Quantitative Genetics (2)

LECTURE 6: BROAD AND NARROW HERITABILITY & ADAPTIVE POTENTIAL

2022

Previous Lecture

- Quantitative traits are characterised by **H^2**
- Estimates partition the relative effects of environmental variation (VE) and genetic variation (VG) on differences in a phenotype (VP) *within a population*.

  $$VP = VG + VE$$

  $$H^2 = VG / VP$$

- Can estimate the influence of genes just by studying the phenotype
- Non-additivity (GxE interaction)

  $$VP = VG + VE + V_{GxE}$$

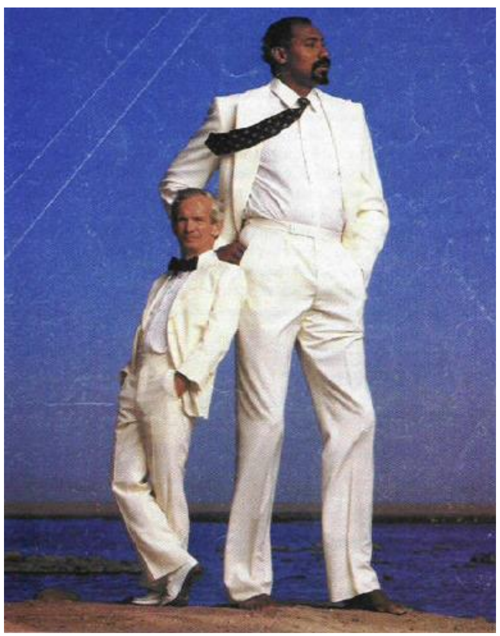
  $$H^2 = VG / VP$$

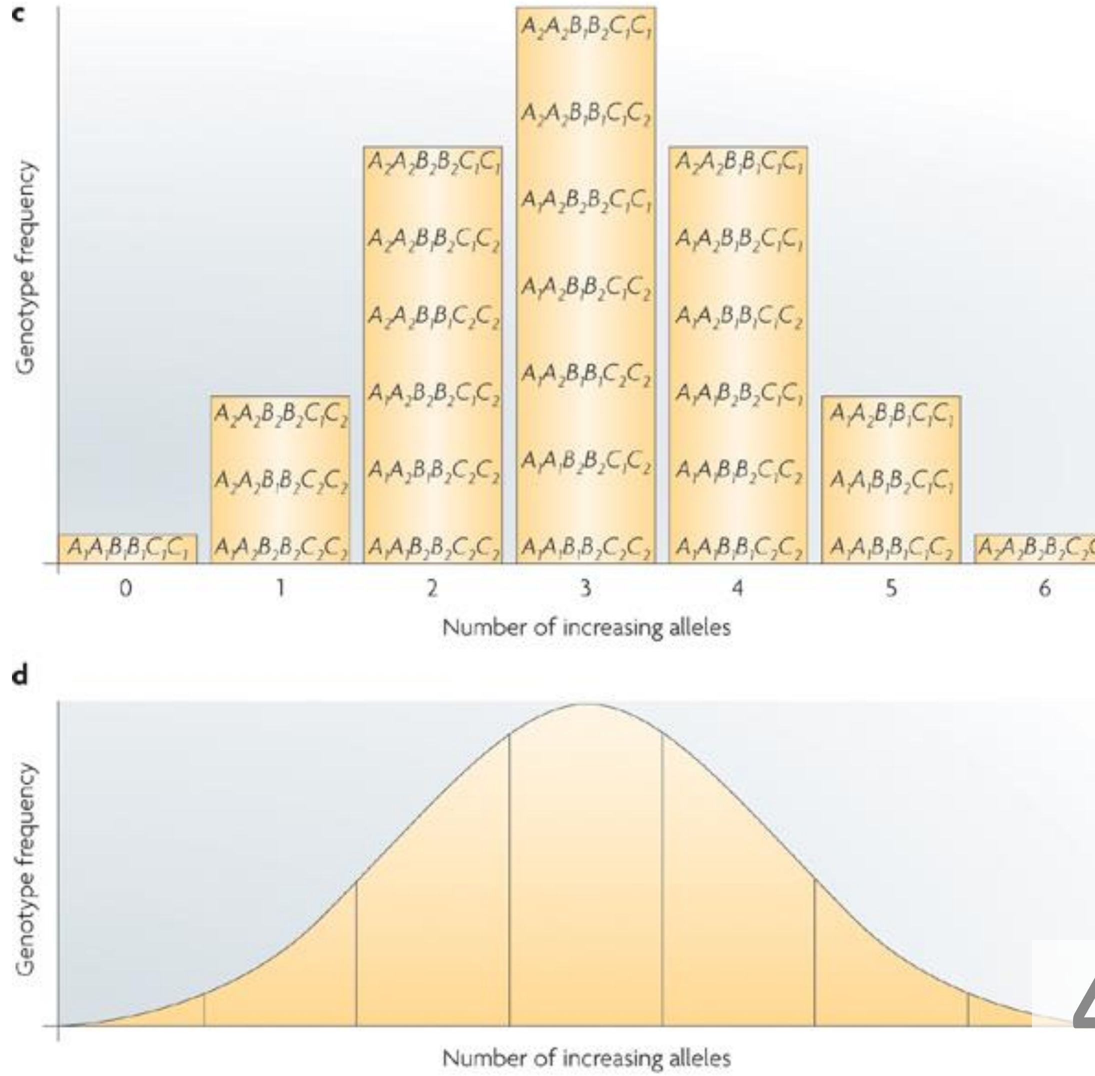
Lecture Outline

- Types of Genetic Variance
- Broad and Narrow Heritability
- Estimation of H^2 and h^2 via Regression
- Heritability and Adaptive Potential
- Estimation of Adaptive Potential (breeders equation)

Types of Genetic Variance

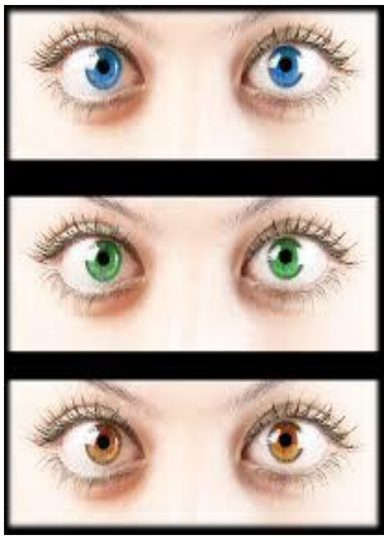
Remember that VG is a cumulative effect of many Mendelian interactions…



