BIO 111 - Principles Of Life I: Biomolecules, Genetics And Evolution

Module: Evolutionary Biology

Part I: Basics of Evolution

Varsha 2025

Ullasa Kodandaramaiah

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

- <u>Erasmus Darwin (1731-1802)</u>

  grandfather of Charles Darwin

  one of the first to propose that species change over time

- <u>*George Cuvier (1769-1832)*</u>

  palaeontologist

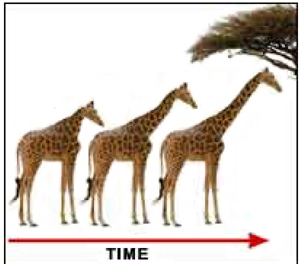
  observed that many species with fossils don't exist any more – *extinctions*

- 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*'

- Charles Darwin and Alfred Wallace

  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

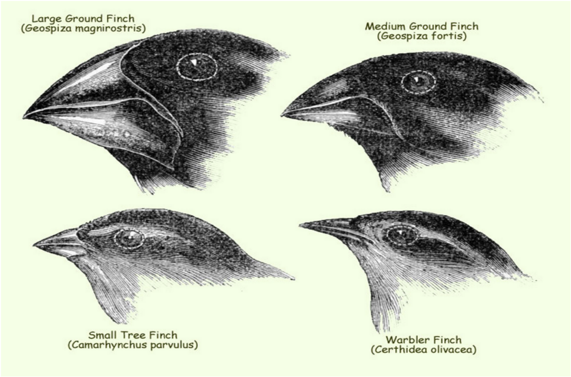
Galápagos Islands

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

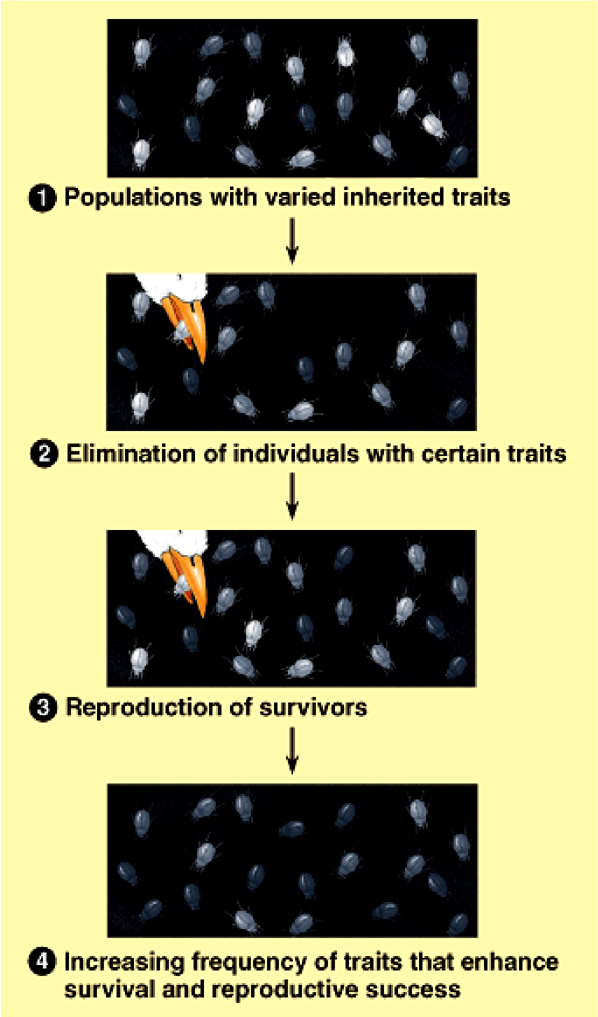
- Knew that many species clearly have certain traits that help them survive in certain environments (i.e. traits affected probability of survival)

Adapted from slides by Merrill Peterson

- 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

EVOLUTION mediated by NATURAL SELECTION

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 through natural selection

(We will discuss in a future lecture how selection can lead to origin of new species)

- **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**

Trait variation – broad term about differences among individuals in a particular trait

- Trait variation can be either *continuous* or *categorical*
- E.g of Continuous: Height, Weight

  E.g of Categorial:

  - Tall/Short (when we classify individuals in a group under these categories)
  - Flower colour in a plant species that has only red, white and pink flowers

When variation in a particular trait is categorical, these categories can be called **trait variants**

- 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 (phenotypes) are determined by one or more genes.

- An *Allele* is a variant of a gene.

Allele frequency: Number of copies of allele/Total number of copies of all alleles of the gene

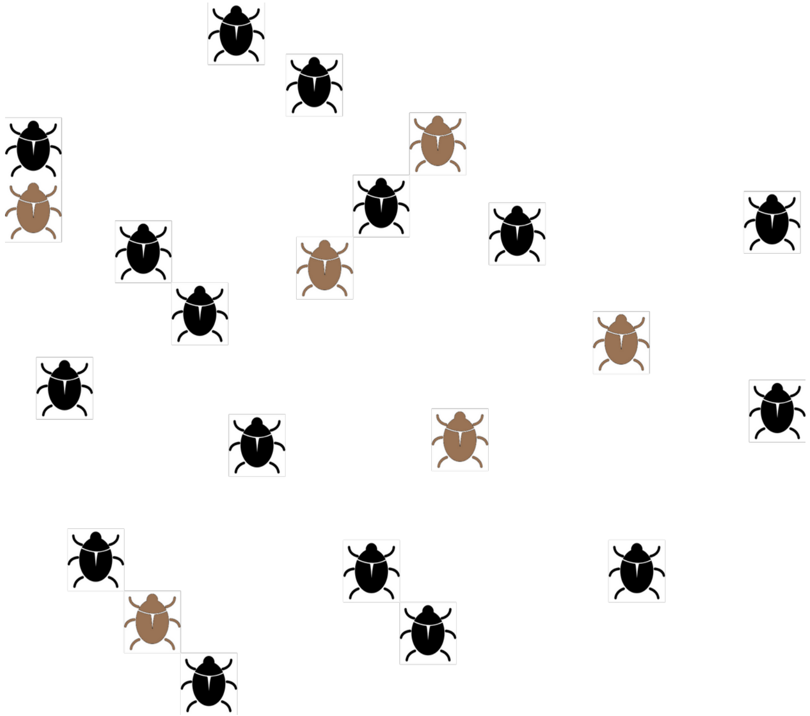
Phenotype/Trait frequency: Proportion of individuals in a population with a phenotype (or trait, or trait variant)

Consider a hypothetical haploid insect species with two 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 : ‘……….ATGGATCACTTGGAG……….’

BR: ‘ ……….ATCGATCACTTGGAG……….’

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

Here, the frequency of *BR* allele is the same as the brown phenotype

After some generations of selection, the frequency of the *BR* allele (and brown phenotype) 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 '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

When allele frequencies of a gene change, the frequencies of phenotypes/traits controlled by the gene also change.

Therefore, the previous definition of evolution - *change in inherited traits of a populations* – is compatible with the one based on allele frequencies

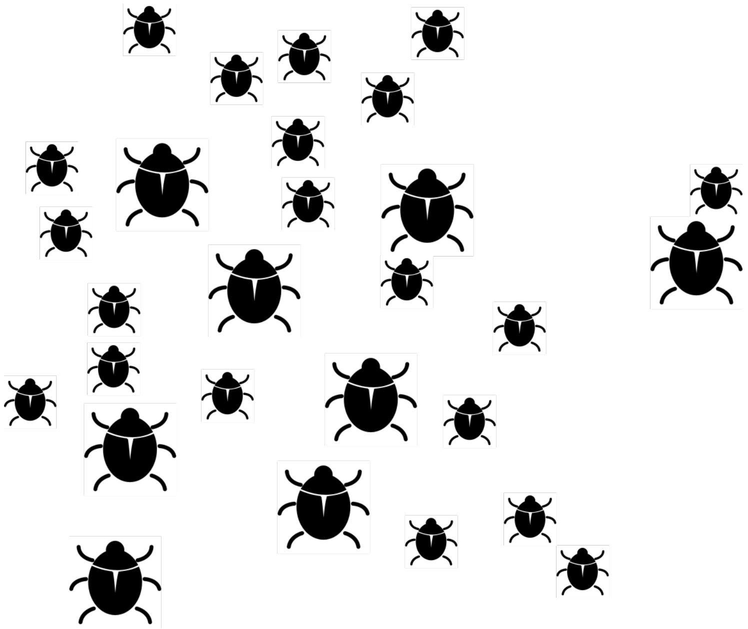
A change in population size is not a necessary component of evolution.

