# Lab 3: Postcranial Skeleton

**Important "big-picture" concepts or trends:**
1. Homologous structures (but often different functions)
2. Regional differentiation of vertebral elements (cervical, thoracic, etc.)
3. Different types of vertebral centra (amphicoelous, procoelous, etc.) among taxa

**Note**: Most of the bones labeled in the different figures are homologous, so you only need to learn many of them once. However, these bones often serve different purposes and as such often look different (e.g., compare the radius and ulna between a frog and human). Remember that these structures usually look the way they do for a reason – form is closely tied to function.

## **Jawless fish (e.g., lamprey)** (pp. 101-113)

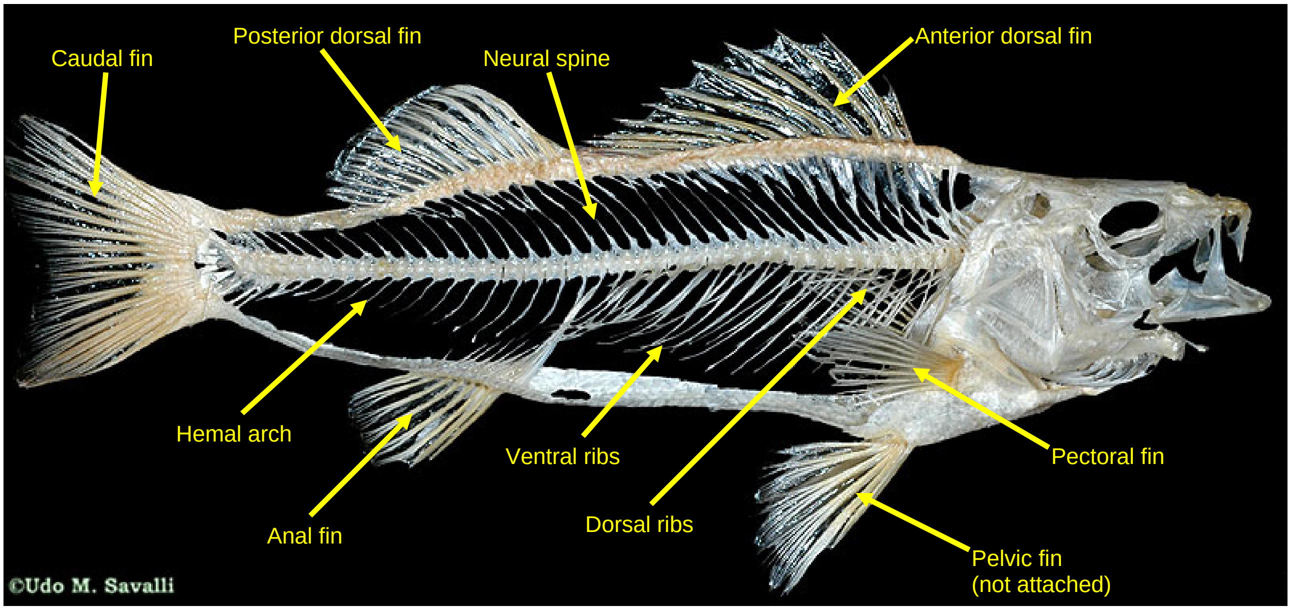
If needed, take a look at a preserved lamprey again to examine the notochord and lack of paired fins (the unpaired fins are the dorsal and caudal fins).

