



THE UNIVERSITY
of EDINBURGH



Biotechnology and
Biological Sciences
Research Council



THE ROYAL
SOCIETY

Response to Selection

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2025-01-30



Learning objectives

Lecture

- Refresh The Response to Selection Theory
- Components of the Breeder's Equation

Practical

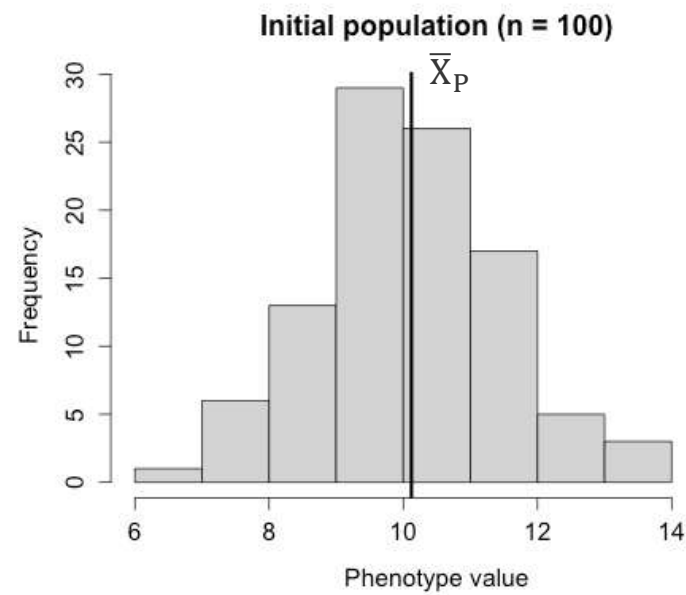
- Simulate Response to Selection of a Single Trait in AlphaSimR

Selective breeding

- **Selection:** Superior individuals with desirable traits are chosen to be the parents of the next generation.
- **Mating:** The selected individuals are then crossed and their offspring inherit the desired traits from their parents.
- **Repeat:** The process repeated over multiple generations to increase the performance of desired traits.

Response to selection to measure or predict the change in performance of traits from one generation to the next.

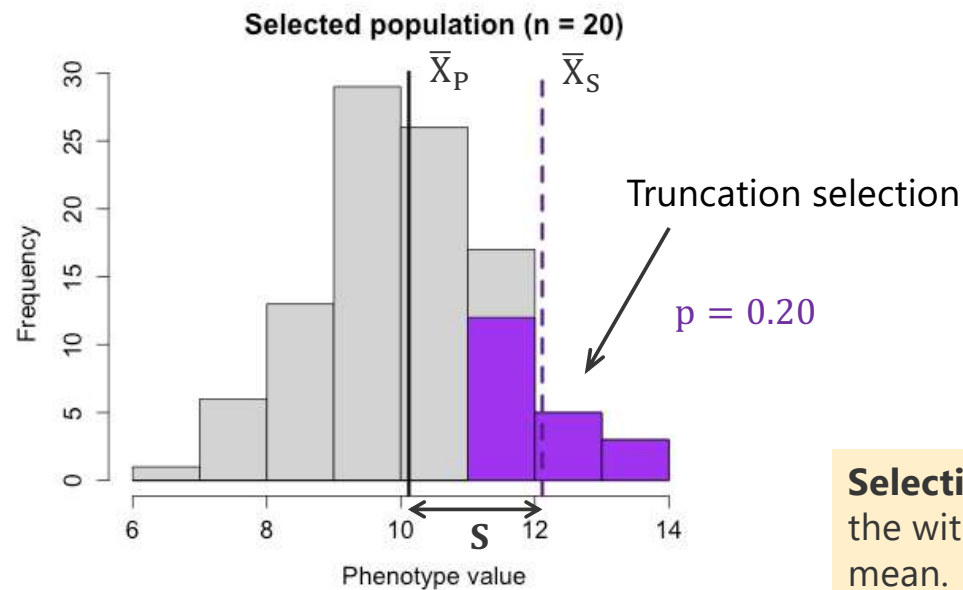
Response to selection



$$\bar{X}_P = 10.12$$

mean of the population

Response to selection: selection



Selection differential measures the within-generation change in mean.

$$\bar{X}_P = 10.12$$

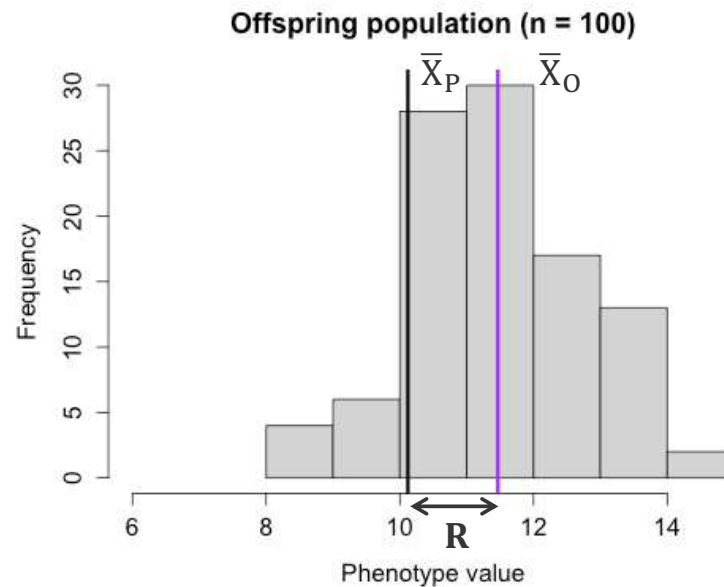
mean of the population

$$\bar{X}_S = 12.11$$

mean of the selected individuals

$$S = \bar{X}_S - \bar{X}_P = 1.99 \text{ selection differential}$$

Response to selection: mating



Response to selection measures the between-generation change in mean.

