Chapter 23
The Evolution of Populations

Question?

- Is the unit of evolution the <u>individual</u> or the <u>population</u>?
- Answer – while evolution effects individuals, it can only be tracked through time by looking at populations.

So what do we study?

- We need to study populations, not individuals.
- We need a method to track the changes in populations over time.
- This is the area of Biology called population genetics.

Population Genetics

- The study of genetic variation in populations.
- Represents the reconciliation of Mendelism and Darwinism.

Modern Synthesis

- Uses population genetics as the means to track and study evolution.
- Looks at the genetic basis of variation and natural selection.

Sources of Variation

- Sexual Reproduction
  - Random Assortment of Chromosomes
  - Random Fertilization
  - Crossing Over
- Mutation

Mutations

- Inherited changes in a gene.
- Rates low in most cases due to DNA repair etc.

Population

- A localized group of individuals of the same species.

Species

- A group of similar organisms.
- A group of populations that could interbreed.

Gene Pool

- The total aggregate of genes in a population.
- If evolution is occurring, then changes <u>must</u> occur in the gene pool of the population over time.

Microevolution

- Changes in the relative frequencies of alleles in the gene pool.

Hardy-Weinberg Theorem

- Developed in 1908.
- Mathematical model of gene pool changes over time.
- Asks – does sexual reproduction by itself cause changes in gene frequency?

Basic Equation
(Allele Frequencies)

- $p + q = 1$
- p = % dominant allele
- q = % recessive allele

Expanded Equation (Genotype Frequencies)

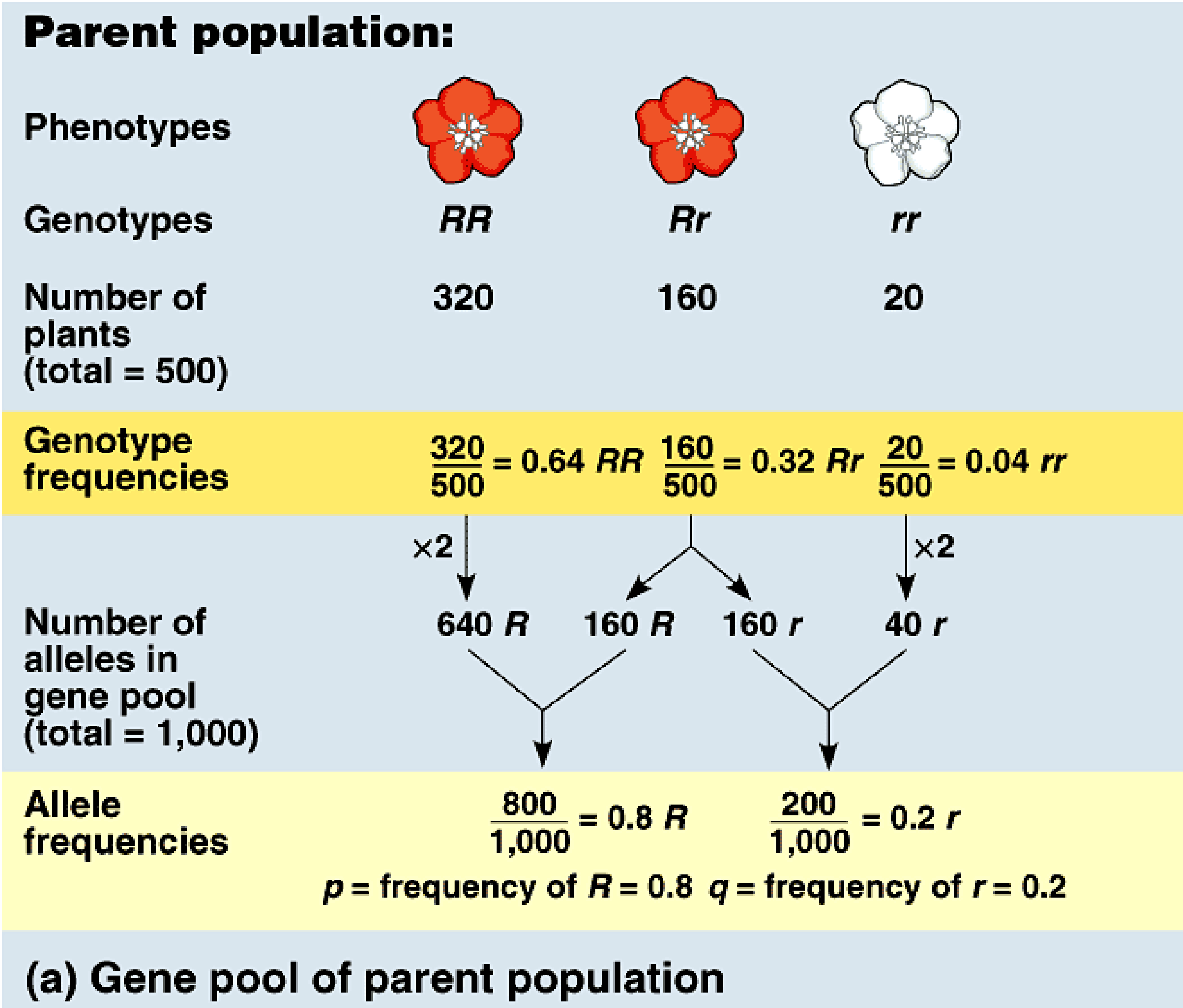
- $p + q = 1$
- $(p + q)^2 = (1)^2$
- $p^2 + 2pq + q^2 = 1$

