BIOL 300 – Foundations of Biology
Summer 2017 – Telleen
Lecture Outline

Evolution and Natural Selection

I. What is Evolution?

- A. Changes over time, building on past and current features
  1. Products evolve
  2. Knowledge evolves
  3. Beliefs evolve
- B. Evolutionary patterns in biology have been noted as far back as Aristotle
- C. Patterns of biological evolution have been observed in three major areas:
  1. Anatomical features
  2. Fossil records
  3. Molecular distances

II. Evolution: Getting from There to Here

- A. The word 'evolution' refers to how entities change through time
- B. In Western culture, the concept of evolution of species goes back to Aristotle
- C. In other cultures and religions, evolution plays a central role (e.g. Taoism)
- D. The concept of evolution helps explain the great paradox of biology:
  In life there exists both unity and diversity
- E. Darwin initially used the phrase "**descent with modification**" to explain the concept of evolution
- F. Prior to Darwin and Wallace, it was widely thought that biological evolution occurred by **inheritance of acquired characteristics**. More specifically, individuals passed on to offspring body and behavior changes acquired during their lives
- G. In contrast, Darwin and Wallace proposed that:
  Variation is an inherent characteristic of all biological populations
  It is not created by experience. This is readily observable in populations.

III. The Rate of Evolution

- A. Different kinds of organisms do evolve at different rates
- B. For example, bacteria evolve much faster than eukaryotes
- C. The rate of evolution also differs within the same group of species
- D. Evolution can occur in spurts, which is called **punctuated equilibrium**
- E. Or it can occur in a gradual, uniform way, called **gradualism**.

IV. How does biological evolution happen?

- A. In other words, How do heritable traits (genes) pass to the next generation?
- B. Theory that individuals evolve
  1. Inheritance of acquired characteristics, which are somehow passed on to offspring.
- C. Theory that populations evolve
  1. Selection of genes already in the population
  2. Changes the gene/allele frequency within a population

V. Evidence for Selection Theory of Change

A. Human directed selection is the most obvious
1. Domestication of plants and animals
2. Breeding for extreme variation (as in cat and dog breeds)

B. Natural Selection (the same process – without human direction)
1. Drug and pesticide resistance in bacteria and other pathogens
2. Analogous anatomy, particularly ecological equivalents
3. Homologous anatomy, variation derived from a common ancestral structure

VI. Darwin, Wallace, and Natural Selection

A. Charles Darwin
1. Was an ordained Anglican minister who was fully convinced that species were immutable
2. In 1831, Darwin took the role of naturalist of the ship HMS Beagle
3. The Beagle set sail on a five-year navigational trip around the world
4. Darwin studied a wide variety of plants and animals across the globe, particularly on the Galapagos Islands
5. His observations eventually convinced him that evolution took place. Some of the major evidence: fossils of extinct species resembled living species in the same area. Galapagos finches differed slightly in appearance, but resembled those on the South American mainland
6. In 1859, he published his book, *On the Origin of Species*. In it, he proposed that evolution occurs through **natural selection**.

B. The Theory of Natural Selection
1. Darwin observed 14 different finch species that differed mainly in beaks and feeding habits
2. He concluded that this resulted from "descent with modification" from a common ancestor, or **evolution**
3. Darwin was familiar with **artificial selection** used by breeders to produce animals/plants with particular traits
4. Darwin proposed that such trait selection could also occur in nature, which he termed **natural selection**
5. Darwin was influenced by Thomas' Malthus' *Essay on the Principle of Population* (1798), which stated that populations increase geometrically, while food supply increases only arithmetically. Thus, food supply will limit population growth
6. Darwin drafted a preliminary transcript in 1842. However, he shelved it for 16 years, probably because of its controversial nature
7. Alfred Russel Wallace independently developed a similar theory. Darwin's correspondence with Wallace finally spurred him to publish his theory in 1859
8. Darwin's *Origin of Species* was disturbing to many because it suggested that humans and apes have a common ancestor
9. Darwin presented this argument directly in a later book, *The Descent of Man*

C. How natural selection produces diversity: The Finch Example

1. Darwin believed that the Galapagos finches all evolved from a single common ancestor
2. The ancestor came from the South American mainland
3. New arrivals occupied different niches and were subject to different environmental pressures
4. This resulted in a cluster of species, a phenomenon known as **adaptive radiation**
5. The 14 finch species that Darwin studied now occupy four types of niches:
    a. Ground finches
    b. Tree finches
    c. Warbler finches
    d. Vegetarian finches

VII. **The Modern Synthesis**

A. By the 1940s, the **Modern Synthesis** had been articulated, which is generally accepted today.

B. The Modern Synthesis describes how evolutionary pressure, such as natural selection, can affect a population's genetic makeup, and, in turn, how this can result in the gradual evolutions of populations and species.