$$\bar{X}_P = 10.12$$

mean of the population

$$\bar{X}_S = 12.11$$

mean of the selected individuals

$$S = \bar{X}_S - \bar{X}_P = 1.99$$

selection differential

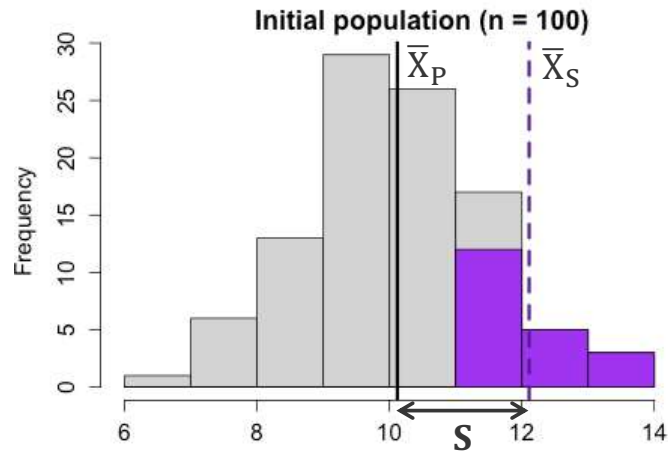
$$\bar{X}_O = 11.46$$

mean of the offspring population

$$R = \bar{X}_O - \bar{X}_P = 1.34$$

response to selection

Response to selection



$$\bar{X}_P = 10.12$$

mean of the population

$$\bar{X}_S = 12.11$$

mean of the selected individuals

$$S = \bar{X}_S - \bar{X}_P = 1.99$$

selection differential

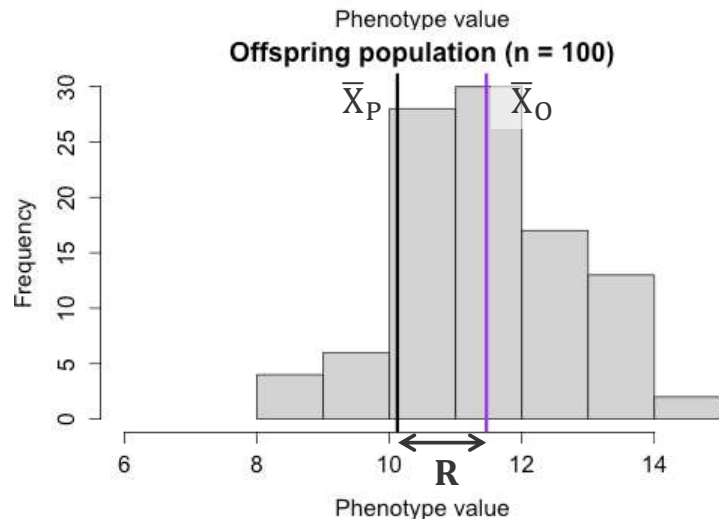
$$\bar{X}_O = 11.46$$

mean of the offspring population

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response to selection

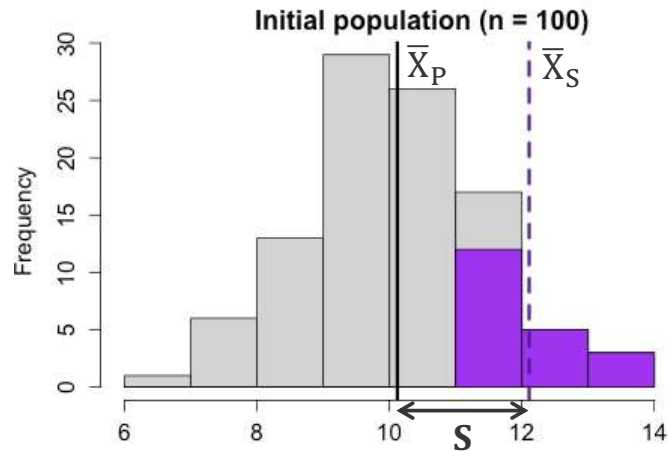
Typically, $\bar{X}_S > \bar{X}_O > \bar{X}_P$



$$\bar{X}_O > \bar{X}_P$$

- Some selected parents have favourable genotypes and pass favourable alleles to their offspring

