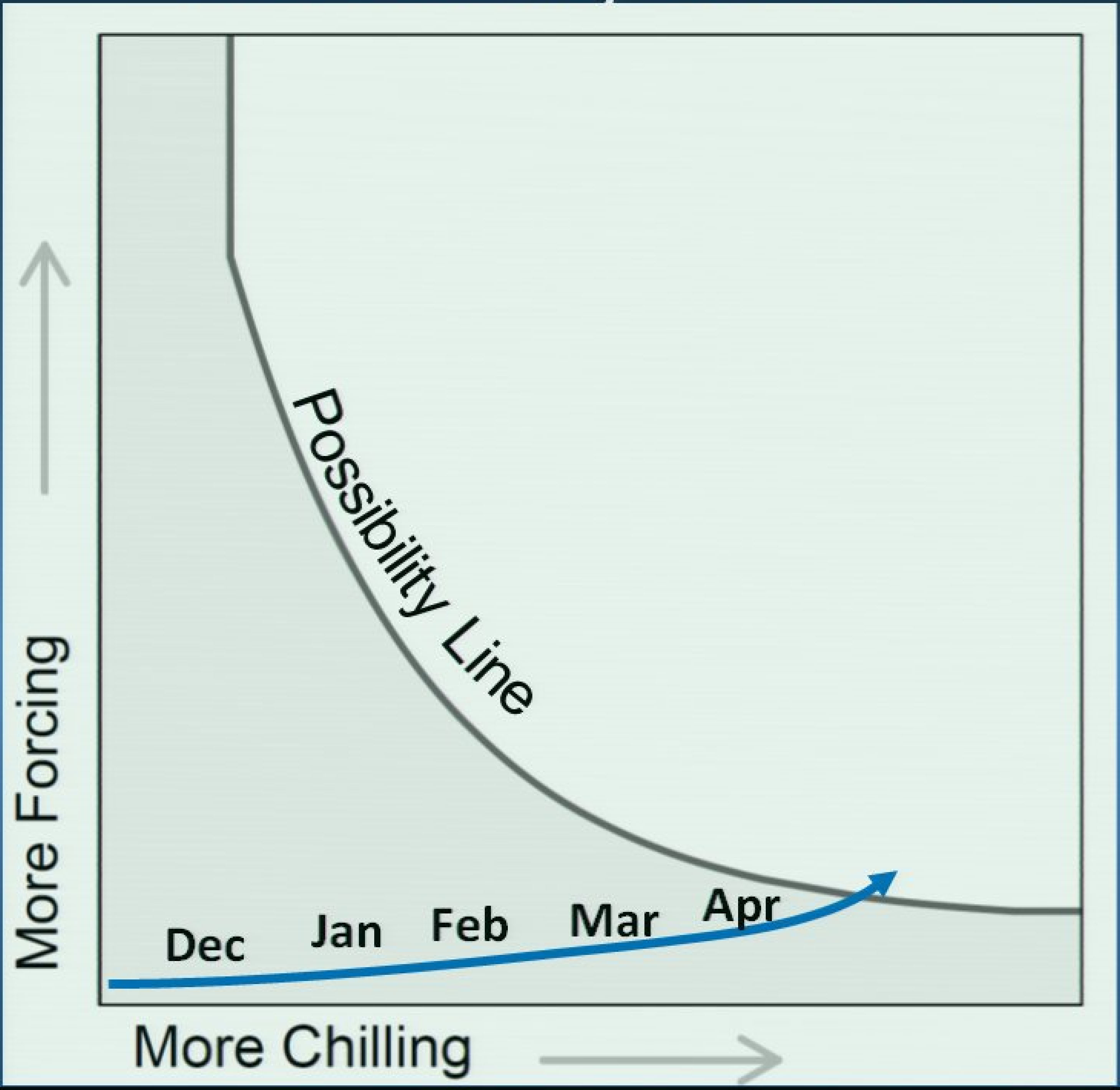
The Possibility-Line Model



The Possibility-Line Model

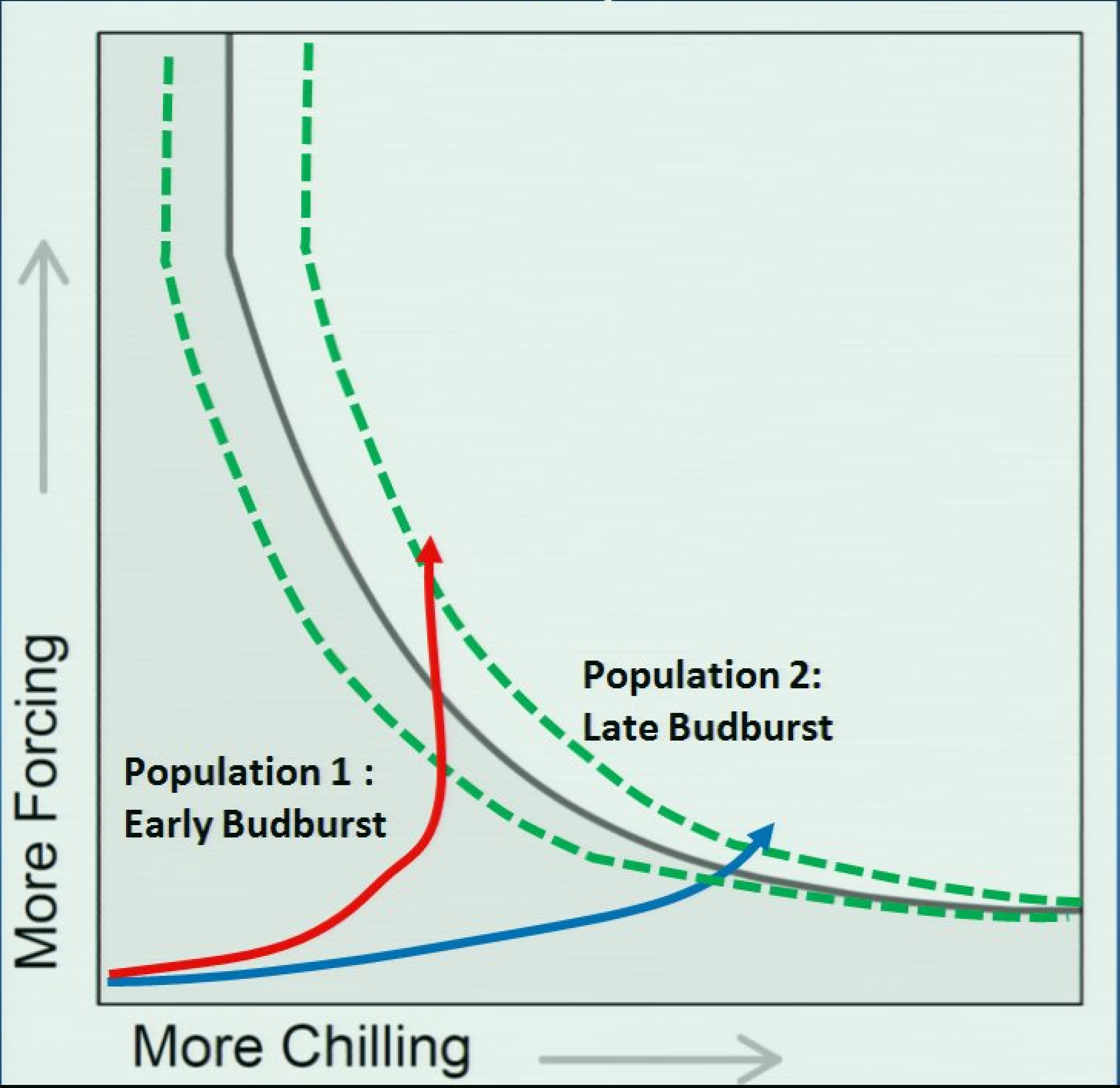


The Possibility-Line Model

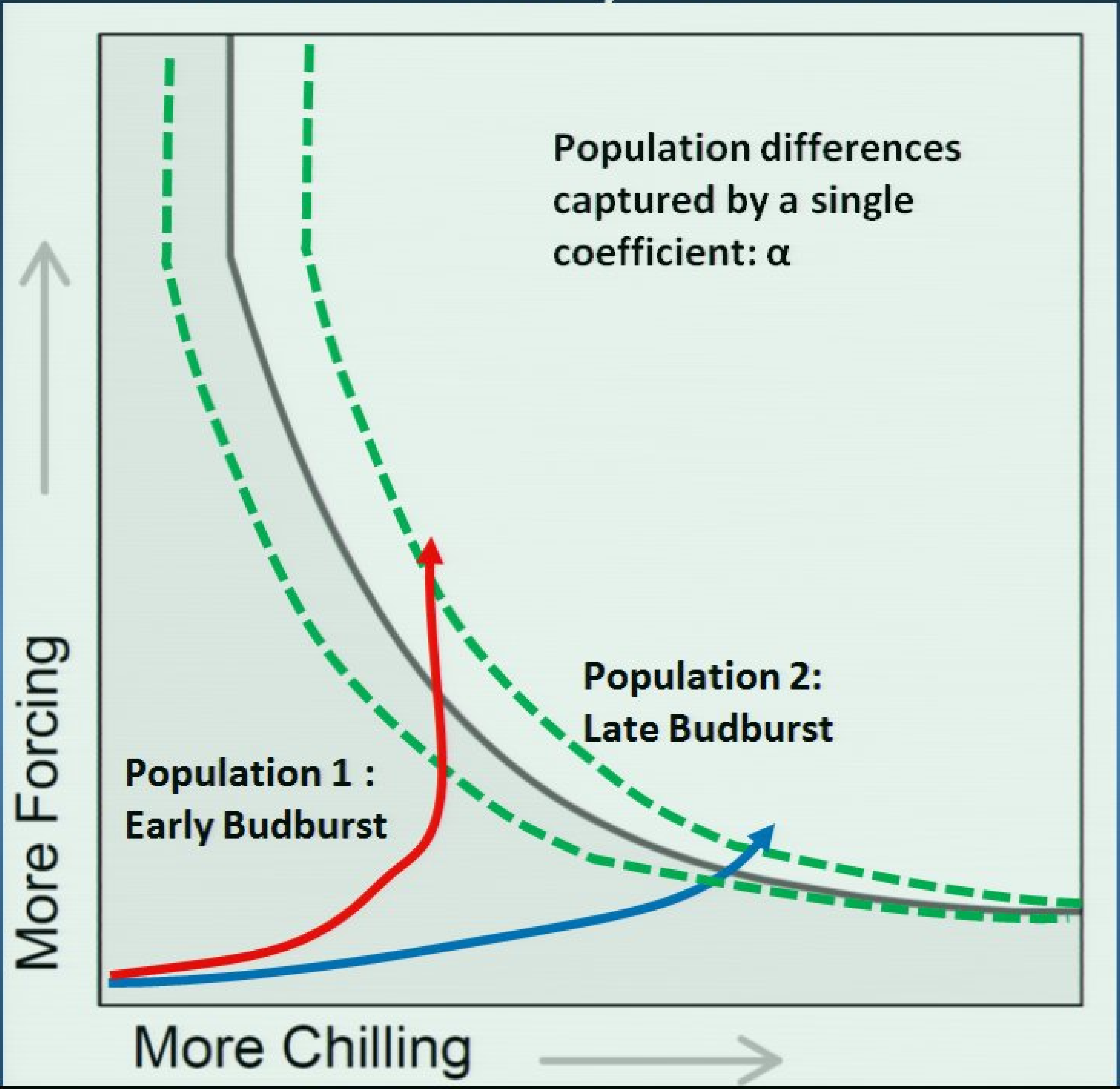


The Possibility-Line Model

The Possibility-Line Model

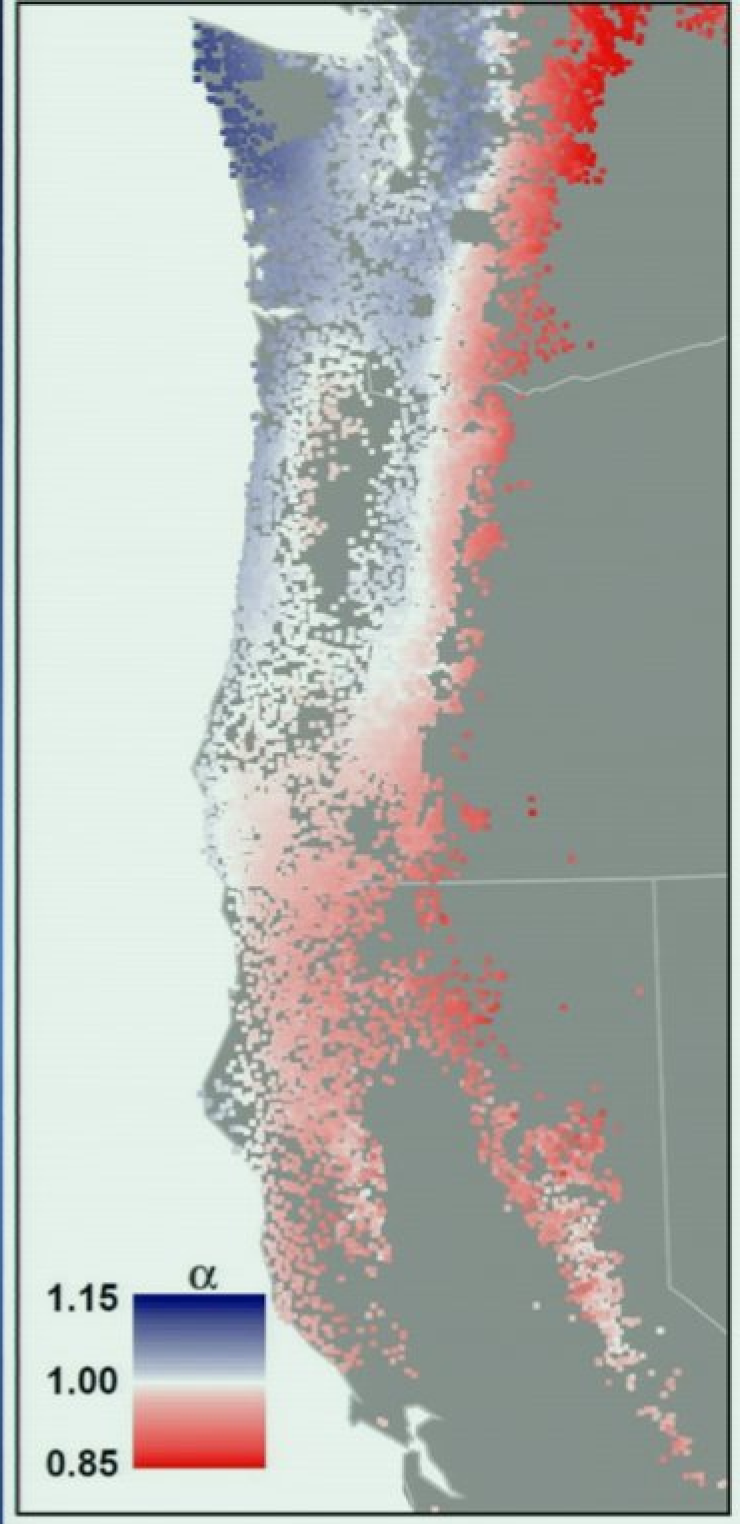


The Possibility-Line Model



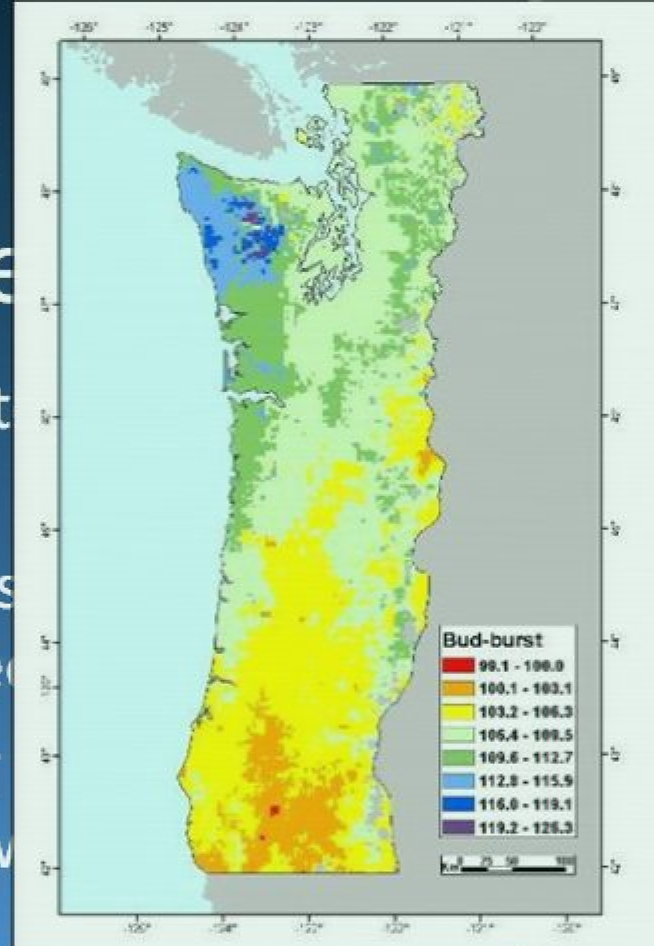
Predicting the Population Coefficient

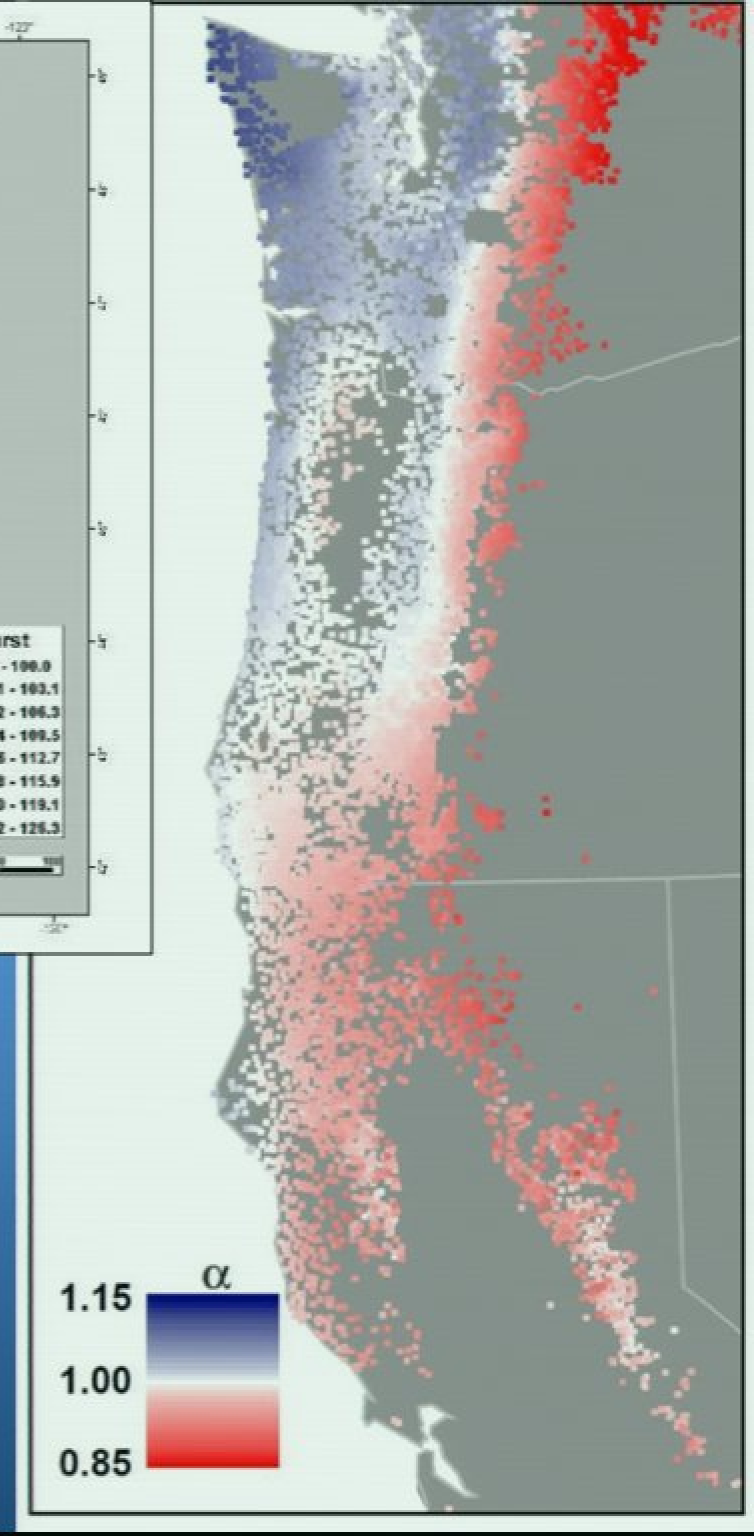
- Coefficient can be predicted from the environment
- Winter temperature and summer precipitation are best predictors
- Less forcing is needed for populations from environments with cold winters and warm, dry summers



Predicting Population Coe

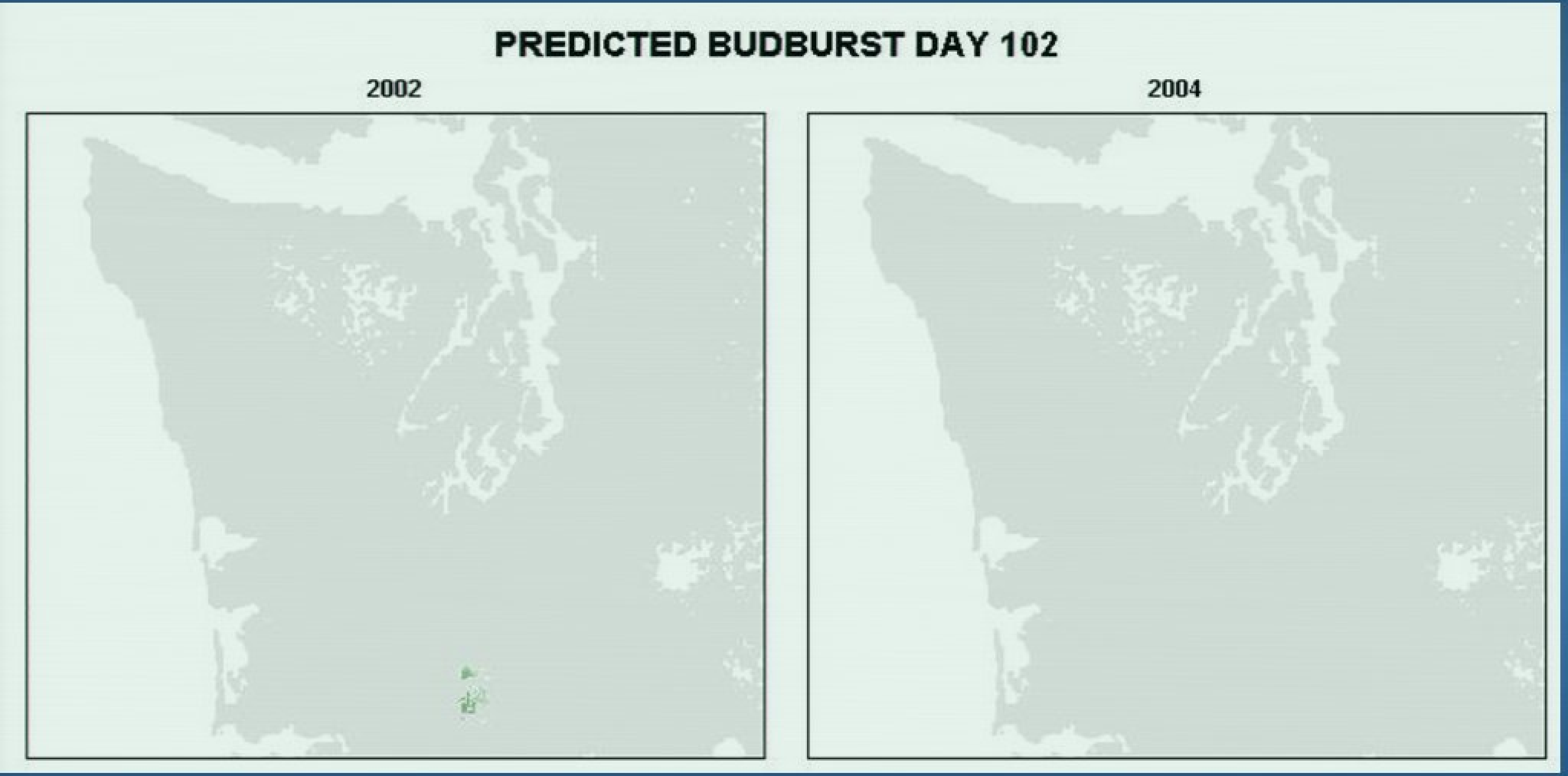
- Coefficient can be predict environment
- Winter temperature and s precipitation are best pre
- Less forcing is needed for environments with cold w dry summers



