ORIGIN OF SPECIES (microevolution)

DR. KOFI OWUSU-DAAKU

POPULATION GENETICS & EVOLUTION

LECTURE IV

INTRODUCTION

Evolution is based on two fundamental principles: genetic variation and natural selection. A modern interpretation of evolution can view these two principles at the species level (macroevolution) and at the level of genes in populations (microevolution).

Biologists and species

- Before we begin to consider how biologists study the evolution of new species, we need to consider how species are defined and identified. A species refers to a group of organisms that maintains a distinctive set of attributes in nature. In its simplest form, *species* means "kind."
- Attempting to determine whether different animals are the same species by appearance (phenotype) is not reliable due to the subtle variations that are displayed.

Species concept 1

Phylogenetic species concept

Various physical characteristics can be analyzed to distinguish between species. These often include morphological (anatomical) traits. In the case of unicellular organisms, characteristics such as cell wall structure and other cellular traits may be examined. Molecular characteristics can also be compared. An advantage of the phylogenetic species concept is that it can be applied to all types of organisms.

- *Quentin Wheeler and Norman Platnick*

Species concept 2

Biological species concept

Two species are often judged to be separate species if they are unable to interbreed in nature to produce viable, fertile offspring.

- Ernst Mayr

Species concept 3

Evolutionary species concept

An analysis of ancestry may help biologists determine if two groups are members of the same species or represent evolutionarily distinct species. Under this a species is derived from a single lineage that is distinct from all other lineages

- George Gaylord Smpson

Species concept 4

Ecological species concept

The ability of organisms to successfully occupy their own ecological niche or habitat, including their use of resources and impact on the environment, may be used to distinguish species.

- Leigh Van Valen

Problem with Mayr's Biological species

- Species are groups of interbreeding natural populations that are reproductively isolated from other such groups."
- As good as it is, this definition is troublesome for organisms that are non-sexually reproducing and those known only from fossils.
- As long as gene flow continues individuals will remain members of a species even though they may be geographically distant.

MICRO - EVOLUTION

Factors promoting species formation

- Genetic divergence is the process whereby local units of a population become reproductively isolated from other units.
- When this happens, genetic drift, natural selection, and mutation are free to operate in each isolated population and thus lead to changes in gene frequencies.

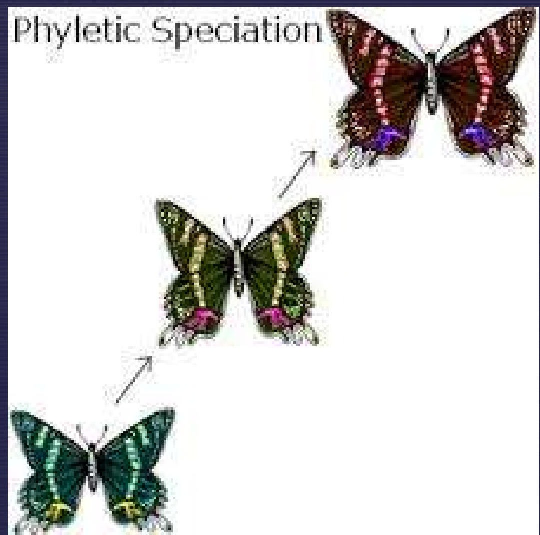
GENETICS OF SPECIATION

- Species may be defined as a group of interbreeding population.
- Speciation is the formation of a new species.
- The whole story of speciation results in new species.
- Almost all the factors affecting the course of evolution are responsible for speciation.

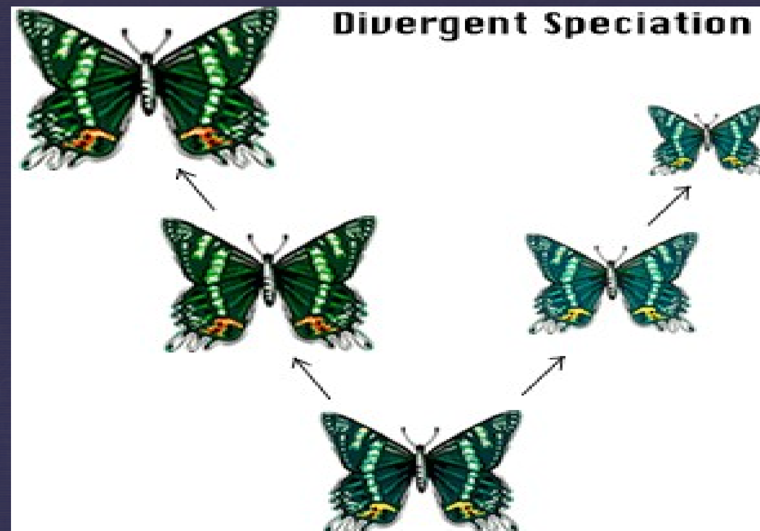
Genetics Of Speciation Cont`d

- During the course of species formation, the race is formed first.
- Gradually inheritable adaptations accumulate, changing environmental act and the race is isolated.
- This isolated race forms the basis of a new race.

- It completely depends on natural selection, which, in turn, is dependent on genetic and ecological variability.
- When one species is transformed into another during the course of time, it is called phyletic speciation.



- When one species splits into two or more species, it is called divergent speciation.



- The speciation may, in turn, be caused by sudden changes in the chromosome structure or may arise due to gradual application of evolutionary forces.

Isolation

- Isolation is a phenomenon by which a species is divided into groups among which free interbreeding is not possible and the mechanism by which isolation is done is called isolating mechanism.
- The term 'isolating mechanism' was introduced by T Dobzhansky (1930).
- The isolation may be:

The separation of two populations or part of a population by geographical barriers (such as forests, mountains, deserts, seas, etc.) is called geographical isolation.

Geographical isolation

BULLOCK'S ORIOLE

BALTIMORE ORIOLE

Spatial Isolation - It is the isolation due to great distance. If a species is well distributed over a wide range of territory without any barrier, it will be difficult for a population situated on the extreme end to interbreed. Such an isolation is called spatial isolation.

Reproductive Isolation

(a) Isolating mechanism which prevents fruitful reproduction is called reproductive isolation.

(b) Reproductive isolation may be pre-zygotic or post-zygotic.

(I) **Pre-Zygotic Isolating Mechanisms -** Pre-zygotic isolating mechanisms are those which prevent interspecific crosses. They may be:

(a) Temporal isolation - Individuals of different species do not mate because they are active at different times of the day or in different seasons.

(b) Behavioural isolation - Potential mates meet but choose members of their own species.

(c) **Mechanical isolation** - Copulation is attempted but transfer of sperm does not take place due to differences in genital parts.

(d) **Ecological isolational** - Populations have different habitat preferences.

(ii) Post-Zygotic Isolating Mechanisms

- These isolating mechanisms are effective after mating. Post-zygotic isolating mechanism may be:

(a) **Gametic incompatibility** - Transfer of sperms occurs but eggs are not fertilised.

(b) **Zygotic mortality** - Fertilisation of egg takes place but the zygote dies.

(c) **Hybrid unviability** - Formation of hybrid embryo occurs but of reduced viability.

(d) **Hybrid sterility** - The hybrid is viable but the resulting adult is sterile.

(e) **Hybrid breakdown** - F_J (first generation) hybrids are viable and fertile but further hybrid generations (F_2 and back crosses) may be unviable or sterile.

- Whatever may be the cause of isolation, there is no doubt about the fact that it is one of the most important factors in the process of speciation.

Speciation in Geographically Isolated Populations

- Allopatric Speciation
- Allopatric refers to the different lands" the two species occupy.
- In this model, a physical barrier cuts off gene flow between two or more populations.
- a The separated populations become reproductively incompatible and cannot interbreed.
- Whether or not a geographical barrier is effective in preventing gene flow depends on how fast and by what means the organism can travel.

The Pace of Geographic Isolation

- 1. Different types of geographical barriers have been observed.
- The Mississippi River changed course abruptly in the 1800's isolating some insects.
- Numerous glaciers have provided a rather slow geographical isolation.
- Movement of continents has caused massive isolation.
- John Graves has observed differences in enzyme structure between fishes on the Atlantic and Pacific sides of the Isthmus of Panama.

Allopatric Speciation on Archipelagos

- An archipelago is an island chain some distance away from a continent.
- The Galapagos finches are an example of speciation.
- Apparently, some finches made the trip from the South American coastline to the isolated islands many years ago.
- Their descendants have spread to other islands and evolved in isolation.

Sympatric Speciation

- In sympatric speciation ("together with others in the homeland"), species arise from within the range of existing species, in the absence of physical or ecological barriers.
- In two crater lakes of East Africa exist cichlid fishes Tilapia. The species in each lake are alike in their mitochondrial DNA and unlike the species in neighboring lakes and streams. The lakes are small so the fish must live in sympatry.

sympatric speciation cont`d

- Polyploidy, the inheritance of three or more of each type of chromosome due to improper separation of chromosomes during meiosis or mitosis, results in rather instantaneous speciation for plants so can be considered sympatric speciation.

Parapatric speciation

- Parapatric speciation may occur where populations share a common border (hybrid zone), even though the borders may be permeable to gene flow.

Factors of Organic Evolution

I. Natural Selection

(a) Natural selection is the differential reproduction of genes or genotypes. It is one of the basic mechanisms of evolution.

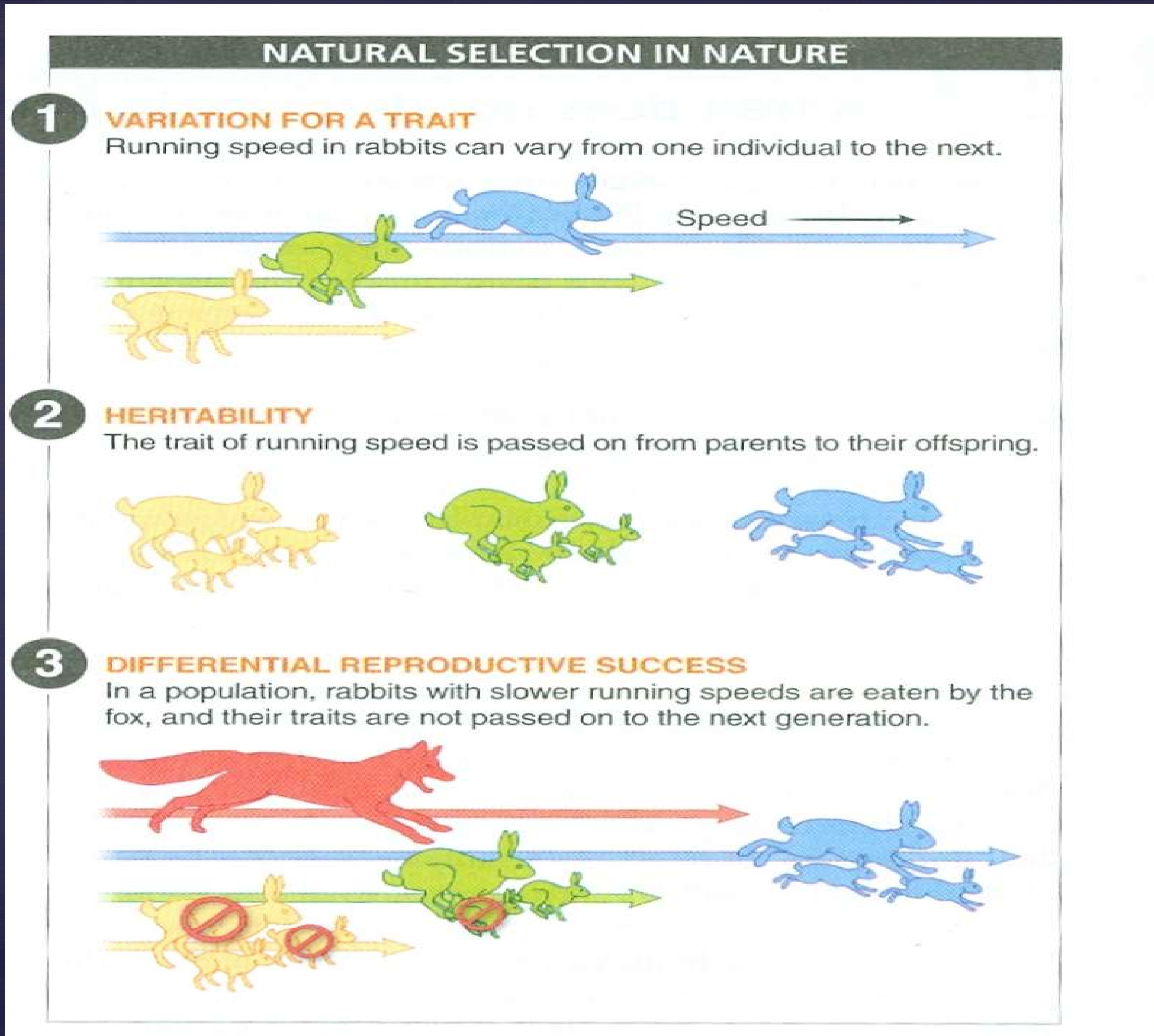
(b) Natural selection is not responsible for evolution. Actually, it is a factor in change.

Natural Selection cont`d

(c) Organisms are dependent on environmental factors for their survival. As there is competition among organisms, only those traits favouring their survival will do so.

(d) Natural selection is not responsible for reproduction.

(e) Natural selection selects only those traits in organisms that have survival value.


NATURAL SELECTION IN NATURE
1
VARIATION FOR A TRAIT
Running speed in rabbits can vary from one individual to the next.
Speed
2
HERITABILITY
The trait of running speed is passed on from parents to their offspring.
3
DIFFERENTIAL REPRODUCTIVE SUCCESS
In a population, rabbits with slower running speeds are eaten by the fox, and their traits are not passed on to the next generation.

- Natural selection does not lead to organisms perfectively adapted to their environment, because
  - Environments can change more quickly than natural selection can adapt organisms;

- Mutation does not produce all possible alleles
- There is not always a single, optimum adaptation for a given environment.

- Natural selection is a mechanism of evolution that occurs when there is heritable variation for a trait, and individual with one version of that trait have greater reproductive success than do individuals with a deferent version of the trait.
- Natural selection can also be thought of the elimination of the alleles that reduce the reproductive rate of individuals carrying those alleles, relative to the reproductive rate of individuals who do not.

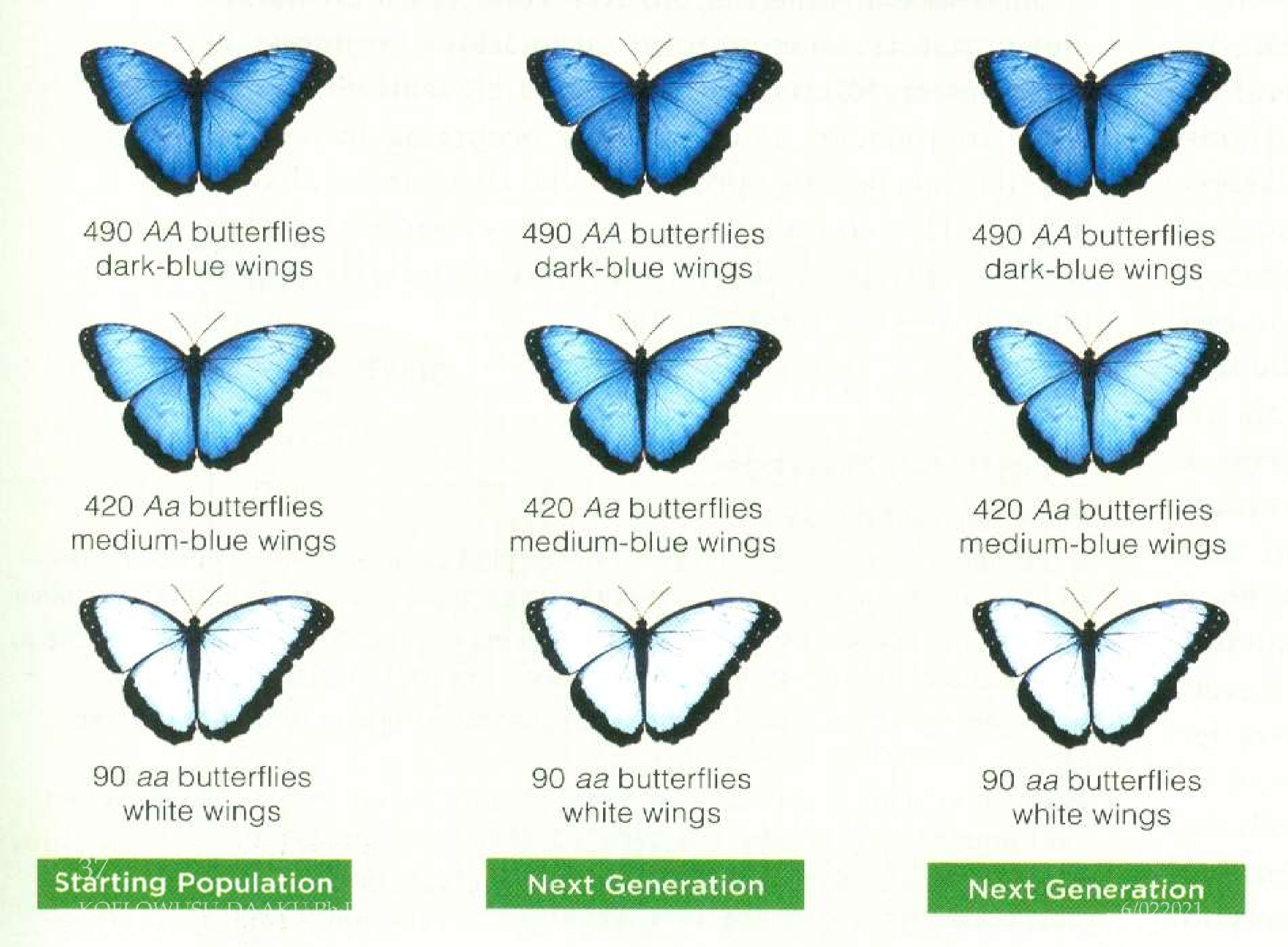
- Acting on multigene traits for which populations show a large range of phenotypes, natural selection can change populations in several ways. These include directional selection, in which the average value for the trait increases or decrease; stabilizing selection, in which the average value of a trait remains the same while extreme versions are selected against; and disruptive selection, in which individuals with extreme phenotypes have the highest fitness.