## **Chondrichthyes (e.g., shark)** (pp. 136-140)

Examine the shark girdles in the jars. Be able to identify the following structures:
**Pectoral girdle: scapulocoracoid bar, coracoid bar, scapular cartilage, suprascapular cartilage, basal pterygiophores, radial pterygiophores, ceratotrichia.**
**Pelvic girdle: puboischiadic bar, metapterygium, clasper, spine.**

## **Osteichthyes (e.g., bowfin and perch)**

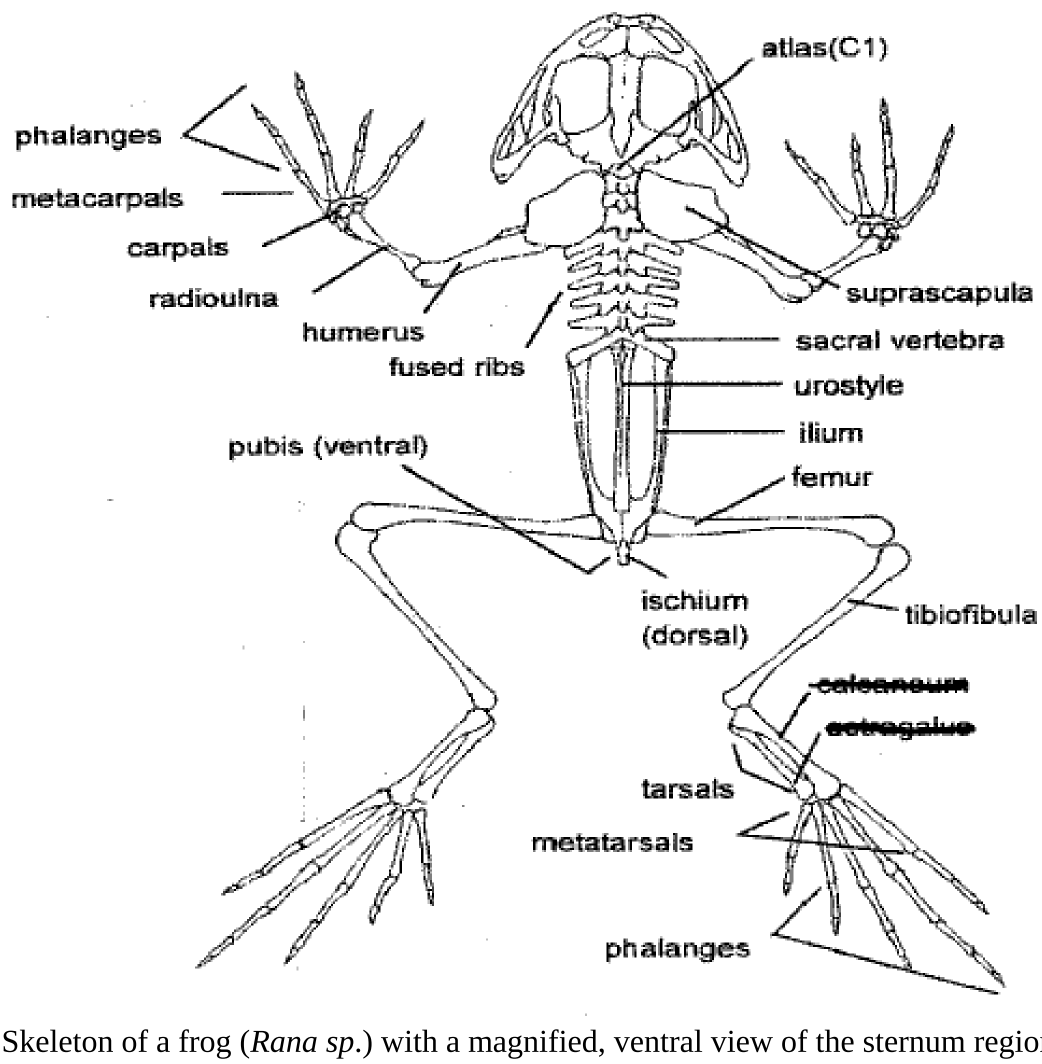
The vertebral column of bony fishes can be divided into trunk and tail vertebrae. The first vertebra is slightly modified for articulation with the skull. The trunk vertebrae are essentially identical, as are the caudal vertebrae. Most fishes (including sharks) possess amphicoelous vertebral centra. The pectoral girdle is firmly articulated with the skull. Be able to identify the **thoracic vertebrae**, **caudal vertebrae**, **neural spine**, **hemal arch**, **centra, ribs, pectoral fins, pelvic fins** (not attached), **anal fin, caudal fin, anterior dorsal fin,** and **posterior dorsal fin** in the perch (see figure below) and bowfin.



