BIOLOGY 1101
LAB 7: MACROEVOLUTION

READING: Please read chapter 14 in your text.

NOTE: Bold words are either defined in the text or in an appendix at the end of this lab.

INTRODUCTION: **Macroevolution** is evolution on a grand scale, and it is what we see when we look at the history of life over large time-scales. Macroevolutionary biology examines major events, like the origin and extinction of life, usually at or above the species level. Scientists reconstruct the past using evidence from sources such as the fossil record, geology, and living organisms. Once we determine what **speciation** and **extinction** events have occurred, we can test hypotheses about the processes involved. The same mechanisms that drive microevolution – **mutation, migration, genetic drift,** and **natural selection** – are at work on a macroevolutionary scale. Life on earth has been accumulating genetic mutations for the past 3.8 billion years, which is more than enough time to see large-scale evolutionary change.

Charles Darwin viewed evolution as a gradual, stepwise process, as populations of species accumulated mutational changes in small increments over a long time. It's difficult to find evidence of **gradualism** in the fossil record, but Darwin attributed the lack of evidence to gaps in the fossil record – a good assumption considering it is unlikely each small evolutionary change would be preserved. In the 1970's, evolutionary scientists suggested the gaps in the fossil record were real and represented periods of morphological stasis. They hypothesized that species undergo long periods – millions of years – with little morphological change, followed by a relatively "quick" burst of evolutionary change that leads to speciation. They called this mode of macroevolution **punctuated equilibrium**. Species evolving in a pattern of punctuated equilibrium won't experience slow, gradual changes in mainstream populations. Instead, isolated populations that exist on the periphery may experience rapid evolutionary change that eventually leads to speciation (Fig 1). It's important to note that these hypotheses are not mutually exclusive, which means one does not preclude the other from occurring.

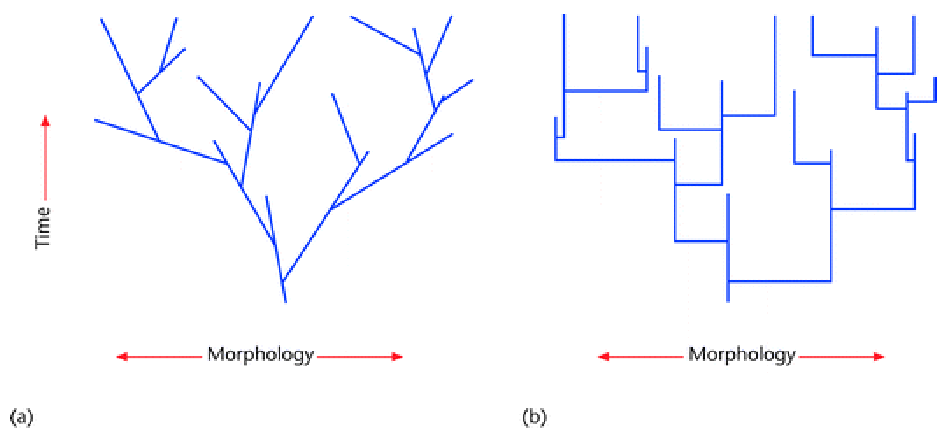


Figure 1. Phylogenetic trees showing (a) the slow accumulation of changes that lead to speciation (gradualism) and (b) periods of stasis followed by bursts of change that lead to speciation (punctuated equilibrium).

Adaptive radiation refers to periods of elevated speciation rates that are hypothesized to coincide with the evolution of an adaptation to a new environment or new way of life. This is, in some ways, the opposite of mass extinctions, in which many species die off as a result of a rapid change in the environment. Adaptive radiation allows multiple speciation events of one lineage or organisms, while mass extinctions affect many groups of organisms simultaneously.

A **cladogram** is a branching diagram that illustrates relationships among groups of organisms. The cladogram to the right shows a period of adaptive radiation (circled), with many forks (or branch points) representing speciation events over a short period of time. The lines are drawn to show a mix of gradualism and punctuated equilibrium. Can you tell which parts of the tree reflect gradual change, and which parts reflect punctuated change?

