Biology 30 – *Forest Genetics in Alberta Case Study*

<u>Gregor Mendel's pea breeding experiments</u> were ideal because he chose an organism that displays **qualitative traits** (traits controlled by one allele, eg. short OR tall, pink OR white) and has a **short life cycle**. That allows selection over multiple generations to occur quite quickly and therefore noticeable changes can develop in a relatively short time.

<u>In Alberta, tree breeding for improvement</u> in growth is an important component of forestry that uses Mendel's genetic concepts as the foundation for creating improved stock for reforestation. Unfortunately, **artificial selection** is never quite as simple as Mendel's, especially when it comes to trees! Trees are incredibly challenging to work with because:

1. They have very **long-life cycles** (80+ years!) so it takes a long time to see the effects!
2. They are **huge** organisms (where do we plant and study them!?)
3. The desired traits are **polygenic** (traits controlled by multiple alleles – which are also called **quantitative traits**). The traits occur on a continuous gradient and because of this, the environment where the tree grows strongly effects how the trait is displayed. Any trait can be selected for as long as the trait is **heritable** (it can be passed from parent to offspring – also known as **progeny**), there is **variation** of the trait in the population and the trait can be **selected** for. We want to develop a new population that either grows bigger in a shorter time period or where all individuals are bigger than average.

Why do we care?

While the majority of tree improvement programs to date are based on selecting trees with increased **wood volume** at harvest and a decreased **rotation period** (the time from this harvest to the next harvest), there is a much more urgent use for tree improvement programs – climate change!

Climate change is very real, and its effects are being felt across Alberta right now. Climate change not only means hotter and drier weather, but also unpredictable weather. Because of their long-life cycles and large size, trees can't get up and move to a cooler and wetter climate while their current environment quickly heats and dries up! Research is showing that trees cannot disperse their seeds far and fast enough to outpace the changing climate.

A mature pine killed by Mountain Pine Beetle in Alberta. Warming temperatures mean that the beetles are spreading east across Canada and outside their native range.

How can we help?

Tree improvement is a division of the forest industry that is using the same basic genetics you've learned to help breed a population of trees that are better adapted to climate change and more resistant to the pests and diseases that accompany it. Depending on the program and species being studied, this involves selecting for drought-tolerant individuals or pest-tolerant individuals, for example, and then planting their progeny in **provenance trials** in areas further south where the climate is warmer to see how well they will do. This testing is used to evaluate the drought tolerance and suitability of both the parent and the progeny. Normally, trees are only planted where they are locally adapted (= they are planted near where the seeds were collected) but climate change is forcing us to test trees in areas where they wouldn't naturally occur (but could survive if they could get there on their own). Forest geneticists are helping trees migrate and adapt in a changing climate.

> <u>For example,</u> we could plant potentially drought-tolerant individuals from the Peace River area down near Calgary where the weather is currently hotter in anticipation of warming temperatures near Peace River. This will help determine which Peace River trees to continue to plant there in the future.

Techniques to decrease the generation time:

Although this is all possible, there is still the problem of long generation times. We can't wait decades for each generation of trees to mature and start producing their own cones before we select for the next generation. That wouldn't be terribly useful. There are techniques being used to decrease the length of each generation:

1. **Grafting – *an ancient and reliable technique!***
   - When a desired tree is selected, branch cuttings (scions) can be grafted onto the rootstock of another tree so that the genetics of the selected tree are maintained but the graft thinks that it is a mature tree and it will begin producing cones or fruit immediately.
2. **Genomic Selection – *new and exciting research in tree improvement!***
   - Training populations are used to collect both phenotypic (observed) traits and the genotype that underlies them. Once correlations are made between the phenotype and genotype, early selection of superior genotypes can be made which will improve the efficiency of field testing by reducing the time require for the completion of a cycle of genetic improvement from 13-20 years to 2-5 years. There are lots of interesting opportunities here!

How does it work?