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.

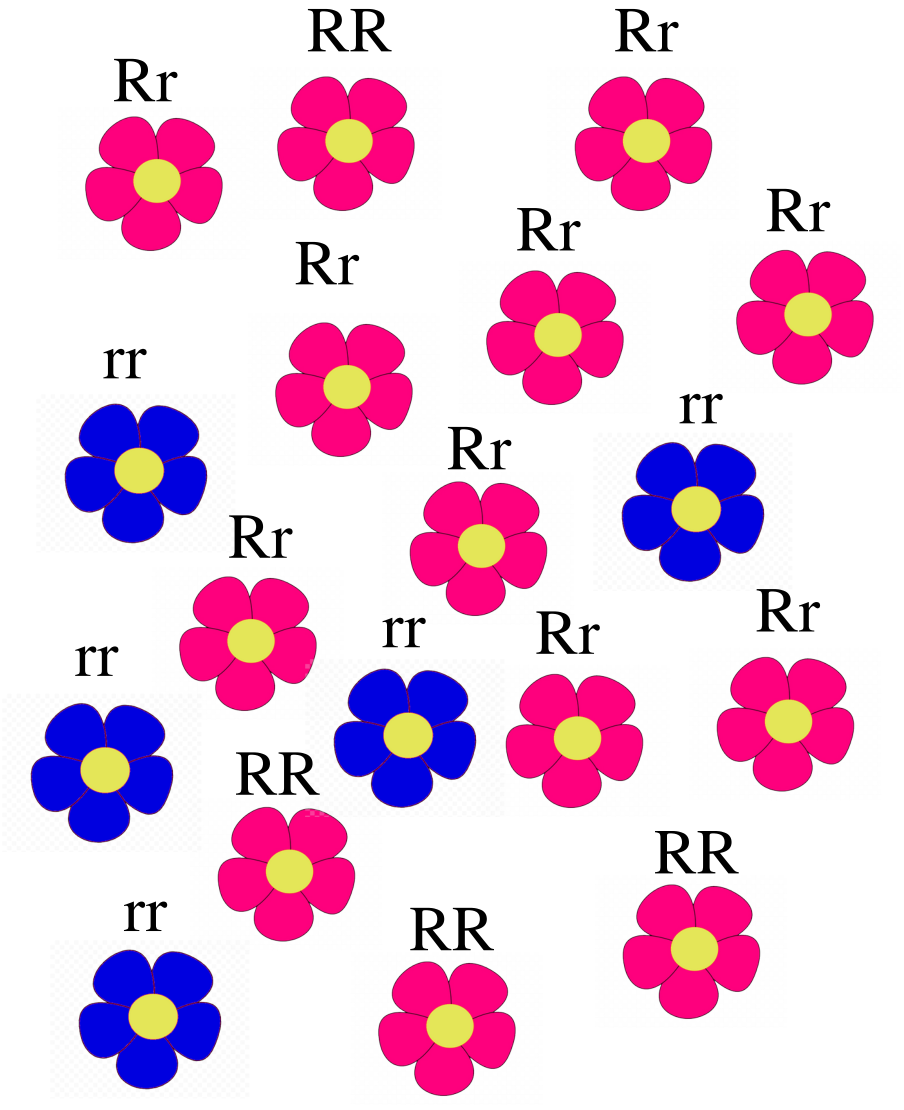
In nature, however, there is usually an upper limit on population size because of resource constraints

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*



In a population, flower colour is determined by a gene with two alleles, R and r. RR and Rr genotypes code for pink flowers, while rr codes for blue flowers

Allele frequency of R: 17/36 = 0.472
Allele frequency of r: 19/36 = 0.528

Phenotype frequency of Pink: 13/18 = 0.722
Phenotype frequency of Blue: 5/18 = 0.278

Reflection point

- Assume that pollinators prefer blue flowers. What do you expect will happen to flower colour and allele frequencies?

Fitness

Related to **Fecundity & Survival**

- ***Evolution favours traits (or trait variants) 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.

A trait or a trait variant can enhance fitness by

improving survival

and/or

increasing fecundity

Important to remember that an individual cannot reproduce if it cannot survive until reproduction.

If *trait A* confers higher fitness compared *trait B*, *trait A* is said to have higher fitness.

Therefore, selection favours *traits/phenotypes/trait variants* that have higher fitness.

Similarly, selection favours *alleles/genotypes* that have higher fitness.

Adaptation

An 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

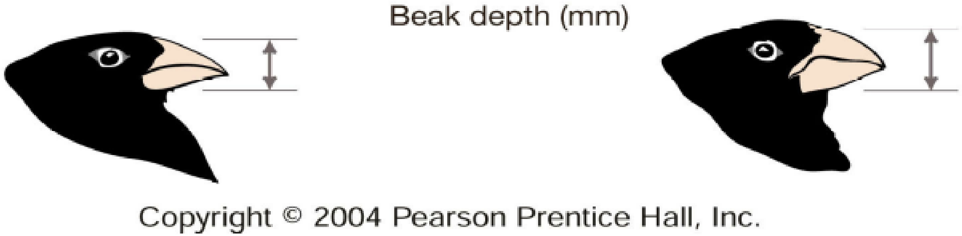
Rosemary and Peter Grant have followed Darwin's finches in the Galápagos island Daphne Major for decades

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

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

Geospiza fortis (Medium ground finch)

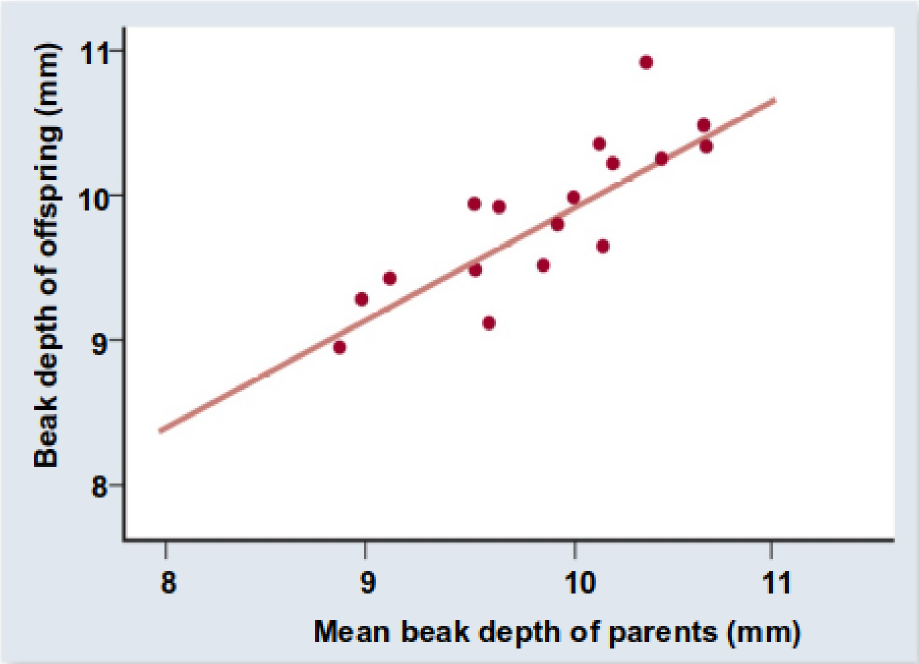
Small beak depth: pointed
Large beak depth: blunt

