Station 1A
Introduction to Vertebrates

Our understanding of vertebrate biology probably surpasses our understanding of most other animal groups. Vertebrates have evolved to occupy most every marine, aquatic and terrestrial habitat on the earth. Vertebrates are very complex, active animals that show a high degree of cephalization by possessing highly evolved organ systems to support their complex behaviors and metabolic demands.

Recall that vertebrates are chordates. In addition to the characteristics that all chordates possess, vertebrates have a jointed endoskeleton composed of cartilage and/or bone (CaPO₄). A prominent feature of this endoskeleton is the vertebral column, derived from the notochord, that encloses the spinal cord and joins the cranium. The cranium surrounds and protects the vertebrate’s brain including 8-12 pair of cranial nerves. Ventral to the vertebral column, is the complete digestive tract and paired kidneys for the removal of metabolic wastes. Red blood cells (RBCs) in the blood deliver oxygen to the tissues with a closed circulatory system that includes a ventral heart with at least two chambers. Vertebrates reproduce sexually and are dioecious.

The Agnathans – Jawless vertebrates

The earliest vertebrates lacked jaws and paired appendages. It was not until much later that jaws evolved from pharyngeal cleft elements which were used to support respiratory gills and in filter feeding. Most jawless vertebrates have since become extinct; however, two extant groups of agnathans: remain; the hagfish and the lampreys.

The hagfish are marine scavengers. Sensitive short tentacles surround the mouth and are used to search for food. Small keratinized tooth-like projections are used to tear at bits of decaying flesh as the hagfish feeds. Hagfish have very small eyes which are thought to have degenerated through the evolutionary process as their ancestors burrowed in soft mud. Their body is covered by mucus which is produced from numerous epidermal mucus glands. This mucus is used for protection as it makes the hagfish very difficult to grasp. Hagfish are known to produce several liters of mucus in less than a minute when disturbed! The endoskeleton of a hagfish is composed entirely of cartilage and the cranium does not completely enclose the brain. The supportive notochord is present in adults. Contraction of body muscles allow for a ‘snake-like’ swimming motion which is not very coordinated or agile.
**Lampreys** are found in freshwater or marine environments. Most lampreys have larvae that filter feed. After the larvae develop into adults, their lifestyle can change dramatically. Most adult lampreys are parasites or predaceous. The large oval mouth of a lamprey is used to attach to the side of a fish or other prey. Using a strong, rasping tongue with keratinized projections, the lamprey bores a hole in the side of its prey and feeds on the blood and other body fluids. The skeleton of a lamprey is composed of cartilage. The notochord also persists into adulthood becoming surrounded by a sheath of cartilage within the individual vertebrae.

**Evolution of jaws and paired fins**

The evolution of **jaws** from pharyngeal cleft elements allowed for some amazing advances in vertebrate evolution. Prior to the development of jaws, ancestral vertebrates had to be filter feeders, detritivores, or parasites. Jaws not only meant that these vertebrates could be better predators but also pharyngeal cleft elements could continue to be refined as more efficient organs of gas exchange (gills). The jawed vertebrates are known as **gnathostomes**. In addition to jaws, gnathostome vertebrates also possess a **lateral-line system** (used to detect vibrations in the water), an increasingly complex brain with enlarged **optic and olfactory lobes** and paired appendages (**pectoral and pelvic fins**).

Review Questions:

1. List the characteristics of vertebrates that other chordates lack.

2. How does a hagfish escape predators?

3. What is a gnathostome?

4. Describe the feeding habits of an adult lamprey.

5. How might paired fins aid swimming locomotion?
Station 1B
Cartilaginous and Bony Fish

**Class Chondrichthyes – Cartilaginous Fish**
There are about 800 extant species of cartilaginous fish. The most familiar forms are the marine sharks and rays. Sharks and other cartilaginous fish have an endoskeleton which is composed completely of cartilage. Only a remnant vestige of the notochord is present within the adult’s vertebrae. Their skin is covered by placoid scales. Placoid scales protrude through the epidermis and give the skin of a shark a unique texture. Each scale is covered by a sheath of hardened enamel and forms a spine which points in a posterior direction. This covering helps to reduce drag and increases the swimming efficiency of the shark. Modified placoid scales are found associated with the jaws of sharks and form the teeth. The teeth of a shark are constantly replaced as new teeth are produced in the shark’s skin. The teeth are not firmly attached to the jaw and are lost quite frequently as the shark feeds.

