GENOMICS IN SOCIETY

Climate Adaptation Studies

What is climate adaptation?

Climate:

- The long-term average or usual weather of a place over many years
- The prevailing weather conditions in a geographic region over a long time period

Adaptation:

- Any heritable trait that increases the fitness of an individual with that trait, compared with individuals without that trait, in a particular environment
- The outcome of selection; change in genes due to environmental changes

What is climate adaptation?

Therefore…

Climate adaptation is the outcome of selection on heritable traits that increase the fitness of an individual in response to changes in the average weather conditions in a geographic region over a long time period, i.e. adaptation that occurs specifically due to climate change.

Climate adaptation – more definitions

"Adaptation refers to adjustments in ecological, social, or economic systems in response to actual or expected climatic stimuli and their effects or impacts. It refers to changes in processes, practices, and structures to moderate potential damages or to benefit from opportunities associated with climate change." – United Nations Climate Change

"Climate change adaptation is the adjustments societies or ecosystems make to limit the negative effects of climate change or to take advantage of opportunities provided by a changing climate." – UC Davis Science & Climate

"Climate change adaptation refers to actions that reduce the negative impact of climate change, while taking advantage of potential new opportunities. It involves adjusting policies and actions because of observed or expected changes in climate. Adaptation can be reactive, occurring in response to climate impacts, or anticipatory, occurring before impacts of climate change are observed." – Natural Resources Canada

→ Alternate definitions consider non-biological/ecological adaptation and include societal concerns

Climate vs. Weather

CLIMATE

- Long-term
- Average or usual weather of a place or region over many years
- Can be predicted based on past trends
- Example: In British Columbia, snow and cold temperatures can be expected for the month of January

WEATHER

- Short-term
- Local atmospheric condition at a time & place
- Can often be unpredictable and does not follow a past trend
- Can change by the minute, hour, day
- Example: Snowing one day, rain the next day

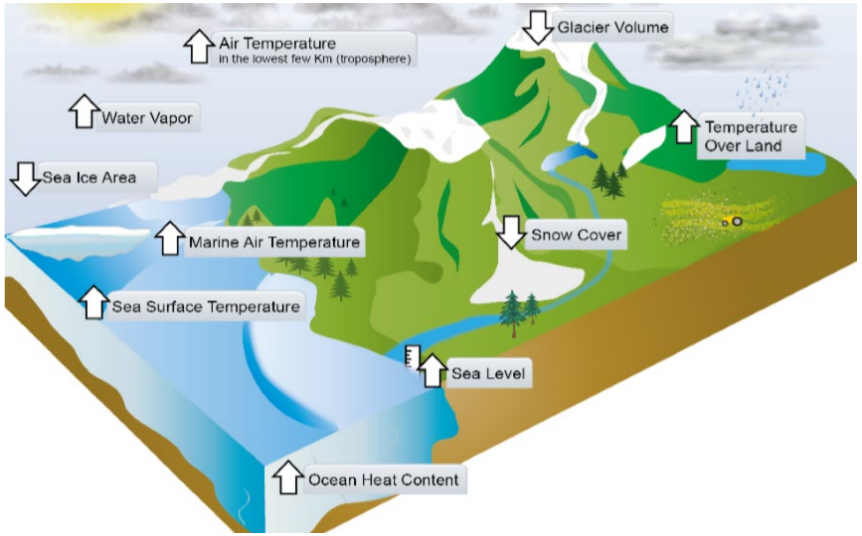
What is climate change?

- The change in the climate of a place; generally covers a large scale over a defined region for a long period of time
- The long-term change in average global weather patterns
- Anthropogenic climate change refers to climatic changes that can be directly attributed to one or more human influences
  - Examples: notable increase in CO_2 emission after World War 2 & the Industrial revolution; increased warming corresponding with increased fossil fuel usage

Why call it climate change instead of global warming?

→ Warming is not the only outcome of changing global climates, there are several cascading effects as result of increasing global surface temperatures

- ‘Climate change’ captures changes in many parts of the climate:
  - More droughts
  - Sea levels rising
  - Stronger storms and hurricanes
  - More extreme heat days
  - More extreme cold days



Why do we need to study climate adaptation?

