Measuring natural selection in populations

Introduction to Evolution and Scientific Inquiry

Dr. Spielman; spielman@rowan.edu

Recall...

Evolution by natural selection will happen if these are **true**:

1. There is **variation** in natural populations
2. The variation is **heritable**
3. More offspring are produced than will survive each generation, because there is a **struggle for existence**

→ **Natural selection tries to maximize the fitness of a population (making the average individual really good at surviving and making babies)**

How do populations of organisms evolve?

- A **population** is a group of organisms of the same species that live in a particular geographic area at the same time and interbreed
- We can ask..
  - What causes natural selection to act?
  - Which traits are favored in a population?
  - What mode of natural selection is acting?
  - How strong is selection in a population?
  - What is the *average fitness* of a population?
  - What other evolutionary forces affect the population?
  - Is a trait in a population evolving?

What causes natural selection to act?

- Natural selection is the process by which organisms adapt to their environment

How would natural selection act on a brown bear in the forest?
A brown bear in the Arctic?
Vice versa?

The origin and future of polar bears

- They evolved ~150,000 years ago from a brown bear ancestor
- Polar bears are *specialized* (highly adapted!) to their environment:
  - Hunt for seals with the "sit and wait" approach
  - They have not evolved to be efficient at walking long distances to hunt
- ...What now?

Modes of natural selection

Modes of selection: Formal definitions

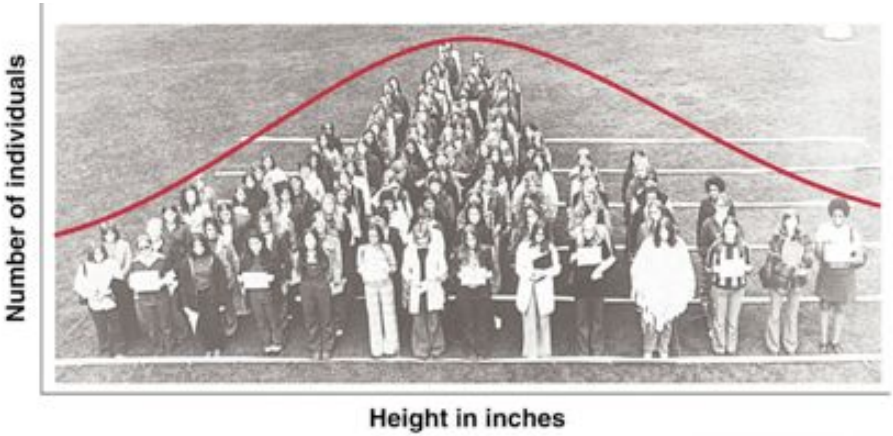
- **Directional selection**
  - Individuals at **one** trait **extreme** are favored

- **Balancing selection**
  - Individuals with an **intermediate** trait value are favored
  - AKA **stabilizing selection**

- **Disruptive selection**
  - Individuals at **both** extremes are favored, i.e. **selection against the mean**