The fusiform body of a shark has several fins which aid in stabilizing body position and directing movements. A pronounced dorsal fin in usually positioned near the midpoint of the trunk and may be followed by a posterior dorsal fin towards the tail. The caudal fin is heterocercal, the vertebral column extending only in the dorsal lobe providing much of the forward thrust during locomotion. Pairs of pectoral and pelvic fins are positioned laterally along the lower portions of the trunk. The pelvic fins of male sharks are elongated and form claspers used during mating.

Sharks have keen vision and sense of smell and use these senses in combination with the lateral line to detect prey in the water. Many sharks also have electrical sensing pits, the ampullae of Lorenzini, located on their heads as an additional sensory tool.

Respiration is accomplished by the flow of water across the internal gills. Water enters through the nostrils or the ventral mouth and flows across the respiratory surface of the gills before it exits the external gill slits. The circulatory system includes a two chambered heart. Blood returning from systemic (body) circulation enters the atrium. As the heart muscle contracts, this blood is forced through a valve into the muscular ventricle. Upon exiting the ventricle, the blood flows though capillary beds along the respiratory surfaces of the gills where gas exchange occurs.

Paired kidneys collect metabolic wastes and empty into the cloaca. The cloaca is a common external opening to the digestive tract (where fecal material is eliminated), the excretory system (where urine is excreted) and the reproductive tract.
Rays (commonly called *stingrays*) are close relatives of sharks and have evolved to be dorso-ventrally flattened which aids them as an ambush predator. Rays prefer soft bottom substrates and can literally bury themselves to await prey. Rays also have a protective *spine* which protrudes from their caudal fin. Venom glands located near the base of this spine can also deliver potent venom to unsuspecting predators that might disturb the ray.

**Class Osteichthyes – Bony Fish**

The *bony fish* represent the greatest diversity in species among all of the vertebrate groups; well over 22,000 extant species of bony fish may be found in aquatic and marine habitats. There is tremendous variation among bony fish groups.

As their name implies, bony fish have an endoskeleton made of *ossified bone*. An *operculum*, a bony plate covering the gills, can be used to move water across the gills. The fins of most bony fish are supported by skeletal elements known as *rays*. These include a *homocercal* caudal fin, *anterior and posterior dorsal fins, pectoral and pelvic fin pairs* as well as a *ventral anal fin*. These fins are highly movable, however, most do not provide much forward thrust during swimming; offering primarily directional control. The forward motion is still accomplished by segmented trunk muscles which move the tail of the fish laterally.

The scales of bony fish tend to form overlapping rows with *mucus* from epidermal glands providing a protective coat of slime. This protective covering not only deters fungal and bacterial infections, but also reduces *drag* as the fish moves through the water. A *swim bladder* arises as a pouch from the digestive tract and is used to regulate buoyancy, as well as functioning in osmoregulation and gas exchange.

Most bony fish have a *terminal mouth*, large *eyes*, external *nostrils* and a *lateral line*; all are adaptations for a predatory lifestyle. Teeth, if present, are associated with the upper and lower jaw skeletal elements.
Review Questions:

1. Where do you find enamel on the body of a shark (technically two places)? What purpose does the enamel serve on each structure?

