

Part I Vertebrate Diversity, Function, and Evolution

~ Chapter 1 ~

The Diversity, Classification, and Evolution of Vertebrates

Objective: To recognise that all vertebrates share basic characteristics reflecting a common ancestry.

1-1 The Vertebrate Story

- 1) Evolution through natural selection is central to vertebrate biology.
- 2) More than 57,000 **extant** (living) species of vertebrates ranging from 0.1 g to 100,000 kg in body weight live in all the habitats on Earth.
- 3) The behaviours of vertebrates are as diverse & complex as their body forms.
- 4) Vertebrates obtain energy from food.
- 5) Carnivores eat other animals & show a wide range of methods of capturing & dispatching the prey, **e.g.** biting, swallowing or injecting poison into their bodies.
- 6) Herbivores eat plants. Plants are easy to catch but hard to chew & digest. Herbivores have specialized teeth & rely on microorganisms to digest the cellulose.
- 7) **Reproduction** is a critical factor in the evolutionary success of an organism. Vertebrates show a range of behaviours associated with mating & reproduction.
- 8) Some are entirely self-sufficient at birth or hatching, whereas others have extended periods of obligatory parental care.

Major Groups of Vertebrates

- 1) Two major groups of vertebrates are distinguished on the basis of an innovation in embryonic development, *the appearance of three membranes formed by tissues that come from the embryo itself.*
- 2) One of these membranes, the **amnion**, surrounds the embryo → animals called **amniotes**.
- 3) **Non-amniotes** are aquatic vertebrates & **amniotes** are terrestrial, but some fishes & amphibians lay non-amniotic eggs on land.
- 4) Among amniotes we can distinguish two major evolutionary lineages:
 - a) **Sauropsida** (reptiles & birds)
 - b) **Synapsida** (mammals)

- 5) Sauropsids & Synapsids represent parallel but independent origins of basic characters such as lung ventilation, kidney function, insulation, and temperature regulation.

Non-Amniotes

- 1) Embryos of non-amniotes are enclosed & protected by membranes that are produced by the female reproductive tract.
- 2) This is similar to the invertebrates & is retained in the fishes and amphibians.
- 3) Hagfishes, lampreys, sharks, rays, ratfishes, bony fishes, salamanders, frogs, and caecilians.

Hagfishes (Myxinoidea) & Lampreys (Petromyzontoidea)

- 1) Elongate, limbless, scaleless, and slimy & have no internal bony tissues.
- 2) They are scavengers and parasites.
- 3) **Hagfishes** are marine & benthic.
- 4) **Lampreys** are migratory; they live in oceans & spawn in rivers.
- 5) Jawless condition is ancestral & is unique among living vertebrates.

Sharks, Rays, & Ratfishes – Chondrichthyes

- 1) Cartilaginous skeletons
- 2) Sharks & rays in group **Elasmobranchii**; differ in body form & habits.
 - a) Many **sharks** are small (15 cm or less); the largest species grows to 10 m.
 - b) **Rays** are dorsoventrally flattened, frequently bottom dwellers that swim with undulations of their extremely broad pectoral fins.
- 3) **Ratfishes** in group **Holocephalii**.
 - a) Single gill cover extends over all four gill openings.
 - b) Long, slender tails and bucktoothed faces.

Bony fishes – Osteichthyes

1. Very diverse; two broad categories are recognised:
 - 1) **Actinopterygians** (ray-finned fishes)
 - 2) **Sarcopterygians** (lobe-finned or fleshy-finned fishes)
2. Ray-finned fishes divided into three lineages:
 - 1) **gars** (Lepisosteiformes, 7 species)
 - 2) **bowfin** (one species); gars + bowfin:

- Have cylindrical bodies, thick scales, & jaws armed with sharp teeth.
 - Lack the specializations of the modern fish jaw mechanisms.
- 3) **Teleostei**; more than 27,000 species.
- Most familiar fishes are teleosts such as the trout.
3. Only eight species of lobe-finned fishes survive.
- 1) Six species of **lungfishes** + two species of **coelacanth**.
 - 2) These are the living fishes most closely related to terrestrial vertebrates.

Salamanders (Urodela), Frogs (Anura), & Caecilians (Gymnophiona)

- 1) Amphibians; live part of their life cycle in water.
- 2) All amphibians have bare skins (lacking scales, hair, or feathers).
- 3) Skin is important in the exchange of water, ions, & gases with their environment.
- 4) **Salamanders** are elongate animals, mostly terrestrial & usually with four legs.
- 5) **Anurans** (frogs, toads, treefrogs) are short-bodied with large heads & large hind legs.
- 6) **Caecilians** are legless aquatic or burrowing animals.