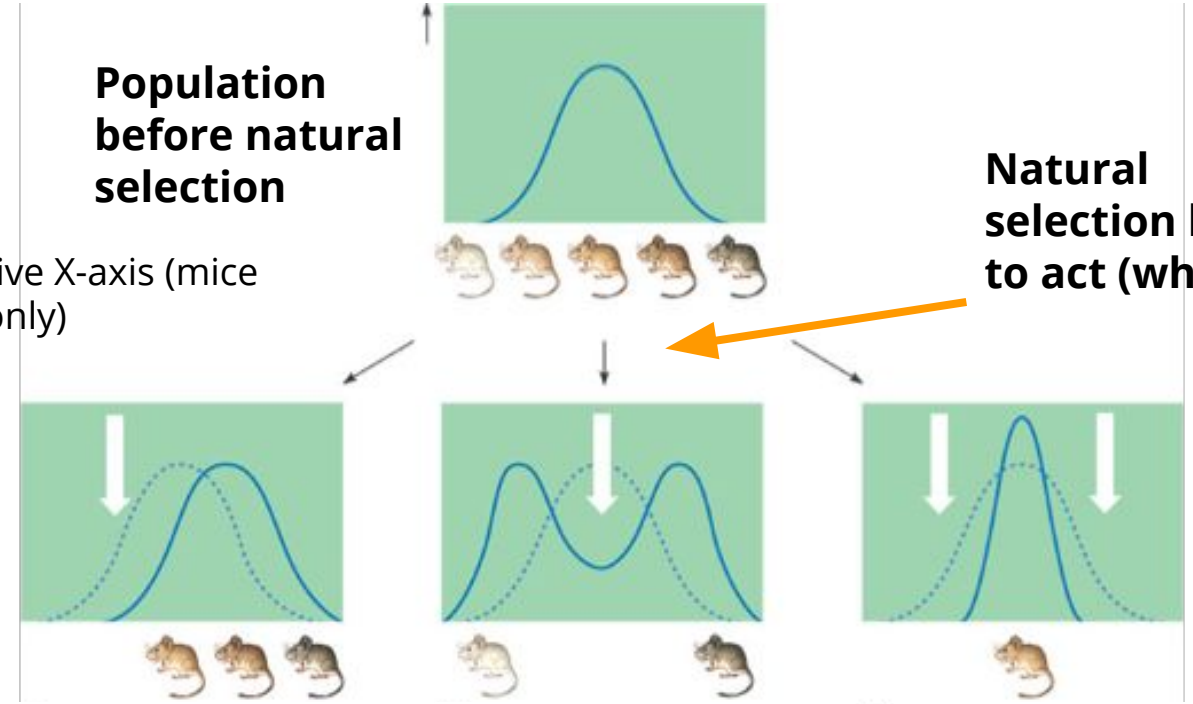
Continuous vs. discrete variation

Natural selection affects different types of traits differently, so we study them differently



Modes of natural selection on *continuous quantitative traits*

Assume quantitative X-axis (mice shown for visual only)



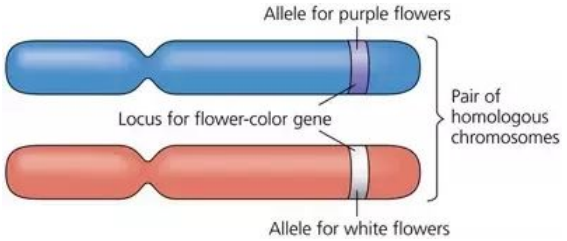
Does variation remain in the populations?

Modes of natural selection on *discrete traits* (like alleles!)

Consider a population where a gene has two alleles, "A" and "a". At the beginning, all is equal: ⅓ are AA ⅓ are Aa ⅓ are aa

Table discussion: What happens to the frequency of genotypes after many generations experiencing...

- **Directional selection?**
- **Balancing selection?**
- **Disruptive selection?**



Modes of natural selection on discrete traits

- Directional selection?
  - Selection will make "AA" the most common genotype (or aa)
  - Eventually, all individuals will be homozygous

Does variation remain in the populations?

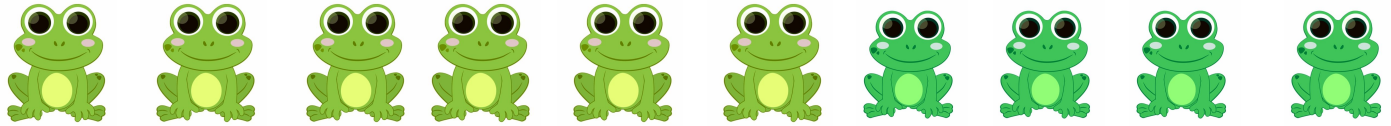
- Balancing selection?
  - Selection will make "Aa" the most common genotype

- Disruptive selection?
  - Selection will make "AA" and "aa" the most common, with very few "Aa"