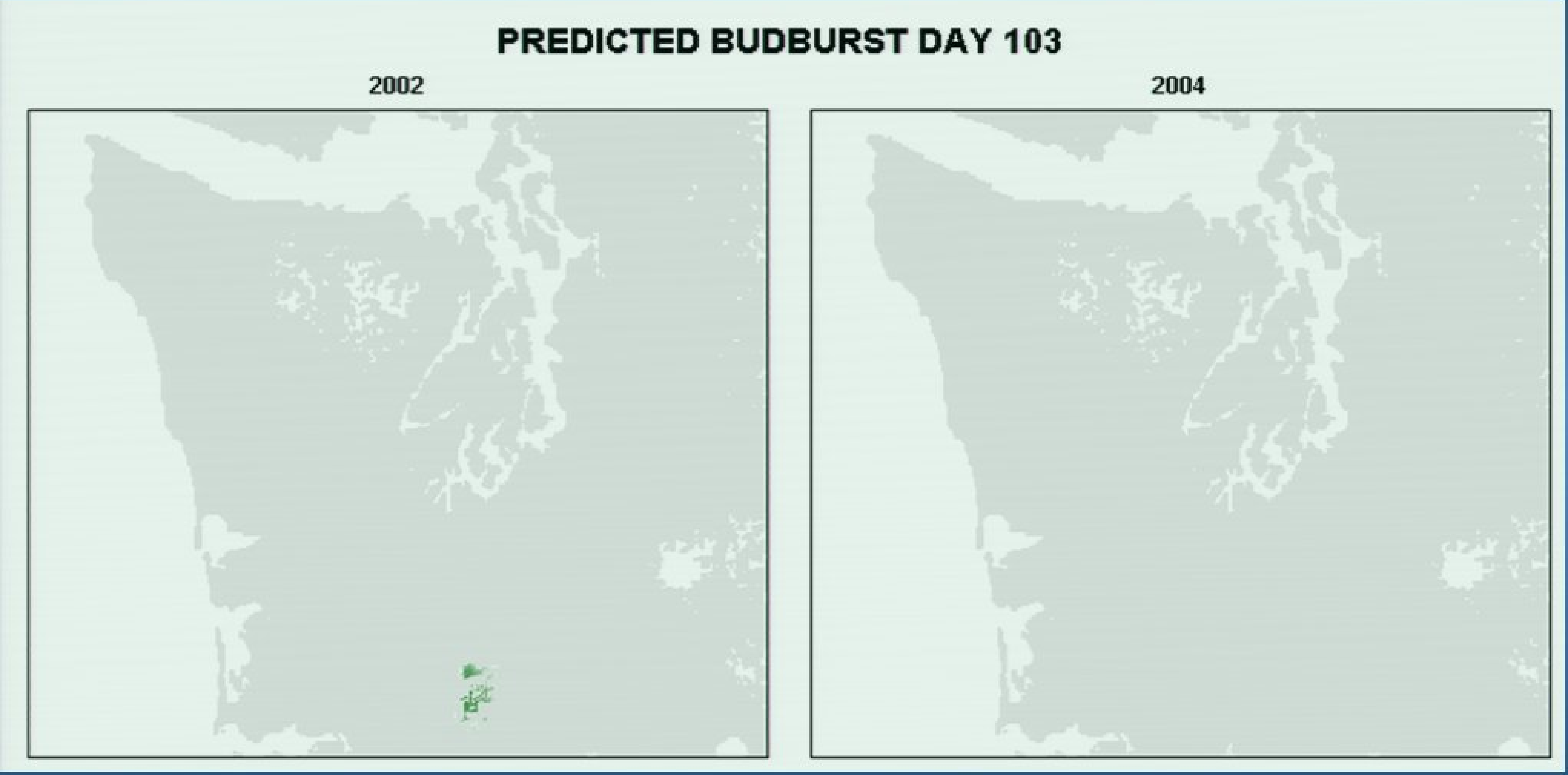


Results similar to those from the earlier genecology study

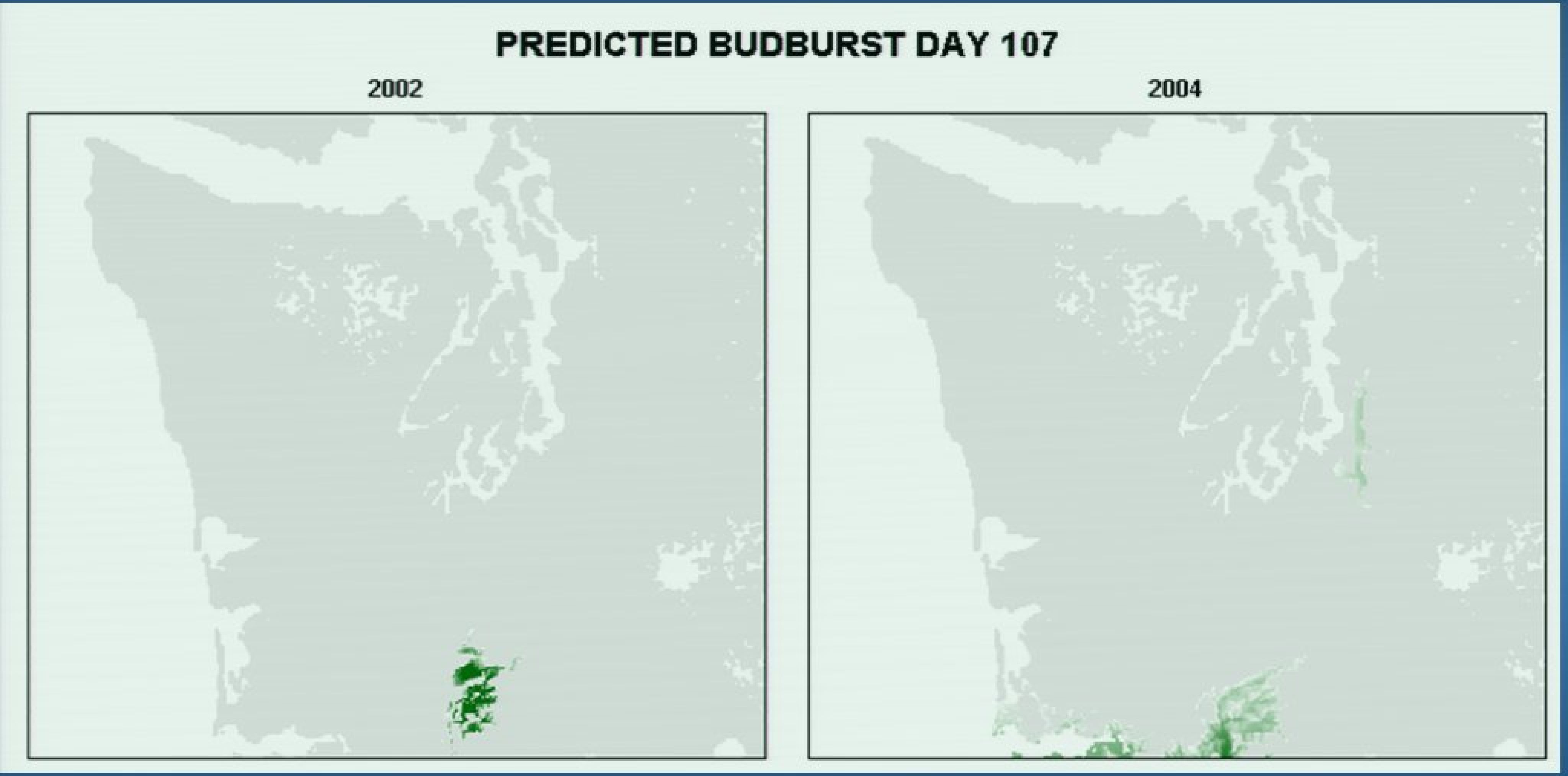
Example: Budburst during a cool spring(2002) and a warm spring (2004).



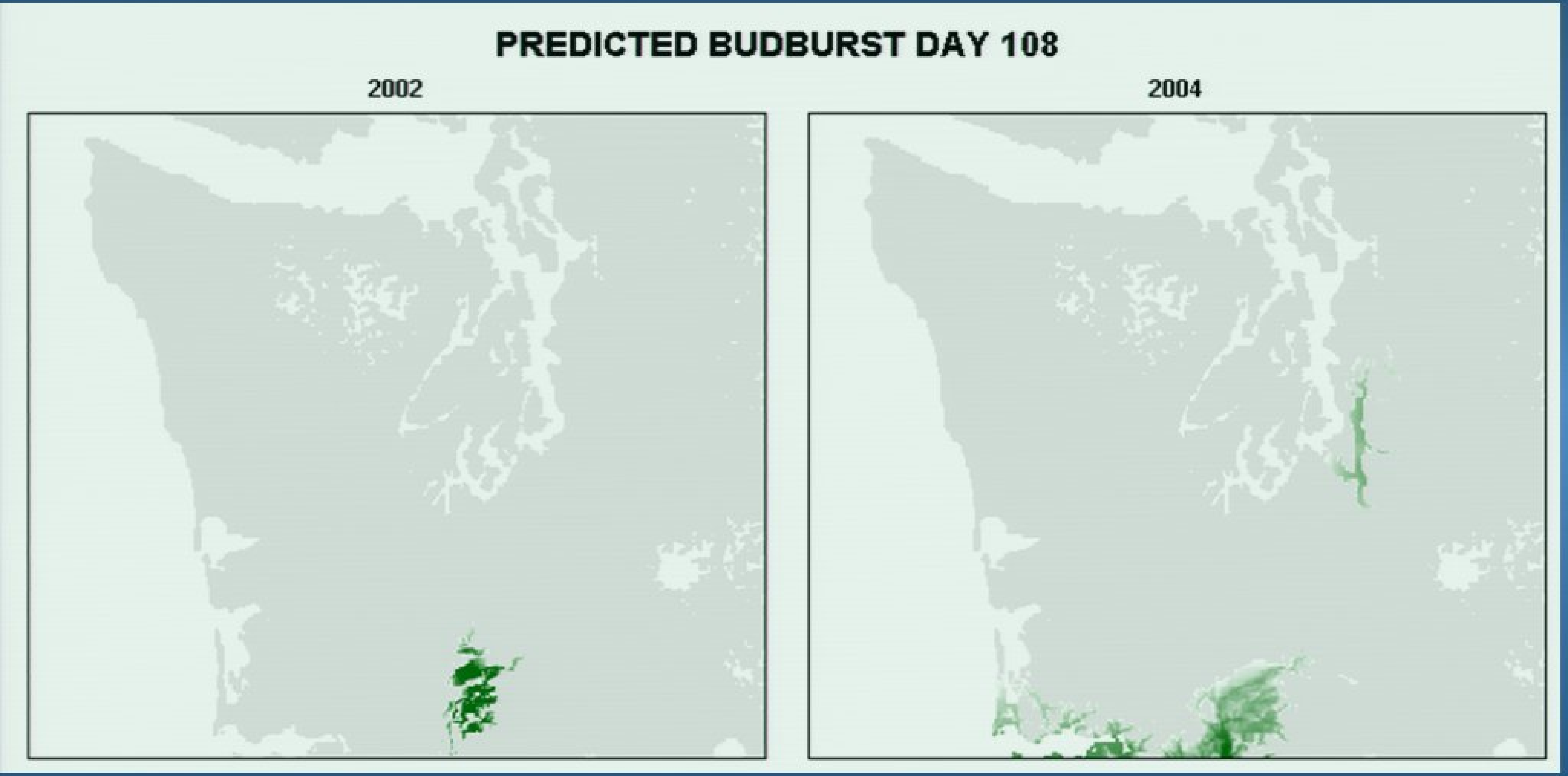
Example: Budburst during a cool spring(2002) and a warm spring (2004).



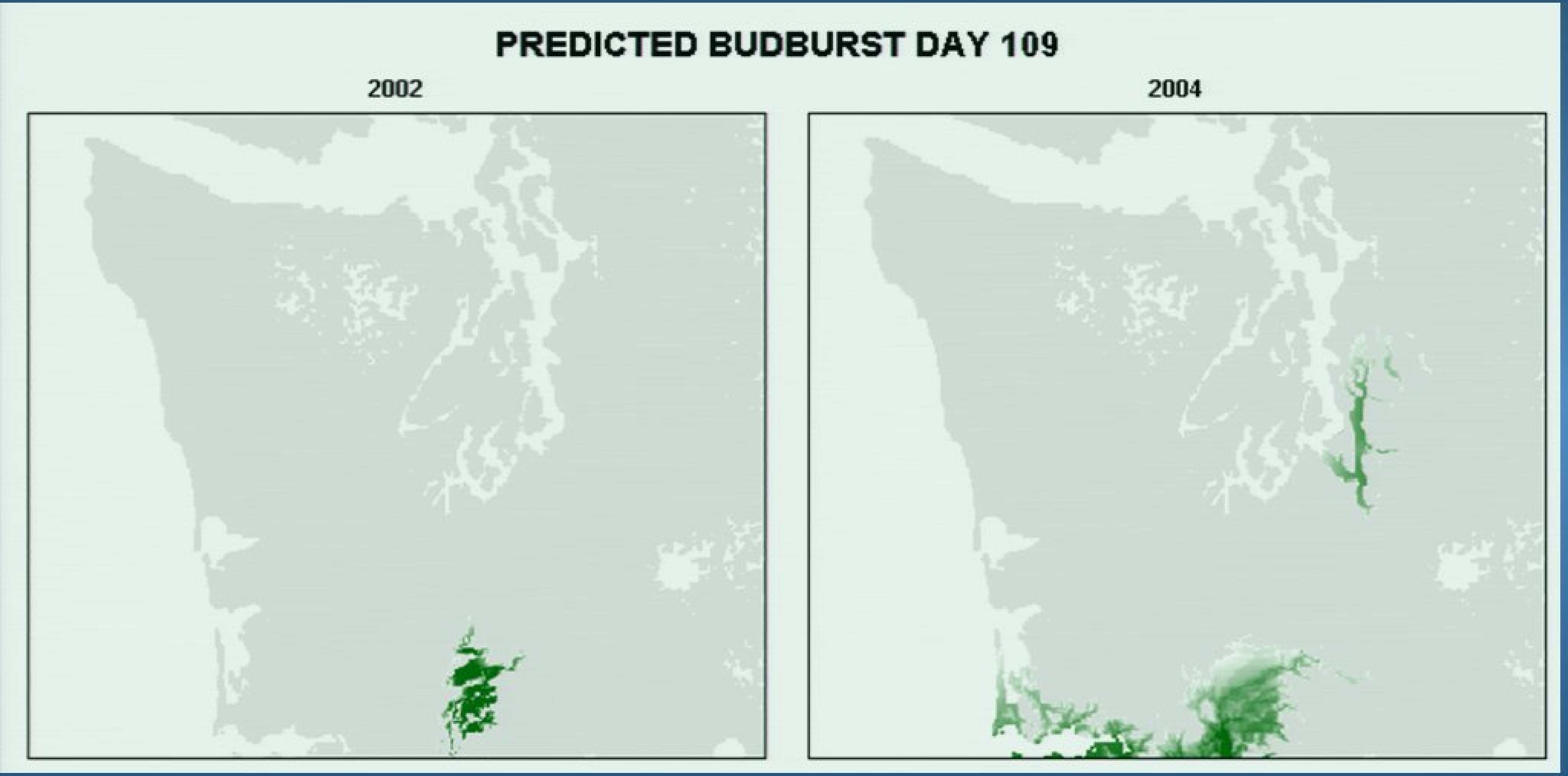
Example: Budburst during a cool spring(2002) and a warm spring (2004).



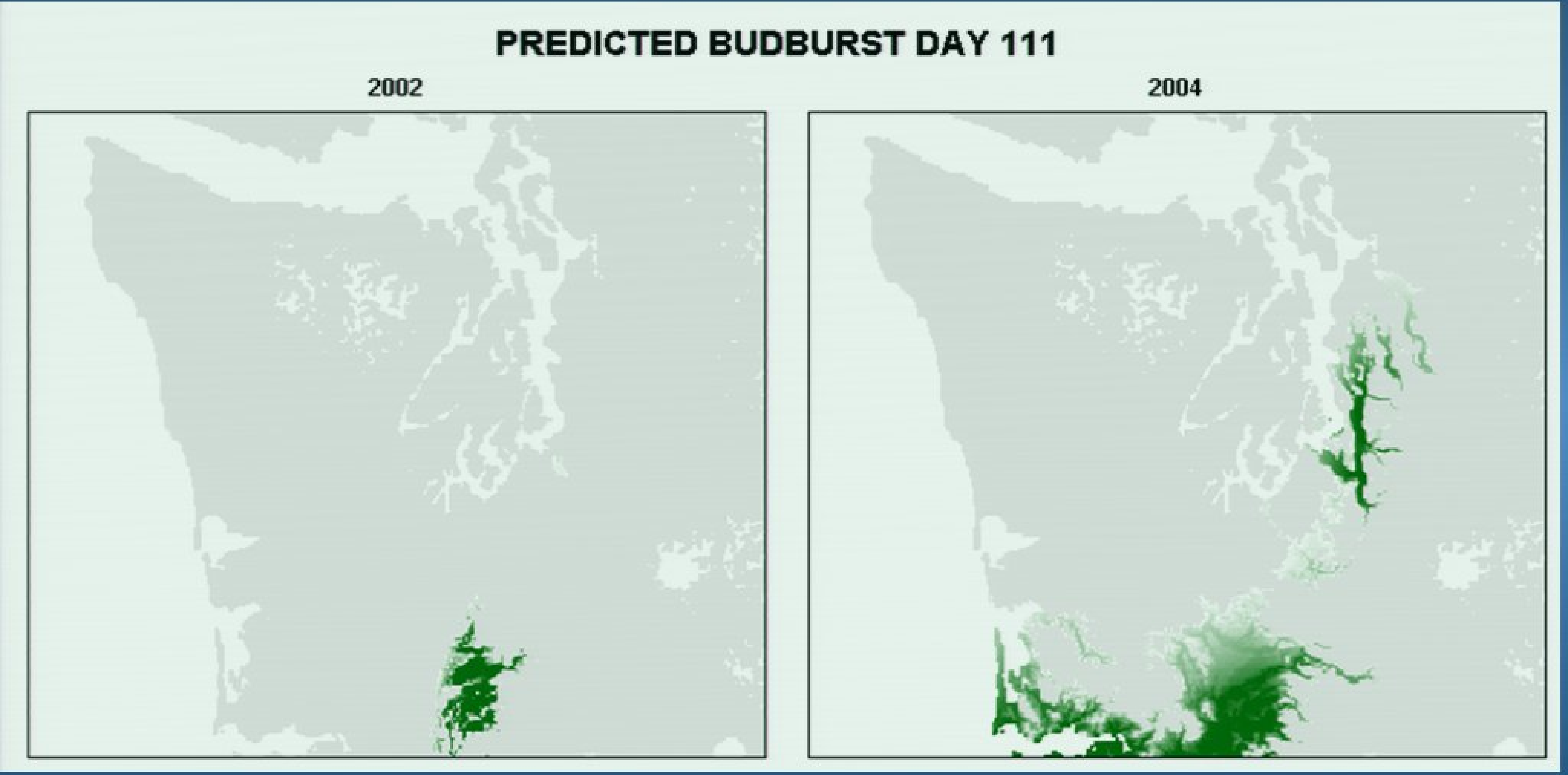
Example: Budburst during a cool spring(2002) and a warm spring (2004).



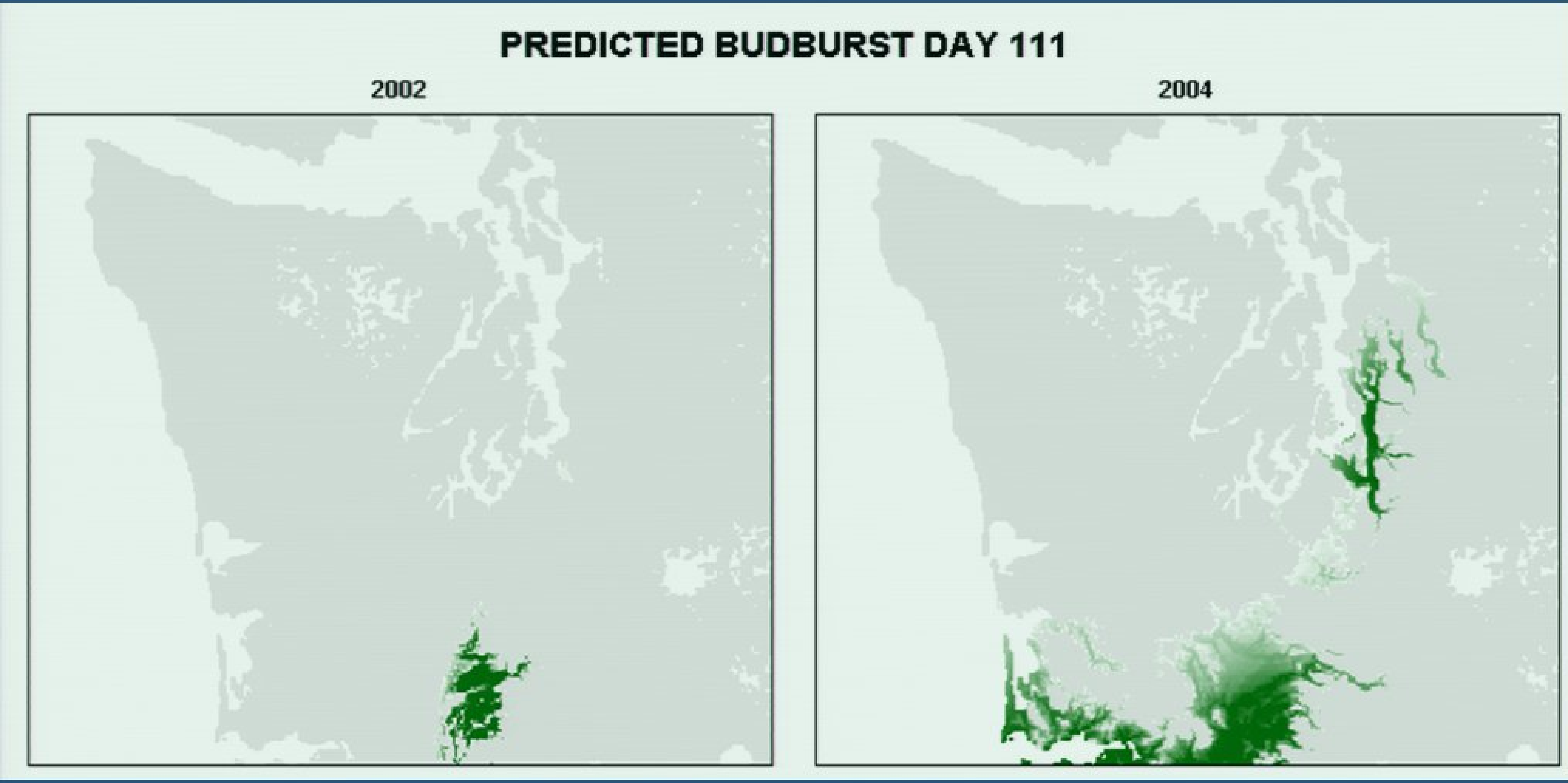
Example: Budburst during a cool spring(2002) and a warm spring (2004).



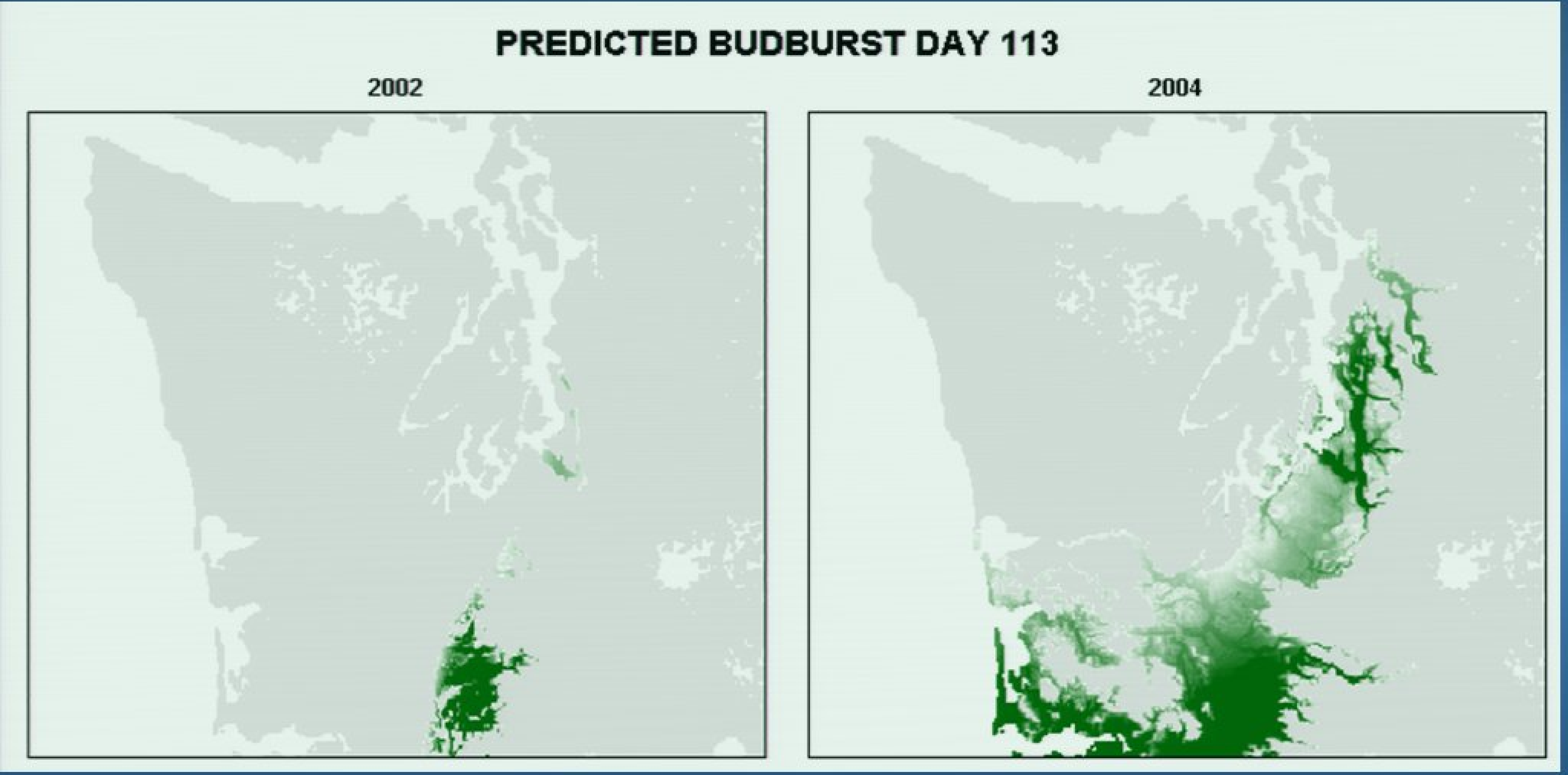
Example: Budburst during a cool spring(2002) and a warm spring (2004).



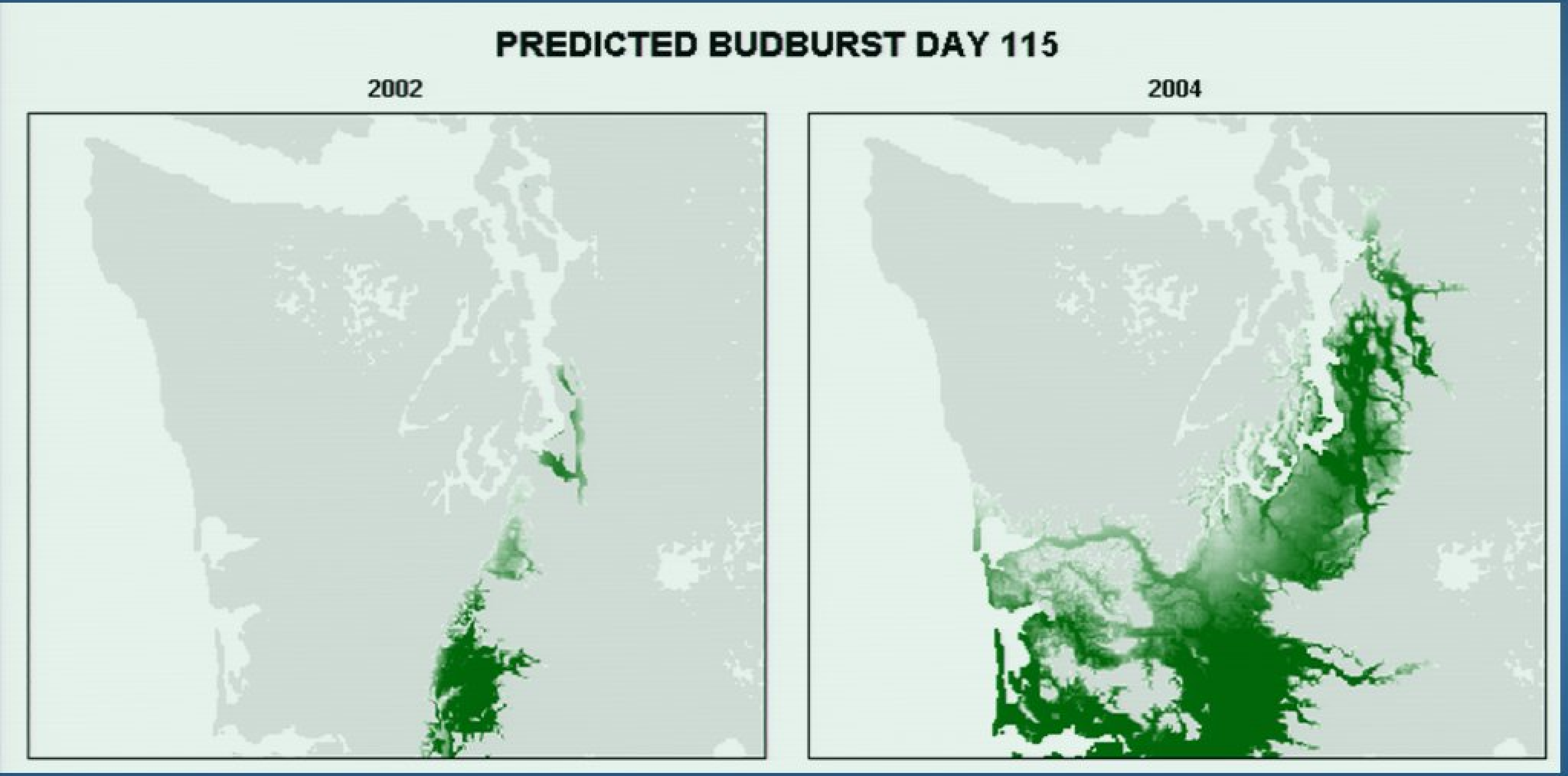
Example: Budburst during a cool spring(2002) and a warm spring (2004).