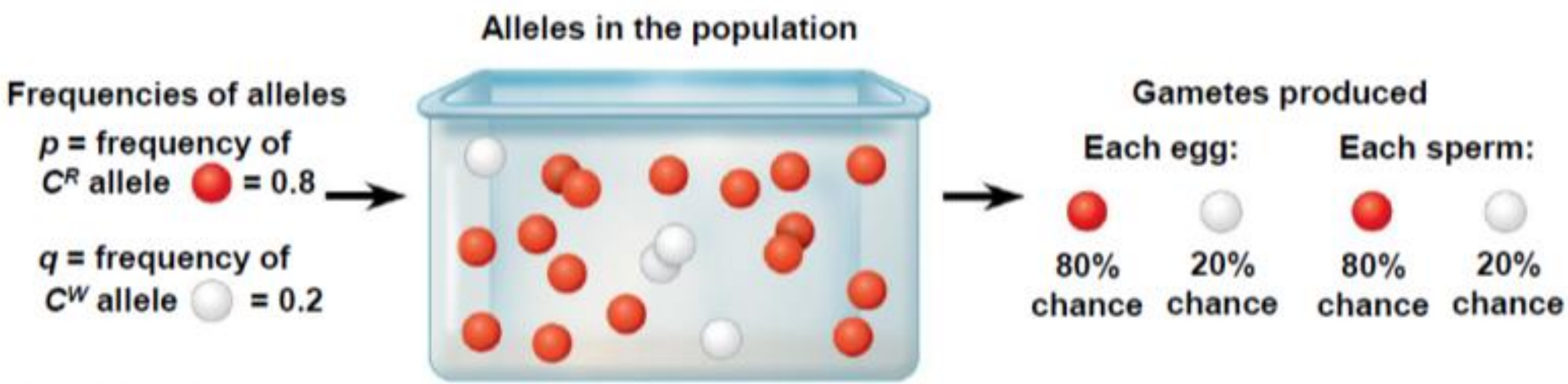
Genotype Frequencies

- p^2 = Homozygous Dominants
  2pq = Heterozygous
  q^2 = Homozygous Recessives

Example Calculation

- Let’s look at a population where:
  - A = red flowers
  - a = white flowers


Parent population:
Phenotypes
Genotypes
RR
Rr
rr
Number of plants (total = 500)
320
160
20
Genotype frequencies
$\frac{320}{500} = 0.64\ RR$
$\frac{160}{500} = 0.32\ Rr$
$\frac{20}{500} = 0.04\ rr$
×2
×2
Number of alleles in gene pool (total = 1,000)
640 R
160 R
160 r
40 r
Allele frequencies
$\frac{800}{1,000} = 0.8\ R$
$\frac{200}{1,000} = 0.2\ r$
p = frequency of R = 0.8
q = frequency of r = 0.2
(a) Gene pool of parent population



Alleles in the population
Frequencies of alleles
p = frequency of
C^R allele = 0.8
q = frequency of
C^W allele = 0.2
Gametes produced
Each egg:
Each sperm:
80% chance
20% chance
80% chance
20% chance

Starting Population

- N = 500
- Red = 480 (320 AA+ 160 Aa)
- White = 20
- Total Genes = 2 x 500 = 1000

Dominant Allele

- A = (320 x 2) + (160 x 1)

  = 800

  = 800/1000

  A = 0.8 = 80%

Recessive Allele

- a = (160 x 1) + (20 x 2)

  = 200/1000

 a = 0.2 = 20%

A and a in HW equation

- Cross: Aa X Aa
- Result = AA + 2Aa + aa
- Remember: A = p, a = q

Substitute the values for A and a

- $p^2 + 2pq + q^2 = 1$

$(.8)^2 + 2(.8)(.2) + (.2)^2 = 1$

$.64 + .32 + .04 = 1$

Dominant Allele

- A = $p^2 + pq$

  = .64 + .16

  = .80

  = 80%

Recessive Allele

- $a = pq + q^2$

  $= .16 + .04$

  $= .20$

  $= 20\%$

Result

- Gene pool is in a state of equilibrium and has <u>not</u> changed because of sexual reproduction.
- <u>No</u> Evolution has occurred.

Importance of Hardy-Weinberg

- Yardstick to measure rates of evolution.
- Predicts that gene frequencies should <u>NOT</u> change over time as long as the HW assumptions hold (no evolution should occur).
- Way to calculate gene frequencies through time.

Hardy-Weinberg Assumptions

1. Large Population
2. Isolation (no migration)
3. No Net Mutations
4. Random Mating
5. No Natural Selection

Example

- What is the frequency of the PKU allele?
- PKU is expressed only if the individual is homozygous recessive (aa).

