

### CH. 1:INTRODUCTION, EVOLUTION, SYSTEMATICS

1. Approximately how many species of animals currently exist on earth? Approximately how many of those are vertebrates?
2. Name the seven “traditional” vertebrate classes and their major subgroups. Include equivalent names as appropriate. For each class, give the approximate number of species. What are gnathostomes, tetrapods, and amniotes?
3. Define the terms “species”, “population” and “gene flow”.
4. Describe the process of natural selection, including Darwin’s postulates. Define all relevant terms (e.g., fitness, adaptation, etc.).
5. Explain the phrase “genetic variation is random with respect to the environment.” Can natural selection create “perfect” organisms? Why or why not? Use examples as appropriate to justify your answer.
6. Compare and contrast anagenesis and cladogenesis.
7. Outline the process of allopatric speciation. What is an adaptive radiation?
8. Define the terms “systematics”, “taxonomy”, and “classification.”
9. Compare and contrast evolutionary systematics and cladistics. On what basic points do members of the two “schools” agree? On what do they disagree? What advantages and disadvantages does each present? Can either be called “correct”? Why or why not? Given a cladogram, be able to correctly interpret the branching pattern it depicts.

### CH. 2: VERTEBRATE RELATIONSHIPS, STRUCTURE AND FUNCTION

1. Who are the chordates? Give the characteristics that “define” the phylum and list the subphyla within the phylum. What is the earliest fossil chordate; how old is it?
2. Who are the vertebrates? What characteristic(s) define(s) this group of chordates?
3. How, in general, do vertebrate body size and activity levels compare to those of non-vertebrate chordates? What general evolutionary challenges does this present?
4. Describe the basic structure and function of the major vertebrate organ systems, being careful to define relevant terms and discuss variation in systems within and among major vertebrate groups as appropriate.
5. Describe the “cost/benefit” model for studying adaptation. Discuss the allocation of energy within individuals and explain the relationship between energy allocation and the

study of adaptation. Be sure to define all relevant terms. Include a discussion of the relationships among standard metabolism, homeostasis, and activity levels.

6. Given the relationships described in #5 above, discuss the two broad sets of strategies organisms can use to maximize reproductive success. Illustrate these strategies using temperature regulation as your example. Be sure to correctly define and outline the major thermoregulatory strategies and to describe the relative advantages and disadvantages (costs/benefits) of each.

### CH. 3: VERTEBRATE ORIGINS AND EARLY RADIATIONS

1. Outline the fossil record of early vertebrates (what kind of fossils, where were they found, when were they formed) from the Cambrian to the Late Silurian.
2. List the three main types of mineralized tissue in vertebrates and describe the basic unit of mineralized tissue. Why is the origin of bone still unclear? Describe the current hypotheses for the origin of bone, including fossil and any other available evidence.
3. Diagram the relationships among the major groups of jawless vertebrates and between the jawless vertebrates and the gnathostomes (i.e., reproduce the diagram I gave you!). To what groups does the name "ostracoderm" apply? Is this a monophyletic group? Defend your answer. Does the current traditional classification system accurately reflect evolutionary relationships within this group? Defend your answer.
4. Describe the basic characteristics shared by the ostracoderms and what we infer about the general ecology of these animals.
5. Is the traditional order Cyclostomata a valid taxon according to cladistic philosophy? Why or why not? What is the current consensus on the phylogenetic position of the Myxinoidea relative to other vertebrates?
6. Compare and contrast the general characteristics of lampreys and hagfish, with special attention to the skeletal system, sensory structures, and gills.
7. Compare and contrast lampreys and hagfish in terms of taxonomic diversity (i.e., approximate number of species and families) and general ecology (habitat, food habits, behavior).
8. Describe the mucus system of hagfish (what is it, how does it work, what is its function?). Describe the unique features of the digestive and circulatory systems of hagfish. Discuss the conservation status of hagfish, with special attention to any features of their biology that place them at particular risk.
9. Describe the complex life history (i.e., general stages from hatching to adult, including

migrations and metamorphoses) of lampreys. Discuss the invasion of the Great Lakes by lampreys and describe efforts currently being used to control them there (see web site for more information).