2. Describe the adaptations seen in the anatomy of a shark to allow for efficient swimming.

3. Describe the sensory structures seen in a shark and indicate how they assist in prey capture.

4. Describe the caudal fin of a shark and compare/contrast to that of a bony fish.

5. What is a cloaca?

6. Describe an operculum and list a vertebrate species that possesses one.

7. Describe the difference between the ventral mouth of a shark and the terminal mouth of a bony fish. Which is better adapted for prey capture? Why?
Station 2A
Class Amphibia – The Amphibians

The **amphibians** represent a transitional group of vertebrates, an interface between the strictly water-dwelling fishes and higher terrestrial groups. The endoskeleton of amphibians is made of bone and is divided into the **axial** (bones of skull and vertebral column) and **appendicular** (bones of pectoral and pelvic girdles) regions. Amphibians were the first **tetrapods** (vertebrates with four limbs) to colonize terrestrial habitats. However, water still plays an important role in their dual (*amphi* = both) life cycle. Fertilization is external and amphibians produce **anamniotic** eggs which are covered in a gelatinous mass and lack a shell. For this reason, these eggs must remain in an aquatic environment to remain alive. When the young emerge, they must continue their development in the aquatic habitat until **metamorphosis** is complete.

Amphibians have poorly developed paired **lungs** and must contract **intercostal** muscles (between the ribs) for ventilation. The addition of lungs in the circulatory pathway necessitated the evolution of a third chamber to the amphibian heart; **right and left atria and a single ventricle**. This type of circulatory system is known as a **dual circulatory system** and is unique to tetrapod vertebrates. In a dual circulatory system, blood enters the right atrium heart from systemic circulation, passes into the inferior ventricle and is routed to the lung capillaries. After gas exchange occurs, the oxygenated blood return to the left atrium of the heart and then to the single ventricle. In the ventricle, oxygenated and deoxygenated blood mix before being routed to the systemic capillaries.

Amphibian skin is smooth, scale-less and contains many glands covering the amphibian with mucus. This protective coat of mucus keeps the skin moist which is important for additional gas exchange to occur across the epidermis. The epidermis is shed periodically (**ecdysis**) and is often consumed by the amphibian as it is being shed. The limbs of amphibians have well-formed **digits** on the distal ends; however, these digits lack **keratinized claws or nails**.

Amphibians are **ectothermic** (rely on the environment for temperature regulation) and rely on behavioral adaptations to place themselves in locations where thermoregulation can occur.

There are several groups of extant amphibians including frogs, toads, newts, salamanders, and sirens.
Frogs have evolved to inhabit most terrestrial environments, including some habitats which are curiously devoid of surface water for much of the year. Frogs have long hind limbs for jumping locomotion. Most have webbing between the digits and many have adhesive pads to assist in climbing. Frogs lack tails and have shortened necks. Most frogs are capable of communication with vocalizations formed by passing air through air sacs in their throats (think of squeaking a balloon).

Toads have skin which appears ‘warty’ due to the large glands. Just posterior to the eyes of toads are large parotoid glands which produce noxious chemicals used in self-defense. The hind limbs of toads are generally much shorter compared to frogs and move in short hops as opposed to long jumps. Like frogs, toads lack tails and have short necks and fixed head positions. Vocalizations are also common in toads using air sacs in the throat.

Salamanders and newts are elongated amphibians with a lizard-like posture. The fore limbs and hind limbs are roughly equal in size. They move by crawling and often use their elongated tail to aid their locomotion. The head of salamanders is moveable. In many forms (such as the waterdogs), the aquatic larval stage is retained if suitable terrestrial environmental conditions are not present. These aquatic forms have enlarged external gills for gas exchange.
Review Questions

1. What characteristics of amphibians support the statement that they are the “interface” between terrestrial tetrapods and aquatic fish?

2. Describe an anamniotic egg.

3. Describe the metamorphic life cycle of a frog.

4. What is dual circulation? In the space below, construct a figure which illustrates the path of blood on one complete circuit through the body of an amphibian.