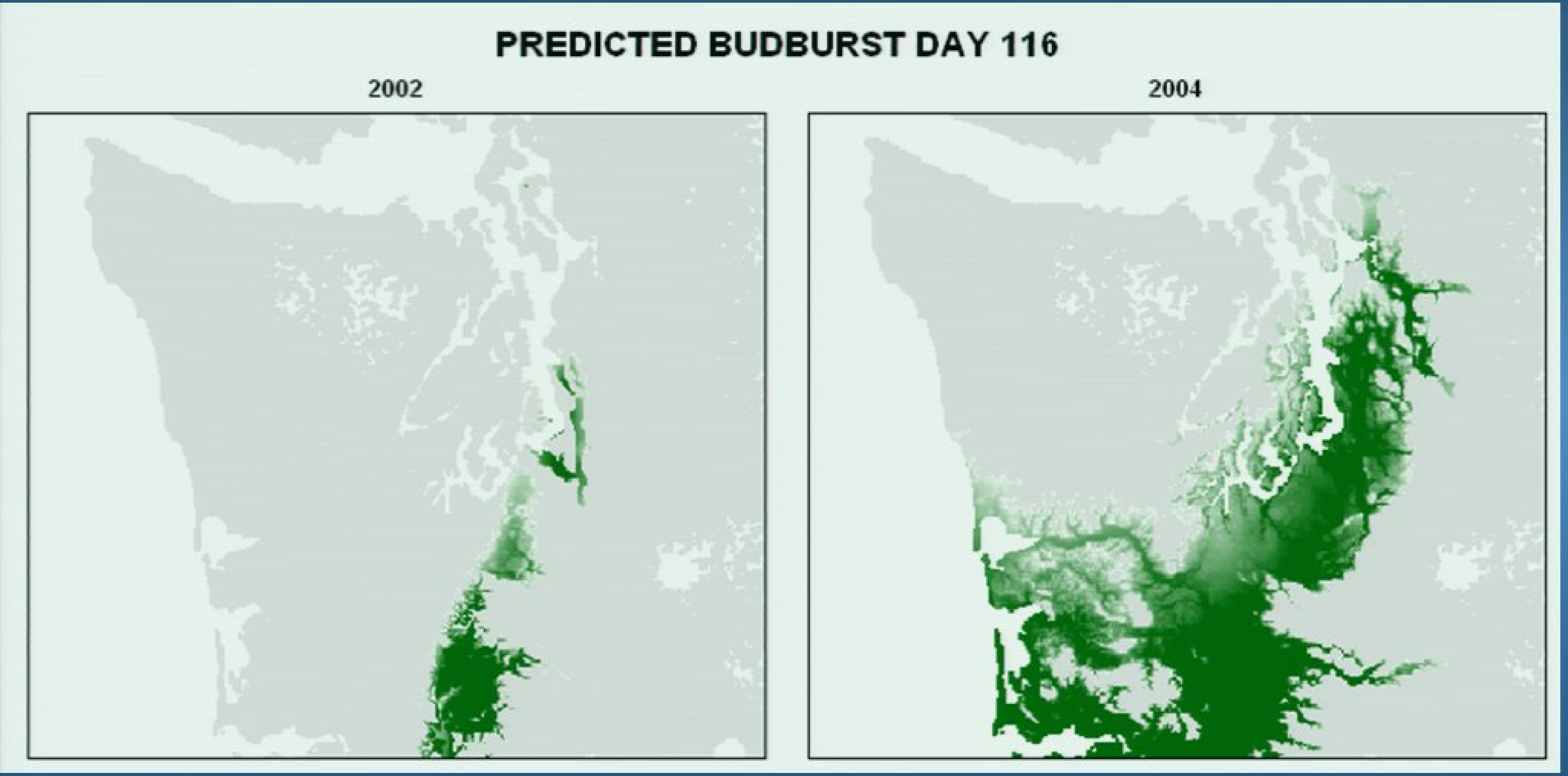
Example: Budburst during a cool spring(2002) and a warm spring (2004).



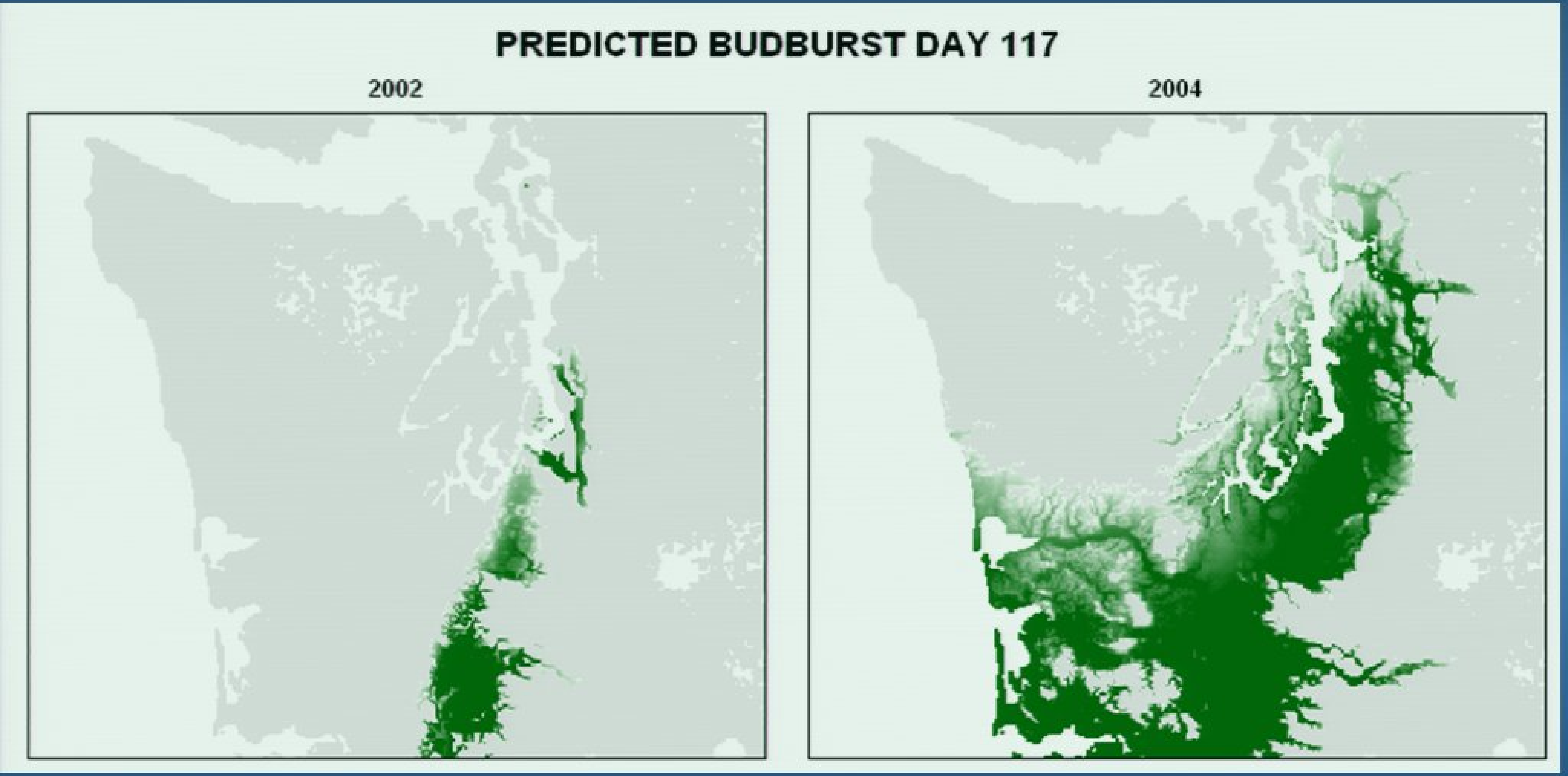
Example: Budburst during a cool spring(2002) and a warm spring (2004).



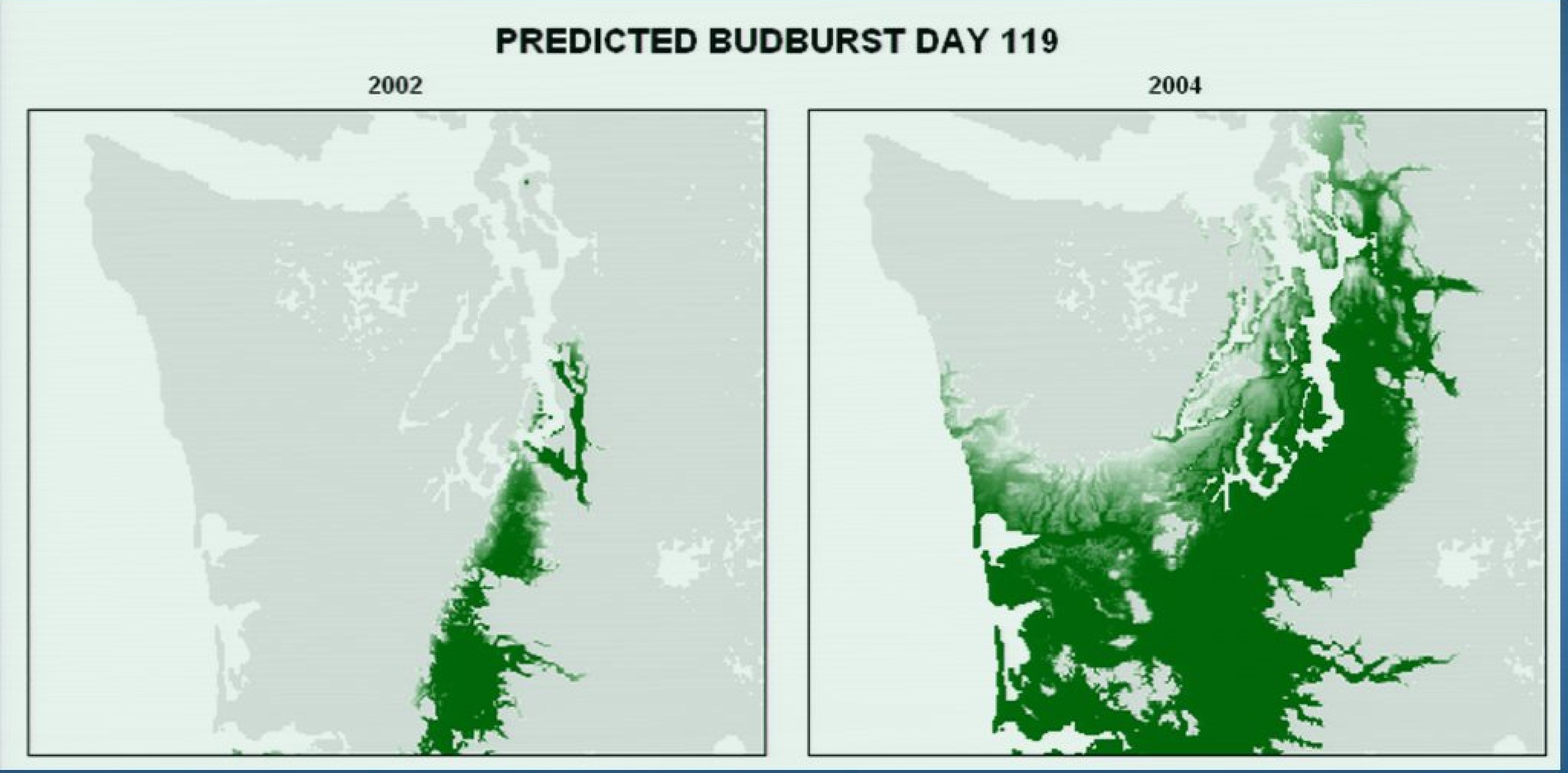
Example: Budburst during a cool spring(2002) and a warm spring (2004).



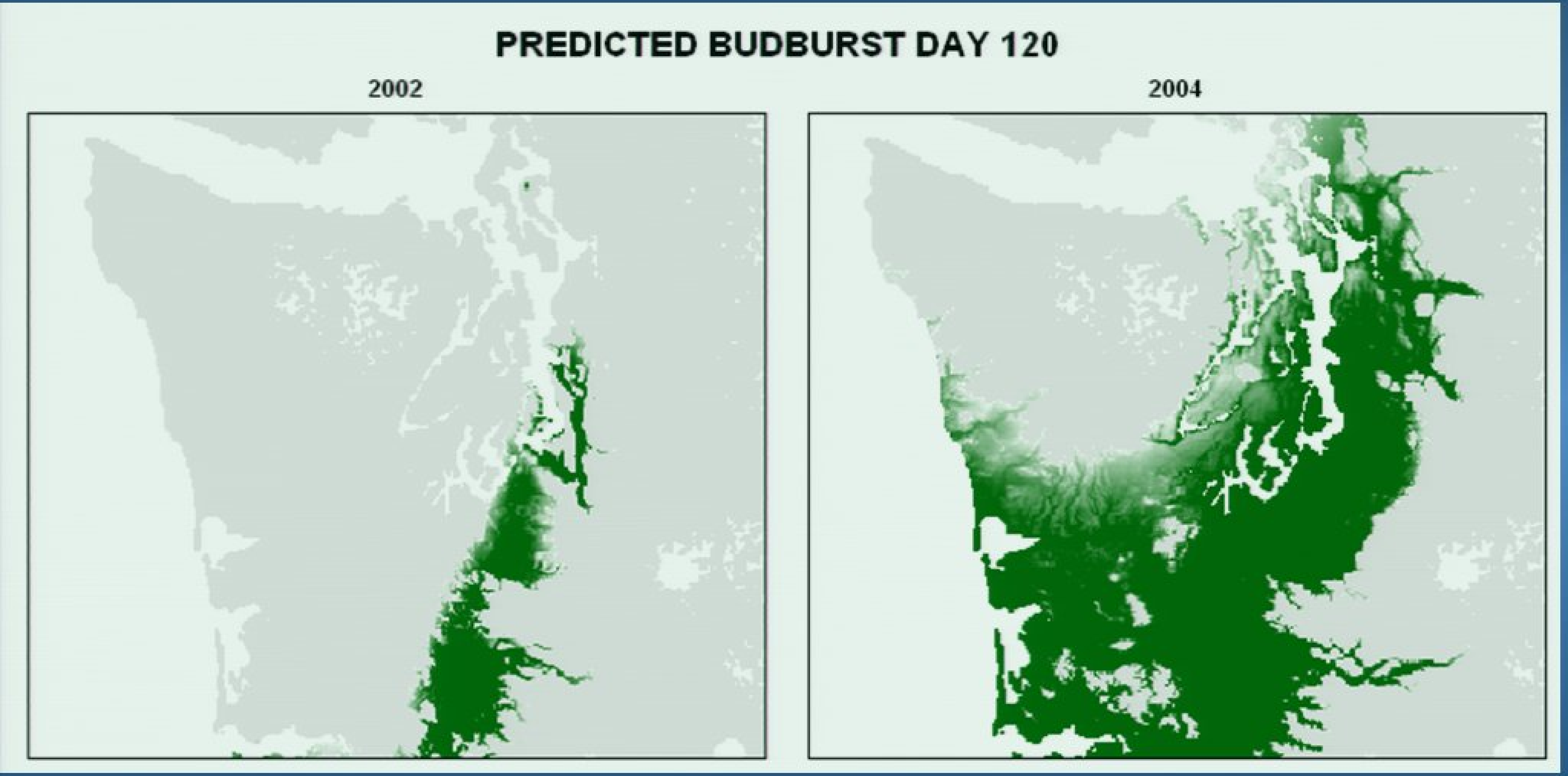
Example: Budburst during a cool spring(2002) and a warm spring (2004).



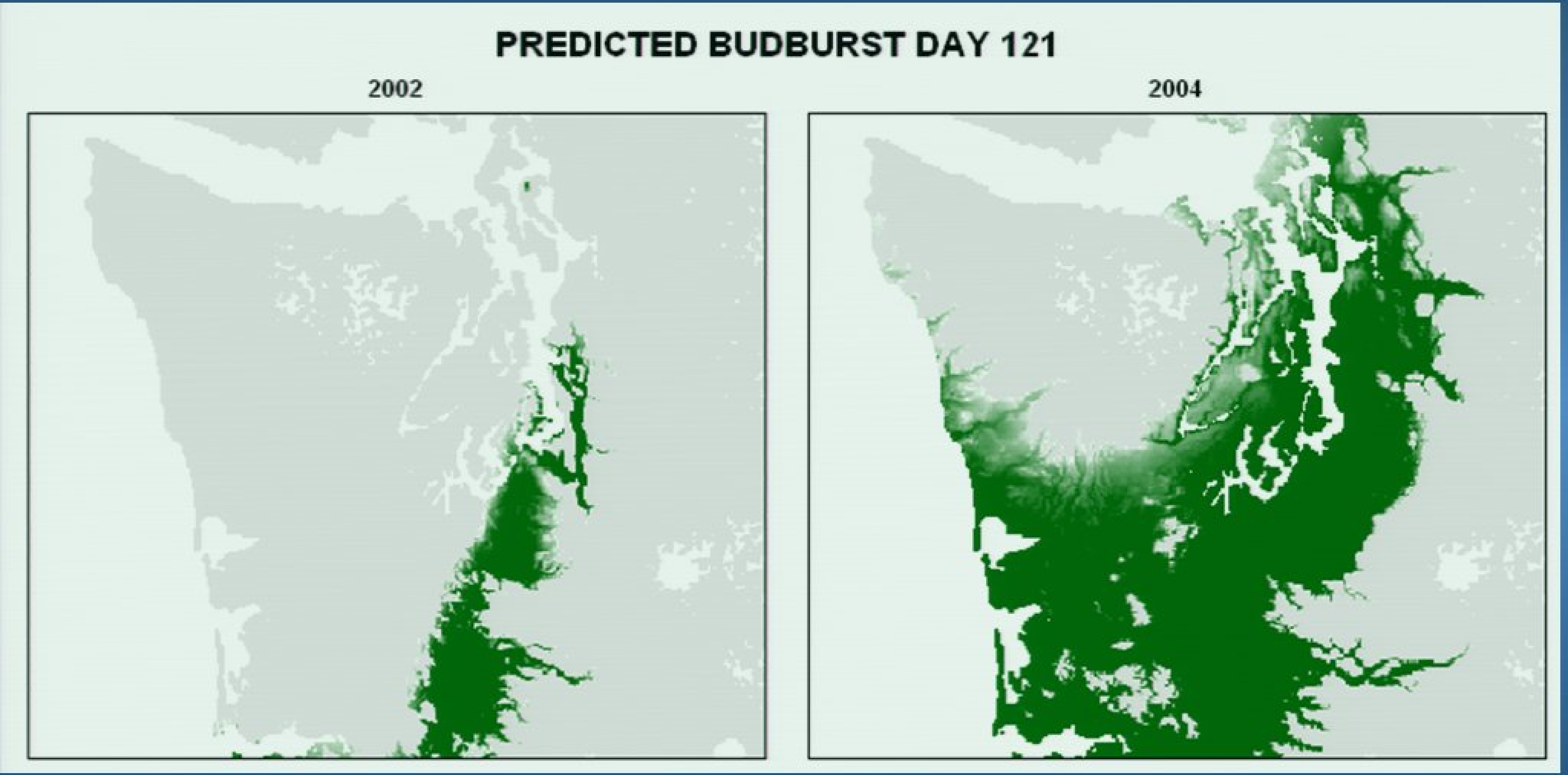
Example: Budburst during a cool spring(2002) and a warm spring (2004).



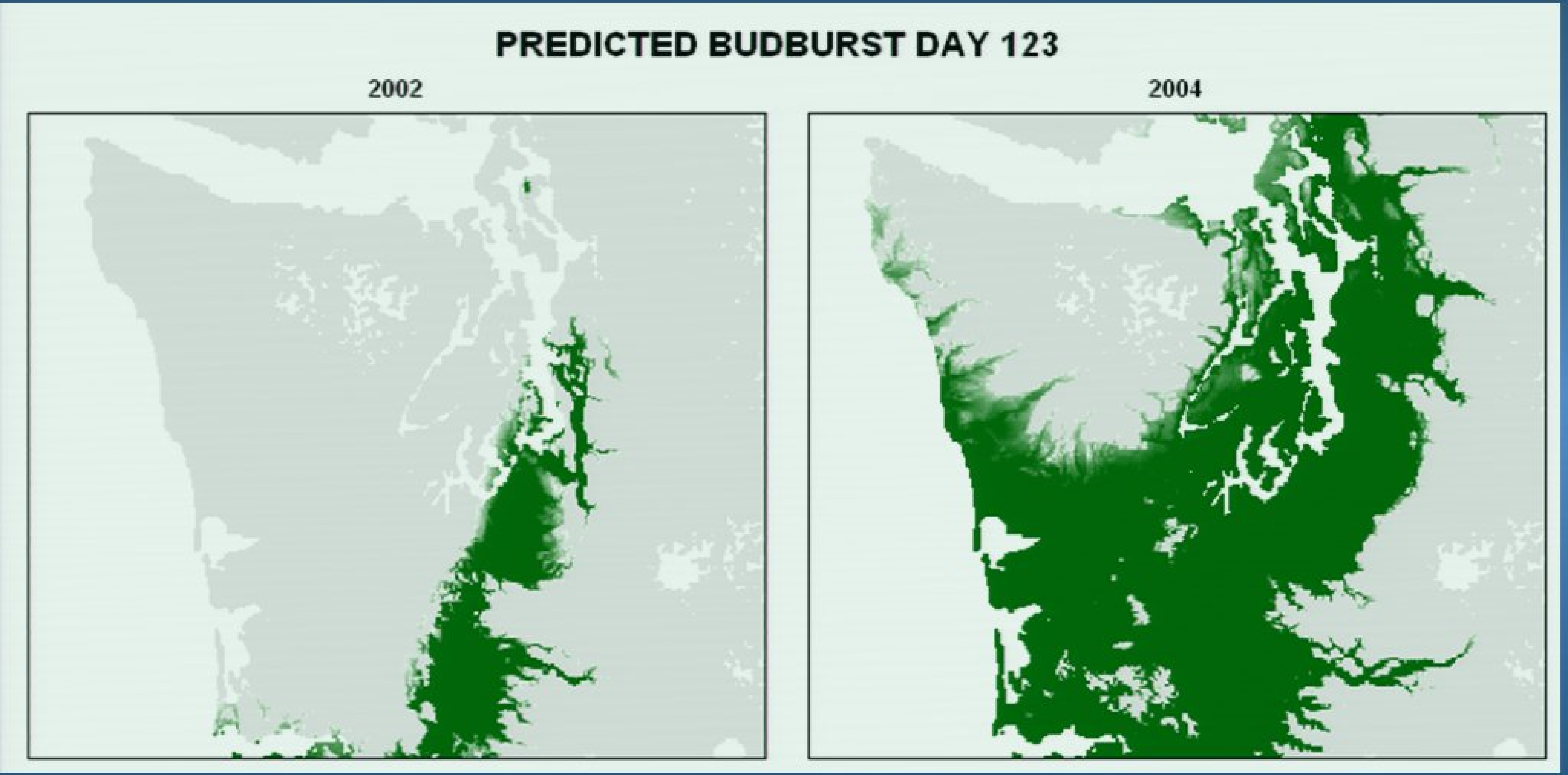
Example: Budburst during a cool spring(2002) and a warm spring (2004).



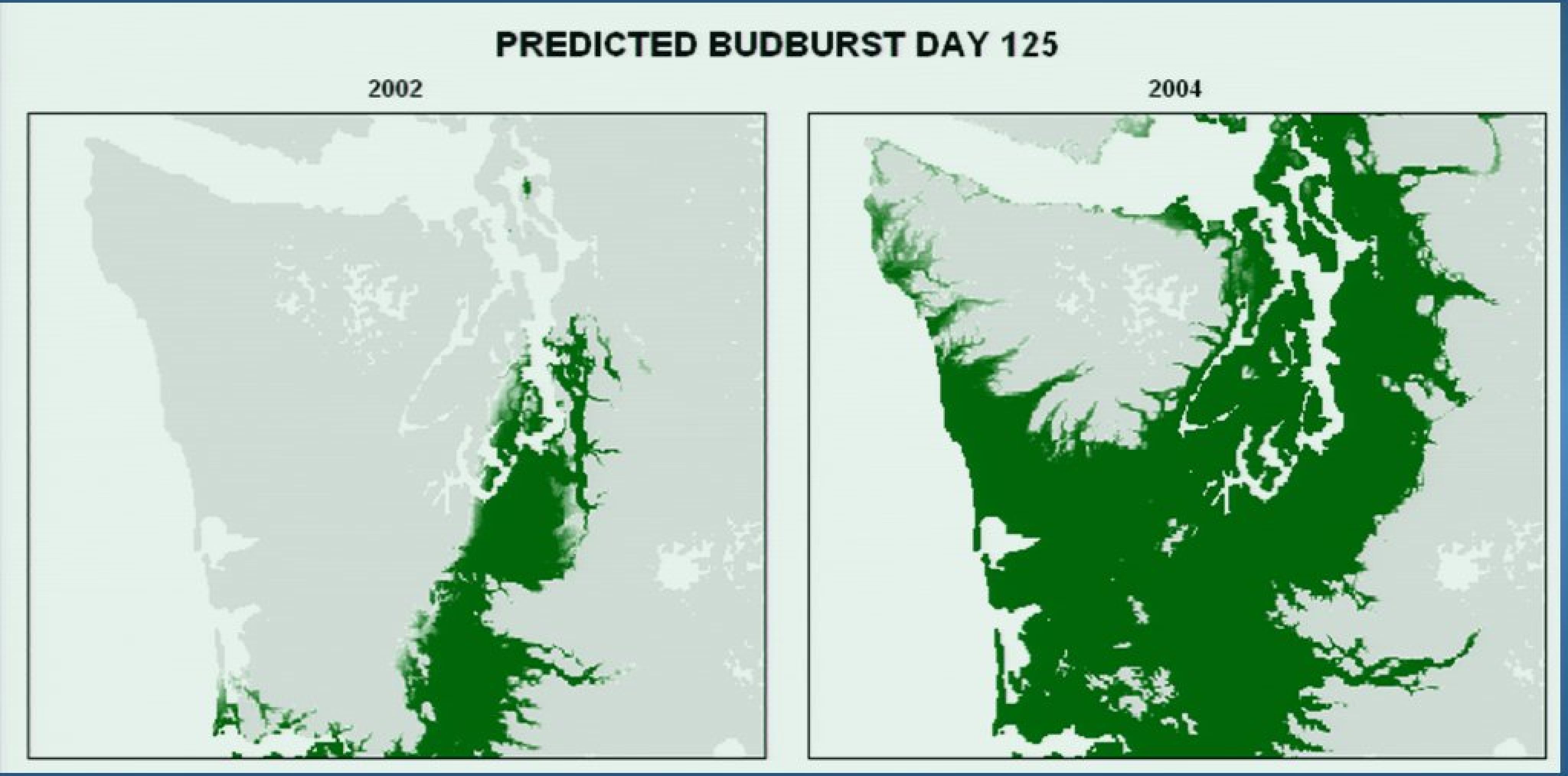
Example: Budburst during a cool spring(2002) and a warm spring (2004).