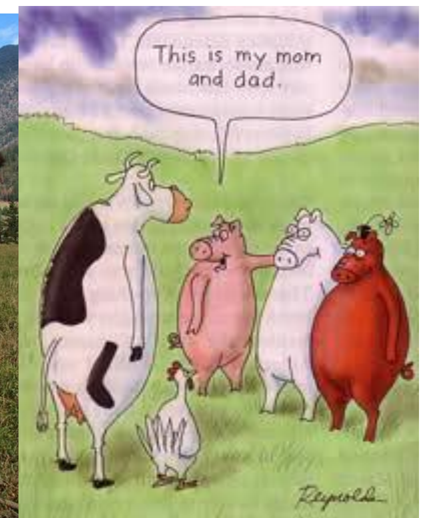


Varieties of Mendelian Genetics

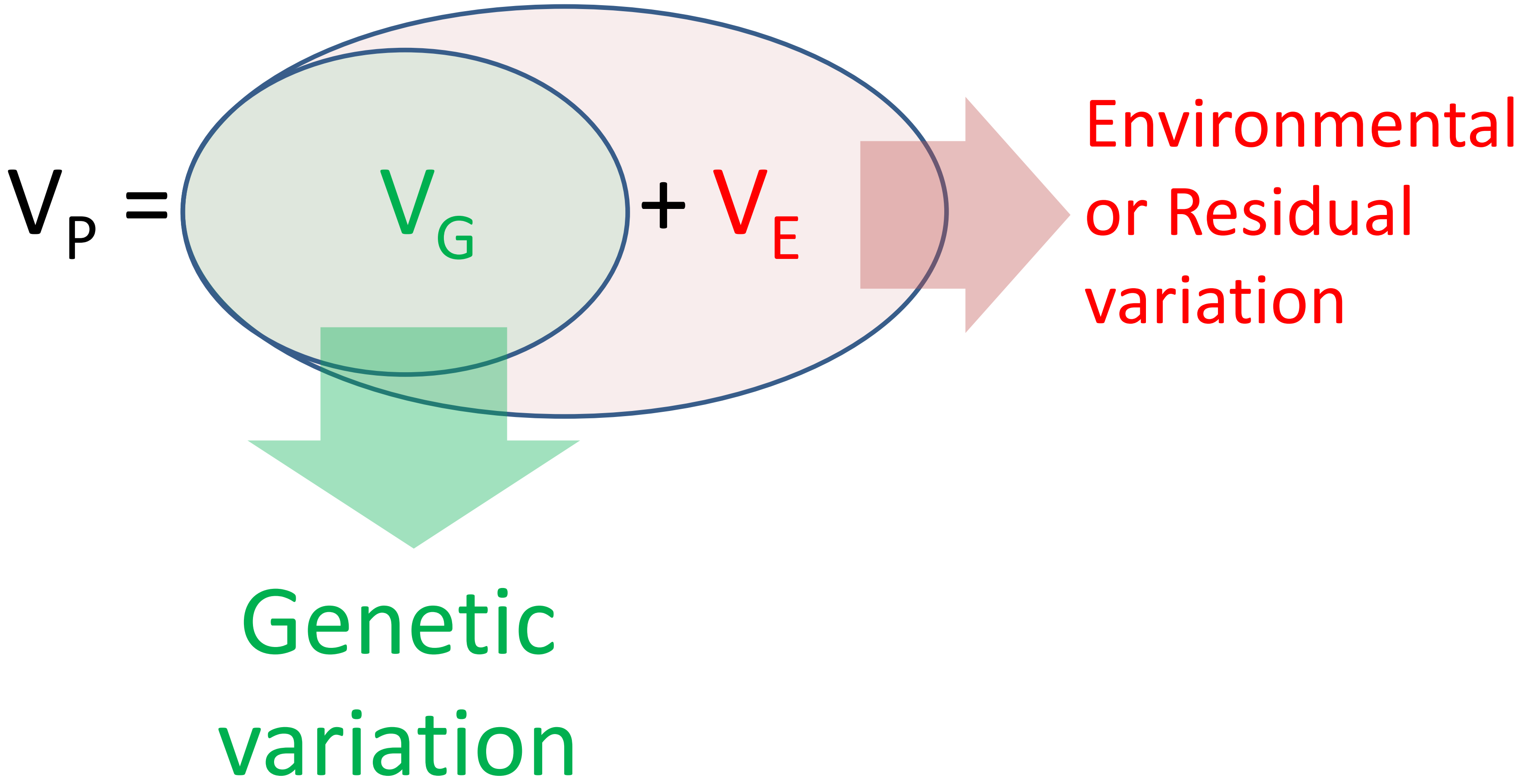
1. <u>Dominance</u>: interaction of alleles at a single loci
2. <u>Epistasis</u>: interaction of alleles at different loci
3. <u>no interaction</u> of alleles or loci



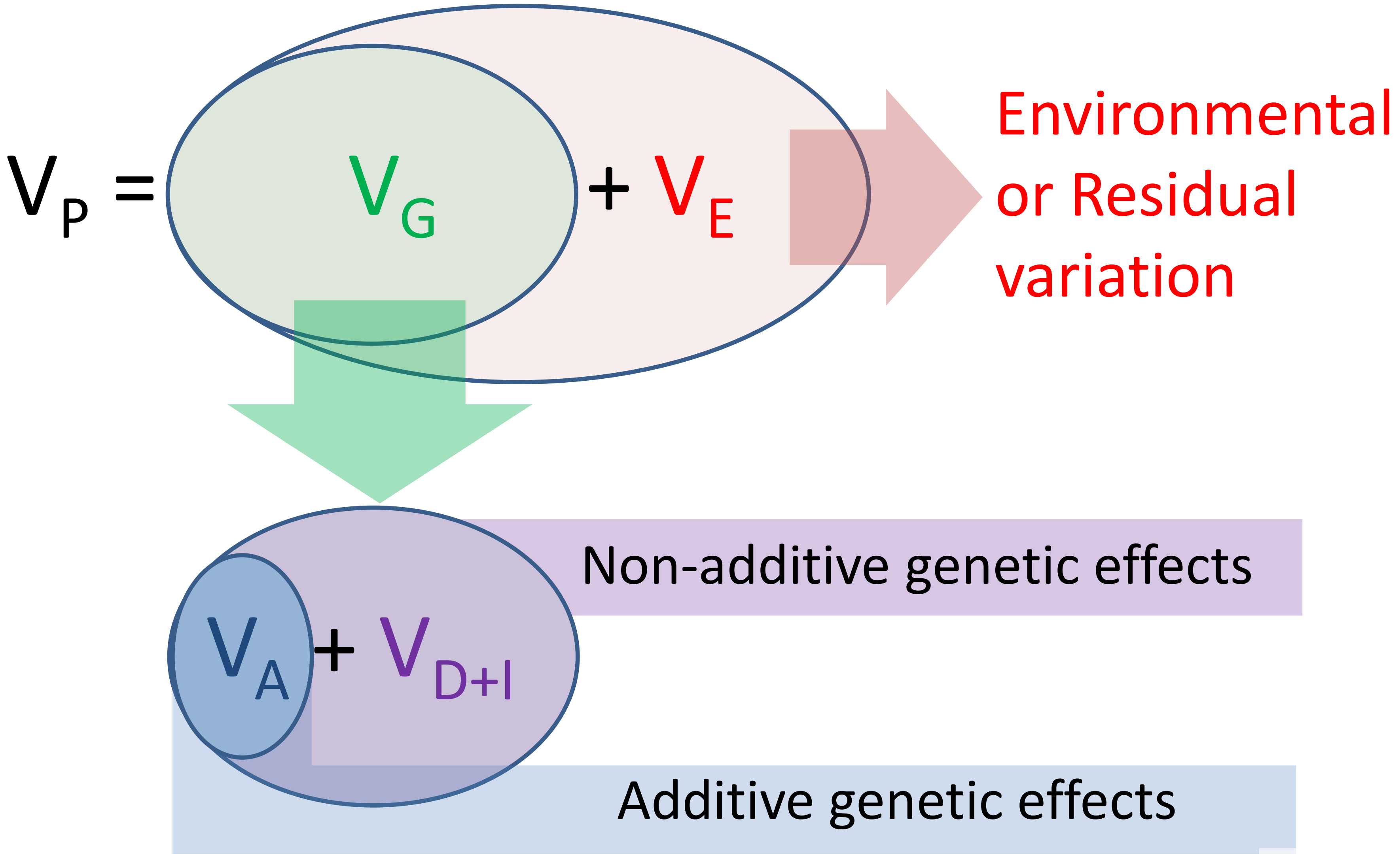
HERC2	*Gey*	Eye Color
BB	GG	**Brown**
BB	Gb	**Brown**
BB	bb	**Brown**
Bb	GG	**Brown**
Bb	Gb	**Brown**
Bb	bb	**Brown**
bb	GG	**Green**
bb	Gb	**Green**
bb	bb	**Blue**



Variance partitioning



Variance partitioning



Variance partitioning

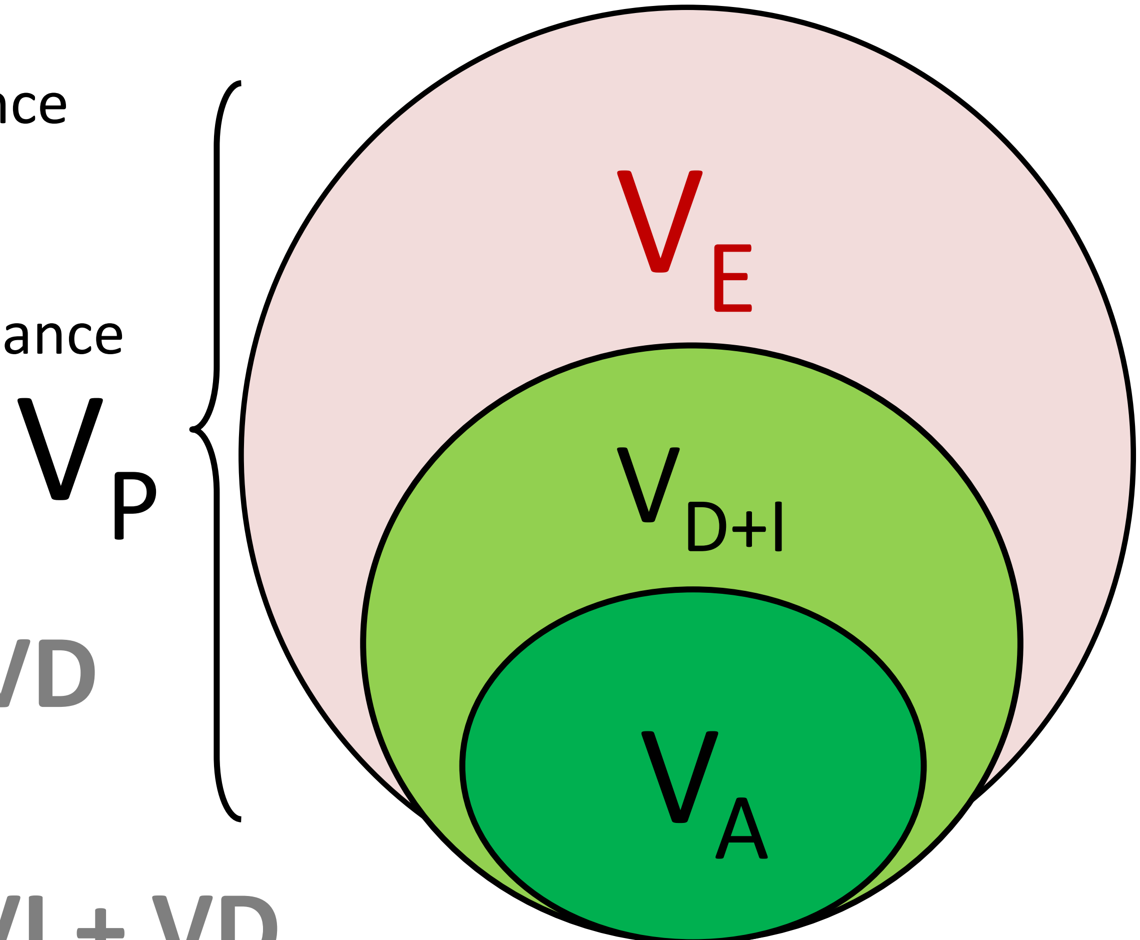
Phenotypic variance: $V_P = V_G + V_E$

Genetic variance (V_G) = $V_A + V_{D+I}$

Overall: $V_P = [V_A + V_{D+I}] + V_E$

Types of Genetic Variance

VP = Phenotypic Variance
VE = Environmental Variance
VD = Dominance Variance
VI = Epistatic Variance
VA = Additive Genetic Variance



VG = VA + VI + VD

VP = VE + VG

VP = VE +VA + VI + VD

Why partition different types of genetic variance?