Generation 0

50% olive

Generation 1



60% olive

Generation 2

70% olive

Generation 3

80% olive

Generation 4

90% olive

Generation 5

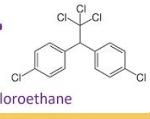
100% olive

Example: Directional selection

- DDT resistance in mosquitoes

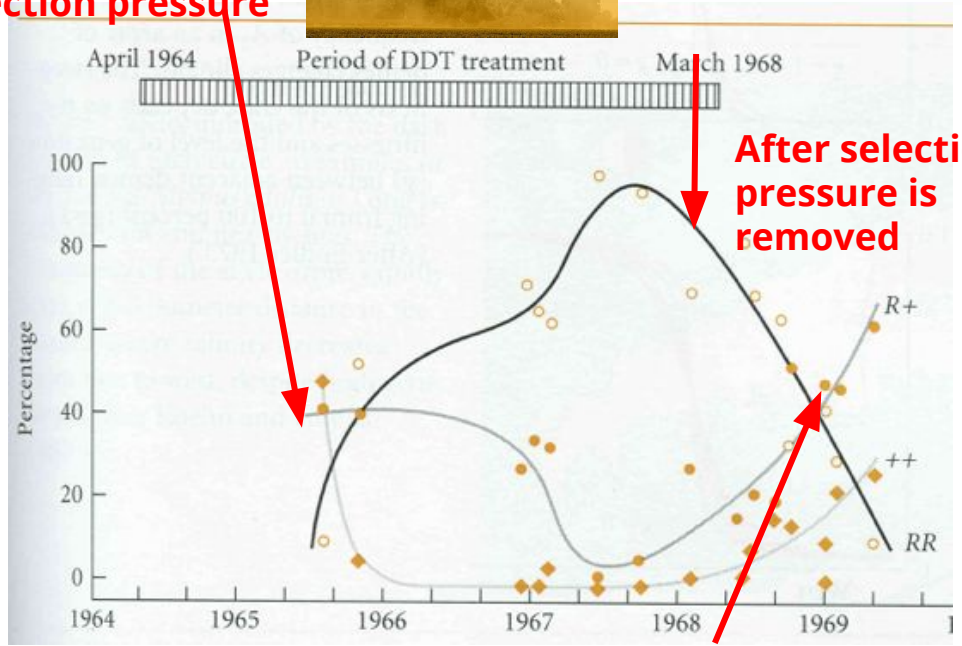
- RR = resistant genotype
  - mosquitoes survive DDT
- R+ and ++ = susceptible genotypes
  - DDT kills mosquitoes
- Which genotype is better for **mosquito fitness?**

DDT



Dichlorodiphenyl trichloroethane

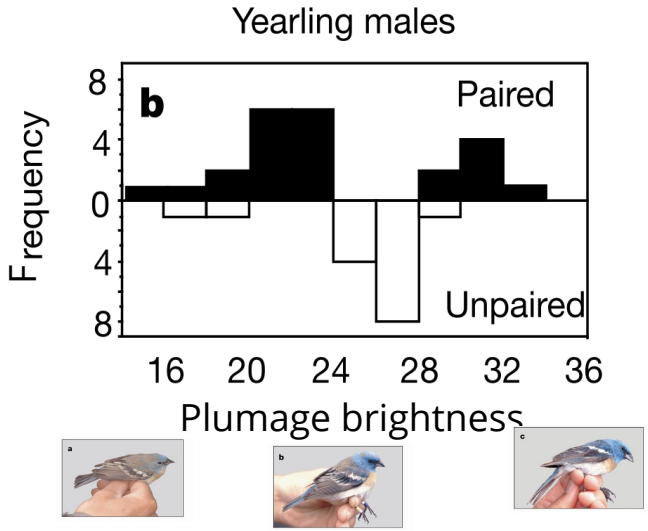
Before (early stages of) selection pressure