10. When did gnathostomes first arise; when did their early radiations take place? Describe the major sets of changes that characterize the gnathostomata and discuss both the general and specific selection pressures that might have favored them.
11. Summarize Mallat's hypothesis for the evolution of jaws from gill arches by describing the structure and function of the four stages he proposes. Be sure to include the proper anatomical names and homologies involved.
12. Describe the function(s)/benefits of jaws and fins (e.g., what "new" functions did they permit; what advantages did they provide).
13. Who were the placoderms?
14. Describe the diversity of jawed and jawless fishes throughout the Devonian. By the Late Devonian, which lineages were still surviving?

#### CHAPTER 5: RADIATION OF THE CHONDRICHTHYES

1. When did the Chondrichthyes originate? When did modern forms first appear? When did modern genera first appear?
2. Diagram the evolutionary relationships among the extant Chondrichthyes, with special attention to relationships among the elasmobranchs. Why are the relationships among modern Chondrichthyes poorly understood?
3. Outline the taxonomy currently used for the Chondrichthyes (i.e., list the major groups and subgroups properly).
4. Describe the major characteristics of modern Chondrichthyes. Which of these is/are derived?
5. Review the general features of the Holocephali, the shark-like Elasmobranchii, and the skates and rays. Compare and contrast the major groups in terms of their distribution and diversity. With what general features of their ecology are most of the features of skates and rays associated? How do skates and rays differ from one another?
6. Describe the sensory modalities used by sharks to capture prey. In what order, apparently, do sharks use these senses as they approach and capture prey?
7. Describe the processes of fertilization, development and birth known to occur in sharks.

Be sure to accurately define relevant terms.

8. Discuss the conservation status of sharks, with special attention to features of their biology that seem to place them at particular risk. Use data from the lecture notes and text to support your discussion.

#### CH 6: OSTEICHTHYES

1. What is the nearest relative (sister group) to the Osteichthyes? When did the Osteichthyes first appear in the fossil record, and when did its two major lineages diverge? Approximately when did the Neopterygii arise, and by what time had most teleost families appeared?
2. Diagram the evolutionary relationships of the Osteichthyes. Is this a monophyletic group? Why or why not? Outline the taxonomy used to describe the major groups of bony
3. Briefly describe the shared, derived characteristics of the Osteichthyes, the Actinopterygii, and the Sarcopterygii. Describe the other important features of Osteichthyes that distinguish them from other extant fish.
4. Describe the general characteristics, distribution and diversity of the Sarcopterygii. What features of coelocanth makes them particularly vulnerable to overexploitation?
5. Describe the general characteristics, distribution and diversity of the Chondrostei, primitive Neopterygians, and Teleostei.
6. Describe the functional trends within the Neopterygii that have led to the success of this group.
7. Discuss the characteristics of deep-sea environments and the adaptations seen in deep-water fish to these conditions.
8. Discuss the conservation status of fresh-water, marine, and coral reef fish. What kinds of threats do these groups face? What difficulties do we face in attempting to conserve them?

#### CH 4: LIVING IN WATER

1. Describe the basic physical properties of water and clearly explain their consequences for aquatic vertebrates (e.g., what kinds of “problems” and/or “benefits” do these properties produce?).
2. Describe the basic structure of gills, with special attention to features that increase its efficiency as a gas exchange structure. What is countercurrent gas exchange, and how,

specifically, is it accomplished in gills?

3. Compare and contrast gill features found in highly active vs. low-activity fish.
4. Compare and contrast gill structure and ventilation mechanisms among lampreys (adults only), Chondrichthyes, and Osteichthyes. Clearly relate structure to function.
5. Describe the variety of accessory respiratory structures (other than lungs) present in fishes. Describe the conditions under which anoxia might occur (so that such structures might be necessary).
6. Which came first, lungs or swim bladders?
7. Describe the ventilation mechanism used by lungfish. Under what conditions is the use of lungs especially important?
8. Describe the general structure and function of swim bladders, including the general mechanisms used to regulate the volume of the swim bladder.
9. Describe the general pattern of blood flow through the body of fishes. How, in general, is this different from the circulatory pattern in mammals?
10. Describe the potential advantages of regional heterothermy and the mechanism(s) used to accomplish it. Be sure to mention why fishes are generally poikilothermic.
11. Describe the modes of chemoreception common in fishes, including some of the functions of those modes (i.e., what kinds of "senses" do they have, and what are those senses used for?).
12. Describe the structure and functions of the lateral line system. Include as many specific functions as possible.
13. Briefly compare and contrast passive and active electric reception and give specific examples of fishes using each modality.
14. To what specific processes do the terms "osmoregulation" and "excretion" apply? Why are they important, and how are they related?
15. Describe the three basic excretory strategies used by vertebrates and discuss the relative advantages and disadvantages of each. In which general group(s) is each found?
16. Describe the osmoregulatory challenges and solutions found in freshwater and marine fish.