PKU Frequency

- PKU is found at the rate of 1/10,000 births.
- PKU = aa = q^2

$q^2 = .0001$

$q = .01$

Dominant Allele

- $p + q = 1$

  $p = 1 - q$

  $p = 1 - .01$

  $p = .99$

Expanded Equation

- $p^2 + 2pq + q^2 = 1$

$(.99)^2 + 2(.99x.01) + (.01)^2 = 1$

$.9801 + .0198 + .0001 = 1$

Final Results

- Normals (AA) = 98.01%
- Carriers (Aa) = 1.98%
- PKU (aa) = .01%

AP Problems Using Hardy-Weinberg

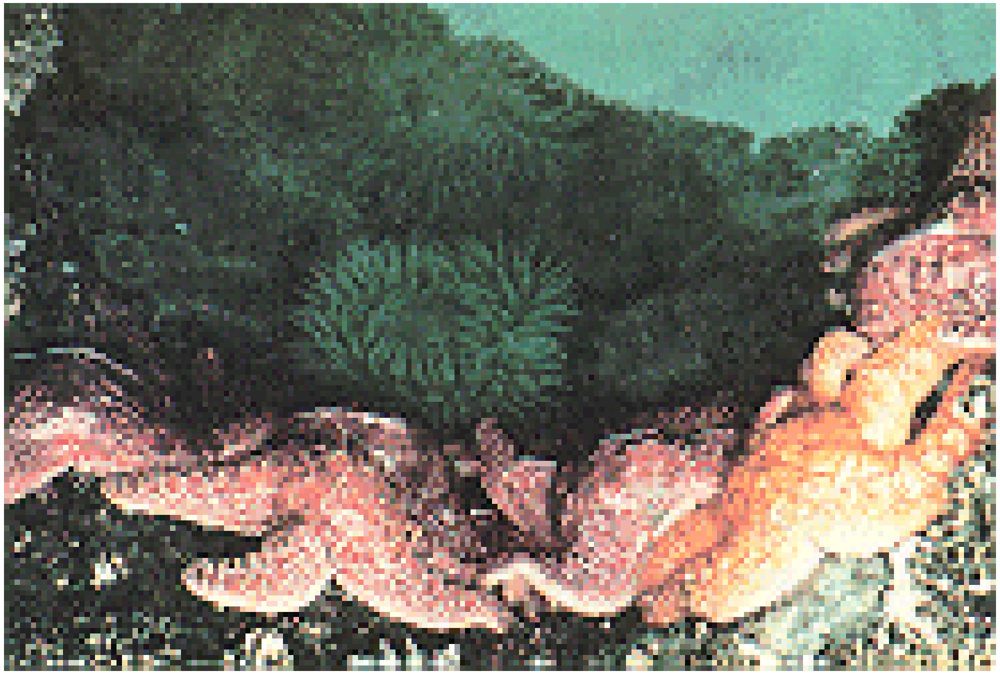
- Solve for q^2 (% of total).
- Solve for q (equation).
- Solve for p (1- q).
- H-W is <u>always</u> on the national AP Bio exam.

If H-W assumptions hold true:

- The gene frequencies will <u>not</u> change over time.
- Evolution will <u>not</u> occur.
- But, how likely will natural populations hold to the H-W assumptions?

Microevolution

- Caused by violations of the 5 H-W assumptions.



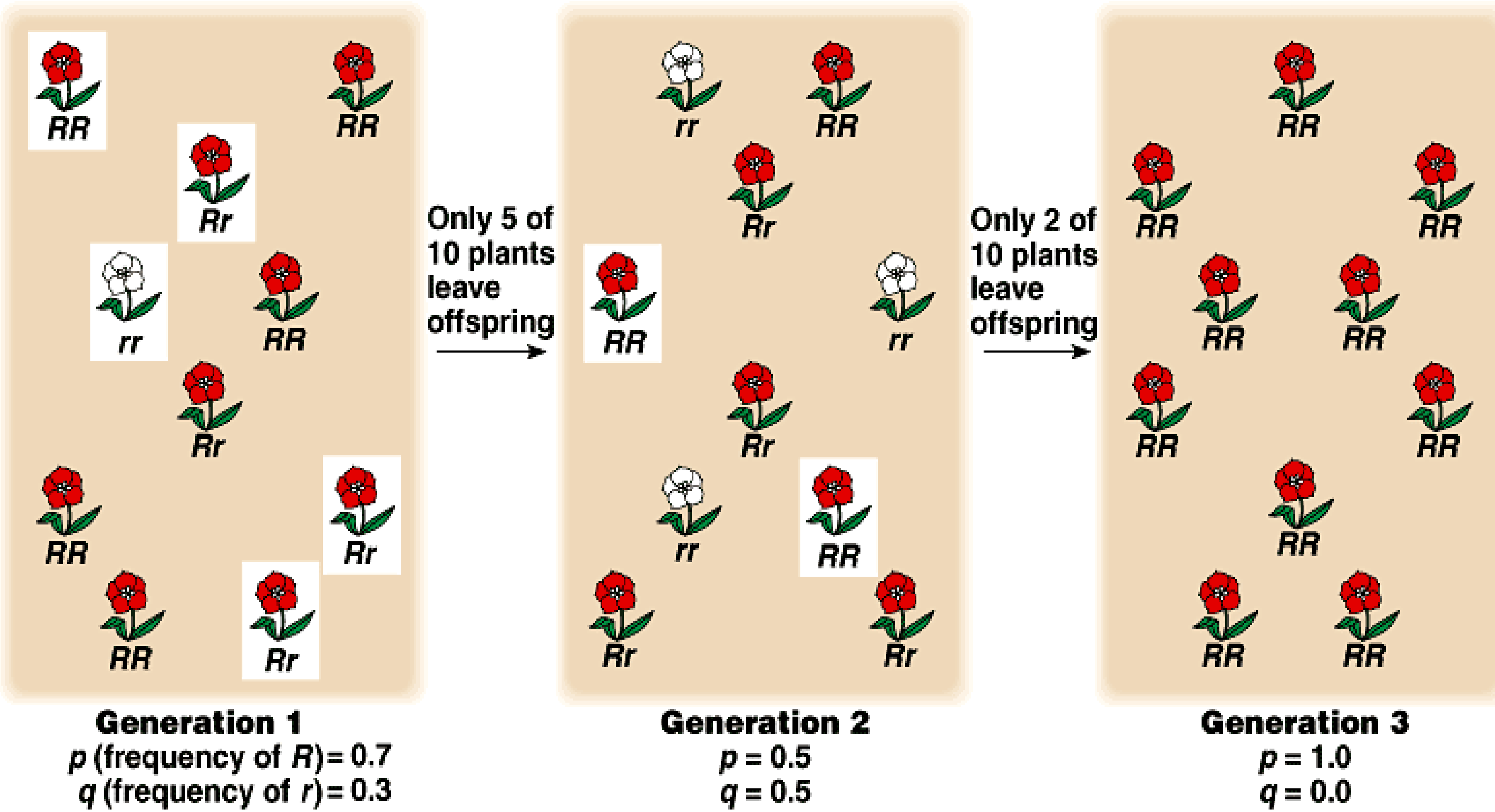
Causes of Microevolution

1. Genetic Drift
2. Gene Flow
3. Mutations
4. Nonrandom Mating
5. Natural Selection

Genetic Drift

- Changes in the gene pool of a small population by chance.
- Types:
  - 1. Bottleneck Effect
  - 2. Founder's Effect