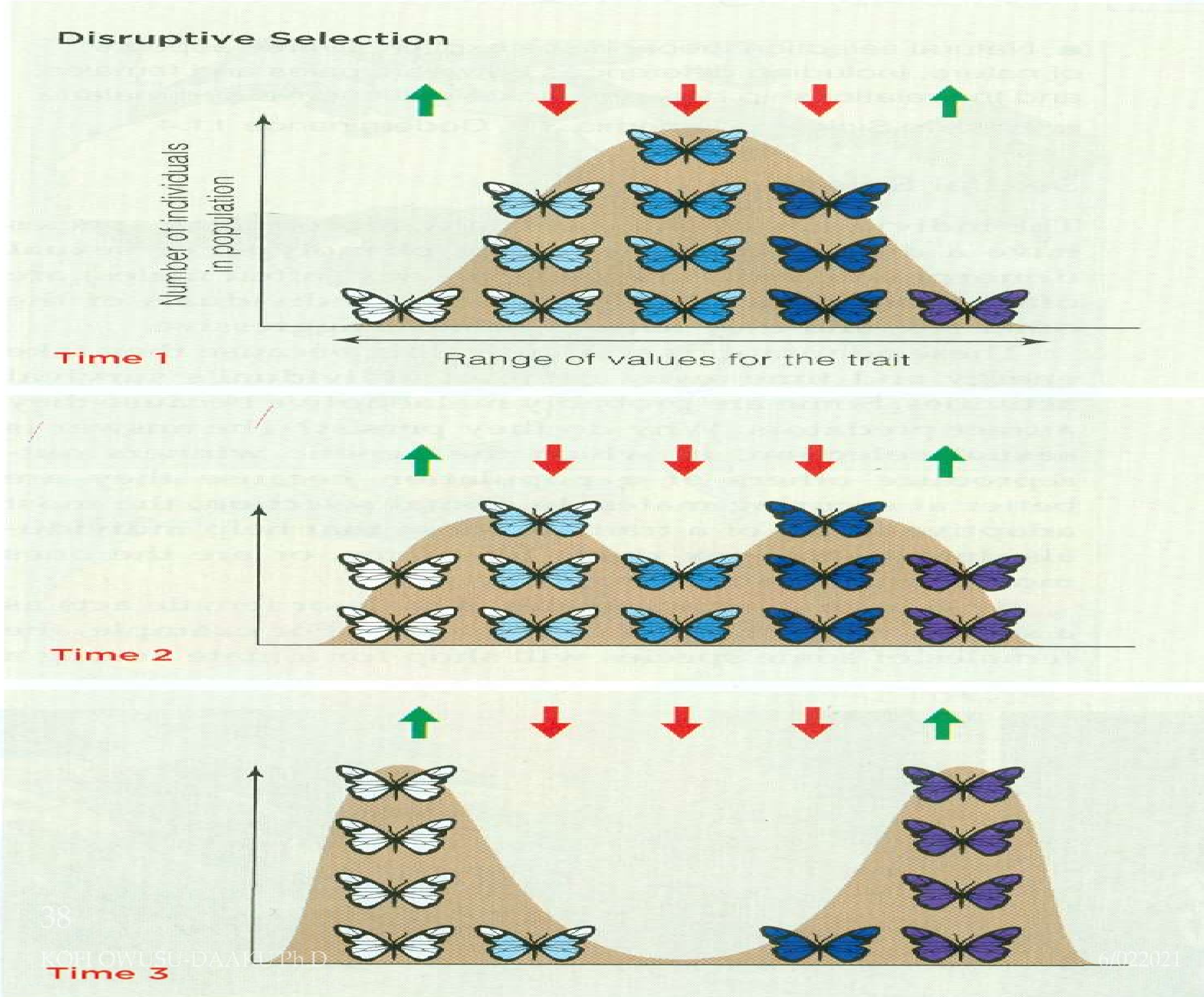
Forms of selection

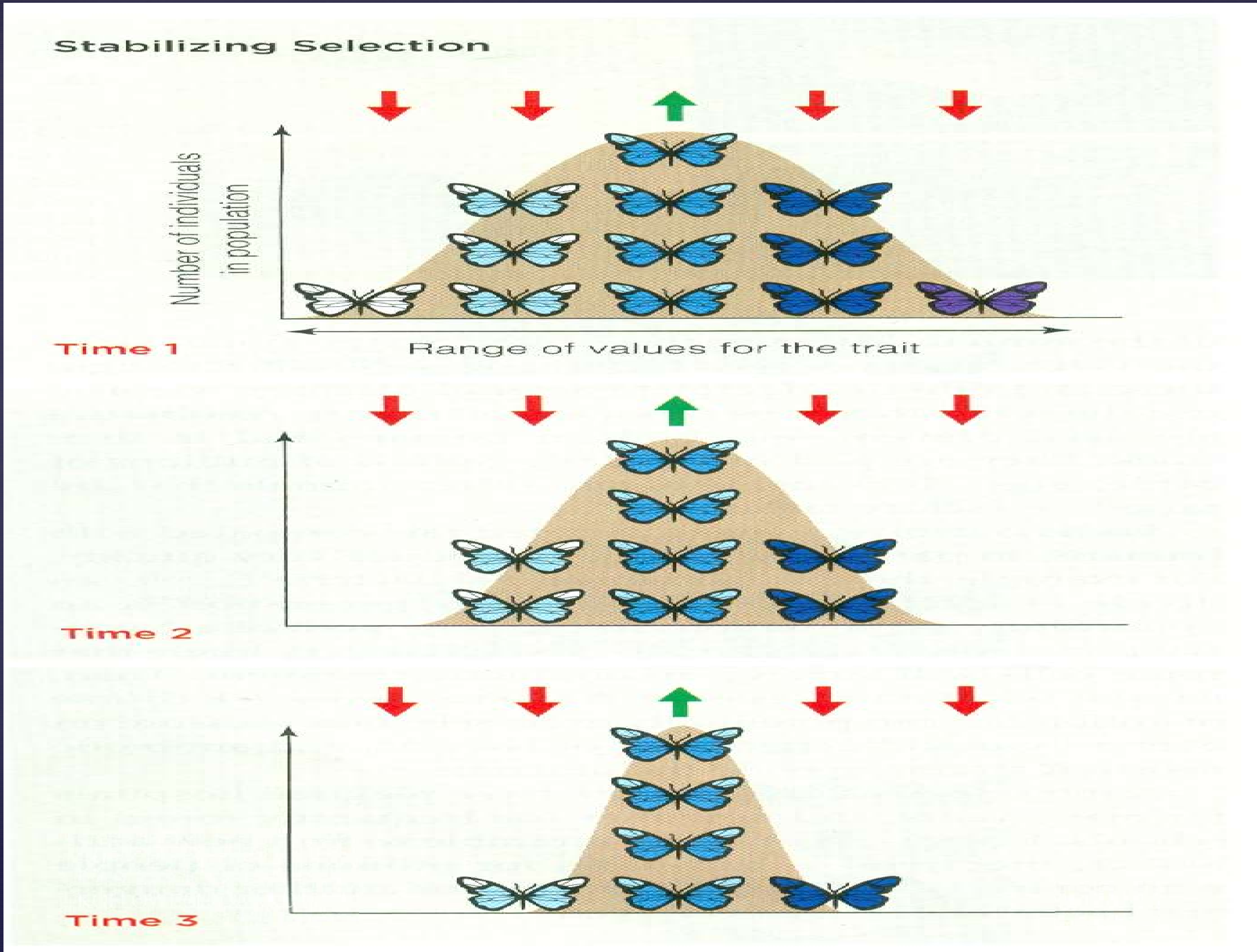
Directional selection

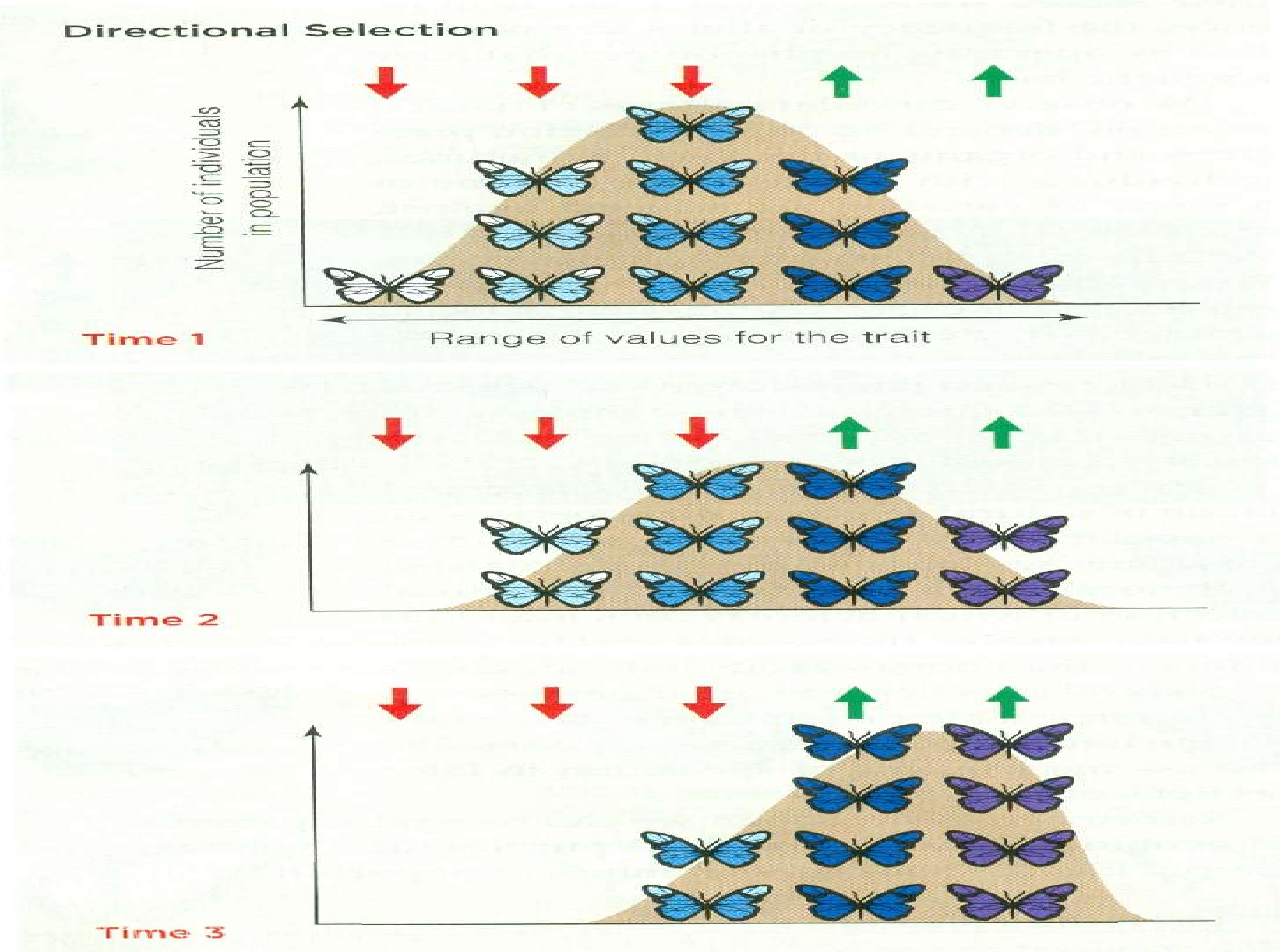
Stabilizing selection

Disruptive selection


490 AA butterflies
dark-blue wings
420 Aa butterflies
medium-blue wings
90 aa butterflies
white wings
Starting Population
490 AA butterflies
dark-blue wings
420 Aa butterflies
medium-blue wings
90 aa butterflies
white wings
Next Generation
490 AA butterflies
dark-blue wings
420 Aa butterflies
medium-blue wings
90 aa butterflies
white wings
Next Generation


Disruptive Selection
Number of individuals in population
Range of values for the trait
Time 1
Time 2
Time 3

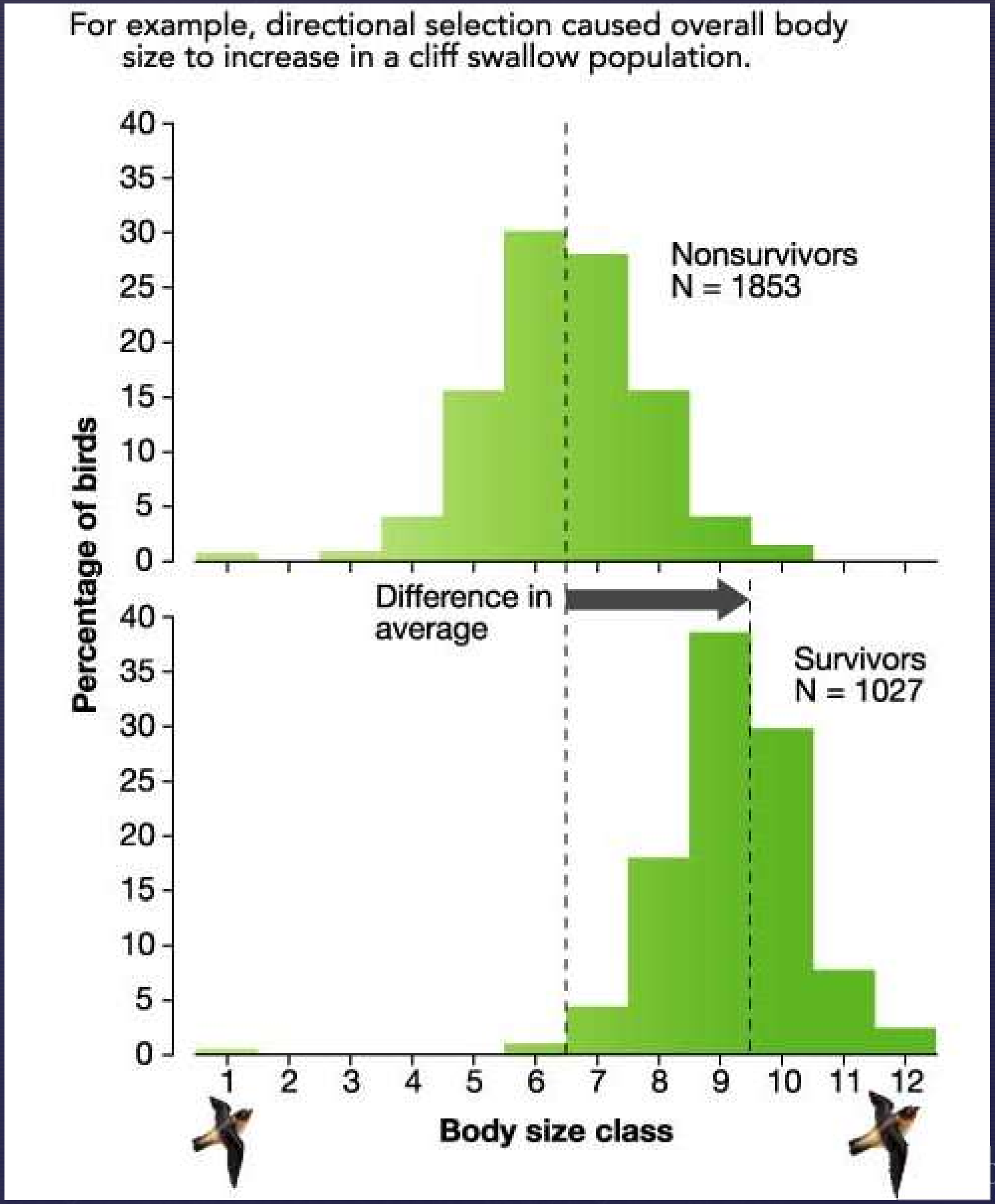

Stabilizing Selection
Number of individuals in population
Range of values for the trait
Time 1
Time 2
Time 3


