Population-level differences in adaptive capacity to climate change in a boreal forest tree, *Populus balsamifera* L.

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Assisted migration

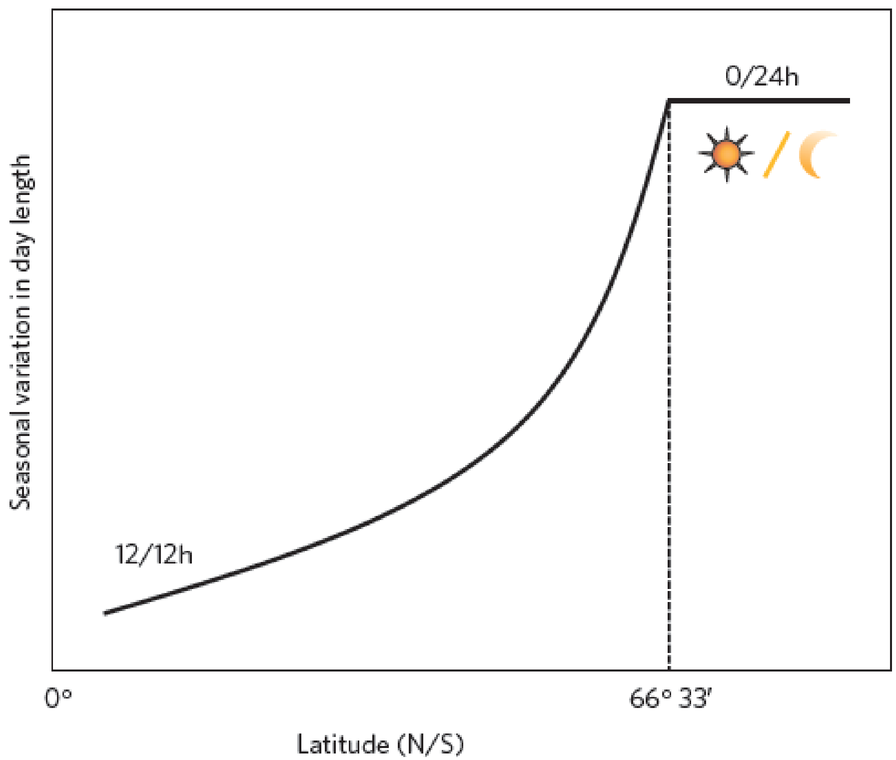
- Transferring populations *beyond* current species' range limits
  - Often used for threated species
- Transferring individuals among populations *within* the species' range limit
  - Can increase the adaptive capacity of a species
  - Less controversial

Local adaptation

- Within a single species, adaptive capacity can vary due to:
  - Evolutionary history
  - Different selection pressures in different parts of species' range
- Local adaptation – populations are locally adapted when populations have the highest relative fitness at their home sites, and lower fitness in other parts of their range (Savolainen et al 2007)
- Local adaptation can result from:
  - Gradients in environment and selection
  - Limited geneflow

Local adaptation in boreal forest trees

- Well-known adaptive cline with latitude
- Result of local adaptation to climate and photoperiod gradients
  - Photoperiod cues inform the trees when to start growing, when to set bud, flower, etc.



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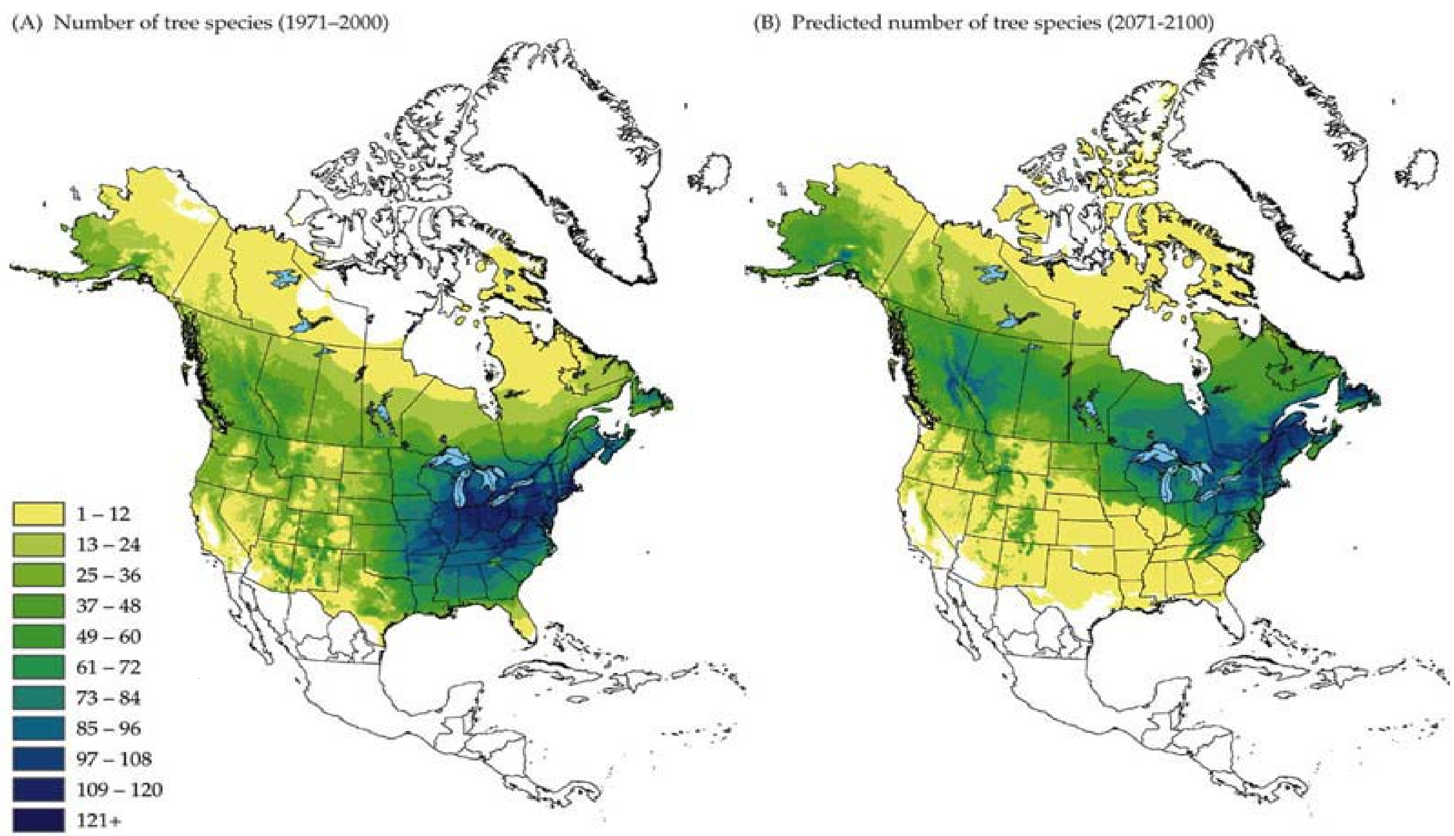
Impacts of local adaptation on adaptive capacity