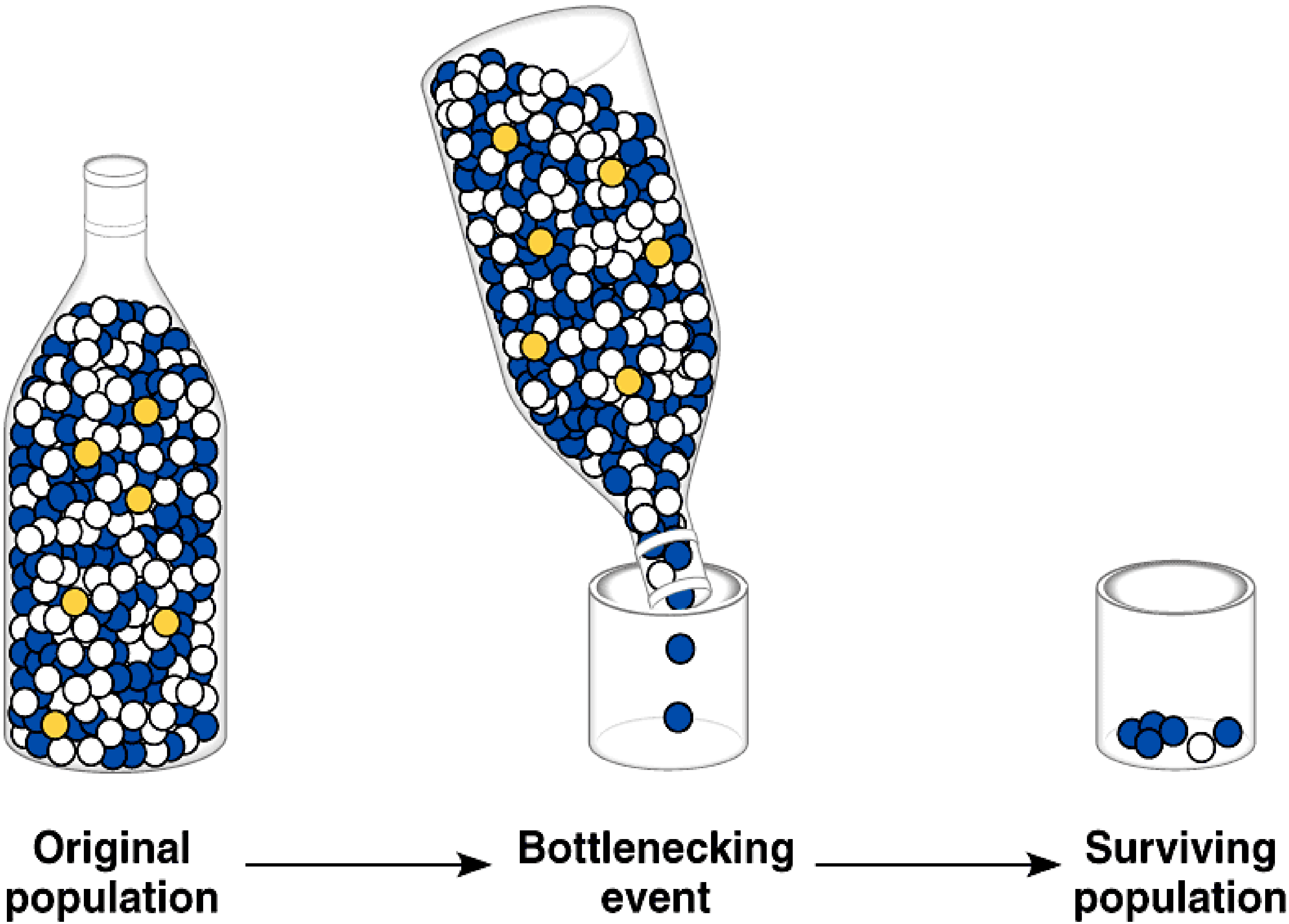
By Chance



RR
RR
Rr
rr
RR
Rr
RR
Rr
RR
Rr
Only 5 of 10 plants leave offspring
rr
RR
Rr
RR
rr
Rr
rr
RR
Rr
Rr
Only 2 of 10 plants leave offspring
RR
RR
RR
RR
RR
RR
RR
RR
RR
RR
Generation 1
p (frequency of R) = 0.7
q (frequency of r) = 0.3
Generation 2
p = 0.5
q = 0.5
Generation 3
p = 1.0
q = 0.0

Bottleneck Effect

- Loss of most of the population by disasters.
- Surviving population may have a different gene pool than the original population.

