Chapter 5
Macroevolution
Processes of Vertebrate and Mammalian Evolution

Chapter Overview
• This chapter concentrates on macroevolution and the intent of your studying this material is to introduce the basic concepts and vocabulary of evolutionary theory as it relates to large time frames. Macroevolution deals with the following:
  o The relationship between macroevolutionary change and the classification of living organisms
  o The nature of species
  o The process by which species change over time
• This chapter is a self-paced study and so there is no lecture on the material.
• Let’s place this in context. There have been 4 significant evolutions (each dependent on the preceding):
  o 1) Inorganic evolution focuses on the origin of the universe and subsequent events (this tends to be studied by physicists and astronomers)
  o 2) Organic evolution looks at the study of life on earth (geologists and evolutionary biologists are researchers who work with these questions)
  o 3) Social evolution deals with questions related to sociality, being part of a social group (biologists and sociologists are often found working in this area.)
  o 4) Cultural evolution examines the emergence and development of cultural systems. (anthropologists and psychologists look at culture in humans and other primates).
• This chapter focuses on organic evolution.

The Human Place in the Organic World
• To deal scientifically with the tremendous diversity of life on the planet, biologists develop a system of classification.
  o Classification:
    • Organizes diversity into categories
    • Indicates evolutionary and genetic relationships
  o Well after I got my biology degree, a new level of classification was added: domain.
    • It groups the 5 (some say 6) kingdoms into three larger groups.
    • These groups consist of Archaea (single-celled organisms), Bacteria, and Eukaryota (having a nucleus and are multi-cellular)
  o Organisms that move about and ingest food (but don’t photosynthesize,) are animals.
    • The kingdom Animalia includes 20 major phyla (singular, phylum)
      • Chordata is one phyla and includes all animals with a nerve cord, gill slits and supporting cord along the back.
      • Most chordates are called vertebrates, animals with segmented, bony spinal columns.
      • In addition to a vertebral column, vertebrates have a brain and sensory structures for sight, smell, and balance
      • Includes 5 classes: bony fishes, cartilaginous fishes,, amphibians, reptiles/birds, and mammals.
    o See the diagram on page 93 for more information.
    o For a very simply organized list of human classification from kingdom to species click here

Principles of Classification 1
• The field that establishes the rules of classification is taxonomy.
Organisms are classified first on the basis of physical similarities.

Basic physical similarities must reflect evolutionary descent in order for them to be useful.

- Classification is required and useful in reflecting evolutionary relationships.
- Biological classification should reflect evolutionary processes, but it requires careful analysis of both living and extinct forms to determine evolutionary relationships.

When looking at similarities and differences between populations, it is important to remember that the basic genetic regulatory mechanisms are highly conserved.

- They have been essentially unchanged for hundreds of millions of years.
- Small changes, though, are the foundation of most of macroevolutionary change.
- Large anatomical changes do NOT necessarily require large major genetic rearrangements.

This set of terms will help clarify evolutionary relationships. Remember, biological similarities, which can arise for different reasons.

- Homology refers to similarity due to descent from a common ancestor.
- Homology is often apparent by comparing the actual structure of different species.
  - Animals may use their anatomical features for different purposes, but the basic shape is the same. (i.e., whale, bird, and humans have similar limb bones).
  - Humans and apes share certain features of their shoulder anatomy enabling them to hang by their arms.
- Remember, the shape is due to a shared descent.

**Principles of Classification 2**

- This set of terms (continued)
  - When organisms give rise to diverse descendants that reflect adaptations to different niches this is called divergent evolution.
    - Classic example of this is the beaks of Darwin’s finches.
    - It is assumed that the similarities are based on common ancestry (homology).
  - Analogies are those similarities based on common function, with no assumed common evolutionary descent.
  - Homoplasy refers to process by which analogies are produced.
    - Birds and flies are both capable of flight but not because of descent from a common ancestor but independent evolution.
    - There are two different types of homoplasy: Parallel evolution and convergent evolution.
      - Parallel evolution is the independent evolution of similar traits in closely related species (i.e., increase in dental size among early human ancestors).
      - Convergent evolution is the independent evolution of similar traits in more distantly related species (i.e., evolution of flight in birds and flies).

