Chapter 13: 
How Populations Evolve

1. Evolution by Natural Selection

2. Evidence for Evolution

3. Molecular Basis of Evolution

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1. Evolution by Natural Selection
What is Evolution all about?

1) The gradual change in the characteristics of a species over time.
   - “common descent with modification”
   - occurs generation by generation
     - individuals don’t evolve, but populations do

2) This gradual change is directed by the process of Natural Selection.
   - external factors select the best adapted individuals for survival and reproduction
   - only those who survive & reproduce pass on their genetic alleles to the next generation
Evolutionary thought was spawned by…

1) The discovery of regional variations in related species throughout the world
   • i.e., with unique adaptations for their region

2) Discovery of fossil remains for various extinct species in characteristic sedimentary layers
   • fossils of same species found in layers of same age

3) Evidence for an earth much older than previously thought
   • due to a better understanding of geological processes
   • provides time for evolution to occur (slowly)

***Ultimately led Charles Darwin and Alfred Wallace to propose the Theory of Evolution in the 1850’s***
Darwin’s Voyage

- his visit to the Galapagos Islands provided his greatest insights into the nature of evolution
Evolution is driven by Natural Selection

Natural selection is the process by which external pressures select the best adapted individuals for survival and reproduction:

• evolutionary success = surviving to reproduce fertile offspring

• the genetic alleles of those best able to survive and reproduce will be passed on, increase in the population

• thus natural selection modifies the genetic make up of a population, generation by generation

• the “direction” of evolution is determined by external pressures (aka, selective factors), which will change over time
Examples of Selective Factors

Weather & Climate (temperature, wind, water)
  • those best adapted to current climate survive…

Availability of Food
  • those best at securing, using available food survive…

Predators & Disease
  • those that evade predators, resist disease survive…

Competition for Mates
  • those most successful at mating leave more offspring
2. Evidence for Evolution
A Variety of Evidence Supports Evolution by Natural Selection

a) The Fossil Record
   • consistent with gradual change over long periods

b) Anatomical (Skeletal) Evidence
   • similarities in skeletal structures

c) Embryological Evidence
   • similarities in embryological development

d) Biochemical/Genetic Evidence
   • conservation of DNA sequences, metabolic processes

e) Observable Natural Selection
   • some species visibly evolve in our lifetimes
a) The Fossil Record

Fossils include more than just bones
- any evidence of a “once living” creature is a fossil
How is the age of a Fossil Known?

1) radiometric dating (e.g., “carbon dating”)
   - measures the level of radioactive isotopes in material
     - each isotope has a characteristic rate of decay (half-life)
   - dead, “fixed” material no longer exchanges atoms with the environment
   - the amount of radioactive isotope remaining can be used to calculate when the material became “fixed”

2) location in sedimentary layers
   - age of sedimentary layer = age of fossil found in it
   - rocky material is also subject to radiometric dating
Age of Fossil = Age of Sediment

- upper layers are younger, deeper layers are older

**similar fossils are found in the same aged layers throughout the world!**
b) **Anatomical Evidence**

- Humerus
- Radius
- Ulna
- Carpals
- Metacarpals
- Phalanges

- Human
- Cat
- Whale
- Bat

- same bone structures modified for different functions
Vestigial Structures

- structures with no apparent function or purpose (e.g., whale, snake “hindlimb” bones)
- consistent with modification of an ancestral structure by evolution
c) Embryological Evidence

Many diverse species are remarkably similar at early embryonic stages:

• e.g., all vertebrates (including humans) initially develop tails, gills, webbed digits (modified with further development)

• consistent with evolution from a common ancestor
Early human & chicken embryos

- young embryos of all vertebrate species have the same basic physical structures which become modified in different ways for each species as development progresses...
d) **Biochemical Evidence**

1) Metabolic processes in all living things are remarkably similar
   - glycolysis, respiration, photosynthesis
   - gene expression (transcription & translation)

2) The genetic code is the same for essentially all forms of life on earth
   - all codons, anti-codons specify the same amino acids in essentially all species

3) Conservation of gene (DNA) & protein sequences, and their function
   - homologous genes between species are remarkably similar in sequence & function
Protein Homology

- the degree of similarity between homologous proteins of different species reflects "evolutionary distance"

**e.g. hemoglobin**

***due to similarities in DNA sequences which encode the amino acids of proteins***
e) Observable Natural Selection

Some populations evolve by natural selection on a time scale that we can observe:

Antibiotic, pesticide resistance
  • antibiotic and pesticide use selects for resistant individuals (more likely to survive & reproduce)

Evolution by natural selection can be observed for organisms with a short generation time
  • e.g., 30 minutes for bacteria vs. ~20 years for humans

**Populations evolve generation by generation, thus species with short generation times tend to evolve faster!**
Selection for Pesticide Resistance

Chromosome with gene conferring resistance to pesticide

Additional applications of the same pesticide will be less effective, and the frequency of resistant insects in the population will grow.

Survivor

Pesticide application
Artificial Selection

Selective breeding controlled by human beings.