Different types of genetic variance can be used to estimate <u>different types of heritability</u>

<u>VD + VI:</u>

- phenotypic consequences are all visible at the next generation
- "refresh" each generation
- Not consistently inherited

Used often for psychological traits: we just want to know which is doing more causal work: genes or environment

Broad Heritability (H^2) = VG / VP

VG = VD + VI + VA

Why partition different types of genetic variance?

Different types of genetic variance can be used to estimate <u>different types of heritability</u>

<u>VA:</u>

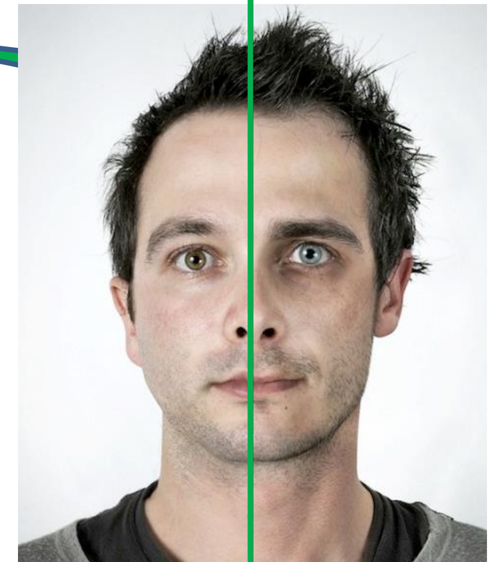
- phenotypic consequences are all visible at the next generation *and at subsequent generations*
- Phenotypic Effects always visible to selection pressures
- Consistently inherited

Used to forecast the evolution of traits over longer time scales: Multiple generations

Can inform us about the 'evolvability' of trait

Narrow Heritability (h^2) VA / VP

$$V_P = [V_A + V_{D+I}] + V_E$$



Sibling A | Sibling B

$$V_P = [V_A + V_{D+I}] + V_E$$

Parent | Offspring

$$V_P = [V_A + V_{D+I}] + V_E$$

$$H^2 = \frac{V_G}{V_P}$$

Broad sense heritability

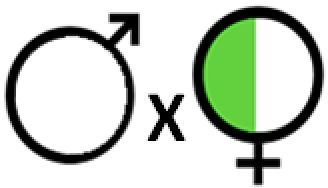
$$V_P = [V_A + V_{D+I}] + V_E$$

$$h^2 = \frac{V_A}{V_P}$$

Narrow sense heritability

Additive effects model

Quantitative genetic basis of phenotypic “greeness”…



Mid-parent value

Mean Parental Phenotype

$\boxed{0.25}$

Sire	Dam
--	-+
--	++
--	--
--	++
--	+-
--	-+
--	+-
--	--
--	-+
--	+-

Sire	Dam
20 -	10 +
	10 -

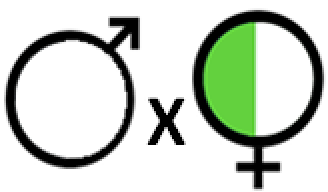
Greeness hypothetically measured from 0 - 1.

Decided by genes at
10 diploid loci
= 10 “on/off” switches

Regardless of genomic position,
+ = more green
- = less green

Additive effects model

Quantitative genetic basis of phenotypic “greeness”…

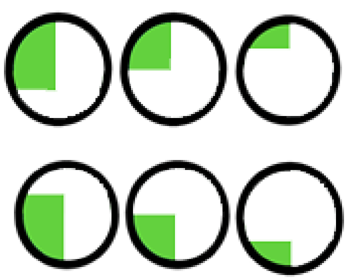


Mean Parental Phenotype

0.25

Sire	Dam
--	-+
--	++
--	--
--	++
--	+-
--	-+
--	+-
--	--
--	-+
--	+-

Sire	Dam
20 -	10 +
	10 -



Family 1

Mean offspring Phenotype

0.25

Offspring average

15 - 5 +

For each offspring:

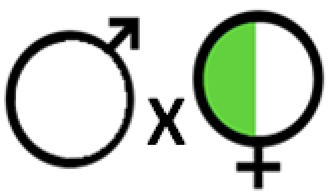
Half (10) genes from father
Other half from mother

Here,
All paternal genes “off” for greeness
50 % of maternal genes “off”

Average of 5 (25%) “on” genes per offspring = 0.25 greeness

Additive effects model

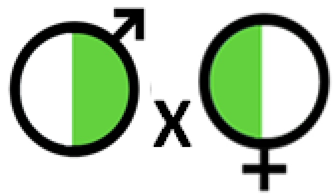
Quantitative genetic basis of phenotypic “greeness”…