Adaptive radiation occurs because individuals within populations respond differently to environmental conditions. When the environment changes, individuals with traits favorable to the new conditions will have a higher survival and reproduction rate than individuals that are poorly adapted to the new environment. Evolutionary biologists use cladograms and phylogenies to reconstruct the history of speciation and extinction. A **phylogeny** is a hypothesis about the evolutionary history of organisms. A **phylogenetic tree** is a cladogram that is scaled relative to time.

LABORATORY OBJECTIVES: The purpose of this laboratory exercise is to introduce you to macroevolution. You will use a cladistic approach to track changes in the fossil record of related species of gastropods. You will also investigate whether ancestral and modern horses experienced adaptive radiation in response to environmental change.

EXERCISES:

Part 1. Imagine that an outcropping of rock has been recently exposed. Geologists find shells embedded in different layers of rock. The layer closest to the surface is the youngest in geologic time, and layers below it are successively older. Assume these shell types have all evolved from a common ancestor. Scientists notice some interesting traits in the shells: older shells have smooth texture and little to no colored banding pattern. Older shells are also thinner with larger apertures (openings).

Your group will examine a group of “fossil” shells and collect data on traits of interest. You will use the data to place the shell types in order from oldest to youngest. You will draw a shell cladogram that shows divergence between each group with each new adaptive trait that was acquired. Finally, you will formulate a hypothesis about why each trait may have evolved.

Evolutionary traits of interest include:

<u>Shell texture</u> – rough texture evolved from smoother texture
<u>Banding pattern</u> – banding (banded coloration) evolved from lack of banding
<u>Shell thickness</u> – thick shells evolved from thinner shells
<u>Relative aperture size</u> – small openings evolved from larger openings

<u>Materials</u>:

- Desktop fossil set – 5 shell groups with 5 shells in each group
    - <u>We know these shells are pretty, but please don't take any home! They are *fantastically difficult* to replace!!!</u>
- Shell morphology layout sheet
- Centimeter ruler
- Caliper

<u>Procedure</u>:

1. Talk with your group and choose two of the four characteristics to examine: **Choose texture or banding, and then choose thickness or aperture size**.
2. Remove the shells from the container. *<u>Use care when handling the shells to avoid breaking them</u>.* There are five shell groups that represent five different geologic times. Shells are numbered on the inside according to their type (1-5). **The numbering doesn't necessarily correspond to the age of the shells.** Record the characteristics for each shell in Table 1, as described below.
3. Using what you know about the evolution of the shell traits (given above), place the shell groups on the shell morphology sheet in order of oldest (bottom) to youngest (top).
4. Construct a cladogram with the group names, and place the adaptive trait in the appropriate spot. See Figure 3 for an example.

**Note: While we have tried to provide shells that are similar in size within each geologic layer, be careful not to let shell size influence your judgment, as we are not taking absolute size into account in this lab.*

Record the measured traits in the data tables on page 62. After all data have been recorded, calculate the mean (average) value for each trait. Grade the shells using the following relative scales:

Texture Scale				
Texture	Very Smooth	Somewhat Smooth	Somewhat Rough	Very Rough
Score	1	2	3	4

Banding Scale				
Banding	No Banding	Light	Medium	Heavy
Score	1	2	3	4

Measure shell thickness: Insert the outer lip of the shell into the caliper and record the thickness in millimeters in the data table.

Measure aperture: Measure the shell aperture by measuring from the inner to the outer lip, and from the posterior canal to the anterior canal (see figure 2). For shells with a long anterior canal, measure from the posterior canal to the start of the anterior canal. Divide the first value by the second value and record the ratio in the table on the next page. We are using this ratio as a relative measure of aperture size to avoid comparing the absolute size of the shells.

Figure 2. Shells with different morphologies, including aperture shape. Black lines are a guide to measuring the aperture.