**Interpreting Evolutionary Relationships 1**

- Some terms we need before we discuss the approaches to the classification and interpretation of evolutionary relationships
  - Primates have remained quite generalized (non-specific) traits as compared to being specialized traits (evolved for a specific function).
  - Primates have also retained many primitive traits (meaning ancestral mammalian traits) mammalian traits, rather than derived traits (meaning recent) that many mammals have...
acquired.
  o Shared traits are exactly what they sound like, as is an unique trait.

• **Which traits are used as part of interpretations?**
  o Ancestral (primitive) traits are not diagnostic of groups that diverged after the character appeared
  o Derived traits are diagnostic of particular evolutionary lineages.
  o Shared traits are considered the most useful for making evolutionary interpretations.
• **Two approaches are used to interpret relationships: Evolutionary systematics and cladistics.**
  o They have some similarities:
    - Both trace evolutionary relationships and construct classifications that reflect these relationships.
    - Both recognize that organisms must be compared for specific features.
    - Both approaches focus exclusively on homologies

**Interpreting Evolutionary Relationships 2**
• **Evolutionary systematics is a more traditional approach.**
  o A traditional approach to classification (and evolutionary interpretation) in which presumed ancestors and descendants are traced in time by analysis of all homologous traits (primitive or derived) when classifying organisms into taxonomic groups.
  o Species sharing the largest number of homologous traits are placed in the same group even if all these traits do not reflect an ancestor-descendent relationship (i.e., crocodiles, lizards, and birds are all grouped together).
  o Uses the phylogenetic tree to illustrate relationships.
    - The phylogenetic tree is a chart showing evolutionary relationships as determined by evolutionary systematics.
    - It contains a time component and implies ancestor descendant relationships.
• **Cladistics is a more recent approach but is more often used in research today.**
  o An approach to classification that attempts to make rigorous evolutionary interpretations based solely on analysis of certain types of homologous characters (those considered to be shared, derived characters).
  o Uses the cladogram to illustrate relationships.
    - A cladogram is a chart showing evolutionary relationships as determined by cladistic analysis.
    - It’s based solely on interpretation of shared derived characters.
    - It contains no time component and does not imply ancestor-descendant relationships.

**Examples of Cladistic Analysis 1**
• **Evolution of cars and trucks**
  o **Diagram a**
    - From a common ancestor of all passenger vehicles, the first major divergence is between cars and trucks (I).
    - A later divergence occurs between luxury cars and sports cars (II).
    - Derived features of each grouping appear after its divergence from other groups
  o **Diagram b**
    - In this “tree,” SUVs diverge from trucks, but like sports cars, have a decorative racing stripe.
    - This is a homoplasys and does not make SUVs sports cars.
    - Classifications based on one characteristic that can appear in different groups can lead to
an incorrect conclusion.

Examples of Cladistic Analysis 2

- **Evolution of birds and dinosaurs**
  - Traditional view, no close relationship.
    1. Theropods, first discovered in 1861
    2. Dated to 150 mya and thought to be related to birds.
  - Revised view, common ancestry of birds and dinosaurs based on 2 new sources of data:
    1. New fossils found in China.
      - These species were probably gliding rather than flying in the true sense.
      - [Want to learn more about the discovery of these finds in China? Visit: Nova: The four winged dinosaur.](#)
    2. The application of cladistics to this question.

Rate of Speciation 1

- The rate at which evolutionary change occurs came into a debate in the 1970s
  - Prior to that time, most evolutionists were of the same mind as Darwin, that change was gradual (called phyletic gradualism).
  - Gradualism is the view that macroevolution is a slow and gradual process.
    - Charles Darwin saw evolution as a process of millions of years.
    - He saw natural selection as the primary mechanism
      - Mutation and drift have little effect on a specific generation.
      - Natural selection acting on initial mutation results in speciation.
    - With gradualism, the fossil record will be a smooth, gradual transition (no gaps). Anagenesis is the term used to refer to this linear evolution
      - It assumes one species evolved directly into a new species over time
      - But at what point is it species A or species B?