Response to selection



$$\bar{X}_P = 10.12$$

mean of the population

$$\bar{X}_S = 12.11$$

mean of the selected individuals

$$S = \bar{X}_S - \bar{X}_P = 1.99$$

selection differential

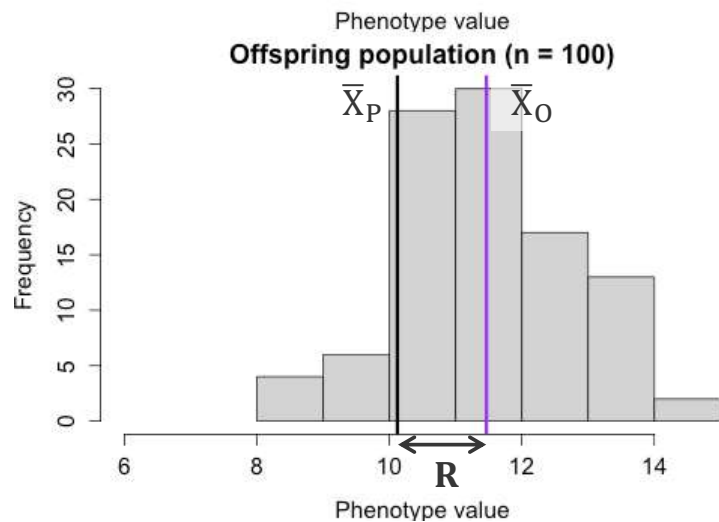
$$\bar{X}_O = 11.46$$

mean of the offspring population

$$R = \bar{X}_O - \bar{X}_P = 1.34$$

response to selection

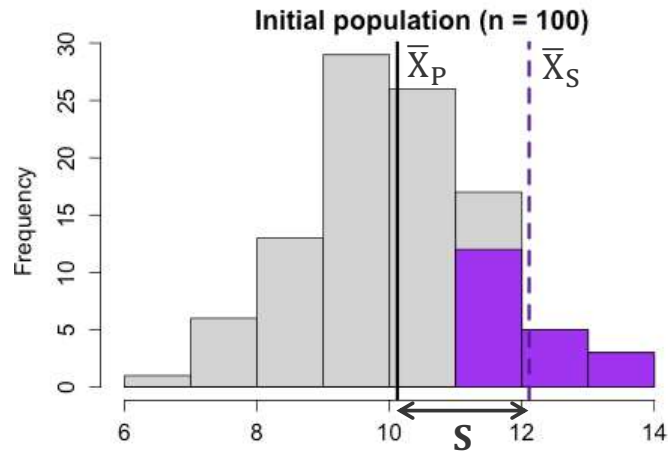
Typically, $\bar{X}_S > \bar{X}_O > \bar{X}_P$



$$\bar{X}_O < \bar{X}_S$$

- Some selected parents do not have favourable genotypes and their good phenotypes result from a favourable environment.
- Alleles, not genotypes, are transmitted and good genotypes are disrupted by Mendelian sampling and recombination.

Response to selection



$$\bar{X}_P = 10.12$$

mean of the population

$$\bar{X}_S = 12.11$$

mean of the selected individuals

$$S = \bar{X}_S - \bar{X}_P = 1.99$$

selection differential

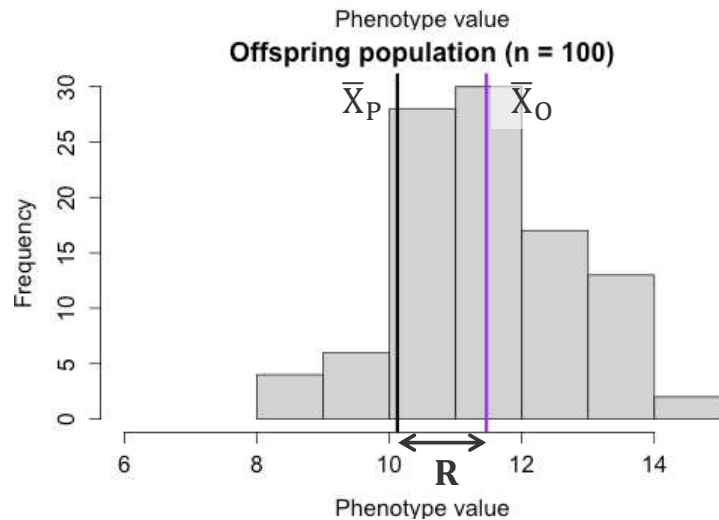
$$\bar{X}_O = 11.46$$

mean of the offspring population

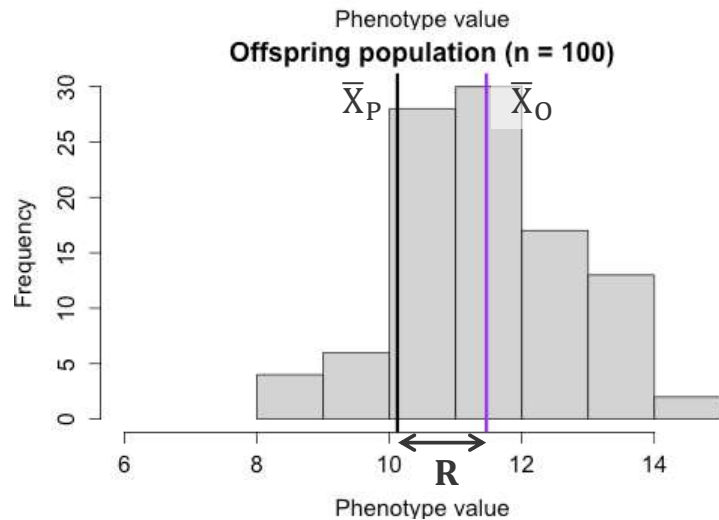
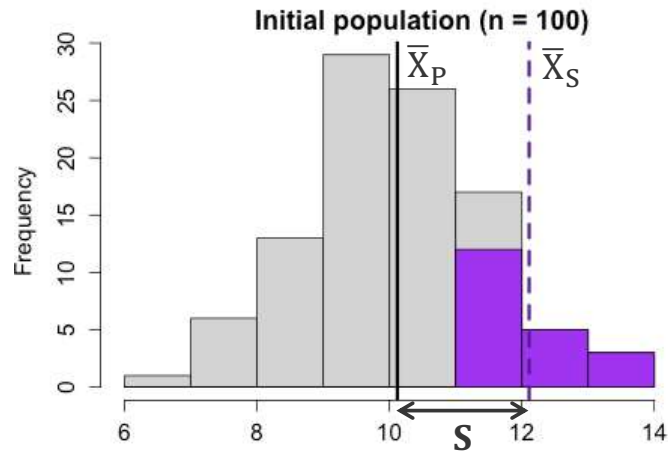
$$R = \bar{X}_O - \bar{X}_P = 1.34$$

