BIO 111: **Ecology and Evolution**

Varsha 2022

Ullasa Kodandaramaiah

IISER THIRUVANANTHAPURAM

School of Biology

MODULE: PRINCIPLES OF EVOLUTIONARY BIOLOGY

Part I - FUNDAMENTAL CONCEPTS

Evolution: change through time

Do species change over time?

Was long believed that all species on earth were created at the same time and that species never change over time

- e.g. Plato (ca. 400 BC) thought that each species was modelled after a 'perfect form', with some deviants

- Erasmus Darwin (1731-1802)

  grandfather of Charles Darwin

  one of the first to propose that species change over time

- *George Cuvier (1769-1832)*

  palaeontologist

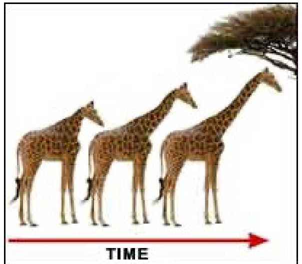
  observed that many species with fossils don't exist any more – *extinctions*

- Jean-Baptiste Lamarck (1744-1829)

first to strongly argue that species change over time and come up with a theory of how change takes place

Lamarckism: use & disuse of organs
inheritance of acquired traits

Argued that giraffes originally had shorter necks. They stretched their necks to feed on vegetation high up a tree and thus their necks got longer. Long necks were inherited by the offspring



- Thomas Malthus (1766-1834)

Malthusian principle

All species have the potential to create far more offspring than there are resources to support

'struggle for existence'

- <u>Charles Darwin and Alfred Wallace</u>

  Exceptionally good naturalists

  Travelled around the world collecting and observing plants and animals

Independently came up with the theory of evolution in the 1850s

Voyage of the *Beagle*: 1831–1836

GALAPAGOS
ISLANDS

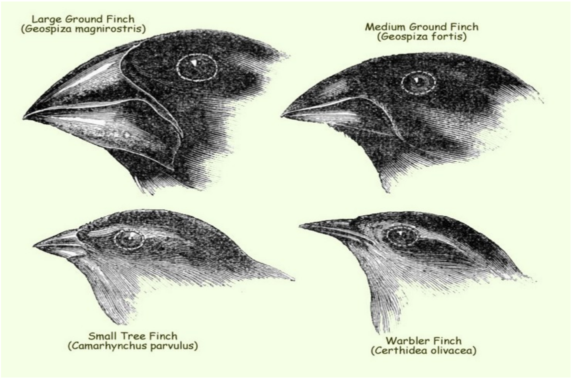
Galápagos Islands

Photo: Wikimedia/ Matthew Field

- Darwin and Wallace observed

variation among individuals within a population of a single species

variation among closely related species



Darwin's finches in the Galapagos archipelago.
Source www.animalcorner.co.uk

Adapted from slides by Merrill Peterson

- They observed that offspring resembled parents – i.e., certain traits are heritable (but they did not have knowledge of Mendelian genetics, which was formulated later)

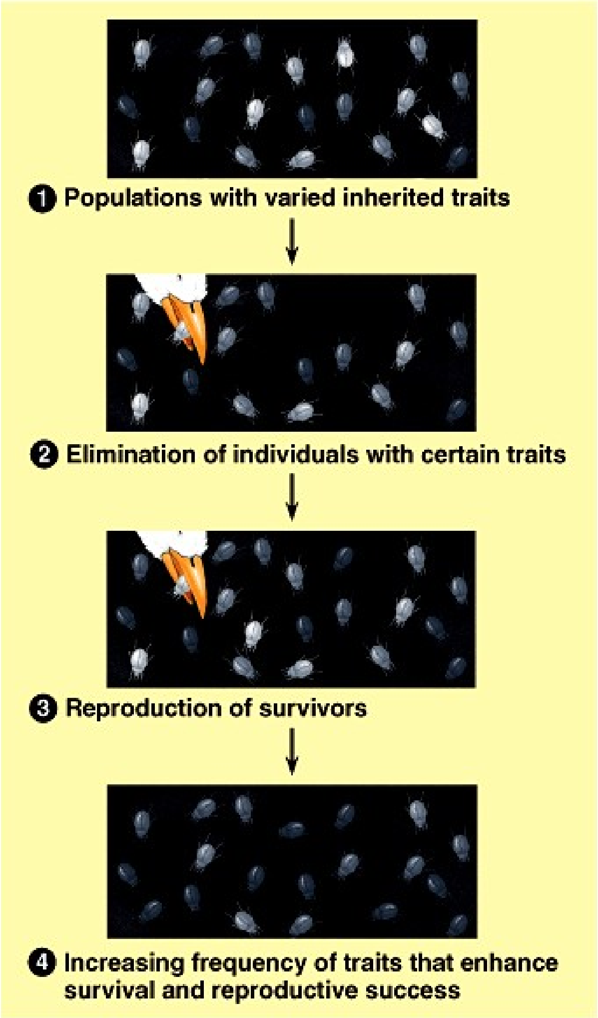
- Knew what selective breeding in plants & animals could lead to

- Knew that many species clearly have certain traits that help them survive in certain environments (i.e. traits affected probability of survival)

- Reasoned that not all off-spring survive because of competition for resources (both were inspired by the Malthusian principle)

- Individuals which have a trait that helps them survive and reproduce will pass on the traits to their offspring, if the traits are heritable

NATURAL SELECTION



1 Populations with varied inherited traits
2 Elimination of individuals with certain traits
3 Reproduction of survivors
4 Increasing frequency of traits that enhance survival and reproductive success

- Over time, the proportion of individuals with the beneficial trait will increase in the population

- Thus, beneficial traits accumulate in a population over generations

<u>EVOLUTION mediated by NATURAL SELECTION</u>

Wallace and Darwin independently came up with this theory. Darwin's famous book '*On The Origin of Species by Means of Natural Selection*' was published in 1858

Descent with Modification: idea that new species are the modified descendants of older (ancestral) species

Argued that ALL species had descended from one or a few original types of life

- **Evolutionary changes are heritable changes**, i.e., those that are transmitted via genetic material from one generation to another

- **Evolution is change in inherited traits of a population across successive generations**

- Selection is by the environment

- Remember that the environment includes both the biotic and abiotic components

Reflection point

- In the example of the insects being predated upon by a bird, what component(s) of the environment select(s) for insect colour?

Individuals do not evolve; Populations evolve

We can also say that traits (or phenotypes) of populations evolve

Tree illustrations from http://clipart-library.com

E.g.; In a particular island population of a palm trees species, taller trees are more likely to die due to wind damage.