5. How does an ectotherm maintain proper body temperature?

6. List an amphibian you observed today with a tail.

7. List an amphibian you observed today with parotoid glands.
Station 2B
Class Reptilia – The Reptiles

The reptiles possess numerous adaptations for a truly terrestrial lifestyle. The skin of a reptile is covered by keratinized scales which must be periodically shed. The bony endoskeleton also has axial and appendicular divisions but there are far more specializations to the skeletal system of reptiles than observed in amphibians. The distal ends of the digits bear keratinized claws or nails in reptiles. Well-developed teeth are found in the jaws of vertebrates and each tooth is similar in shape and function (homodont dentition).

Reptiles also possess a three-chambered heart. However, a partial interventricular septum divides the ventricle and provides for a better separation of oxygenated and deoxygenated blood. Highly evolved lungs function more efficiently at gas exchange than amphibians. As ectotherms, reptiles on the environment and behavior for thermoregulation.

While these adaptations allow for a more terrestrial lifestyle, perhaps the most important evolutionary adaptation which allowed for a completely terrestrial existence in reptiles was the amniotic egg. Enclosed in a protective shell, this egg contained membranes that surrounded the developing embryo. The development is direct and hatchlings emerge from the shelled eggs as miniature replicas of their parents. This also allowed for internal fertilization mechanisms to evolve and male reptiles possess a copulatory organ known as the hemipenis.

Extant reptile groups include crocodilians, turtles, lizards and snakes.

Crocodilians are semi-aquatic reptiles. They spend considerable time in the water but return to dry land to lay their eggs. They are well adapted as an aquatic predator. The eyes and nostrils of crocodilians are located in a superior position (dorsally) and many times are the only part of the animal above water when seeking to ambush prey. Powerful jaws with large teeth grab prey. Broad, muscular tails are used in swimming. American alligators are common crocodilians in the United States. Once hunted to the verge of extinction, they have made a tremendous comeback. Females construct large incubator nests from available vegetation and soil to maintain a constant temperature over the eggs. Interestingly the temperature of the nest determines the sex of the hatchlings; warm temperatures produce males, cooler temperatures produce females.

American Alligator
**Turtles** are unique reptiles with a two-part protective shell. The dorsal portion is known as the **carapace** and the ventral portion is known as the **plastron**. The shell is formed from skeletal elements associated with the ribs, vertebrae and sternum and is covered by dermal plates called **scutes**. Turtles lack teeth but have a sharpened keratinized **beak** used to tear food into suitable sized pieces. Turtles can be found in aquatic, marine or terrestrial habitats. Observing the limbs of a turtle can give you insight into the preferred habitat. Turtles with short, powerful limbs with long claws are adapted to a terrestrial lifestyle, such as **box turtles** and tortoises. Turtles, such as red-eared sliders having webbing between the digits may be semi-aquatic, while **sea turtles** have limbs that are flattened into flippers and have no apparent digits or claws.

**Snakes** evolved from fossorial (burrowing) lizards and have lost the pectoral and pelvic girdles as a result. The eyes of a snake are not protected by eyelids (hence the wives’ tale that snakes never sleep!). Snakes have keen sense of smell using their forked tongues to literally taste the air. The forked nature of the tongue allows olfaction to be directional as well. To compensate for lost appendages, snakes have the ability to utilize **cranial kinesis** (moveable skull bones) to swallow food items whole; often much larger than the diameter of their own heads. Snakes overpower their prey by constricting and suffocation (like a python or kingsnake) or by using venom (like cobras and pit vipers). Snake venom is produced by modified salivary glands and is delivered by hollow or grooved **fangs**. Pit vipers use **heat-sensitive pit organs** located anterior to the eyes to aid in prey capture.