Rate of Speciation 1

- In some cases we lack transitional forms,
  - For some this is evidence of the fallacy of evolution
  - For researchers this became a challenge that was finally explained by the concept of punctuated equilibrium
- After the 1970s, evolutionists came to realize that some cases of change went much faster and punctuated equilibrium as a mechanism was added.
  - Punctuated equilibrium is the view that the pattern of macroevolution consists of long periods of time when little change occurs (stasis) and short periods of time when rapid evolutionary change occurs.
  - This model infers that most genetic change occurs during speciation. Mutation occurs in a small, isolated population and then spreads rapidly due to inbreeding and genetic drift.
  - Stabilizing selection and other factors act to keep a species the same over time
Because some new species appear so rapidly we do not see transitional forms. The fossil record usually will not show the initial changes.

You can watch a myriad of videos on evolution topics here.

Definition of Species 1
• What is a species?
  o The most common definition of a species is that described by the biological species concept (BSC) wherein species can be defined in terms of reproductive capability.
  o Organisms are classified in the same species if:
    • Individuals from two populations are capable of breeding naturally and
    • They produce fertile offspring.
  o The BSC assumes two organisms either belong to same species or not (mutually exclusive), but this may not be always clear:
    • Example of gypsy moths shows how this is not an absolute
      • Far away populations produce infertile offspring
      • Closer together produce fertile offspring
    • An example is the dog-wolf-coyote-jackal issue
    • We think of them as different species, but actually different subspecies
    • Another question, not yet settled, is if they can bred with the fox (very different number of chromosomes)

Definition of Species 2
• What is a species? (continued)
  o It is by the process of speciation by which a new species evolves from a prior species. Speciation is the most basic process in macroevolution.
  o The precondition for speciation is isolation; as long as gene flow is possible then mutations tend to mix back into the population. Isolation can occur a number of ways:
    • Geographic isolation
    • Reproductive isolation (pre-mating or post-mating incapabilities)
    • Behavioral isolation
  o Speciation model:
    • Step 1: A and B have not yet diverged
    • Step 2: A and B are just beginning to diverge.
      • Genetic differences accumulate (mutation, genetic drift)
      • If different habitats, different selective pressures
    • Step 3: A and B have diverged to a point where they’re no longer able to reproduce; speciation is complete

Interpretation of The Fossil Record 1
• The BSC is difficult to utilize when examining the fossil record, for all the obvious reasons surrounding the inability to test for viability of offspring when the species are dead.
• Therefore, we use morphological traits (the phenotype) as the focus of research. There are challenges and these include:
  • In sexually reproducing species there are going to be variations within the species due to recombination (individual variation).
  • There is the issue of sexual dimorphism: differences in physical characteristics between males and females of the same species.
• Recognizing fossil species
  • One way we handle the problems with not being able to use the BSC on the fossil record is by using living species as models for comparison.
In living species, variation is linked to differences due to:
• Intraspecific differences based on variation seen within the same species; for instance, a famous American Express commercial that shows Will Chamberlain and Willie Shoemaker together.
• Interspecific differences based on variation beyond that seen within the same species to include additional aspects seen between two different species.
• We determine which type of difference is found in living species and use these observations to make interpretations of fossil specimens.

Interpretation of The Fossil Record 2
• Recognizing fossil species (continued)
  o Living species show us that the boundaries between species can be difficult.
  o Dealing with extinct species is even harder.
    • There is the issue of patterns of variation spatially
    • There is also the issue of patterns of variation temporally
  o This means even greater variation will be seen in paleospecies: a species defined from fossil evidence, rather than by use of the BSC.
  o Linnean taxonomy is designed for classification at a single static point of time, not for the dynamics of paleospecies. This leads to significant debate between lumpers and splitters
    • Lumpers see the differences as the normal variations in a species over time and geography
    • Splitters see the differences as indications of speciation events (new species coming into being)
• Recognition of fossil genera
  o A genus is a group of species composed of members more closely related to each other than to species from any other genus.
  o Species that are members of the same genus share the same broad adaptive zone.
  o Members of the same genus should all share derived characters not seen in members of other genera.