Over several generations, shorter tree height could be favoured, and the proportion of short trees may increase, leading to a change in the **average tree height of the population**. Thus, the **tree height of the population has evolved.**

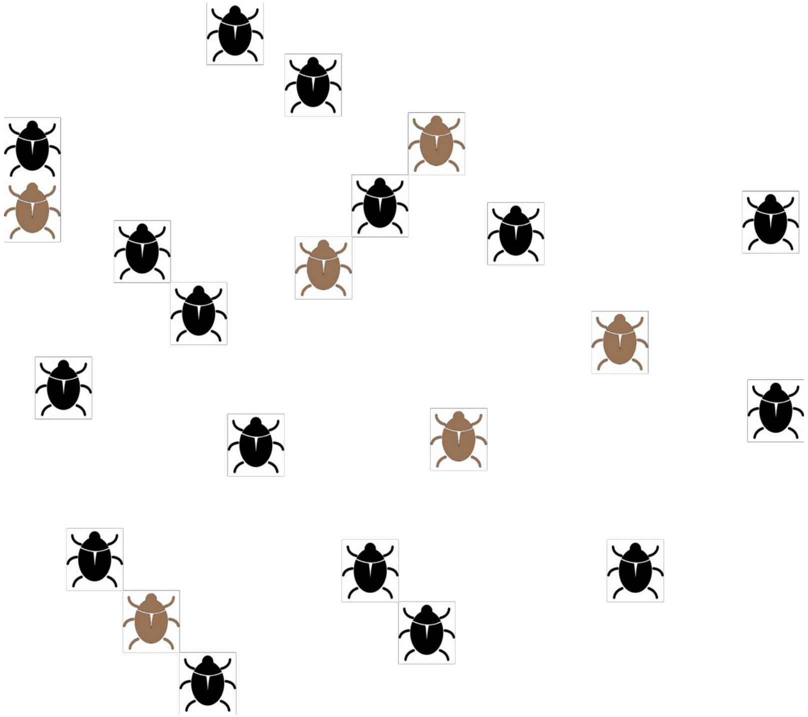
- Traits are determined by one or more genes.
- An *Allele* is a variant of a gene.
- *Allele frequency* is the proportion of individuals in a population with a particular allele

Consider an insect species with colour morphs (or colour ‘types’). Colour in this species is determined by a particular **gene** with 2 variants. Each variant has a unique DNA sequence. The variants are the ‘**alleles**’ of that particular gene. Individuals with the first allele are black – lets call this allele *BL*. Ones with the second allele are brown – lets call this allele *BR*.

BL : ‘…………ATGGGATCACTTGGAG……….’

BR: ‘…………ATCGGATCACTTGGAG……….’

The insect lives in a habitat dominated by brown sand that matches the colour of the *BR* allele phenotype. What happens to allele frequencies if predators selectively feed on black ones?



Frequency of *BR*: 6/22 = 0.273 (27.3%)
Frequency of *BL*: 16/22 = 0.727 (72.7%)

After some generations of selection, the frequency of *BR* will increase and may even reach 1.

Reflection point

- In a graph, plot the expected change in allele frequencies over time

Evolution results in changes in allele frequencies in populations

Evolution can be defined as 'a change in the *frequency of alleles* within a *gene pool* from one generation to the next'

A gene pool is the total collection of genes in a population at any time point

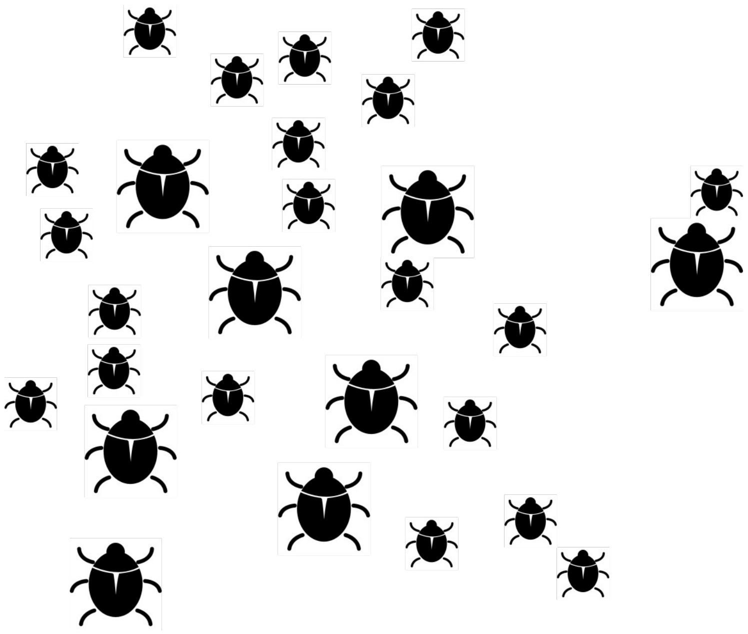
A change in population size is not a necessary component of evolution.

A population can change in size over time, but retain the same allele frequencies. In this case, the population has not evolved.

On the contrary, allele frequencies may change without a change in population size. In this case, the population has evolved.

In nature, however, there is usually an upper limit on population size because of resource constraints

In this insect species, there are two morphs (types): small and large. Size is determined by a single gene. On average, the large morph has higher **fecundity.** **Fecundity=Total number of offspring**



Even if both morphs survive equally well, it is expected that the larger morph will become more frequent (common) in the population

Thus, *a trait may evolve through selection even without differences in survival*

Fitness

Related to **Fecundity & Survival**

- ***Evolution favours traits that increase fitness***
- Consider individual 'A' – small, frail and diseased. It produces an offspring before death and the offspring goes on to reproduce. Consider another individual 'B' - strong, large and free from disease, but does not reproduce.

'A' has higher *fitness* from the point of evolution.

Adaptation

Adaptation is a **trait that helps an organism to maintain or increase fitness in *a given environment***.

Adaptations are the result of past selection pressures

Adaptations are not perfect

Evidence for evolution: Darwin's finches

Rosemary and Peter Grant have followed Darwin's finches in the Galápagos island Daphne Major for decades

- **Droughts:** higher proportion of larger seeds

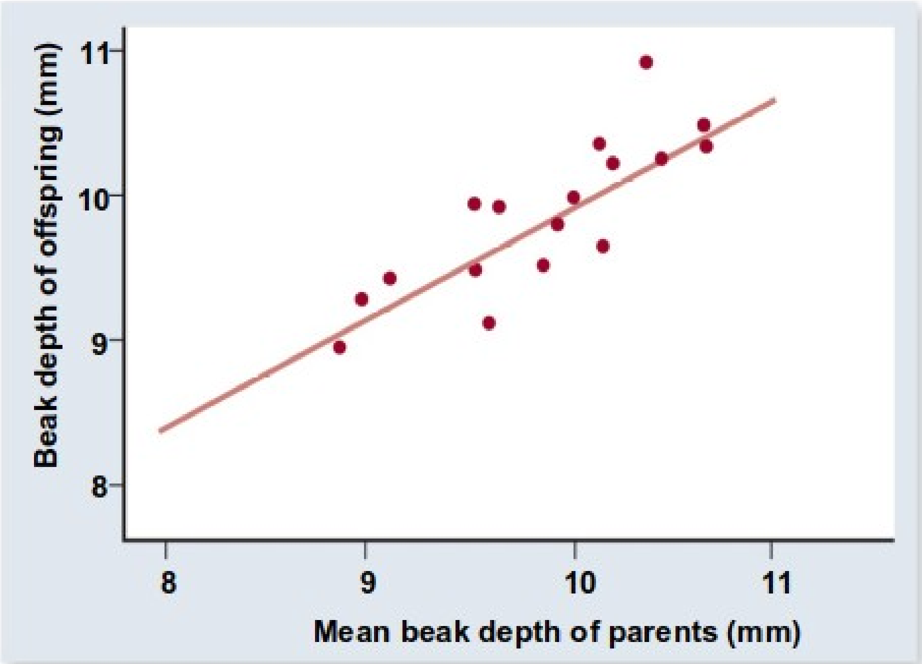
- **Normal rains:** higher proportion of smaller seeds