C. This connects **microevolution** and **macroevolution**:

1. Microevolution – gradual changes of a population over time
2. Macroevolution – processes that give rise to new species and higher taxonomic groups with widely divergent characters

VIII. Evidence for Evolution

A. Evidence for evolution comes from the following areas:

1. Fossil record
2. Molecular record
3. Anatomical record

B. The Fossil Record

1. Provides the most direct evidence for evolution
2. Fossils are the preserved remains, tracks, or traces of once-living organisms. They form when organisms become buried in sediment and calcium in hard surfaces mineralizes
3. However, fossilization is relatively rare and some types of organisms (especially those with soft bodies) do not fossilize, so some gaps in the fossil record are actually predicted by science!
4. Arraying fossils according to age provides evidence of successive evolutionary change
5. Fossils have been found linking all major groups
6. The forms linking mammals to reptiles are particularly well known

C. The Molecular Record: Evolutionary Distance

1. New alleles arise by mutations and they come to predominance through favorable selection

2. Thus, evolutionary changes involve a continual accumulation of genetic changes
3. Distantly-related organisms accumulate a greater number of evolutionary differences than closely-related ones. An example of this is seen among vertebrates in the 146 amino acid hemoglobin beta chain
4. This same pattern of divergence is seen with DNA sequences, such as the cytochrome c gene
5. The changes appear to accumulate at a constant rate. This phenomenon is referred to as a **molecular clock**.
6. However, different proteins evolve at different rates

D. The Anatomical Record: Ontogeny

1. **Ontogeny** is the pattern of development from an embryo to the adult organism
2. Ontogeny recapitulates phylogeny
3. For example, all vertebrates share a basic set of developmental instructions (and we can see the similarities in early development)
4. **Homologous structures** have different structure and/or function, but are all derived from the same part of a common ancestor. The forelimbs of vertebrates are an excellent example.
5. **Homologous structures** are the result of divergent evolutions, in which the same organism/structure/protein evolves different form or function due to differing environmental pressures
6. **Analogous structures** resemble each other as a result of parallel evolutionary adaptations to similar environments. Wings in birds, dinosaurs, and bats are a great example.
7. **Analogous structures** are the result of convergent evolution, in which different organisms adapt in similar fashion when challenged by similar opportunities
8. **Vestigial organs** are structures that are no longer in use, such as the human appendix. Apes have a much larger appendix that is involved in digestion. Vestigial organs are the remnants of evolution

IX. Evolution's Critics

A. Critics of evolution raise several principal objections:

1. Evolution is not solidly demonstrated
2. There are no fossil intermediates
3. The intelligent design/irreducible complexity argument
4. Evolution violates the 2nd law of thermodynamics
5. Proteins are too improbable
6. Natural selection does not imply evolution

B. However, none of these objections has held up to scientific scrutiny

C. Common Misunderstandings of Evolution

1. Evolution is "just a theory"
2. Individuals evolve
3. Evolution explains the origin of life
4. Organisms evolve on purpose

5. Evolution is controversial among scientists
6. Other “theories” should be taught

X. Population Genetics: The Hardy-Weinberg Rule

A. **Population genetics** is the study of the properties of genes in a population

B. Genetic variation in populations puzzled scientists: Dominant alleles were believed to drive recessive alleles out of populations

C. In 1908, G. Hardy and W. Weinberg pointed out that in large populations with random mating, **allele frequencies** remain constant. Dominant alleles do not, in fact replace recessive ones.