response to selection

$$\bar{X}_O = 10.12 + 1.34 = 11.46$$



Response to selection



$$\bar{X}_P = 10.12$$

mean of the population

$$\bar{X}_S = 12.11$$

mean of the selected individuals

$$S = \bar{X}_S - \bar{X}_P = 1.99$$

selection differential

$$\bar{X}_O = 11.46$$

mean of the offspring population

$$R = \bar{X}_O - \bar{X}_P = 1.34$$

response to selection

$$\bar{X}_O = 10.12 + 1.34 = 11.46$$

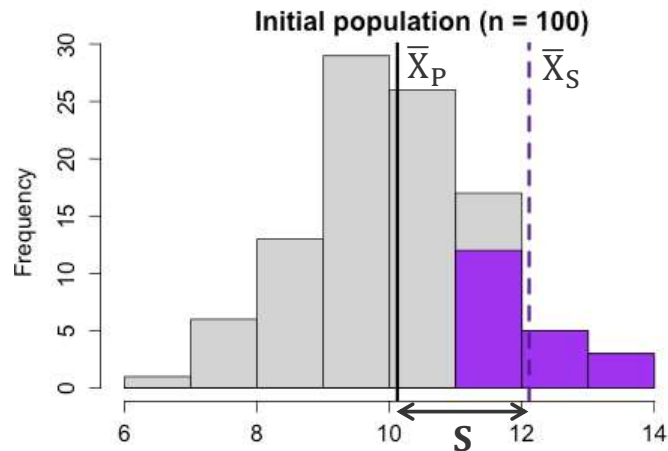
$$\bar{X}_O = \bar{X}_P + R = \bar{X}_P + h^2 S$$

$$R = h^2 S$$

h^2 is the proportion of S that gets transmitted to the next generation.

S is a measure of selection, R the actual response. One can get lots of selection but no response.

Effect of selection on variance

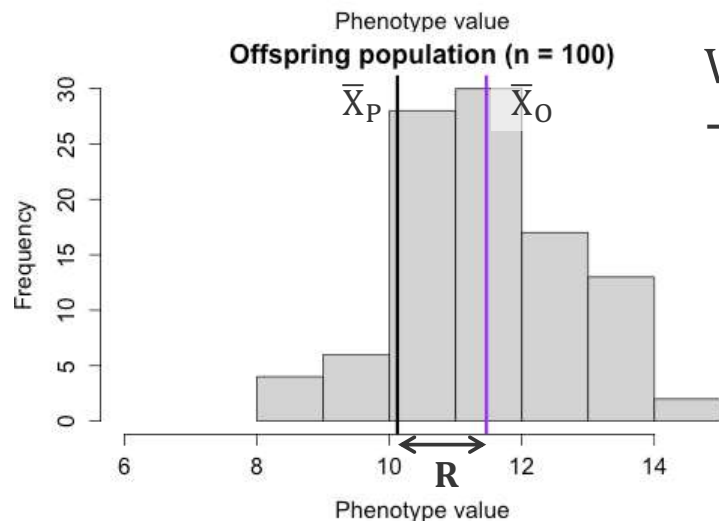


$V_{P_P} = 1.96$ variance of the parental population

$V_{P_S} = 0.50$ variance of the selected population

→ Variance of selected individuals is reduced by factor k

$$V_{P_S} = (1 - k)V_{P_P}, \text{ where } k = i(i - x) \text{ (Bulmer, 1971)}$$



$V_{P_O} = 1.60$ variance of the new population

→ Variance partially recovered in a new population by Mendelian sampling and recombination among offspring

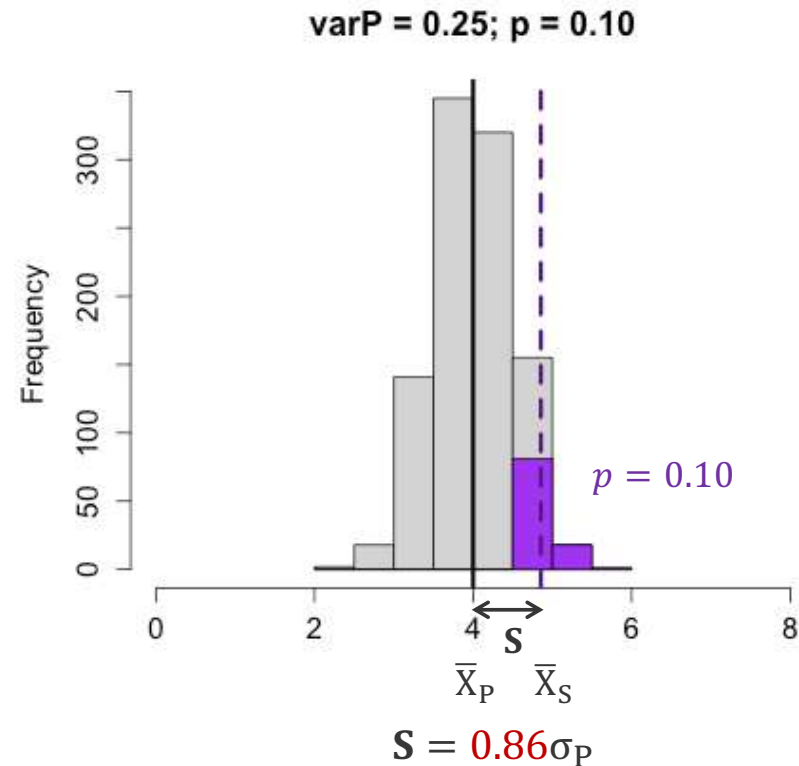
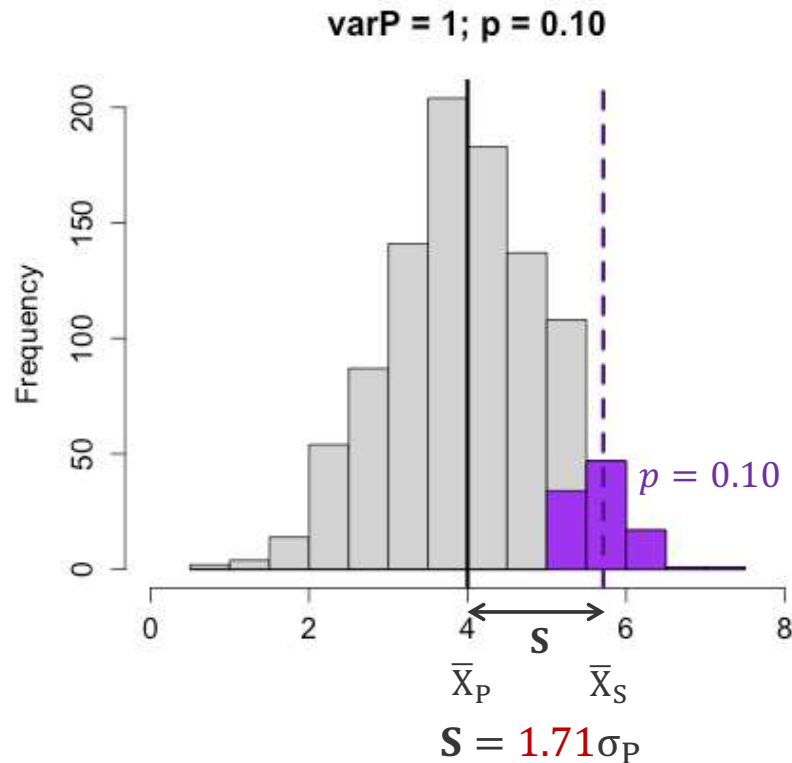
$$V_{P_O} = (1 - 1/2h^4k)V_{P_P}$$