Directional Selection
Number of individuals in population
Range of values for the trait
Time 1
Time 2
Time 3

population before selection

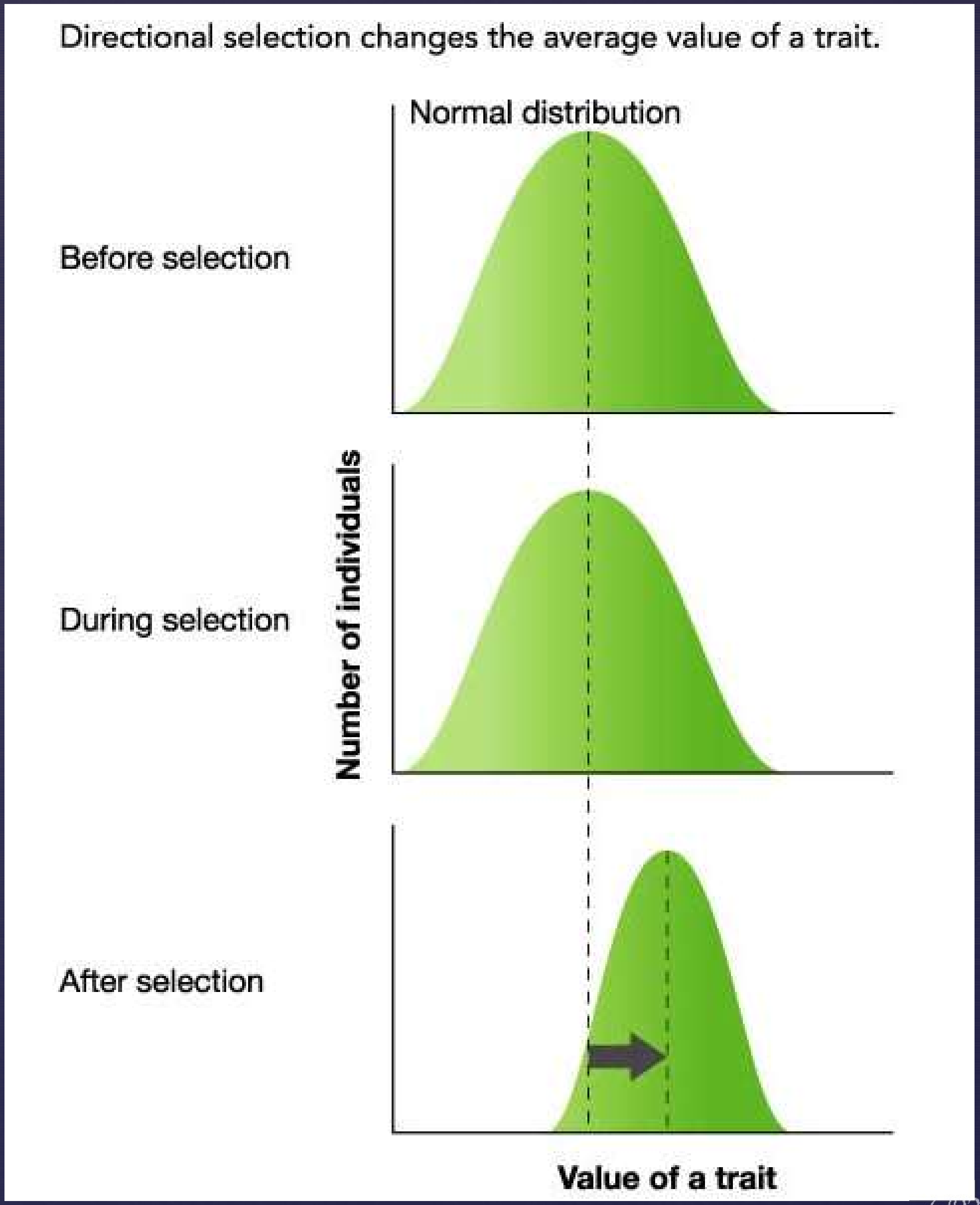

directional selection

Directional selection

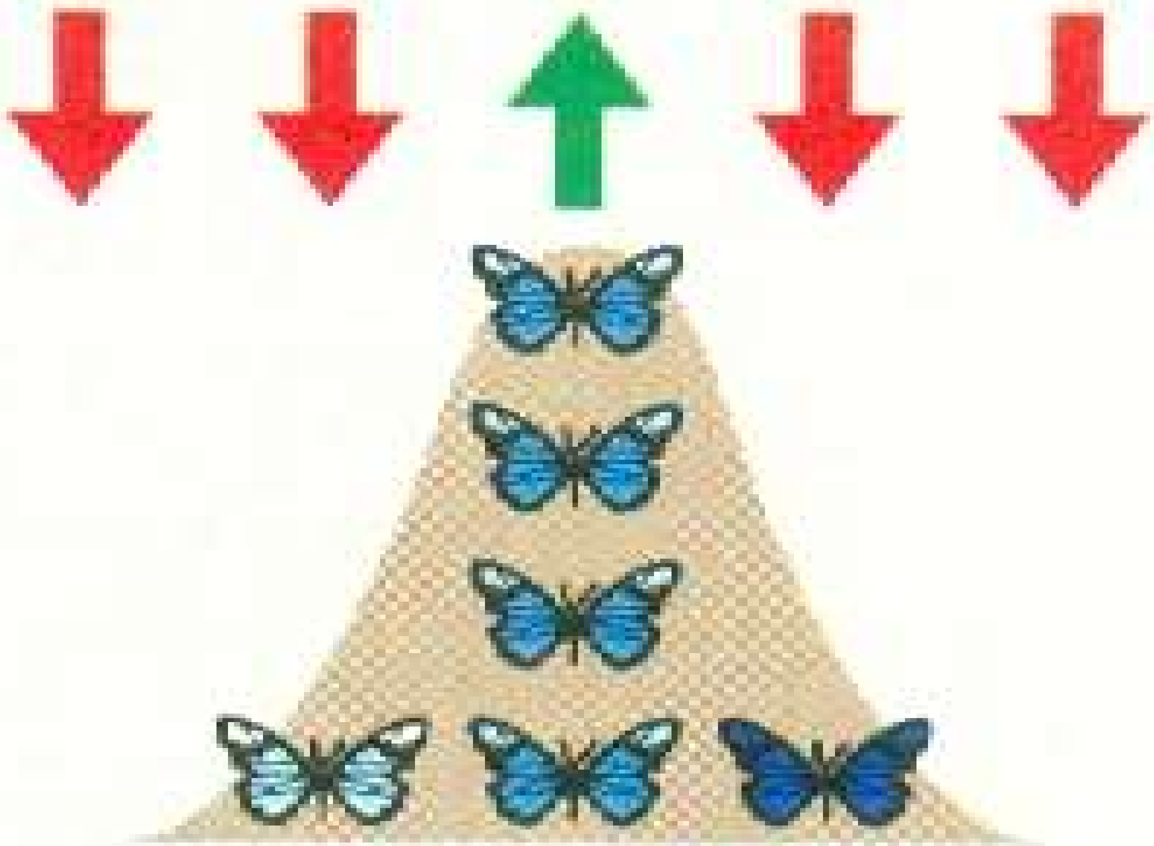


Directional selection

changes the population mean

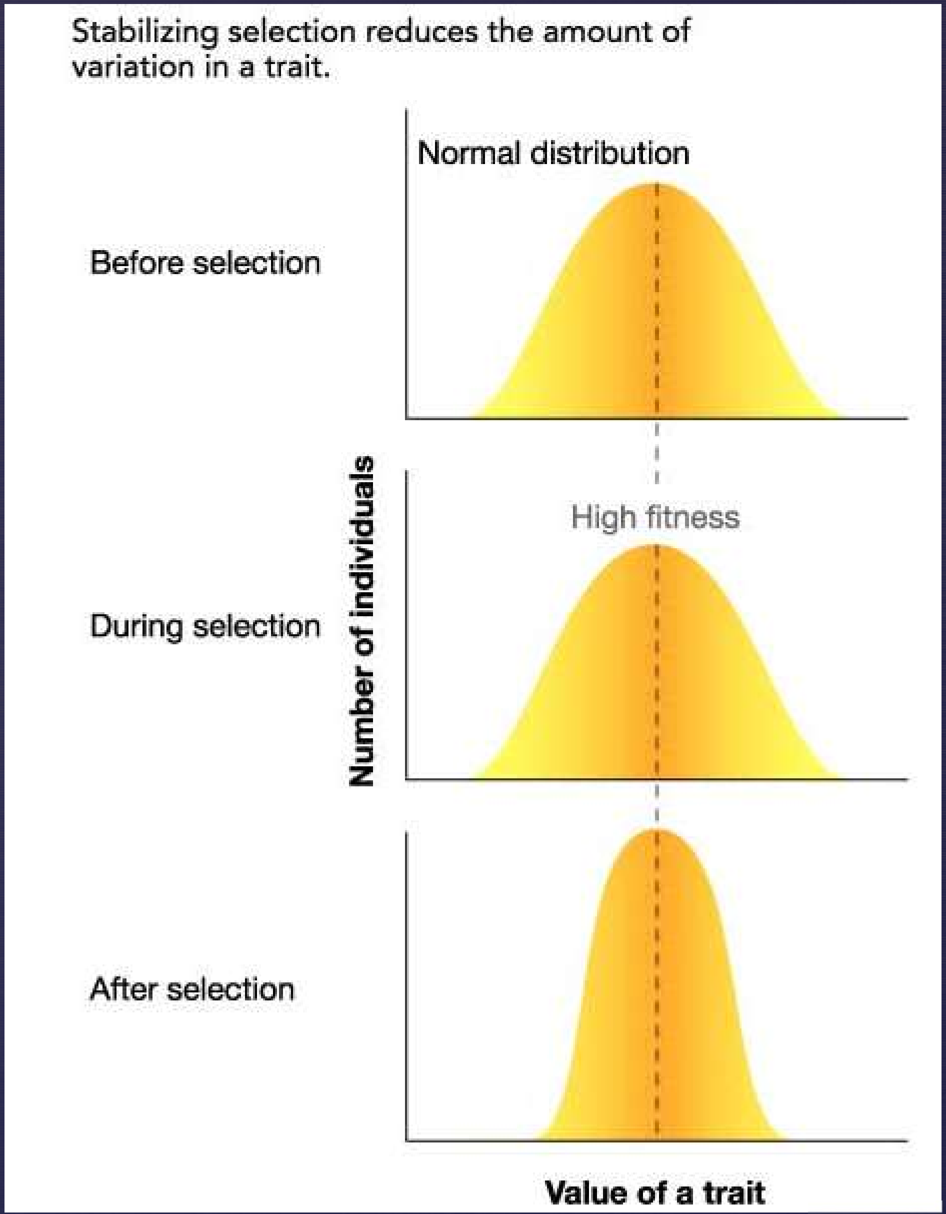


stabilizing selection

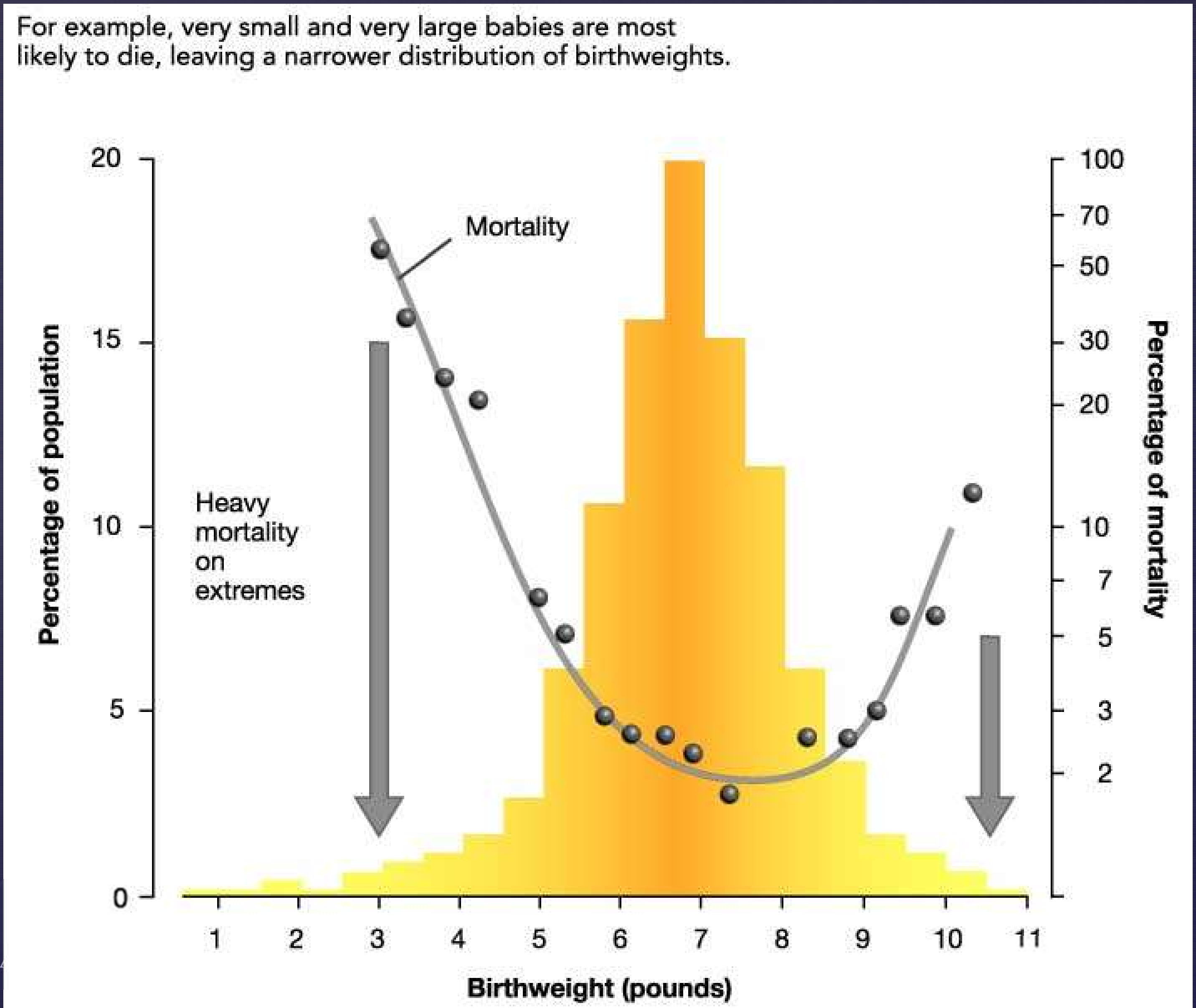


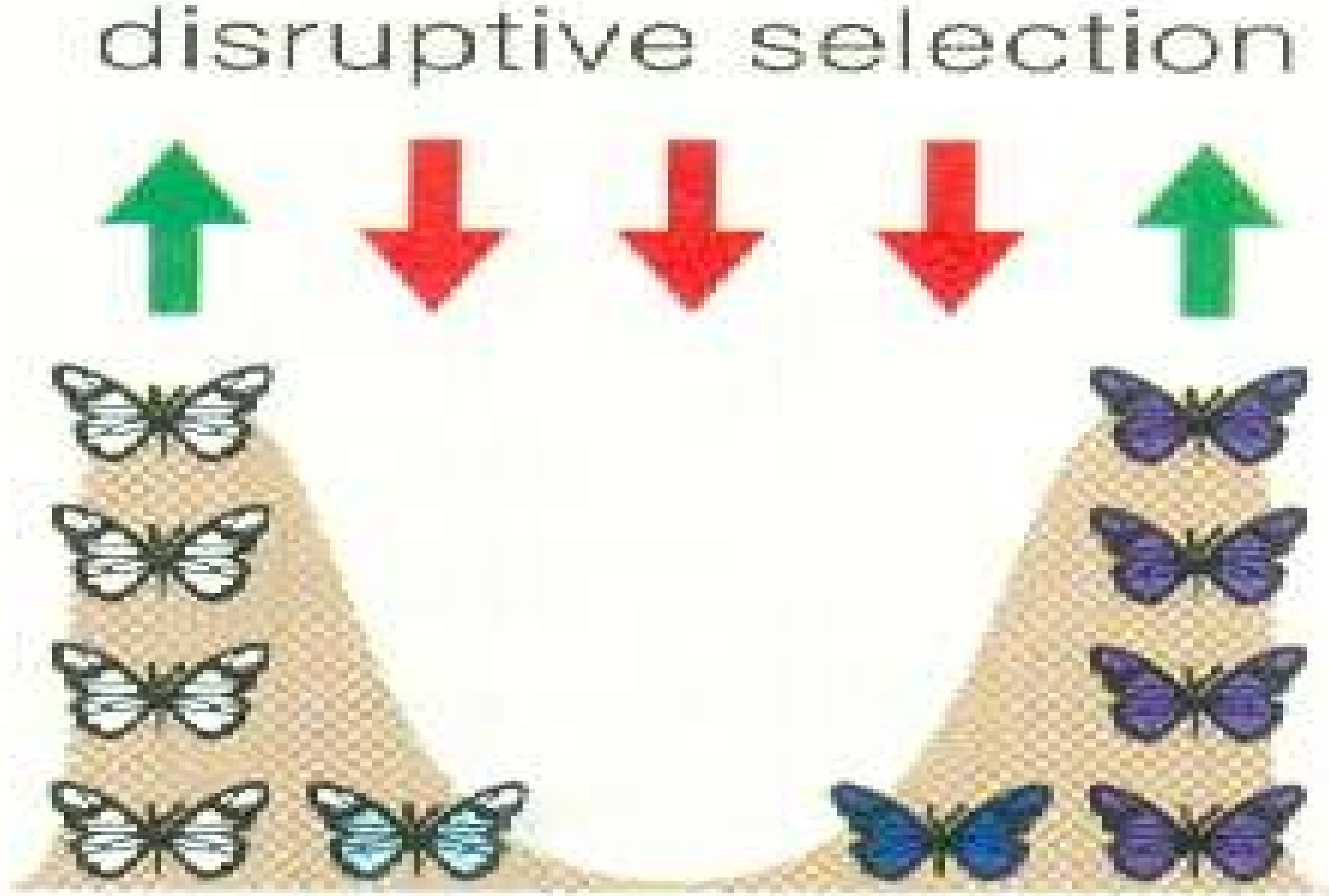
Stabilizing selection