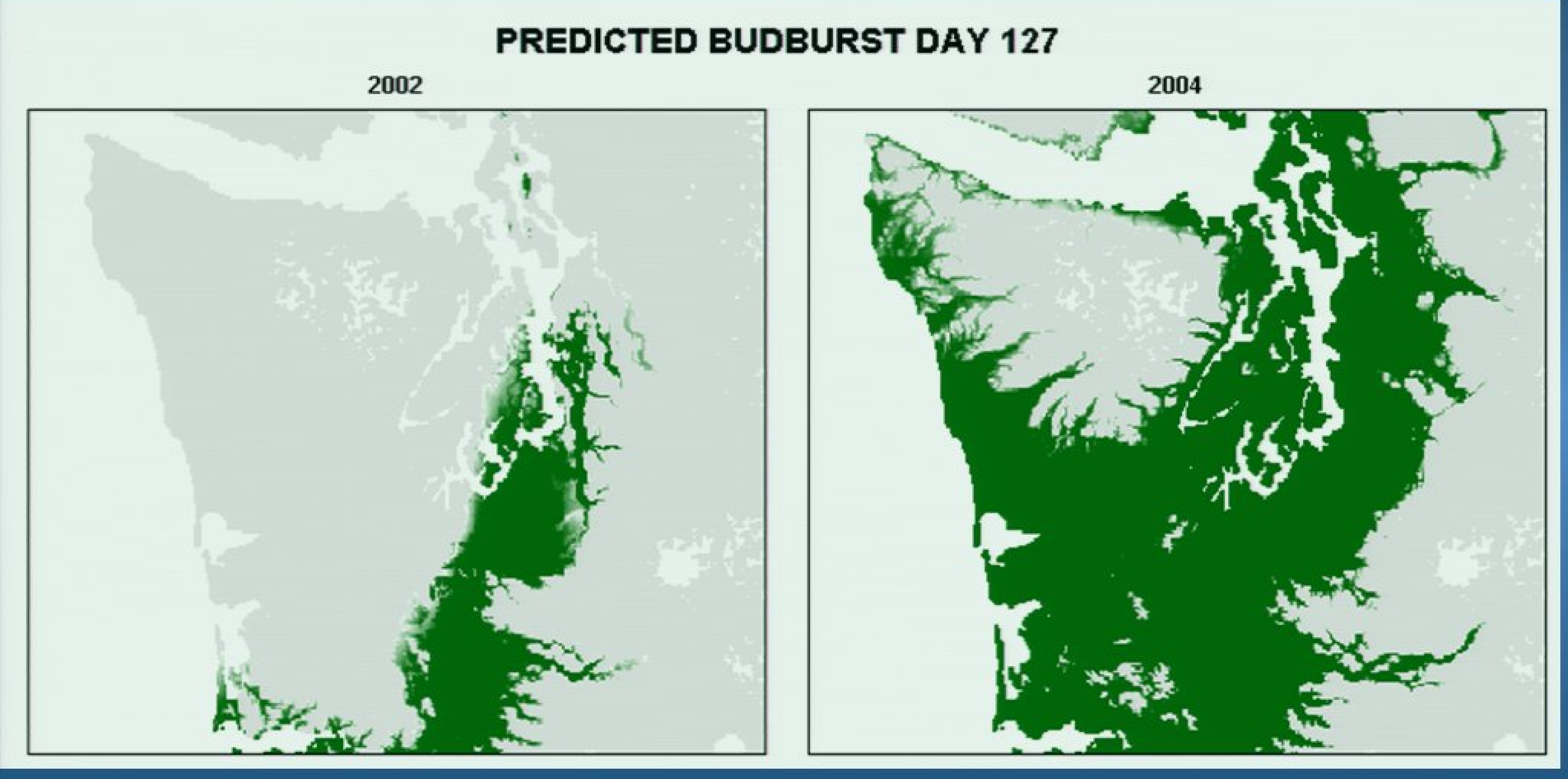
Example: Budburst during a cool spring(2002) and a warm spring (2004).



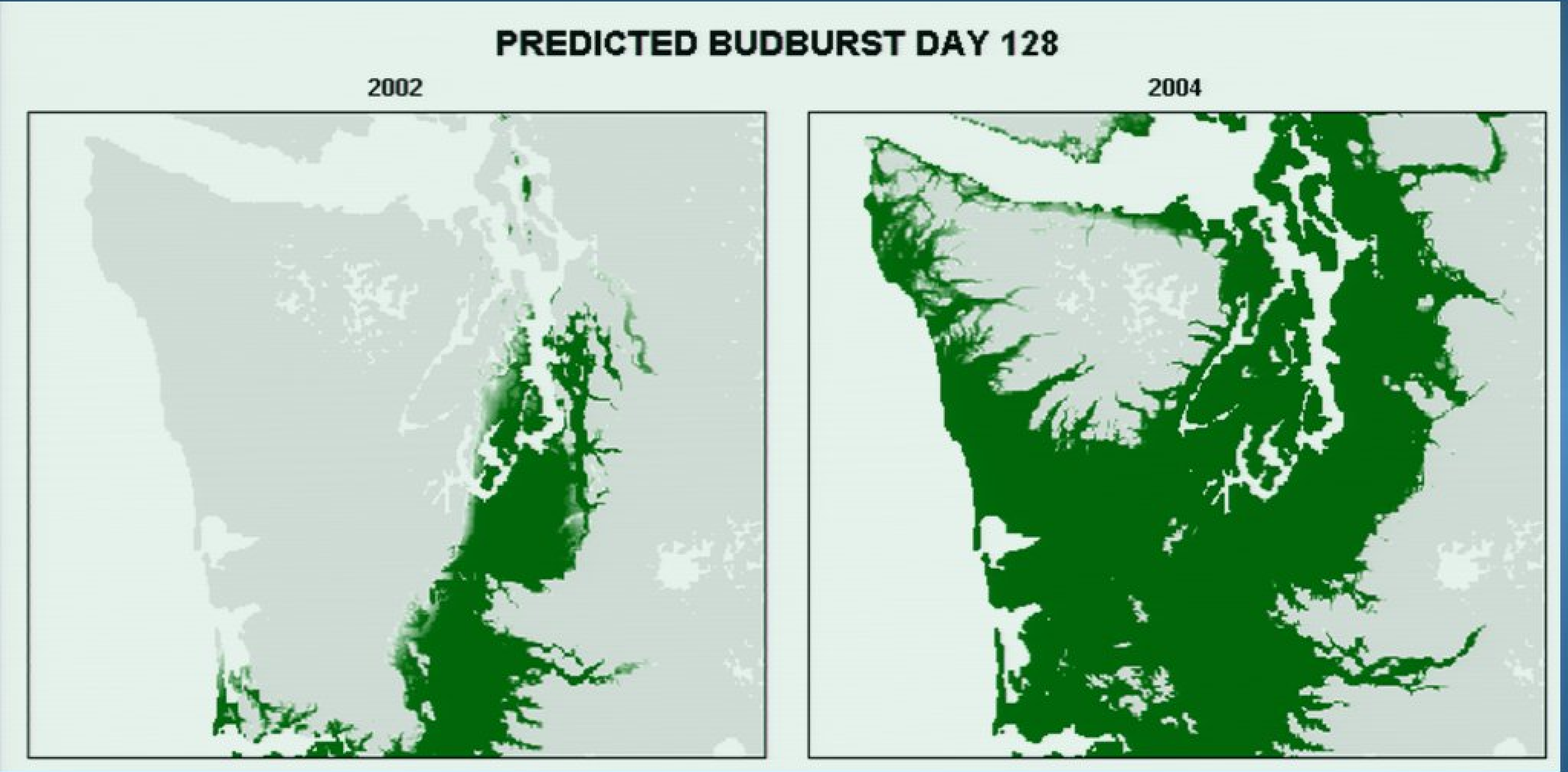
Example: Budburst during a cool spring(2002) and a warm spring (2004).



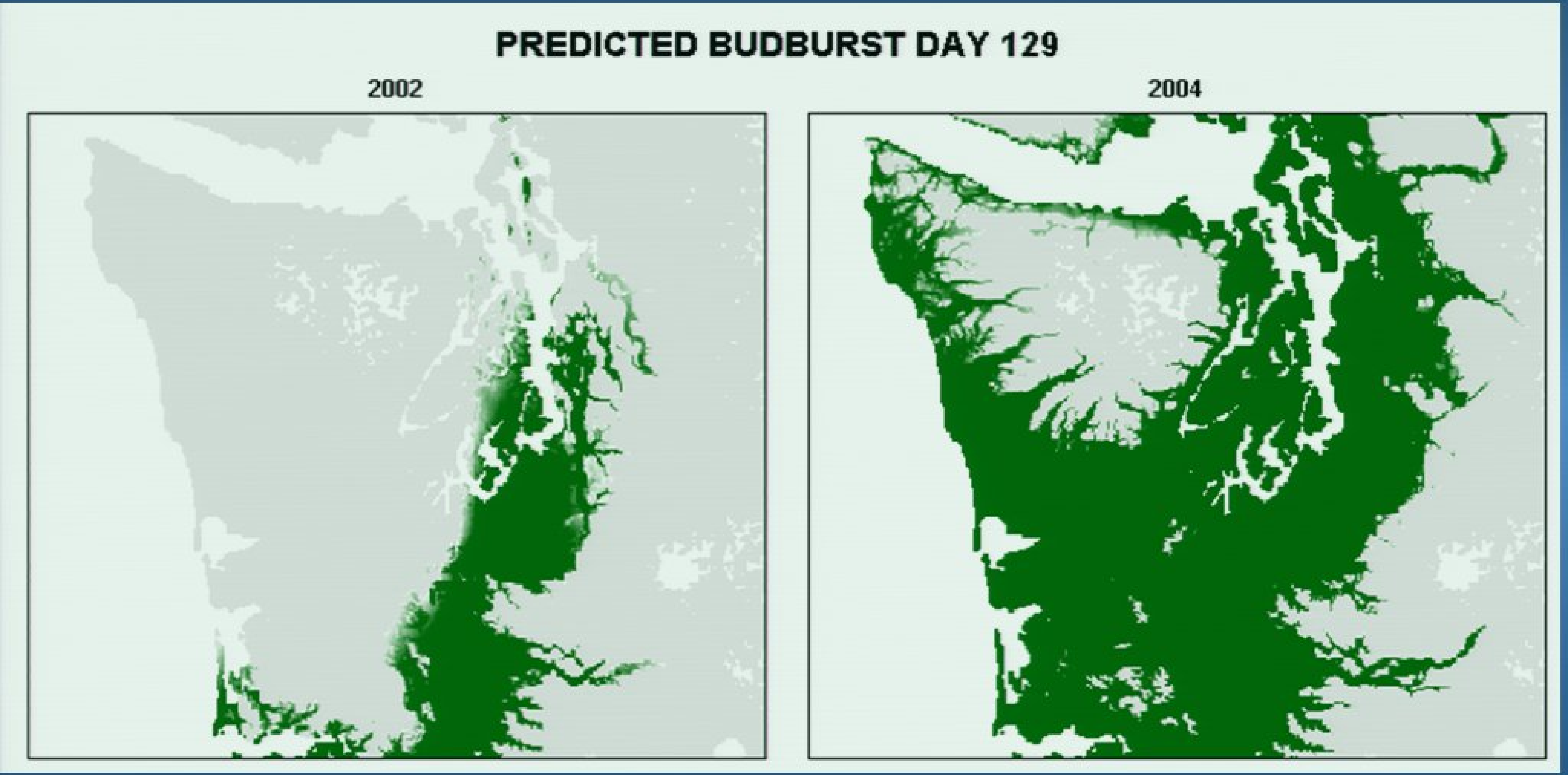
Example: Budburst during a cool spring(2002) and a warm spring (2004).



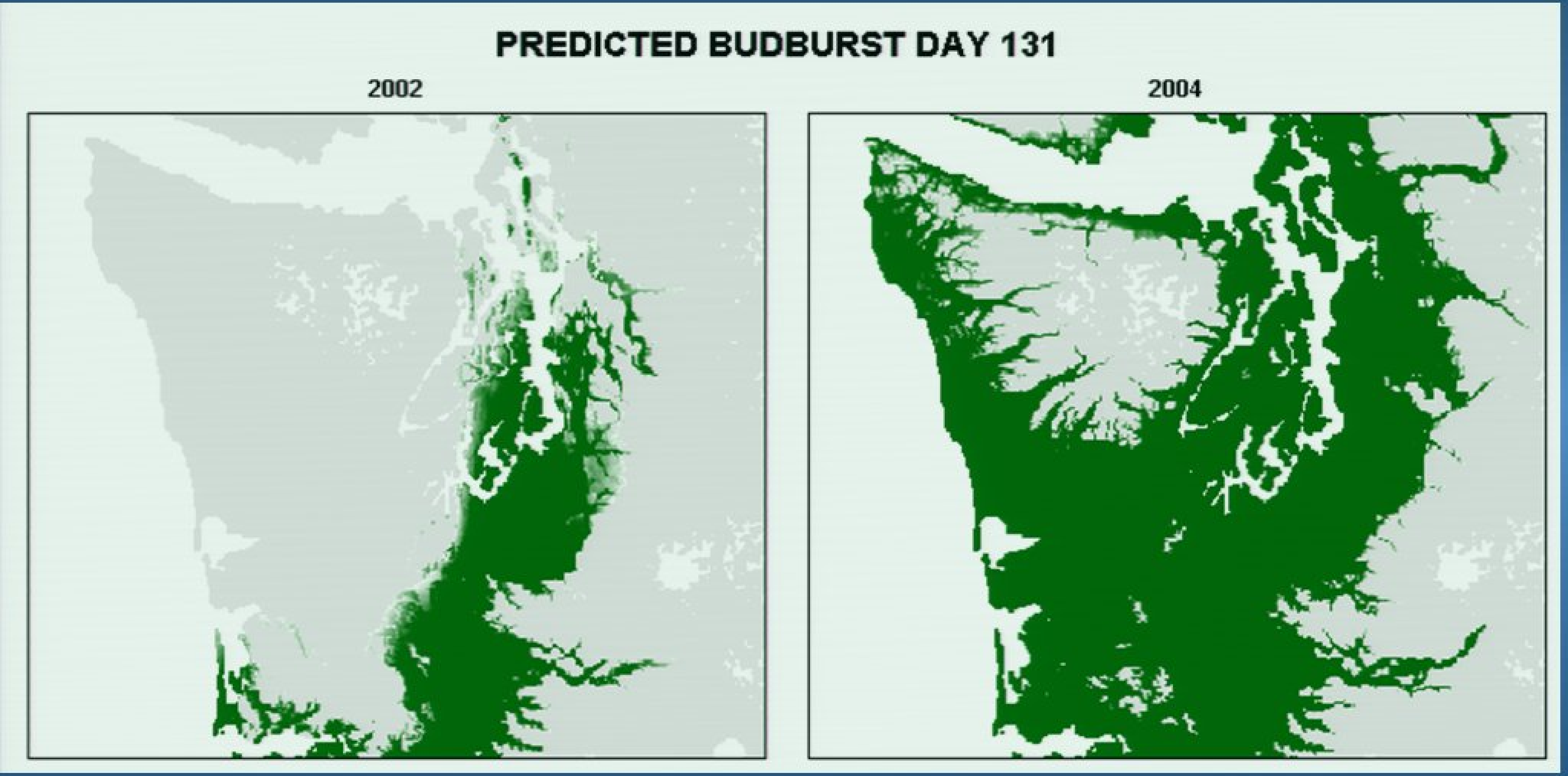
Example: Budburst during a cool spring(2002) and a warm spring (2004).



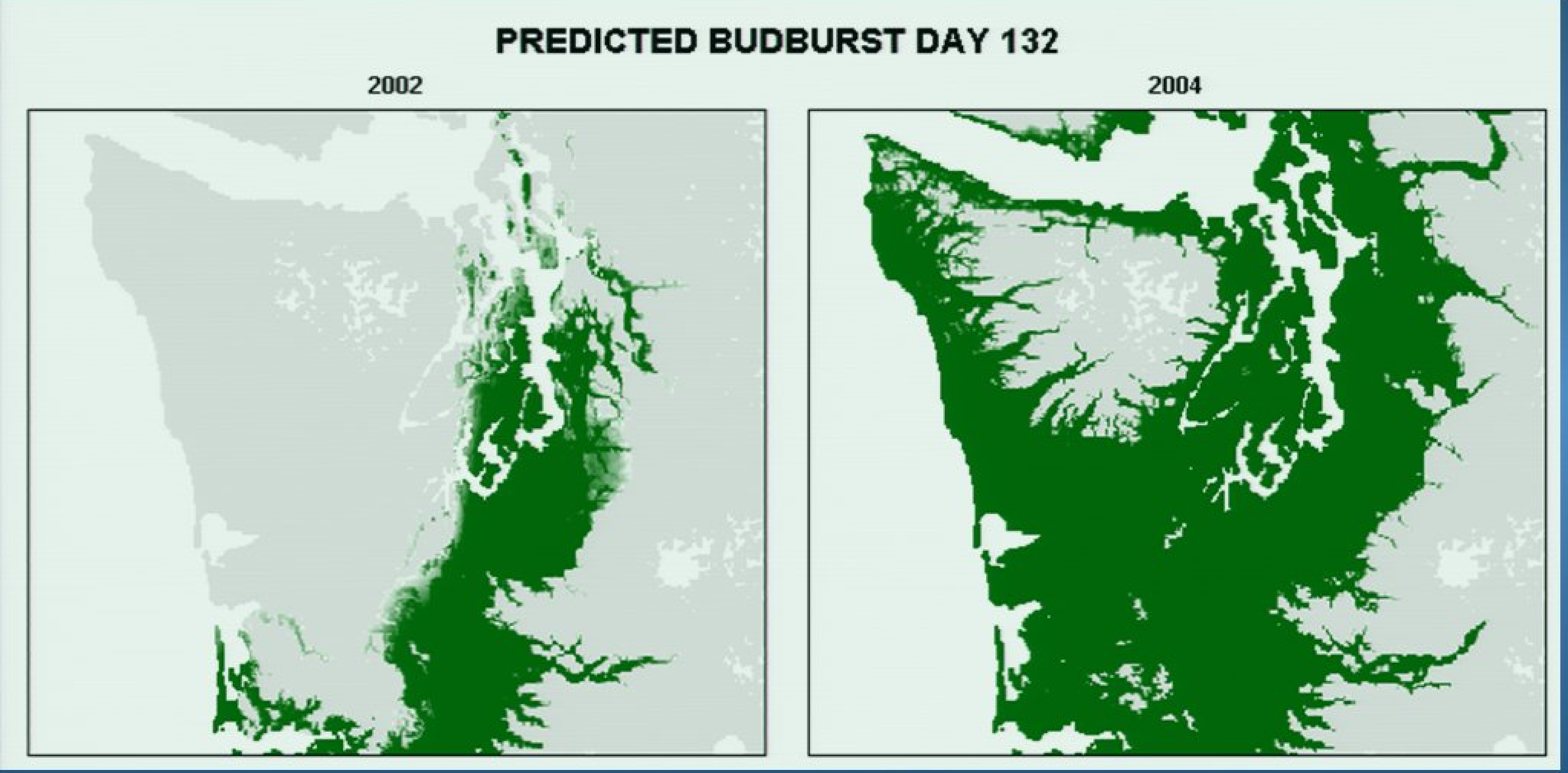
Example: Budburst during a cool spring(2002) and a warm spring (2004).



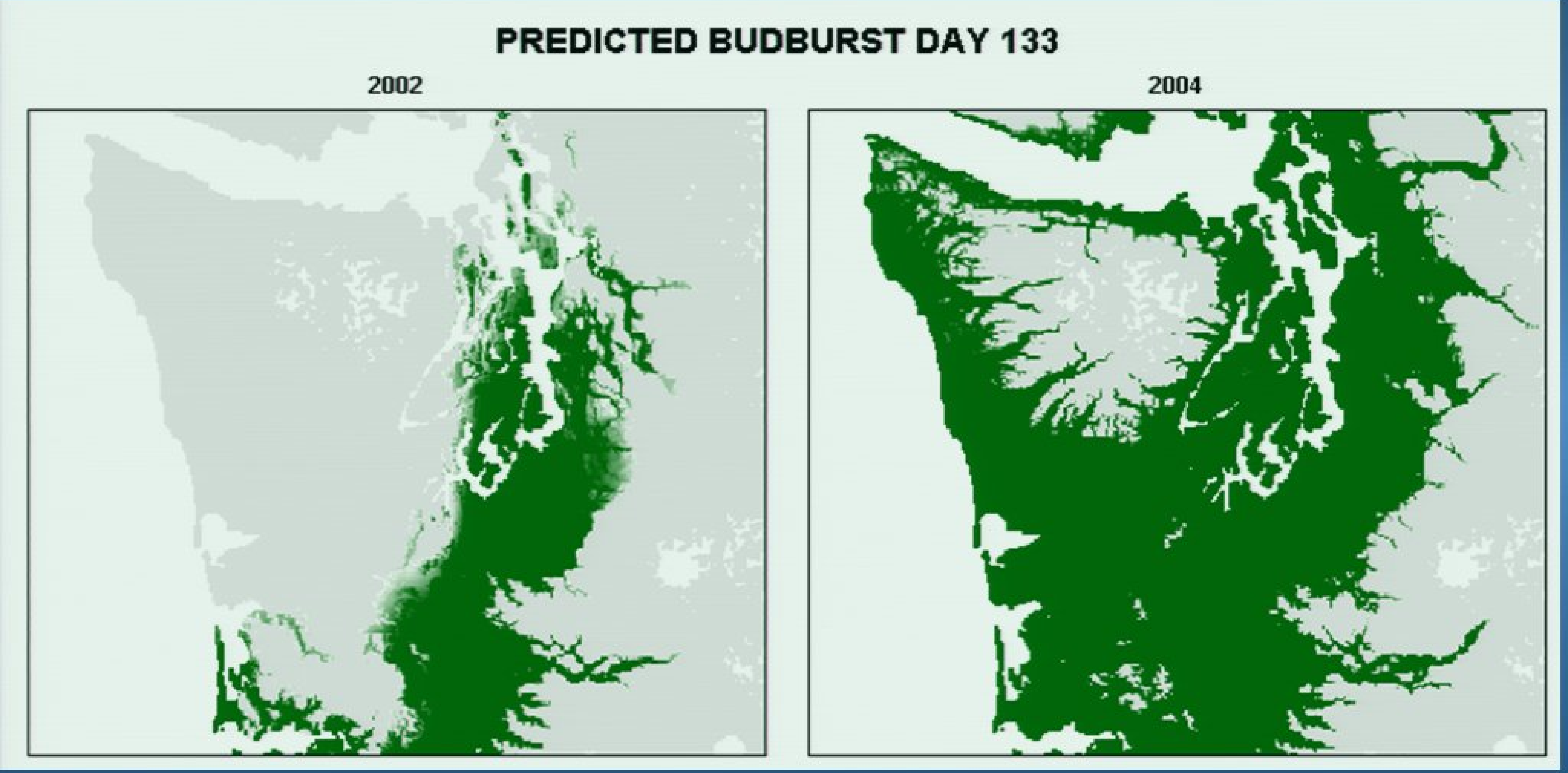
Example: Budburst during a cool spring(2002) and a warm spring (2004).



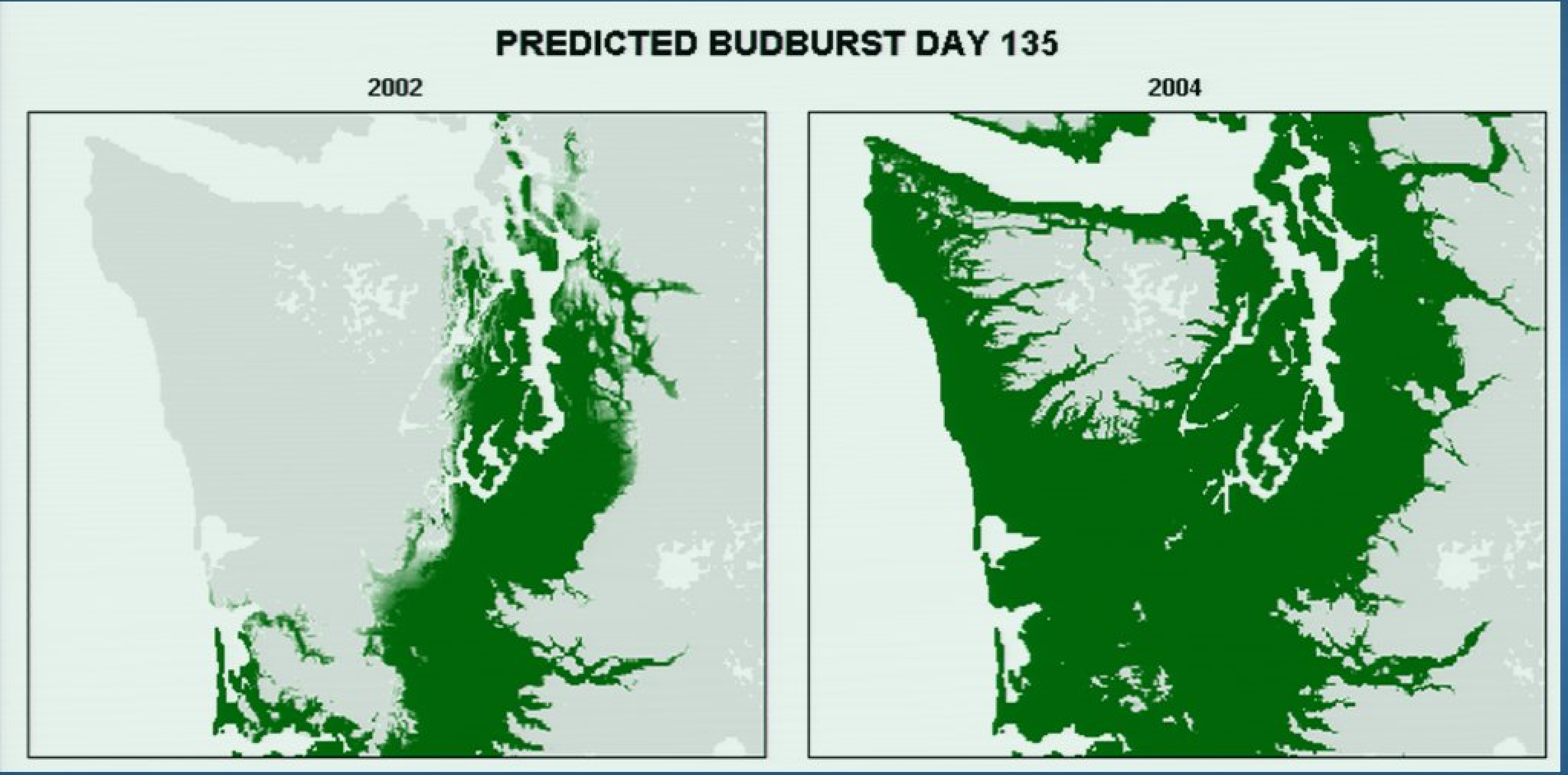
Example: Budburst during a cool spring(2002) and a warm spring (2004).