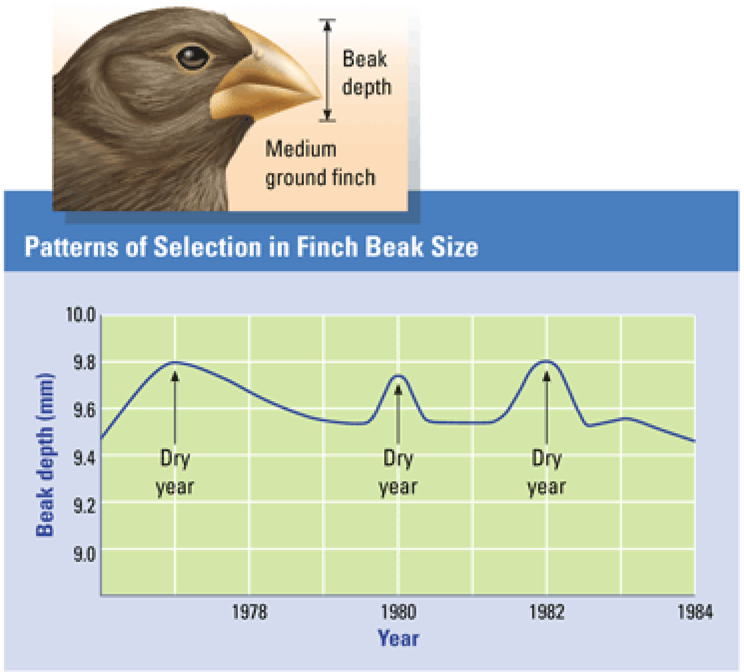


Adapted from slide by Joan Sharp, Pearson Education Inc

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

- Beak depth varies across years, and is greater during the dry years.
- Strong evidence for evolution by natural selection

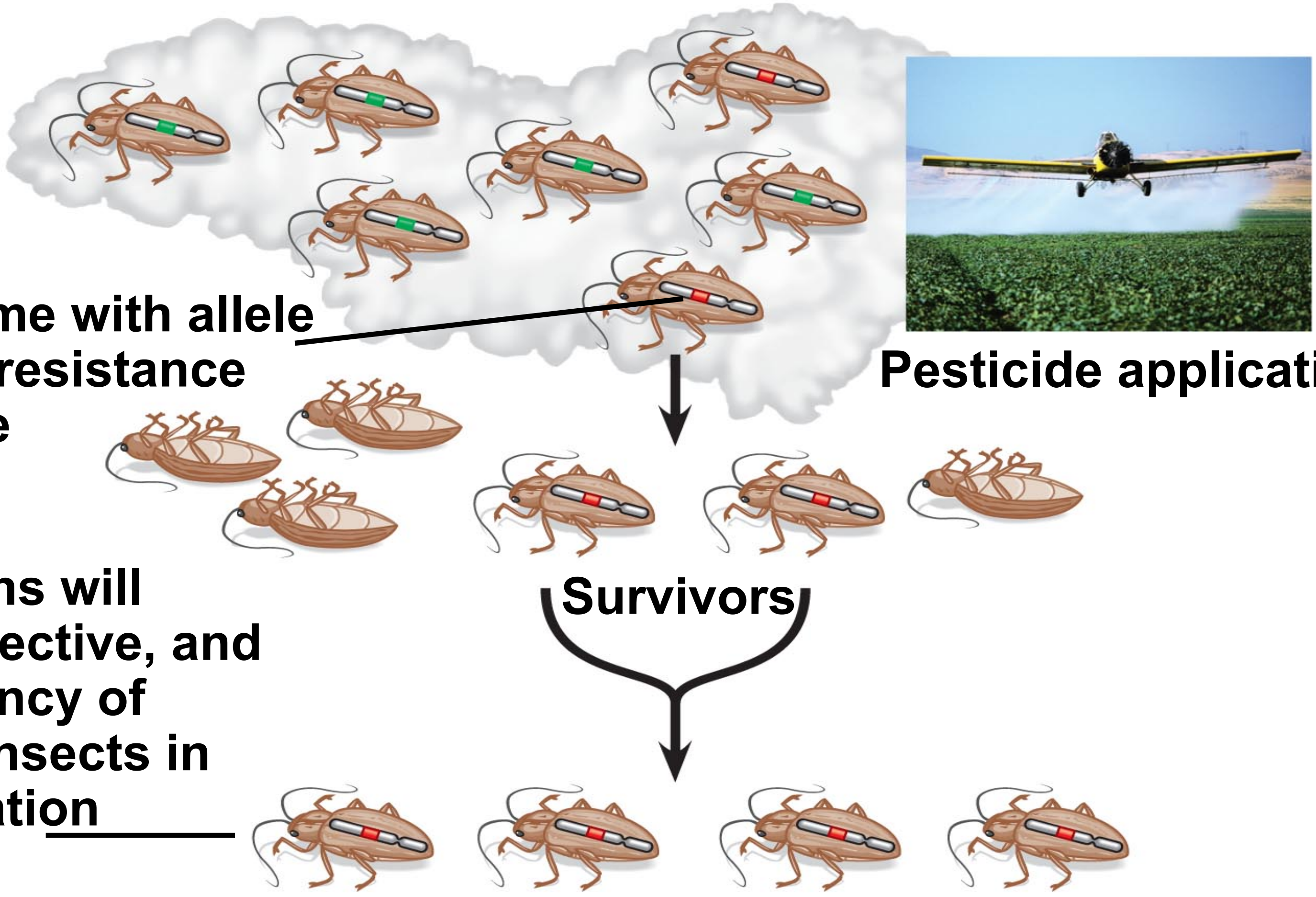
Development of pesticide resistance in insects

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

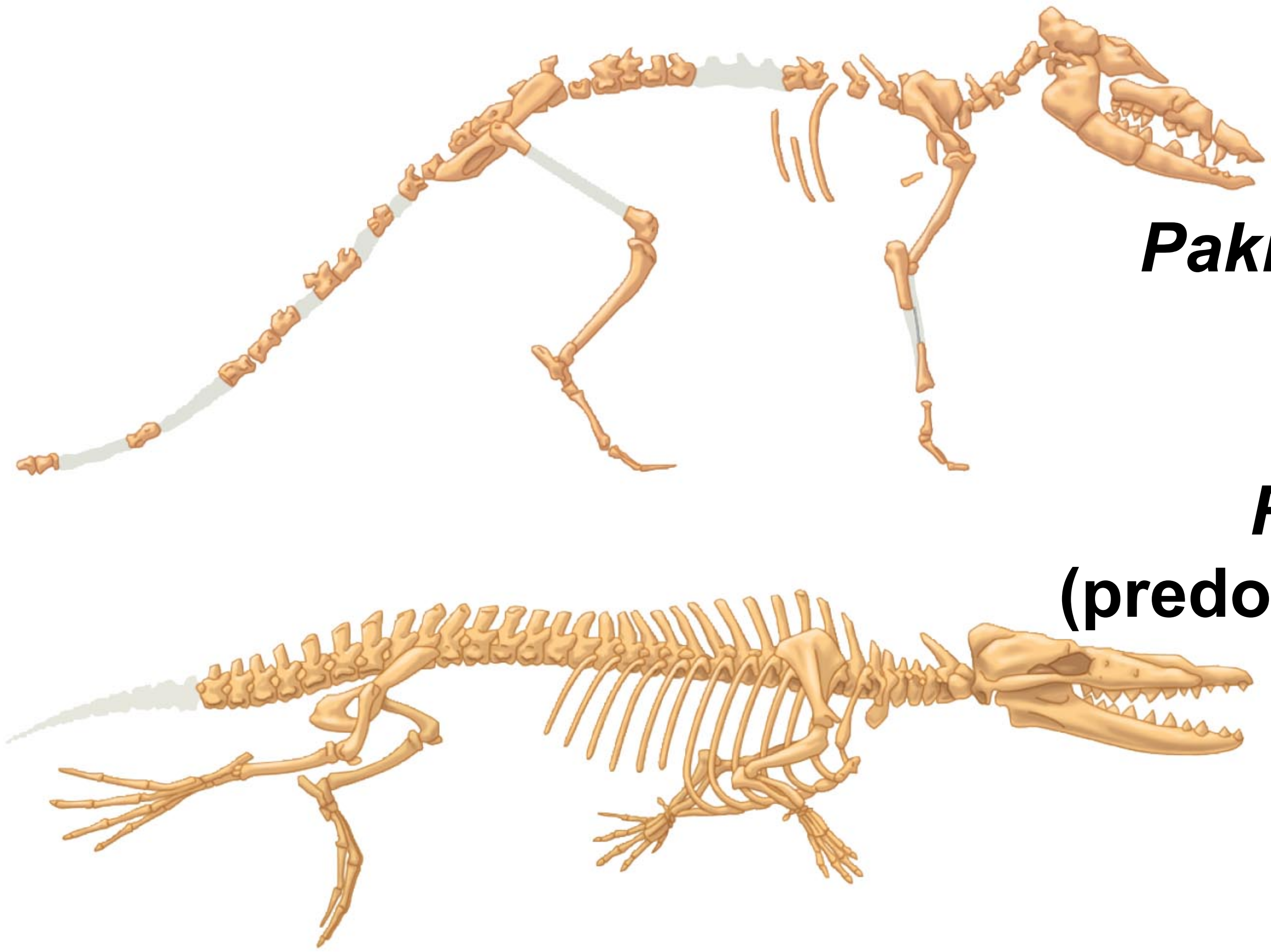
- Industrial melanism in *Biston betularia* (Peppered moth)