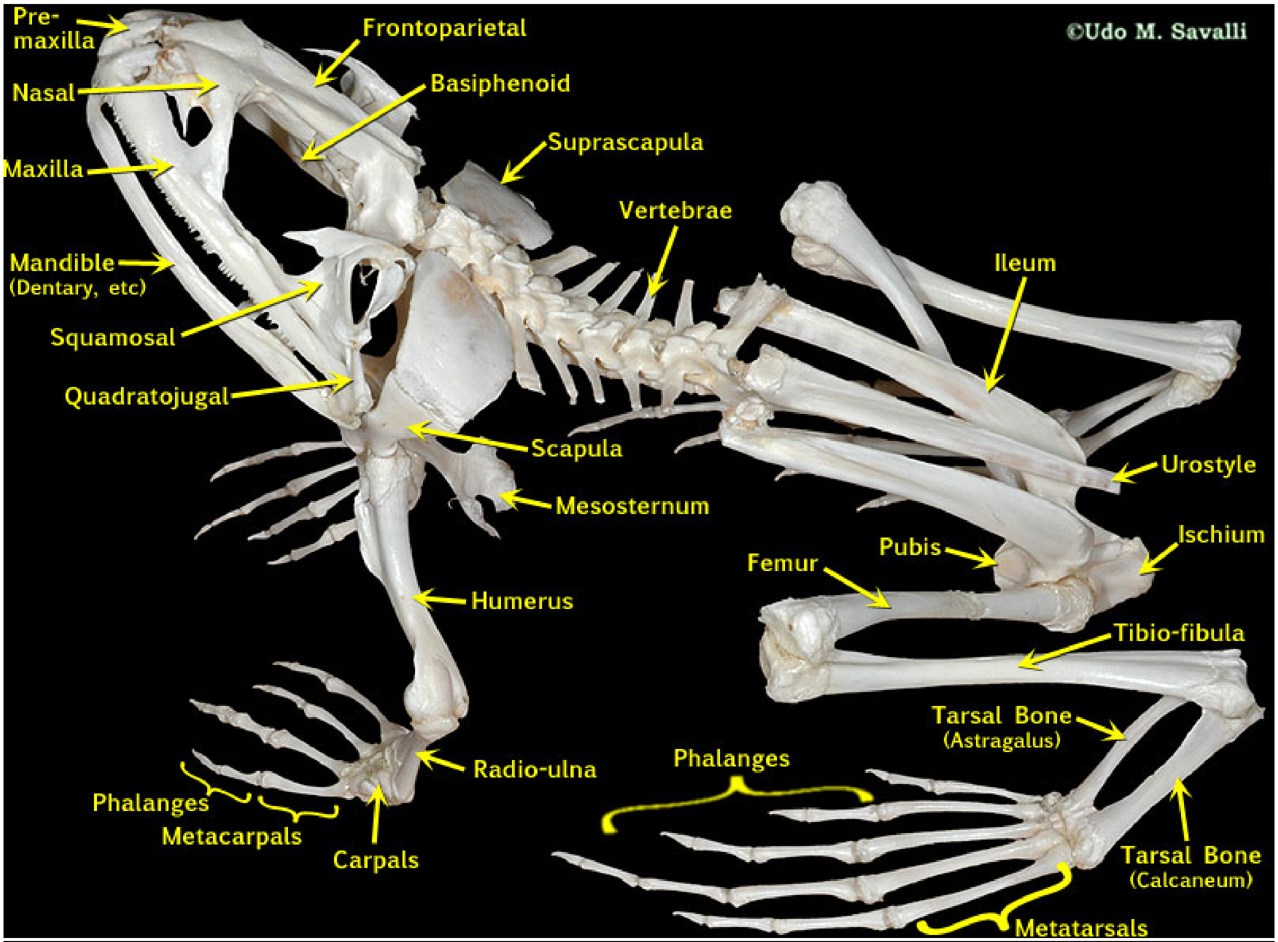
**<u>Amphibians (e.g., bullfrog, mudpuppy, etc.)</u>** <u>(pp. 220-224)</u>