Amniotes

- 1) An additional set of membranes associated with the embryo appeared during the evolution of vertebrates. Called **fetal membranes** because they are derived from the embryo itself rather than from the reproductive tract of the mother.
- 2) **Amniotes** (*mammals & reptiles including birds*) are more terrestrial than **non-amniotes** (*fishes & amphibians*), but there are secondarily aquatic amniotes e.g. sea turtles & whales.
- 3) Terrestrial life requires efficient systems to extract oxygen from air and transport it via the circulatory system to the tissues & to remove waste and keep body temperature stable.
- 4) These systems evolved independently in the two lineages:
 - **Sauropsid amniotes** (turtles, lizards, snakes & birds)
 - **Synapsid amniotes** (mammals)

Turtles – Testudinia

- 1) Morphological modifications associated with shell make turtles extremely peculiar animals.
- 2) The only vertebrates with shoulders (**pectoral girdle**) & hips (**pelvic girdle**) inside the ribs.

Tuatara, Lizards, and Snakes – Lepidosauria

- 1) Recognised by scale-covered skin & characteristics of skull.
- 2) Two species of **tuatara**, stocky-bodied animals still survive.
- 3) **Lizards** and **snakes** are numerous.

Alligators and Crocodiles – Crocodylia

- 1) In the same evolutionary lineage as dinosaurs & birds.
- 2) The 23 species of crocodylians are semiaquatic predators with long snouts & numerous teeth.
- 3) Range in size from saltwater crocodile (up to 7 m long) to freshwater crocodiles (< 1 m).
- 4) Skin contains many bones that lie beneath the scales.
- 5) Crocodylians are noted for the parental care they provide for their eggs & young.

Birds – Aves

- 1) Birds are a lineage of dinosaurs.
- 2) Diversified into more than 9,760 species.
- 3) Feathers are characteristic of **extant** birds, and evolved before flight.

Synapsid Amniotes

- 1) There are three groups of mammals:
 1. **Monotremes (prototheria)**; the platypus & echidna): these mammals lay eggs.
 2. **Marsupials (metatherians)**
 3. **Placentals (eutherians)**
- 2) All mammals feed their young with milk.

Mammals – Mammalia

- 1) Extant mammals include about 4800 species, most of which are **eutherian (placental)**.
- 2) Both eutherians & marsupials possess a placenta.
- 3) **Placenta** is a structure that transfers nutrients from mother to embryo & removes waste products of embryo's metabolism.
- 4) **Eutherians** have a more extensive system of *placentation* & a *long gestation* period.
- 5) **Marsupials** have a *short gestation* period & give birth to very immature young such as kangaroos, koalas, and wombats.

1-2 Classification of Vertebrates

Classification and Names

- ❖ The Linnaean system uses binomial nomenclature to designate species, and arranges species into hierarchical categories (**taxa**) for classification.
- ❖ Another recent method is based on evolutionary relationships.

Binomial Nomenclature

- 1) The scientific naming of the species published between 1735 & 1758 became a standard.
- 2) Binomial (two-word) name is assigned to each species e.g. *Homo sapien* (wise human).

Hierarchical Groups: The Higher Taxa

- 1) Linnaeus & others developed a natural system of classification. The **species** is the basic level of biological classification.
 - 2) But the definition of a species has been contentious, partly because criteria that have been used to identify *extant species* don't work for *fossil species*.
 - 3) Similar species are grouped together in a **genus** based on characters that define the genus.
 - 4) The most commonly used characters were anatomical, but now these characters should be supported by genetic information.
 - 5) Genera are placed in **families – orders – classes**, and animal classes in **phyla**.
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1-3 Phylogenetic Systematics

- ❖ All methods of classifying organisms are based on similarities among the species, but some similarities are more significant than others.
- ❖ **Example:** nearly all vertebrates have paired limbs, but only a few kinds have mammary glands. Therefore, knowing that the species in question have mammary glands tells you more about the closeness of their relationship than knowing that they have paired limbs.

Phylogenetic Systematics (Cladistics)

- 1) A way to assess the relative importance of different characteristics was developed in the mid-twentieth century by Hennig, who introduced a method of determining evolutionary relationships called **phylogenetic systematics**.
- 2) An evolutionary lineage is a **clade** (=branch) & phylogenetic systematics is called **cladistics**.
- 3) Cladistics recognises only groups of organisms that are related by common descent.
- 4) The groups of organisms recognised by cladistics are called *natural groups*. They are linked in a nested series of ancestor–descendant relationships that trace the evolutionary history of the group. These groups can be identified only on the basis of **derived characters**.
- 5) *Derived* means “different from the ancestral condition.” A derived character is called an **apomorphy**, e.g. the feet of terrestrial vertebrates have distinctive bones – the carpals, tarsals, & digits. This arrangement of foot bones is different from the ancestral pattern seen in lobe-finned fishes.
- 6) Thus, the terrestrial pattern of foot bones is a **shared derived character** of terrestrial vertebrates. Shared derived characters are called **synapomorphies**.
- 7) Organisms also share ancestral characters (i.e. that they have inherited unchanged), called **plesiomorphies**. Terrestrial vertebrates inherited a vertebral column from lobe-finned fishes.