- The rate of climate change is preceding the rate at which some species are able to adapt
  - i.e. the climate is changing faster than species are able to adapt to the changes
- Some species may require human intervention to be able to persist in different climates
- We need to study how or if species are able to adapt to the climate so we can make management decisions about how to help the species survive and adapt to future/predicted climates

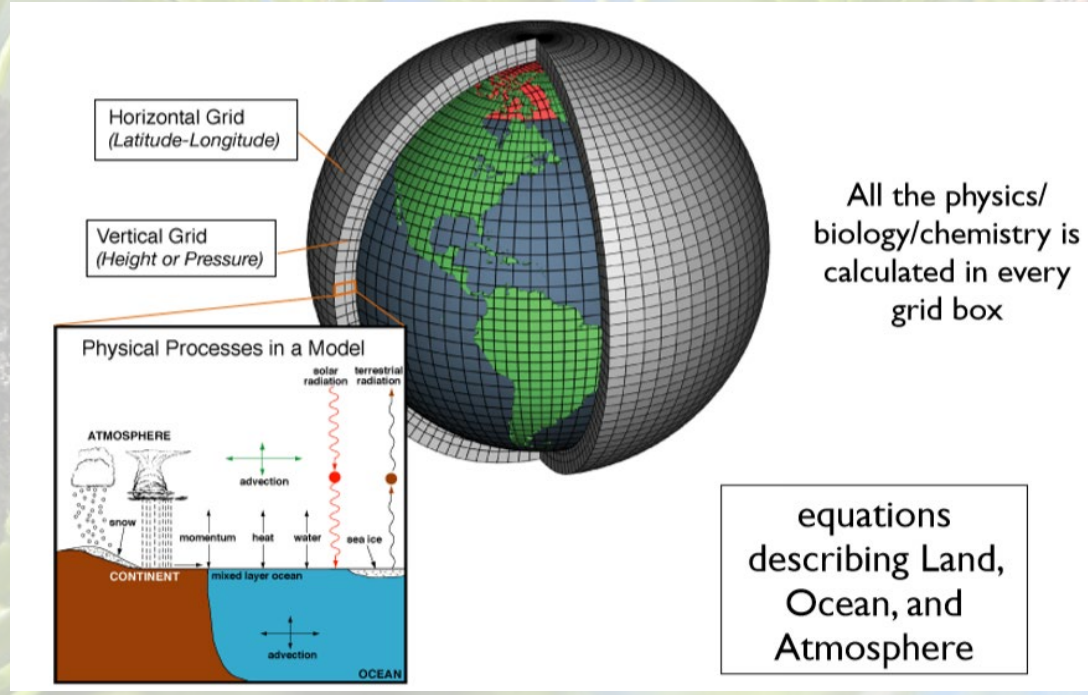
→ We need to understand how species already adapt to climate change to manage for predicted changes and prevent further biodiversity losses

How do we study climate adaptation?

- Research is conducted in using field experiments and lab analysis
- Multiple methods are used in tandem, including:
  - Climate models (statistical, geographical)
  - Common gardens
  - Provenance trials
  - Genome sequencing

Climate Modelling

- Climate models are statistical models that use observational or experimental data to make predictions about future temperatures given projected climate change conditions
- Example: using data from the last 50 years showing the average annual surface temperature and precipitation in British Columbia, researchers can make a model to predict and map what the surface temperatures and precipitation will be in 2050, 2080, and so on



- Climate models can be used to simulate the Earth's changing climate patterns, including entire continents, countries, states/provinces, and localities