Geospiza fortis (Medium ground finch)

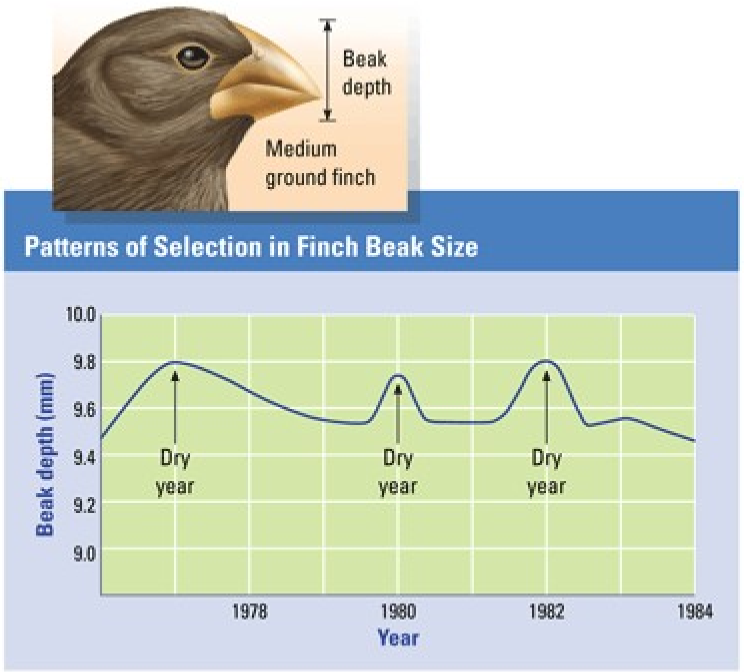
Small beak depth: pointed
Large beak depth: blunt

Adapted from slide by Joan Sharp, Pearson Education Inc

The figure plots beak depths of multiple offspring and their parents. Each red dot represents i) beak depth of an offspring on the y axis, and ii) average beak depth of its parents on the x axis. The straight line depicts the overall trend.



We can conclude that there is a correlation between offspring and parent beak size, which in turn indicates that **beak size is heritable**



https://bodell.mtchs.org/OnlineBio/BIOCD/text/chapter14/concept14.4.html

Reflection point

- If larger beaks can process both smaller and larger seeds, why are larger beaks not selected during all years?

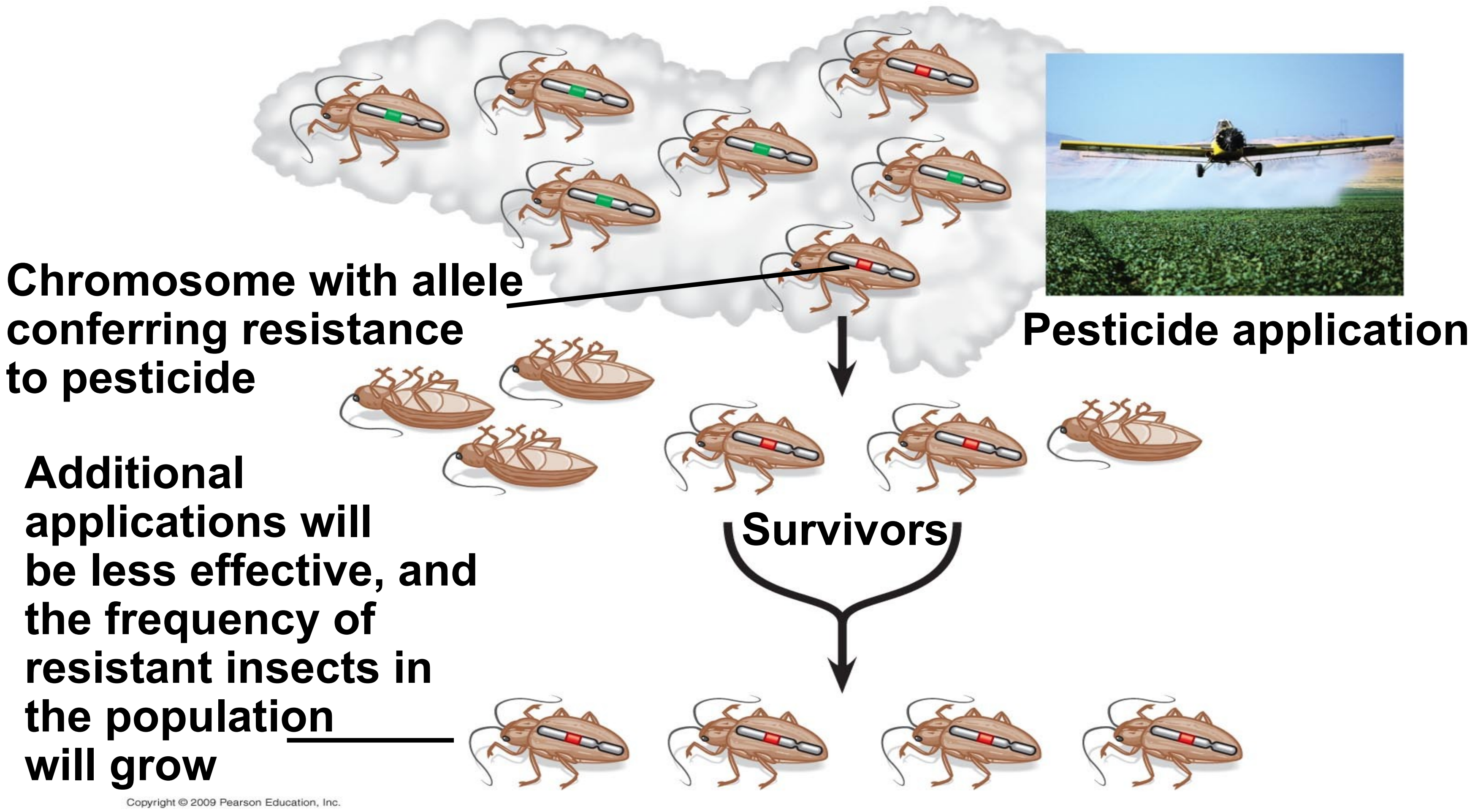
Development of pesticide resistance in insects

Initial use of pesticides favors those few insects that have genes for pesticide resistance

With continued use of pesticides, resistant insects flourish and vulnerable insects die