- Assuming environment is relatively constant, local adaptation is beneficial
- In a changing climate, some populations of a locally-adapted species may react differently than others
- Population-level differences in adaptive capacity
  - Differences in:
    - Genetic diversity
    - Phenotypic plasticity
    - Physiological tolerances

Boreal forest – impacts of climate change

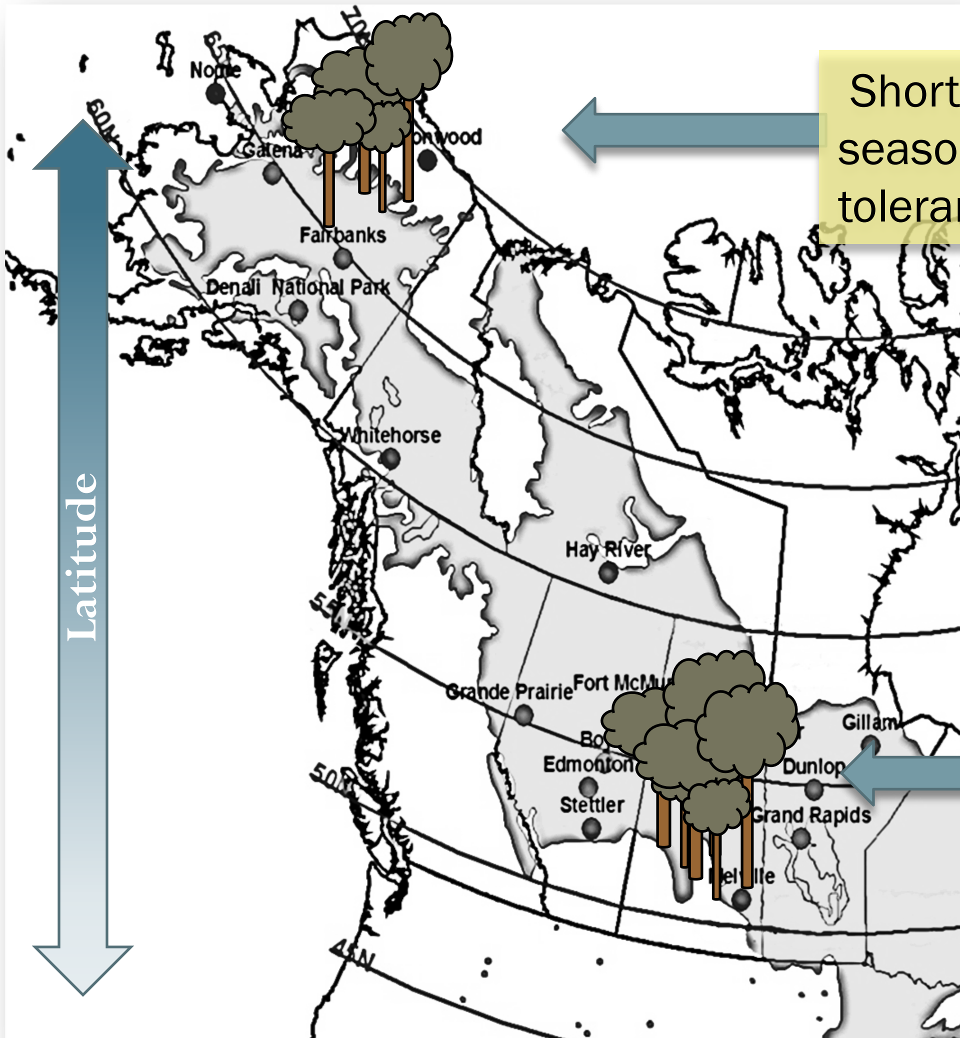
- Northward expansion of species range limits
  - Treeline advance
  - Distribution shifts

(McKenney et al. 2011)



Local adaptation, plasticity, and migration

1. Genotypic variation across a species' range (local adaptation)



Short growing season/investment in cold tolerance traits

Long growing season, warm adapted

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Genetics, plasticity, and migration