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

Adapted from slide by Joan Sharp, Pearson Education Inc

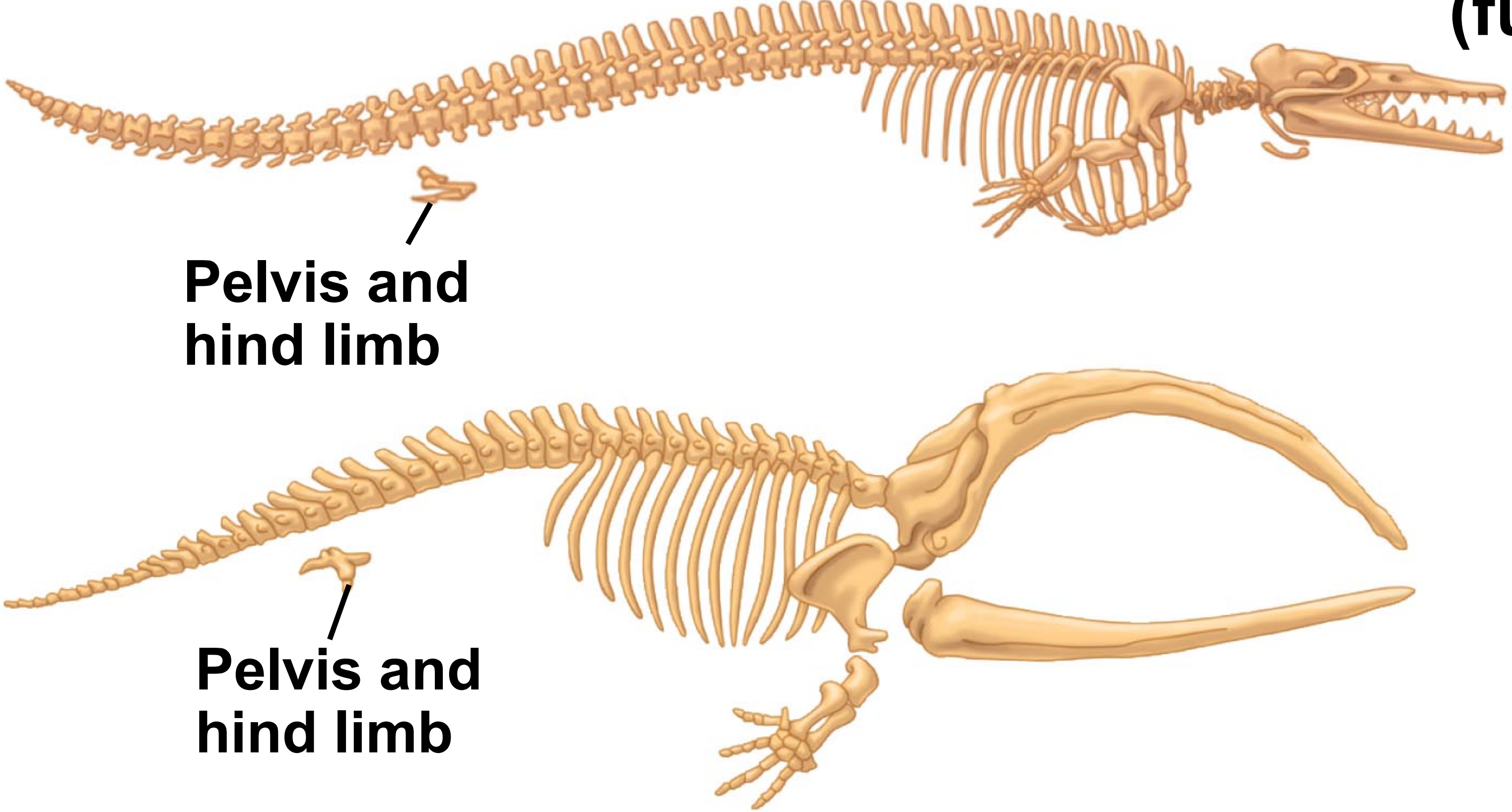


***Pakicetus* (terrestrial)**

Rhodocetus
(predominantly aquatic)

Adapted from slide by Joan Sharp, Pearson Education Inc

Dorudon
(fully aquatic)



Balaena
(recent whale ancestor)

Reflection point

- In the finch population that we discussed in the class, larger beaks can process both smaller and larger seeds. If so, why are larger beaks not selected during all years?

Selection pressures may conflict, leading to *tradeoffs*

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?

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

If there is no difference in fitness between two traits, selection does not favour one of them

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

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

Capra ibex (Alpine ibex) climbing up steep slopes

https://www.youtube.com/watch?v=RG9TMn1FJzc

Reflection point

Ficus species (Photo: JM Garg/Wikimedia)

Ficus species (Photo: Steve Canipe/Pics4Learning)

- How did the ability to climb steep walls evolve in the ibex?
- Why do many plants grow on man-made walls?
- Were walls part of the environment that selected for traits comprising the ability of
  - the ibex to climbing such walls?
  - plants to grow on such walls?

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

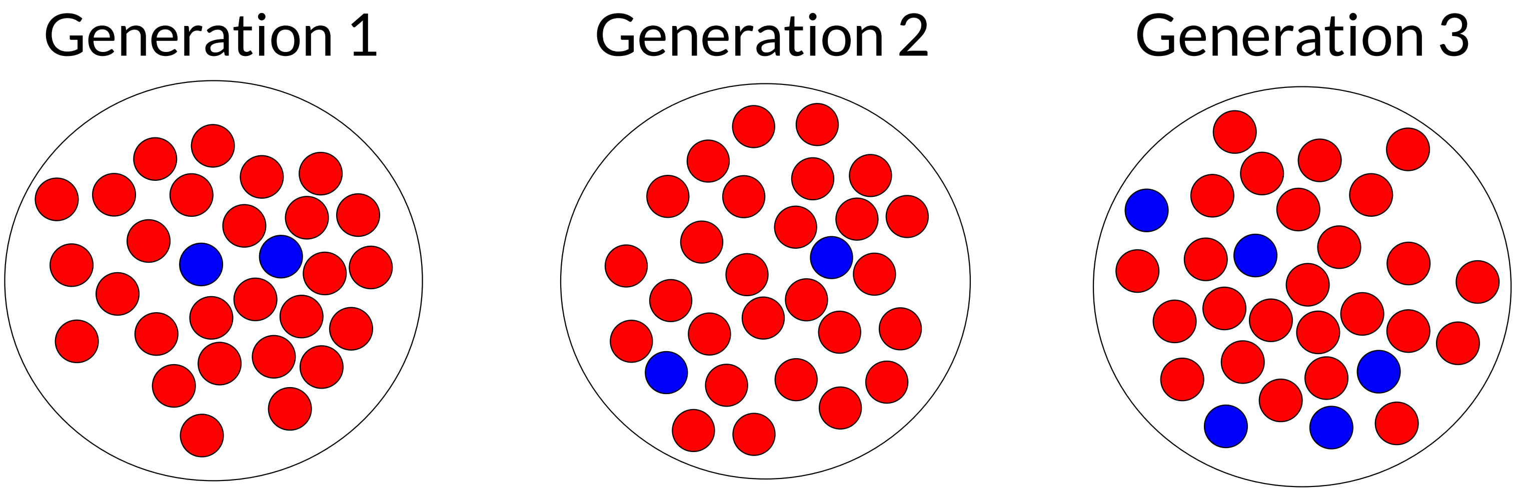
- When a new recombinant or mutant genotype arises, there is no tendency for it to arise in the direction of improved adaptation
- Natural selection imposes direction on evolution, using undirected variation

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 - “**change in the allele frequencies of a population due to chance**”

