General Biology: Broad Patterns of Evolution

AI-Generated Study Guide

(Based on lectures delivered by Dr. Ty C.M. Hoffman)

I. Defining Macroevolution
Evolution can be studied at different scales. **Microevolution** is defined as the change in allele frequency (represented by P and Q values in the Hardy-Weinberg model) in a population over generations, meaning evolution at the population level. **Macroevolution** refers to broad patterns of evolution and involves studying evolutionary trends at broader levels, above the population, dealing with huge groups and taxa.

II. Geological Time and the History of Life
Earth's Age and Eons
The planet Earth is approximately 4.6 billion years old. The history of Earth is organized hierarchically into spans of time: **Eons**, **Eras**, **Periods**, and **Epochs**.
There are four major Eons:

1. **Hadian Eon:** The earliest Eon, pre-biological, characterized by a hot, "hellish" state before life existed.
2. **Archean Eon**
3. **Proterozoic Eon**
4. **Phanerozoic Eon:** The eon we currently live in. Although it occupies most of the detailed geological table, it represents only the last half billion years, during which almost all familiar life forms came into existence.

Timeline of Life

- The first successful life (prokaryotic cells) began roughly 3.5 billion years ago.
- The first 1 billion years of Earth's history were entirely lifeless.
- For nearly two billion years (from 3.5 billion years ago to roughly 1.8 billion years ago), life consisted only of prokaryotes.
- The first eukaryotic cells appeared approximately 1.8 billion years ago, though they were initially single-celled organisms.
- Life started in the oceans, and it was a long time before organisms invaded the land. Nothing lived on land until about 500 million years ago.

The Role of Fossils
Fossils are crucial for dating events and understanding the duration of taxa.

- The very oldest fossils are **stromatolites**, which are fossilized remnants of colonies of prokaryotic species.

III. Absolute Dating Using Radioisotopes

Dating fossils allows scientists to determine when evolutionary events occurred.

• **Relative Dating:** Compares fossils based on their position in strata (deeper is older). This provides comparative age but not absolute age.

• **Absolute Dating:** Provides the actual age in years and relies on radioactive isotopes.

◦ **Isotopes** are atoms of the same element that differ in their number of neutrons. The number of protons determines the element type.

◦ Some heavy isotopes are radioactive and unstable, decaying into other substances.

Half-Life and Molecular Clocks

The rate of decay is described by an isotope's **half-life**, which is the amount of time required for half of the original parent isotope to decay into a different substance.

• Decay is relative: half of whatever amount is present will disappear in one half-life.

• Living organisms continuously take in these isotopes from their surroundings, maintaining a consistent radioactive signature. Upon death, this intake stops, and the radioactive material begins to decay, starting the "molecular clock."

• By measuring the fraction of the parent isotope remaining in a fossil, scientists can determine how many half-lives have passed, yielding an absolute date for the fossil.

IV. Macroevolutionary Changes and Trends

Evolution of Structure and Function

Macroevolutionary examples involve drastic changes in structure and function across huge taxonomic groups.

• An example is the evolution of **mammalian ear bones**. In ancient ancestors (reptiles and amphibians), certain skull bones formed the hinge for the jaw. Over millions of years, these bones changed shape and location, taking on a completely new function in mammals: the tiny auditory ossicles (hammer, anvil, stirrup) amplify sound waves in the middle ear.

Factors Determining Taxon Size

The number of species (speciosity) within a large group (taxon) depends on two major factors:

1. **Speciation:** The creation of new species.
2. **Extinction:** The loss of species (they do not come back).

V. Continental Drift and Isolation

The Earth's crust consists of tectonic plates, which are thin rafts floating on a liquid interior (mantle and core).

• **Plate Tectonics (Continental Drift):** These rafts move very slowly and continuously.

• This is significant for biology because organisms are passengers on these moving land masses.

• The movement of continents causes **isolation** between groups that were once connected, leading to **allopatric speciation**.

• **Pangaea:** About 250 million years ago, all land masses were fused into one supercontinent called Pangaea ("all of Earth"). This supercontinent later split into Laurasia and Gondwana, and eventually into the familiar continents, which continue to shift.