### CH 7, 8: THE ORIGIN OF TETRAPODS

1. Describe the abiotic and biotic conditions of terrestrial and aquatic environments through the Devonian. Relate these conditions to the selection pressures that presumably favored the invasion of terrestrial habitats by vertebrates.
2. Discuss the challenges represented by life on land compared to life in the water.
3. Describe the evidence that the earliest tetrapods were aquatic. Discuss the kinds of selection pressures that might have favored the evolution of “terrestrial features” in aquatic animals.
4. Describe the major changes involved in the transition to life on land. Be sure to explain both the structural changes and their functions.
5. Compare and contrast the general features of *Acanthostega* and *Ichthyostega*. What do these animals tell us about the evolution of early tetrapods?
6. Describe the relationships and taxonomy of the tetrapods. Which groups may be considered (structurally) transitional between life in water and life on land? When did the earliest tetrapod radiations take place, and who were the “major characters” in those radiations?
7. Briefly describe the ecological diversity represented by the extinct batrachomorphs. In what way(s) were these animals similar to/different from modern amphibians?

### CH. 9: LISSAMPHIBIA -- MODERN AMPHIBIA

1. Briefly describe the fossil record for the modern amphibians and explain why the systematic relationships among the three major groups remain unresolved.
2. Give the scientific names (including synonyms as appropriate), approximate taxonomic diversity, general distribution, and basic characteristics of the three major groups of modern amphibians.
3. Briefly describe the general features of the Lissamphibia, with special attention to traits that differ between them and aquatic vertebrates.
4. Describe the features of the skin that allow it to be used as a site of gas exchange. Explain any constraints that these features might impose, and the mechanisms (if any) by which those constraints are minimized.
5. Discuss the feeding specializations of plethodontid salamanders and describe how those feeding specializations have affected other aspects of plethodontid biology (what

evolutionary tradeoffs has this involved?).

6. Describe the basic life history pattern common (or at least ancestral) to modern amphibians. What do we currently think the general advantage of this mode of reproduction is? To what extent is this mode of reproduction required by the structure/function of the anamniote egg?
7. Describe the range of variation on this general life history pattern illustrated by tropical frogs and ambystomid salamanders. Be sure to explain the general and specific conditions under which each group is most likely to exhibit this variation.
8. Using information from your text and the on-line resources provided on the course website, describe the conservation status of amphibians. Why do amphibians make good "indicator species", and what do experts currently think is causing the current problems in amphibian populations world-wide? Be sure to list specific causes where those have been identified.

#### CH. 8: ORIGIN AND EARLY RADIATION OF AMNIOTES

1. When did the amniotes first arise and radiate? Describe the important elements of the geology, climate, flora/fauna of the time, and relate those to the early amniote radiations.
2. Describe the relationships among the major amniote groups, including the major extinct lineages commonly thought of as "dinosaurs." Are ichthyosaurs, plesiosaurs, pelycosaur, and pterosaurs dinosaurs? Defend your answer.
3. Give the traditional classification for the major amniote lineages. Give a cladistic defense of the proposition that mammals and birds should be included within the Class Reptilia. Give a traditional defense of the proposition that birds and mammals should constitute separate classes.
4. Describe the "big picture" trends in early amniote evolution, being sure to identify the shared, derived characters of the group as appropriate. Relate these to specific changes taking place in the egg (give a full description of the structure and function of the amniote egg!), integument, limbs/girdles, head/neck, and respiratory and circulatory systems. Discuss how these changes are interrelated, using specific examples to illustrate.

#### CH. 10, 14: TURTLES AND SELECTED ARCHOSAURS

1. Briefly describe the taxonomic diversity and geographic distribution of turtles. Describe the general anatomy of the skeleton and carapace in these animals. What is unique about the structure of the pectoral limb and girdle in this group?