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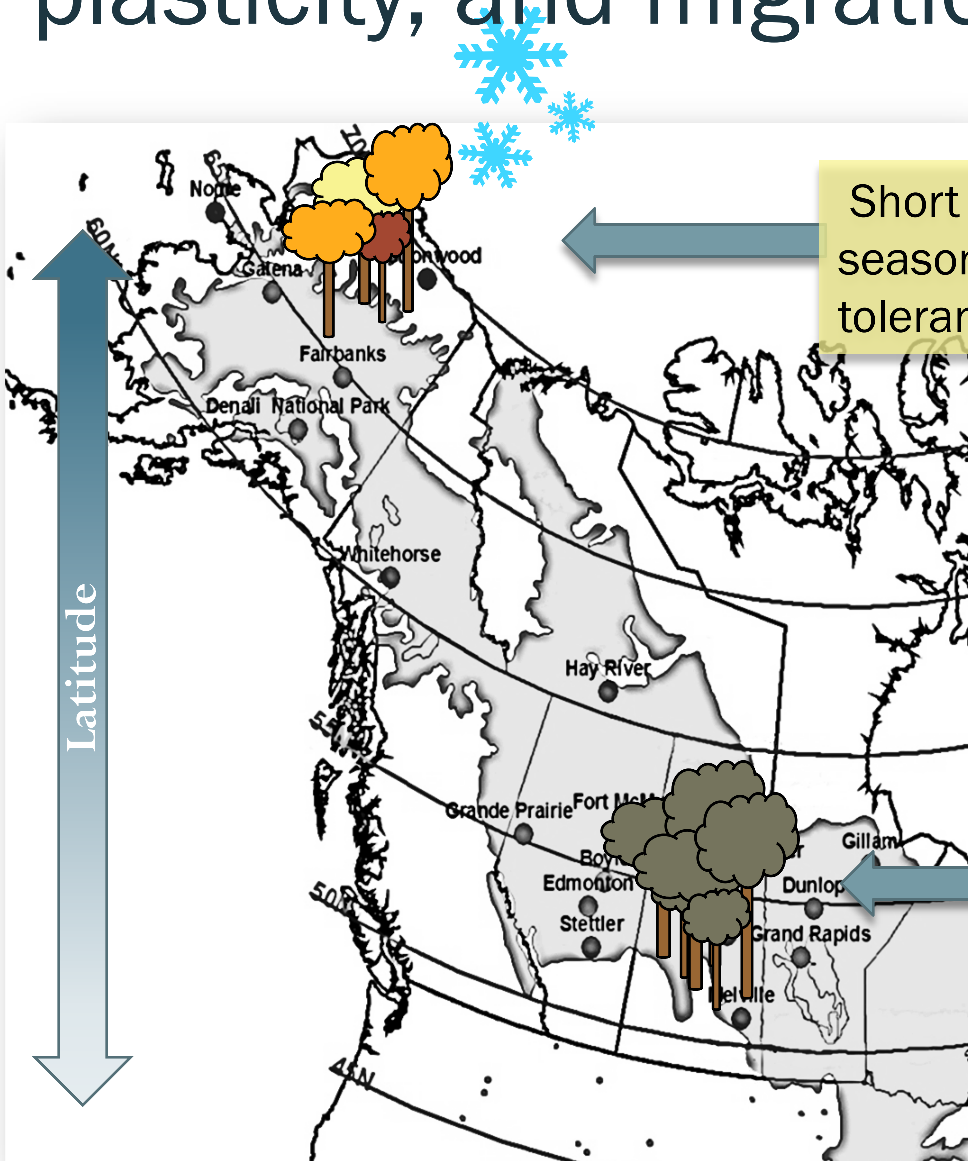

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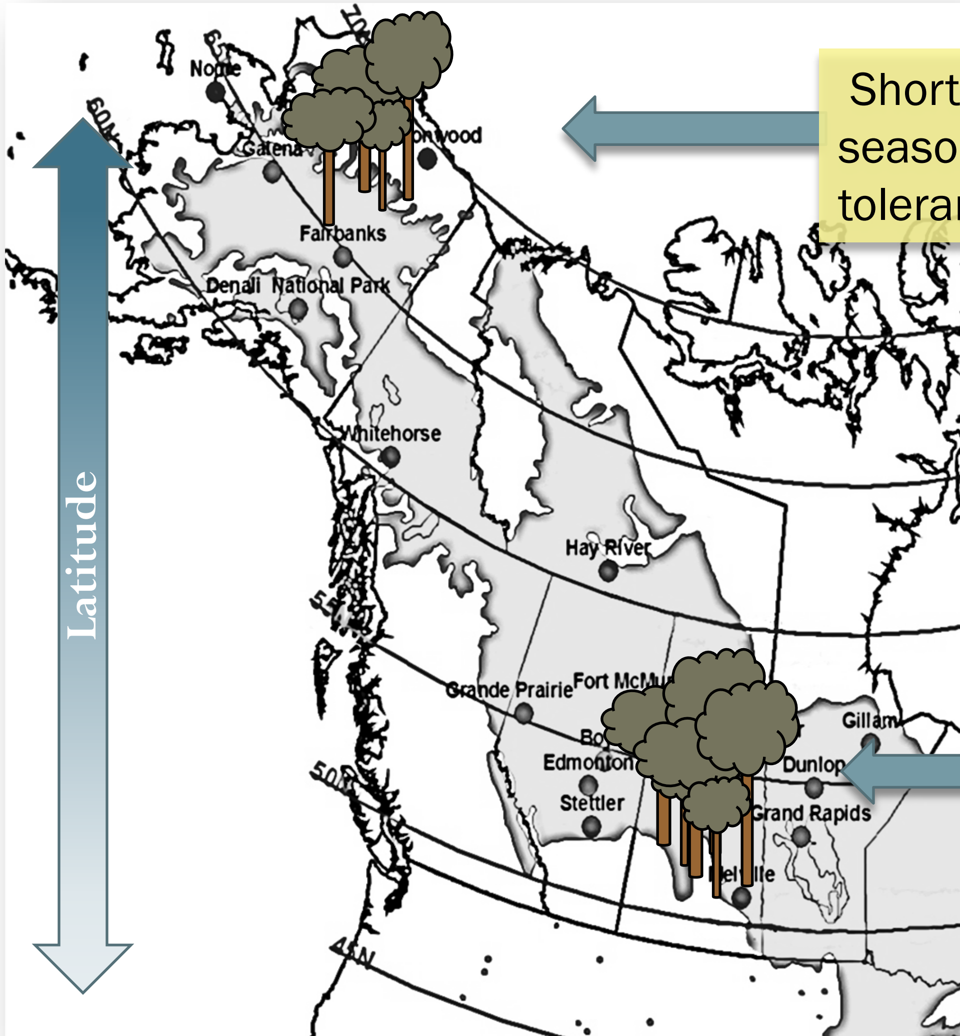