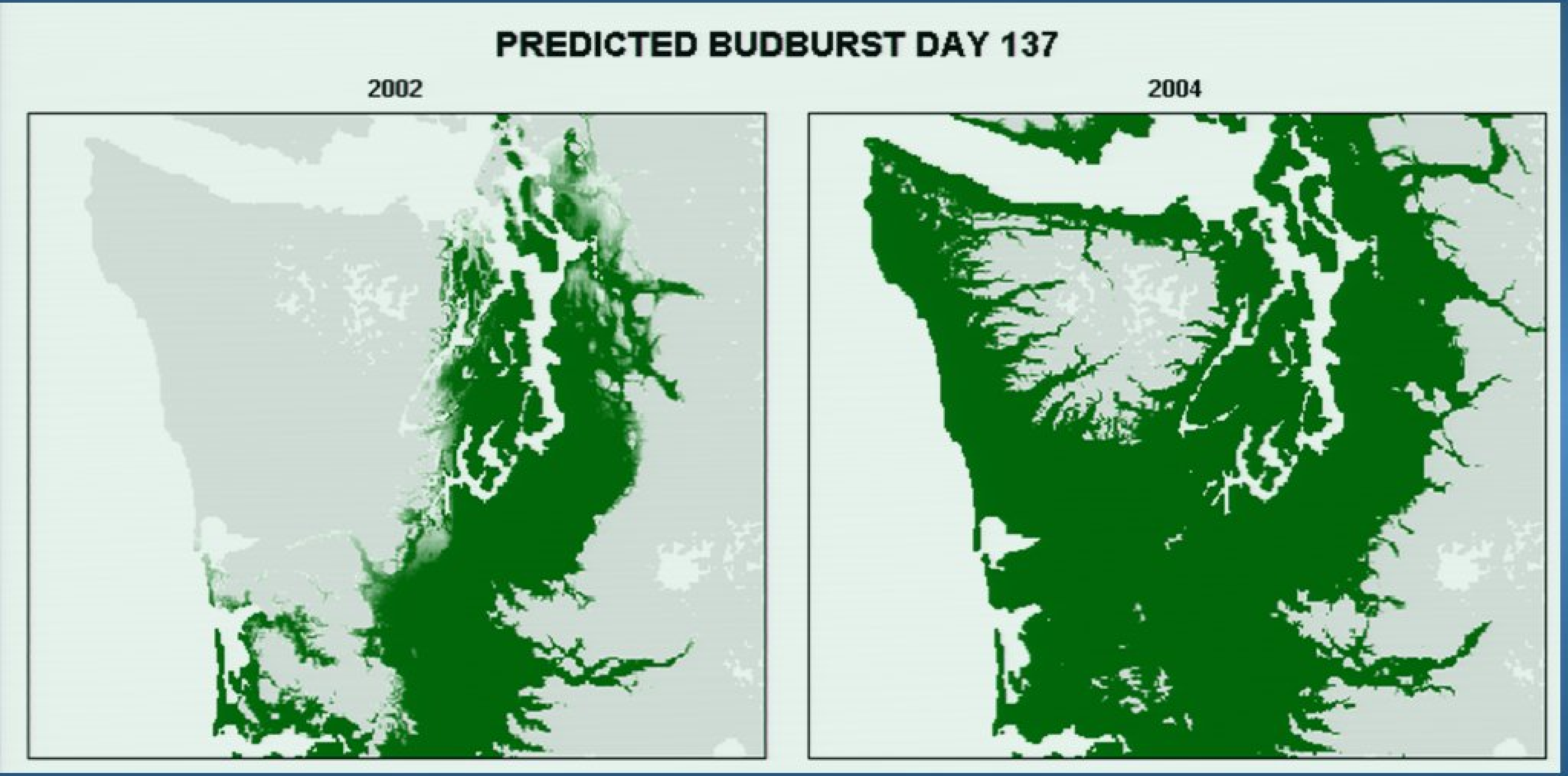
Example: Budburst during a cool spring(2002) and a warm spring (2004).



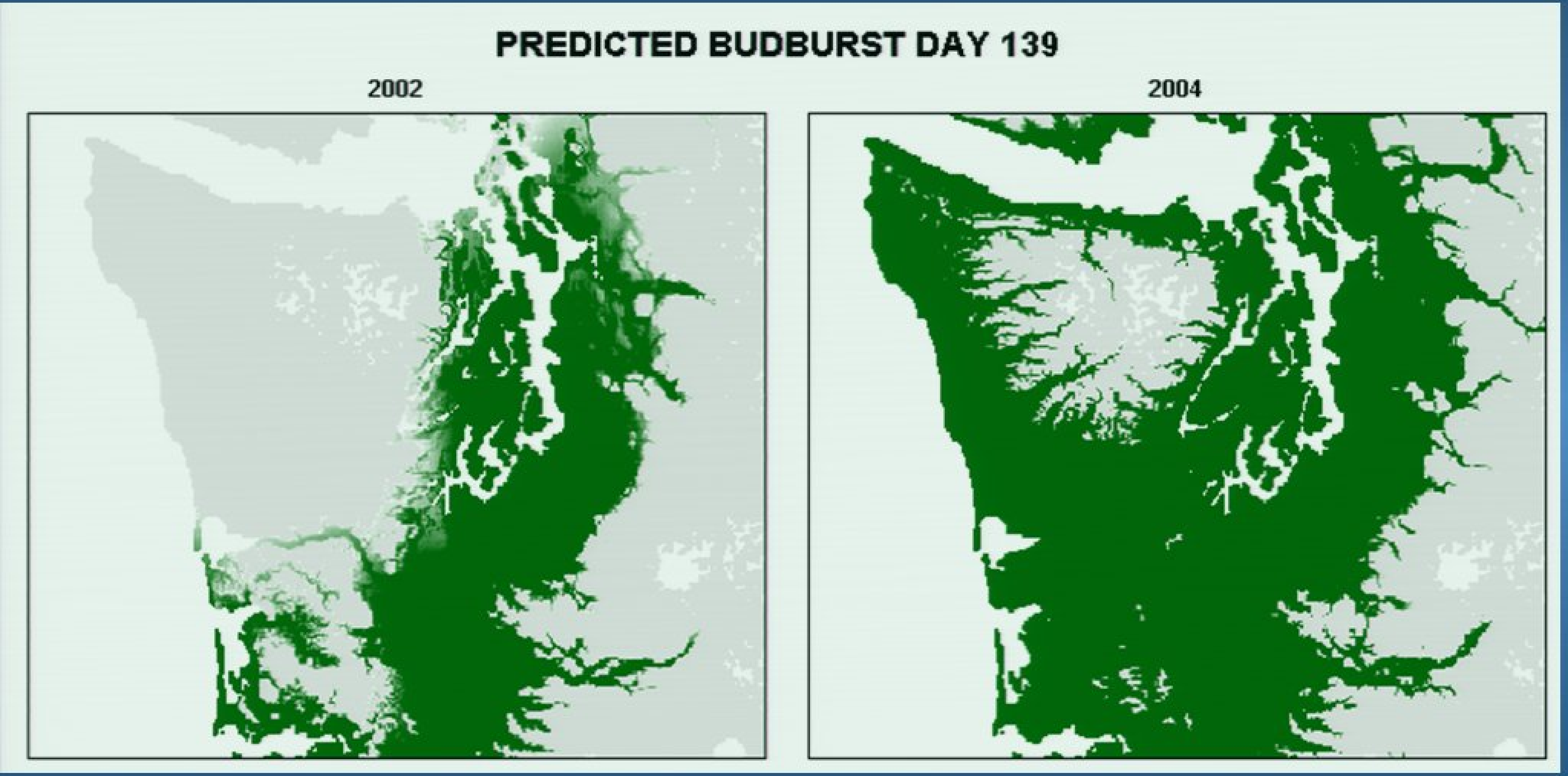
Example: Budburst during a cool spring(2002) and a warm spring (2004).



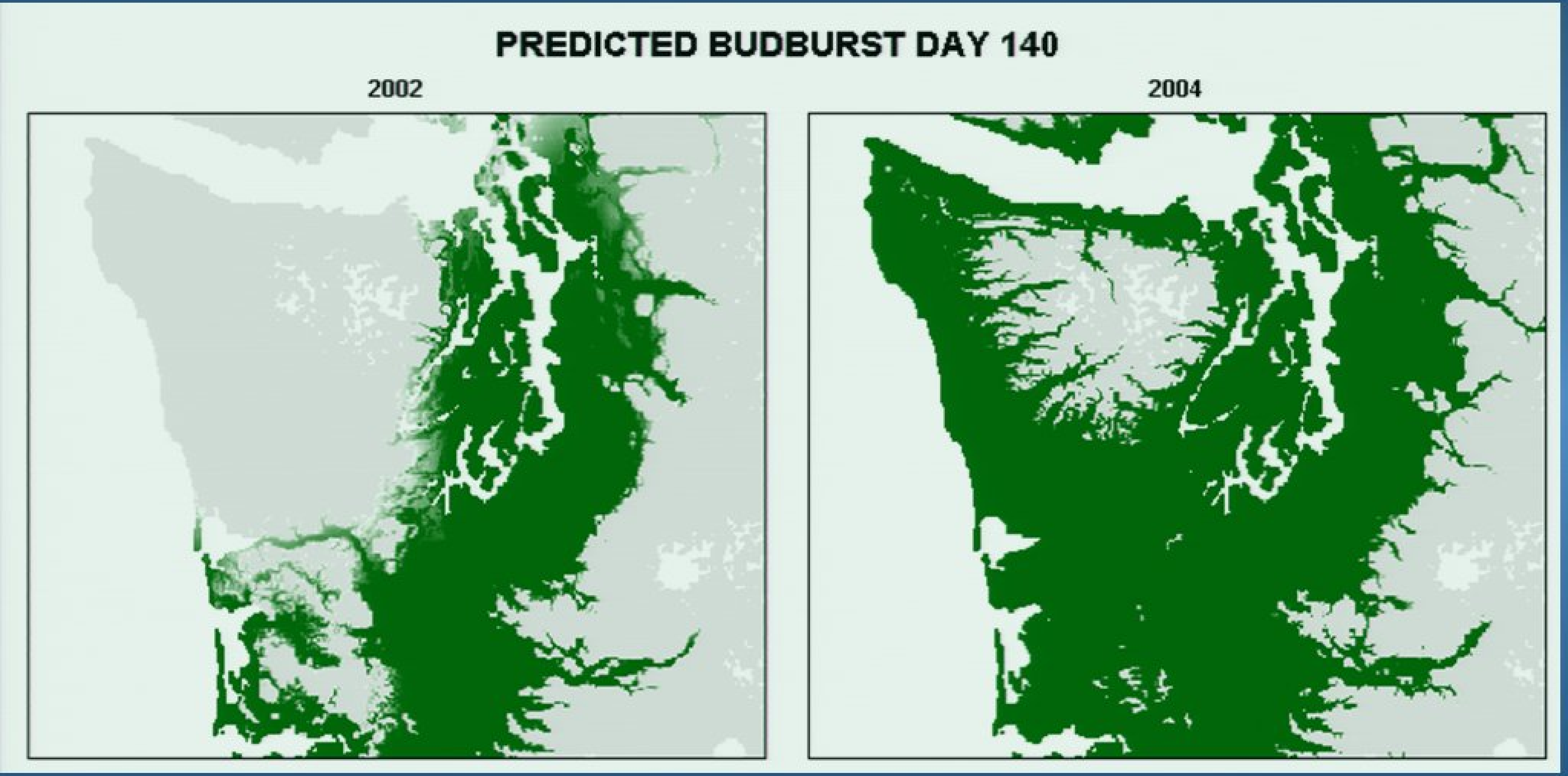
Example: Budburst during a cool spring(2002) and a warm spring (2004).



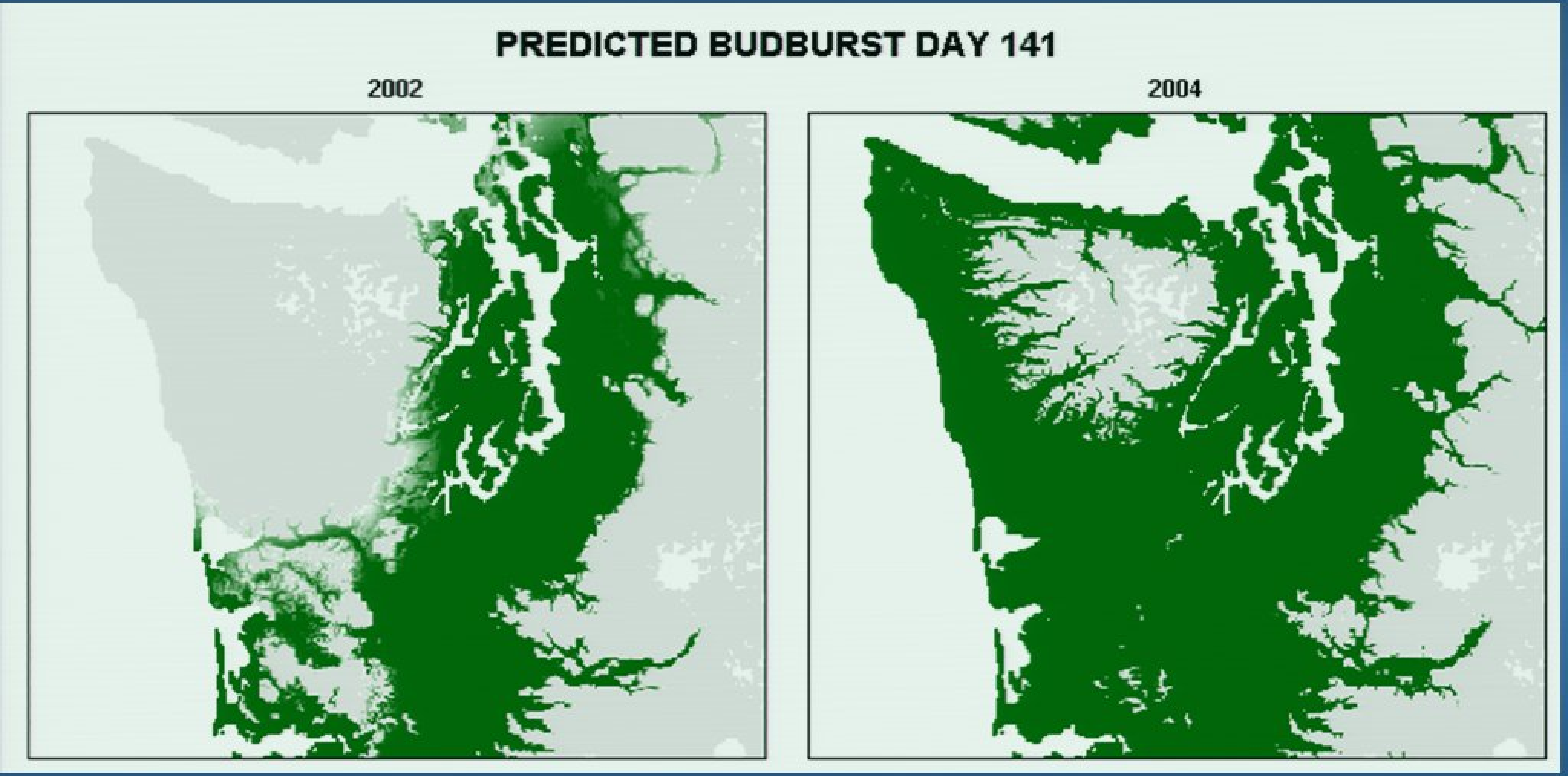
Example: Budburst during a cool spring(2002) and a warm spring (2004).



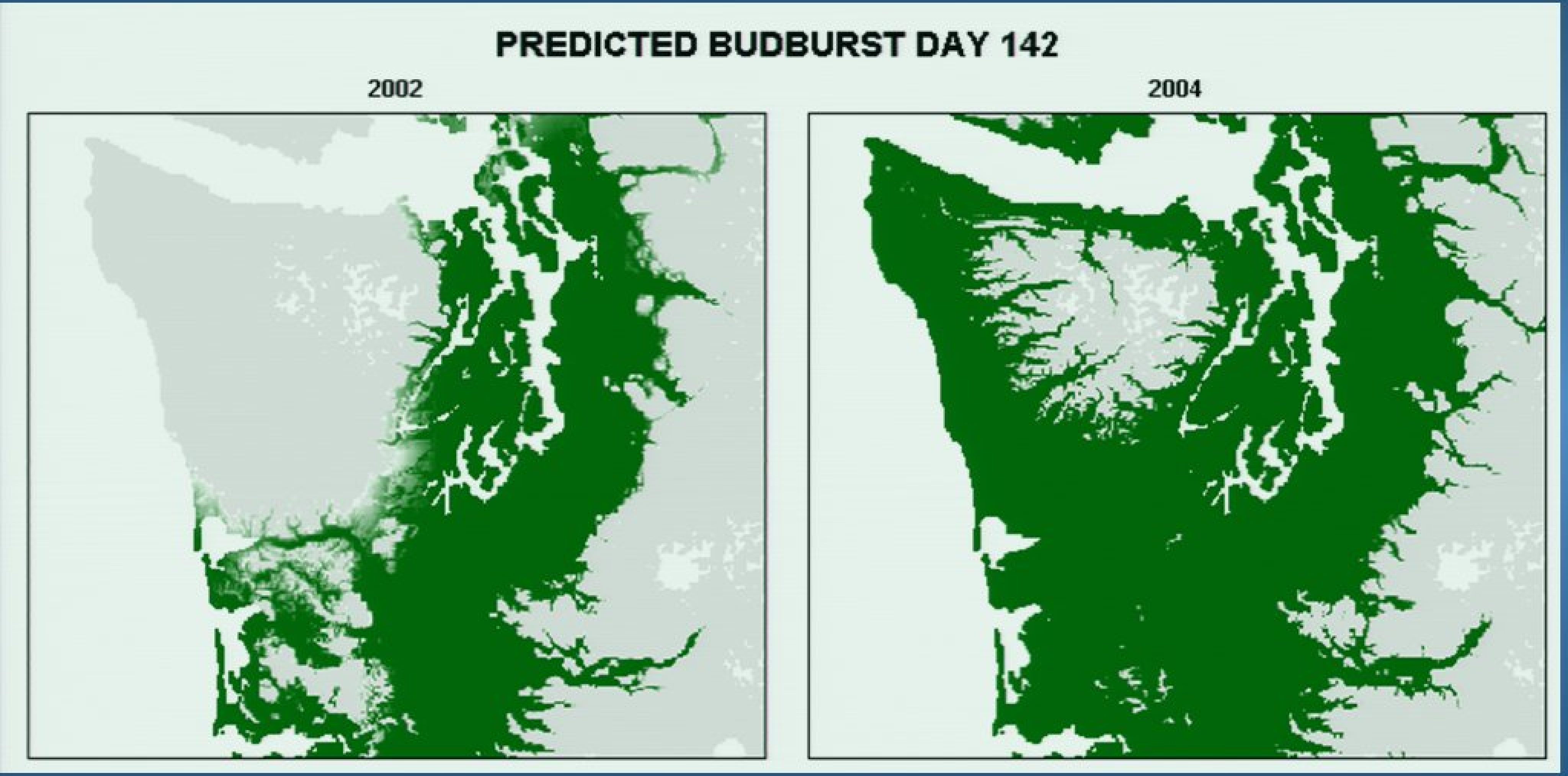
Example: Budburst during a cool spring(2002) and a warm spring (2004).



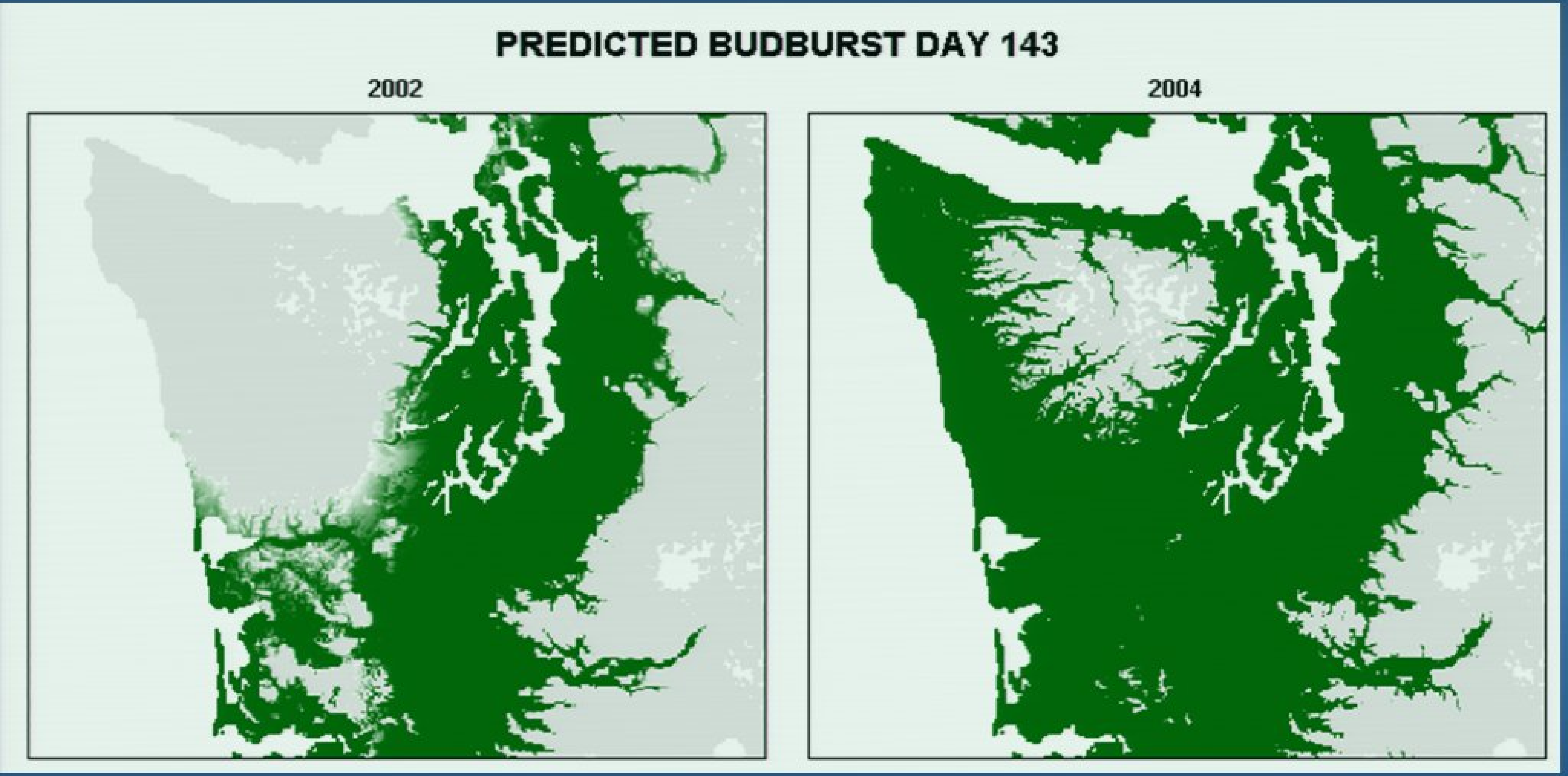
Example: Budburst during a cool spring(2002) and a warm spring (2004).



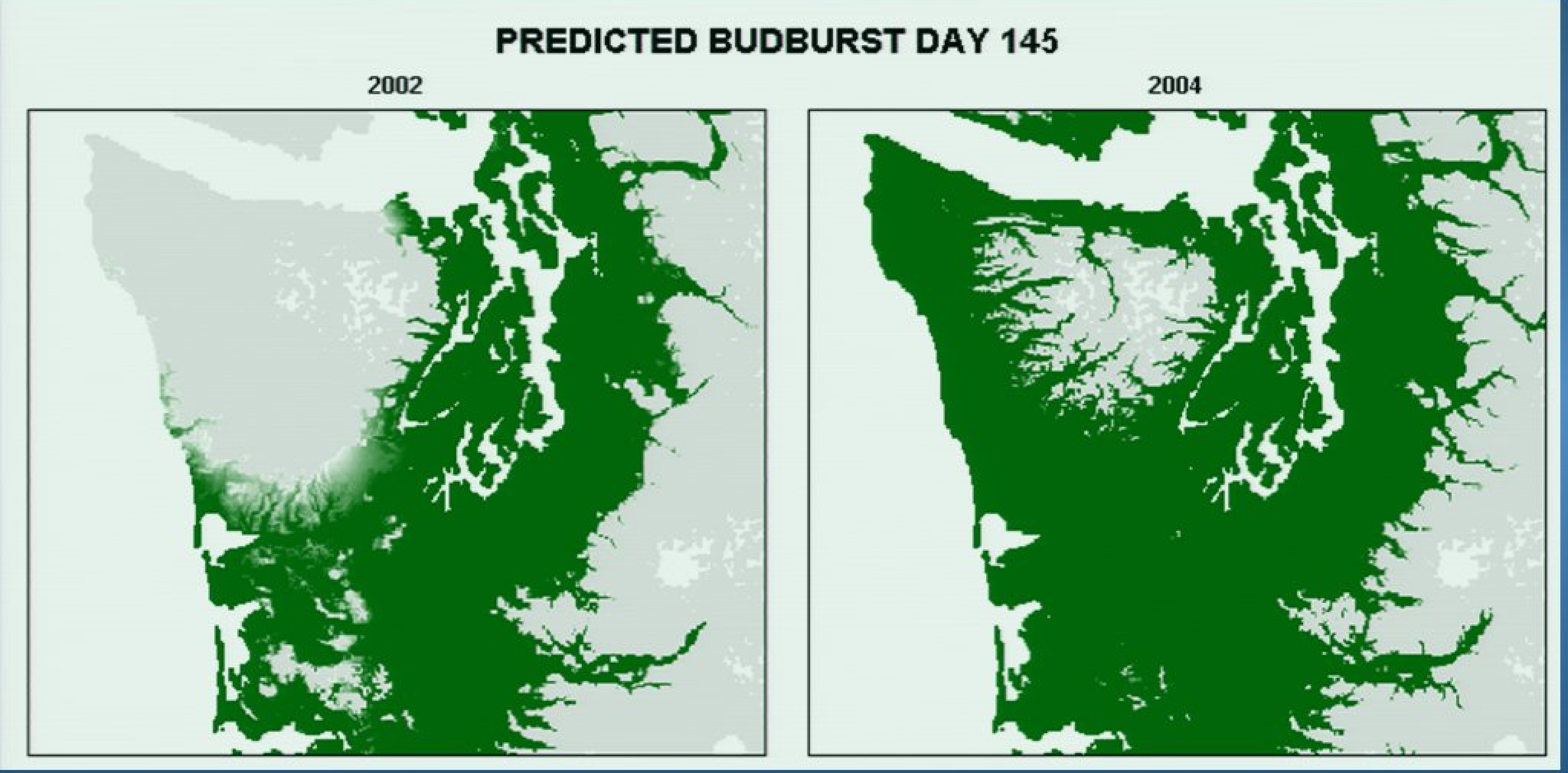
Example: Budburst during a cool spring(2002) and a warm spring (2004).