Proportion of resistant insects increases over time

Adapted from slide by Joan Sharp, Pearson Education Inc



Slide by Joan Sharp, Pearson Education Inc

More examples

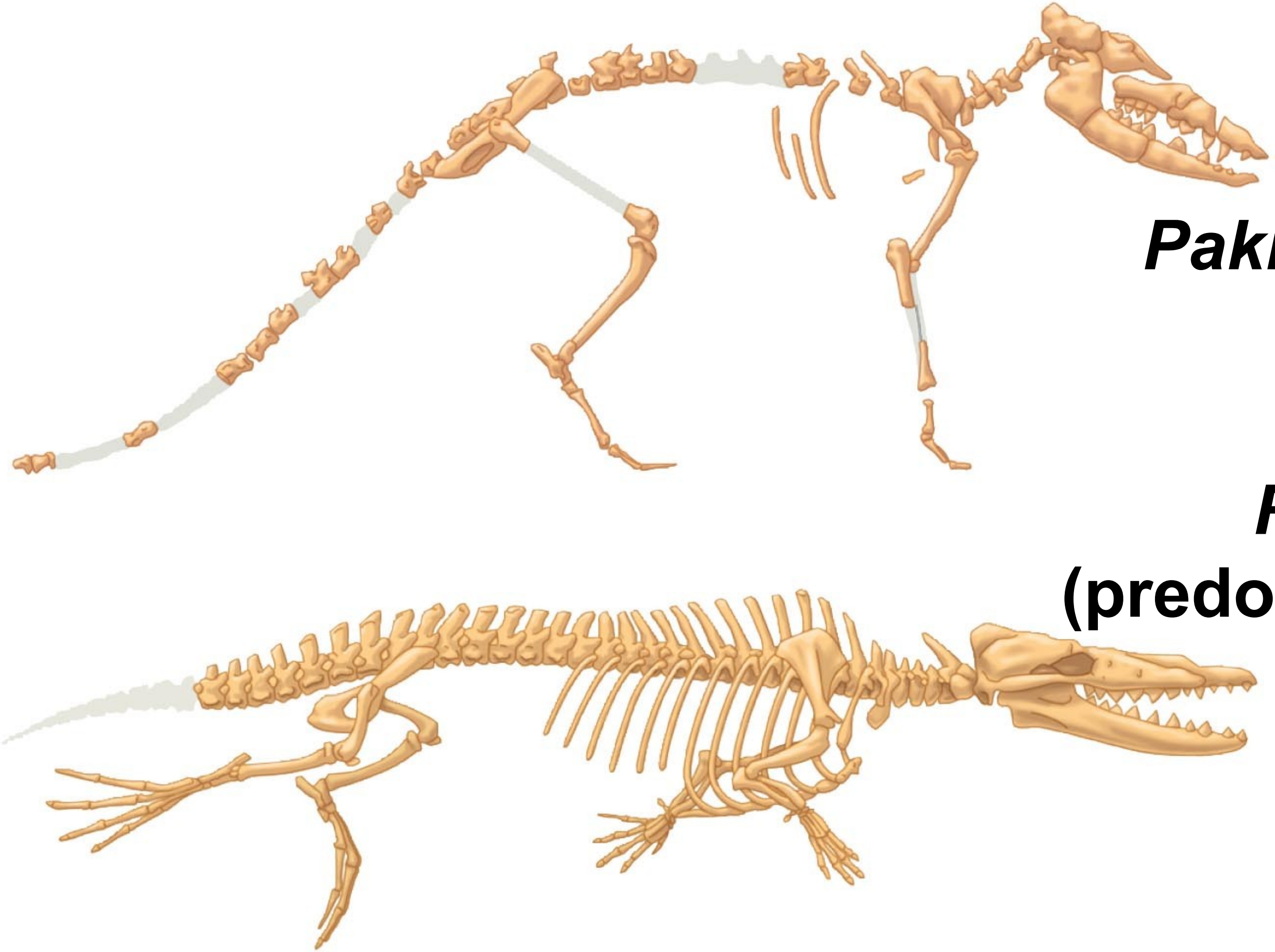
- Antibiotic resistance

- Industrial melanism in *Biston betularia* (Peppered moth)

Evidence for evolution from fossils

Many fossils link early extinct species with species living today

e.g. A series of fossils documents the evolution of whales from a group of land mammals

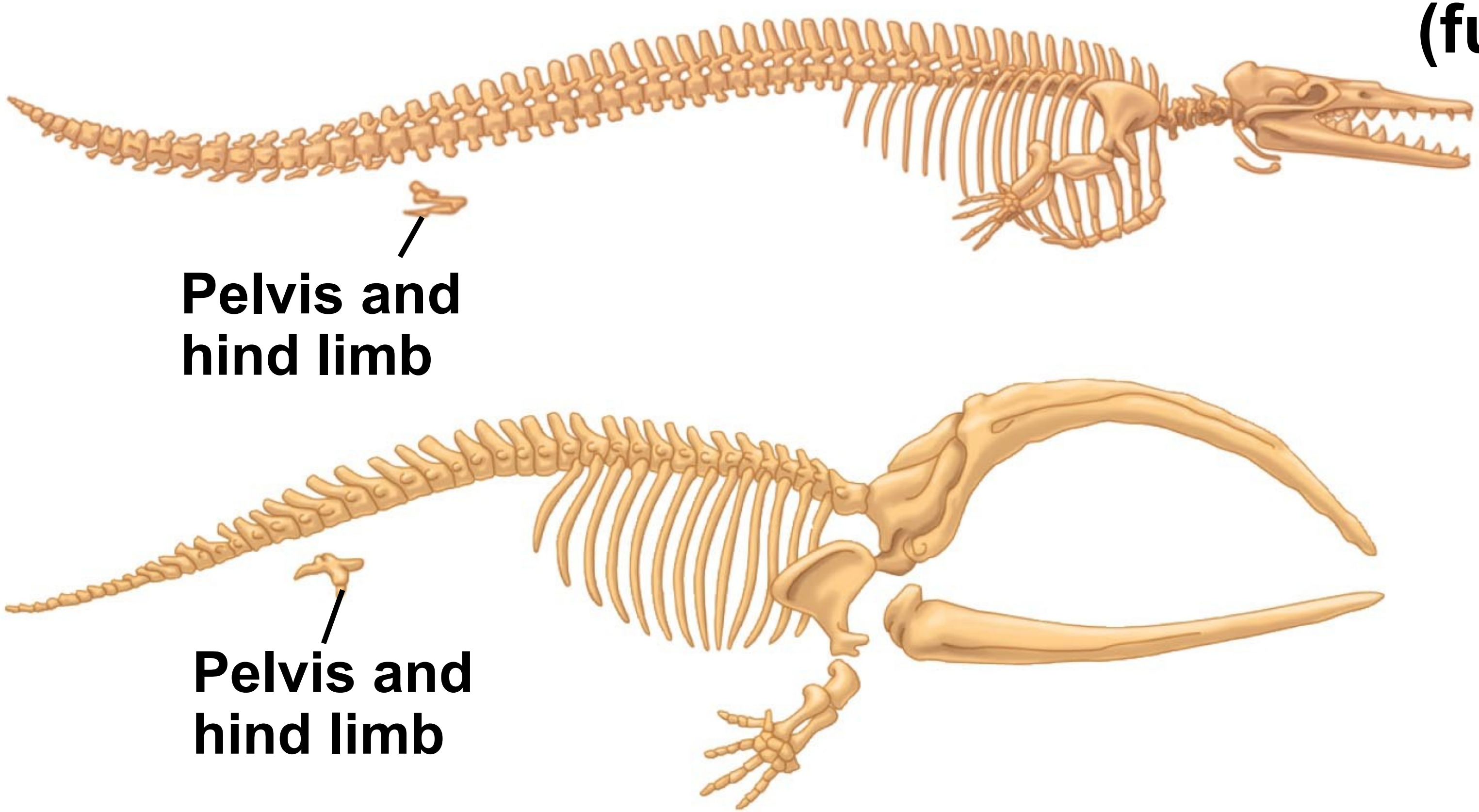


Pakicetus **(terrestrial)**

Rhodocetus
(predominantly aquatic)

Adapted from slide by Joan Sharp, Pearson Education Inc

Dorudon
(fully aquatic)



Balaena
(recent whale ancestor)

Prerequisites for evolution by natural selection

1) Variation in traits

- acts on *existing* variation.

  e.g. Mice cannot be directly selected to have larger wings (but can be selected to have longer teeth). However, if wings appeared in a mouse population due a novel mutation, the frequency of wings can increase through selection

2) Heritability

unless a trait is heritable, natural selection cannot act on it.