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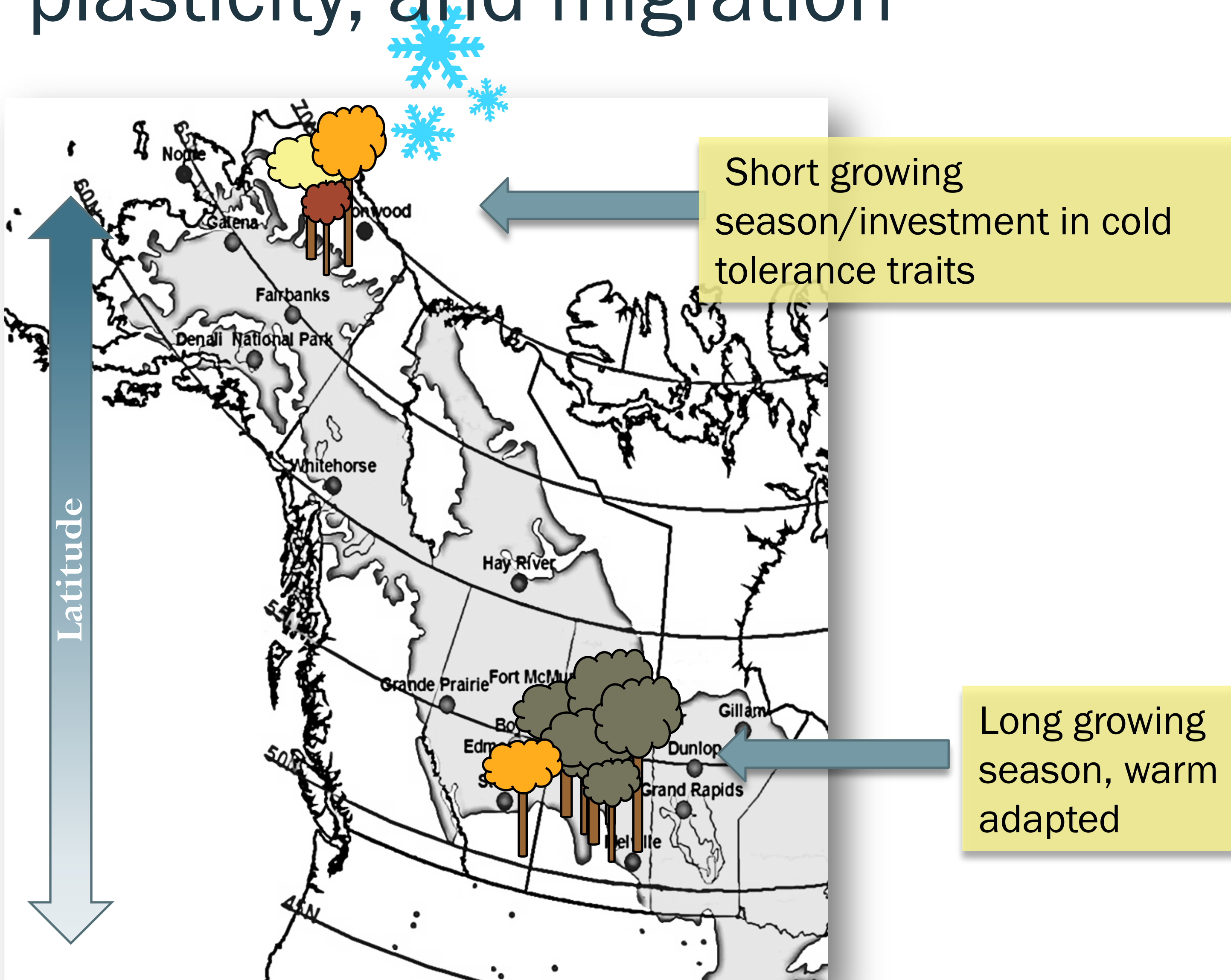

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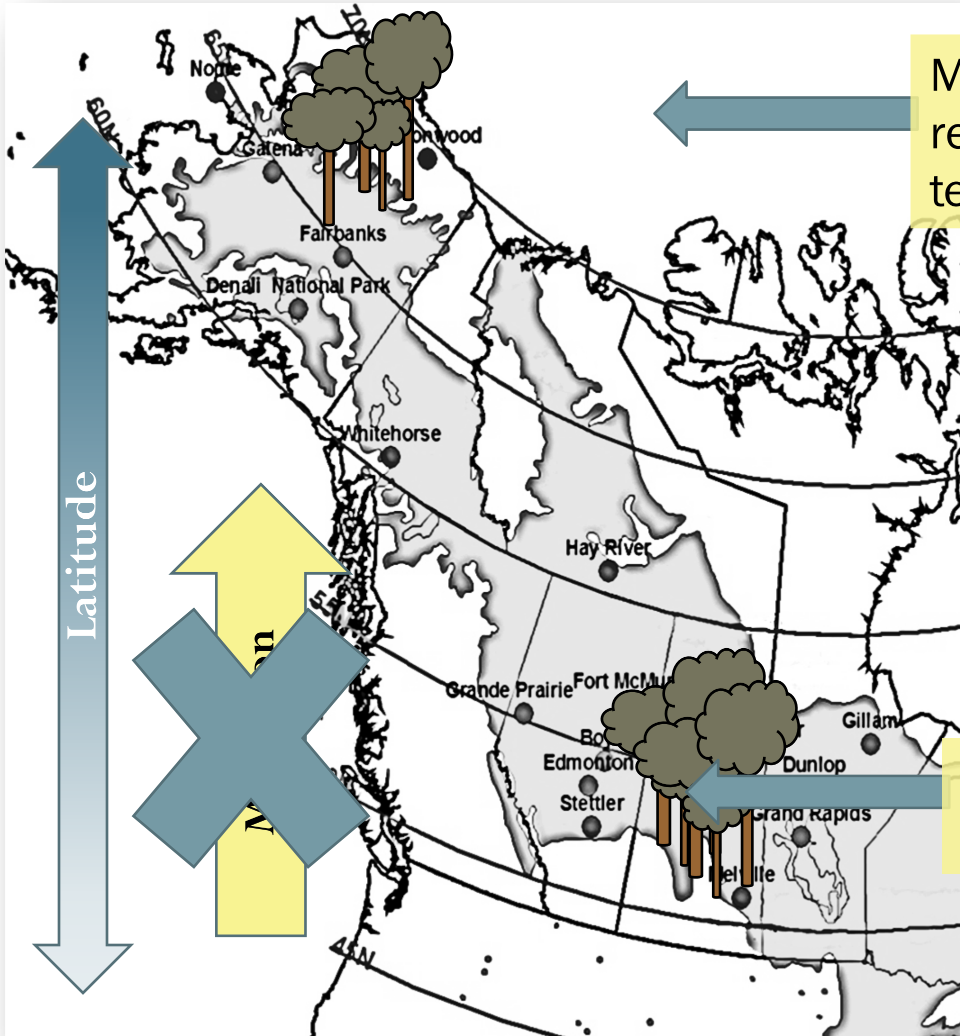
Genetics, plasticity, and migration