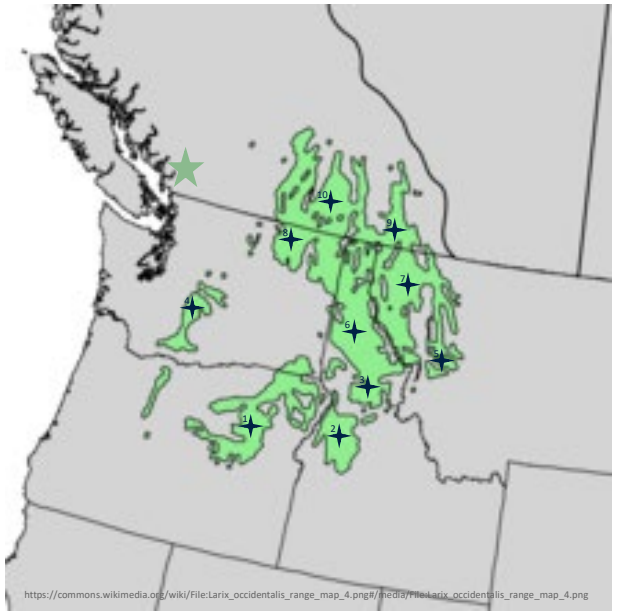
Common Garden Studies

- These field studies test the effect of the environment by moving two or more species from their native/origin environments into a common environment
- In a forestry context, seeds are often collected from a single tree species throughout its range and planted in a common environment to analyze genetic adaptation and variation within the species, or foresters use common garden experiments to test multiple tree species adaptation to determine where they should be planted as the climate changes
- These experiments are a classical way to test if there is a genetic component to differences in traits within and among populations

→ Importantly, common garden studies plant species outside of their native range

Common Garden Studies – western larch example

Western larch range in North America:



symbol represents where seed are collected from throughout western larch's range

symbol represents the location of the common garden

1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
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Replicates of seed collected from 10 different locations are planted in the common garden to be grown in a common environment

Steps to establish a common garden:

1. Collect seed from throughout the species range.
2. Germinate the seed in a greenhouse until samples reach the seedling stage and can be transplanted.
3. Plant the seedlings outside in a control environment.
4. Allow samples to grow, and observe phenotypic differences.

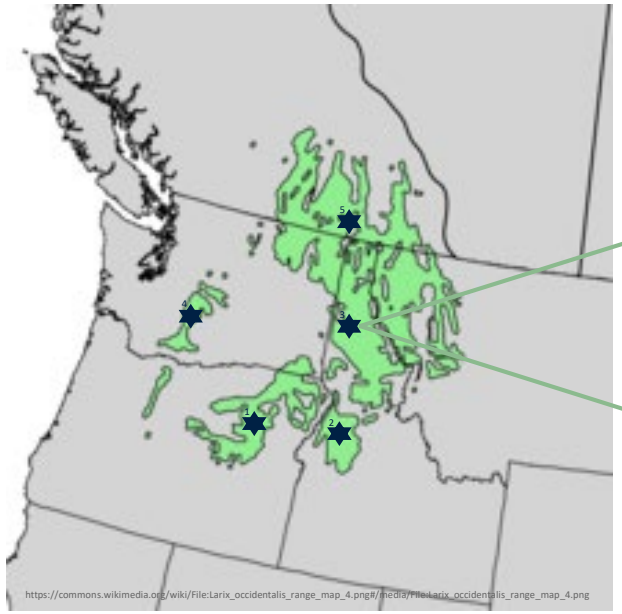
Provenance Trials

- Provenance trials are a special type of long-term plantation experiment that help researchers understand how trees are adapted to different environmental conditions through genetic adaptation or phenotypic plasticity
    - Phenotypic plasticity: expression of a different phenotype by the same genotype in a different environment
- Seeds are collected from throughout the species' range or specific areas of interest
- Two or more test site locations are established throughout the species range that represent different environments and the seeds collected from different locations are planted at these test sites
- Test sites will include seed that originates from that location and seed that originates from different locations

→ Importantly, provenance trials test for local adaptation by transplanting individuals of the same species within their native range

Provenance Trials – western larch example

Western larch range in North America:



★ symbol represents the different provenances within the species range where trials are conducted

In this example, 5 provenances have been sampled and a trial has been established in each. Provenance 3 is shown in bold to indicate that it has been planted in its provenance of origin.

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5 5 5 5 5 5 5 5 5 5 5 5 5 5 5

Provenances 1, 2, 4, and 5 originate from populations within the species native range that have different environmental clines. These provenances may be locally adapted to their origin locations and may exhibit decreased fitness when grown outside their origin location.

Steps to establish a provenance trial:

1. Collect seed from different and/or phenotypically distinct populations throughout the species native range.
2. Plant the seeds in common gardens located in each of the provenances sampled. For example, if there are 5 provenances sampled, there will be 5 common gardens established.
3. Allow samples to grow, and observe phenotypic differences.
4. Genotype samples for evidence of local adaptation and/or phenotypic plasticity.

Identifying Climate Adaptive Traits

Traits:

- Aka phenotypes, the detectable physical and physiological traits of an individual, which are determined by its genetic makeup. Also the specific trait associated with a particular allele.