3) Differences in fitness

there can be no selection if there is no difference in fitness.

Natural selection has no goal, no predefined end point, no race for perfection.

Organisms DO NOT purposefully acquire traits that they need

Natural selection DOES NOT act for the benefit of a species or provide what it needs

- Humans *(Homo sapiens)* are also a product of evolution

- Like other organisms, the presence of many traits we have (including behaviours) can be easily explained by an inherent 'drive' to increase fitness

    Evolutionary psychology

Reflection points

- Why did you do the things that you did today (e.g., consumed breakfast, took a shower)?
- Why are you reading this?

Try to think in terms of explanations related to evolution and fitness.

Reflection point

- Are traits in human beings evolving?

Artificial selection

Artificial selection is induced by man. It has predefined goals & end point and strives for ‘perfection’

Examples of artificial selection

Rice plants with more and heavier seeds

More lipid content in oilseeds

Larger fruits

A dog with long legs or floppy ears

A cow that yields more milk

A domestic cat with the spots of a jungle cat

Adapted from slide by Hema Somanathan

Reflection point

- Language tends to change over time. Are there parallels between biological evolution and the way languages change?
- Likewise, are there parallels between biological evolution and the way cuisine changes?

Selection pressures may conflict, leading to *trade-offs*

Adapted from slide by Jana Vamosi

Reflection point

Consider body size in a population of prey animals. Assume that larger size confers higher fitness because of greater tolerance to harsh climatic conditions, and that smaller size confers greater fitness due to predator avoidance. What might happen to body size of the population?

Sources of heritable Variation

Mutations are the main source of variation

- A mutation can is caused when the chromosomal machinery makes a mistake. For e.g., during replication
  - a nucleotide is ‘lost’ (*deletion*)
  - a nucleotide is added (*insertion*)
  - a nucleotide is replaced with another (*substitution*)

Mutations create new alleles.

Mutation at the Phenotype Level

- Mutations (or, the alleles created by them) can be:
  - beneficial
  - detrimental
  - Neutral

  But this depends on the environment.

Adapted from slides by Jana Vamosi

Other sources of variation

- *Gene flow*: immigration can bring in new genetic material into a population
- *Recombination*
- *Gene duplication* or *Chromosomal duplication*: If a gene is duplicated, a copy can undergo mutation without affecting the other copy

Adapted from slides by Jana Vamosi

Variation is random

- When a new recombinant or mutant genotype arises, there is no tendency for it to arise in the direction of improved adaptation

- Natural selection imposes direction on evolution, using undirected variation

Adapted from slides by Jana Vamosi

Genetic Drift

Traits can evolve even without natural selection through chance. This is called *Genetic Drift* (or Random Genetic Drift)

Genetic drift - "**a change in the gene pool of a population due to chance**"

- In practice, not easy to know whether a trait has evolved due to selection or drift

Example of genetic drift in a small population – '*founder effect*'