Most **lizards** are agile runners and climbers with powerful forelimbs and hindlimbs. Typically the digits have **claws** used to maintain traction as they move. Most lizards have **external ear openings** to allow for the collection of sound waves. In addition to auditory sense, lizards have keen eyesight (the eyes are protected by movable **eyelids**) and a well-developed olfactory sense which utilizes the nostrils and a sensitive tongue.
Review Questions

1. Describe why an amniotic egg is an important adaptation for a terrestrial existence.

2. What is the interventricular septum?

3. List three characteristics unique to reptiles.

4. Name the two portions of a box turtle’s shell.

5. How is sex determined in American alligators?

6. Name a pit viper you observed today.

7. Name a lizard you observed today.

8. What are pit organs used for?

9. What is cranial kinesis?
**Station 3A**
**Class Aves – The Birds**

**Birds** have been described as living dinosaurs and there is some truth to this statement. Birds do possess several reptilian-like characteristics. They lay a shelled, amniotic egg, regions of their bodies are covered by scales and they have several skeletal characteristics in common with **Theropod** dinosaurs.

Birds as a group have adapted to a volant lifestyle and are capable of powered flight. In general the avian body has evolved to be light-weight and powerful. Their bodies are covered with **feathers**, keratinized epidermal structures that are thought to have evolved as a thermoregulation mechanism and only secondarily assisted with flight. The bone endoskeleton of birds illustrates many adaptations for flight. The fore limbs have been modified into **wings**, an airfoil used to generate lift. Most of the bones are hollow and are strengthened by internal supportive struts. There is also a reduction in the overall number of bones; many are fused, such as in the fore limb or the pelvis, or are reduced such as most caudal vertebrae. The ventral sternum is **keeled** to provide a large surface area for the flight muscles (**pectoralis muscles**).

Birds do not have teeth, rather keratinized **beaks or bills** are adapted to the particular feeding niche of the bird species.

The avian heart has four chambers; a **complete interventricular septum** divides the right and left ventricles providing for efficient delivery of oxygenated blood to the tissues. The lungs of birds are considered to be the most advanced in any vertebrate group. The **parabronchial** lungs utilize a counter-current mechanism and pairs of **air sacs** to efficiently exchange oxygen for carbon dioxide. These adaptations allow for higher metabolism and allow birds to function as **endotherms**, using distributed metabolic heat to maintain body temperature.

Additional weight reduction adaptations can be seen in the urogenital system. Female birds only have **one functional set of reproductive organs** to produce their shelled eggs. Additionally, birds do not possess a **urinary bladder**. Metabolic waste is excreted in the form of solid uric acid crystals with fecal material through the cloaca.

Most birds exhibit **sexual dimorphism** and have complex courtship behaviors which involve **song and/or visual displays**. Typically one or both parents care for the eggs in the nest and assist with the rearing of the young.

Northern Bobwhites. Female above left, male right
Review Questions

1. Observe the bird beak specializations below. For each species briefly describe how the beak is adapted to forage on a particular food type. If you are not sure of what the particular bird forages on, use the internet for assistance.

   Merlin
   Northern Cardinal
   Mallard
   Pelican
   Pine Warbler
   Ruby-throated Hummingbird

2. List three skeletal adaptations for flight seen in birds.

3. List two characteristics birds share with reptiles.
Station 3B
Class Mammalia – The Mammals

The endothermic mammals’ bodies are covered with hair, keratinized epidermal structures which are used in tactile senses, protection or thermoregulation. Some are completely covered by dense fur while others may only have a few stiff hairs surrounding the eyes, ears or nose. In addition, mammals produce milk in paired mammary glands located on the ventral surface of the trunk.

Mammalian teeth are heterodont; each tooth is shaped differently providing different functions. Most mammals have incisors located at the anterior of the oral cavity followed by canines, premolars and molars. Incisors may be used for clipping while long canines may be used to dispatch prey quickly. The cheek teeth (molars and premolars) are used to grind, chop or crush food before it is swallowed.

The heart of a mammal has four chambers and efficiently delivers oxygenated blood to the body tissues via enucleated (lacks nucleus) red blood cells. Mammals are the only vertebrate group possessing this type of red blood cell. A muscular diaphragm controls the ventilation of the lungs by changing the volume of the thoracic cavity.