*Recall the definition for *adaptation* (slide #2)

Therefore… Climate adaptive traits are traits that improve the fitness of an individual in response to climate change, i.e. phenotypic changes that have been selected for to help individuals and/or populations persist in the rapidly changing climate.

→ Example: height is trait that varies within tree species, so western larch trees that grow taller naturally may have improved fitness in warmer climates than those trees which aren't as tall; so, we select for tall trees

Identifying Climate Adaptive Traits via Genome Sequencing

- As provenance trials and common garden studies progress, researchers are able to identify morphological differences in their samples, for example, if there are various height differences among samples
- Researchers can use genome sequencing techniques to determine if there are genetic differences between the samples that grow at different heights, i.e. are the genetic instructions in shorter trees different than those in taller trees?
- Genome sequencing is a laboratory technique used to determine the exact sequence of bases (A, C, G, T) in a DNA molecule, i.e. it's a way for researchers to essentially 'fingerprint' a sample and determine its whole genetic makeup to then be able to look for differences between several genomes from several different samples which display morphological variations

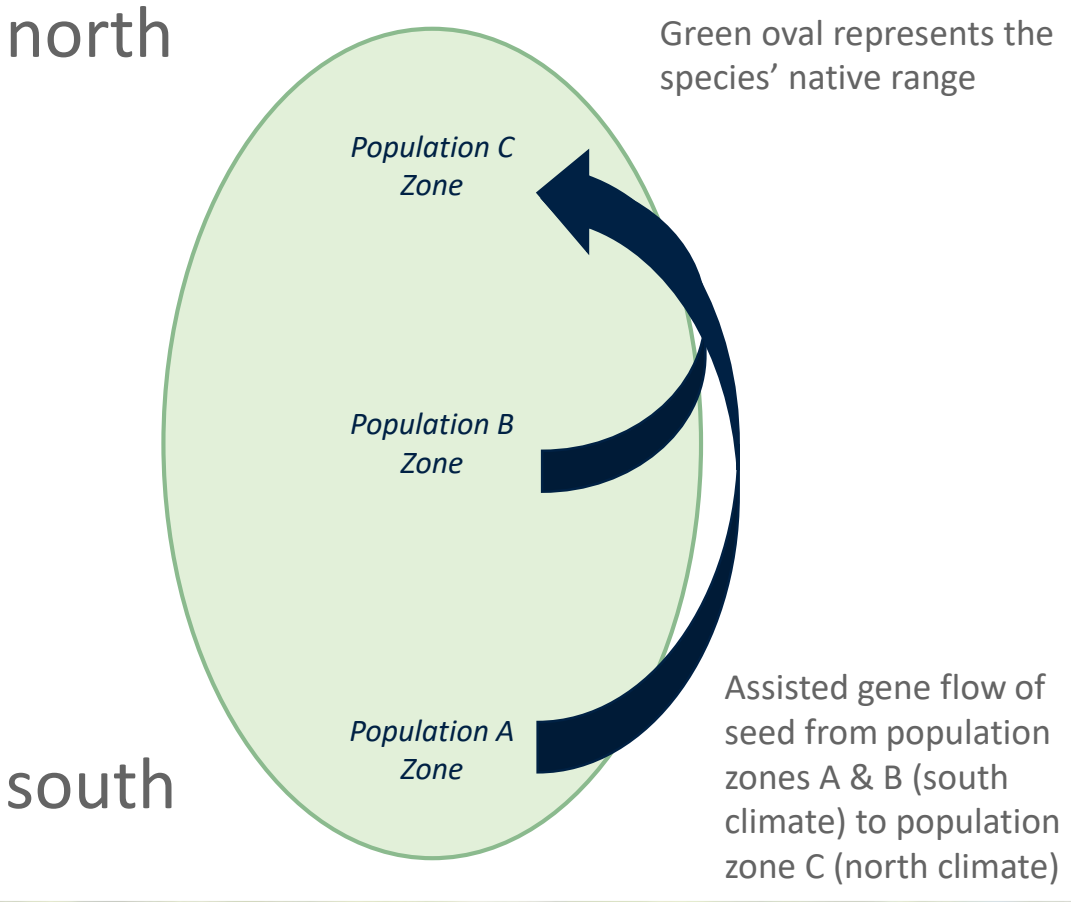
Phenotypic Plasticity

- A different way to understand climate adaptive traits is through the concept of *phenotypic plasticity:*
  - The ability to change phenotype (morphology, behaviour, etc.) due to environmental changes; the expression of a different phenotype by the same genotype in a different environment
  - Example: tree height is controlled by the genotype for height, but in southern populations a tree grows tall, but seeds planted from the southern population in a northern population grow shorter – this phenomenon can be observed in common garden experiments or provenance trials