1. Genotypic variation across a species' range (local adaptation)

2.Genotype can determine amplitude of plasticity

3. Local adaptation can determine responses to climate change



May be limited in response to increased temperatures

Southern genotypes may migrate northward

Research question

- Does adaptation to local environments affect species' intrinsic adaptive capacity to respond to climate change (temperature and growing season length increase?
  - Genetic differences:
    - Do populations from the north and south differ in their potential growth in a northern environment?
  - Plastic responses:
    - Is there a phenotypic response to warming (acclimation)?
  - Genotype x plasticity:
    - Do genotypes from the north and south of a species' range respond differently to increased temperatures?

Research approach

- To test for affects of local adaptation on the acclimation and migration potential of boreal forest tree species
  - Compare growth and plasticity of different genotypes growing in the same environment (genetic differences)
  - Grow same genotypes in two environments (plasticity)
  - Compare genetic diversity across latitude

- Important to have samples from large gradients in species range to capture the majority of genetic and plastic variation

Artificial warming experiments

Experiment 1

Common garden

Experiment 2

Growth chambers

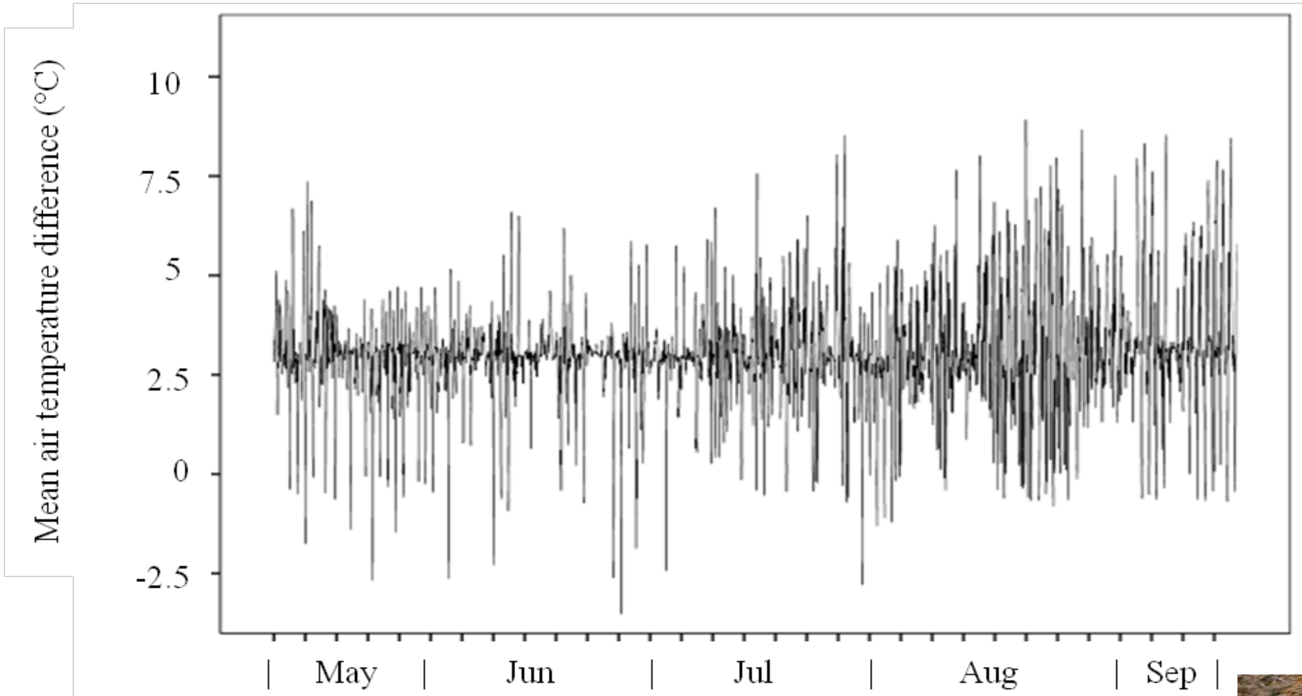
Artificial warming experiments

- Common garden
  - ‘Natural setting’
  - Test effects of warming throughout growing season
    - Photoperiod
  - Passive warming
    - Variable magnitude/consistency of warming treatment
  - Cannot control all environmental variation

Artificial warming experiments

- Growth chambers
  - Focuses only on temperature differences
  - Can control for:
    - Soil characteristics
    - Nutrients
    - Water
    - Light
    - Humidity
  - Unnatural environment