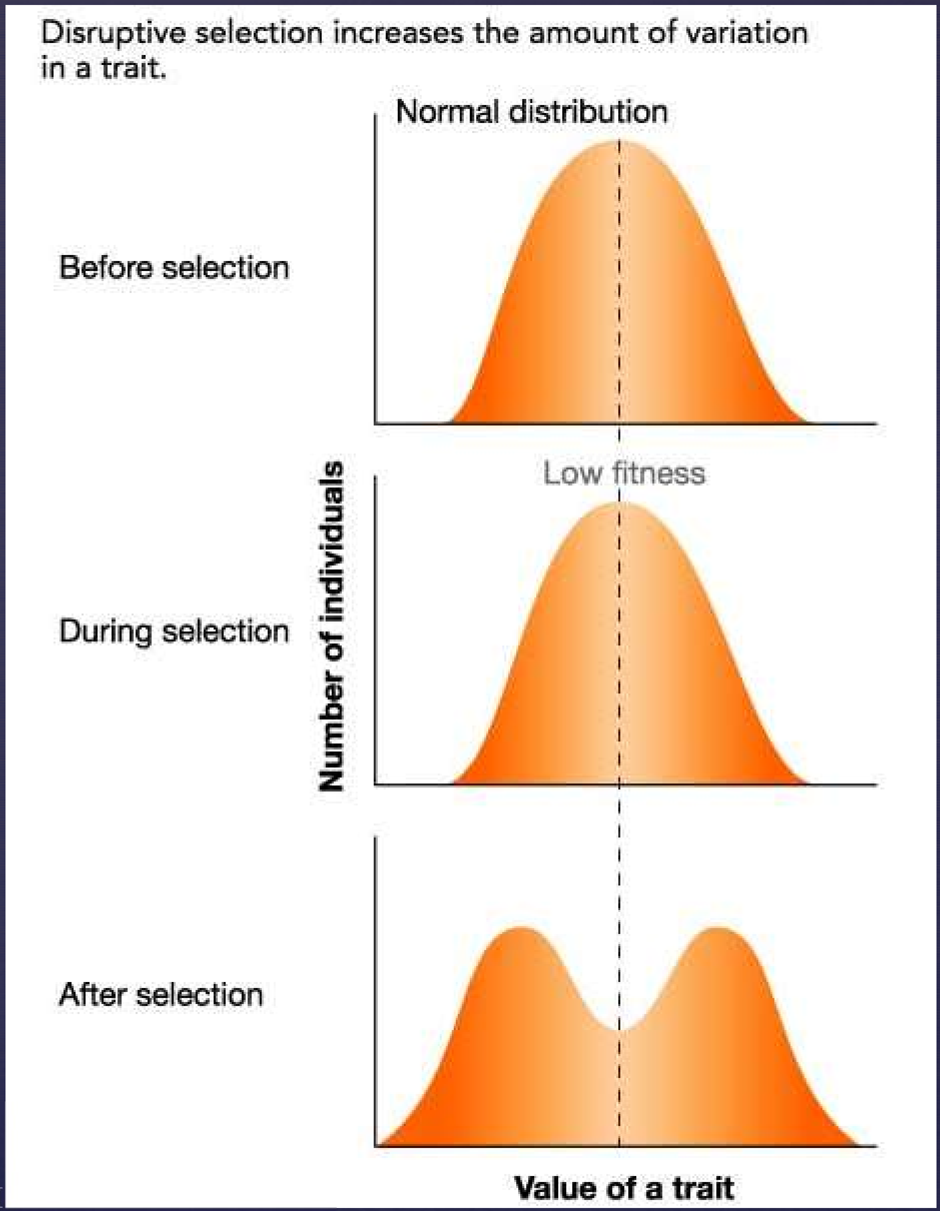
reduces variation



Stabilizing selection




disruptive selection

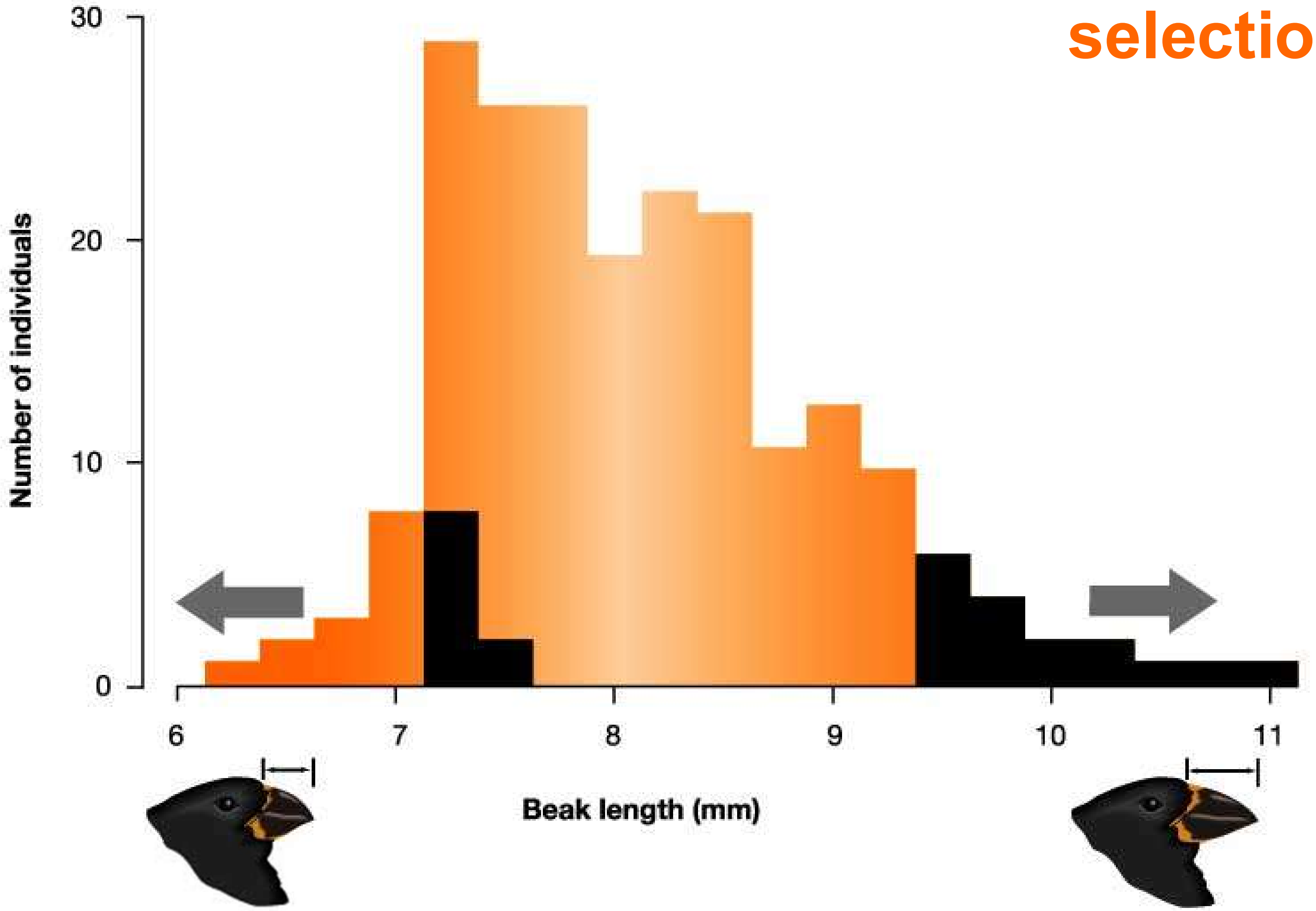


Disruptive selection

increases variation

Disruptive selection

For example, only juvenile blackbellied seedcrackers with very long or very short beaks survived long enough to breed.



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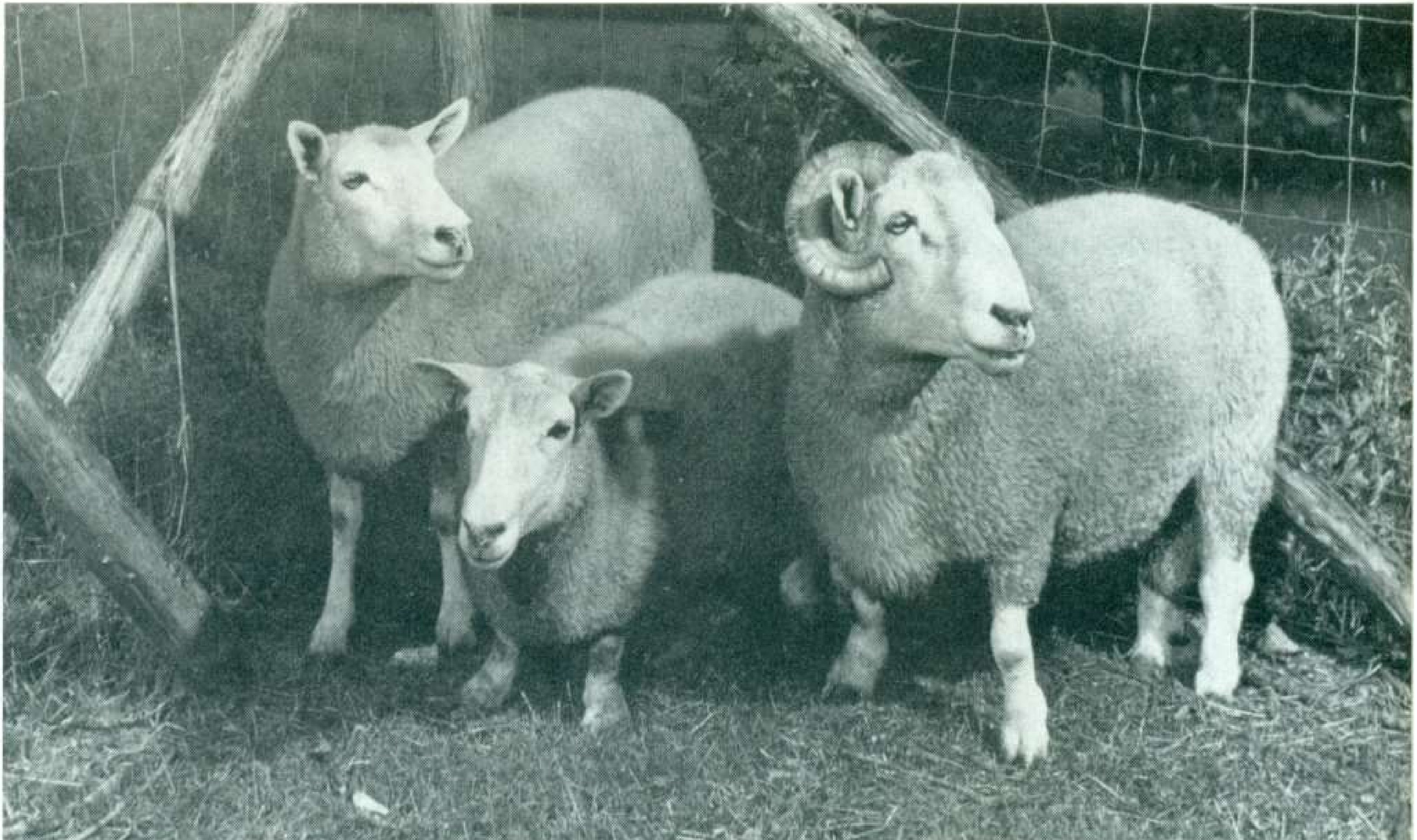
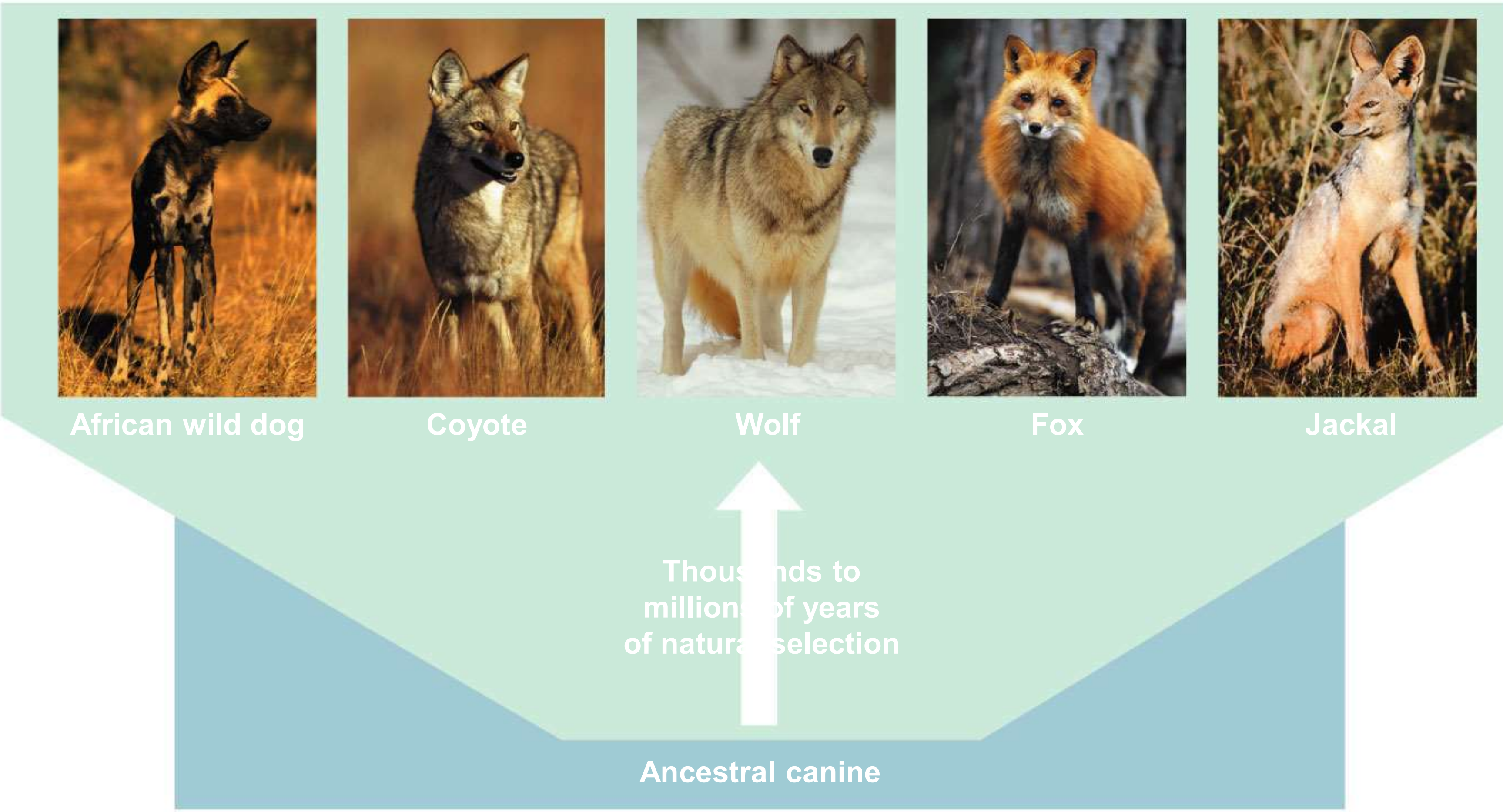
EVIDENCE OF EVOLUTION -MICROEVOLUTION