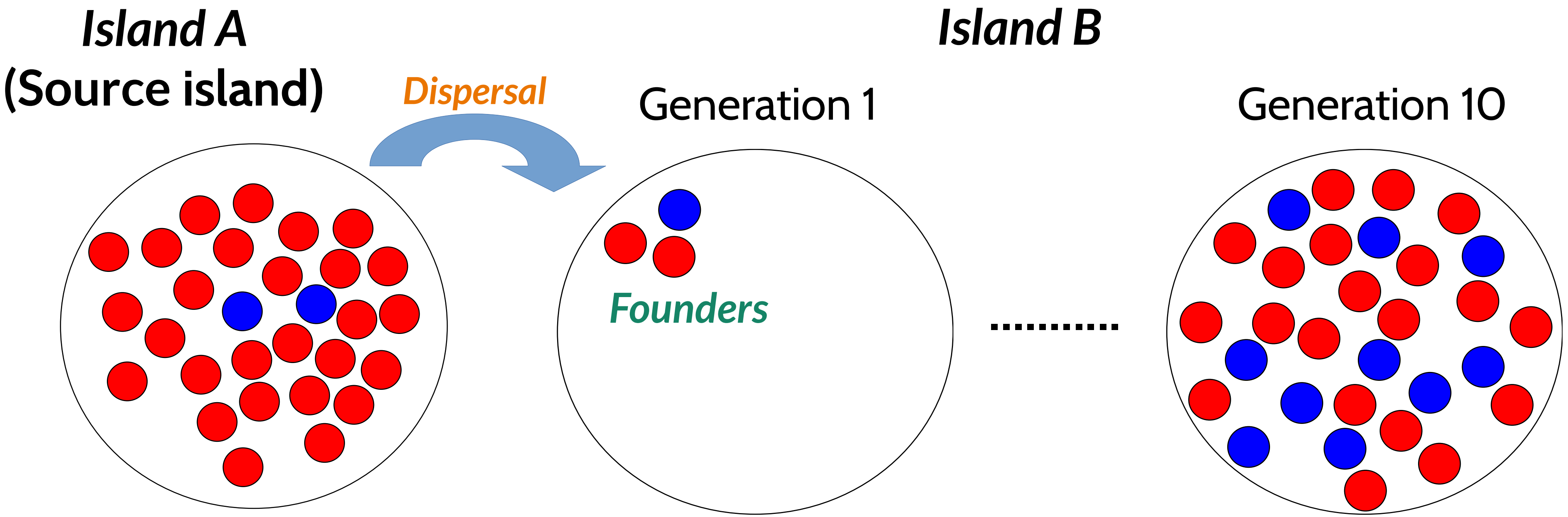


Assume that blue and red represent two alleles of a gene. Both alleles have the same fitness, and, therefore, selection does not favour either blue or red. The frequency of blue does not change from Generation 1 to 2. In Generation 3, the frequency of blue increases due to random chance, without any influence of natural selection. Therefore, the population has evolved through genetic drift.

The probability of genetic drift tends to be higher when population size is smaller.

Further, the rate of evolution (i.e., rate of change in allele frequencies) through genetic drift is greater when population size is smaller.

Genetic drift through '*Founder effect*'



A small number of individual disperse from Island A into a new island - Island B – to start (i.e., found) a new population. These individuals are called *founders.* The founders represent the first population on the island.

Genetic drift through '*Founder effect*'

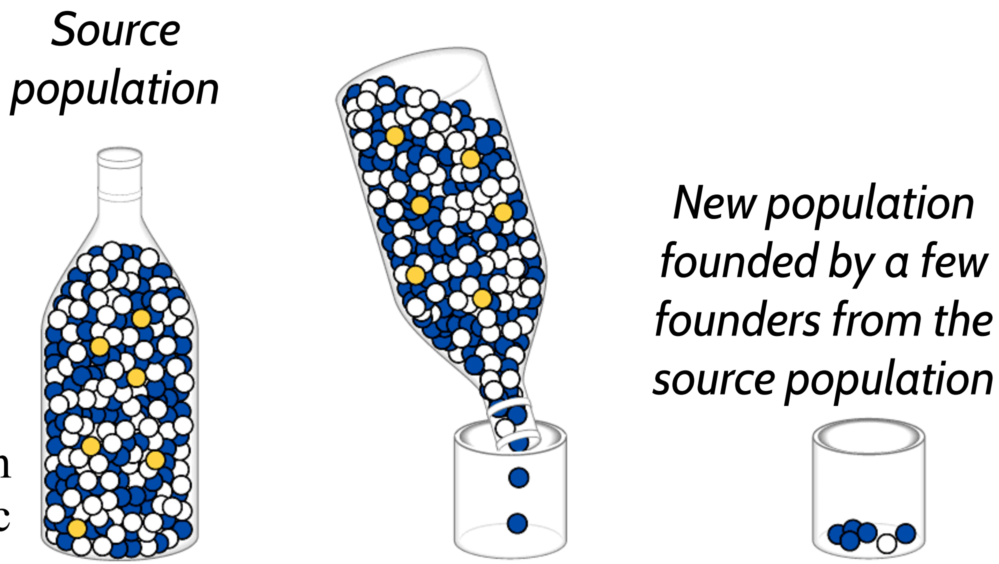
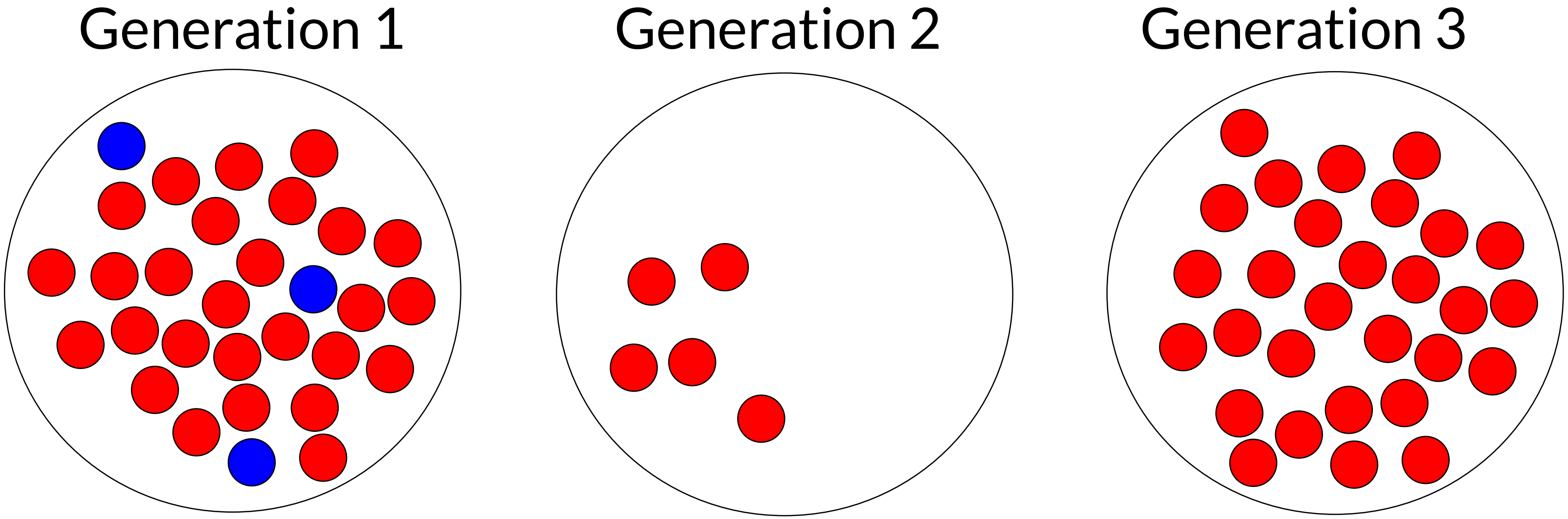


Fig source: Pearson Education Inc

After multiple generations, the population size in Island B increases. The allele frequencies in the new population are different to the allele frequencies in the original population. This is an example of *founder effect*, which is a special case of genetic drift. Note that the source population does not necessarily evolve.