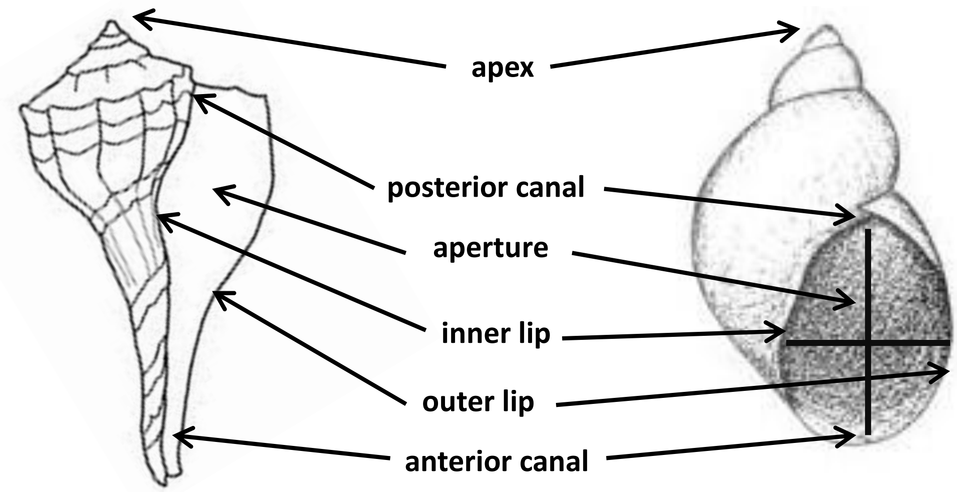
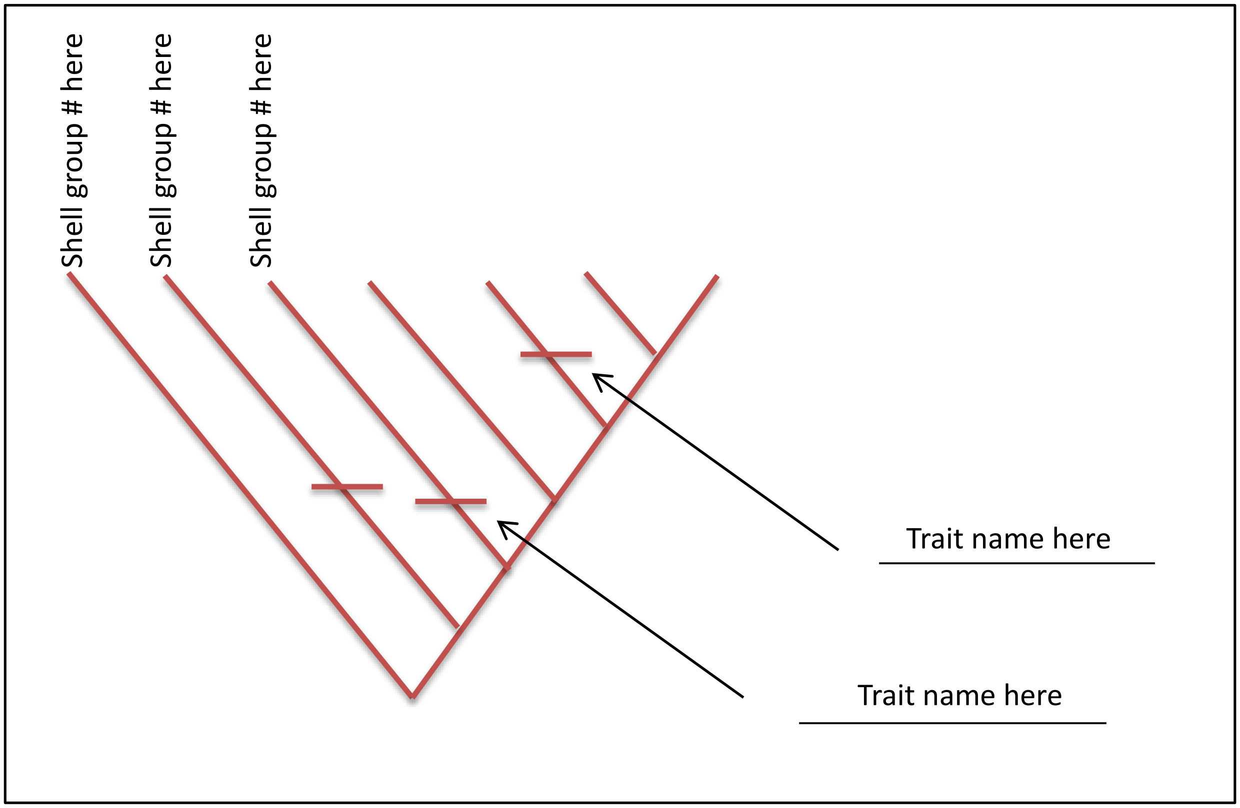


Table 1. Data table for shell characteristics.