- modern human civilization has produced such extremely ***strong selection pressures on some organisms that if one looks at small-scale evolutionary phenomena (known as microevolution), it is possible to observe not only the results but also the actual process of evolution by natural selection. e.g.***
- ***Selective breeding***
- ***Industrial melanism***
- ***insecticide resistance***
- ***antibiotic resistance***

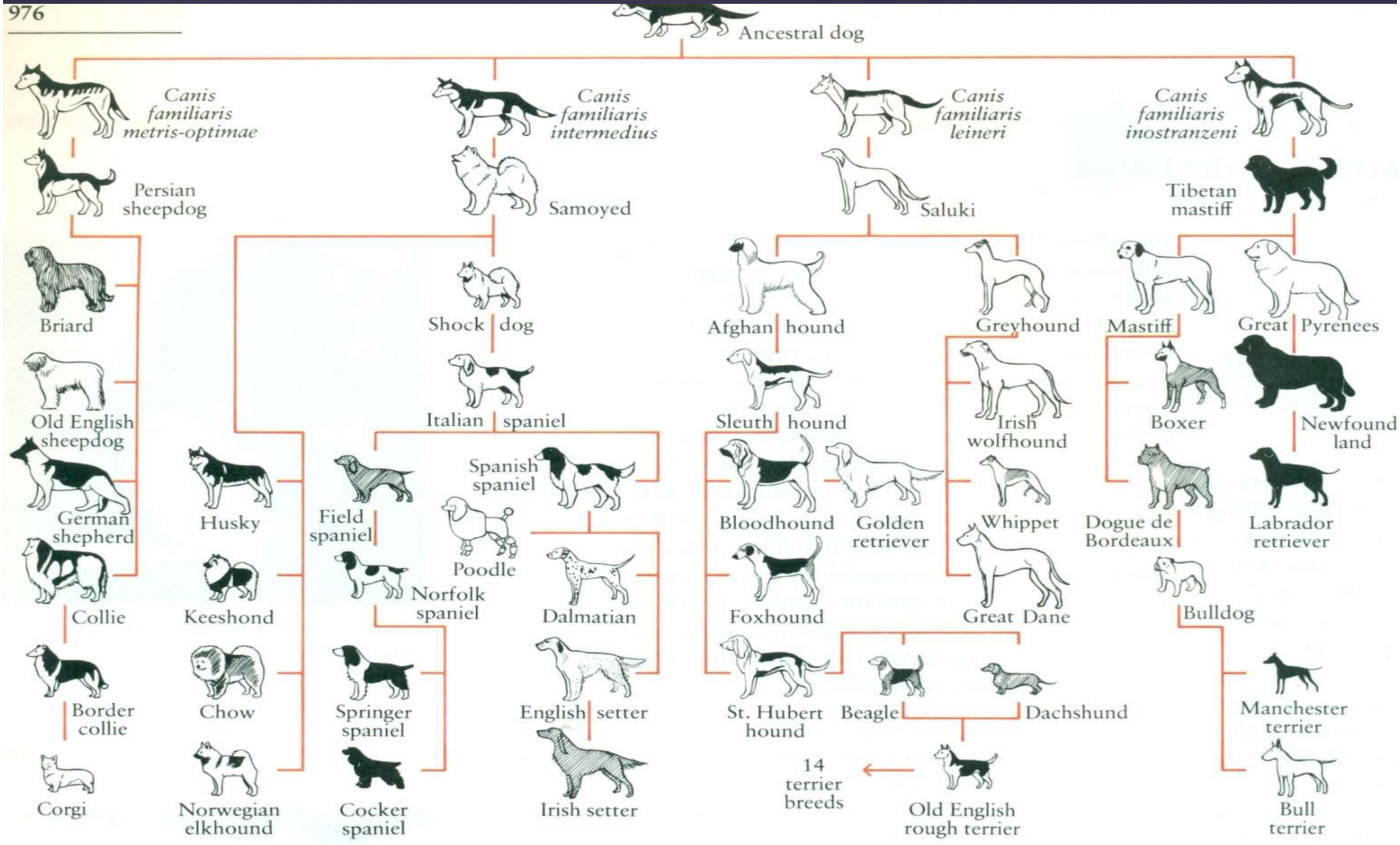


56 SELECTIVE BREEDING

LE 13-2c

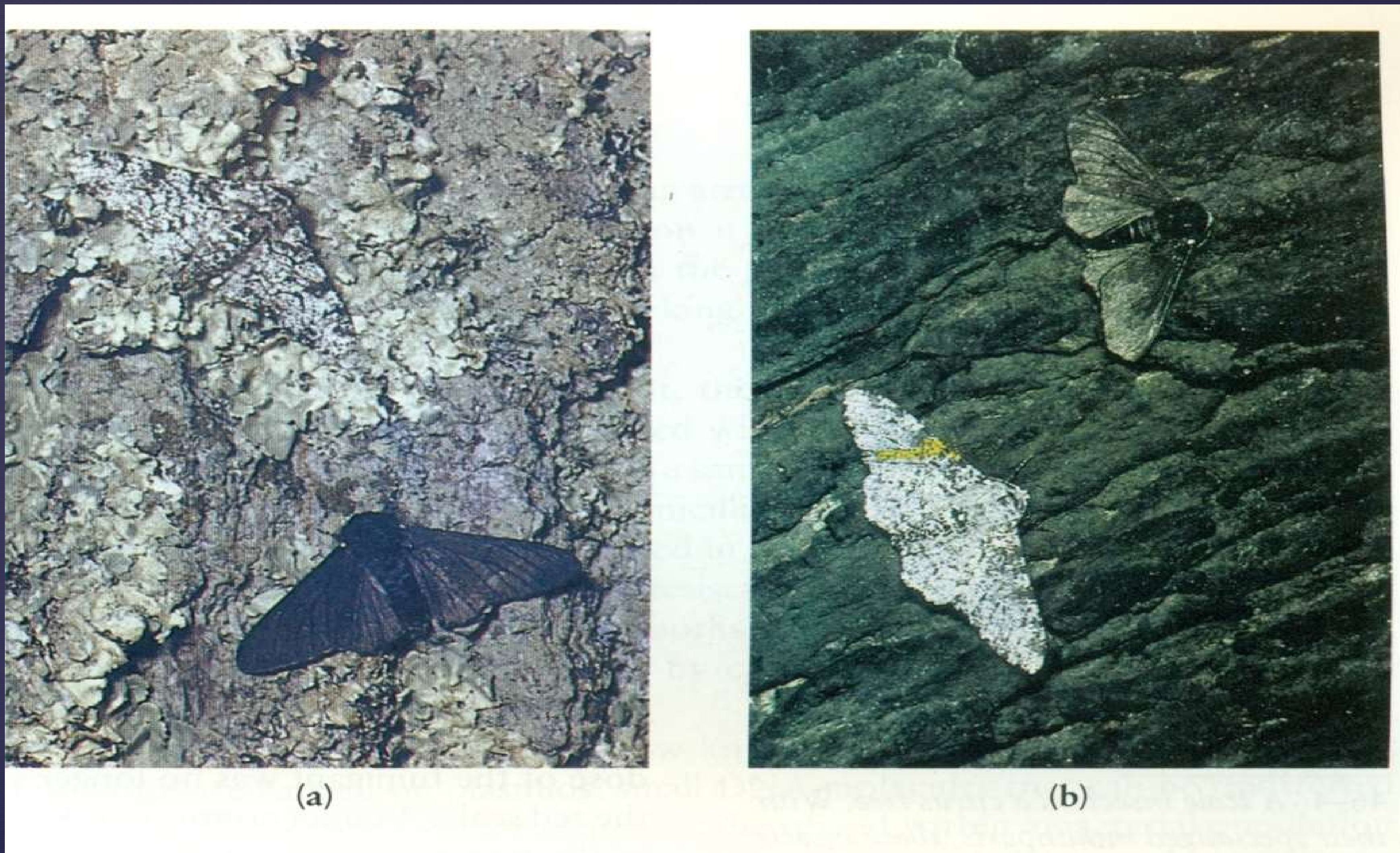


African wild dog
Coyote
Wolf
Fox
Jackal
Thousands to
millions of years
of natural selection
Ancestral canine



ALL BREEDS OF DOGS HAVE BEEN PRODUCED BY ARTIFICIAL SELECTION
A demonstration of the tremendous potential for variability in a single species.

INDUSTRIAL MELANISM

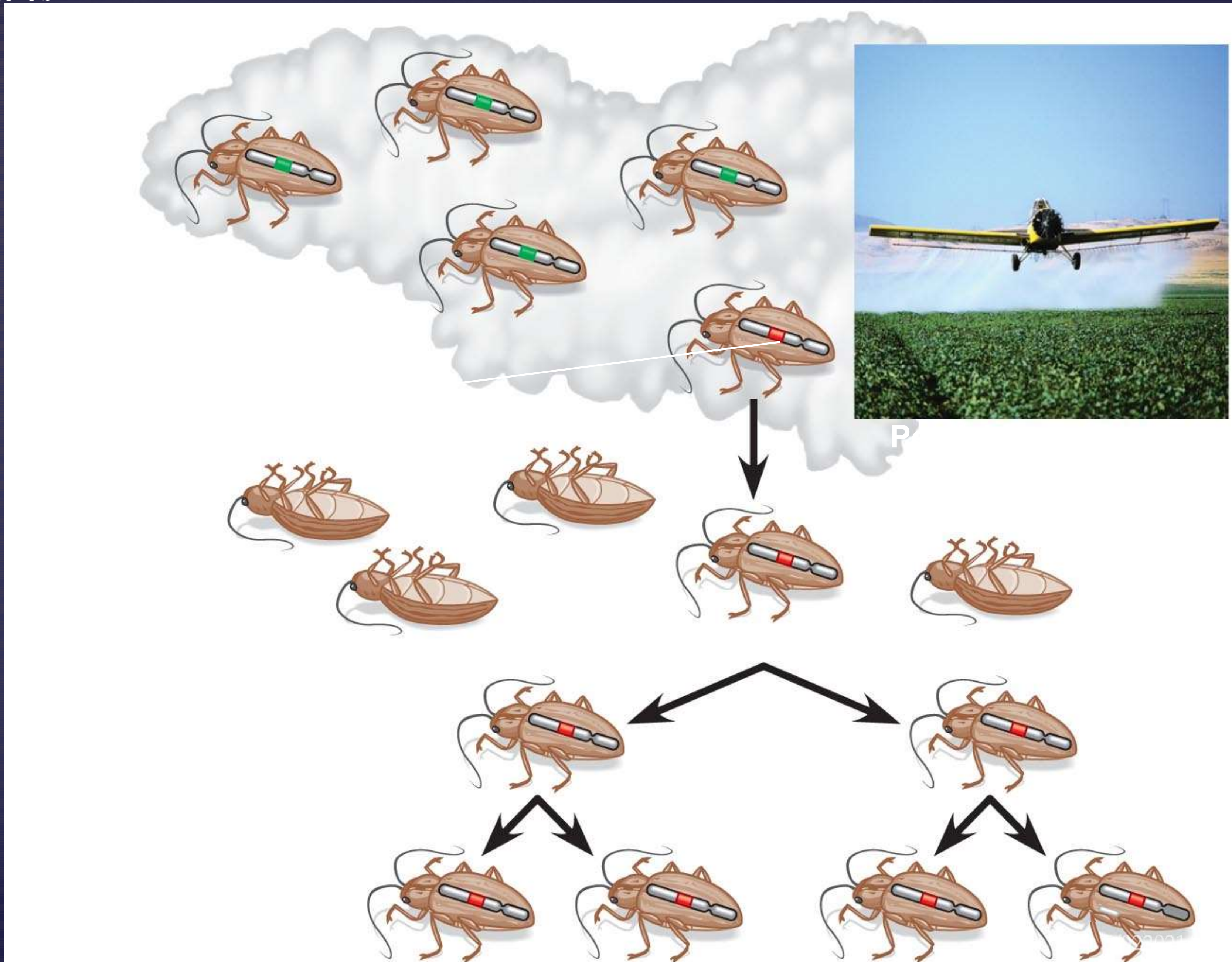


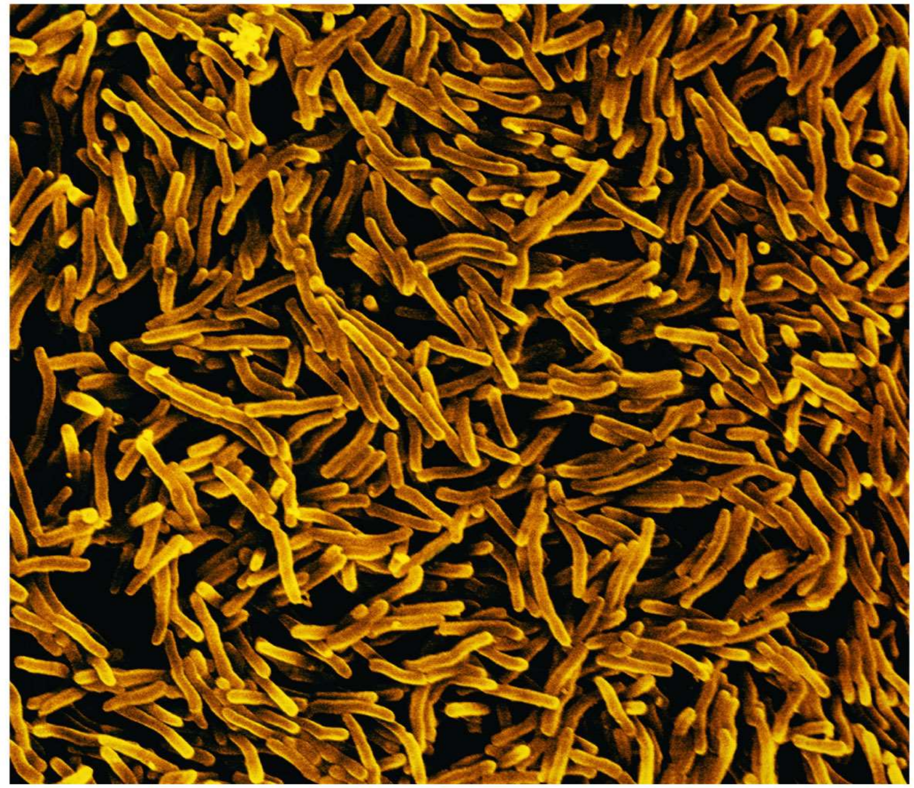
TWO VARIETIES OF BISTON BETULARIA(THE PEPPERED MOTH) RESTING ON
A.LICHEN COVERED TREE TRUNK   B. A DARK TREE TRUNK

INSECTICIDE RESISTANCE

- Organochlorine
- Organophosphates
- Carbamates Pyurethroids

LE 13-5b





CONNECTION

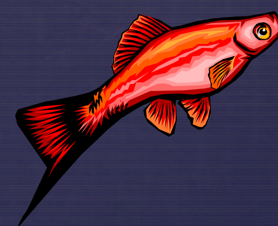
- The evolution of antibiotic resistance in bacteria is a serious public health concern
  - Natural selection has led to the evolution of antibiotic-resistant bacteria
  - Overuse and misuse of antibiotics has contributed to the proliferation of antibiotic-resistant strains
    - Example: tuberculosis
    - Recent outbreak of antibiotic resistant Staphylococus aureus at paediatric ward at Korle-Bu

- Darwin found convincing evidence for his ideas in the results of **artificial selection**
  - The selective breeding of domesticated plants and animals

Variations on natural selection

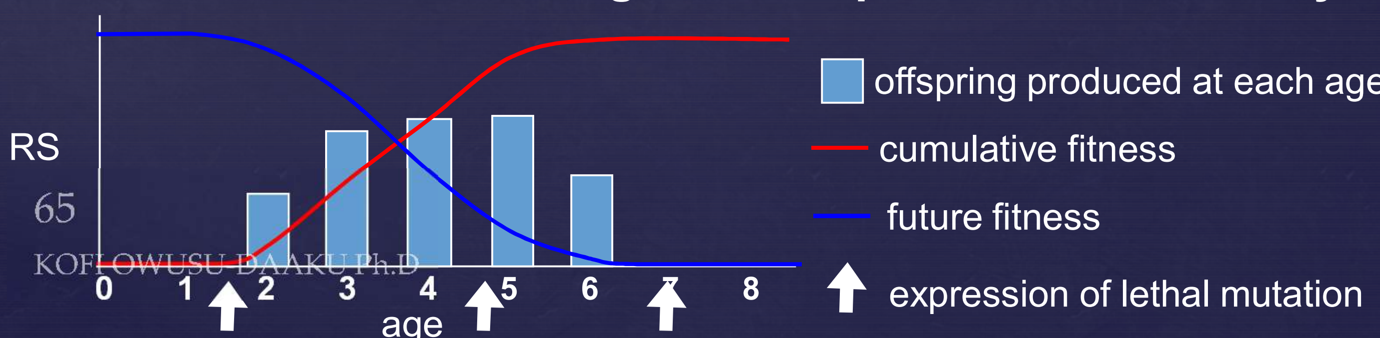
<u>Sexual selection</u> – selection via differences in mating success

What happens when selection acts differently on a trait in males and females?