Amphibians represent the earliest extant examples of the vertebrate transition onto land. As they were no longer supported by hydrostatic buoyancy, their vertebral columns evolved a series of processes to help support their body mass. The centra of many amphibians are procoelous or opisthocoelous, but some retain the ancestral amphicoelous condition (e.g., *Necturus*). Amphibians have well-developed prezygapophyses and postzygapophyses (see pp. 221-222). As in all tetrapods, the pectoral girdle has separated from the skull and now rests in a muscular sling (see pp. 222-223). Why was this arrangement more advantageous (see p. 223)? Focus on the handouts but refer to the lab manual when relevant.

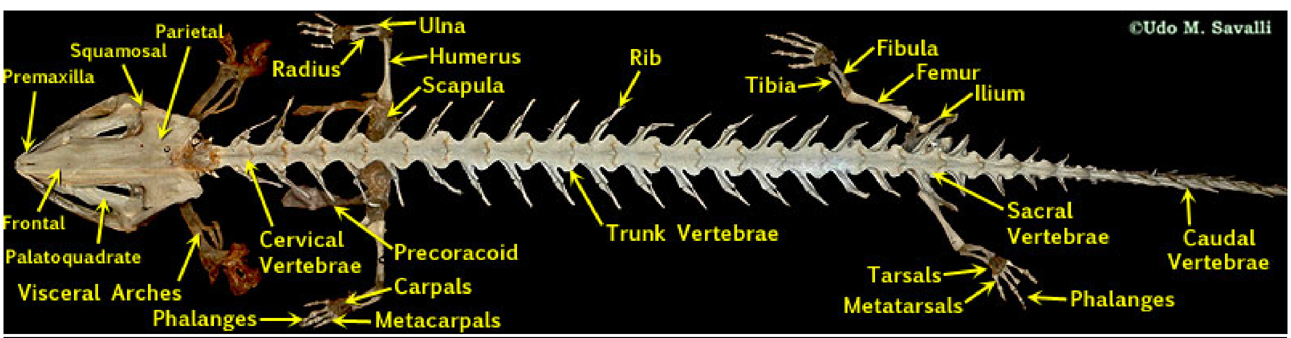
Be able to identify the following structures in salamanders (*Necturus*): **atlas, thoracic/trunk vertebrae, sacral vertebra, caudal vertebrae, centrum, neural spine, neural arch, hemal arch, ribs, coracoid, scapula, humerus, radius, ulna, carpals, metacarpels, phalanges, pubis, ischium, ilium, femur, tibia, fibula, tarsals, metatarsals, phalanges**, as well as the following structures in anurans (*Rana*; see figures below): **atlas, thoracic vertebrae, sacral vertebra, centrum, neural spine, neural arch, ribs, sternum, coracoid, scapula, suprascapula, humerus, radioulna, carpals, metacarpels, phalanges, pubis, ischium, ilium, urostyle, femur, tibiofibula, tarsals, metatarsals,** and **phalanges**.




Skeleton of a frog (*Rana sp.*) with a magnified, ventral view of the sternum region.