Group	Shell no.	Characteristic #1 (texture OR pattern)	Characteristic #2 (thickness OR aperture size)
1	1		
	2		
	3		
	4		
	5		
	Mean		
2	1		
	2		
	3		
	4		
	5		
	Mean		
3	1		
	2		
	3		
	4		
	5		
	Mean		
4	1		
	2		
	3		
	4		
	5		
	Mean		
5	1		
	2		
	3		
	4		
	5		
	Mean		

Figure 3. Example of a cladogram that shows the divergence of each shell type with the adaptive trait that distinguishes it from the others.



Questions

1. Assuming these traits are products of natural selection, what selective pressures do you think these gastropods experienced? (*Hint: what sort of environment would induce these evolutionary changes?)* Write a separate hypothesis for what may have caused the appearance of each trait.

   Texture:

   ____

   ____

   ____

Banding:

Shell thickness:

Aperture size:

2. Although you have seen a general evolutionary trend in the shell traits as you move from older to younger fossils, there was likely some variation among the individuals of each group. What explanation can you provide for variation among individuals within a group?

Part 2. The evolution of the horse has been studied extensively, in part because the fossil record provides an excellent example of macroevolution. Horses went through a dramatic evolution in the size and shape of their teeth, as well as in the shape of their muzzles and feet in the Tertiary Period of the Cenozoic Era (~65 MYA to ~2 MYA). The pattern of evolution coincides with a change in habitat from brushy woodland to grasslands in North America. Scientists have hypothesized that high-crowned teeth and square muzzles enabled horses to shift from eating softer foods like leaves to tougher foods like grasses. Longer limbs and a single toe gave horses the speed they needed to outrun predators in the open grasslands.

Your goal is to test the hypothesis that a change to grasslands led to the evolution of teeth and limbs that were better adapted to that environment. You will be placing horse taxa on a time-line. You will then collect data from the fossil record and place it on the time-line to see whether the evolution of horse teeth and limbs coincided with changes in the environment.

Materials:

- Horse cladogram and time table (Table 2 and Figure 4)
- Drawings of molars (2 parts – width of top and height of crown)
- Drawings of limbs
- Centimeter ruler
- Time-line

Procedure:

1. Using Figure 4 and Table 2 for reference, write the name of each horse genus at its appropriate time to the right of the accompanying time-line.
2. Start by comparing different fossils of horse teeth. For each fossil, you should have a cut-out that shows the width of the crown (the top) and the height of the crown (side). Using your ruler, measure each tooth's crown height and crown width. Do not include the root in crown height. Divide the crown height by the width and record the value in Table 3.
3. Now, compare the cut-outs that represent different fossils of horse limbs. Count the number of toes on the front and back feet of each fossil, and measure the length of the front limb. Record these values in Table 3.
4. Record the tooth ratio value, the number of toes, and the limb length for each horse genus on the left side of the time-line.

Table 2. Horse taxa with approximate time in which they lived.

Taxon	**Approx. time period**
Hyracotherium	55-49 MYA
Orohippus	50 MYA
Mesohippus	40-30 MYA
Anchitherium	25 MYA
Merychippus	23-13 MYA
Hipparion	23-1 MYA
Equus	1 MYA-present

Figure 4. Cladogram featuring some of the horse taxa from the geologic past.