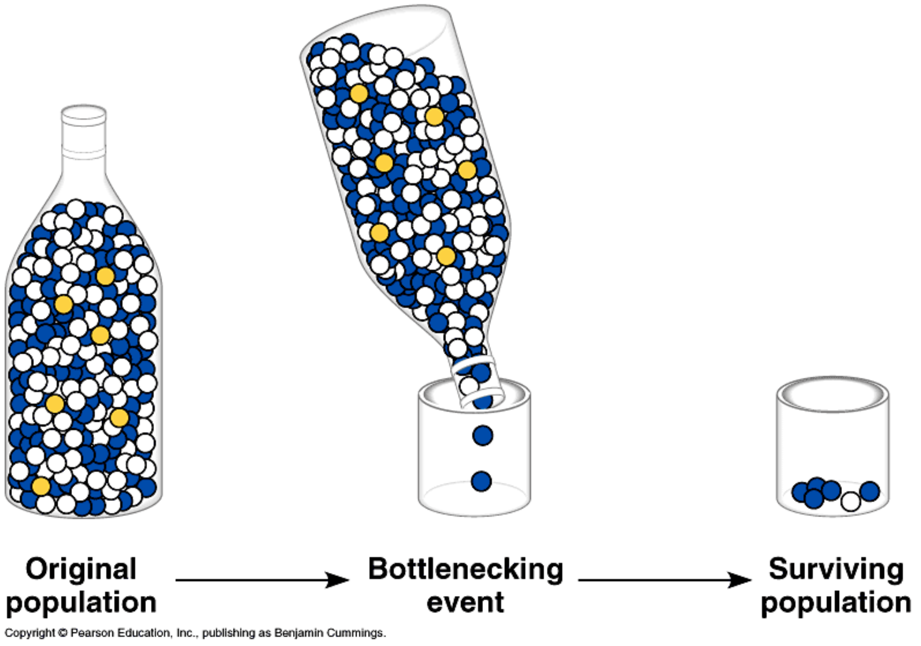


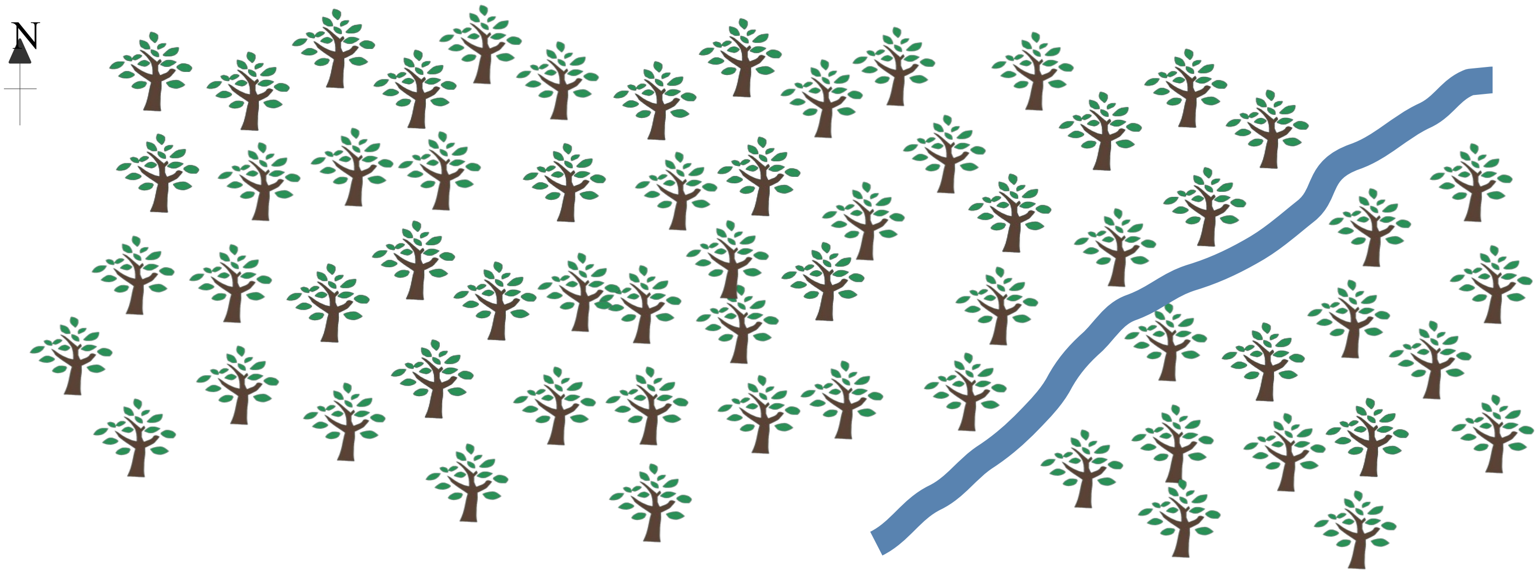
Fig source: Pearson Education Inc

Founder effect is one way in which a population undergoes genetic drift.

- A *bottleneck effect* can also lead genetic drift. Here, the population is reduced to a small size (i.e., small number of individuals) and population size can later increase.

- Genetic drift can happen even without *founder* and *bottleneck effects*

Reflection point



Tree image source: KnowItSome via Wikimedia Commons

A forest fire spreads starts from the North West, and spreads until the river, leading to high mortality in the tree population. Allele frequencies change after forest fire.

Was the change in allele frequency a result of selection?

Allele frequencies within a population can change through

- Selection
- Genetic Drift
- Gene flow (both *immigration* and *emigration*)

Therefore, all of the above processes can lead to evolution of a population

Reflection point

We often state that a phenotype or trait has a particular 'function'. For e.g., one can say that a polar bear's thick fur has a function.

What is 'function' from an evolutionary perspective?

Concepts: Frequency Distribution and Histograms

(Worked example discussed in the class)

Frequency distributions of heights of people in a population

Frequency (absolute & relative)

Mean, Variance, Range, Mode

Fitness function: Relationship between a trait and the fitness it confers

Fitness proxy: Since fitness cannot be measured directly, we can instead measure something that should be strongly correlated with fitness.

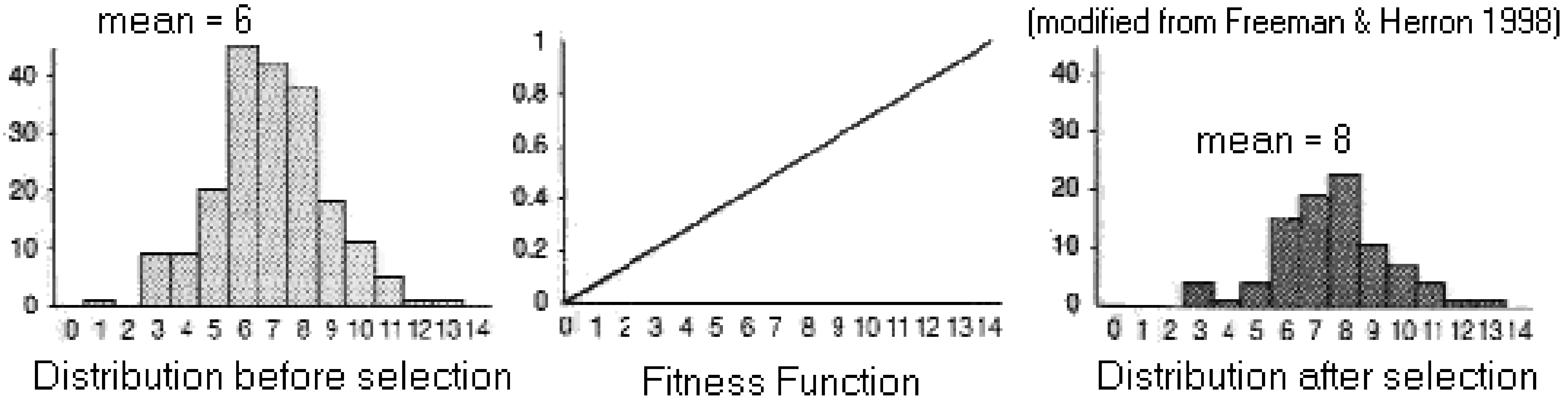
- E.g., Survival rate (or, survival proportion), fecundity, time taken to attack (in case of traits that function against predation), germination percent, growth rate

Types of Selection

Three types identified based on how selection changes trait distributions

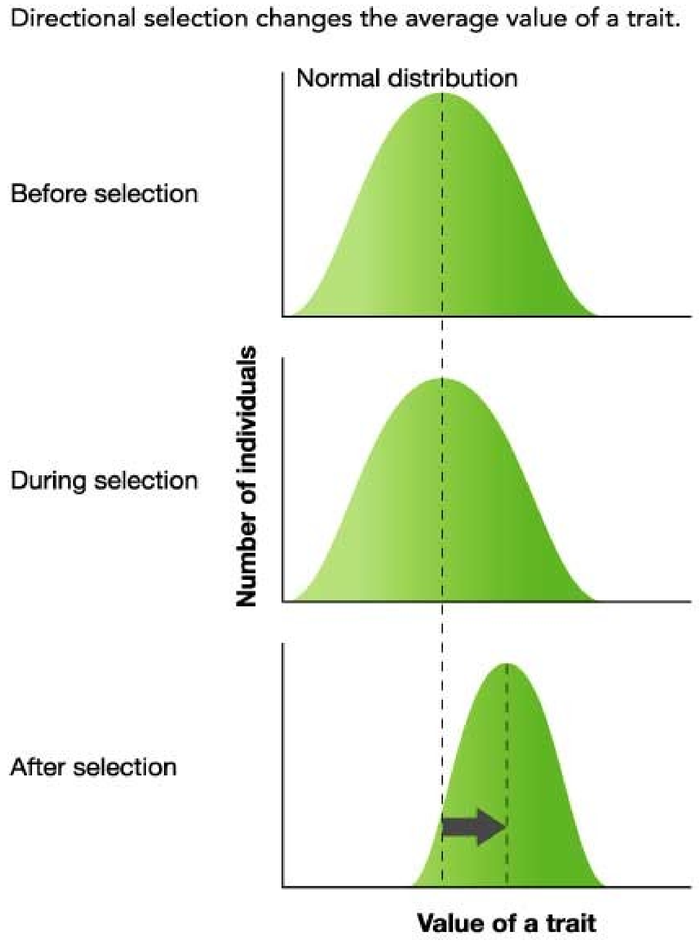
- Directional selection
- Stabilizing selection
- Disruptive selection

Directional Selection



Selection favours extreme (highest or lowest) trait values. This leads to a shift in the distribution towards higher or lower values. *Increases/decreases mean*