Assisted Gene Flow

- The managed movement of individuals or gametes between populations within species ranges to mitigate local maladaptation in the short and long term; moving seed **within** its native range.
- Within a species range, planting seed from one population in another population to help a population adapt to a changing climate
    - e.g. planting seed from southern (warmer) populations in northern (colder) populations as northern populations are expected to become warmer as the climate changes

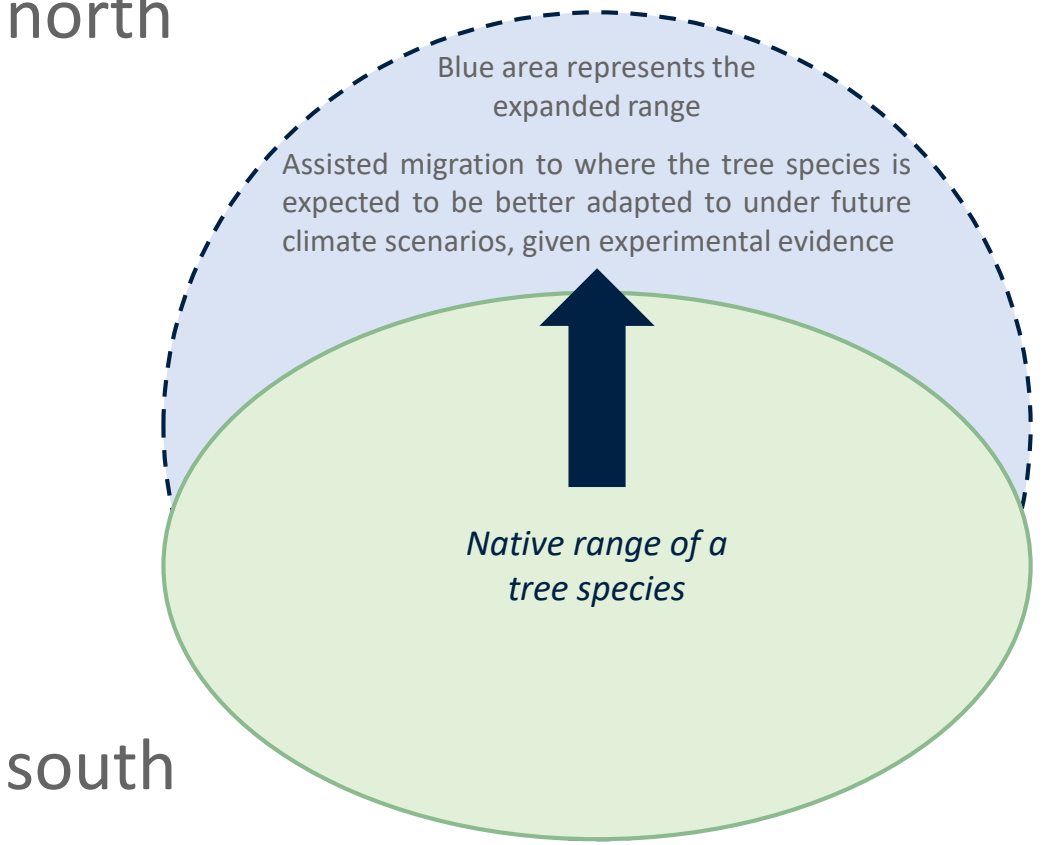
→ Provenance trials can be used to decide if assisted gene flow is a possible forest management action



Assisted Migration

- The human-assisted movement of plants or animals to more climatically suitable habitats
- In a forestry, moving seed **outside** of its native range
- Moving plants/planting seed beyond/outside their current native ranges to facilitate adaptation to a changing climate
    - e.g. planting seedlings further north (colder climate) outside the range as the current northern portion of a species range becomes warmer.

→ Common gardens can be used to decide if assisted migration is a possible forest management action



The Whole Process