Interpretation of The Fossil Record 3
• Recognition of fossil genera (continued)
  o Like with the species, we cannot use BSC for the fossil record.
  o We can use the observation that species that are of the same genus share the same broad adaptive zone.
    • An adaptive zone represents a general ecological lifestyle that is more basic than the narrower ecological niche that characterized the single species.
    • Ecological niche is defined by the positions of species within their physical and biological environments, together making up the ecosystem.
    • A species' ecological niche is defined by such components as diet, terrain, vegetation, type of predators, relationships with other species, and activity patterns, and each niche is unique to a given species.
  o Teeth are often the most preserved parts and they provide excellent general ecological inferences.
  o Cladistics also helps in that members of a genus share derived traits not found in other groups of species.

What are Fossils and How Do They Form?
• Fossils are the traces of ancient organisms.
  o The oldest are about 3 billion years old and are very small
These fossils are referred to as microfossils

- The form in several ways
  - Mineralization occurs very slowly as water carrying minerals, such as silica or iron, seeps into the tiny spaces within a bone. In some cases, the original minerals within the bone or tooth can be completely replaced.
  - Traces of life forms also include insects trapped in tree sap, leaf imprints, footprints, skeletal remains and remains of digestive tracts
- Taphonomy is the study of how bones and other materials come to be buried in the earth and preserved as fossils.

### Vertebrate Evolutionary History 1

- Geologists have organized our earth history into eras, periods, and epochs.
  - It is called the geological time scale
  - Commonly used by geologists and paleoanthropologists.
- The geological eras are separated by major extinction events and are:
  - Paleozoic era: Vertebrates appeared 500 million years ago (mya).
  - Mesozoic era: Reptiles were dominant land vertebrate, placental mammals appeared 70 mya.
  - Cenozoic era: Divided into Tertiary and Quaternary periods and 7 epochs.
    - These epochs are: Paleocene epoch (65 mya), Eocene epoch (56 mya), Oligocene epoch (33 mya), Miocene epoch (23 mya), Pliocene epoch (5 mya), Pleistocene epoch (1.8 mya), Holocene epoch (0.01 mya)
    - It will be very helpful to memorize these epochs as they dominate the second half of the course.

### Vertebrate Evolutionary History 2

- Life on earth has been strongly influenced by continental drift, the movement of continents on sliding plates of the earth’s surface.
- As a result, the positions of large landmasses have shifted drastically during the earth’s history.
- During the Mesozoic, Pangea is breaking up into a northern landmass (Laurasia) and a southern landmass (Gondwanaland).
- Note that by the start of the Cenozoic (65 mya) the continents have started to break up from each other

![Map of continents](image)

### Mammalian Evolution

- The Cenozoic era, the Age of Mammals.
- Mammals exhibit a number of shared traits:
  - The enlargement of the cerebrum, especially the neocortex, which controls higher brain functions, resulting in more nerve cells
  - A longer, more intense period of growth in utero
o Distinctive dentition, termed a heterodont (different kinds of teeth), with 3 incisors, 1 canine, 4 premolars, and 3 molars in each quarter of mouth
o Maintenance of constant internal body temperature, warm-bloodedness, and endothermic (Able to maintain internal body temperature by producing energy through metabolic processes within cells; characteristic of mammals, birds, and perhaps some dinosaurs)

• Emergence of the major mammalian groups
  o Egg-laying mammals, or monotremes - extremely primitive
  o Pouched mammals, or marsupials - young are born extremely immature and must complete development in an external pouch.
  o Placental mammals develop over a longer period of time inside the mother, made possible by development of the placenta which provides for fetal nourishment.

Processes of Macroevolution
• Operate on the whole species, rather than on individuals or populations
• Take a longer period of time to have a noticeable impact
• Adaptive radiation is a process that takes place when a life form rapidly takes advantage of the many newly available ecological niches.
  o A species, or group of species, will diverge into as many variations as two factors allow:
    • Its adaptive potential
    • The adaptive opportunities of the available niches.
  o The mammalian radiation was made possible by the extinction of dinosaurs
  o On a smaller scale, Darwin’s finches are another example.
• We need to remember that 99% of all species that have ever existed have become extinct.
  o In modern times we see evidence of species extinction
  o The dodo bird, the passenger pigeon, and many others.
• What causes extinction?
  o One source is where a species is no longer adapted to an environment, it may die.
  o Or another species becomes better adapted to the same environment and out-competes (competitive exclusion principle)
  o In fact, extinction seems to be the fate of all species