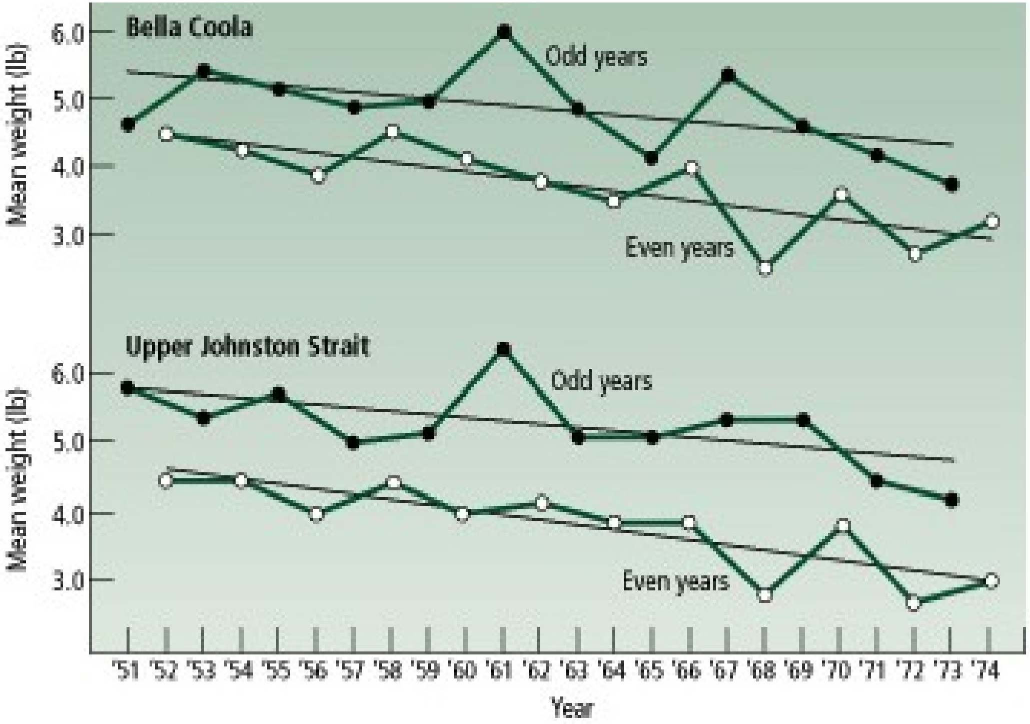
Range may also change along with change in mean



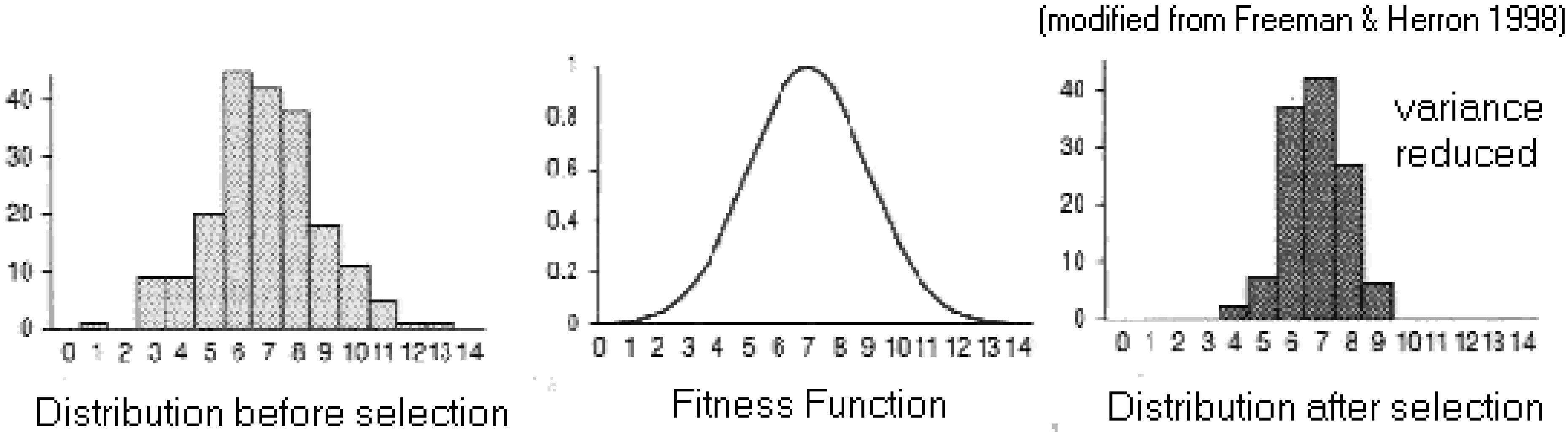
Adapted from slides by Allison Welch

Directional selection by fishing on pink salmon *Onchorhynchus gorbuscha*. The graph shows the decrease in size of pink salmon caught in two rivers in British Columbia since 1950, driven by selective fishing for the large individuals. Two lines are drawn for each river: one for the salmon caught in odd-numbered years, the other for even years. Salmon caught in odd years are consistently heavier, presumably because of the two year life cycle of the salmon. From Ricker (1981)

Figure source:
Blackwell scientific



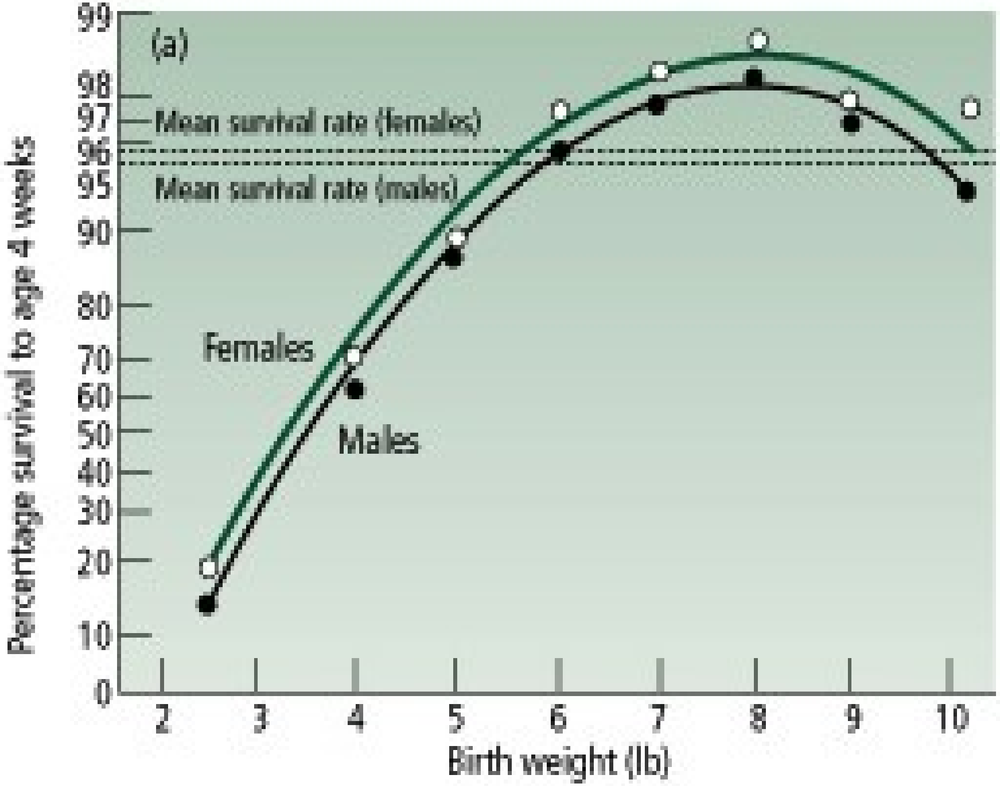
Stabilizing Selection



Selection favours intermediate trait values.