2. Briefly discuss the patterns of variation in general turtle morphology and relate these to variations in general ecology.
3. Briefly explain the general structure and function of the heart and lungs in turtles.
4. Describe the “alternative” mechanisms used by some turtles to exchange gases. In what kinds of turtles are these mechanisms found?
5. Describe the major reproductive characteristics of turtles (include a discussion of temperature-dependent sex determination). Discuss the implications of their reproductive biology for efforts to conserve turtles.
6. Briefly describe the major threats to turtles. In general, do turtles represent a threatened group of animals? Defend your answer.
7. Describe the evolutionary relationships among the Archosauria and between the Archosauria and other tetrapods.
8. What are the two groups of true dinosaurs? Describe the general change(s) in hip morphology (structure and function) that characterize true dinosaurs and discuss the evolutionary consequence(s) of those changes for dinosaur body forms.
9. Give a brief (the level of detail covered in class) overview of morphological and ecological diversity within each group. Which group includes the ancestors of birds?
10. When did true crocodylians first appear? When did they reach their peak of diversity and body size?
11. How many species of crocodylians currently survive? List the families of modern crocodylians and describe the general distribution and habitat(s) of each.
12. Describe the major differences between alligators and crocodiles.
13. Describe the basic form and function of crocodylians, including adaptations to their semiaquatic habits.
14. Discuss the conservation status of modern crocodylians, including the major threats they face and potential difficulties in conserving them.

#### CH. 11: MODERN LEPIDOSAURS

1. What two groups comprise the modern lepidosaurs? Briefly compare the relatively diversity of the groups.

2. Give a brief overview of the biology of the tuatara, including the ecological relationship(s) between tuatara and sea bird colonies.
3. List and briefly discuss the general characteristics of the squamate reptiles and their systematics and diversity.
4. Defend the view that the term "lizard", as describing organisms distinct from snakes and amphisbaenians, is taxonomically meaningless and should be abandoned. Defend the view that the term "lizard" is useful and should be retained.
5. What are amphisbaenians? Give a brief overview of their biology.
6. Give a brief (but accurate!) overview of lizard diversity, with attention to (1) body size; (2) habitat; (3) food habits; (4) the presence/absence of leglessness; and (5) locomotor specializations.
7. Describe the pattern of correlation between foraging mode and characteristics of behavior, predation, physiology, body form, and sociality in lizards. Be sure to explain the mechanisms (i.e., the "why" and "how") responsible for those correlations.
8. Why do snakes exhibit relatively little morphological variation in spite of their ecological diversity? Describe the adaptations of sea snakes to their extreme aquatic habits.
9. What are the two major hypotheses for the evolution of leglessness in snakes?
10. Describe the general differences in body form you would expect to see among arboreal, fossorial, and aquatic snakes.
11. Describe the role of kinetic skulls in the ability of snakes to attain large body size. Be sure to briefly describe the general structure and function of the kinetic skull.
12. Discuss the trade-offs between efficient constriction and rapid terrestrial locomotion. How have some snakes dealt evolutionarily with those constraints?
13. Briefly describe the three major venom delivery modes and list the major groups of snakes using each.
14. Discuss the conservation status of lepidosaurs.

CH. 11, 12, 15, 22: THERMOREGULATION

1. List and describe the routes of energy exchange between organisms and the environment. For each route, explain whether the organism gains or loses heat (if both, explain the conditions for each) and describe the factors that regulate the rate of heat exchange.

Which routes are particularly important for ectotherms? For endotherms?

2. Define "active temperature range". List and describe the common behavioral and physiological mechanisms ectotherms use to keep their body temperatures within that range.
3. Describe the relative costs and benefits of ectothermy in both general and specific terms, with attention to the underlying mechanisms responsible for each.
4. Explain the consequences of ectothermy for terrestrial ecosystem function. Relate this to conservation of biodiversity.
5. Describe the general costs and benefits of endothermy. List and describe the four main characteristics of mammalian/avian energetics. Which of these is the primary cause of the high cost of thermoregulation in these animals?
6. Why do birds/mammals maintain relatively high body temperatures? What is our current explanation for why they maintain such high metabolic rates?
7. Describe, in general terms, the consequences of their energetics on overall anatomy and physiology in birds and mammals.
8. Describe and diagram the basic mechanisms of thermoregulation in birds and mammals, with special attention to the patterns of changes in body temperature and metabolic rate across a wide range of ambient temperatures. How would these patterns change with changes in insulation?
9. Discuss the current hypotheses for the origin of the energetic patterns in birds and in mammals.

#### CH. 15, 16: BIRDS

1. From which group of vertebrates are birds descended? What is the earliest fossil bird, and how old is it?
2. Briefly outline the three major radiations of birds, including when the radiations took place, what groups were involved, and the ecological correlates of each.
3. Describe the diversity and distribution of modern birds.
4. Discuss the general structure and functions of feathers. Describe the differences in structure and function among contour feathers, down feathers, and filoplumes/bristles, being sure to relate differences in structure to differences in function.