Selection differential

Selection differential is a function of

- the trait variability, and
- the proportion of individuals selected.

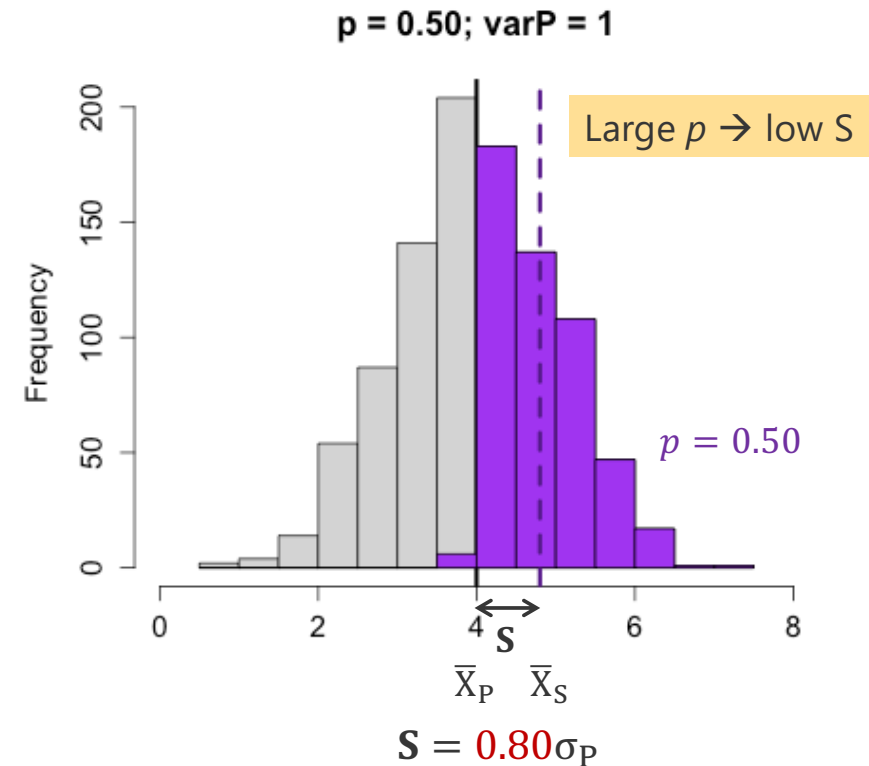
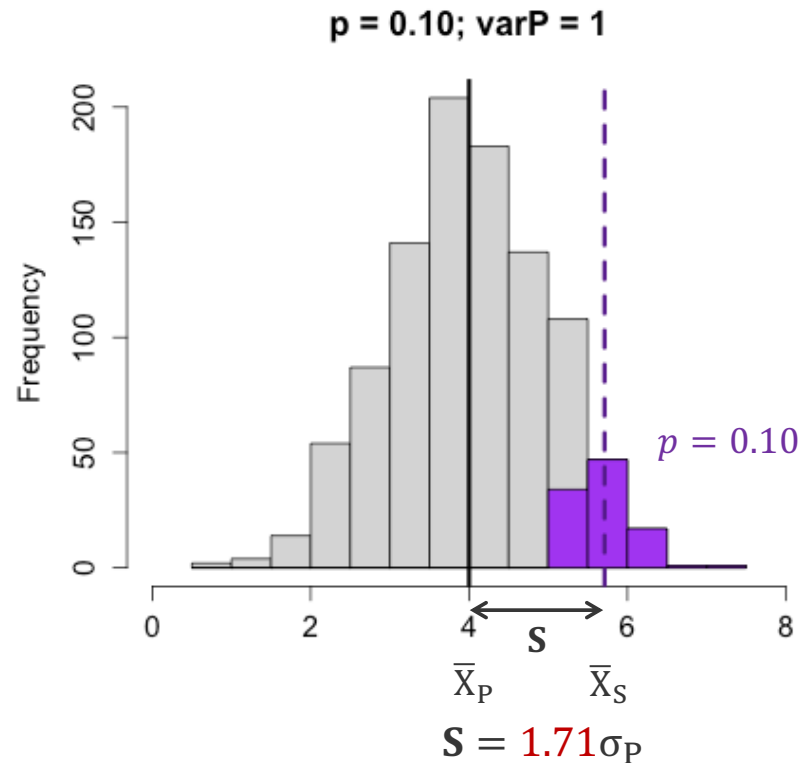
Selection differential: variability of the trait