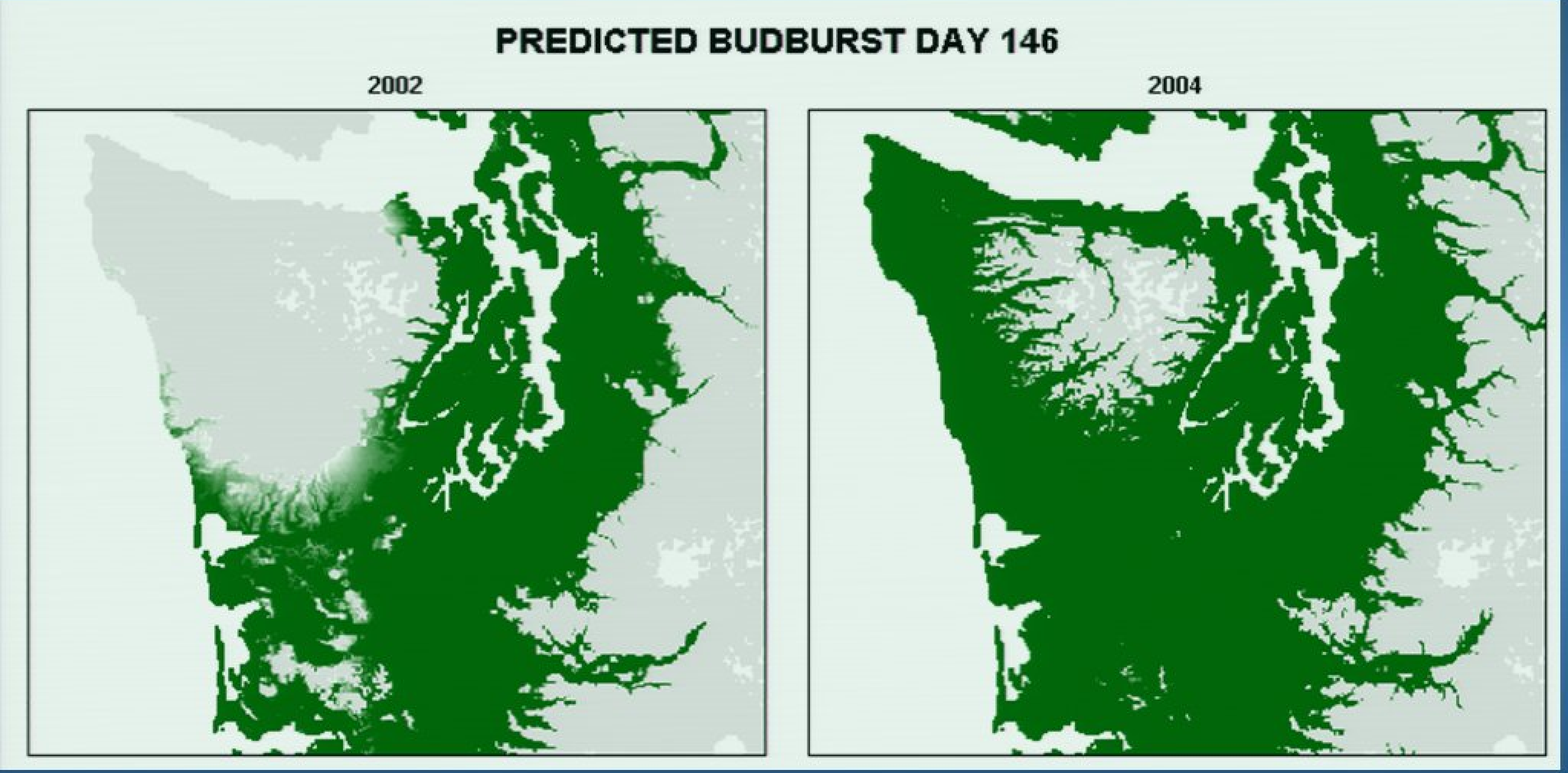
Example: Budburst during a cool spring(2002) and a warm spring (2004).



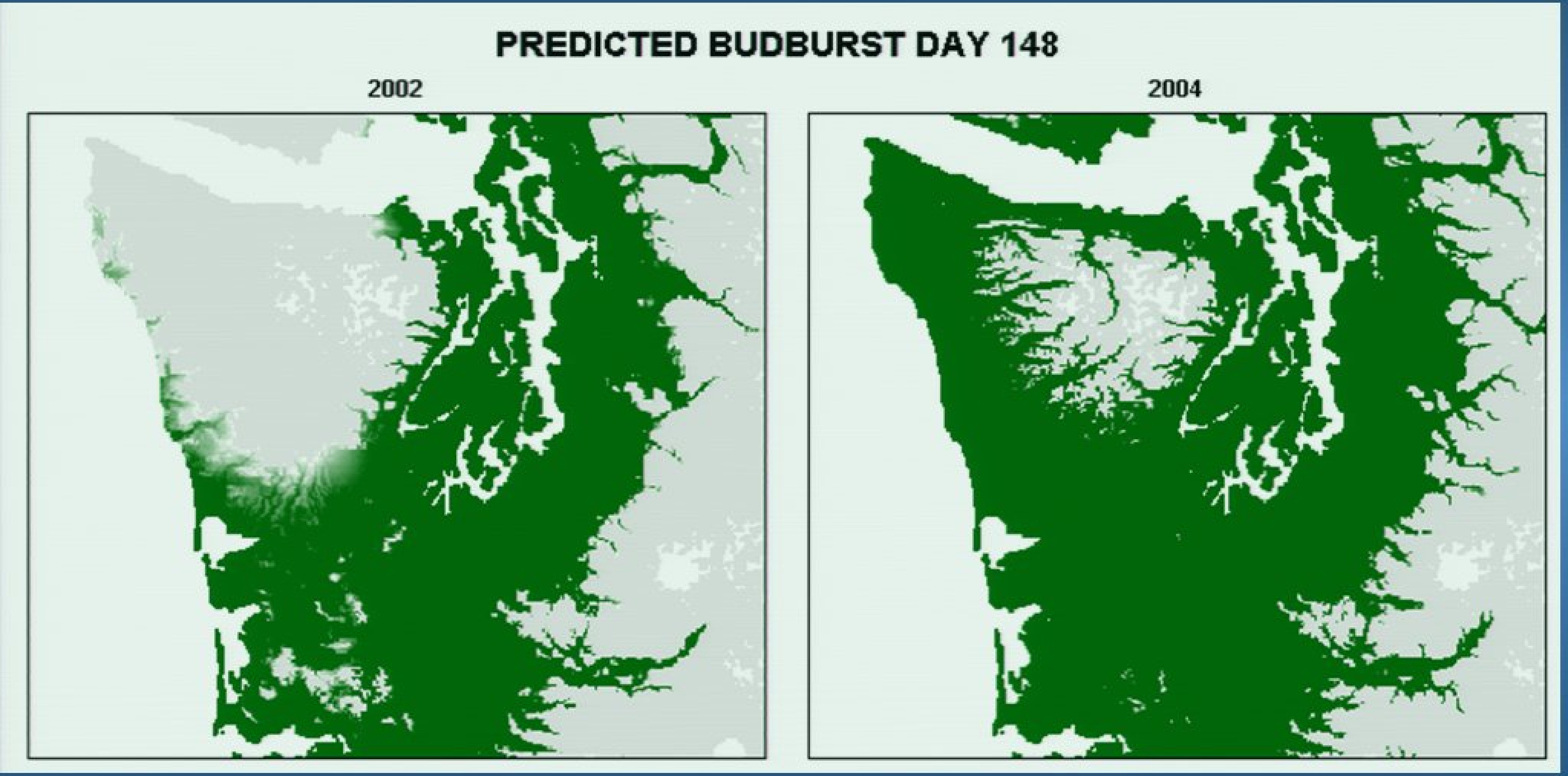
Example: Budburst during a cool spring(2002) and a warm spring (2004).



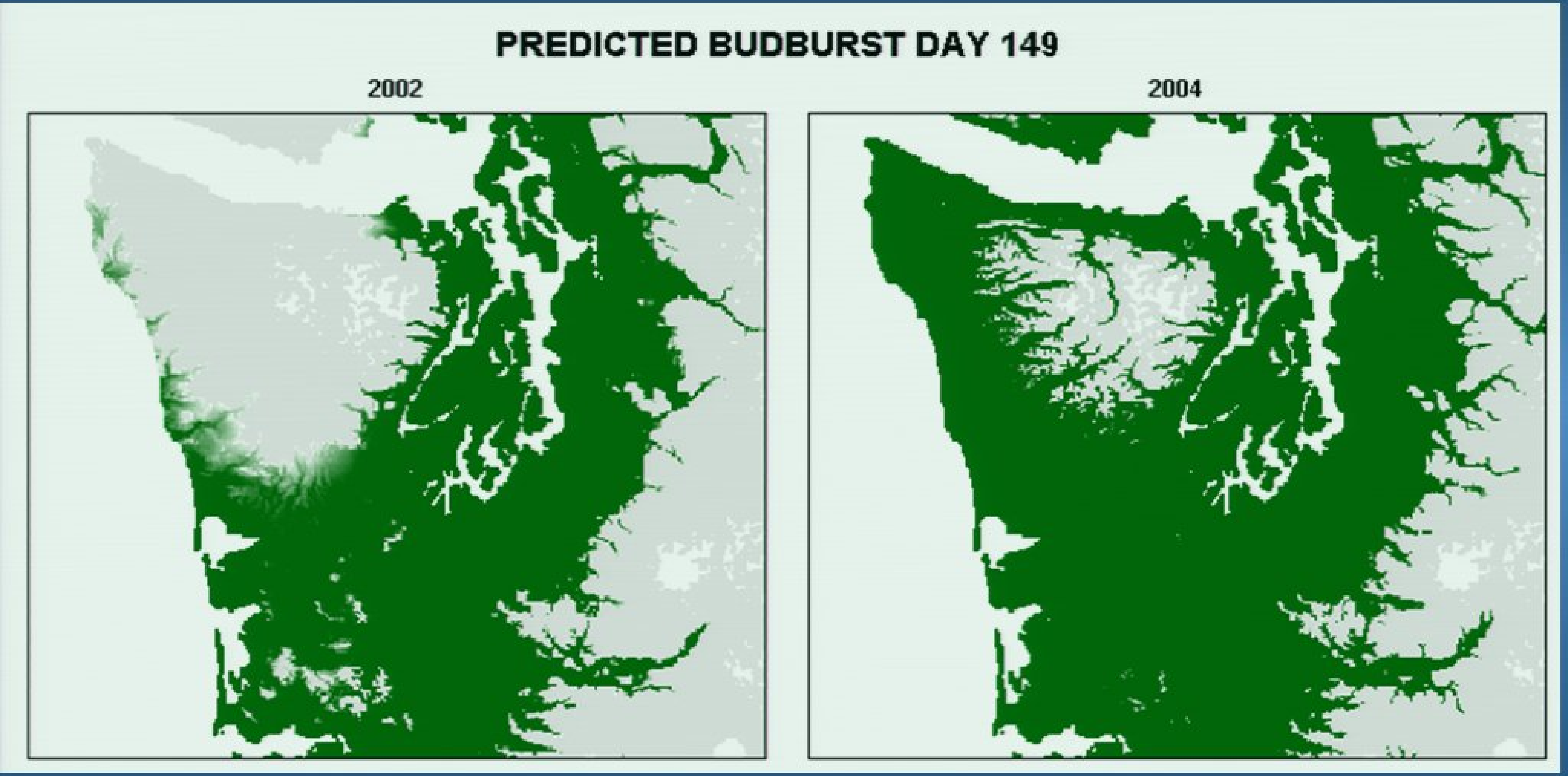
Example: Budburst during a cool spring(2002) and a warm spring (2004).



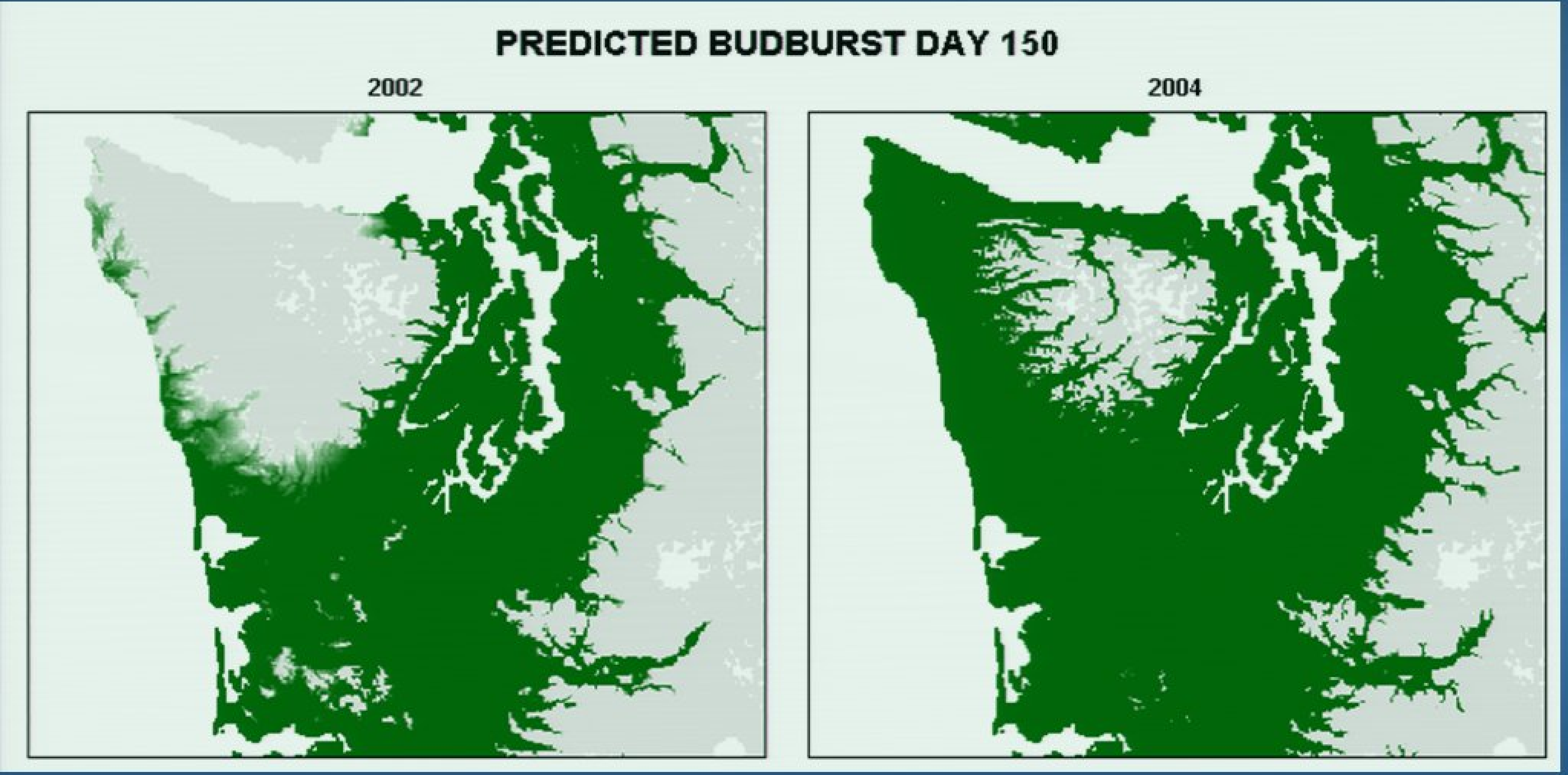
Example: Budburst during a cool spring(2002) and a warm spring (2004).



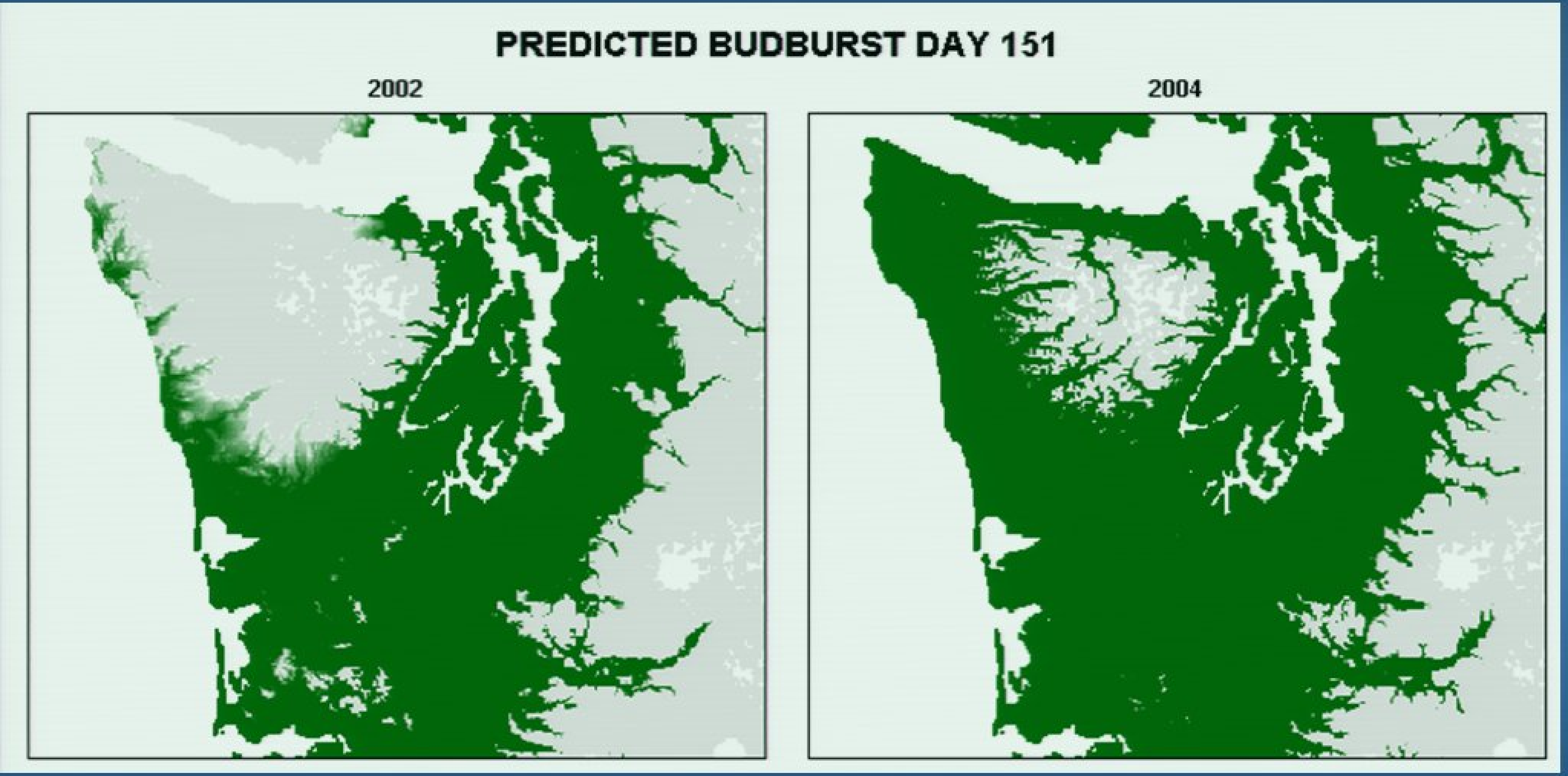
Example: Budburst during a cool spring(2002) and a warm spring (2004).



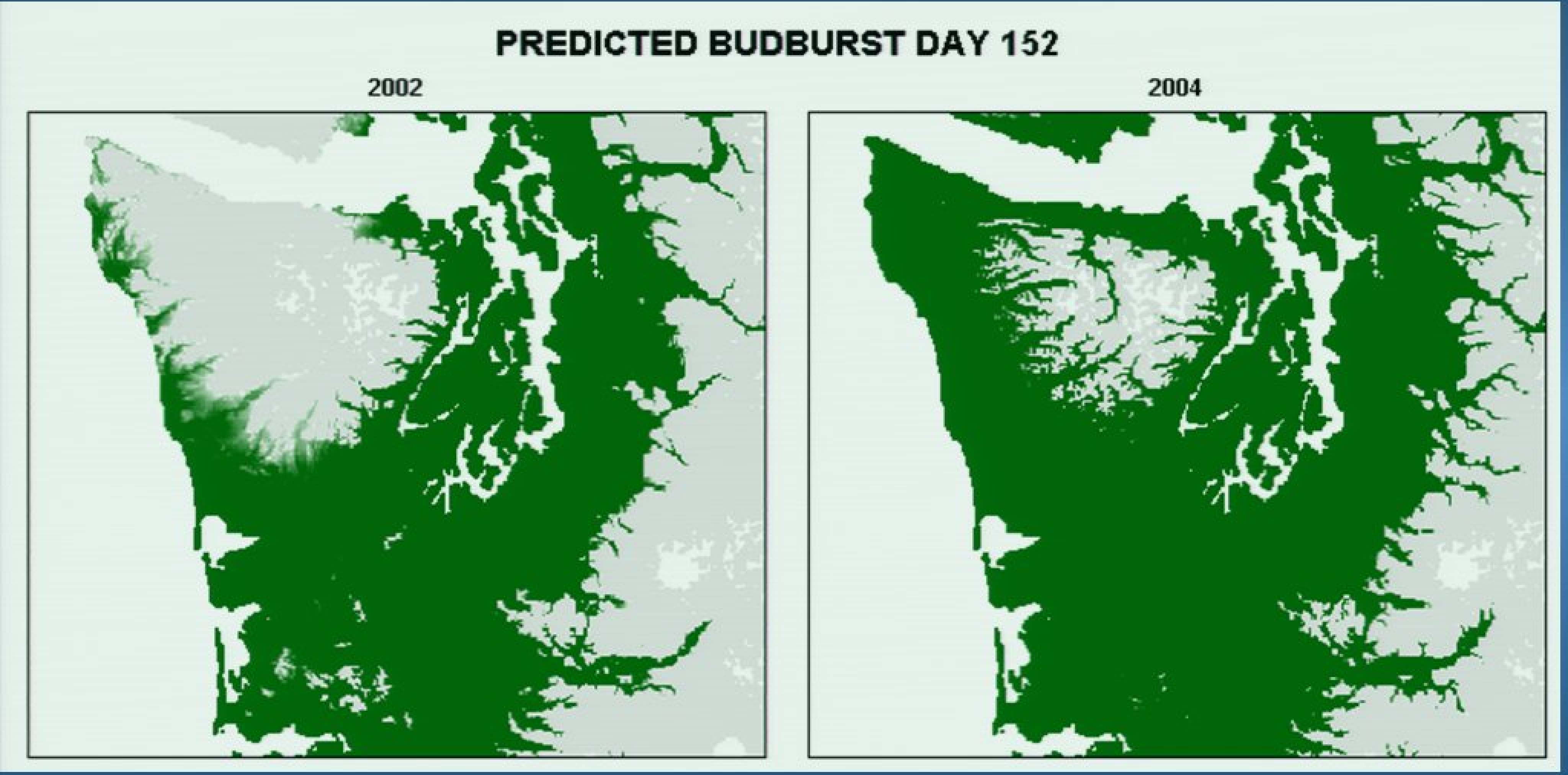
Example: Budburst during a cool spring(2002) and a warm spring (2004).



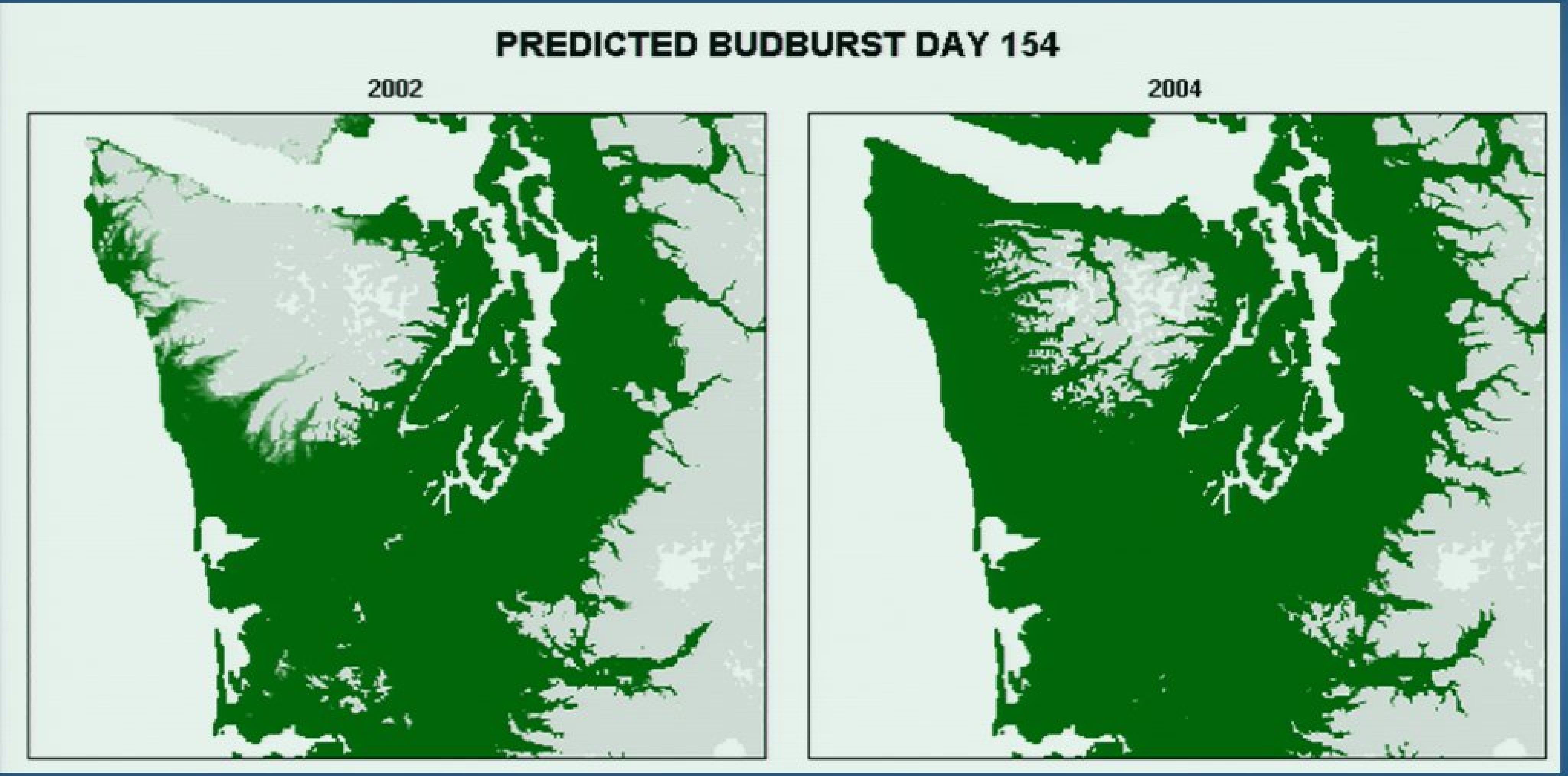
Example: Budburst during a cool spring(2002) and a warm spring (2004).



