Chapter 13: How Populations Evolve

1. Evolution by Natural Selection
2. Evidence for Evolution
3. Molecular Basis of Evolution

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***

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**Darwin's Voyage**

- his visit to the Galapagos Islands provided his greatest insights into the nature of evolution

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**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

• 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
• 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"

<table>
<thead>
<tr>
<th>Species</th>
<th>Percent of amino acids that are identical in the protein's sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human</td>
<td>100%</td>
</tr>
<tr>
<td>Rhesus Monkey</td>
<td>86%</td>
</tr>
<tr>
<td>Mouse</td>
<td>74%</td>
</tr>
<tr>
<td>Chicken</td>
<td>39%</td>
</tr>
<tr>
<td>Frog</td>
<td>14%</td>
</tr>
<tr>
<td>Lepus</td>
<td>4%</td>
</tr>
</tbody>
</table>

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 select for resistance, and the frequency of resistant insects in the population will grow.
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>
</tbody>
</table>

70% PP, 20% Pp, 10% pp
P = 0.8 or 80%; p = 0.2 or 20%
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>Number of animals (total = 500)</td>
<td>320</td>
<td>160</td>
<td>20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Genotype frequencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>WW</td>
</tr>
<tr>
<td>Ww</td>
</tr>
<tr>
<td>ww</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number of alleles in gene pool (total = 1000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>640 W</td>
</tr>
<tr>
<td>160 W, 160 w</td>
</tr>
<tr>
<td>40 w</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Allele frequencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>W</td>
</tr>
<tr>
<td>w</td>
</tr>
</tbody>
</table>

The Hardy-Weinberg Equation
If the allele frequencies for a particular gene are known for a population, the following equation can be used to determine the proportions of each genotype:

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

p = frequency of “A” (or “W”) allele
q = frequency of “a” (or “w”) allele
Recombination of alleles from parent generation

**Genotype frequencies**

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>WW</td>
<td>0.64</td>
</tr>
<tr>
<td>Ww</td>
<td>0.32</td>
</tr>
<tr>
<td>ww</td>
<td>0.04</td>
</tr>
</tbody>
</table>

**Allele frequencies**

<table>
<thead>
<tr>
<th>Allele</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>W</td>
<td>0.8</td>
</tr>
<tr>
<td>w</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Next generation:

**W**

- egg

- sperm

- **W**

  - p = 0.8

  - q = 0.2

- **w**

  - p = 0.8

  - q = 0.2

**SPERM**

- WW

  - p\(^2\) = 0.64

- Ww

  - pq = 0.16

- wW

  - qp = 0.16

- ww

  - q\(^2\) = 0.04

**Allele Frequency & the Punnett Square**

- multiplying frequencies for each allele gives the frequency of each genotype

**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!***
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

Chapter 14: The Origin of Species
What is a Species?

Biological species concept:
- interbreed and producing fertile offspring in the wild

Other species concepts are necessary for organisms that reproduce asexually:
- morphological species concept: classification based on the similarity of observable phenotypes
- ecological species concept: classification based on the similarity of ecological requirements (niches)
- phylogenetic species concept: classification based on genetic similarity (DNA & protein sequences, etc)

Speciation

The generation of new species (speciation) from a single existing species is the basis of macroevolution and requires long periods of time plus the following:

1) reproductive isolation of distinct populations of a given species
   - no mixing of genetic alleles (i.e., no interbreeding) between the populations
   - typically due to geographic barriers
2) each population experiences different selective pressures
   - each population follows a different evolutionary path

Geographic Isolation of Darwin’s Finches

- migration of finch species from South America to the Galapagos Islands, then to surrounding islands
- natural selection over time in each unique environment produced new species of finch that could no longer interbreed!