$$i = (\bar{X}_S - \bar{X}_P) / \sigma_P = S / \sigma_P \rightarrow \mathbf{S = i\sigma_P}$$

Selection intensity = how many standard deviations the mean of selected individuals is away from the population mean.

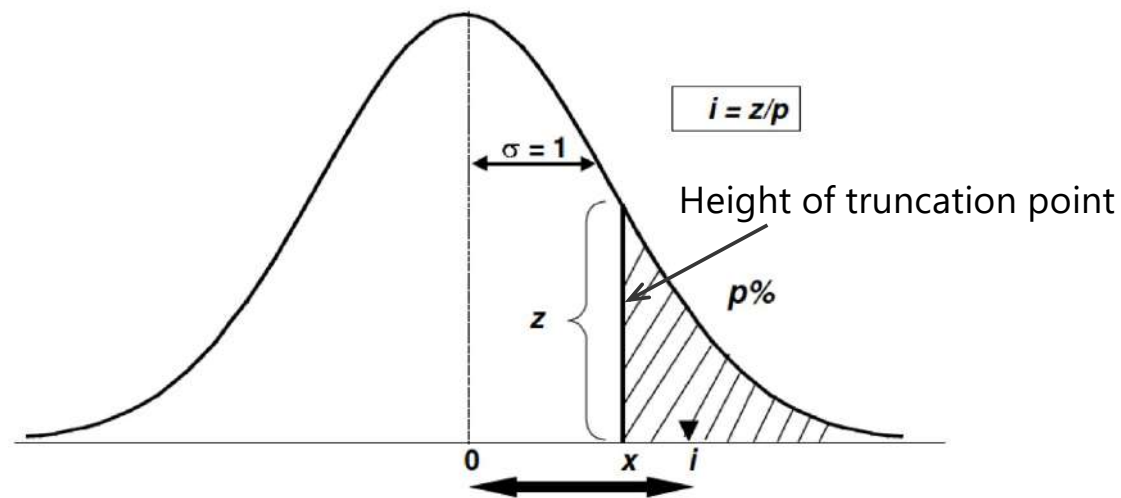
Selection differential: proportion of selected



$$\mathbf{i} = (\bar{X}_S - \bar{X}_P)/\sigma_P = S/\sigma_P \rightarrow \mathbf{S} = \mathbf{i}\sigma_P = \mathbf{(z/p)}\sigma_P$$

The proportion of selected individuals can be translated into **expected selected intensity** (assuming the trait is normally distributed).

Selection differential: proportion of selected



In R command: $i = \text{dnorm}(\text{qnorm}(1 - p))/p$

$$i = (\bar{X}_S - \bar{X}_P)/\sigma_P = S/\sigma_P \rightarrow S = i\sigma_P = (z/p)\sigma_P$$

Expected selection intensity = allows a breeder to choose an expected value of i before selection to calculate an expected gain

The Breeder's Equation

$$R = h^2 S = h^2 i \sigma_P = h^2 (z/p) \sigma_P$$

The Breeder's Equation

We can express h^2 in terms of accuracy

$$R = h^2 S = h^2 i \sigma_P = h^2 (z/p) \sigma_P$$



$$R = b_{AP} i \sigma_P$$



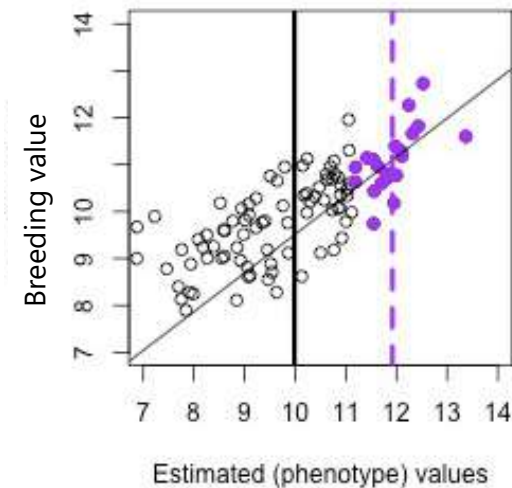
$$R = \frac{r\sigma_A}{\cancel{\sigma_P}} i \cancel{\sigma_P}$$