- dramatic differences in form & behavior result from selective breeding over “short” evolutionary time periods
- illustrates the capacity for evolutionary change
3. Molecular Basis of Evolution
Evolution Changes the “Gene Pool”

All alleles for all genes in a population of a species constitute the gene pool:

- it is convenient to focus on specific genes and their alleles in a population
- e.g., alleles for the “flower color” gene in a population of pea plants
- there are 2 alleles/gene for each individual in a population of a diploid species

population = 100 pea plants
“flower color” gene pool = 200 alleles

Not all alleles are the same!
Allele Frequency

Within a population, the proportion of each allele for a given gene is the allele frequency.

e.g., let’s consider some populations of 100 pea plants regarding the “flower color” gene:

<table>
<thead>
<tr>
<th>population</th>
<th>allele freq.</th>
</tr>
</thead>
<tbody>
<tr>
<td>all PP</td>
<td>P = 1.0 or 100%</td>
</tr>
<tr>
<td>all Pp</td>
<td>P &amp; p each = 0.5 or 50%</td>
</tr>
<tr>
<td>1 PP: 2 Pp: 1 pp</td>
<td>P &amp; p each = 0.5 or 50%</td>
</tr>
<tr>
<td>70% PP, 20% Pp, 10% pp</td>
<td>P = 0.8 or 80%; p = 0.2 or 20 %</td>
</tr>
</tbody>
</table>

Change in allele frequencies over time = Evolution!
### Illustration of Allele Frequency

<table>
<thead>
<tr>
<th>Phenotypes</th>
<th>Ww</th>
<th>Ww</th>
<th>ww</th>
</tr>
</thead>
<tbody>
<tr>
<td>Genotypes</td>
<td>WW</td>
<td>Ww</td>
<td>ww</td>
</tr>
<tr>
<td>Number of animals (total = 500)</td>
<td>320</td>
<td>160</td>
<td>20</td>
</tr>
<tr>
<td>Genotype frequencies</td>
<td>(\frac{320}{500} = 0.64)</td>
<td>(\frac{160}{500} = 0.32)</td>
<td>(\frac{20}{500} = 0.04)</td>
</tr>
<tr>
<td>Number of alleles in gene pool (total = 1,000)</td>
<td>640 W</td>
<td>160 W + 160 w</td>
<td>40 w</td>
</tr>
<tr>
<td>Allele frequencies</td>
<td>(\frac{800}{1,000} = 0.8 , W)</td>
<td>(\frac{200}{1,000} = 0.2 , w)</td>
<td></td>
</tr>
</tbody>
</table>
How are Different Alleles Produced?

By mutation.

Mutation is simply the change in the DNA sequence of a gene (creating new allele).

Mutation is random, rare, and occurs in a number of ways:

• mistakes in DNA replication & repair, cell division

• DNA damage due to high-energy radiation (UV, gamma, x-rays), carcinogenic chemicals

**Evolution concerns only mutations that are passed on to next generation (via gametes)**
Not all Mutations are “Bad”

Mutations can have 1 of 3 effects:

1) mutations can have no effect
   • i.e., the ability of the organism to survive and reproduce is not affected

2) mutations can be detrimental
   • the ability of the organism to survive and reproduce is negatively affected

3) mutations can be beneficial (rarest kind)
   • the ability of the organism to survive and reproduce is improved by the mutation

**beneficial mutations are selected for over time...**
Natural Selection for the Sickle Cell Allele

- in regions of malaria, carriers of the sickle allele (h) of the hemoglobin gene are favored
  - provides malaria resistance (along with mild anemia)
  - keeps the “h” allele frequency high
How do Allele Frequencies change?

1) Natural Selection
   - external selective pressures determine which individuals pass on their genetic alleles

2) Genetic Drift
   - random events that affect reproductive success regardless of an individual’s “fitness”
     - e.g., freak accidents, natural disasters
   - more of a problem the smaller the population size
     - e.g., the loss of 10 individuals due to a freak accident will have a much greater effect on allele frequencies in a population of 100 than a population of 100,000
The Hardy-Weinberg Principle

Godfrey Hardy and Wilhelm Weinberg in 1908 reasoned that the following conditions must be met for a population to NOT evolve (i.e., for allele frequencies to remain unchanged, at equilibrium):

1) no mutation (i.e., no new genetic alleles are produced)
2) no gene flow (i.e., no immigration or emigration)
3) all mating is random
4) no natural selection (all reproduce with equal success)
5) very large population size (no genetic drift)

***Since NO natural populations meet all these conditions, ALL populations must evolve!***
The Hardy-Weinberg Equation

If the allele frequencies for a particular gene are known for a population, the following equation can be used to predict the proportions of each genotype:

\[ p^2 + 2pq + q^2 = 1 \]

\( p \) = frequency of one allele for a gene

\( q \) = frequency of a 2\textsuperscript{nd} allele for that gene

e.g. “A” frequency = 0.6

“A” frequency = 0.6

“a” frequency = 0.4

\( AA \) = (0.6)^2 = 0.36 or 36%

\( Aa \) = 2(0.6 x 0.4) = 0.48 or 48%

\( aa \) = (0.4)^2 = 0.16 or 16%
Hardy-Weinberg equation & the Punnett Square

Instead of a specific cross the square is used for a population

- multiplying frequencies for each allele indicates the frequency of ea genotype in a population
Requirements for Long Term Species Survival

1) Genetic Variation
   • selective factors will eventually change
     • climate change, new diseases, predators…
   • genetic variability in the population “ensures” that some will survive

2) Sufficient Population Size & Distribution
   • smaller, localized populations are more to susceptible random loss of genetic variability
     • freak accidents, natural disasters, etc, can eliminate beneficial alleles in very small populations
Key Terms for Chapter 13

- evolution
- natural selection, selective factors
- artificial selection
- vestigial structures
- radiometric dating
- gene pool, allele frequency, mutation
- Hardy-Weinberg principle, genetic drift

Relevant Review Questions:
3, 4, 8-10