Warming effect



Average warming = 3 °C

Diurnal warming = 3.42 °C

Nocturnal warming = 2.51°C

Populus balsamifera L. (balsam poplar) Latitudinal sampling 50-70 °N

Warming treatments test for plasticity

Latitudinal sampling tests for genetic differences

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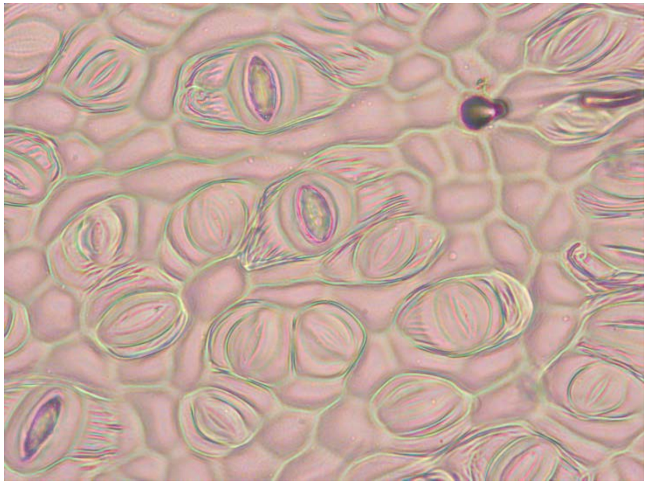
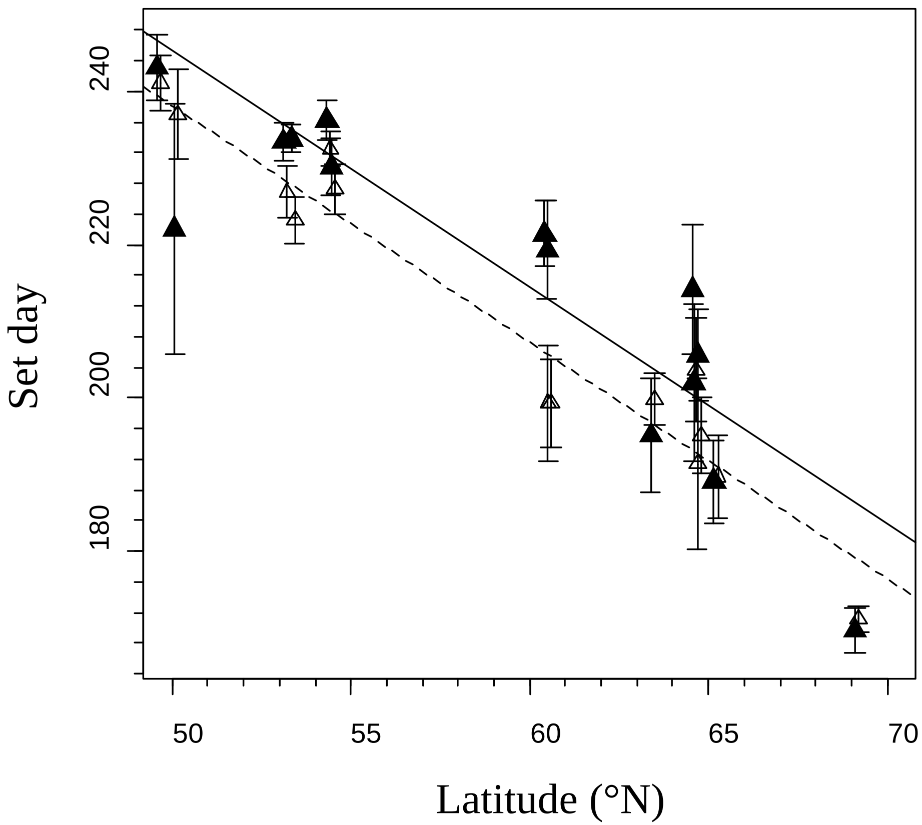
Effects of warming and source latitude on:

- Growth
  - Height
  - Diameter
  - Leaves
  - Lateral buds
- Phenology
  - Bud flush
  - Bud set
- Cold injury & cold tolerance
- Leaf physiology/morphology
  - Photosynthesis
  - Foliar Nitrogen
  - Stomatal Density



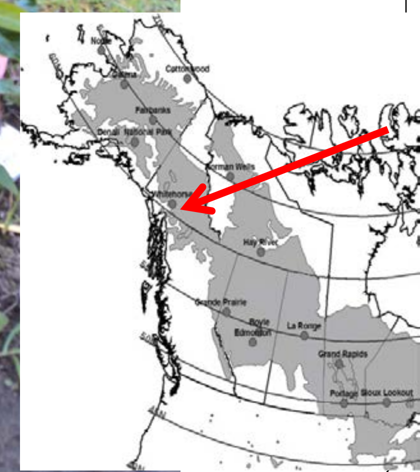
Adaptive capacity is higher than expected in northern populations

- Northern populations have higher plasticity than predicted
- Phenological traits (e.g., bud set) is influenced by temperature
  - Contrasts widely-held view that bud set is determined by genetics only in poplar
- Northern genotypes have lower genetic diversity (Olson et al 2013)