$$R = ri\sigma_A$$

$$h^2 = b_{AP} = \frac{r\sigma_A}{\sigma_P}$$

$$a = \bar{x} + b_{AP}x + e, \text{ where } b_{AP} = h^2$$



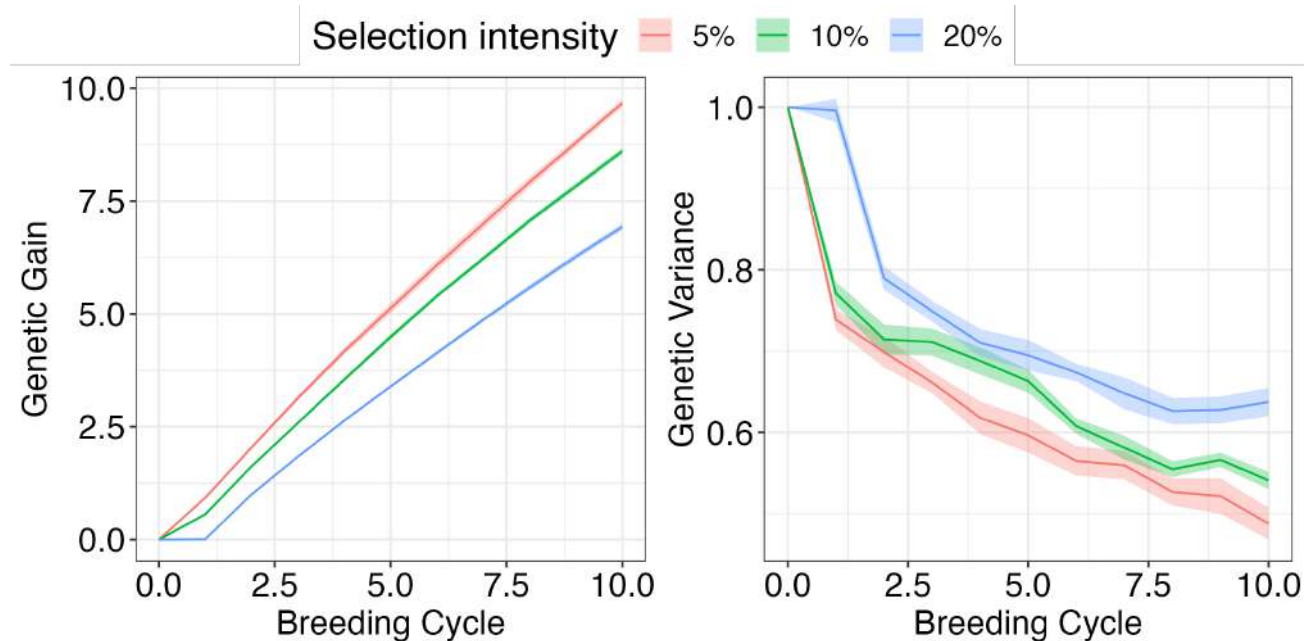
The Breeder's Equation – *key drivers of selection*

$$\Delta G = \frac{ir\sigma_A}{L} \text{ (Lush, 1937)}$$

i	selection intensity
r	accuracy of selection
σ_A	genetic variance
L	generation interval
ΔG	expected gain per unit of time

Selection intensity (i)

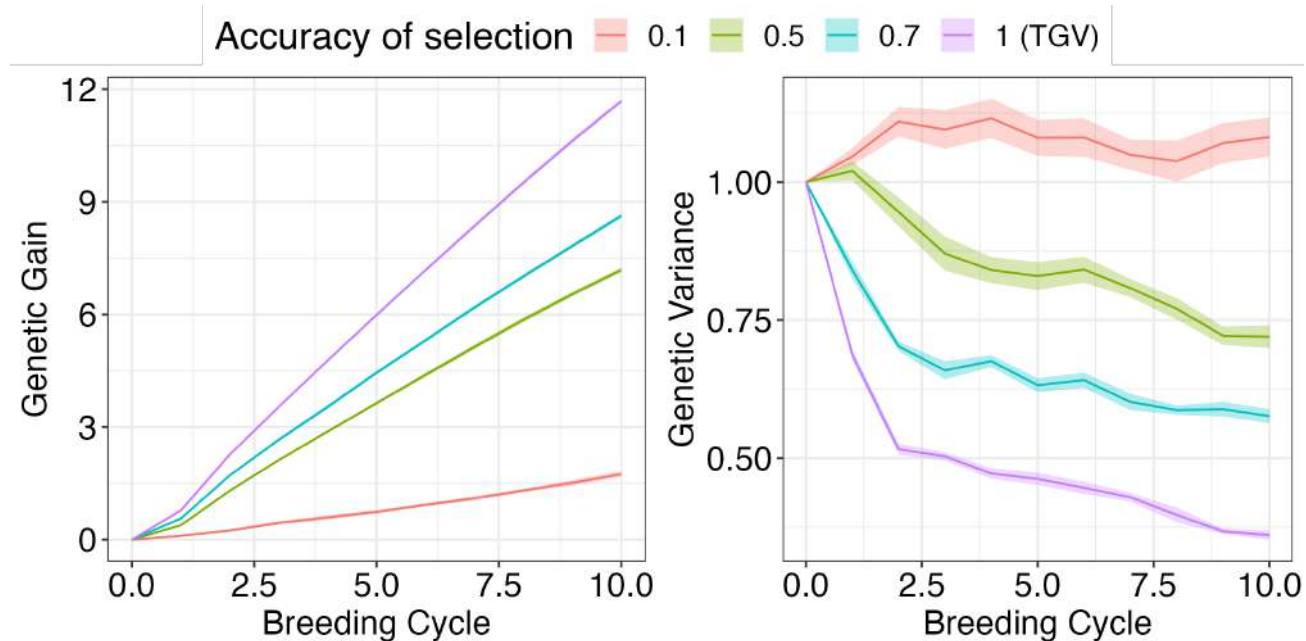
higher intensity \rightarrow more gain, more inbreeding, more genetic variance loss



Increase i : genotype more individuals without phenotypes

Accuracy of selection (r)