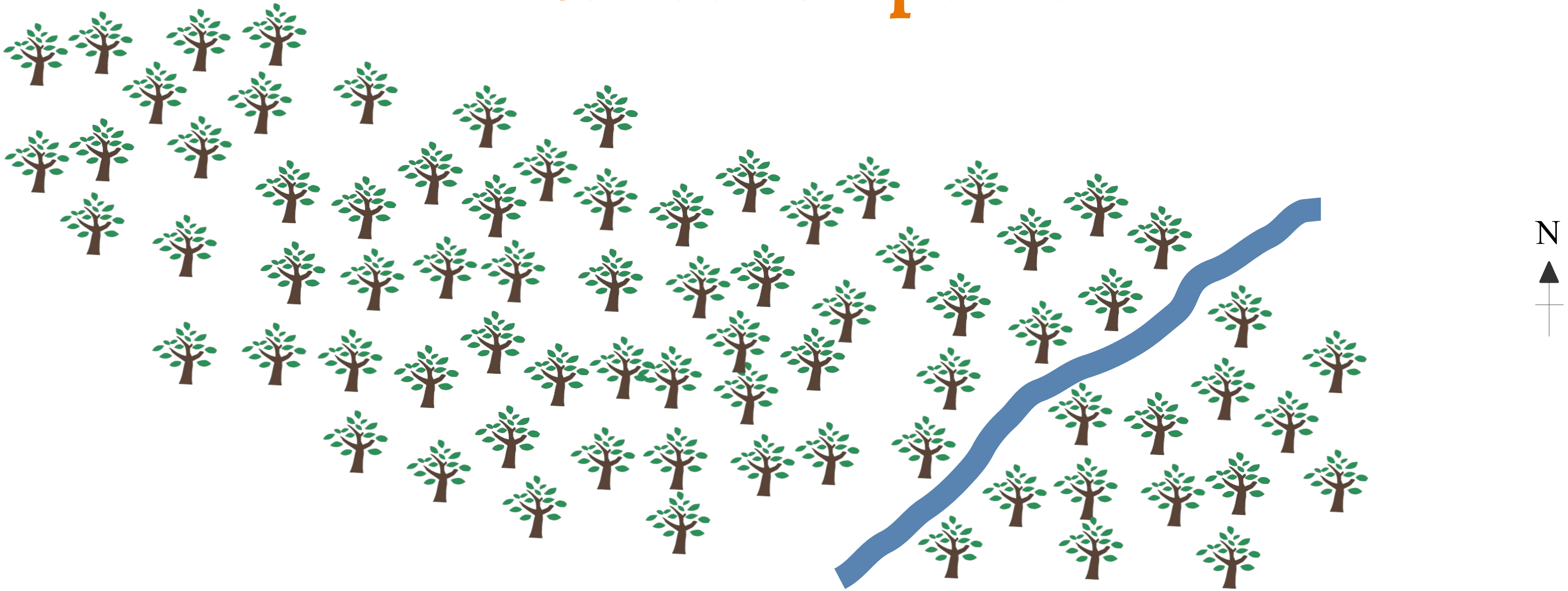
Genetic drift through '*Bottleneck effect*'



A population may also go through a reduction in population size, such that only a small number of individuals are left at one point in time, i.e, the population goes through a bottleneck. The population size may increase later. But, the allele frequences may have changed through random chance. This is an example of genetic drift through the *bottleneck effect*.

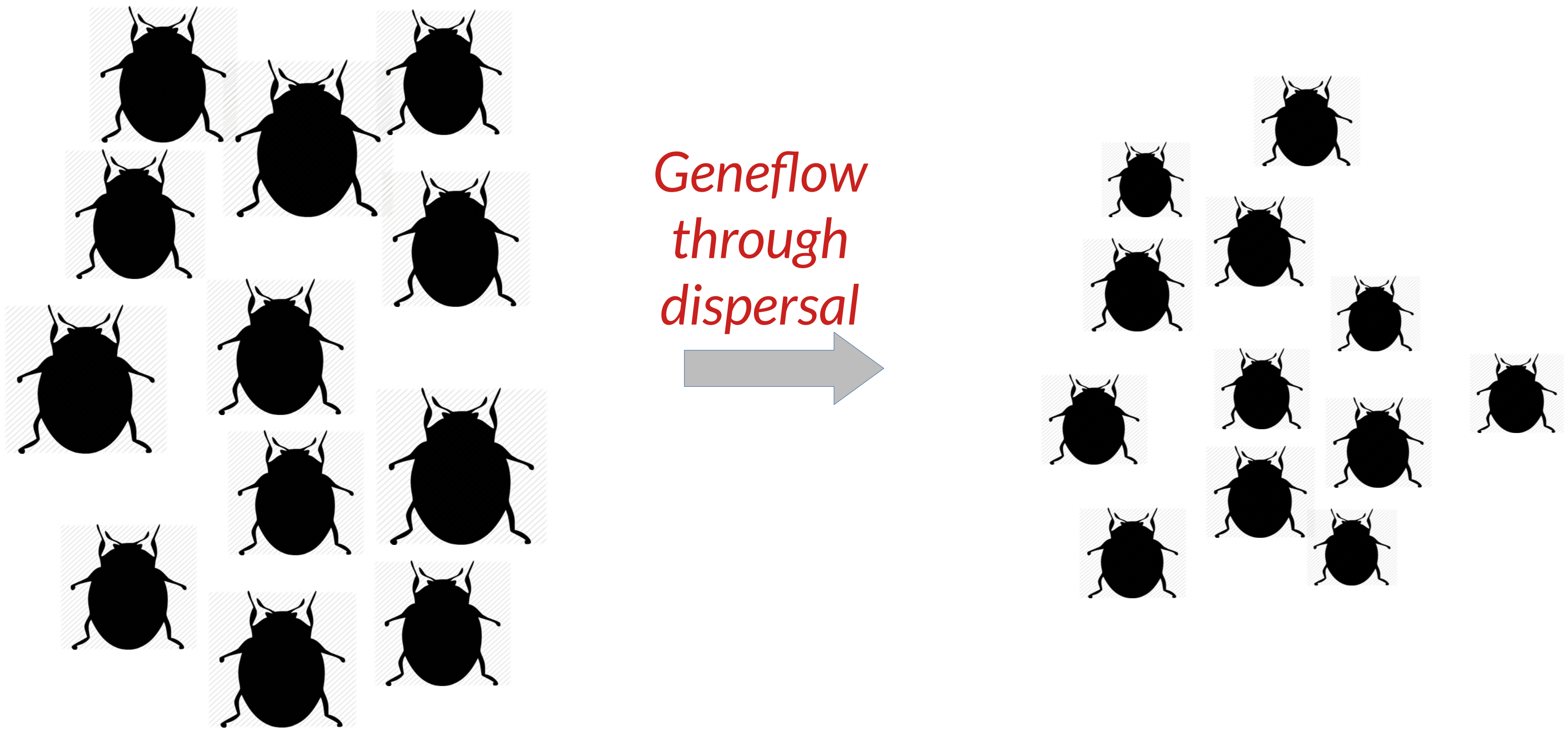
- Genetic drift does not always involve founder or bottleneck effects.
- Founder effect and Bottleneck effect are special types of genetic drift.
- In practice, it is not always easy to determine whether a trait we see today has evolved due to through natural selection or genetic drift . However, if a trait provides a fitness benefit today, we can conclude that it quite likely evolved through natural selection

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 due to selection or genetic drift?



Consider two populations of an insect species. Body size of population 1 is greater. If a proportion of individuals from Population 1 disperse into Population 2, there is *emigration from* Population 1 and *immigration into* Population 2. Both emigration and immigration can lead to changes in (i) allele frequences, and (ii) average body in their respective populations

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

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.

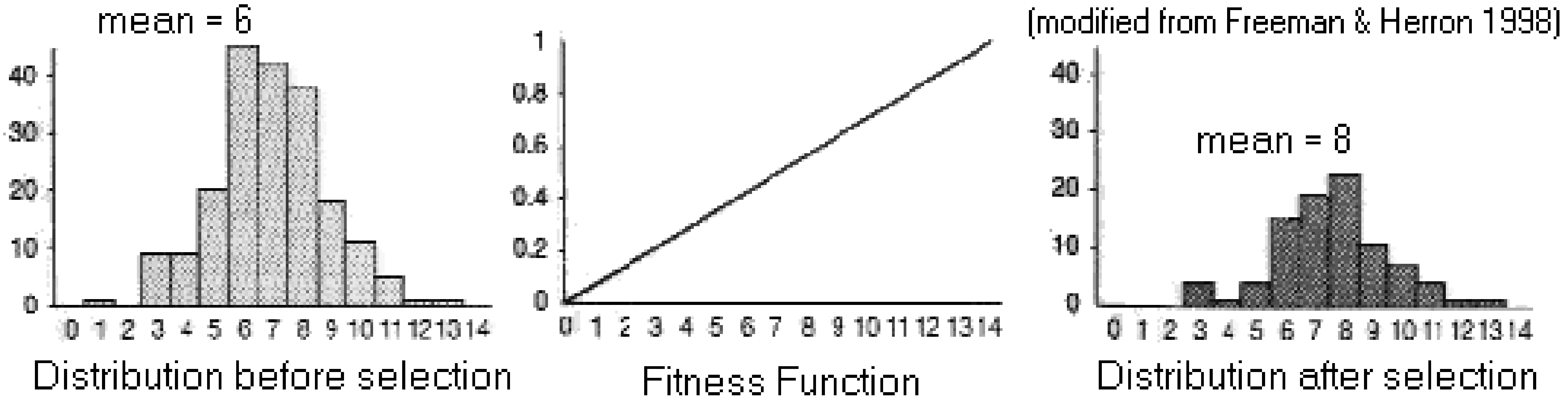
- E.g., Survival rate (or, survival proportion), fecundity, time taken to attack (in case of traits that function against predation), germination percent, growth rate