Cladograms

- ❖ **Figure 1–3:** Three **cladograms** (diagrams showing hypothetical sequences of branching during evolution) showing the possible evolutionary relationships of three taxa.
- ❖ Consider three characters – the number of toes on the front foot, the skin covering, and the tail.
 - 1) In the *ancestral character state* there are five toes on the front foot, and scaly skin. In the *derived state* there are four toes and no scales. As for the tail, the ancestral state is present & the derived state is absent.
 - 2) Figure 1–3 shows the distribution of those three character states in the three taxa.
 - **Taxon 1** – five toes on the front feet, lack scales, & have a tail.
 - **Taxon 2** – five toes, scaly skins, and no tails.
 - **Taxon 3** – four toes, scaly skins, and no tails.
 - 3) How can we use this information to decipher the evolutionary relationships of the three groups of animals?
 - 4) The most **parsimonious** phylogeny (i.e. the evolutionary relationship requiring the fewest number of changes) is represented by the leftmost diagram in Figure 1–3.
 - 5) Only three changes are needed to produce the derived character states:
 - In the evolution of taxon 1, scales are lost.
 - In the evolution of the lineage including taxon 2 + taxon 3, the tail is lost.

- In the evolution of taxon 3, a toe is lost from the front foot.
- 6) The most plausible phylogeny is the one requiring the fewest changes.

So what is a phylogeny?

- 1) A hypothesis about the evolutionary relationships of the groups included. It can be tested when new data become available; if it fails, the hypothesis (cladogram) is replaced.
- 2) **Important:** phylogenetic systematics enables us to frame testable hypotheses about the sequence of events during evolution.
- 3) **Central issue** of phylogenetic systematic: How do scientists know which character state is ancestral (plesiomorphic) & which is derived (apomorphic)?
- 4) That is, how can we determine the direction (**polarity**) of evolutionary transformation of the characters?
- 5) By comparing the characters we are using with an **outgroup** that consists of the closest relatives of the **ingroup** (i.e. the organisms we are studying).
- 6) A well-chosen outgroup will possess ancestral character states compared to the ingroup. **For example**, lobe-finned fishes are an appropriate outgroup for terrestrial vertebrates.

Figure 1–4: Phylogenetic relationships of extant vertebrates. Note that the cladistic groupings are nested progressively; that is all placental mammals are **therians**, all therians are **synapsids**, all synapsids are **amniotes**, all amniotes are **tetrapods**, and so on.. See legend in the textbook p.11.

Figure 1–5: Using a cladogram to make inferences about behaviour. The cladogram shows the relationships of the Archosauria, the evolutionary lineage that includes living crocodilians & birds. (Phytosaurs were crocodile-like animals & pterosaurs were flying reptiles.) Both extant groups – crocodilians & birds – display extensive parental care of eggs and young. The most parsimonious explanation assumes that parental care is an ancestral character of the archosaur lineage.

Determining Phylogenetic Relationships

- 1) The derived characters used to group species into higher taxa must be inherited through common ancestry, i.e. they are **homologous** similarities.
- 2) Straightforward notion; but in practice, determination of common ancestry can be complex.
- 3) **For example**, birds & bats have wings that are modified forelimbs.
 - a) But the wings were *not inherited from a common ancestor* with wings.
 - b) Evolutionary lineages of birds (Sauropsida) & bats (Synapsida) diverged long ago.

- c) And wings *evolved independently* in the two groups.
 - d) This process is called **convergent evolution**.
- 4) **Parallel evolution** describes the situation in which *species that have diverged relatively recently develop similar specializations*, e.g. the long hind legs used for jumping in the two lineages of rodents, the kangaroo rats & the jerboa.
- 5) **Reversal evolution** can produce similar structures in distantly related organisms, **e.g.** sharks & whales have similar body forms, but they arrived at that body form from different directions.
- 6) Convergence, parallelism, and reversal are forms of **homoplasy**.
- a) Homoplastic similarities do not indicate common ancestry.
 - b) *Convergence & parallelism* give an appearance of similarity (as in the wings of birds & bats) that is not the result of common evolutionary origin.
 - c) In contrast, *reversal* conceals similarity (e.g. between whales & their four-legged terrestrial ancestors) that is the result of common evolutionary origin.

Figure (slide): Phylogeny is used for conservation using genetic information.

Summary

- 1) Majority of species fall into one of two major divisions of bony fishes (**Osteichthyes**):
 - i. aquatic ray-finned fishes (**Actinopterygii**)
 - ii. primarily terrestrial lobe-finned fishes & tetrapods (**Sarcopterygii**)
- 2) Phylogenetic systematics (**cladistics**) classifies animals on the basis of shared derived character states.
- 3) Natural evolutionary groups can be defined only by these derived characters; retention of ancestral characters does not provide information about evolutionary lineages.
- 4) Application of this principle produces groupings of animals that reflect evolutionary history as accurately as we can discern it, and forms a basis for making hypotheses about evolution.