Mean Parental Phenotype

0.25

Mid-parent value

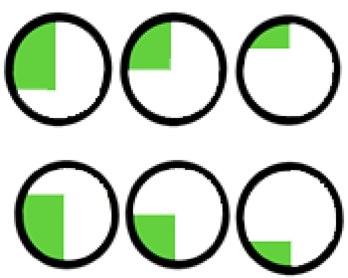


Mean Parental Phenotype

0.50

Sire	Dam
-+	-+
--	++
++	--
-+	++
+-	+-
-+	-+
--	+-
++	--
--	-+
++	+-

Sire	Dam
10 +	10 +
10-	10 -



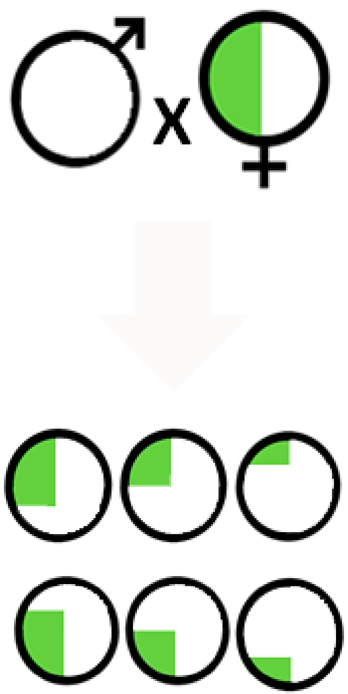
Family 1

Mean offspring Phenotype

0.25

Additive effects model

Quantitative genetic basis of phenotypic “greeness”…



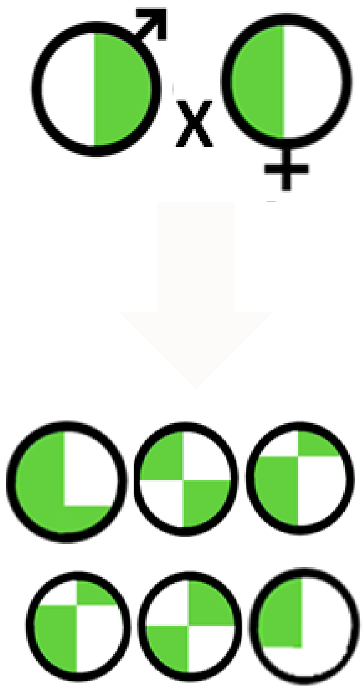
Mean Parental Phenotype

0.25

Mean offspring Phenotype

0.25

Family 1



Mean Parental Phenotype

0.50

Mean offspring Phenotype

0.50

Family 2

Sire	**Dam**
-+	-+
--	++
++	--
-+	++
+-	+-
-+	-+
--	+-
++	--
--	-+
++	+-

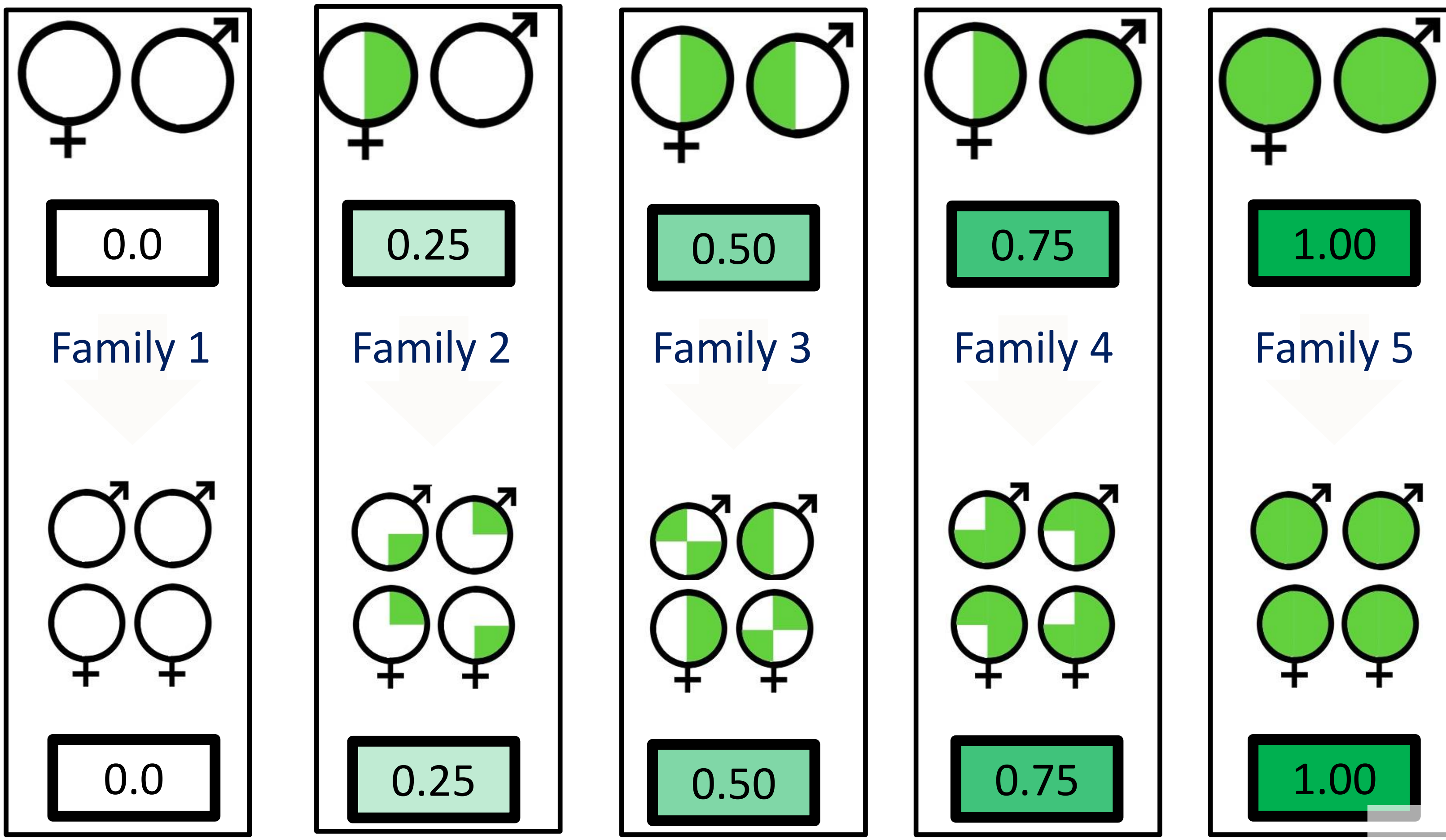
Sire	**Dam**
10 +	10 +
10-	10 -

Offspring average

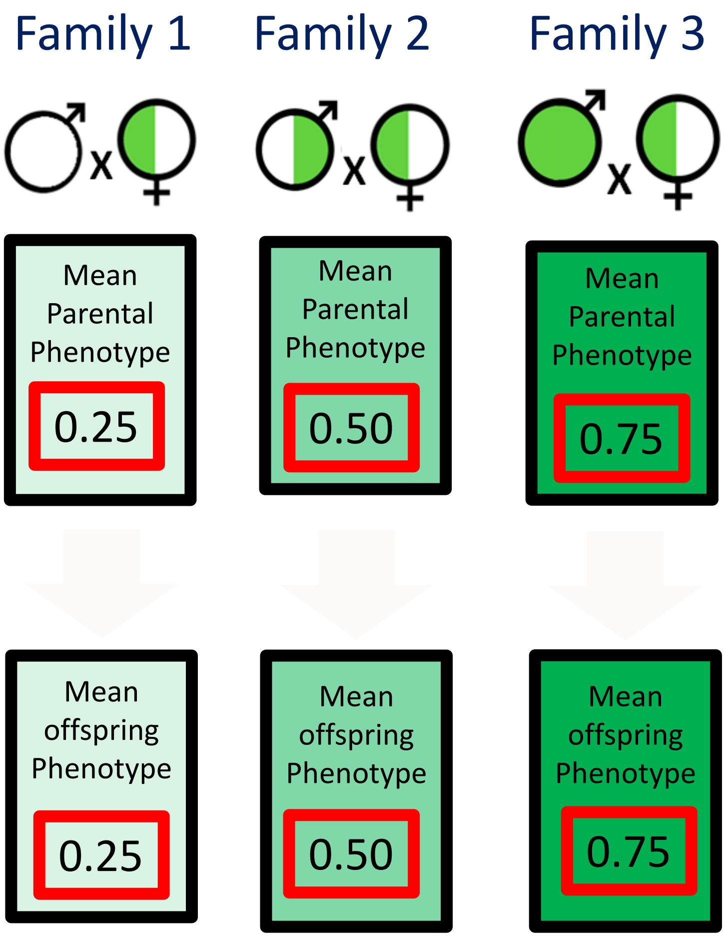
10 - 10 +

h^2 from a parent-offspring regression:

$$h^2 = \frac{V_A}{V_P}$$

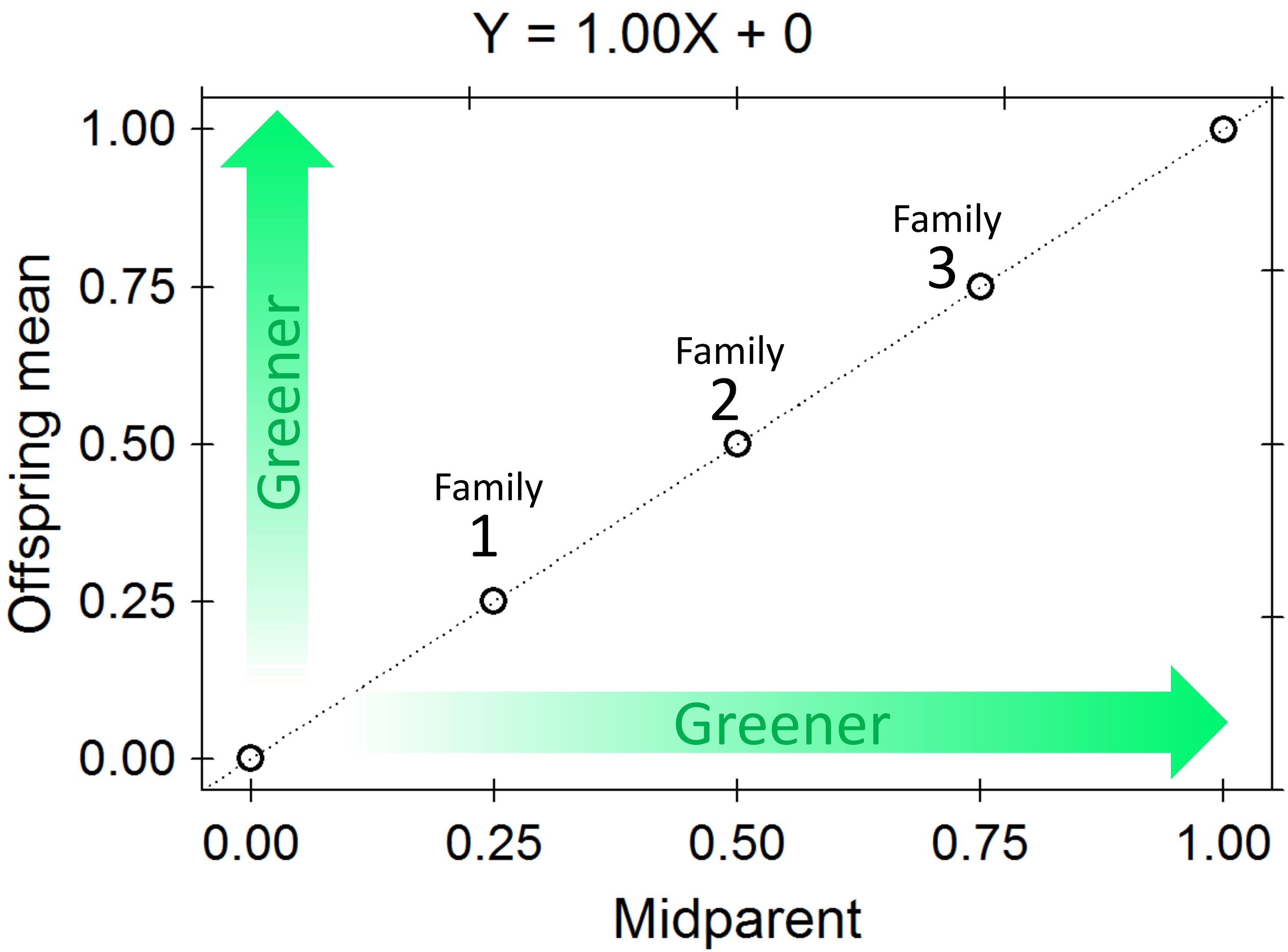


Regression: parents vs. offspring

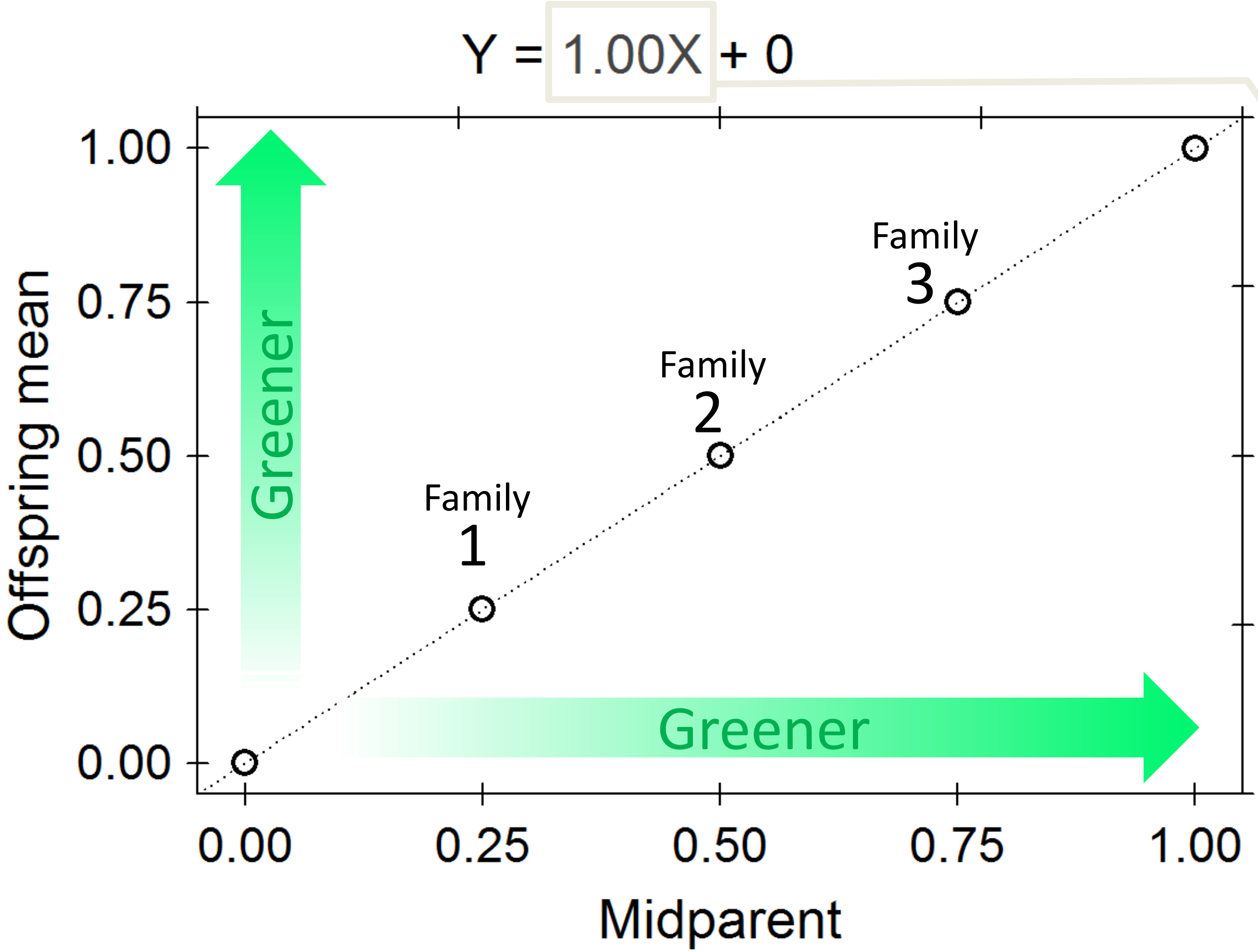


Family	Mid-parent (X-variable)	Offspring mean (Y)
1	0.25	0.25
2	0.50	0.50
3	0.75	0.75

Parent-offspring regression:



Parent-offspring regression:



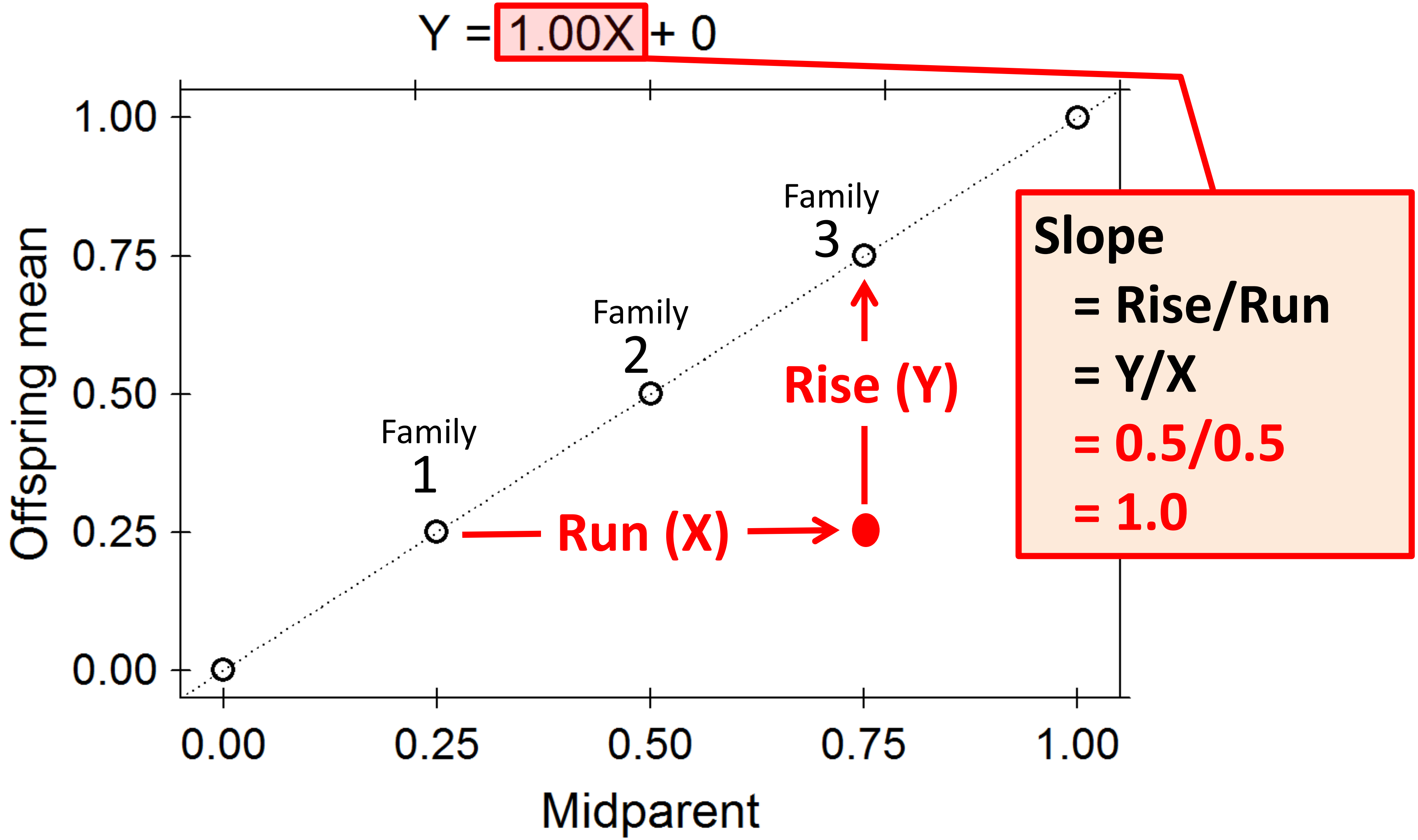
This gives **Heritability** **(h^2)**

i.e. $h^2 = 1$

$$h^2 = \frac{V_A}{V_P}$$

Example 1:

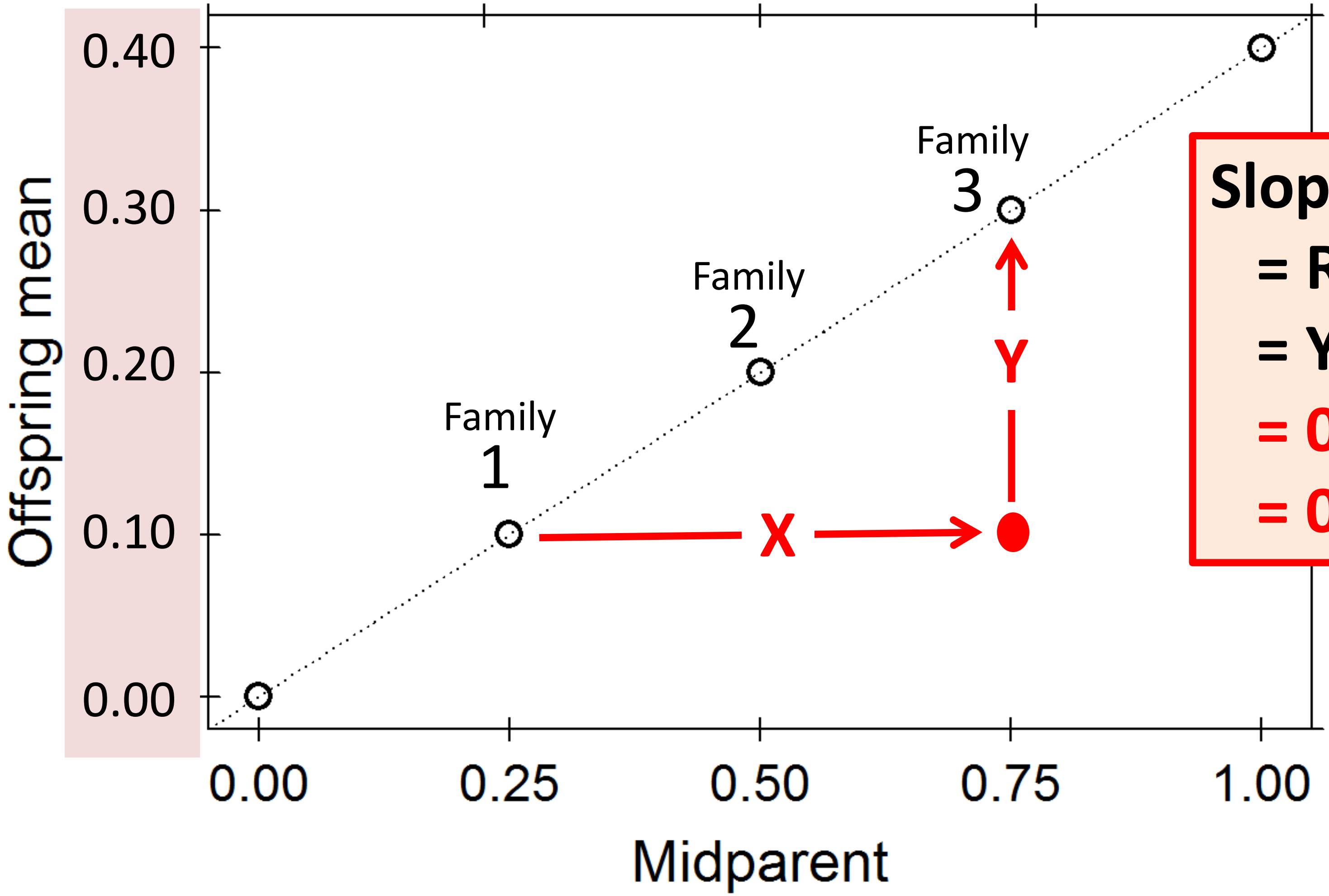
h^2 from a Parent-offspring regression



$$h^2 = \frac{V_A}{V_P}$$

Example 2:

h^2 from a Parent-offspring regression



Slope
= Rise/Run
= Y/X
= 0.2/0.5
= 0.4

i.e. **h^2 = 0.4**

Heritability and Evolution

- The heritability of a trait determines its ‘ability’ to respond to selection, according to the breeder’s equation (a prediction of evolutionary change):

$$R = h^2 \times S \qquad h^2=0\text{, then } R=0$$

  - R = response to selection
  - S = selection differential (difference between selected mean and population mean
  - h^2 = heritability

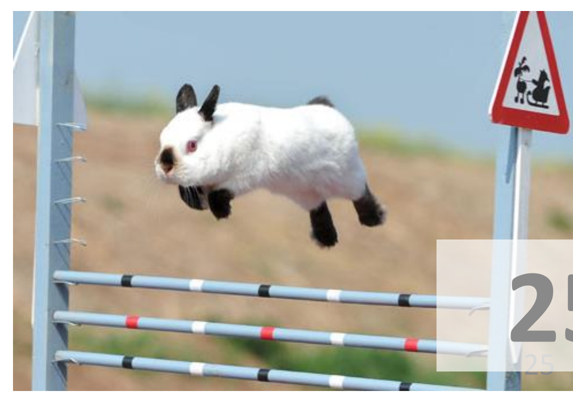
<u>Needs to be heritable for selection to act</u>

Breeders Equation – Example 1

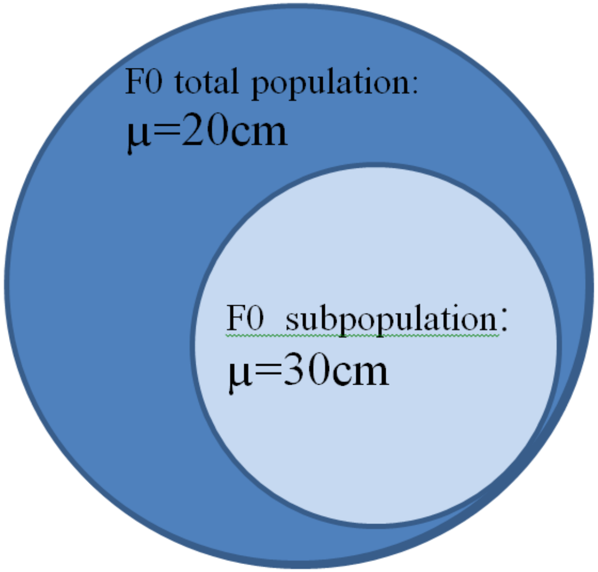
Example:

- F0 Bunnies can jump, on average, to **20cm** high
- We know that jumping in bunnies is heritable (has some genetic basis), $h^2=0.3$
- We want to breed the best (highest jumping) bunnies for the next generation (F1) in order to win the kanninhopning championships
- What do we do?
- Select the highest jumping bunnies!





Breeders Equation – Example 1



Step 1: Select the highest jumping bunnies! Breed those with mean jumping height of **30cm**

Step 2: Estimate selection differential:

(S)=**30-20** = 10

Step 3: Using the breeders equation, and the heritability estimate for jumping (h^2 =0.3), calculate the response to selection

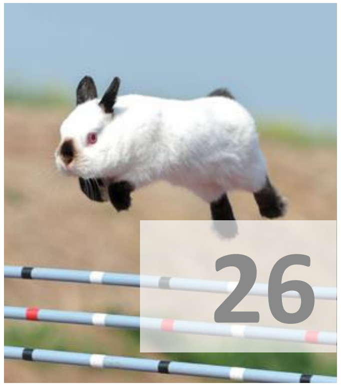
R = $\mathbf{h^2S}$

R = **0.3 x 10** = 3

Step 4: estimate the next generation by adding R to the original (F0) mean (20cm)

F0 + R = 20 + 3 =23

Expected F1 mean=**23.** We have increased the mean of the trait by 3 units.



Breeders Equation – Example 2

F0 mermaids can swim, on average, 10km before exhausting

We know that swimming distance is heritable, h^2=0.65

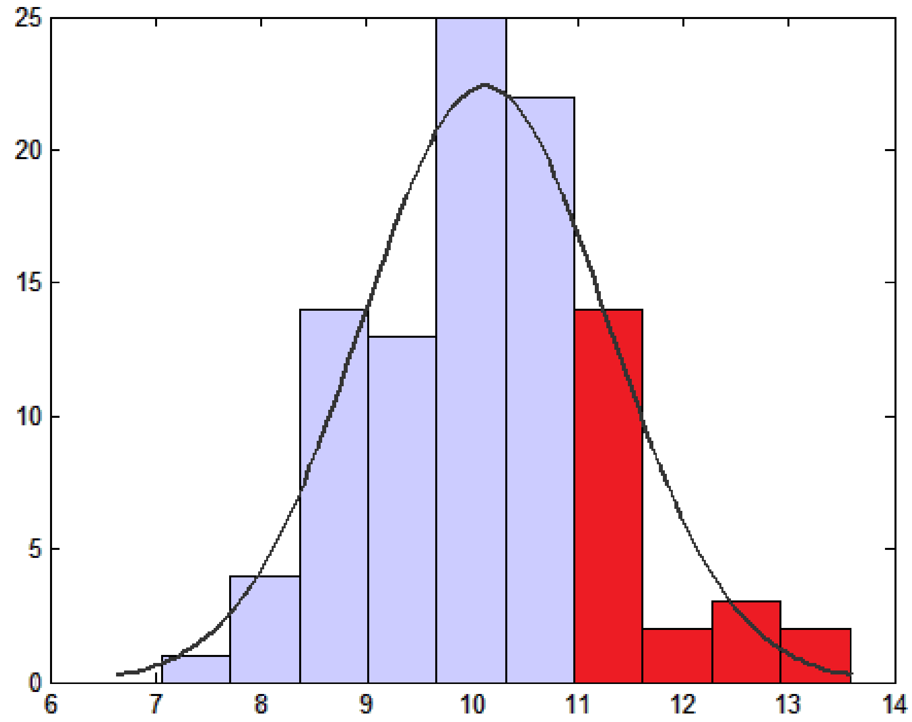
In a high predation environment, only mermaids that can swim for 11km or more survive being eaten by sharks.