<u>Life history evolution</u> –

What happens when selection acts differently on a trait during different portions of the life cycle?



Variations on natural selection

<u>Phenotypic plasticity</u> – genotype expressed differently in different environments

(a) Leaves of the same plant

Grown in shade Grown in sun

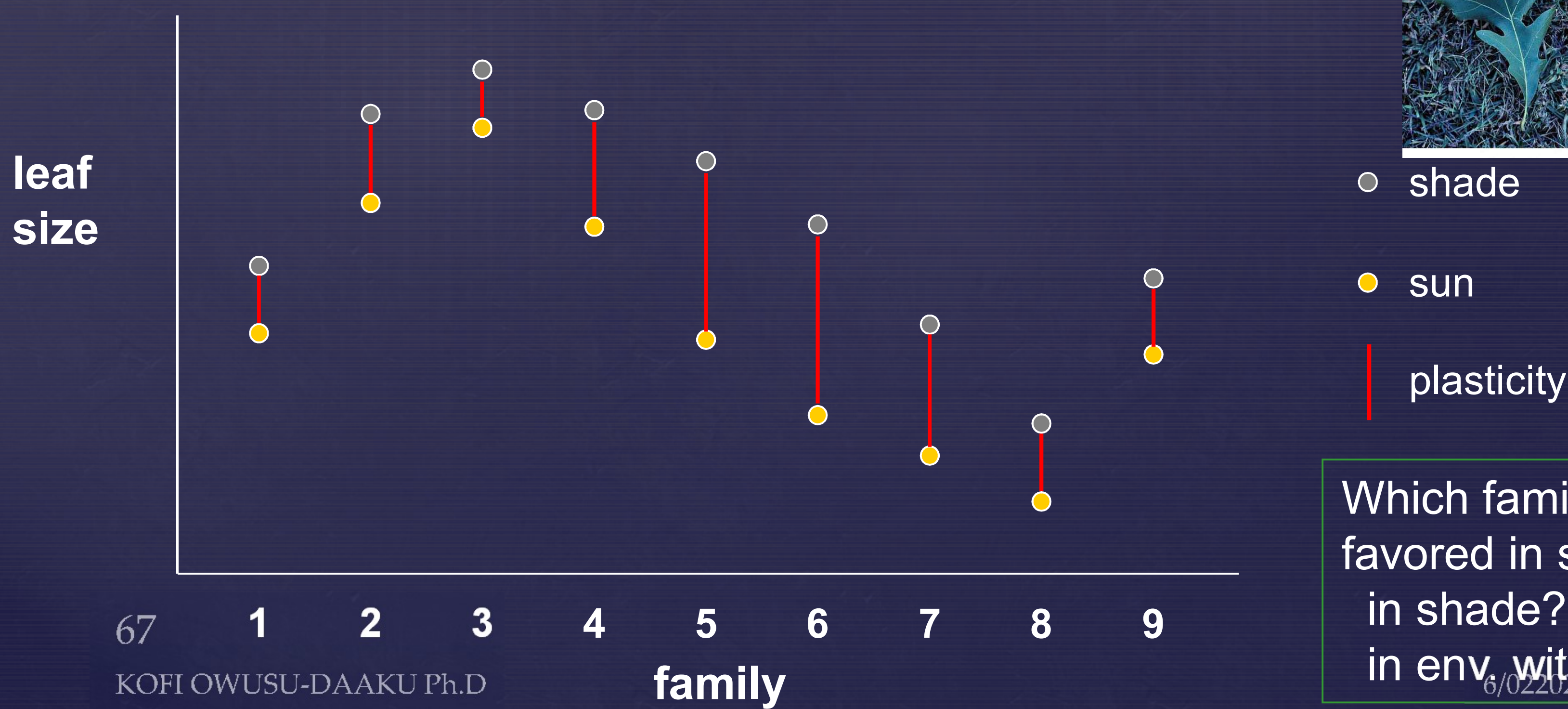
(b) Individuals of the same species

Grown in the open Grown in crowded conditions

Variations on natural selection

Phenotypic plasticity can evolve if: heritable
under selection

Genetic variation in phenotypic plasticity

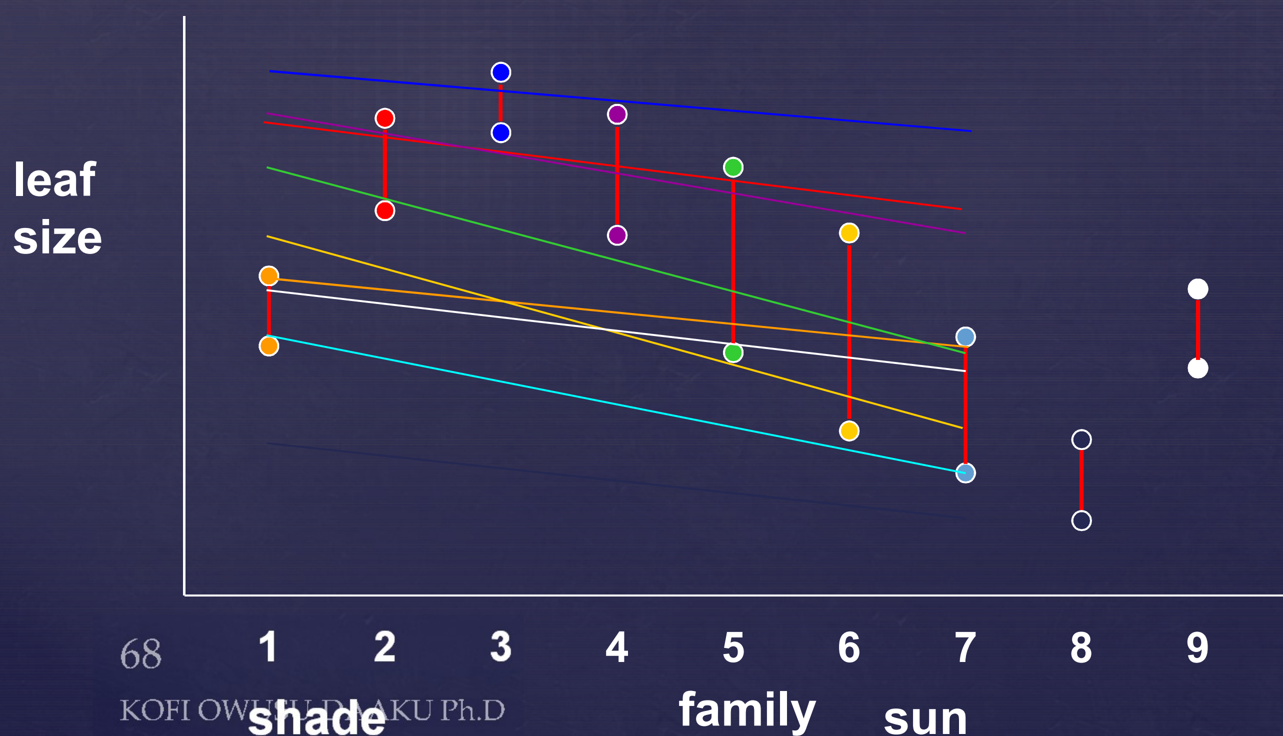


Which families are favored in sun?
in shade?
in env. with both?

Variations on natural selection

Phenotypic plasticity can evolve if: heritable
under selection

Genetic variation in phenotypic plasticity

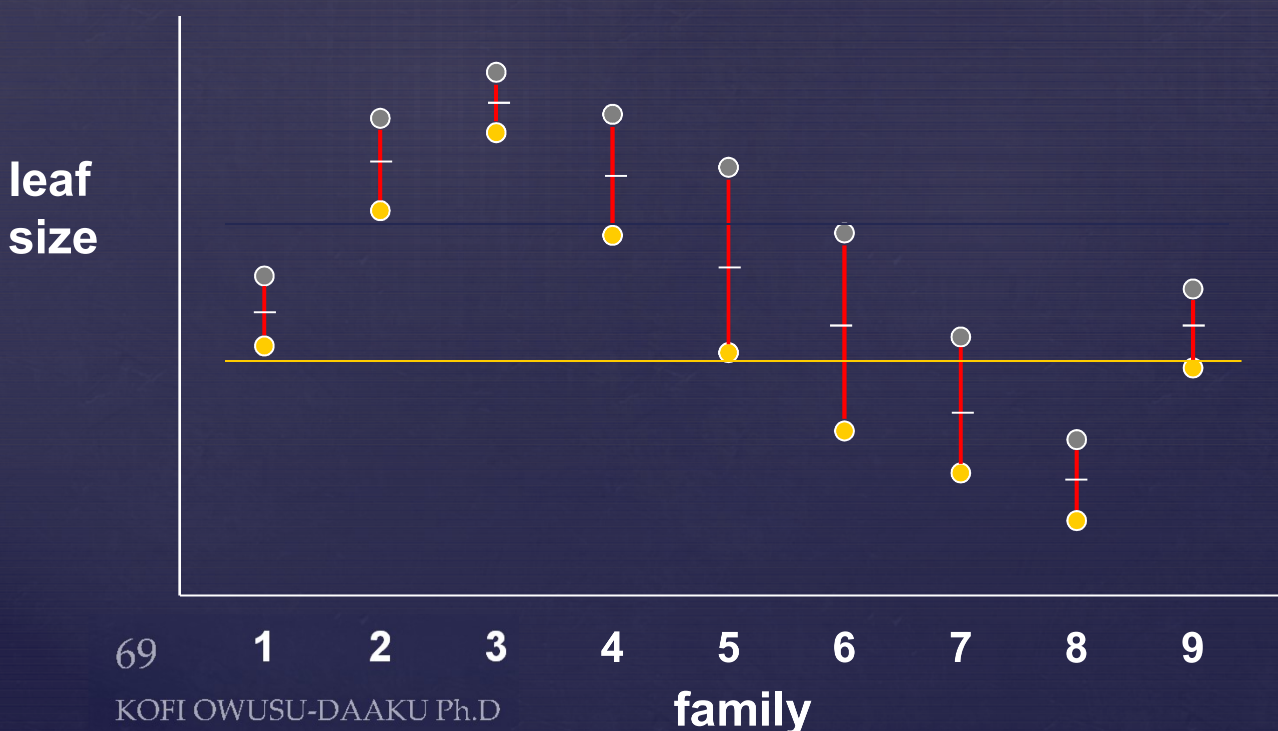


Which families are favored in sun?
in shade?
in env. with both?

Variations on natural selection

Phenotypic plasticity can evolve if: heritable
under selection

Genetic variation in phenotypic plasticity



Is there V_P?
variation among all dots

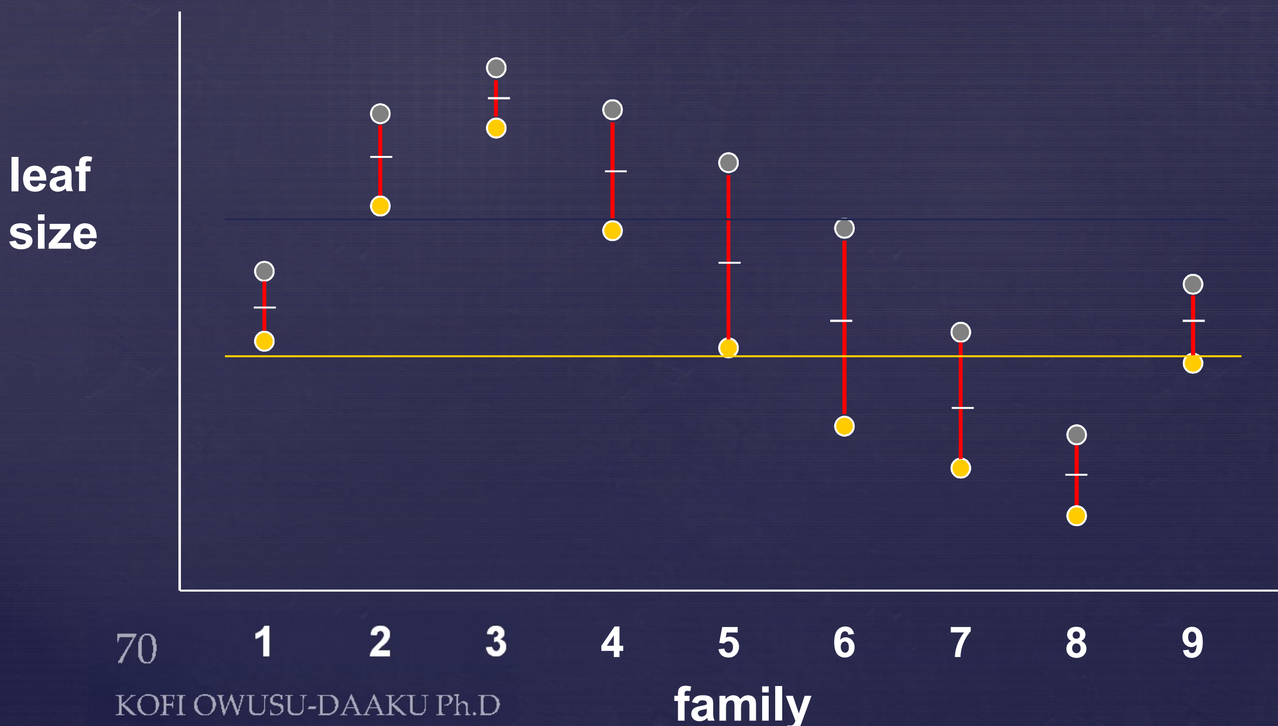
Is there V_G?
variation among family means

Is there V_E?
variation btwn sun & shade means

Variations on natural selection

Phenotypic plasticity can evolve if: heritable
under selection

Genetic variation in phenotypic plasticity



Is there V_P?
Is there V_G?
Is there V_E?

What accounts for variation in plasticity?

$V_{G \times E}$

Variations on natural selection

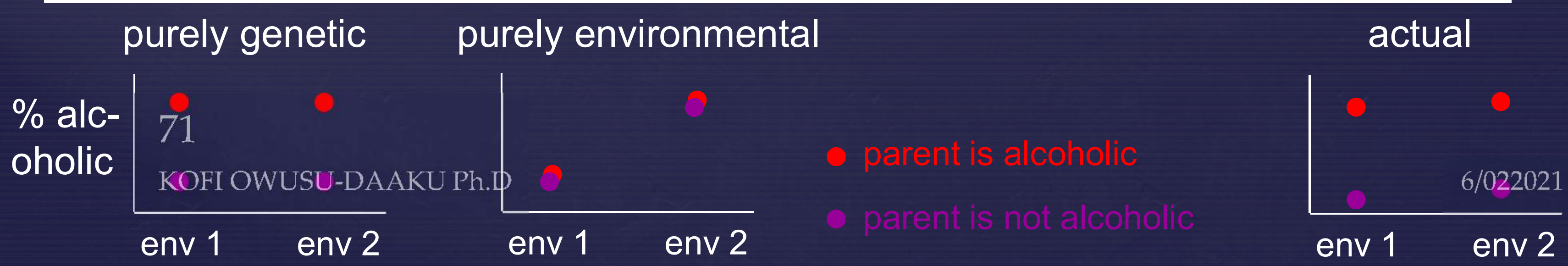
Phenotypic plasticity can evolve

$$V_P = V_G + V_E + V_{G \times E}$$

genotype x environment interaction

Teen-onset alcoholism

Genetic predisposition? (biological parent alcoholic)	**Environmental predisposition?** (foster parent alcoholic)	Percentage of adopted boys who abused alcohol as adults
NO	NO	1.9%
NO	YES	4.1%
YES	NO	16.9%
YES	YES	17.9%



Variations on natural selection

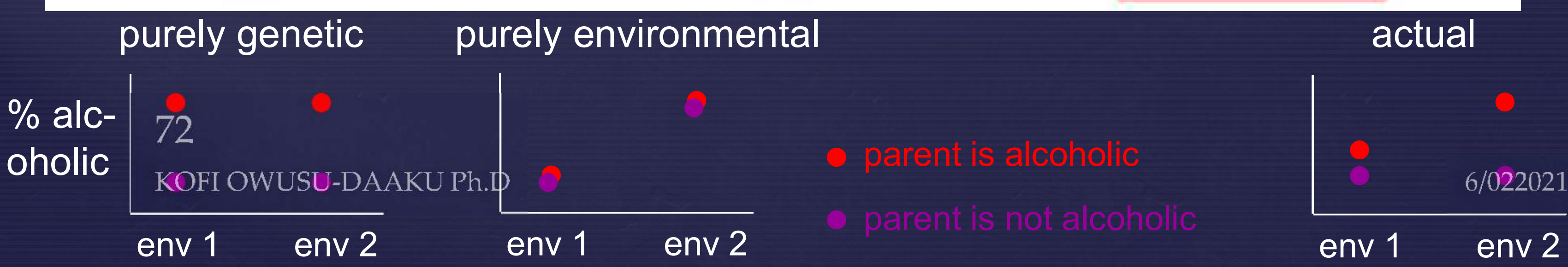
Phenotypic plasticity can evolve

$$V_P = V_G + V_E + V_{G \times E}$$

genotype x environment interaction

Adult-onset alcoholism

Genetic predisposition? (biological parent alcoholic)	Environmental predisposition? (foster parent alcoholic)	Percentage of adopted boys who abused alcohol as adults
NO	NO	4.3%
NO	YES	4.2%
YES	NO	6.7%
YES	YES	11.6%



How does **selection** cause change in allele frequencies?