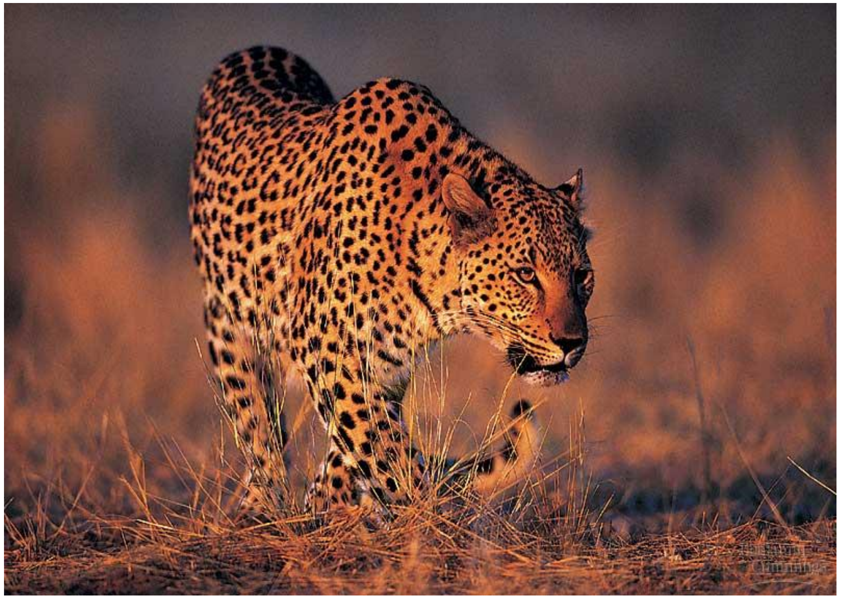

Original population
Bottlenecking event
Surviving population

Result

- Some alleles lost.
- Other alleles are over-represented.
- Genetic variation usually lost.

Importance

- Reduction of population size may reduce gene pool for evolution to work with.
- Ex: Cheetahs



Founder's Effect

- Genetic drift in a new colony that separates from a parent population.
- Ex: Old-Order Amish

Result

- Genetic variation reduced.
- Some alleles increase in frequency while others are lost (as compared to the parent population).

Importance

- Very common on islands and with other groups that don't interbreed.

Gene Flow

- Movement of genes in/out of a population.
- Ex:
  - Immigration
  - Emigration

Result

- Changes in gene frequencies within a population.
- Immigration often brings new alleles into populations increasing genetic diversity.

Result - Mutations

- May change gene frequencies (small population).
- Source of new alleles for selection.
- Often lost by genetic drift.

Nonrandom Mating

- Failure to choose mates at random from the population.

Causes

- Inbreeding within the same “neighborhood”.
- Assortative mating (like with like).

Result

- Increases the number of homozygous loci.
- Does not in itself alter the overall gene frequencies in the population.

Natural Selection

- Differential success in survival and reproduction.
- Result - Shifts in gene frequencies.

Fitness - Darwinian

- The relative contribution an individual makes to the gene pool of the next generation.

Relative Fitness

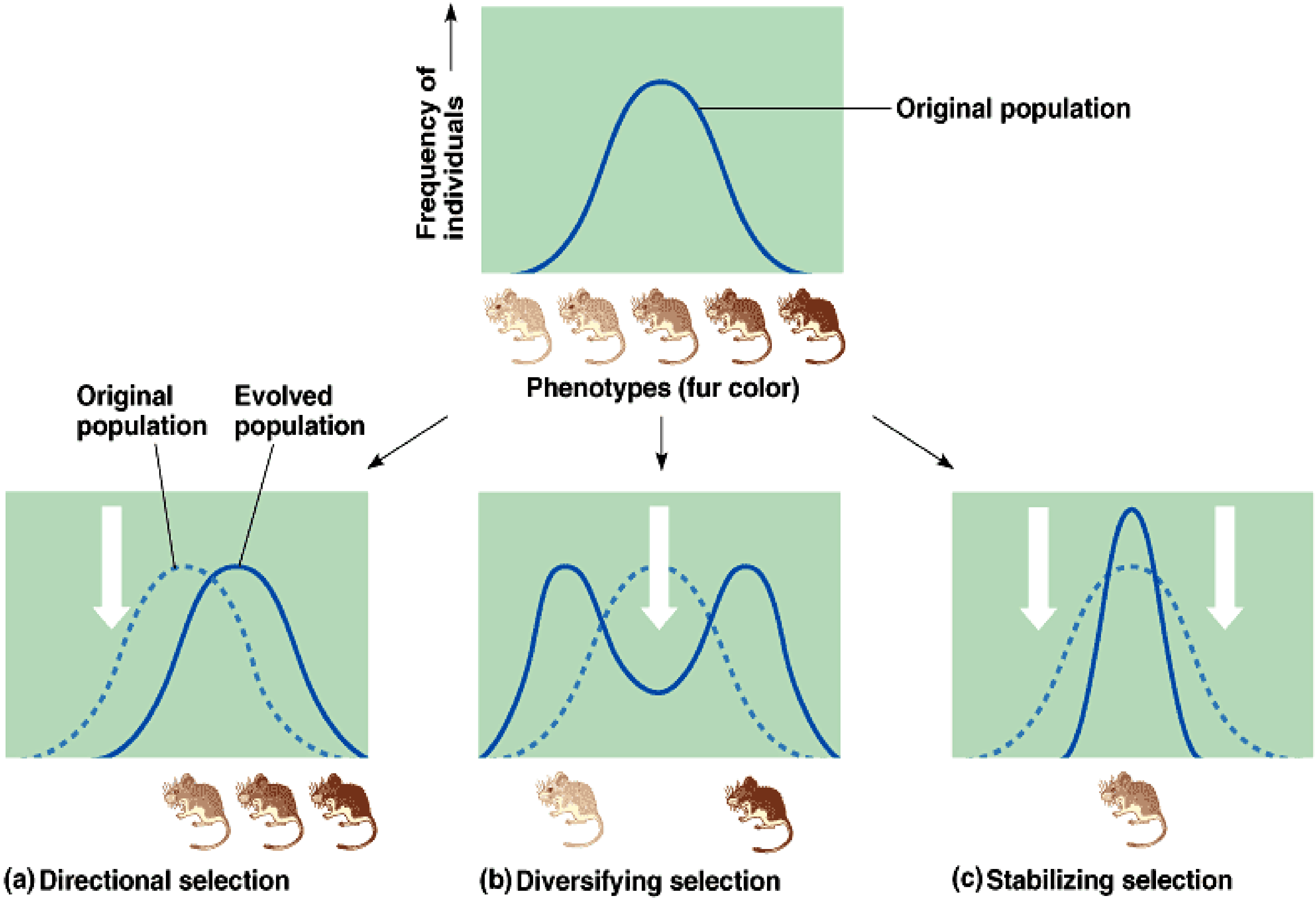
- Contribution of one genotype to the next generation compared to other genotypes.