5. Describe the adaptations of the musculoskeletal system of birds to flight. Be sure to be able to identify components of the musculoskeletal system on a diagram such as the one used in class.
6. Discuss the respiratory system of birds. Explain how and why this system provides more efficient gas exchange than is found in mammals.
7. Briefly outline the major features of reproduction in birds.
8. Describe the constraints on body size in birds imposed by high metabolic rates and powered flight. What is/was the largest bird that flies? What is/was the largest bird?
9. Define aspect ratio and camber and explain how each of these features affects flight. With what kinds of ecological habits are high and low aspect ratio wings associated? High and low camber wings?
10. Describe variation in the hind limb and beaks of birds and relate that variation to differences in locomotion and food habits.
11. Briefly outline the sequence of changes that led to flight in birds, and to the improvement in flight seen in modern birds. During which stages can we legitimately say that changes were associated with adaptations to flight, and during which are adaptations associated with functions other than flight (approximately)?
12. Compare and contrast the “ground-up” and “trees-down” hypotheses for the origin of flight in birds.

#### CH. 17, 19, 20: MAMMALS

1. To what amniote lineage to mammals belong? Briefly outline the three major radiations in this group.
2. Who are the synapsids, pelycosaur, therapsids, and cynodonts?
3. With what general niche were trends in pre-mammalian evolution throughout the Mesozoic associated? Describe those trends in general terms (i.e., what were the general results of the changes), then discuss the key changes in detail.
4. Discuss the evolution of the middle ear bones in mammals, including the two hypotheses for “why” it happened the way it did.
5. Who is the earliest “true mammal”, and how old is it? What basic characteristics do we use to distinguish fossil mammals from their closest non-mammalian relatives?

6. Describe Blackburn's hypothesis for the evolution of lactation and discuss the major selective benefits of lactation.
7. Briefly outline the three major radiations of "true mammals". With which of those radiations is the major diversification in form and function of mammals associated?
8. Describe the evolutionary relationships (and proper terms) among monotremes, marsupials, and placental mammals. Briefly compare and contrast these groups.

### COMPREHENSIVE MATERIAL FOR FINAL EXAM

1. Diagram the current hypothesis for the evolutionary relationships among the following groups of extant vertebrates: Cephalochordata, Myxinoidea, Petromyzontoidea, Chondrichthyes, Actinopterygii, Actinistia, Dipnoi, Gymnophiona, Anura, Urodela, Testudomorpha, Lepidosauria, Crocodilia, Aves, Mammalia
2. On the diagram for #1, indicate which group(s) are included within the: "traditional" Agnatha, Gnathostomata, "traditional" Osteichthyes, "traditional" Sarcopterygii, Tetrapoda, Amniota, Diapsida, Synapsida, "traditional" Reptilia, modern Amphibia
3. On the diagram for #1, indicate the origin of the following characteristics: pharyngeal slits; dorsal hollow nerve tube; notochord; postanal tail; bilateral symmetry; gill bars composed of a series of elements; jaws; cleidoic egg; bone; anamniote egg; opercular gills; paired fins with internall, medially arranged bones; lung/swim bladder derived from gut; limbs with 1 proximal and 2 distal bones; extra-embryonic membranes; skin modified for gas exchange; neck; robust rib cage; sacral vertebra(e); urinary bladder; epidermal (keratin) scales; buccal pulse lung; aspiration lung; completely subdivided ventricles; feathers; fur; mammary glands; endothermic homeothermy
4. For each of the seven "traditional" vertebrate classes, give the (1) approximate time of its origin and (2) the approximate number of extant species it includes. Approximately how many species of animals currently exist on earth?
5. Give one good vertebrate example (with explanation) of each of the following:
  - a. a trait originally favored by selection for one "function" is used (and subsequently modified) for a novel function
  - b. new phenotypic trait opens "new" ecological niches; this results in an adaptive radiation
  - c. a change in the external environment (biotic or abiotic) opens "new" ecological niches; this results in an adaptive radiation
  - d. a change in the timing of development leads to novel phenotypes
  - e. cladists and evolutionary ("traditional") systematists disagree on how to name and classify (group) a set of related taxa
  - f. selection does not act on single traits in isolation (changes in one trait have effects on other traits)
  - g. over time, evolution by natural selection leads to increasingly perfect organisms (hint: I generally avoid trick questions, but sometimes . . .)