Of the remaining mermaids, their average swimming distance was 12.5km

What is the expected mean swimming distance for the offspring (F1) of these surviving mermaid's?

Breeders Equation – Example 2

F0 mermaids μ=10km
h^2=0.65
Breeding F0 μ=12.5km



<u>Selection Differential</u>:
(S) = **12.5-10** = 2.5
<u>Response to Selection</u>:
R = **h^2S**
R = **0.65 x 2.5** = 1.625

Estimate the next generation (F1) mean (μ) by adding R to the original (F0) μ (10km)

F0 + R = 10 + 1.625 =11.625

Expected F1 mean=**11.625km.** We have increased the mean of the trait by 1.625km.

Quantitative genetics, heritability, natural selection & adaptive potential

Genetic basis

↓

Heritability (h^2)

↓

Potential to respond to selection

Described by:

Breeder's equation $R = h^2 S$

h^2, adaptive potential & climate change….

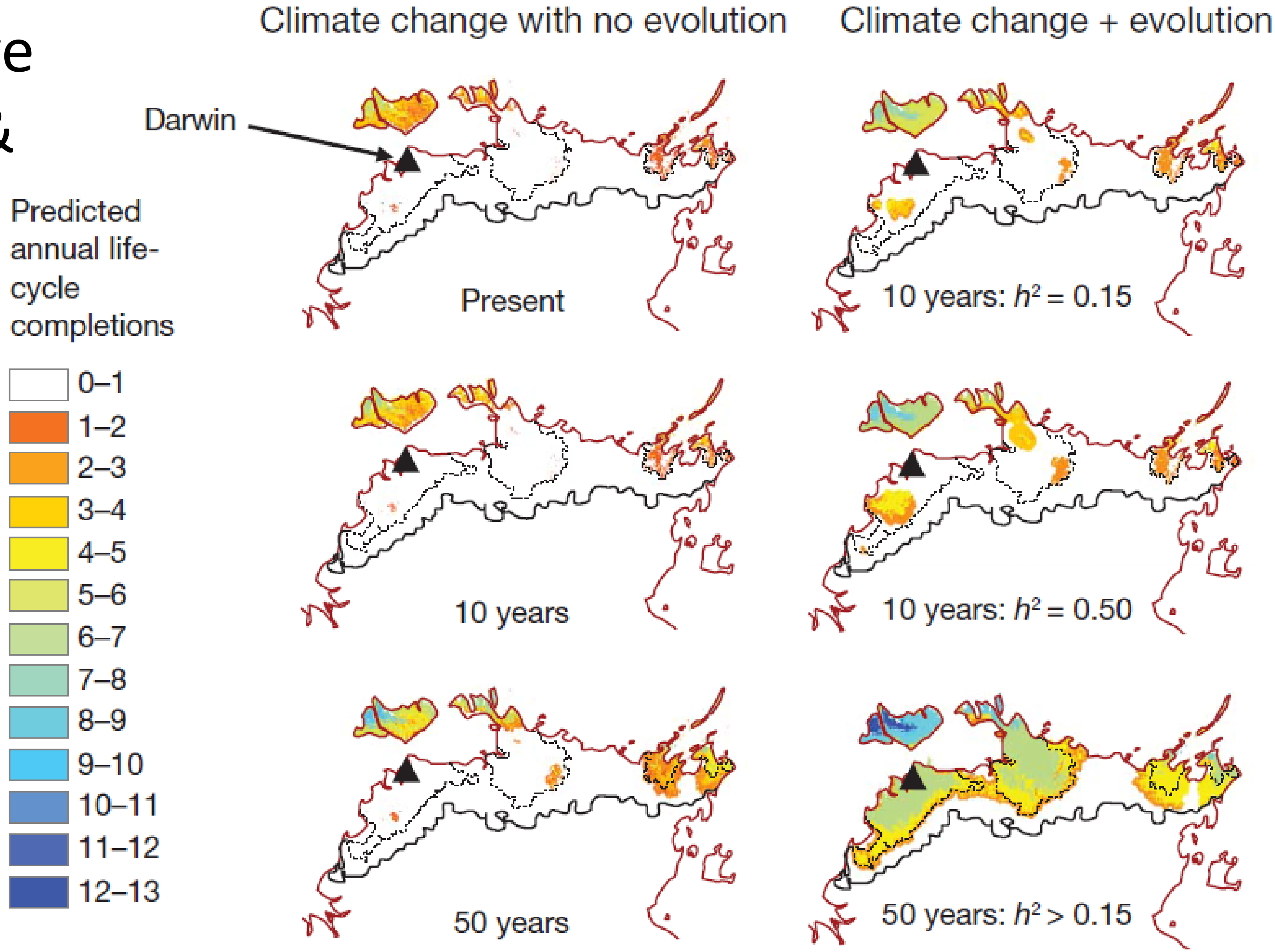


Figure 1 | Potential effect of evolution in egg desiccation resistance on life-cycle completions of the mosquito *Aedes aegypti* in the region around Darwin, Australia. Predictions are based on a mechanistic model of mosquito

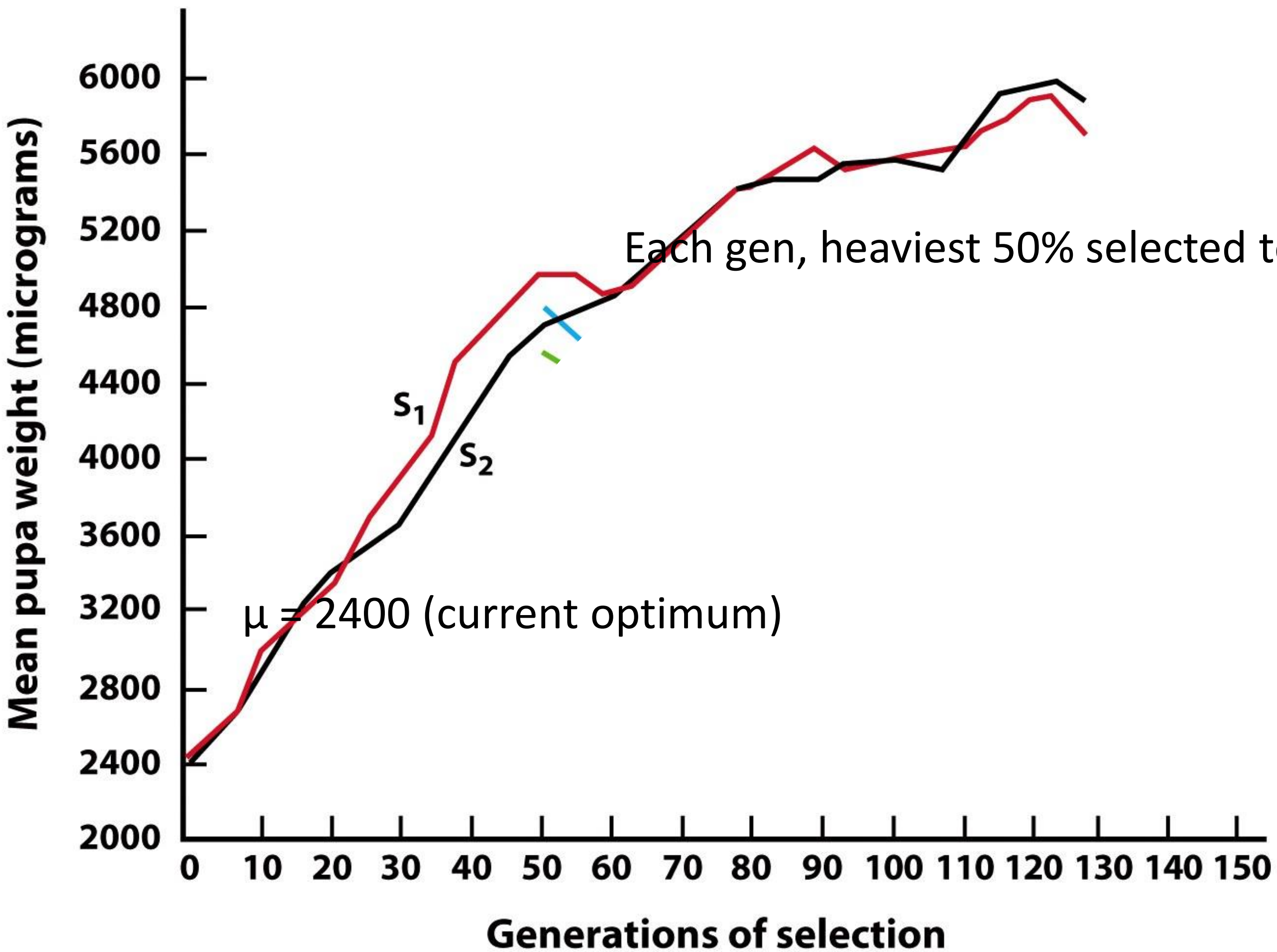
Some positive news in the face of Climate Change?