Rate of Selection

- Differs between dominant and recessive alleles.
- Selection pressure by the environment.

Modes of Natural Selection

1. Stabilizing
2. Directional
3. Diversifying
4. Sexual

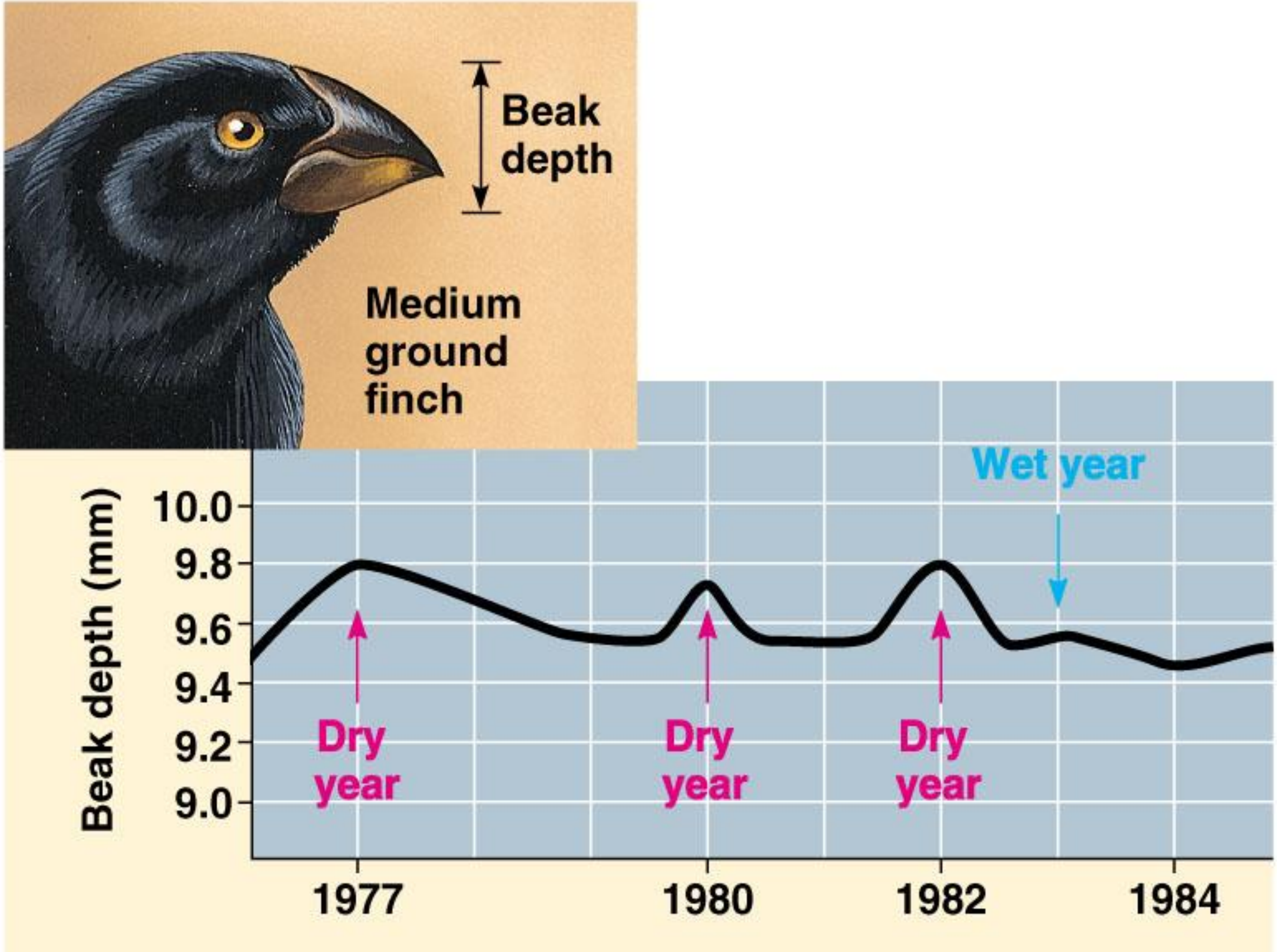

Frequency of individuals
Original population
Phenotypes (fur color)
Original population
Evolved population
(a) Directional selection
(b) Diversifying selection
(c) Stabilizing selection

Stabilizing

- Selection toward the average and against the extremes.
- Ex: birth weight in humans

Directional Selection

- Selection toward one extreme.
- Ex: running speeds in race animals.
- Ex. Galapagos Finch beak size and food source.