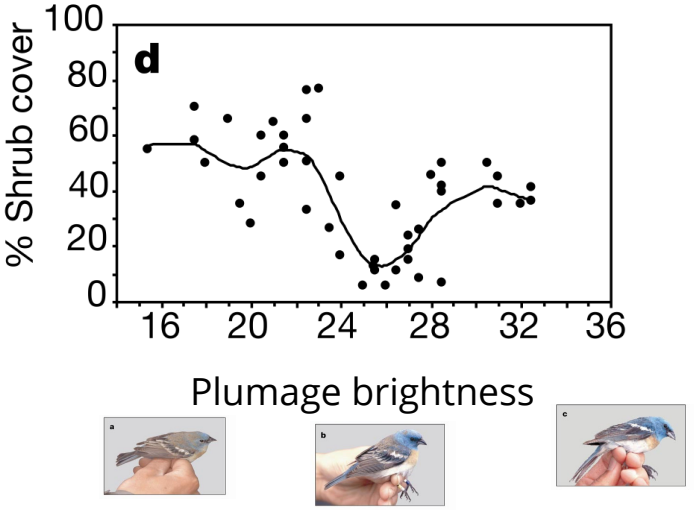


After selection pressure is removed

Why the change?

Example: Disruptive selection



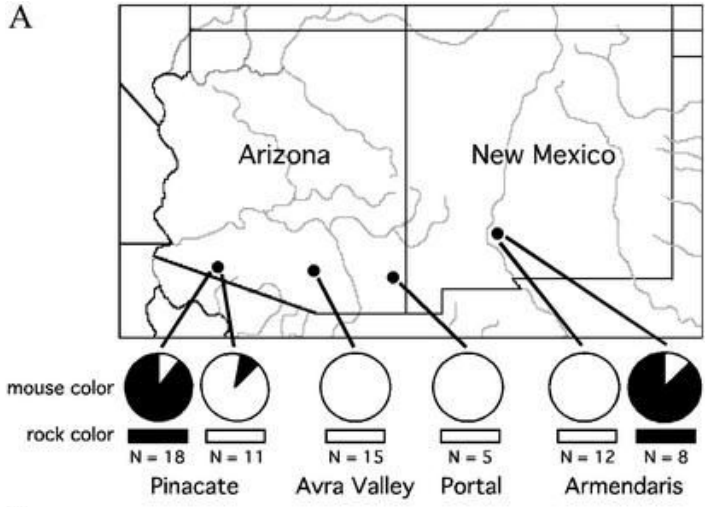


Example: Disruptive selection (could be viewed as directional too!)