Types of Selection

Three types identified based on how selection changes trait distributions

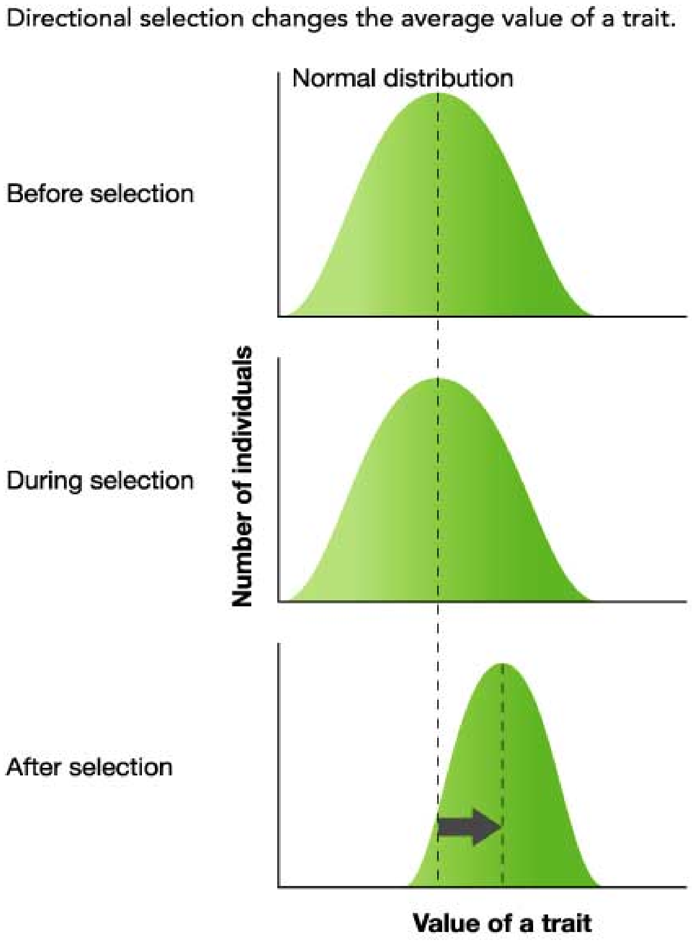
- Directional selection
- Stabilizing selection
- Disruptive selection

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 or may not change



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)

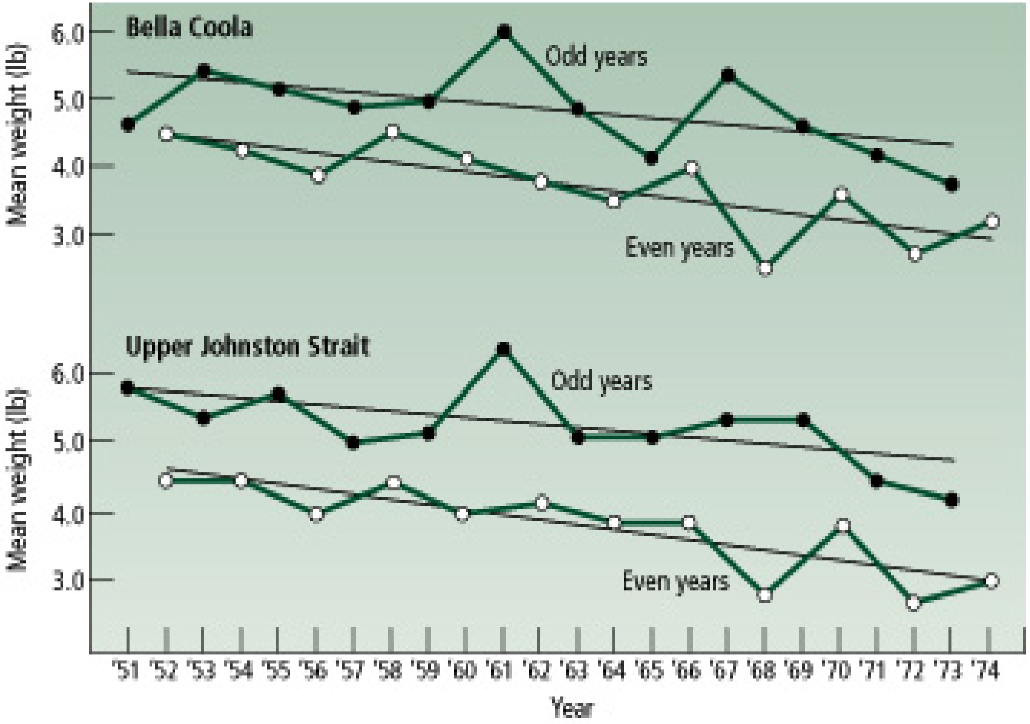
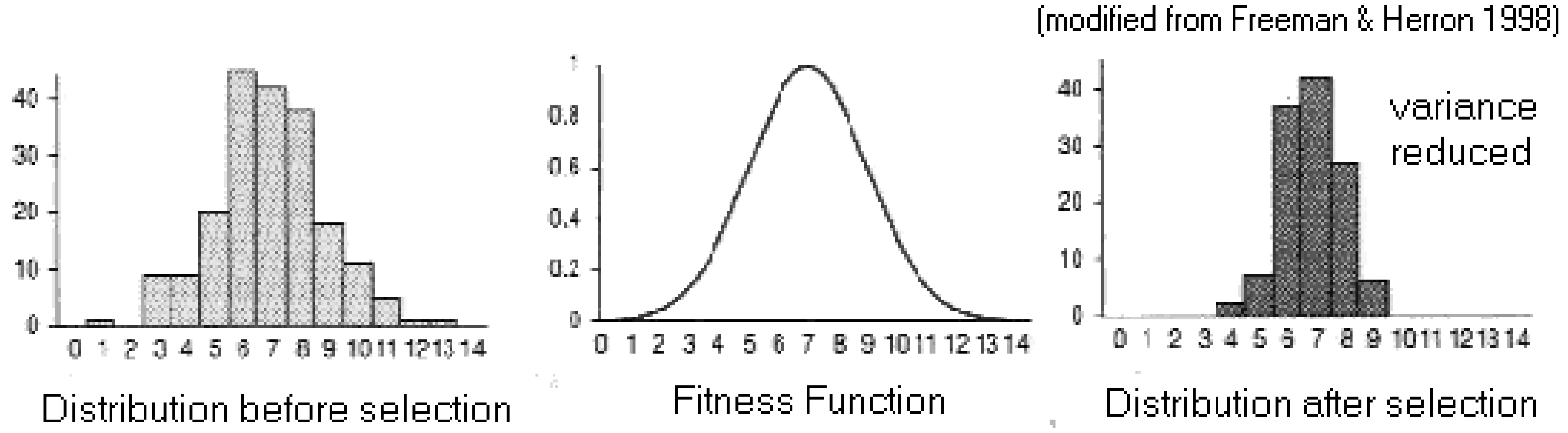