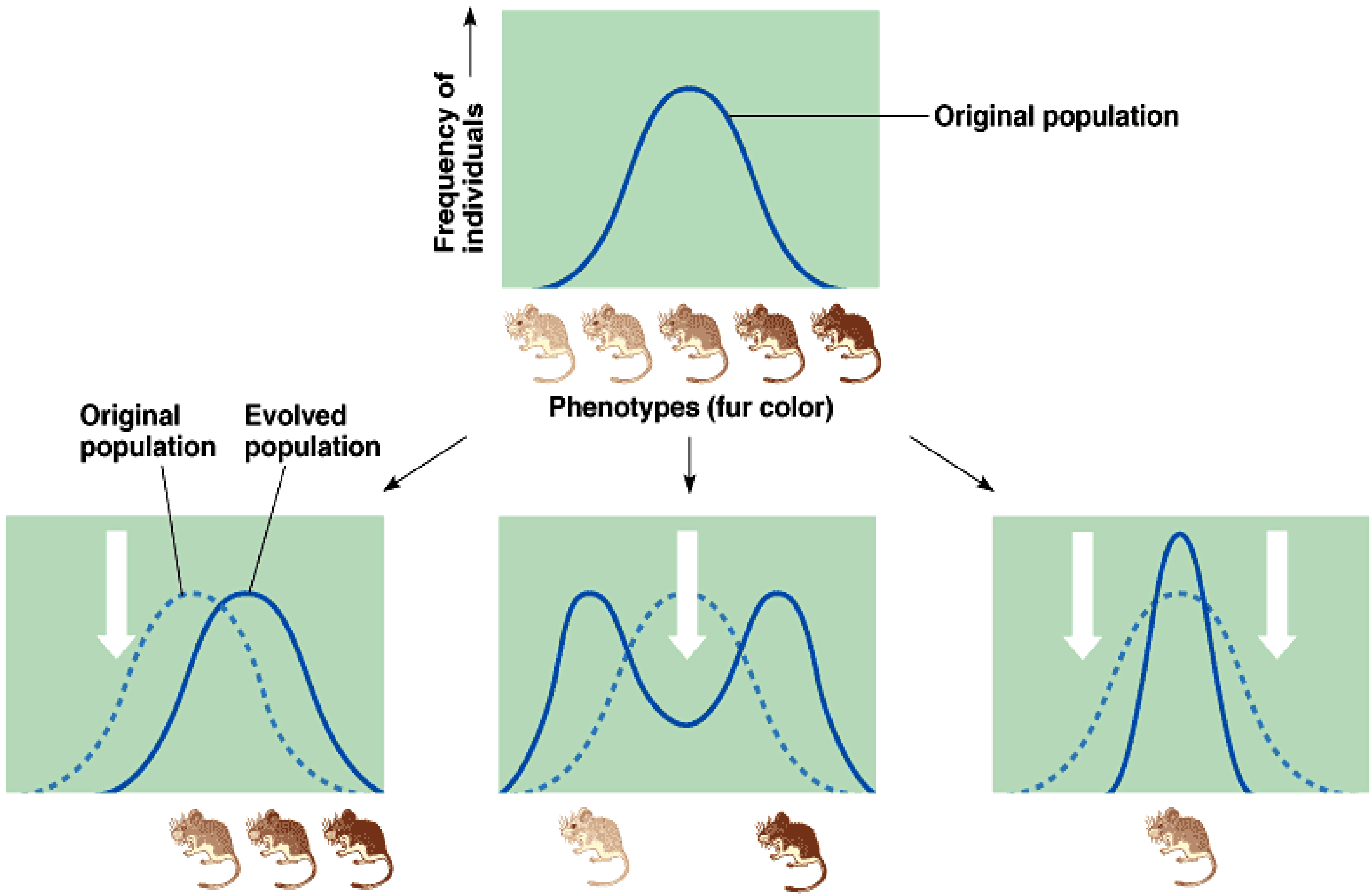
Beak depth
Medium ground finch
Wet year
10.0
9.8
9.6
9.4
9.2
9.0
Beak depth (mm)
Dry year
Dry year
Dry year
1977
1980
1982
1984

Diversifying

- Selection toward both extremes and against the norm.
- Ex: bill size in birds

Comment

- Diversifying Selection - can split a species into several new species if it continues for a long enough period of time and the populations don’t interbreed.



(a) Directional selection

(b) Diversifying selection

(c) Stabilizing selection

Sexual Mate selection

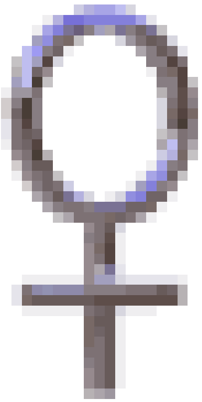
- May not be adaptive to the environment, but increases reproduction success of the individual.
- This is a VERY important selection type for species.

Result

- Sexual dimorphism.
- Secondary sexual features for attracting mates.

Comments

- Females may drive sexual selection and dimorphism since they often "choose" the mate.



Preserving Genetic Variation

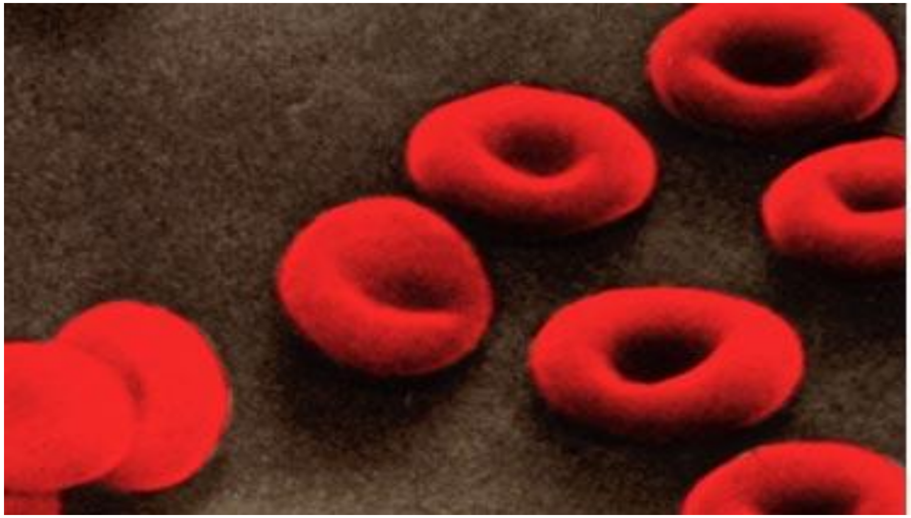
1. Diploidy - preserves recessives as heterozygotes.
2. Balanced Polymorphisms - preservation of diversity by natural selection.