Relative fitness of genotypes affects outcome of evolution.

1.0 for AA
1.0 for Aa
<1.0 for aa

Deleterious recessive allele – maintained at low levels, "hidden" in carriers.

=
<1.0 for AA
<1.0 for Aa
1.0 for aa

Deleterious dominant allele – removed from population by selection

1.0 for AA
<1.0 for Aa
<<1.0 for aa

Incomplete dominance – deleterious allele will be removed from population by selection

Use AlleleA1 to try it out.

How does **selection** cause change in allele frequencies?

Relative fitness of genotypes affects outcome of evolution.

<1.0 for AA
1.0 for Aa
<1.0 for aa

Heterozygote advantage – carriers have highest fitness

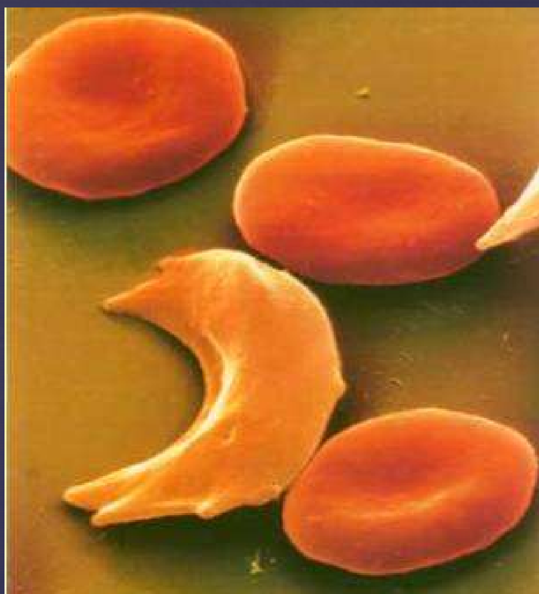
<1.0 for AA
1.0 for Aa
<<1.0 for aa

Heterozygote advantage – deleterious "recessive" maintained at moderate levels

advantage in heterozygote
offsets
disadvantage in homozygote

Use AlleleA1 to try it out.

Case study: Sickle cell disease



aa – abnormal ß hemoglobin
sickle-cell disease

very low fitness

AA – normal ß hemoglobin

Aa – both ß hemoglobins

Case study: Sickle cell disease

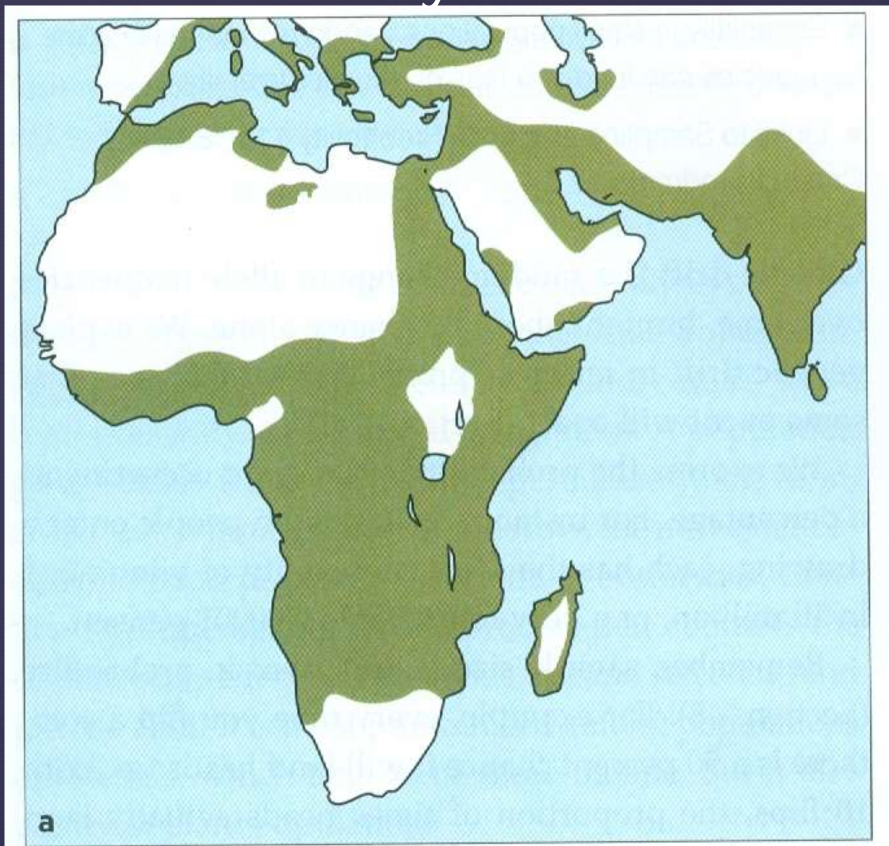
aa – abnormal ß hemoglobin sickle-cell disease — **very low fitness**

AA – normal ß hemoglobin vulnerable to malaria — **intermed. fitness**

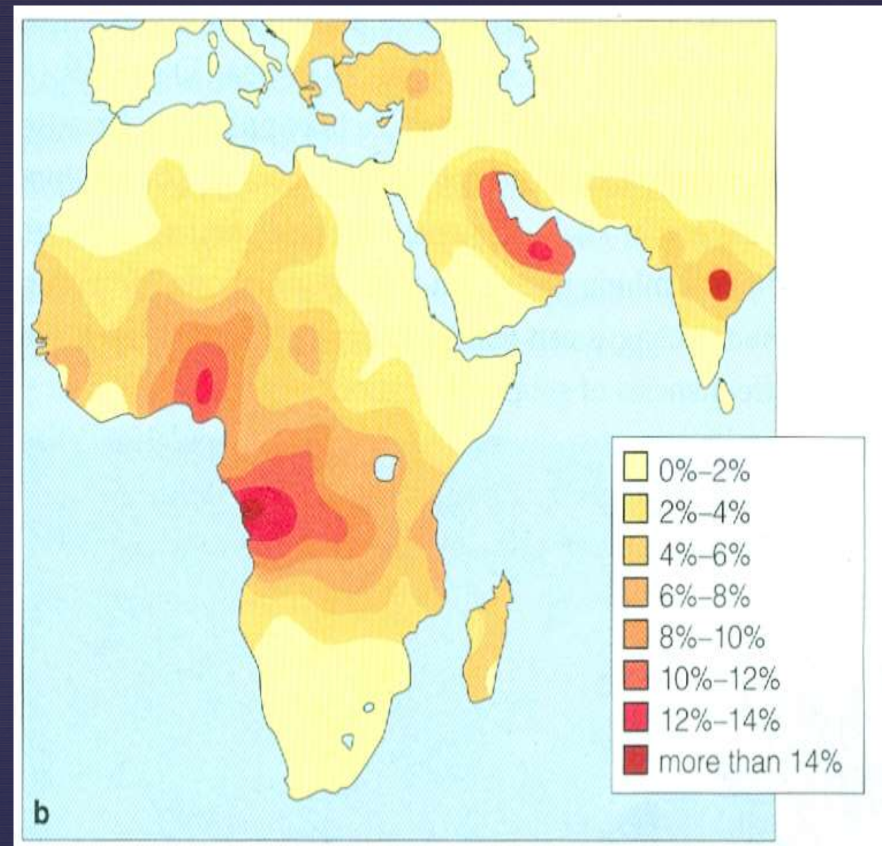
Aa – both ß hemoglobins resistant to malaria — **high fitness**

Heterozygote advantage in populations with malaria.

Case study: Sickle cell disease



Distribution of malaria



Distribution of sickle cell allele

Natural selection favored heterozygotes (Aa) in some areas (parts of Africa), but not others (most of Europe).

Mutation Theory

- The Mutation Theory was proposed by Hugo de Vries (1901).
- de Vries was a Dutch botanist and one of the discoverers of Mendel's law.
- He pointed out that new species arise from the existing species by a sudden change called mutation.

Mutation Theory cont`d

- de Vries suggested that large-scale variations occurring in a population are the result of mutations that take place frequently, leading to formation of new species.
- Mutations are sudden, unpredictable and inheritable changes in an individual organism and are the main source by which new species arise during the course of evolution.

Mutation Theory cont`d

- de Vries worked on the plant evening prime rose (*Oenothera lamarckiana)*.
- The mutation observed by de Vries in *Oenothera lamarckiana* was due to chromosomal variants.

- de Vries found several types of mutations that occurred in plants:

(a) Progressive - Introducing a wholly new character and generally resulting in the formation of new species.

(b) Retrogressive - Loss of a trait.

(c) Digressive - Activation of a trait which is long latent in a species.

Mutation Theory cont`d

(d) de Vries found retrogressive and digressive mutations as following Mendel's law, while progressive mutations did not follow Mendel's law.

II. Mutation

(a) A sudden change in the characteristics of an organism is called mutation.

(b) Mutation involves change in genes or chromosomes or genetic material.

Mutation cont`d

(c) Mutations cause variation in a population and are the source of all new alleles within the population.
(d) Mutations simply change the allele frequencies and do not determine the direction of evolution.
(e) Mutation is a very slow process that causes a change in the genetic composition of a population gradually.

Mutation cont`d

(f) Mutation occurs in any direction.

(g) Mutations are mostly harmful.

(h) Mutations playa key role in the process of evolution as they are responsible for genetic variation, which acts as raw material for evolution.

- Mutation is an alteration of the base-pair sequence in an individual's DNA. If such an alteration changes an allele in an individual's gamete-producing cells, this constitutes evolution within the population. Mutations can be caused by high-energy radiation or chemicals in the environment, and also can appear alleles can be created within a population, and thus it generates the variation on which natural selection can act.

III. Genetic Drift

(a)Genetic drift is the sudden change in the gene frequency in a population.

(b) Genetic drift has greater impacts on smaller populations.

(c) Genetic drift may also occur through random sampling error.

(d) Genetic drift becomes fixed when one allele is entirely replaced by another or the death of one allele occurs.

(e) The process of genetic drift may increase by bottleneck effect or founder effect as genetic drift works more properly in small populations.

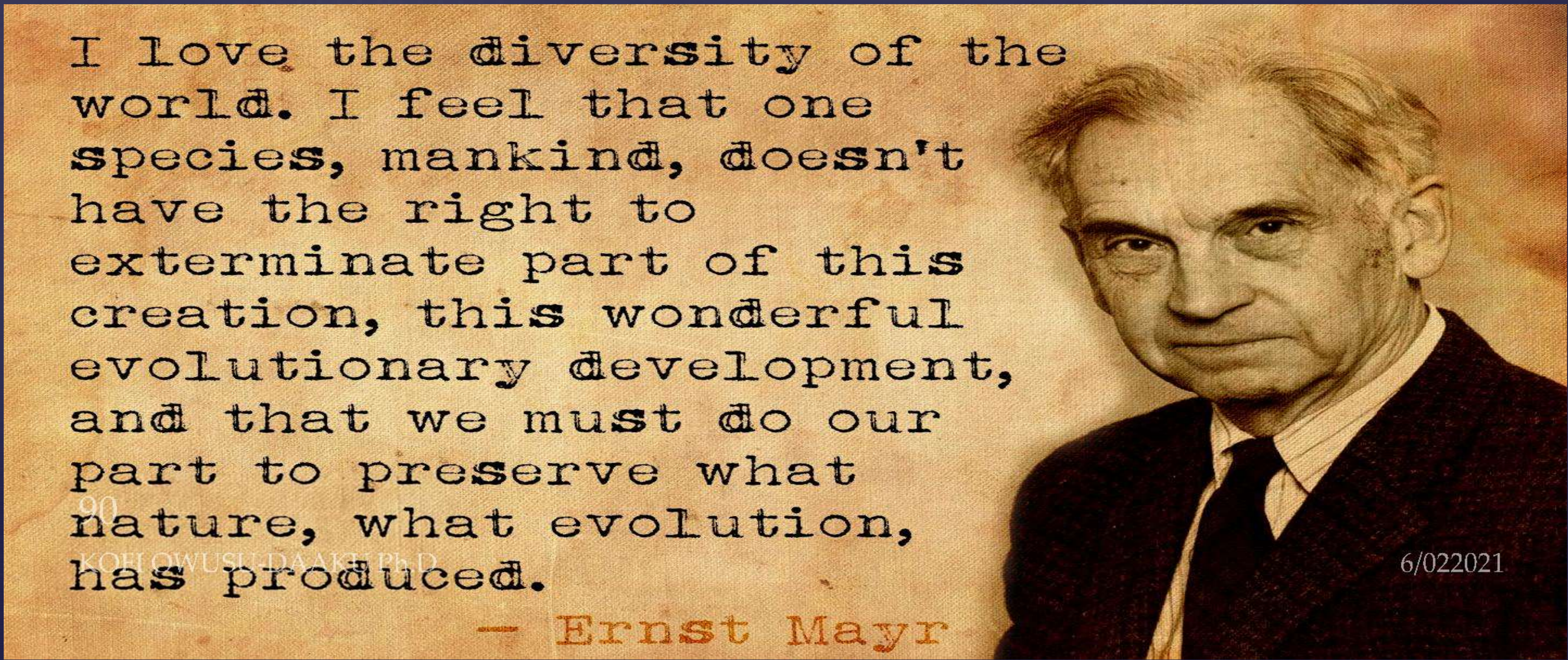
(f) Genetic effect does not work to produce adaptation.

- Genetic drift is random change in allele frequencies within a population, unrelated to the alleles' influence on reproductive success. Genetic drift is a significant agent of evolution change, primary in small populations.

IV. Founder Effect

(a) Founder effect is an important example of genetic drift in humans.

(b) The concept of founder effect was discussed by Ernst Mayr (1952).



Founder Effect cont`d

(c) When a small group of individuals becomes separated from the main population due to geographical barrier, the founder effect occurs. Thus, the formation of a new genotype in a new settlement area is known as founder effect.

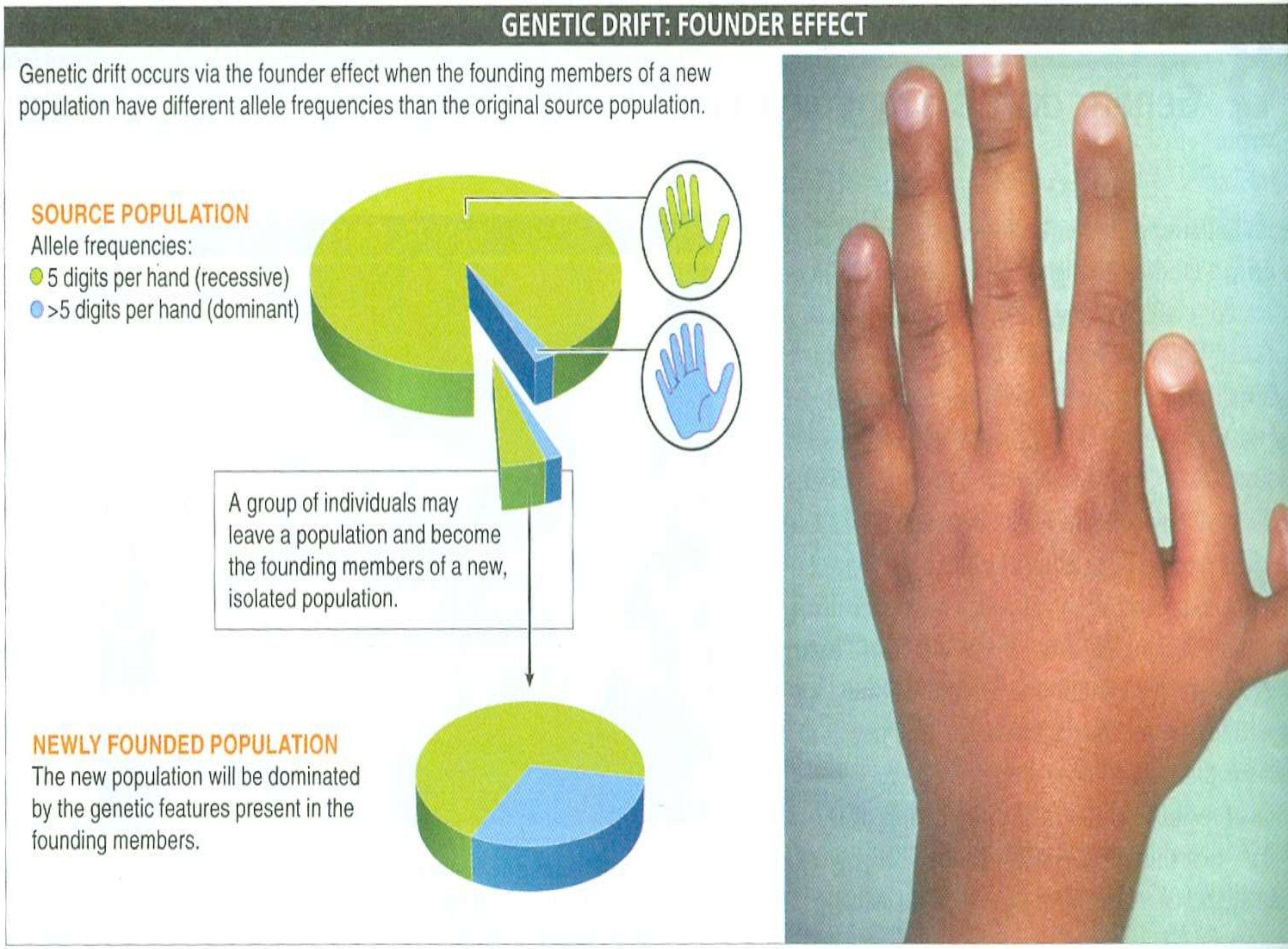


FIGURE 8-13 One way that genetic drift occurs: the founder effect.