Most mammals give birth to live young which receive embryonic nourishment via the placenta. Only the monotremes (duck-billed platypus and echidna) found in Australia reproduce by laying a shelled egg. Marsupial (i.e. opossum, kangaroos, kolas) mammals have very short gestation periods and the young complete their development within the marsupium (pouch). True placental mammals (i.e. rodents, bats, elephants, humans) have longer gestation periods and greater placental attachment within the uterus of the female.
The mammalian ear uses three tiny bones called **ossicles** (*malleus, incus and stapes*) attached to a tympanic membrane.

Mammals have evolved to occupy most marine, aquatic and terrestrial habitats. They have complex behavior patterns, well developed central nervous systems and may communicate with a combination of vocalizations, postures and gestures.

Review Questions:

1. Describe heterodont dentition.

2. What are mammary glands used for?

3. Could you tell the difference between the blood of an elephant and the blood of a frog by looking through a microscope? How?

4. Describe three ways in which hair may be protective.

5. Name a marsupial native to Texas.

6. What are ossicles?
Class Activity
Frog Dissection

Use the laminated sheets to guide your dissection and label the figure as a study aid.

- Obtain a preserved frog, dissection tray, scalpel, scissors, dissection probe, forceps and several pins.
- Observe the external anatomy of the frog. You should be able to identify the eyes, nictitating membrane (clear covering which slides across the eye), the tympanum (used for auditory sense), the fore and hind limbs, the lateral folds, external nares (nostrils) and the cloacal opening.
- Observe the oral cavity by carefully inserting the scissors into the mouth and cutting the articulation of the upper (maxillae) and lower (mandible) jaw. Once open you should be able to observe the internal nares, opening to the esophagus, the tongue, the maxillary teeth and the vomerine teeth.
- Place the frog in the dissection tray ventral side up and carefully make an incision (with the scissors or scalpel) from the junction of the hind legs along the ventral longitudinal axis cranially to the throat. Take care to only cut through the outer dermis, the body wall muscles and expose the coelomic cavity’ do not puncture the abdominal organs. You will have to cut through the pelvic and pectoral girdles.
- Make transverse incisions laterally from just anterior to the hind legs and just posterior to the fore limbs creating a “flap” of dermal and muscular tissue on each side which you may pin back to expose the abdominal cavity.
- The most prominent organ in the abdomen is the three-lobed liver. Carefully expose the dorsal surface of the median lobe to locate the gall bladder. You may have to use a probe and deflect the liver from view.
- You should be able to see the curved stomach which leads to the small intestine and large intestine. Notice the density of the tissues in these organs; there is a lot of muscle tissue surrounding the digestive tract.
- Locate the cloacal cavity where the large intestine joins the urinary bladder.
- Locate the pancreas within the connective tissues between the stomach and small intestine.
- Locate the spleen, an oval organ which is positioned centrally in the connective tissues surrounding the small intestine.
- Lining the dorsal body wall are numerous finger-like fat bodies used for energy storage.
- Most of these frogs are females, so you will only be able to locate the ovaries (and if full of eggs are quite obvious) and the oviducts which lead to the cloaca.
- If not exposed, open the pericardium to locate the heart.
- Locate the small lungs which may be found along the dorsal body wall just superior to the liver.
- When you are finished, place your frog and any loose parts in the trash, wash your instruments and pans and place paper towels on the counters to dry.
Frog Anatomy

External anatomy. Label eye, tympanum, lateral fold, fore limb, hind limb, nictitating membrane, external nares, internal nares, vomerine teeth, maxillary teeth, cloacal opening, and tongue

Internal anatomy. Label liver, gall bladder, stomach, fat bodies, small intestine, large intestine, cloaca, spleen, urinary bladder, ovary, oviduct, pancreas, lungs, and heart