Adaptive Radiation

Adaptive radiation describes the massive amount of speciation occurring within a lineage in a given amount of time.

• On a phylogenetic tree, adaptive radiation is represented by the **flaring out** or widening of a lineage.

• Adaptive radiation is often observed when a group enters a newly available environment (like the newly formed volcanic islands of Hawaii) that is unexploited, allowing natural selection to operate rapidly with reduced competition.

• Adaptive radiation rates are unequal: Eutherian mammals (our lineage) have been far more successful in terms of speciation than Monotreme mammals.

VI. Extinction Events

Extinction is a naturally occurring biological process. However, a **mass extinction event** is characterized by a sudden, drastic increase in the rate of extinction above the normal background level. Five major mass extinction events have occurred in the last half billion years of life on land.

• **The Permian Extinction (The Biggest):** Occurred at the end of the Permian period. This was the largest mass extinction event, eliminating about 90% of all groups of organisms. It was largely caused by out-of-control volcanic activity leading to global warming.

• **The Cretaceous Extinction:** Occurred 65.5 million years ago. About 75% of all groups disappeared. This event killed almost all non-avian dinosaurs and most other species, opening up ecological opportunities that led to the subsequent explosion of mammals. Evidence suggests it was caused substantially by an asteroid collision that blocked photosynthesis.

The Current Threat

Current extinction rates are increasing rapidly, suggesting the beginning of a sixth mass extinction. Unlike previous events, this one is being caused by human activity, particularly through human-caused global warming. Data show that historically, warmer temperatures have been associated with three of the five major mass extinctions.

Post-Extinction Ecology

Fossil records show that populations surviving mass extinctions become comprised of an increasingly higher percentage of predators.

VII. Development and Morphological Change

Major morphological differences between species do not always require vast genetic differences. Organisms like humans and chimpanzees are genetically nearly identical (98-99%) but appear drastically different.

Heterochrony

Heterochrony (meaning "different time") refers to differences in developmental timing between species. These timing differences, controlled by specific genes, cause certain body parts to develop much faster or slower than others, resulting in major morphological changes.

• For example, differences in skull shape (large braincase in humans vs. powerful jaw in chimpanzees) are due to heterochrony acting on largely the same set of genes.

• **Pedamorphosis** is a specific type of heterochrony where a species retains its juvenile (youth) form into adulthood, such as a salamander retaining external gills.

Developmental and Homeotic Genes

• **Developmental Genes** are protein-coding genes whose proteins act as **switches** that turn other genes (the majority of the DNA) on or off during development.
• **Homeotic Genes (Hox Genes)** are examples of developmental genes that control the development of major body parts. Small mutations in these controlling genes can cause large-scale evolutionary differences, such as determining the number of legs or appendages, simply by changing *when* or *where* genes are expressed in the body.

VIII. The Gradual Nature of Macroevolution
Large-scale changes in macroevolution do not occur in a single step; rather, evolution proceeds by adjusting structures that were already present, utilizing small advantages at each stage.
The Evolution of the Eye
The complex structure of the eye is often cited as something that cannot have evolved gradually. However, the evolutionary progression shows that having "half an eyeball" is advantageous at every step:
1. **Light-sensitive patch:** Simple pigmented cells detect only the presence or absence of light. This is an advantage over having no light sensing ability.
2. **Invaginated patch:** The patch forms a slight inpocketing (a small cave). This allows the organism to determine the *direction* from which the light is coming.
3. **Pinhole eye with water droplet:** Further invagination almost seals off, trapping a droplet of water. This droplet acts as a rudimentary lens, bending light rays and enabling the first formation of a rudimentary image.
4. **Sealed off with cellular lens:** The structure fully seals off, and a cellular structure becomes a more advanced lens, improving focus.
5. **Accommodation:** Muscles connect to the lens, allowing the organism to change its thickness to autofocus (accommodation).
Because the adaptive advantages are so great at each step, eyes evolved independently (analogously) in many different lineages.