1. **Parent trees** are selected from the forest. Seeds are collected from the biggest, tallest, straightest, most drought resistance…etc trees they can find.
2. To remove (or at least minimize!) any environmental effects, offspring from the parent trees (known as **progeny** in this case) are planted in a **"common garden"** setting (imagine a flat, farm field). Testing the progeny will allow the geneticists to understand which parent trees were only big because they grew on a particularly good site and which trees were doing okay but were on a terrible site.
3. Over the years the progeny are measured regularly and **Breeding values (BV)** are calculated to rank the wild parents based on their offspring's performance relative to the average of all offspring in the progeny trial. The best parents are bred with each other in hopes of producing even better offspring from the crosses.
4. Eventually the ultimate trees will be selected. Those parent trees will be propagated, and their seeds will be used to grow millions of adapted seedlings to be planted for reforestation in the local area.
5. This process is repeated with different species in different areas to create many locally adapted genotypes.

The uniform "common garden" setting of a progeny trial in Alberta. Here, a field technician is measuring the height of the progeny to gain information about the parents of these trees.

Case Study: Breeder's equation

Geneticists use a formula called the Breeder's equation to predict the changes they expect to see in the next generation after a round of selection. For trees, the **response to selection (R)** is measured in terms of height gain. We want to maximize this gain every generation.

Response to Selection = Selection differential x Heritability

$$R = S \times h^2$$

As breeder's, we have control over the **selection differential (S),** which is the difference between the mean of the whole parent population and the mean of the individuals selected for breeding. If the difference is larger, that means that we are selecting a small proportion of the parents (the very best individuals), whose mean height differs widely from the whole. If the difference is smaller, that means that we are selecting a larger portion of the population with a mean closer to the whole.

We do **NOT** have control over the **heritability (h^2)** of the trait. It varies from 0 to 1 and it represents the fraction of the variation of that trait that can be attributed to genetics. If the trait is 100% heritable, it will have a value of 1 and it is likely a **qualitative** trait like eye colour which has no environmental effect. Tree height is **quantitative,** and it varies based on both genetics and the environment. Therefore, we must make assumptions about the heritability based on previous research.

Question: A tree breeder already has an orchard where the progeny from previously selected trees are growing. From these, the breeder wants to select the best and tallest trees to breed together to create a new generation of even taller trees. The average height of the whole orchard is 13 metres. If heritability of height is assumed to be 0.5 and constant, the breeder can vary the **Selection Differential (S).**

Option 1) She could select a variety of good and elite individuals with an average height of 15m?

S =15m – 13m = 2m

$R = S \times h^2$ then **R = 2m x 0.5 = 1m**

The response to selection is 1m, so she can expect the next generation of trees to **be 13m + 1m = 14m tall on average**

Option 2) She could select only elite (=very tall) individuals with an average height of 17m?

S =19m – 13m = 6m

$R = S \times h^2$ then **R = 6m x 0.5 = 3m**

The response to selection is 2m, so she can expect the next generation of trees to be 13m + 3m = **16m tall on average. This sounds like the better option!** ***What's the potential problem with this strategy??***

Ideally, we want higher heritability (as close to 1 as possible) as this results in higher gains. Although we can't control this directly, we can eliminate as much environmental variation as possible by planting them in "common gardens" before we make our selections so that only genetic differences shine through. We can also increase the response to selection (R), as we did in this example, by selecting only elite individuals that differ even more from the group mean. Potential Problem: **Although this may very well increase the gain in the next generation, it means that less variable individuals (= a smaller effective population size) are selected and therefore the incidence of inbreeding is more likely.**

If you want to learn more…

- Alberta Agriculture and Forestry. 2018. Tree Improvement and Adaptation. https://www.agric.gov.ab.ca/app21/forestrypage?cat1=Forest%20Health%20and%20Adaptation&cat2=Tree%20Improvement%20and%20Adaptation

- Alberta Environment and Parks. 2013. Four-part series about reforestation in Alberta. https://albertaep.wordpress.com/2013/08/19/clones-bunkers-and-banks-the-complex-science-behind-preserving-albertas-forests/

If you want to see it all in person, arrange a field trip to the **Alberta Tree Improvement & Seed Centre (ATISC)** and the **Smoky Lake Tree Nursery** in Smoky Lake, Alberta (two hours north east of Edmonton). Here you can see everything including the provincial seed bunker, examples of grafting, progeny trials, seed orchards, seedling nursery and more!