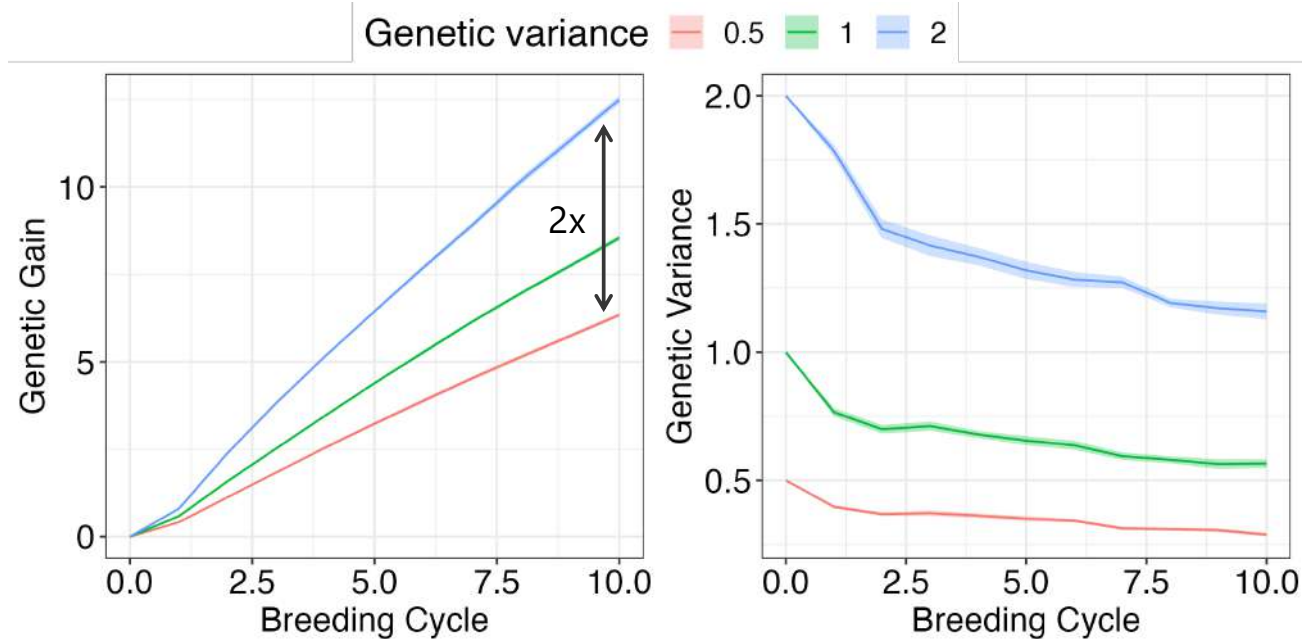
higher accuracy \rightarrow more gain, more inbreeding, more genetic variance loss



Increase r : more information, indirect selection, good phenotypes, good experimental design, kinship information

Genetic variance (σ_A)

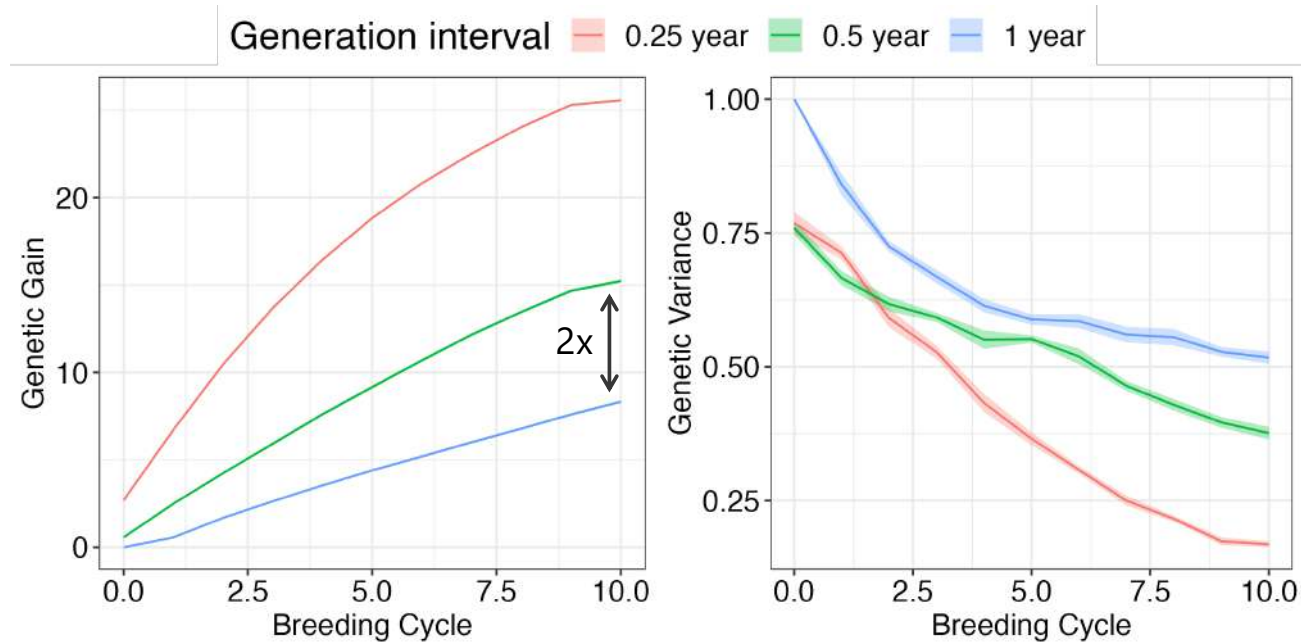
higher genetic variance \rightarrow more gain



Maintain σ_A : minimising inbreeding, introgression of new genetic material (\downarrow mean)

Generation interval (L)

increased generation interval → increase in response, more inbreeding, more genetic variance loss



Increase L: early genotype selection (with/without phenotypes), make crosses ahead of results, out of season nurseries

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Practical

Work through `08_Selection_single_trait.Rmd`



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