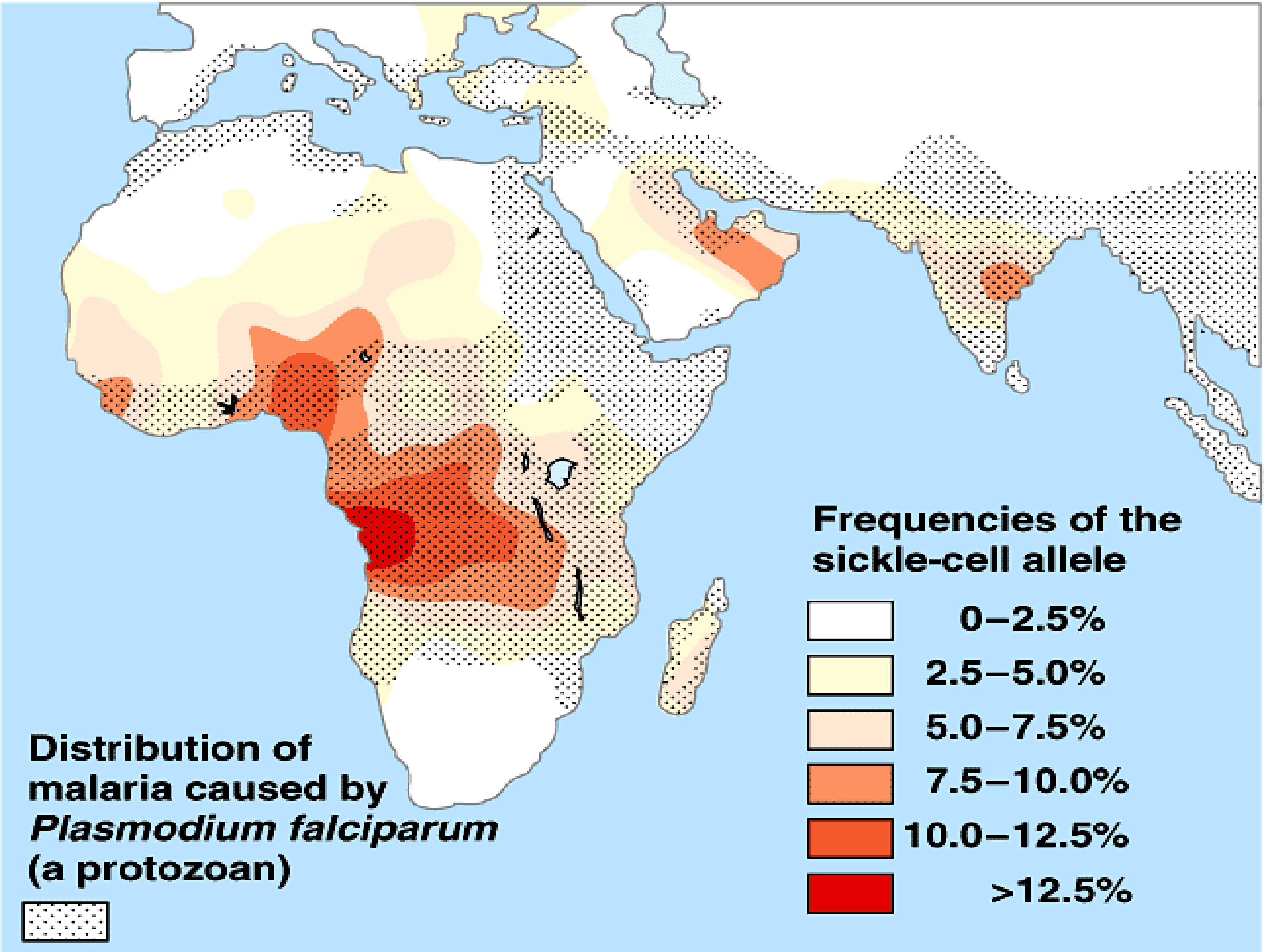
Example

- Heterozygote Advantage - When the heterozygote or hybrid survives better than the homozygotes. Also called Hybrid vigor.

Result

- Can't bred "true“ and the diversity of the population is maintained.
- Ex – Sickle Cell Anemia




Frequencies of the sickle-cell allele
0–2.5%
2.5–5.0%
5.0–7.5%
7.5–10.0%
10.0–12.5%
>12.5%
Distribution of malaria caused by *Plasmodium falciparum* (a protozoan)

Comment

- Population geneticists think that ALL genes that persist in a population must have had a selective advantage at one time.
- Ex – Sickle Cell and Malaria, Tay-Sachs and Tuberculosis

Question

- Does evolution result in perfect organisms?

Answer - No

1. Historical Constraints
2. Compromises
3. Non-adaptive Evolution (chance)
4. Available variations – most come from using a current gene in a new way.

Summary

- Know the difference between a species and a population.
- Know that the unit of evolution is the population and not the individual.
- Know the H-W equations and how to use them in calculations.
- Know the H-W assumptions and what happens if each is violated.

Summary

- Know the various modes of natural selection.
- Identify various means to introduce genetic variation into populations.