(this is an example of adaptive radiation)
Two Models of Evolutionary Change

**gradualism**
- Changes accumulate gradually

**punctuated equilibrium**
- Large changes appear suddenly followed by periods of little change

Evolution of Complex Structures

Complex structures such as the animal eye appear to have evolved gradually as shown by increasingly complex light-sensing structures in more advanced species of mollusc.

Key Terms for Chapter 14

- **species**: biological, morphological & phylogenetic definitions
- **speciation**
- **reproductive, geographic isolation**
- **gradualism vs punctuated equilibrium**

Relevant Review Questions:
- 3, 4, 8, 11
Chapter 16A:
The Origins of Life on Earth

How Did Life Begin?
No one can say for sure, however scientists have proposed various scenarios, all of which are consistent with:

1) all natural laws
   • i.e., what we know about the nature of physics, chemistry, biology…

2) all physical evidence
   • i.e., fossils, geological, astronomical evidence

***Many prefer other explanations for life’s origins, however the goal of science is to explain such things in terms of the natural world***

The Early Earth
The oldest evidence for life on earth dates to \(\approx 3.5\) billion years ago.
Geologic evidence for this time indicates the atmosphere at this time was composed of:

- ammonia (NH\(_3\))
- methane (CH\(_4\))
- hydrogen (H\(_2\))
- hydrogen sulfide (H\(_2\)S)
- water (H\(_2\)O)
- hydrochloric acid (HCl)
- carbon dioxide (CO\(_2\))
- nitrogen (N\(_2\))

Notice there is no oxygen (O\(_2\))!

***This is important because it avoids the degradation of organic compound by oxygen***
How did Molecules of Life Originate?

Since 1953, Stanley Miller and others attempted to recreate early earth conditions in the lab, resulting in the formation of:

- amino acids & peptides
- nucleotides & ATP

Such experiments show nature’s capacity to produce some of the molecules of life.

The First “Enzymes”

For life to arise, the molecules of life must:
1) store information (like DNA, RNA)
2) reproduce themselves
3) catalyze biochemical reactions
4) be enclosed in some sort of “container” to keep them together

One molecule can do the first 3 of these: RNA
- yes, some RNA molecules have been shown to reproduce and/or to have enzymatic activity (i.e., “ribozymes”)

Phospholipids form microsomes (enclosed spheres) which can account for our 4th requirement.

The Earliest Organisms

The 1st organisms were certainly single-celled anaerobic (i.e., don’t use O₂) prokaryotes:
- simplest type of living organism
- early atmosphere lacked oxygen (O₂)

To be followed by photosynthetic prokaryotes:
- exploiting a vast source of energy
- would contribute oxygen to the atmosphere

To be followed by aerobic (i.e., use O₂) prokaryotes:
- protected from oxygen (a very reactive molecule)
- access to much more energy (via respiration)
What about Eukaryotes?

The endosymbiont hypothesis proposes that mitochondria & chloroplasts arose due to a symbiotic relationship between:

• prokaryotic anaerobes and aerobes

• prokaryotic anaerobes and photosynthetic prokaryotes

Such relationships exist even today!

"other organelles are thought to have been acquired in similar ways"

In addition...

Further supporting the endosymbiont hypothesis is the fact that mitochondria and chloroplasts have many prokaryotic features:

1) they have their own, single, circular DNA

2) they have their own ribosomes which are more similar to those of prokaryotes
   • encoded by genes in mitochondrial, chloroplast DNA

3) they have their own tRNA which are more similar to those of prokaryotes
   • encoded by genes in mitochondrial, chloroplast DNA

…then came Multicellular Organisms

Once eukaryotic cells came to be, they were certainly followed by multicellular eukaryotes:

• many primitive multicellular aggregates (such as some algae) exist today

At this point in life’s history, we can envision evolution producing, over vast periods of time, the immense variety of multicellular organisms we see today…
Key Terms for Chapter 16A

- ribozymes
- microsomes
- anaerobic, aerobic
- endosymbiont

Relevant Review Questions:
3, 4, 7, 12