Models use CURRENT behaviour and physiological limits

Adaptive potential -> fitter individuals are selected and represented in the next generation

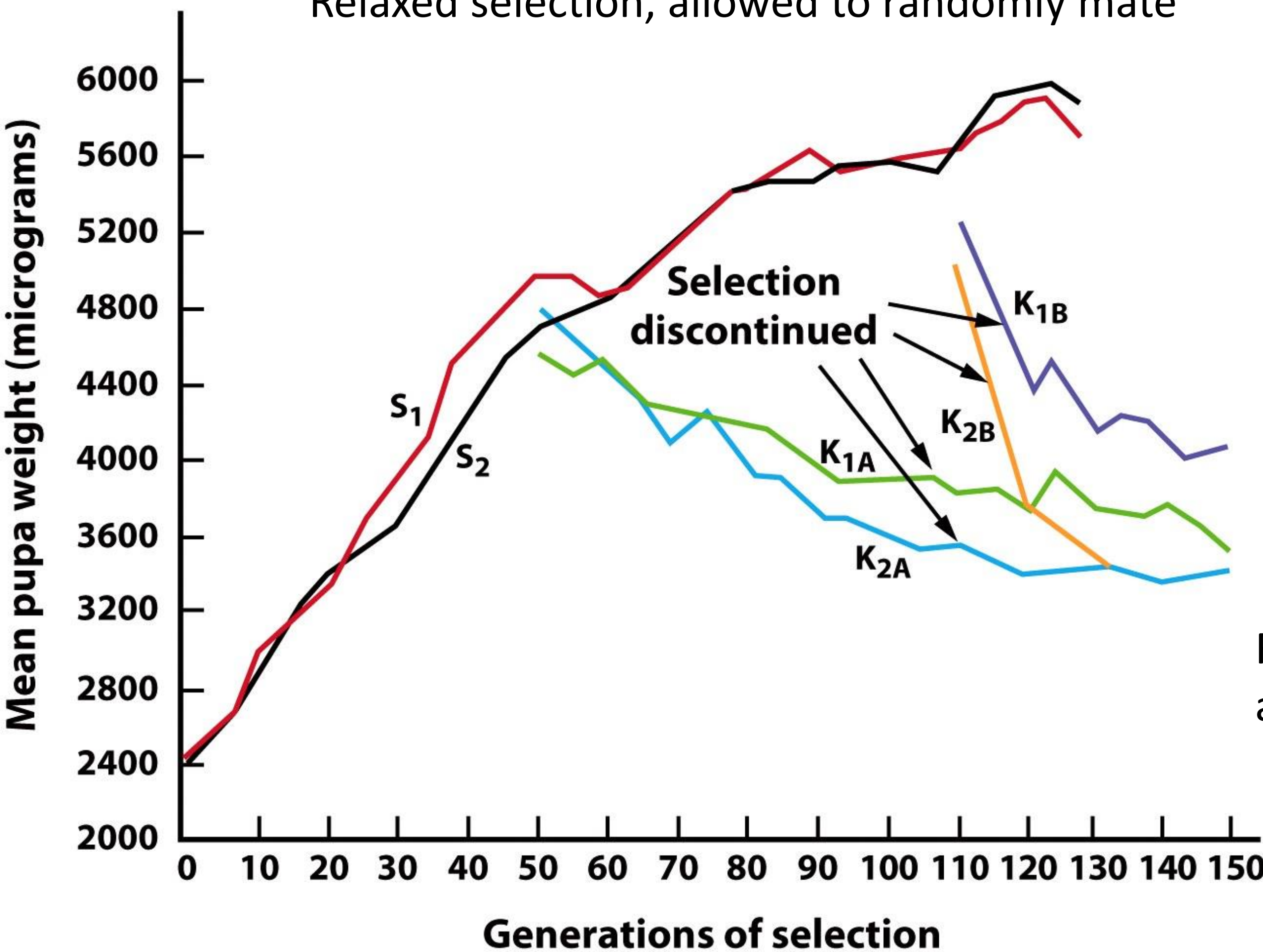
Dependent on: degree of heritability, speed of environmental change, amount of existing genetic variation, generation time

Artificial selection on pupal weight in flour beetles



Artificial selection on pupal weight in flour beetles

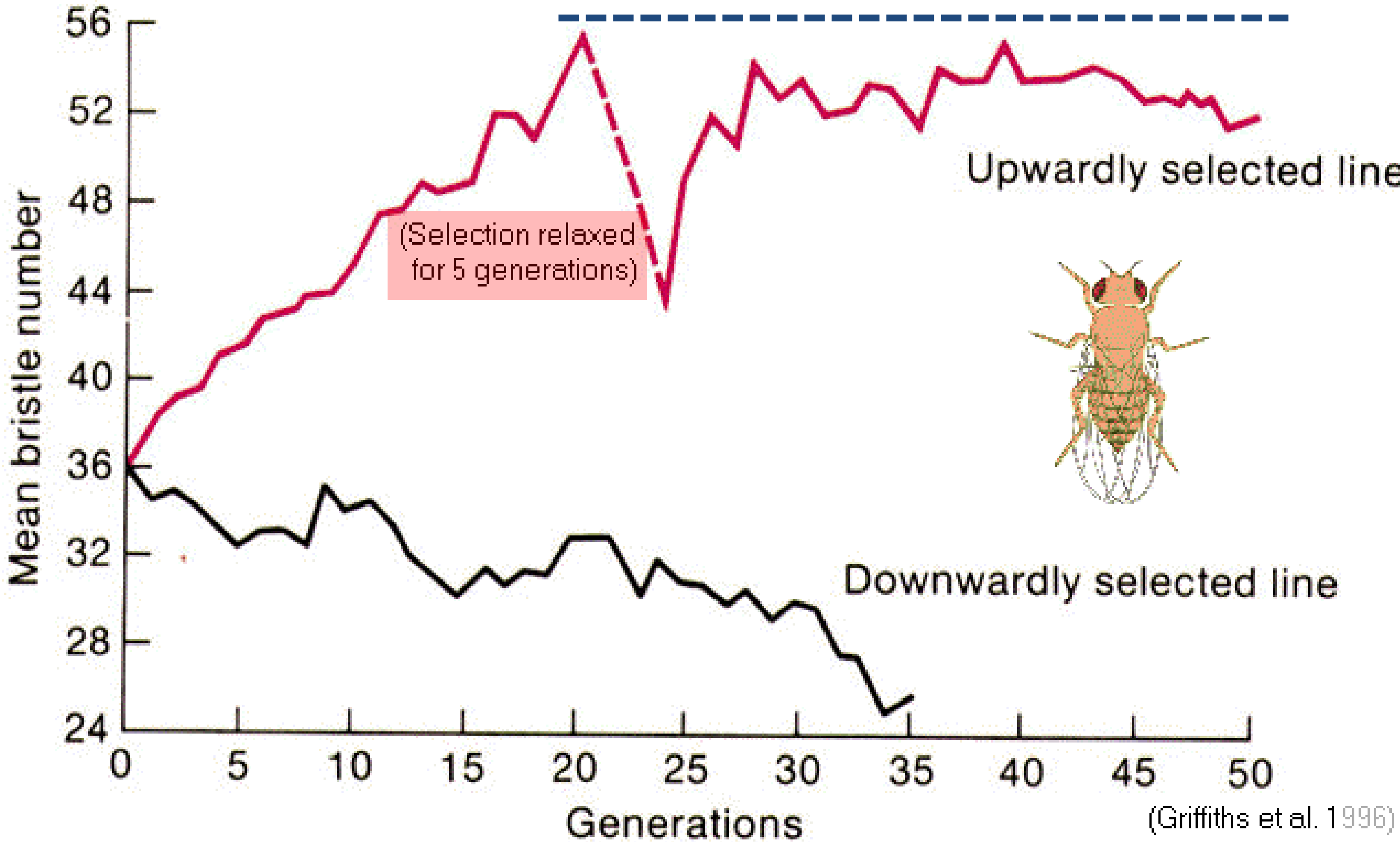
Relaxed selection, allowed to randomly mate



Adaptive “rebound”

Rebound back to adaptive optimum

Selection eventually hits a limit (asymptote)…



(Griffiths et al. 1996)

Need to Know Formulae

Broad Sense

$VP = VG + VE$

$H^2 = VG/VP$

Narrow Sense

$VP = VG + VE$

$VG = VA + VD + VI$

$h^2 = VA/VP$

Adaptive Potential

$R = h^2S$

VP = phenotypic variance

VG = genotypic variance

VE = environmental variance

VA = additive genetic variance

VI = epistatic genetic variance

VD = dominance genetic variance

H^2 = broad heritability

h^2 = narrow heritability

S = response to selection

Summary

- VG = VD + VI + VA
- Narrow (h^2) and Broad (H^2) Heritability
- Narrow: (mid)parent offspring regression
- Broad: sibling regression
- Traits must be heritable to be selected upon (breeders equation – h^2)
- Heritability can tell us about the genetic ‘robustness’ of an organism in changing environments