Reduces variance.

Adapted from slides by Jana Vamosi

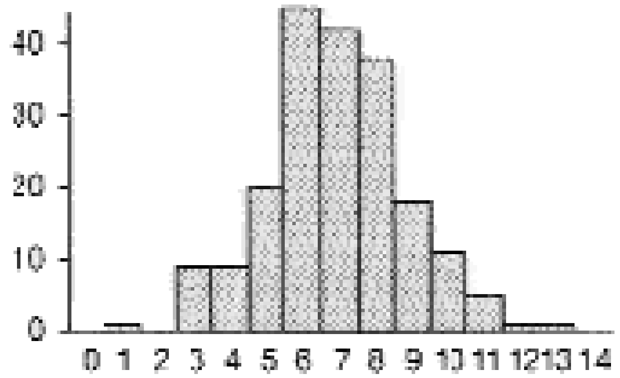


In humans, babies of intermediate
birth weight have higher chance of survival

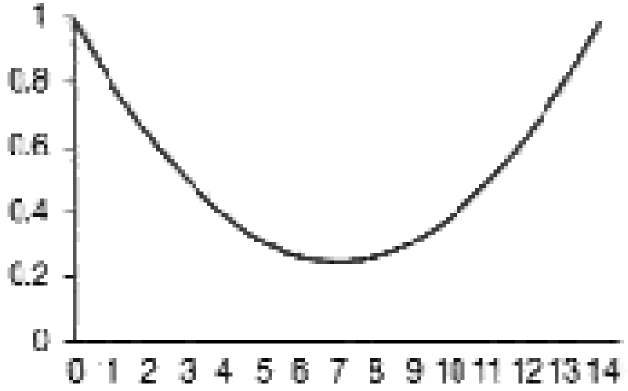
Figure source: Blackwell scientific

Disruptive Selection

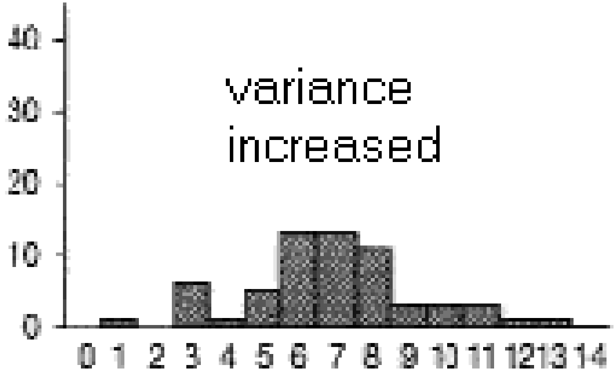
(modified from Freeman & Herron 1998)



Distribution before selection



Fitness Function



Distribution after selection

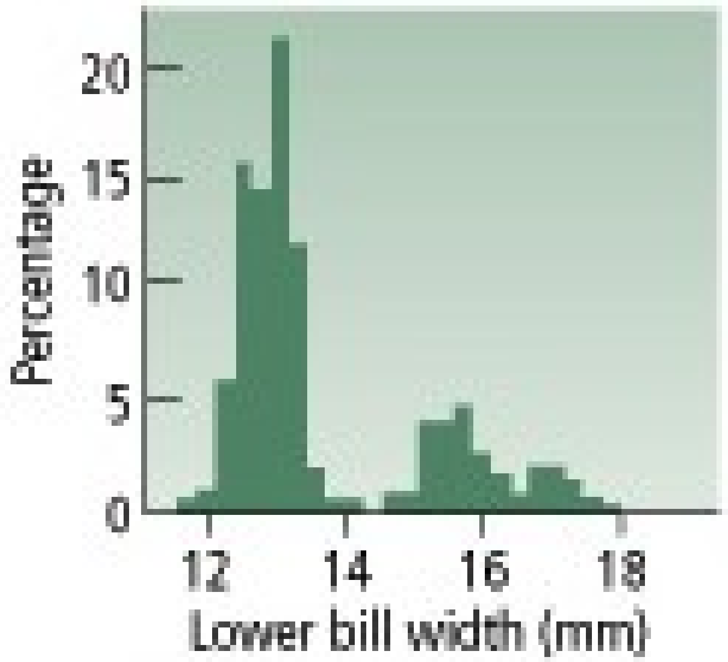
Selection favours the extremes trait values.

Increases variance. Can lead to a bimodal distribution

Adapted from slides by Jana Vamosi

In the seedcracking finch, *Pyrenestes ostrinus*, beak size is bimodally distributed. Very large and very small bills are beneficial for eating large and small seeds, respectively.

Figure source:
Blackwell scientific



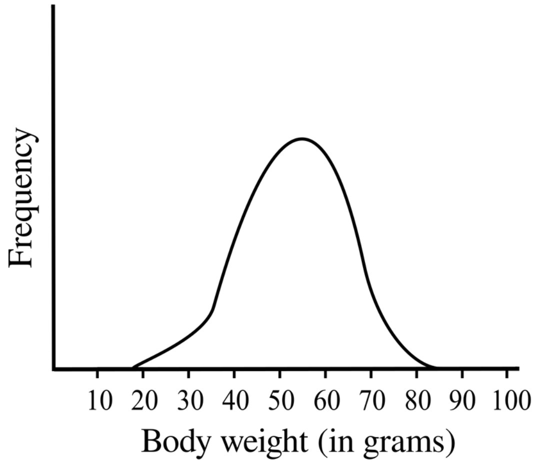
Directional selection – change in population mean

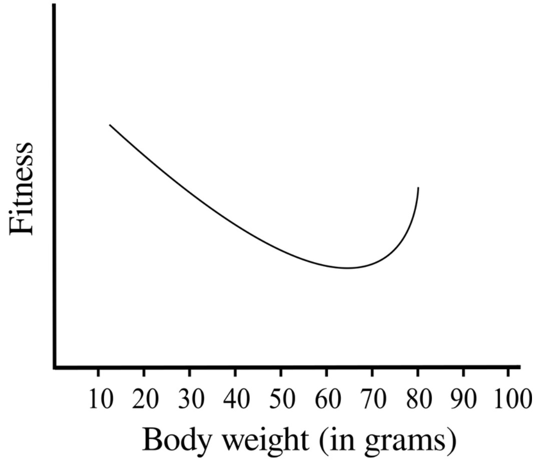
Stabilizing selection – reduced variation, no change in mean

Disruptive selection – increased variance, no change in mean

In nature, selection can be a combination of two or more types of selection

Reflection point





Given the distribution of body size and fitness function in a rodent population, can you predict how the distribution will look like after many generations?

Selection is also sometimes classified under

- **Viability/Survival selection**
- **Fecundity/Fertility selection**