XTRATUF


XTRATUF
Nome
Cottonwood
Denali National Park
Whitehorse
Hay River
Grande Prairie
Boyle
La Ronge
Grand Rapids
Portage
Sioux Lookout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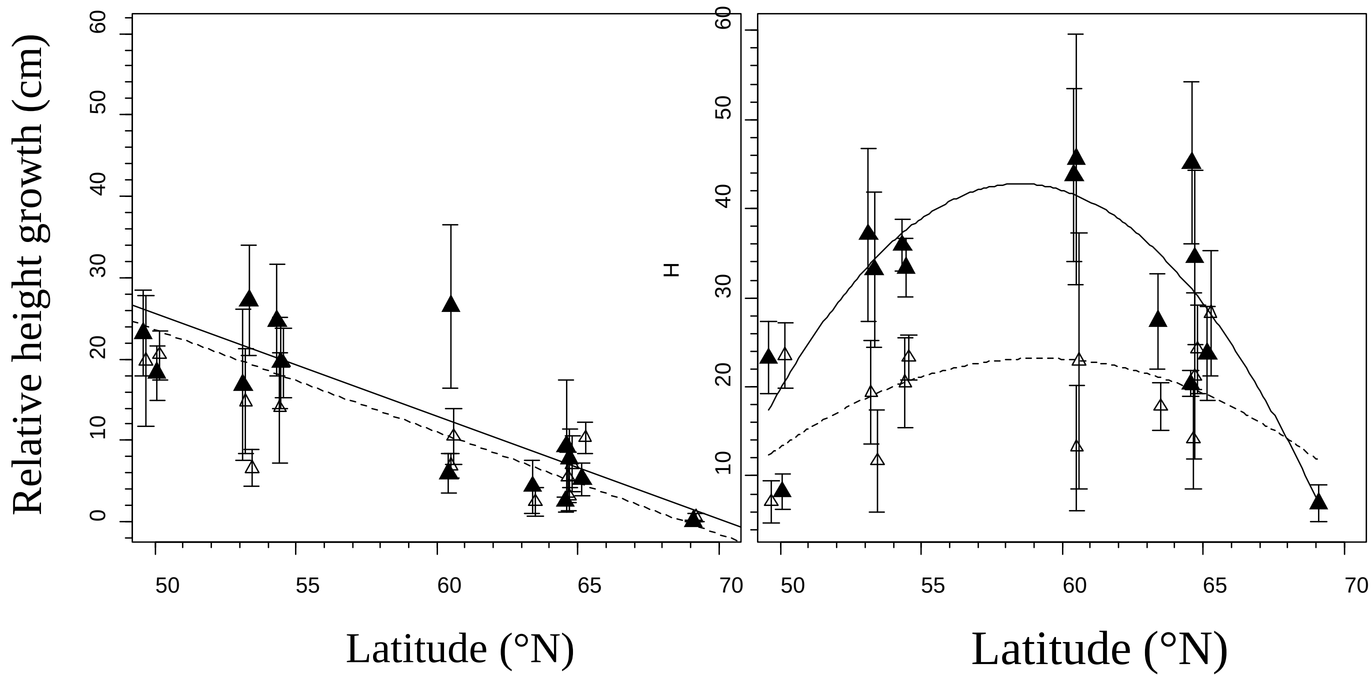
Southern populations have highest growth rates in northern environment

- Genotypes from southern populations grew consistently larger than northern genotypes
- But southern genotypes also had highest incidence of cold injury



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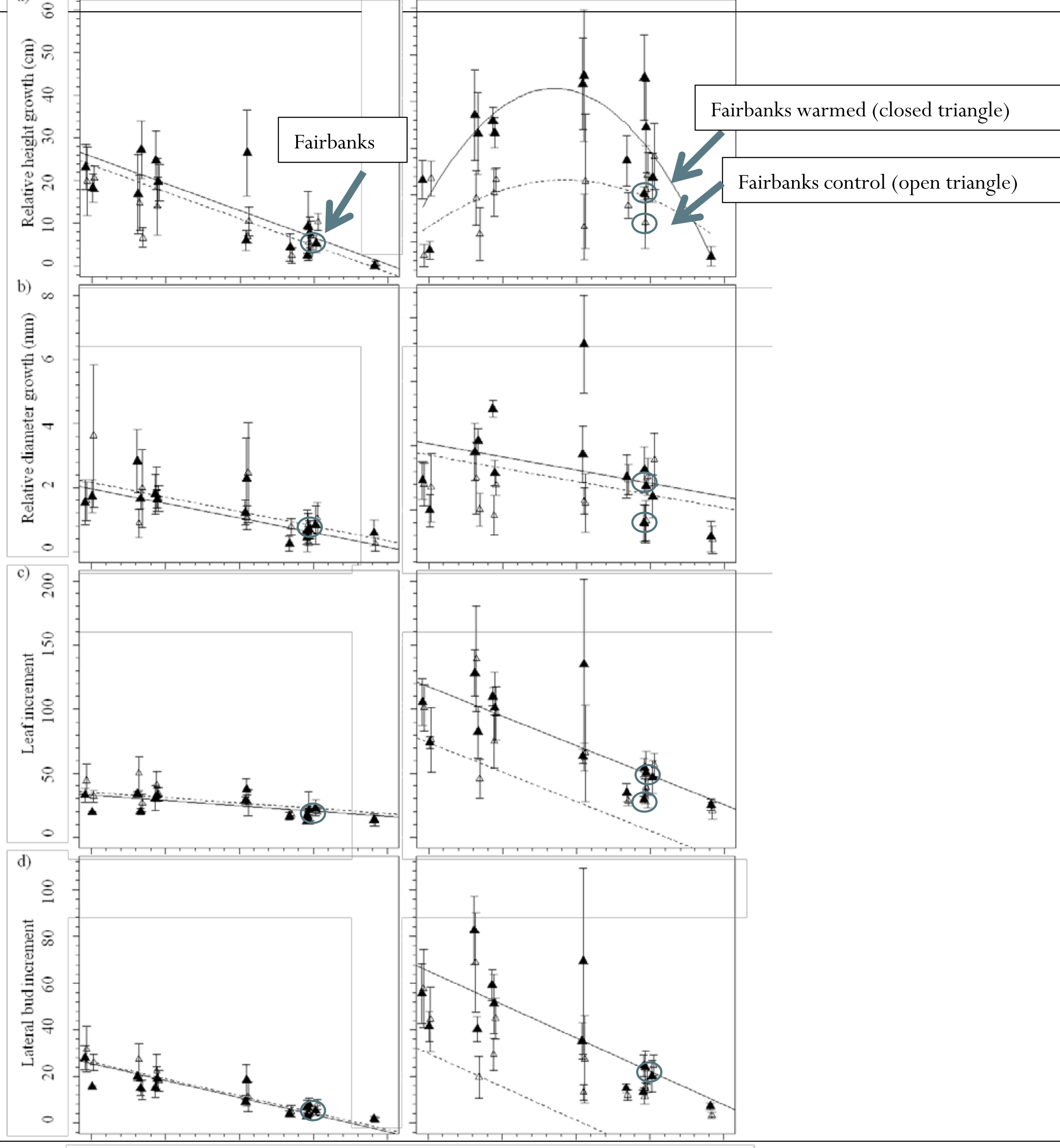