D. Hardy and Weinberg came to their conclusion by analyzing allele frequencies In successive generations:

$$\text{Frequency} = \frac{\text{\# of individuals within a category}}{\text{Total \# of individuals being considered}}$$

E. If a population of 100 cats has 84 black and 16 white, then the frequencies of Black and white phenotypes are 0.84 and 0.16, respectively

F. A population in **Hardy-Weinberg equilibrium** is not evolving

G. The Hardy-Weinberg equilibrium equation:

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

where p^2 = individuals homozygous for allele B
$2pq$ = individuals heterozygous for B and b
q^2 = individuals homozygous for allele b

H. By convention, the more common allele (B) is designated p and the less common allele (b) is designated q

I. **$p + q = 1$**

J. Calculating allele frequencies: See Cat example from lecture

XI. Why allele frequencies change

A. The Hardy-Weinberg equation is true only if the following five assumptions are met:
1. Large population size
2. Random mating
3. No mutation
4. No migration
5. No natural selection

B. Five evolutionary forces can significantly alter the allele frequencies of a population:
1. Genetic drift
2. Non-random mating

3. Mutation
4. Migration (gene flow)
5. Selection

C. Genetic Drift
1. Random losses of alleles (more likely to occur in smaller populations)
2. **Founder effect**: Small groups of individuals establish a population in a new location. The new group now only has the genetic diversity present in the founding individuals
3. **Bottleneck effect**: A sudden decrease in population size to natural forces

D. Non-random Mating
1. Mating that occurs more or less frequently than expected by chance
2. **Inbreeding**: mating with relatives increases homozygosity
3. **Outbreeding**: mating with non-relatives increases heterozygosity
4. Only affects genotype frequencies, but does not alter allele frequencies

F. Mutation
1. Errors in DNA replication or DNA damage
2. The ultimate source of new variation
3. Mutation rates are too low to significantly alter allele frequencies on their own

G. Migration (or gene flow)
1. Movement of individuals from one population to another (a very potent agent of change)
2. **Immigration**: movement into a population
3. **Emigration**: movement out of a population

H. Selection
1. Some individuals leave behind more offspring than others
   a. **Artificial selection**: Breeder selects for desired characters
   b. **Natural selection**: Environment selects for adapted characters
2. Selection is a statistical concept
3. One cannot predict the fate of any single individual
4. But it is possible to predict which kind of individual will tend to become more common in a population

XII. The Biological Species Concept

A. **Speciation** is the species-forming process

B. It involves progressive change
1. Local populations become increasingly specialized
2. Natural selection acts to keep them different enough

C. Ernst Mayr coined the **biological species concept**:
"Species are groups of actually or potentially interbreeding natural populations, which are reproductively isolated from other such groups"

D. **Reproductively Isolated Populations** are populations whose members do not mate with each other or who cannot produce fertile offspring

E. **Allopatric speciation** refers to speciation events that occur when the original population are geographically isolated, while **sympatric speciation** refers to situations where the populations diverge in the same geographic area

XIII. Isolating Mechanisms

A. **Reproductive isolating mechanisms** are the barriers that prevent genetic exchange between species

B. They come in two flavors:

1. **Prezygotic isolating mechanisms**, which prevent the formation of zygotes
2. **Postzygotic isolating mechanisms**, which prevent the proper functioning of zygotes *after* they have formed

C. Prezygotic Isolating Mechanisms:

1. **Geographical isolation**: Species occur in different areas, often separated by physical boundaries
2. **Ecological isolation**: Species may occur in the same geographic area, but utilize different portions of the environment: Lion/Tiger example in text/lecture
3. **Behavioral isolation**: Courtship and mating rituals prevent mating and keep the species distinct
4. **Temporal isolation**: Some species reproduce or are active at different times of day/year. For example, two related plant species that bloom at different times of the year
5. **Mechanical isolation**: Structural differences prevent mating. In many arthropods, the sexual organs vary widely in morphology and are the primary basis for distinguishing species
6. **Prevention of gamete fusion**: Molecular/cellular mechanisms that prevent gamete fusion altogether even if mating does occur

D. Postzygotic Isolating Mechanisms such as **hybrid inviability** and **hybrid sterility** prevent development and/or reproduction

XIV. Working with the Biological Species Concept

A. Speciation is a two-part process

1. Identical populations must diverge
2. Reproductive isolation must evolve to maintain these differences

B. Speciation occurs much more readily in the absence of gene flow. This is much more likely in geographically isolated populations

C. Populations can become isolated for several reasons:

1. New Colonization
2. Barriers to movement
3. Extinction of intermediate populations