Desert environment

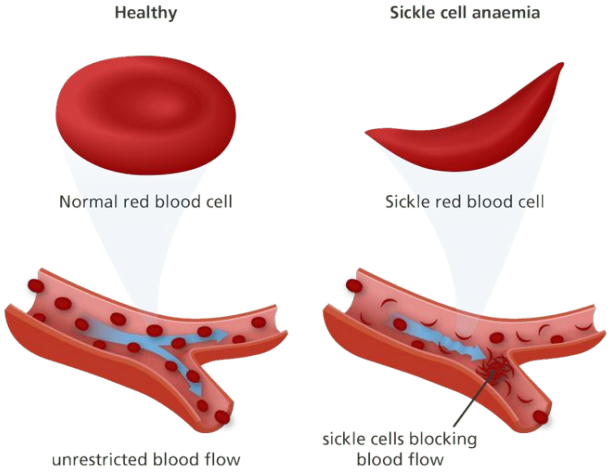
Lava pit environment

Close match between phenotype and environment

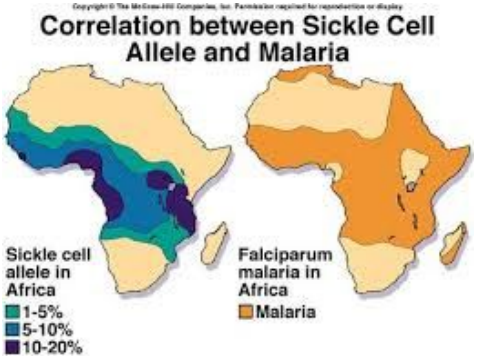


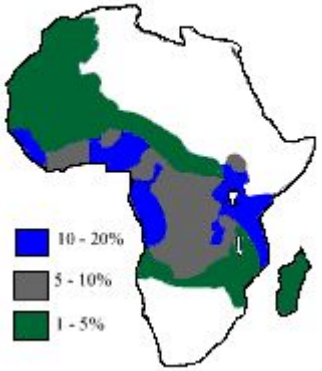
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC154334/

Example: Balancing selection



- Sickle cell anemia is a recessive genetic disorder caused by **S** allele (**A** is the “wild type”)
  - SS = sickle cell
  - SA, AA = healthy (but what is SA?)
- SS is up to 20% in certain regions...?????





Quantifying selection in populations

How strong is natural selection in a population?

- We measure fitness using survival or fecundity.

Scenario:

There are 1,000 dragonflies in a population. Some dragonflies are blue and some are red. On average, birds eat 50% of blue dragonflies and 25% of red dragonflies.

→ 50% of blue survive. 75% of red survive.

We quantify selection using *relative fitness* and *selection coefficients*

75% of red survive. 50% of blue survive.

	Red morph	**Blue morph**	Notes
Absolute Fitness	**0.75**	**0.50**	*The actual measurements*
Relative fitness, ***w*** (normalized survivorship)	0.75 / 0.75 = **1.0**	0.5 / 0.75 = **0.67**	*Divide by the largest value in the population*
Selection coefficient, ***s***	1 - 1 = **0**	1 - 0.67 = **0.33**	s = 1 - w

Survival of these two phenotypes, *relative to each other*.
For every 10 surviving red dragonflies, we expect ~6.7 blue dragonflies will survive.

The strength of selection acting *against* the trait.
S = 0 → *relatively*, no selection against the trait (most fit phenotype)
S = 1 → complete selection against the trait (no survivors)

Mean fitness of populations

	Red morph	Blue morph
Absolute Fitness	**0.75**	**0.50**
Relative fitness, ***w***	**1.0**	**0.67**
Selection coefficient, ***s***	**0**	**0.33**

Imagine a population with 1 blue morph and 1 red morph. What is the mean fitness of the population?

(1.0 + 0.67) / 2 = 0.833

Imagine a population with 2 red morphs and 1 blue morph (so *N=3*). What is the mean fitness of the population?

(1.0 + 1.0 + 0.67) / 3 = 0.89

Mean fitness of populations

$$\bar{w} = \sum_{i}^{N} F_i w_i$$

N = total number of phenotype

i = each phenotype (genotype)

F = frequency of phenotype.

w = fitness of phenotype

Population with 2 red morphs and 1 blue morph. Fitness?

(1.0 + 1.0 + 0.67) / 3 = **0.89**

2/3 x 1.0 + 1/3 x 0.67 = **0.89**

Over time, natural selection will act to *increase the POPULATION fitness*.

A classic example: peppered moths (*Biston betularia*)

Melanic

“Typical”

- Melanic form was first seen in 1848
  - Frequency of 1-10% in industrial areas by 1890
  - Frequency >99% in Manchester by 1948.
  - Typical form remained common in rural areas

- Kettlewell asked, “Does color affect survival?"

Kettlewell's capture/recapture results (1955)

Polluted Area

	White	Black
Number released	137	447
Number recaptured	18	123
Percent recaptured	**13.1%**	**27.5%**

Unpolluted Area

	White	Black
Number released	393	406
Number recaptured	54	19
Percent recaptured	**13.7%**	**4.7%**

	White morph	Black morph
Polluted	**13.1%**	**27.5%**
Unpolluted	**13.7%**	**4.7%**

These survival measurements represent "**ABSOLUTE FITNESS**"