Relative height growth (cm)
Fairbanks
Fairbanks warmed (closed triangle)
Fairbanks control (open triangle)
b)
Relative diameter growth (mm)
c)
Leaf increment
d)
Lateral bud increment

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Southern populations have highest growth rates in northern environment

- In growth chamber (absence of seasons), southern genotypes had competitive advantage in both control and warmed conditions

Adaptational Lag

- **Local genotypes of balsam poplar (trees originally collected from Fairbanks source populations) were not the best performers at either ambient or warmed conditions, when planted in Fairbanks, Alaska.**
- **This may be evidence of an adaptational lag in response to the recent 1.4 °C warming nearly 50 % increase in the growing season length (Wendler and Shulski 2009) documented for the region.**
- **This adaptation lag was increased when the cuttings were experimentally warmed, suggesting that local trees may continue to decline with future warming.**

Adaptational Lag

- **Overall, the best-performing genotypes were those collected from 5-10 ° south of Fairbanks (Robertson 2012, Robertson *et al*., in review).**

Choosing best genotypes for Region III

- Genetic clines (e.g., bud set and height growth) are plotted against mean annual temperature of source environments.
- Can model the severity of the expected adaptational lag given that degree of warming.

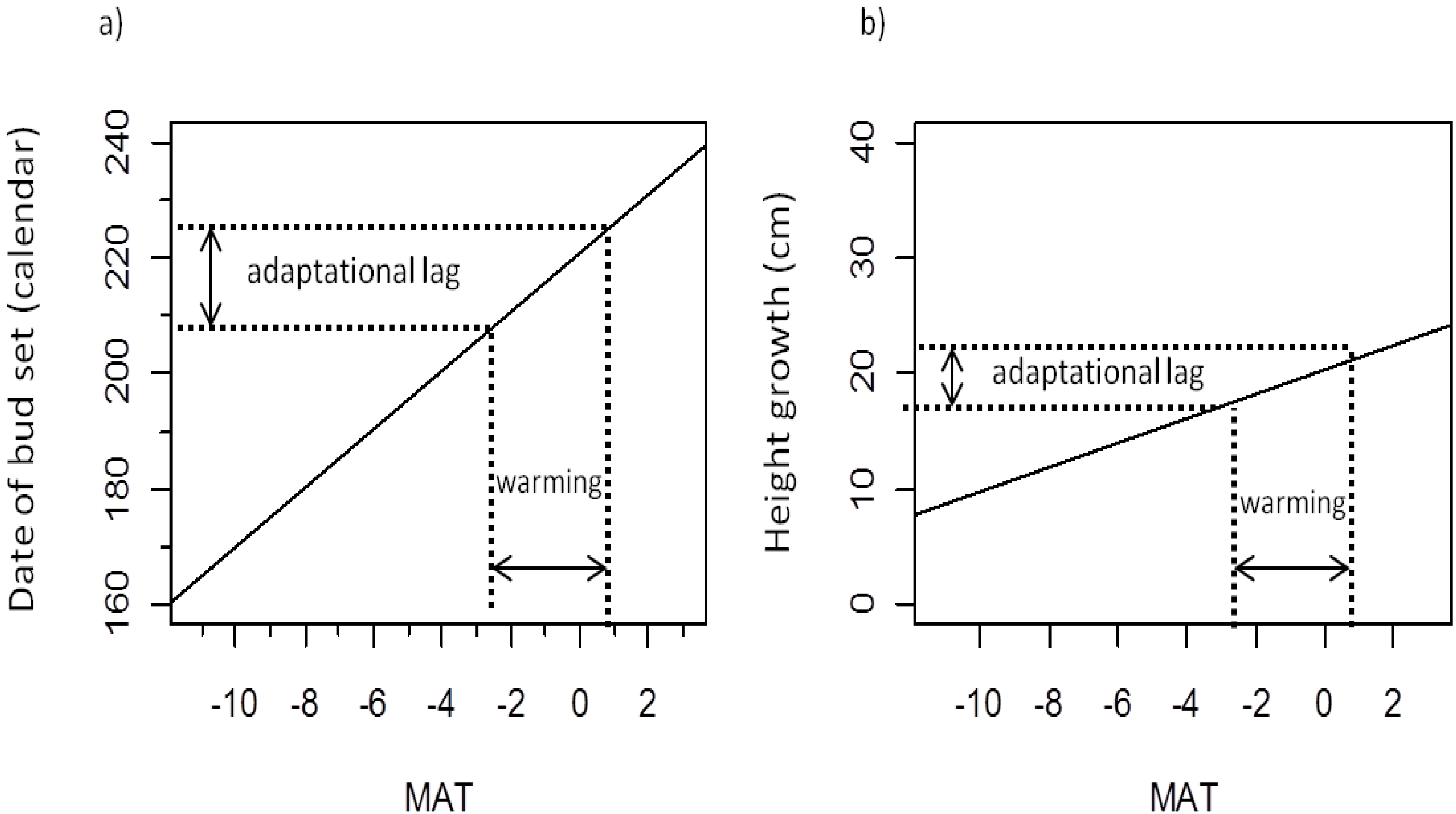

Figure 5.1 Genetic clines along gradients in mean annual temperature for mean calendar date of bud set (a), and for total height growth (b). The horizontal arrow illustrates the degree of experimental warming (3 °C/5.4 °F) and the vertical arrow represents the predicted adaptational lag for that amount of warming. Data are from Chapter 4; figure is adapted from Aitken et al. (2008).

Questions?

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Quantifying intrinsic adaptive capacity of balsam poplar:

- Genetic diversity & geneflow
  - Genome-level nucleotide diversity and linkage disequilibrium to estimate effective population size
- Degree of local adaptation
  - Compare differences among populations to within populations
    - Phenotypic, physiological, epigenetic, functional genes
- Acclimation potential
  - Plasticity in a warmed environment
    - Phenotypic, physiological, epigenetic, gene expression*
- Migration capacity
  - Colonization success in a northern environment