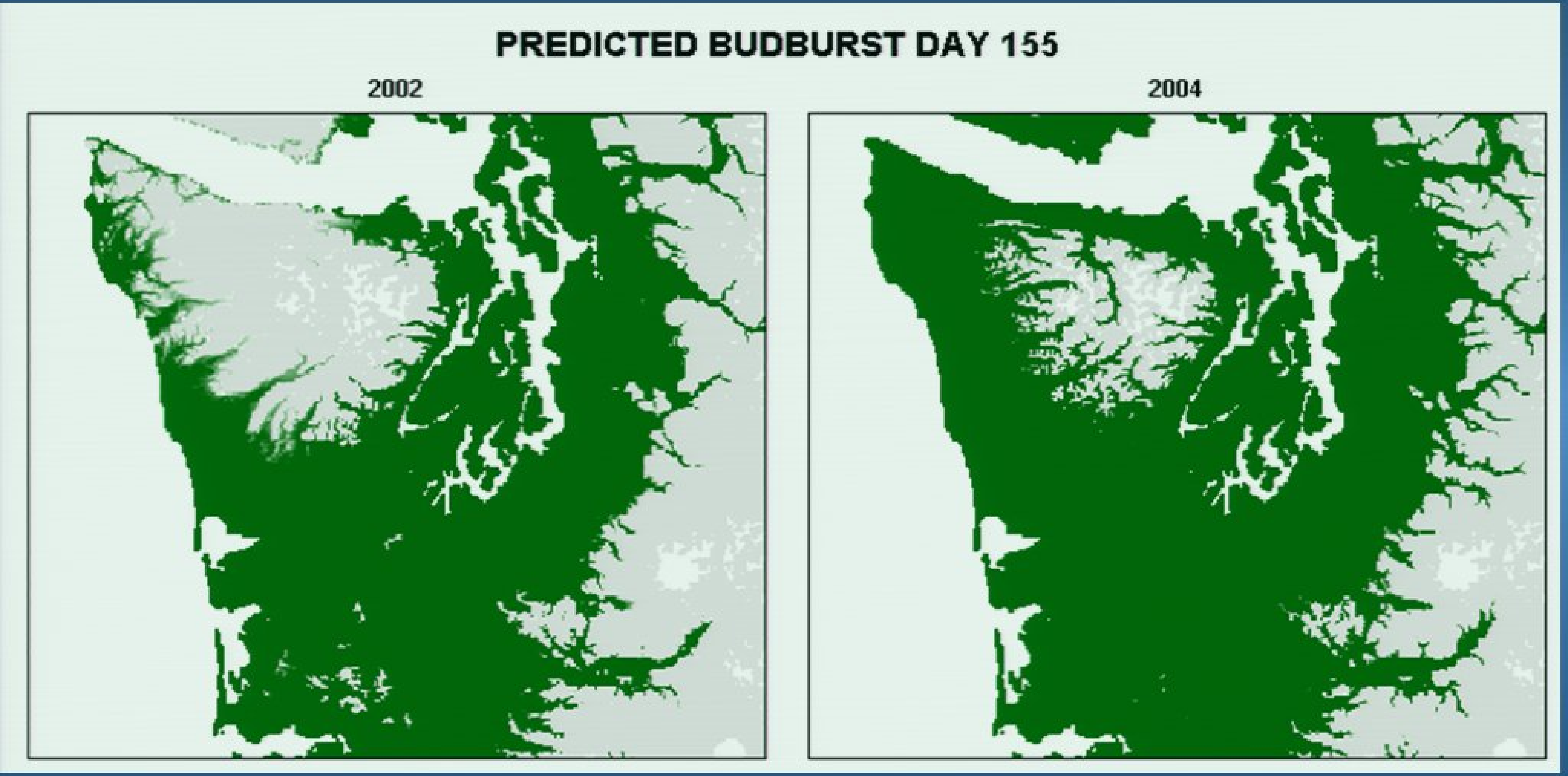
Example: Budburst during a cool spring(2002) and a warm spring (2004).



Example: Budburst during a cool spring(2002) and a warm spring (2004).



Example: Budburst during a cool spring(2002) and a warm spring (2004).



Next step: Evaluate and refine model based on field sites of the Seed-Source Movement Trial

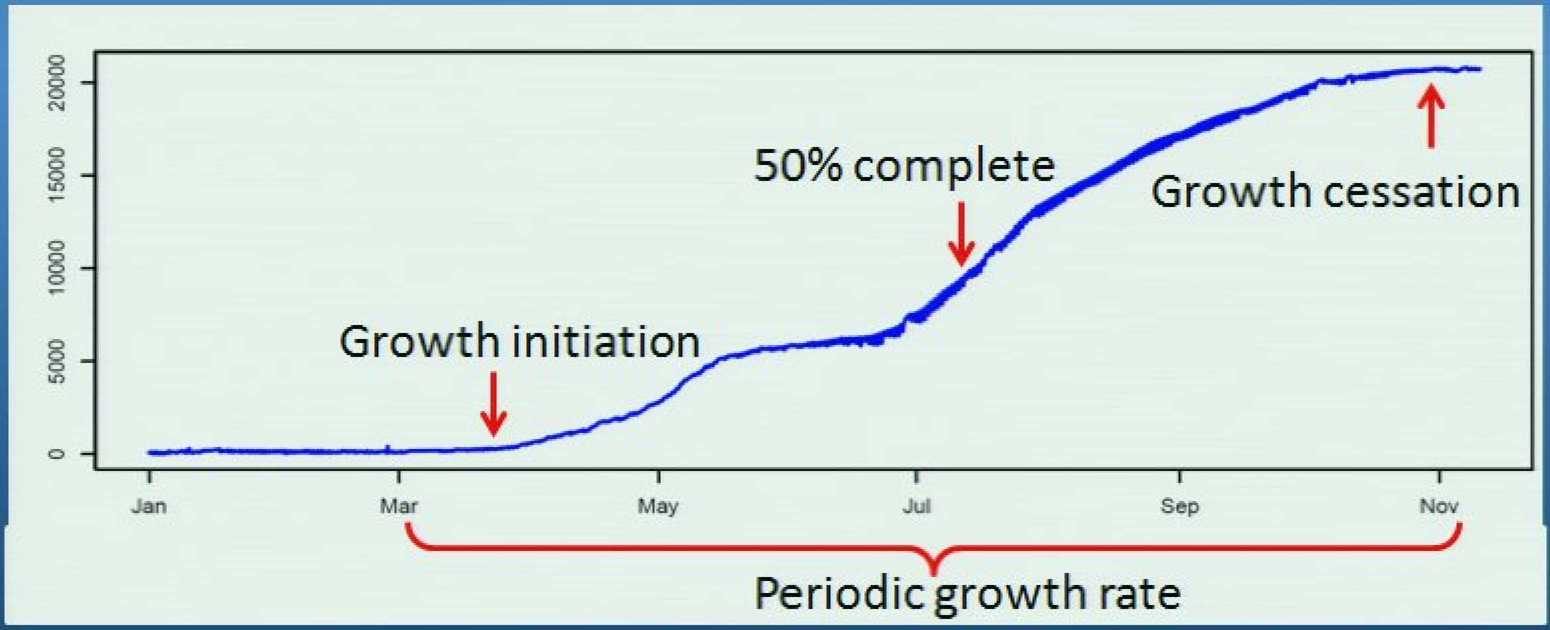
Dates when 50% of trees had budburst

Site	2010	2011	Difference
Buckhorn	April 6	May 2	+ 26 days
Doorstop	April 30	May 24	+ 24 days
Evans Creek	April 18	May 5	+ 17 days
Floras	April 22	May 6	+ 14 days
Jammer	April 8	May 3	+ 25 days
Nortons	April 15	April 30	+ 15 days
Slice Butte	April 13	April 28	+ 15 days
Soda 320	May 5	May 23	+ 18 days
Stone Nursery	April 9	April 21	+ 12 days

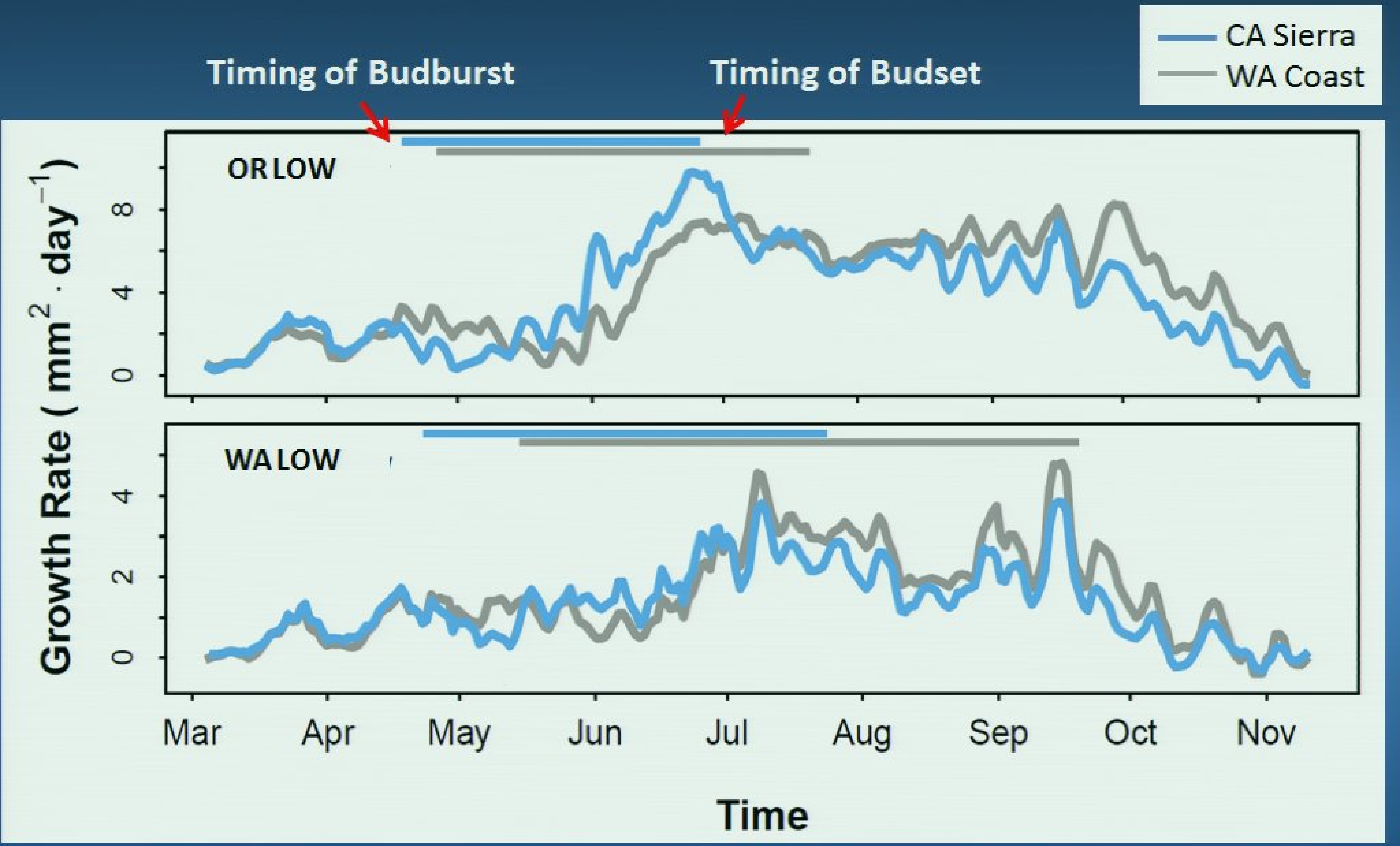
- Large differences among sites, years and populations
- Model works well at most sites but may need some adjustments or better temperature data for one site in one year, in particular

Cambial Phenology

- Refers to annual pattern of secondary (diameter) growth
- Much less information than for events like budburst and flowering
- Growth measured continuously with dendrometers or periodically with calipers



Growth rates from dendrometers in 2010



Drought Hardiness

- ~280 trees from 7 regions at each of 3 test sites
- Measured at two dates in summer 2012:
  - water saturation deficit
  - minimum transpiration
- Also have data on budburst, budset, intermediate height growth, cambial phenology and growth, and cold hardiness on same trees

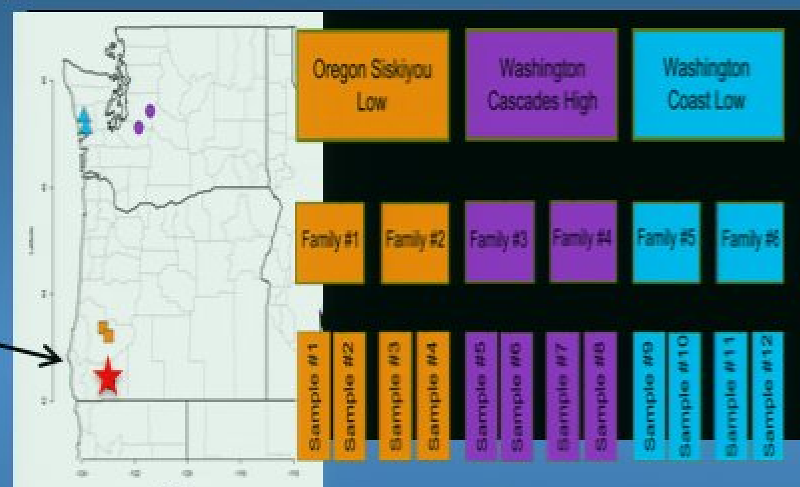
Cold Hardiness

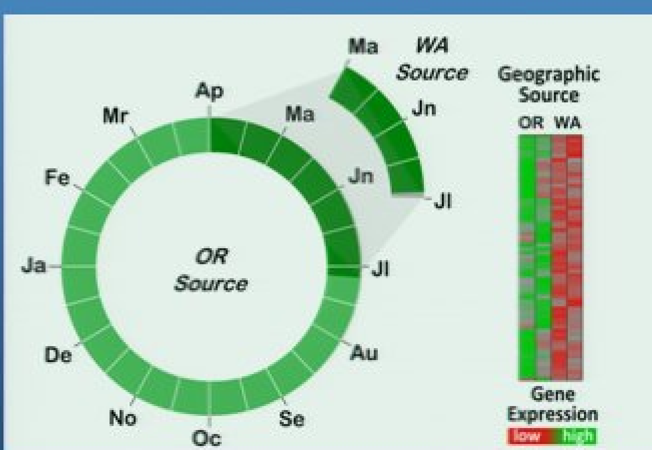
- ~280 trees from 7 regions at each of 3 test sites
- Sampled 4 branches in early October and early November, 2012
- Frozen in programmable freezer to 4 test temperatures and visually scored for cold injury (needles, bud and stem)

Genomics of adaptation: Variation in gene expression

- Which expressed genes and what portion of the transcriptome show significant variation in transcript abundance?
  - among provenances
  - among seasons
- Which expressed genes show a correlated response?
  - with weather or seasonal factors (temperature, precip, aridity, day length)
  - with phenotypic variation (budburst, growth/elongation, budset, dormancy)

Stone Nursery





Across 90,731 genes, found significant variation:

Date: 20,068
Source: 3,308

Some general findings from studies of adaptation in forest trees

- Forest tree populations are at least moderately locally-adapted
  - Some populations show adaptive lag

Some general findings (cont.)

- Forest tree populations are at least moderately locally-adapted
  - Some populations show adaptive lag
- Species show different patterns and degrees of local adaptation

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

Some general findings (cont.)

- Forest tree populations are at least moderately locally-adapted
  - Some populations show adaptive lag
- Species show different patterns and degrees of local adaptation
- Most forest trees species show significant variation for:
  - Timing of bud set and bud flush
  - Cold hardiness
  - Growth

Some general findings (cont.)

- Forest tree populations are at least moderately locally-adapted
  - Some populations show adaptive lag
- Species show different patterns and degrees of local adaptation
- Most forest trees species show significant variation for:
  - Timing of bud set and bud flush
  - Cold hardiness
  - Growth
- Traits correlate most strongly with:
  - Minimum temperatures
  - # of frost-free days
  - Drought indices

Some general findings (cont.)

- Forest tree populations are at least moderately locally-adapted
  - Some populations show adaptive lag
- Species show different patterns and degrees of local adaptation
- Most forest trees species show significant variation for:
  - Timing of bud set and bud flush
  - Cold hardiness
  - Growth
- Traits correlate most strongly with:
  - Minimum temperatures
  - # of frost-free days
  - Drought indices
- Patterns reflect adaptation of annual growth and dormancy cycles to local temperature and drought regimes

Some general findings (cont.)

- Forest tree populations are at least moderately locally-adapted
  - Some populations show adaptive lag
- Species show different patterns and degrees of local adaptation
- Most forest trees species show significant variation for:
  - Timing of bud set and bud flush
  - Cold hardiness
  - Growth
- Traits correlate most strongly with:
  - Minimum temperatures
  - # of frost-free days
  - Drought indices
- Patterns reflect adaptation of annual growth and dormancy cycles to local temperature and drought regimes
- Provenance tests may show broader adaptation than indicated by genecology studies
  - May depend on age and rare climatic events

Management Options for Responding to Climate Change

What are the consequences of different management options for the health, productivity, and sustainability of future forests and grasslands considering climate change?

Management options for climate change:

1. Do nothing

Management options for climate change:

1. Do nothing

Three possibilities when environments change:

1. Stay
   - Environmental change is not biologically significant
   - Acclimate by modifying individuals to new environment (phenotypic plasticity)
   - Evolve through natural selection

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
    - Growth

- 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 is the potential for adaptation via natural selection?

Important factors include:

- Generation turnover
- Fecundity
- Intensity of selection
- Genetic/phenotypic variation
- Heritabilities

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

Three possibilities when environments change:

1. Stay
   - Environmental change is not biologically significant
   - Acclimate by modifying individuals to new environment (phenotypic plasticity)
   - Evolve through natural selection
2. Move
   - Migrate to new habitats

What is the potential for migration?

- Estimates of past migration rates vary
  - Davis and Shaw 2001: 200-400 m per yr
  - Aitken et al. 2008: 100-200 m per yr
  - Gugger et al. 2010 (Doug-fir): 50-220 m per yr
- But current rates of climate change require 3000-5000 m per yr

Three possibilities when environments change:

1. Stay
   - Environmental change is not biologically significant
   - Acclimate by modifying individuals to new environment (phenotypic plasticity)
   - Evolve through natural selection
2. Move
   - Migrate to new habitats
3. Decline and disappear
   - Reductions in health, productivity
   - Extinction of local populations

Management options for climate change:

1. Do nothing
2. Use silvicultural measures to ensure resiliency and resist change

Silvicultural options include:

- Density management
- Fuels management
- Pest management
- Reforestation/restoration

Management options for climate change:

1. Do nothing
2. Use silvicultural measures to ensure resiliency and resist change
3. Promote natural migration and gene flow

Avoid fragmentation and maintain corridors for gene flow

But,

- Seed migration may not be sufficient
- Pollen flow may be limited by temperature-associated flowering phenology

Management options for climate change:

1. Do nothing
2. Use silvicultural measures to ensure resiliency and resist change
3. Promote natural migration and gene flow
4. Select and breed for adaptive traits within species/populations

Selection and breeding

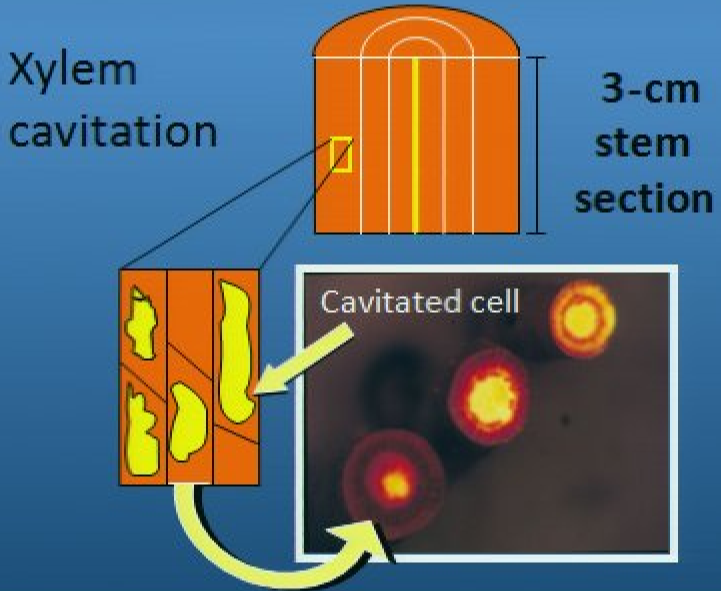
Breed for resistance or tolerance to pests

- A long-term, expensive, difficult prospect.
- Key pests are being addressed – which others will become problematic?

Breed for drought hardiness and growth phenology

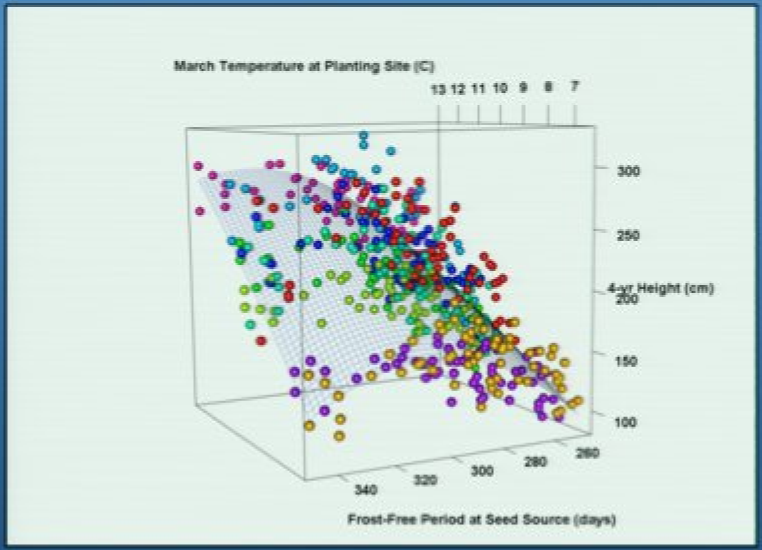
- Tests have been developed to assess cold and drought hardiness.
- But breeding per se may not be needed – rely on assisted migration instead?

Testing for drought hardiness

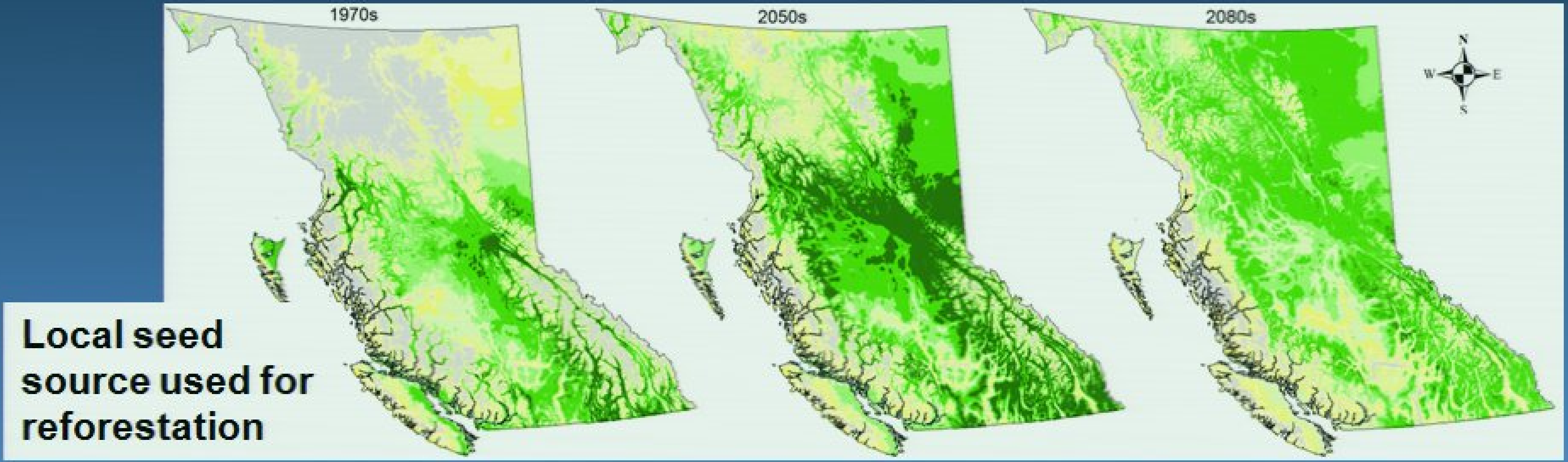


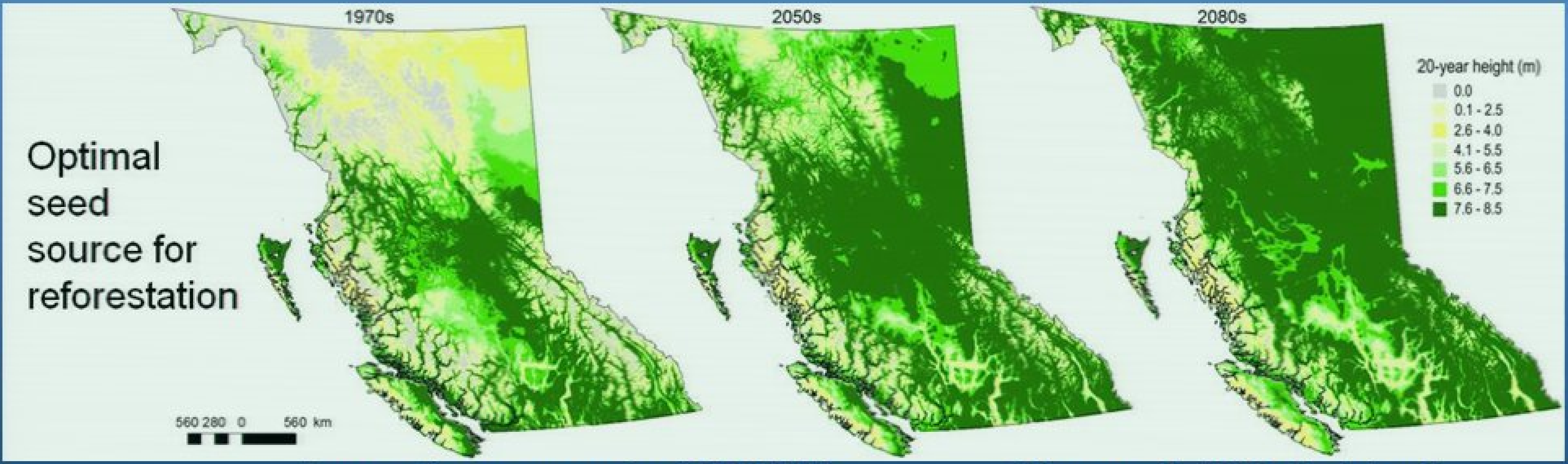
Management options for climate change:

1. Do nothing
2. Use silvicultural measures to ensure resiliency and resist change
3. Promote natural migration and gene flow
4. Select and breed for adaptive traits within species/populations
5. Gradually change species and seed sources for reforestation or restoration in anticipation of warming or in response to problems (assisted migration)



Lodgepole pine productivity predicted from response functions





Future climate scenario: CGCM2 A2x

Wang et al. 2010. Ecol. Appl.