Figure source:
Blackwell scientific

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

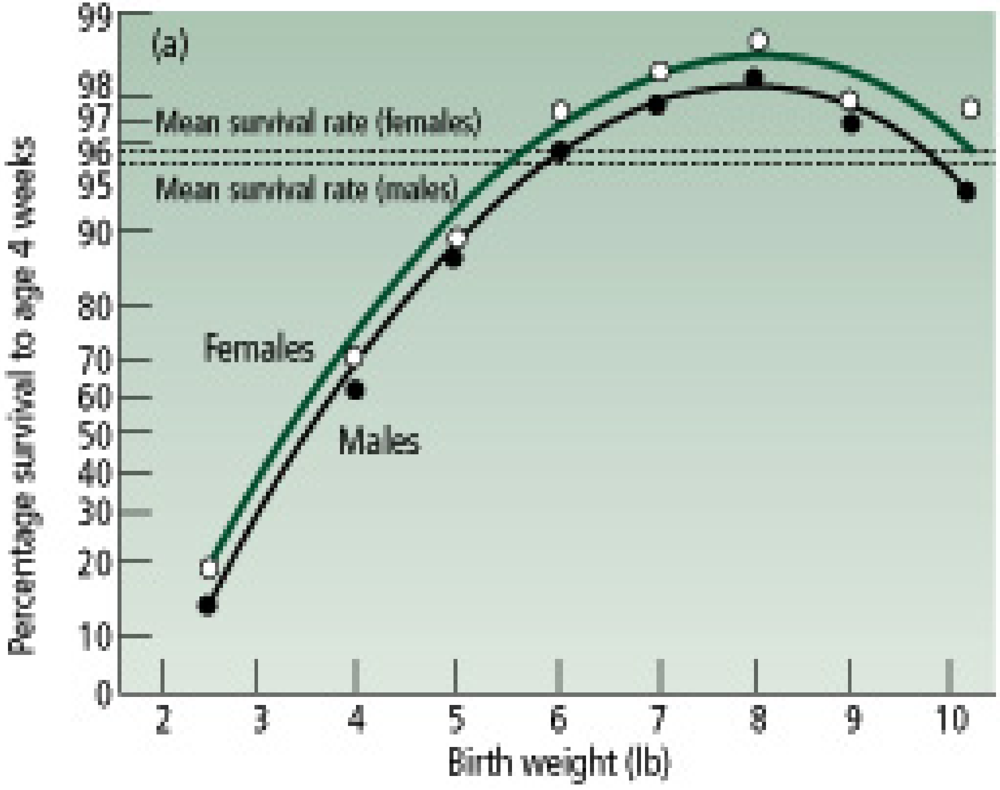
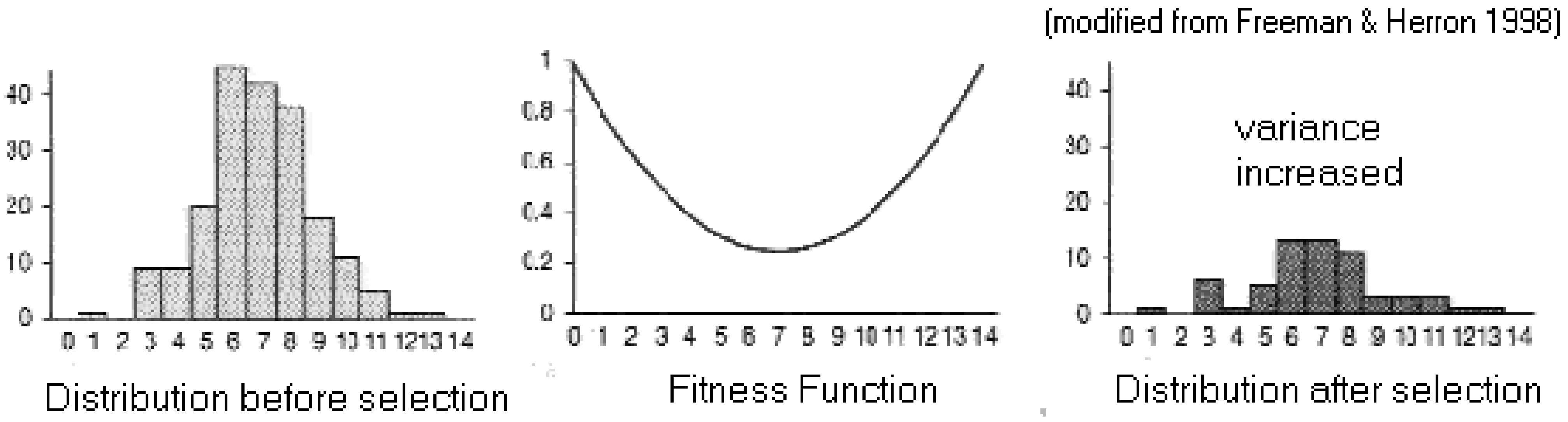


Figure source: Blackwell scientific

Disruptive Selection



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.

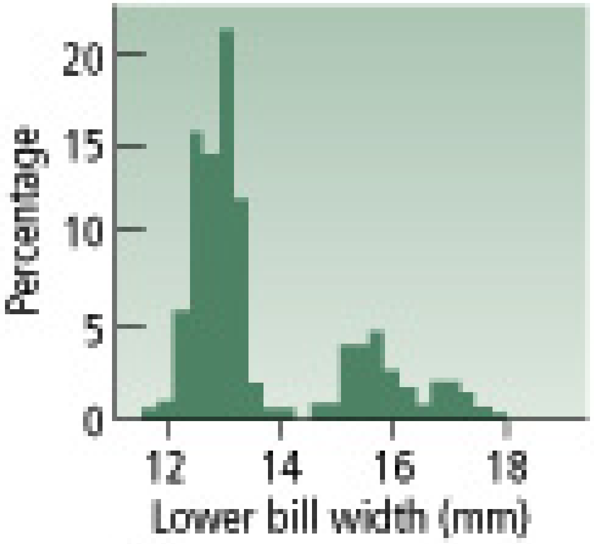


Figure source: Blackwell scientific

Photo: Tom Smith/phys.org

Reading exercise

- Find an example from literature where disruptive selection has led to the evolution of two morphs within a species

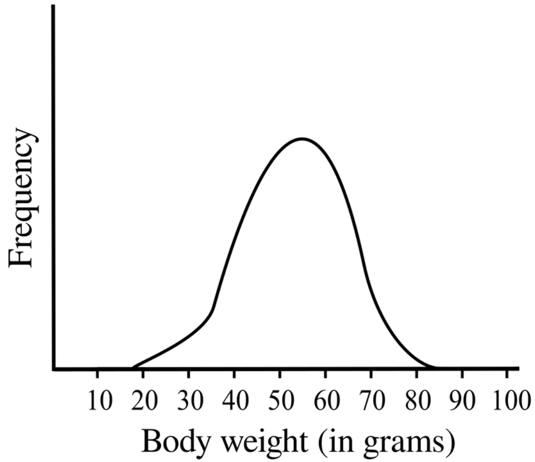
Directional selection – change in population mean

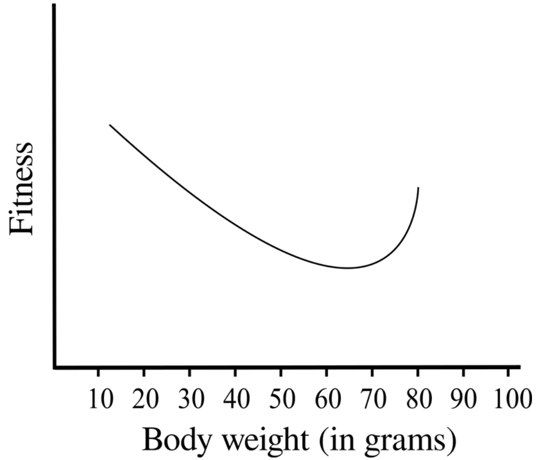
Stabilizing selection – reduced variation, no change in mean

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?

Paradisaea rudolphi
(Blue Bird-of-Paradise)

Paradisaea apoda
(Greater Bird-of-Paradise)

Photos: Tim Laman (www.timlaman.com)

Antilope cervicapra (Blackbuck)
Photo: Hari K Patibanda/openverse.cm

Phidippus putnami (Photo: Thomas Shahan/Wikimedia)

Courtship in birds of paradise
https://www.youtube.com/watch?v=nWfyw51DQfU

Hercules beetles fighting
https://www.youtube.com/watch?v=EjvLOAIxbNQ

Types of Selection - continued

We often distinguish between ***natural*** and ***sexual selection***. Sexual selection is a special type of natural selection wherein traits are selected

- by preferences in the opposite sex: *inter-sexual selection* (mate choice), or
- due to competition between members of the same sex to acquire mates: *intra-sexual selection* (competition)

Sexually selected traits enhance reproductive success, but may be detrimental to survival (tradeoff)