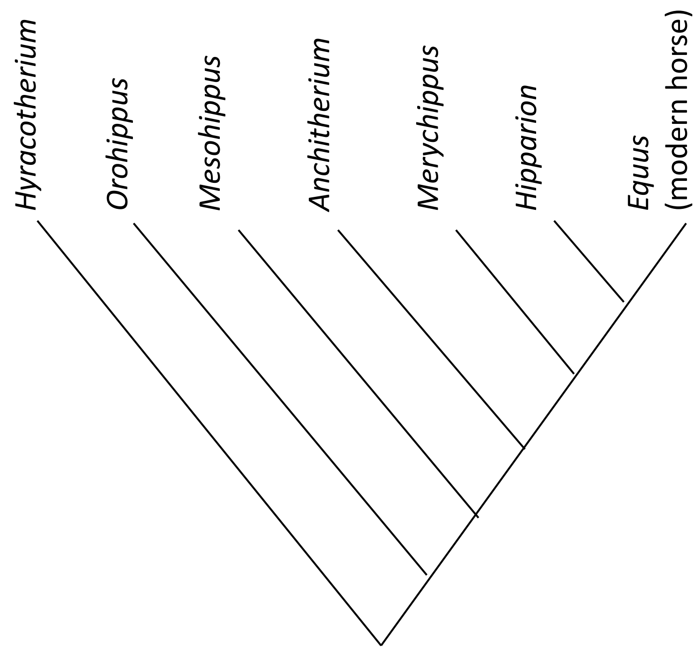


Table 3. Horse fossil measurements.

Taxon	**crown height, cm**	**crown width, cm**	**ratio ht/width**	**# toes, front**	**# toes, back**	**front limb length, cm**
Hyracotherium						
Orohippus						
Mesohippus						
Anchitherium						
Merychipppus						
Hipparion						
Equus						

Questions:

1. Scientists have hypothesized that horses evolved longer crowned-teeth and longer limbs with fewer toes in response to a change in the environment. If this is correct, what pattern do you expect to see in the tooth crown height/width ratios?

2. Look at the time-line. Does the fossil evidence support the hypothesis that a change to grasslands in North America was followed by the evolution of adaptive traits to a grassland environment? Explain why or why not.

3. Can you think of an alternative explanation for the evolution of these traits in horses, other than habitat change? State your explanation in the form of a hypothesis.

Comprehension Questions

Make sure you understand and can answer the following questions, as the concepts may appear on a lab practical exam. You do not need to answer them during the lab period.

1. What is the difference between microevolution and macroevolution? What are the mechanisms that drive evolution (common to both micro- and macroevolution)?

2. How does gradualism differ from punctuated equilibrium? How are the two hypotheses similar?

3. The shells you examined came from gastropod species that evolved certain characteristics in response to environmental pressures, driven by the non-random process called ______________________________.