Founder Effect cont`d

(d) In rare instances, the founder effect may lead to speciation and subsequent evolution of a new species.

(e) The founder effect is common in island populations, which become cut-off from the main population.

(f) The founder effect is also known as allopatric speciation.

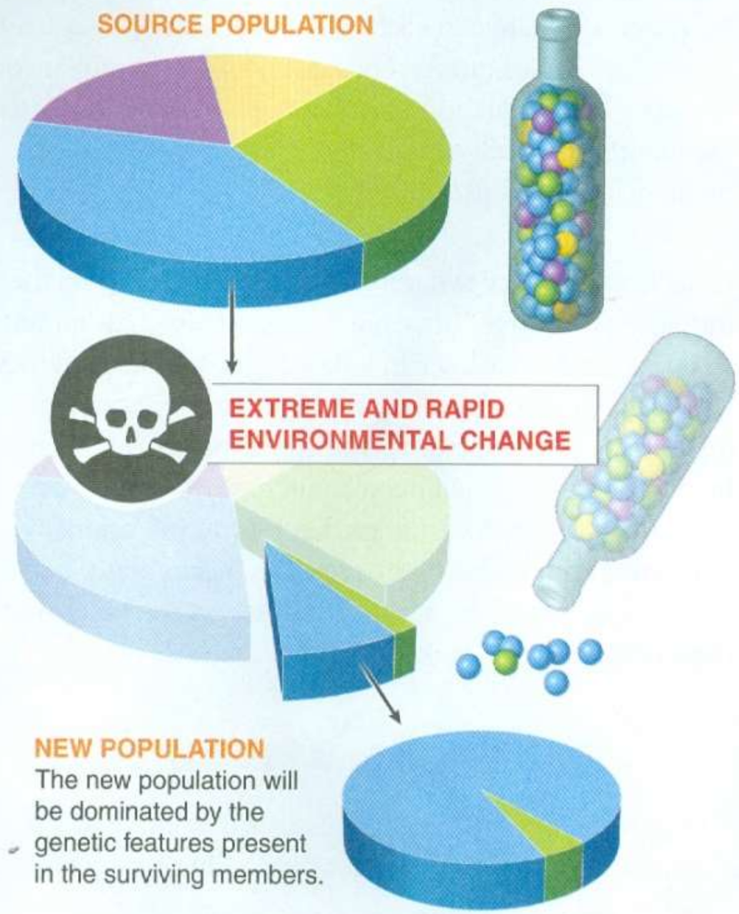
V. Bottleneck Effect

(a) A sudden reduction in the number of individuals in a population from natural disasters like earthquakes, habitat destruction and predation is known as the bottleneck effect.

(b) The bottleneck effect prevents the majority of genotypes from participating in the production of the next generation.

GENETIC DRIFT: BOTTLENECK EFFECT

Genetic drift occurs via the bottleneck effect when famine, disease, or rapid environmental change causes the deaths of a large, random proportion of the population, and the surviving individuals have different allele frequencies than the original population.



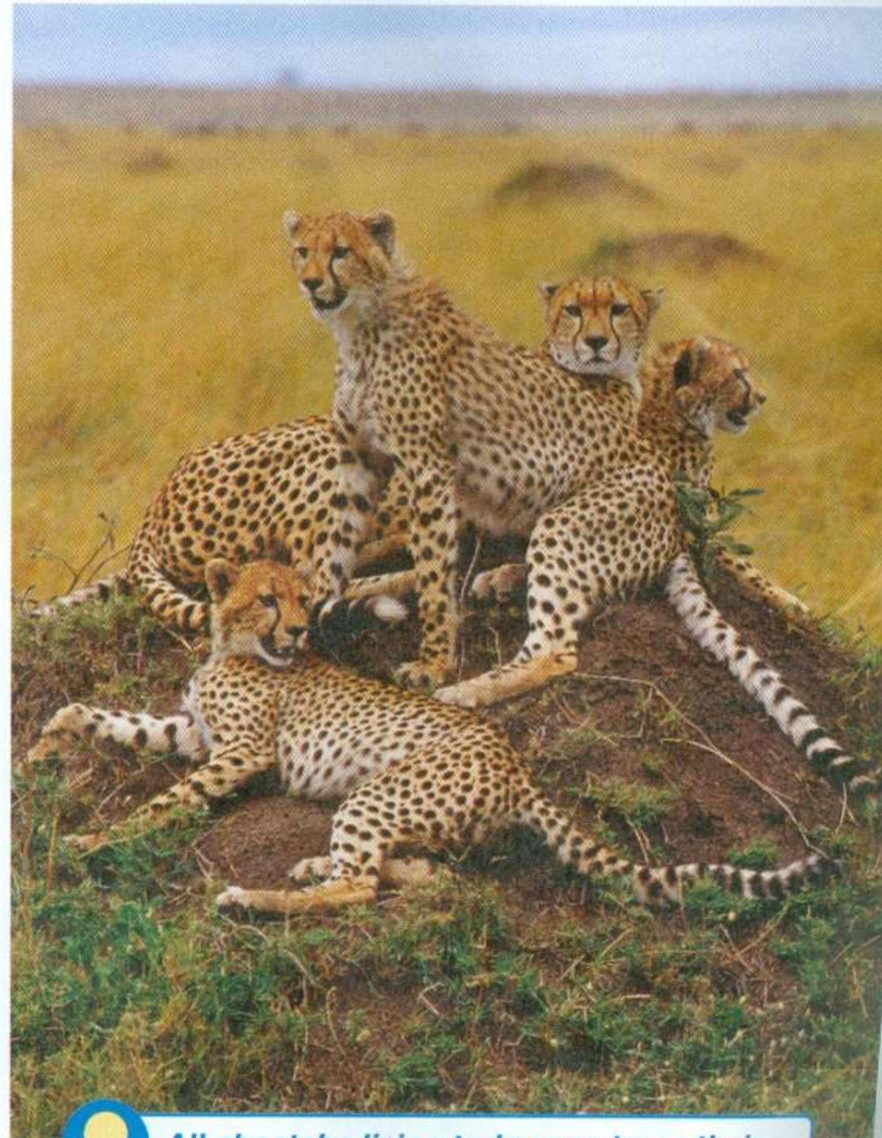


FIGURE 8-14 Another way that genetic drift occurs: the bottleneck effect.

All cheetahs living today can trace their ancestry back to a dozen or so individuals that happened to survive a population bottleneck about 10,000 years ago!

Bottleneck Effect cont`d

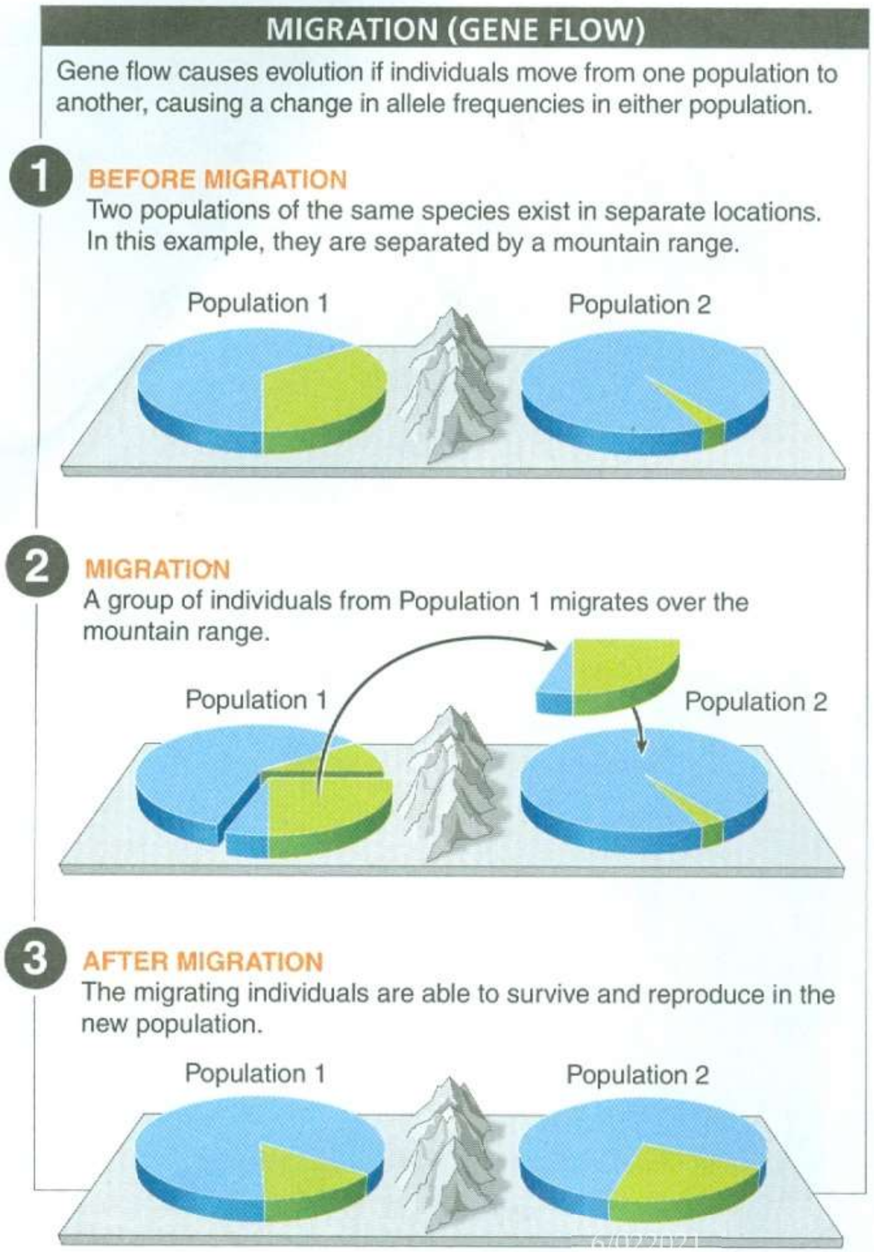
(c) Generally, the bottleneck effect is not associated with genetic advantage.

(d) Natural selection, mutation and genetic drift are the major factors of evolution. They cause changes in genotypes and phenotypes over a period of time.

VI. Gene Flow

(a) Movement of genes from one population to another is known as gene flow.

(b) It is also known as migration.



<u>How</u> does migration cause change in allele frequencies?

Population 1 ("island")

"fixed"

950 AA
0 Aa
0 aa

← 50 aa

Population 2 ("mainland")

0% AA
0% Aa
100% aa

"fixed"

Allele freq. before migration:

Did allele frequencies change?

Allele freq. after migration:

Is the population in Hardy-Weinberg equilibrium?

$$p^2 = (0.95)^2 = 0.9025$$
$$2pq = 2(0.95)(0.05) = 0.0950$$
$$q^2 = (0.05)^2 = 0.0025$$

What if migration continued over many generations?

Migration makes population more similar

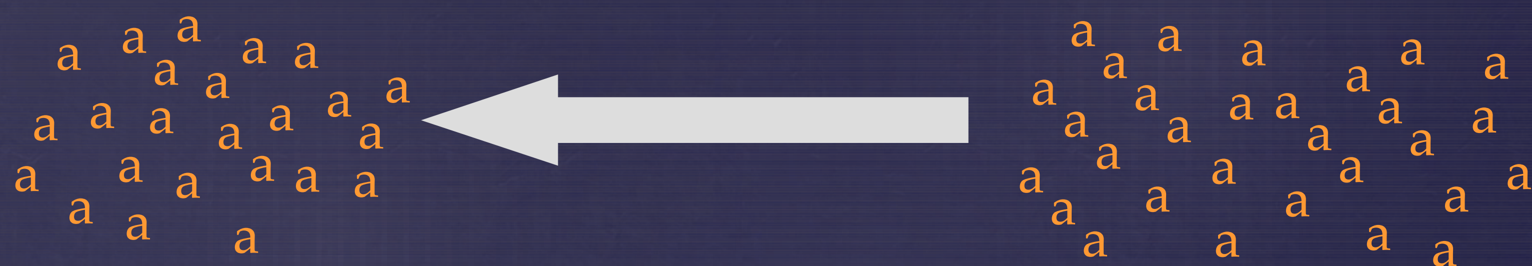
AlleleA1 simulation – one-way migration (gene flow)

Population 1 (“island”)	Population 2 (“mainland”)

Migration makes population more similar

AlleleA1 simulation – one-way migration (gene flow)

Population 1 (“island”) | Population 2 (“mainland”)



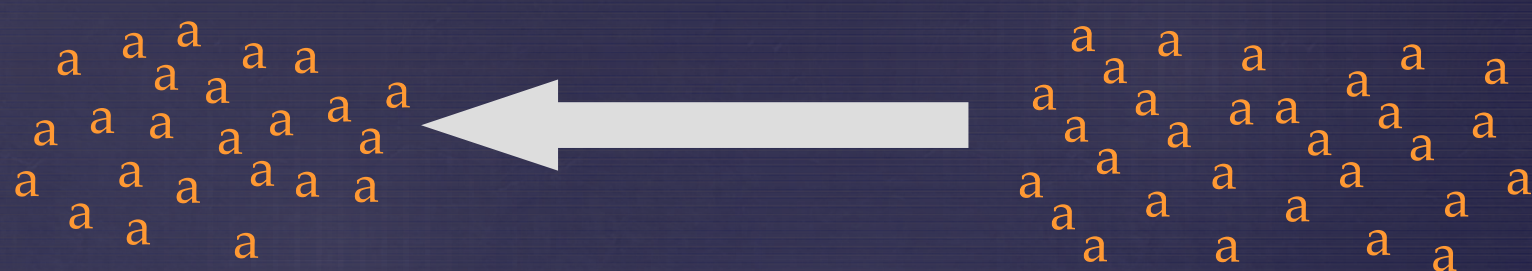
Real life – gene flow can be one-way or two-way

Population 1 | Population 2

Migration makes population more similar

AlleleA1 simulation – one-way migration (gene flow)

Population 1 (“island”)	Population 2 (“mainland”)



Real life – gene flow can be one-way or two-way

Population 1	Population 2

Gene Flow cont`d

- (c) Mutation developing in one population may spread to other populations through gene flow. It leads to introduction of new allele in the population.
- (d) Gene flow may prevent evolution by preventing adaptation or accelerate evolution by spreading new genes or a combinations of genes.

- Migration, or gene flow, leads to change in allele frequencies in a population as individuals move into or out of the population

VII. Nonrandom Mating

- A mating in which mates are selected on the basis of physical or behavioural traits is called non-random mating.
- It is also known as assortative mating.

Nonrandom Mating cont`d

- Assortative mating of similar or dissimilar genotypes leads to formation of excess of homozygotes or heterozygotes, respectively.
- Any departure from random mating upsets the equilibrium distribution of genotypes in a population.

Rules of Organic Evolution

- Some rules associated with evolution are as follows:
- Allen's **Rule** - Allen's Rule states that the extremities such as ears, tails and limbs of animals inhabiting colder regions are smaller than those of their counterparts living in warmer regions.
- Bergman's **Rule** - Warm-blooded animals living in colder regions have larger body parts than those living in a hot climate.

- Cope's **Rule** - Animals have a tendency to increase in body size during the course of evolution. However, this is not true for all taxonomic classes or clades.
- Dolle's **Rule** - Dolle's rule states that evolution does not occur in the opposite direction. Characteristics once developed do not develop again.

- Gause's **Principle** - It states that two or more species of organisms having similar environmental need cannot exist for a long time in an area due to similar needs; competition will develop between them in due course of time.
- Gloger's **Rule** - The colouration of some animals is effected by temperature, light and moisture. Many mammals, birds and insects living in a warm, humid climate have darker colour than their counterparts living in a dry climate.