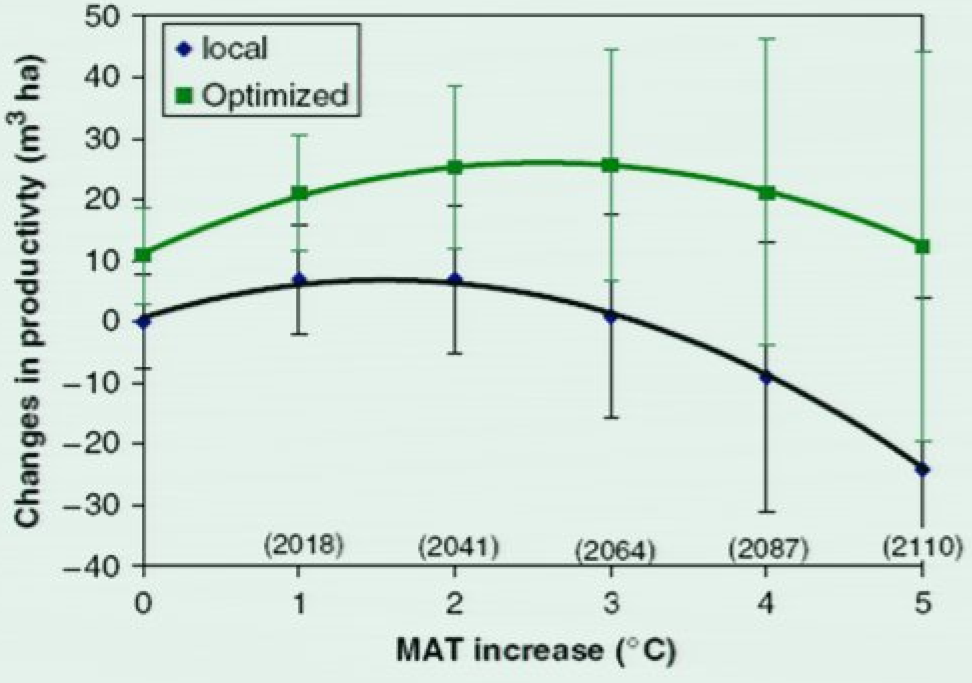
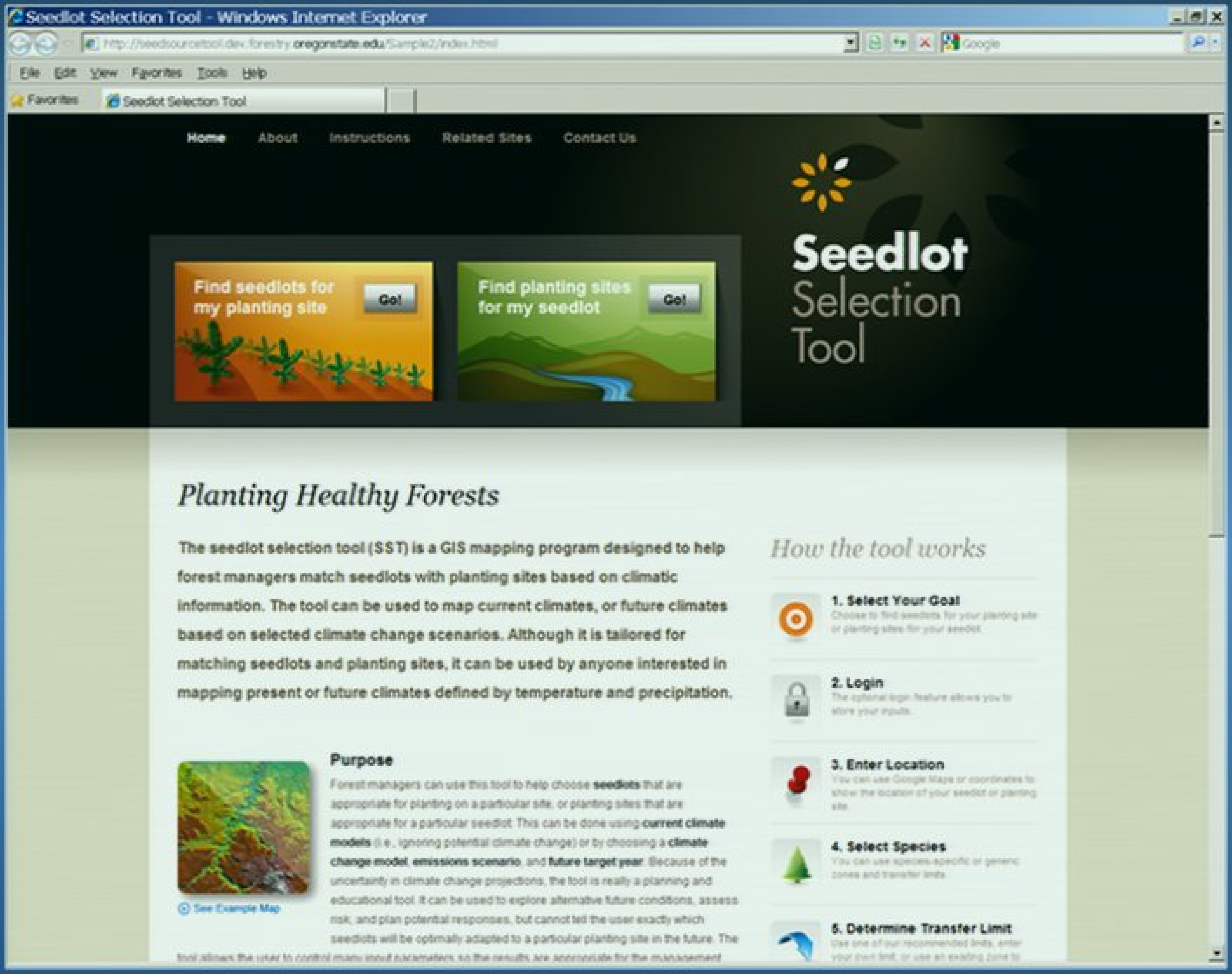


Fig. 8 Predicted changes in productivity of lodgepole pine across all seed planning units in BC for local seed vs. most productive seed source for future climates. Each increase of 1 °C in mean annual temperature (MAT) is accompanied by an increase of 1.8% increases in mean annual precipitation. Error bars indicate the 90% confidential interval for predicted means.

Using local sources, increased productivity by 7% up to 1.5ºC (2030), but decreased productivity above 2ºC.

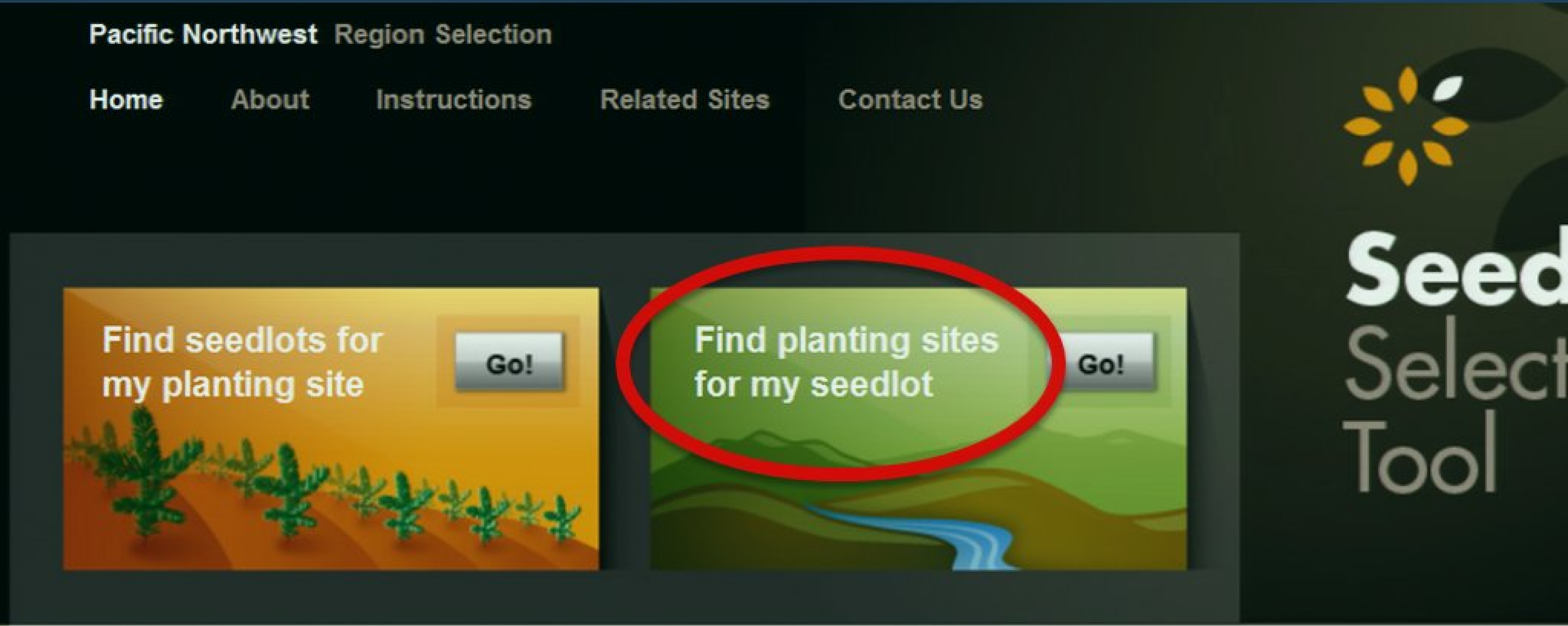
Using assisted migration, can increase productivity considerably.

Seedlot Selection Tool (SST)



http://sst.forestry.oregonstate.edu/pnw/

Select your goal

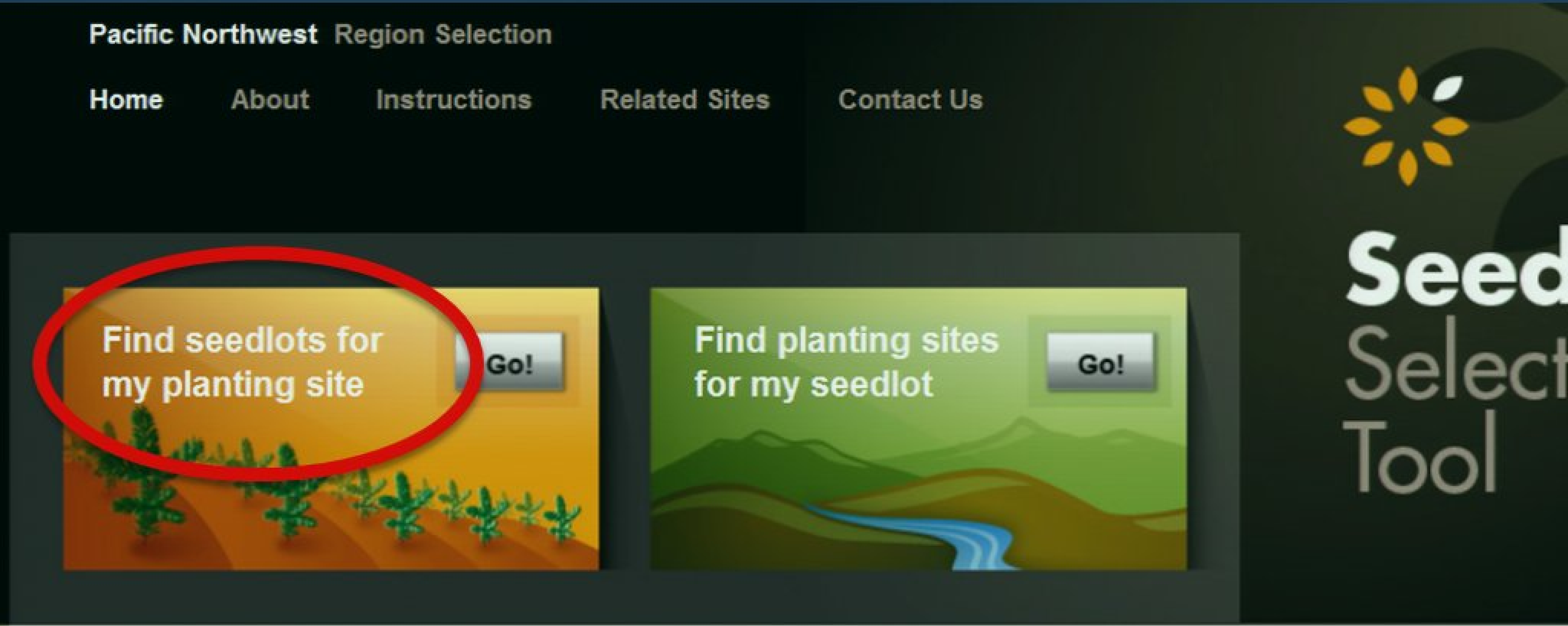


Given a specific <u>seedlot</u> …

Where is it expected to be well adapted today?…

And in the future given a climate change scenario?

Select your goal

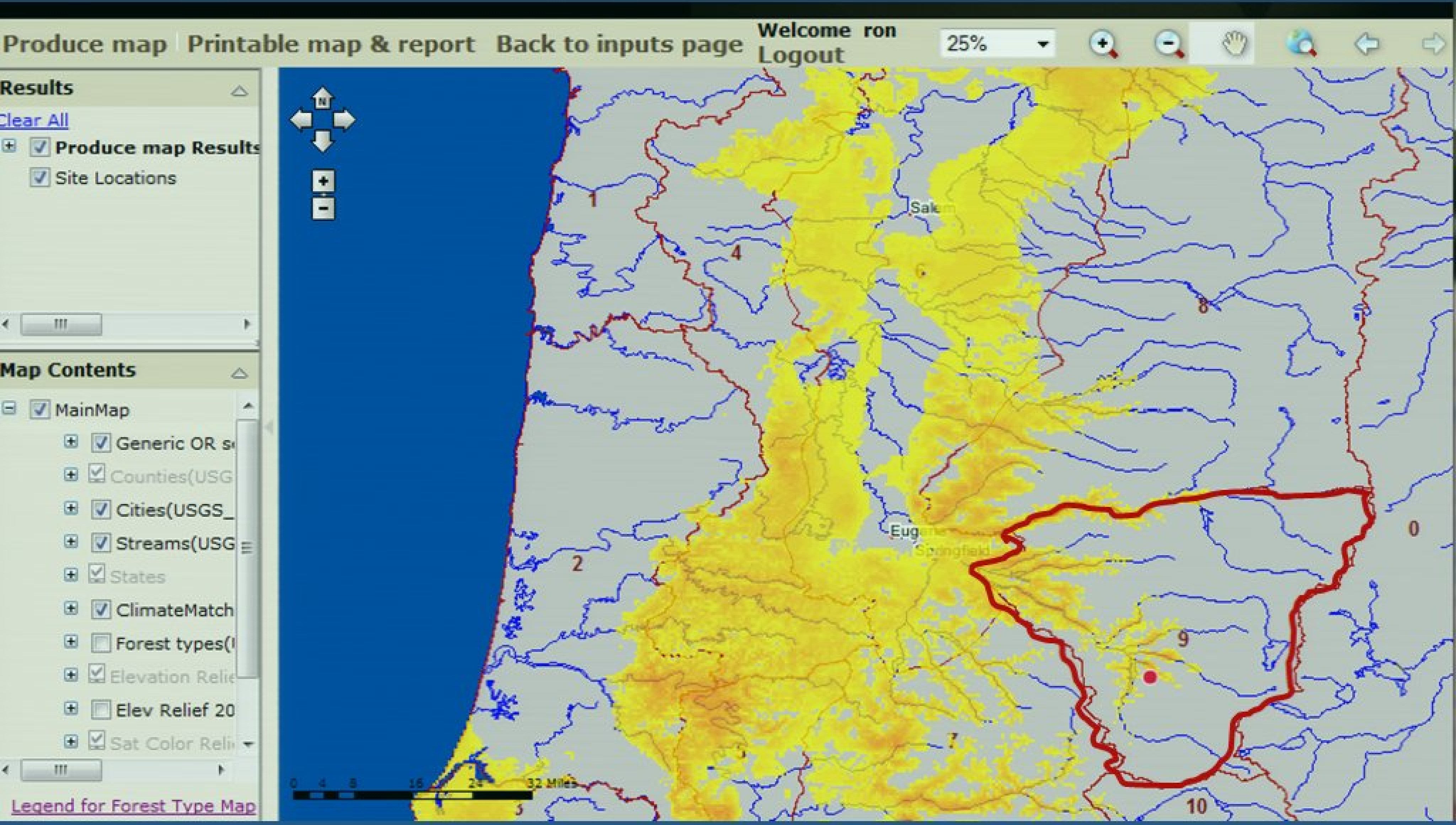


Given a specific <u>planting site</u> …

<u>Which seedlot</u> is well adapted today?…

And in the future given a climate change scenario?

Map results


Produce map
Printable map & report
Back to inputs page
Welcome ron
Logout
25%
Results
Clear All
Produce map Results
Site Locations
Map Contents
MainMap
Generic OR s
Counties(USG
Cities(USGS_
Streams(USG
States
ClimateMatch
Forest types(
Elevation Relie
Elev Relief 20
Sat Color Reli
Legend for Forest Type Map
Salem
Eugene
Springfield
1
2
4
6
8
9
10
0
0 4 8 16 24 32 Miles

Management options for climate change:

1. Do nothing
2. Use silvicultural measures to ensure resiliency and resist change
3. Promote natural migration and gene flow
4. Select and breed for adaptive traits within species/populations
5. Gradually change species and seed sources for reforestation or restoration in anticipation of warming or in response to problems (assisted migration)
6. Enhance species and genetic diversity
    - Maintain diversity within seed sources
    - Deploy species and/or provenance mixtures within sites and across landscapes
    - Allow for selection with higher planting densities, thinning
    - Establish genetic outposts for facilitating gene flow into adjacent native stands – small number may be effective

Management options for climate change:

1. Do nothing
2. Use silvicultural measures to ensure resiliency and resist change
3. Promote natural migration and gene flow
4. Select and breed for adaptive traits within species/populations
5. Gradually change species and seed sources for reforestation or restoration in anticipation of warming or in response to problems (assisted migration)
6. Enhance species and genetic diversity
7. Ensure that our genetic heritage is preserved (gene conservation)

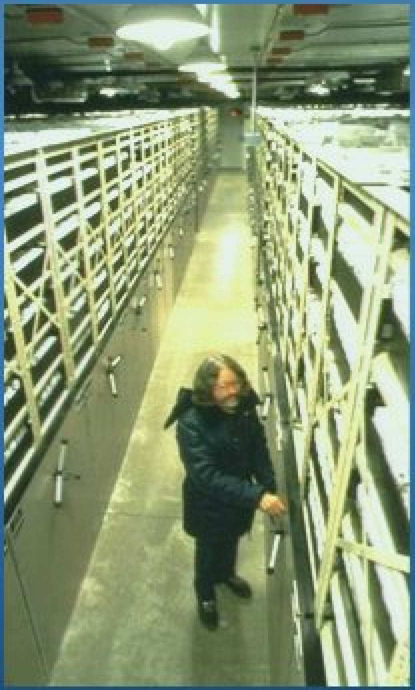
Conserving genetic diversity

In situ conservation

- Locate reserves in areas of high environmental and genetic diversity
- Reduce disturbance probability and intensity
  - thinning, prescribed fire, fuels reduction, insect traps
- Supplement existing variation with genetic outposts

Ex situ conservation

- Seed collections becomes more important with increasing threats to *in situ* reserves
- Assisted migration (plantings) may also be considered a form of *ex situ* conservation



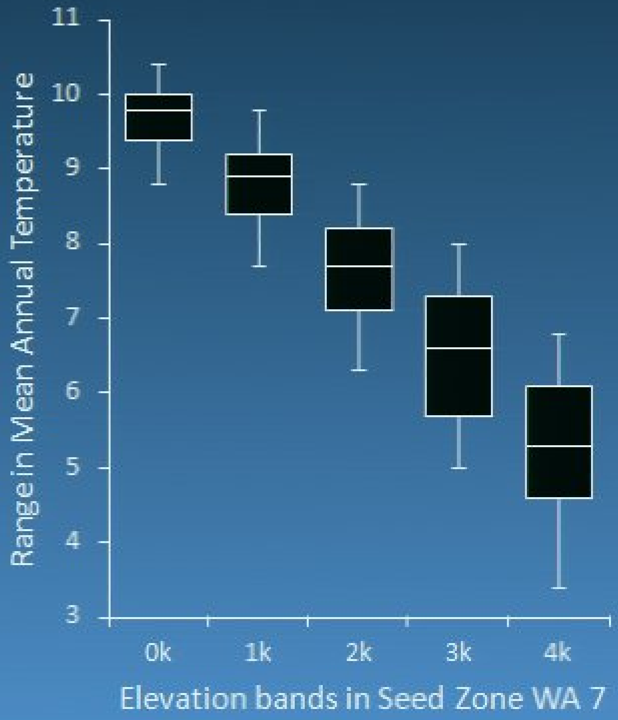
Priorities for gene conservation

- Long-lived species
- Genetic specialists
- Species or populations with low dispersal potential
- Species or populations with low genetic variation
  - Inbreeding species
  - Small populations
- Fragmented, disjunct populations
- Populations at the trailing edge of climate change
- Species or populations with "nowhere to go"
- Rare or endemic species
- Populations threatened from habitat loss, fire, disease, insects
- High economic or social value

Personal thoughts and recommendations

- Decisions now may have long-term implications.
- Most critical phase is stand establishment; although climate is a moving target, chose sources adapted to climates of the next 20 yrs.
- Large moves are not necessary; move to planting sites that are 2°C cooler than present; within current seed movement guidelines.

Transfer distances within current seed zones



Douglas-Fir Seed Zones

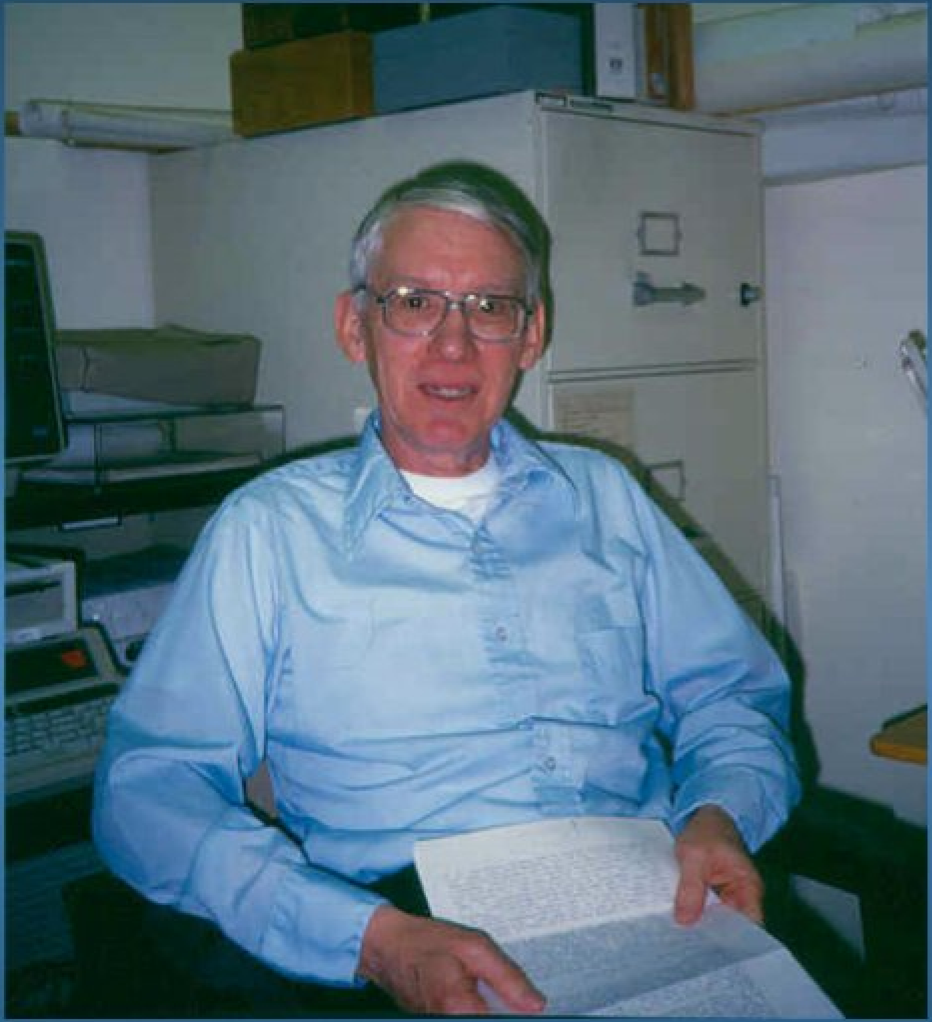
Transfer Distances in °C Mean Annual Temperature for Different Percentile Temperatures Within Zones

	25th – 75th	5th – 95th	Maximum
Zone WA 7 3000-4000’	1.5	3.4	4.2
Average all zones	1.0	2.2	3.2
Greatest all zones (WA 10)	3.6	6.3	8.2

Personal thoughts and recommendations

- Decisions now may have long-term implications.
- Most critical phase is stand establishment; although climate is a moving target, chose sources adapted to climates of the next 20 yrs.
- Large moves are not necessary; move to planting sites that are 2°C cooler than present; within current seed movement guidelines.
- Use mixtures of seed sources to account for uncertainty and climate change over the life of a stand.
- Seed zones and seed movement guidelines should be based on climate rather than geography.
- Seed collections should be bulked over a smaller climatic range than current seed zones.
- Research is important, but lack of knowledge is not an excuse for inaction.

Bob Campbell 1927-2013



Video of Genetic Variation in Terminal Growth Phenology

Think about:

1. Why do the differences between sources exist?
2. How important are those differences for determining sources for reforestation?

Video of Genetic Variation in Terminal Growth Phenology

Think about:

1. Why do the differences between sources exist?
2. How important are those differences for determining sources for reforestation?

For more information, please visit the US Forest Service Reforestation, Nurseries & Genetics Resources website at **http://rngr.net**