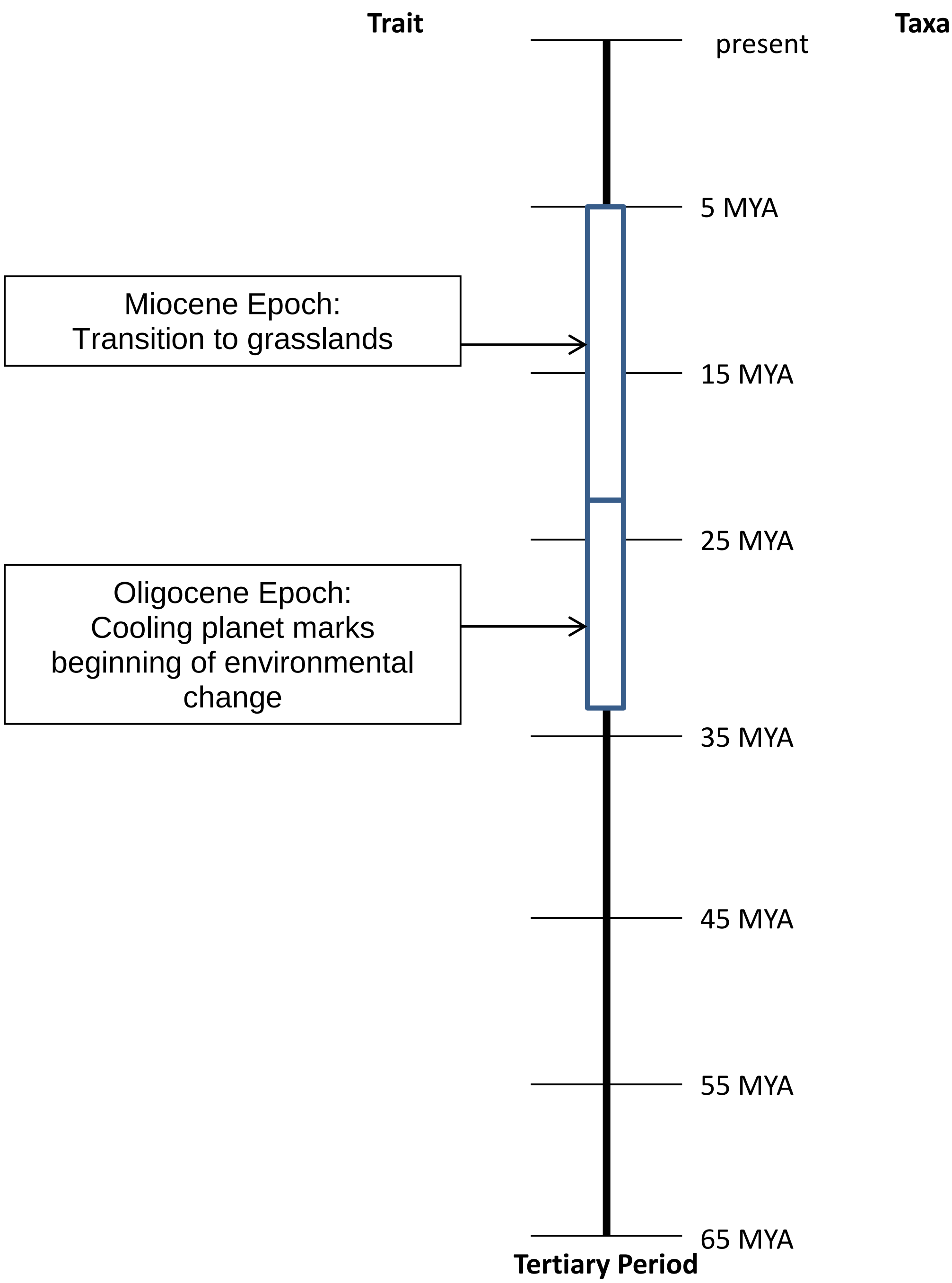
4. A branching diagram that illustrates relationships among organisms is called a _______________________. A branching diagram that adds a time component to the relationships is a called a ______________________________.

SHELL MORPHOLOGY LAYOUT SHEET

Youngest 1					
2					
TIME 3					
4					
Oldest 5					

Place the five shells from each group in the rows. Each row represents a geologic layer, from oldest on the bottom to youngest at the top. Trace the evolution of each trait from layer 5 (oldest fossils) to layer 1 (youngest fossils).

TIMELINE OF HORSE EVOLUTION



Place each horse genus to the right of the time-line. Draw a line out from the time-line at the approximate year in which the horse taxon first appeared in evolutionary history. Next, place each adaptive trait to the left of the time-line at the approximate time when it appeared.

APPENDIX

Definitions

Cladogram – A branching diagram that illustrates relationships among groups of organisms.

Extinction – A process in which species or groups of species cease to exist.

Genetic Drift – A change in the gene frequency within a population that is due to random processes.

Gradualism – A hypothesis that describes macroevolution as a gradual, stepwise process in which populations of species accumulate mutational changes in small increments over a long time that eventually lead to speciation.

Macroevolution – Evolutionary change at or above the species level, including the origin of evolutionary novelty and new taxonomic groups and the impact of mass extinctions on the diversity of life and its subsequent recovery.

Migration – The movement of groups of organisms from one region to another.

Mutation – A change in the nucleotide sequence of DNA; a major source of genetic diversity.

Natural Selection – A non-random process in which organisms with certain inherited characteristics are more likely to survive and reproduce than are organisms with other characteristics; unequal reproductive success.

Phylogenetic Tree – A branching diagram that represents a hypothesis about evolutionary relationships among organisms.

Phylogeny – A hypothesis about the evolutionary history of organisms.

Punctuated Equilibrium – A hypothesis that describes macroevolution as a process in which species undergo long periods – millions of years – with no morphological change, followed by a relatively "quick" burst of evolutionary change that leads to speciation.

Speciation – An evolutionary process in which one species splits into two or more species.

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