Bullfrog skeleton (figure by U. Savalli)



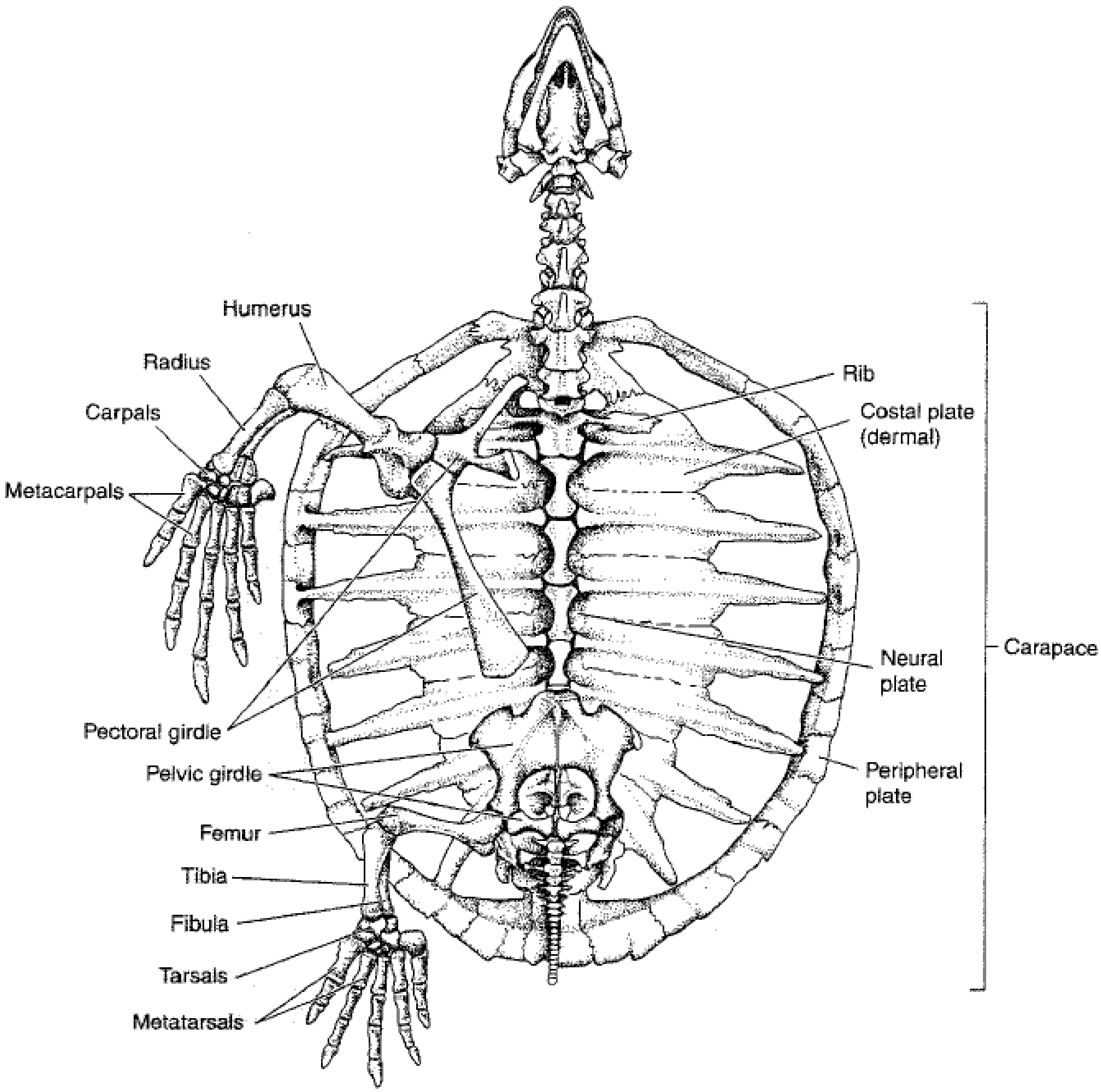

Mudpuppy skeleton (figure by U. Savalli)

**Reptiles (e.g., turtle, snake)** (see notes below)

Focus on the notes below. Examine the prepared skeletons.

Be able to identify the following structures in turtles: **carapace, plastron, atlas, axis, cervical vertebrae, thoracic vertebrae, sacral vertebrae, caudal vertebrae, humerus, radius, ulna, carpals, metacarpals, phalanges, pectoral girdle, femur, tibia, fibula,** and **phalanges**.

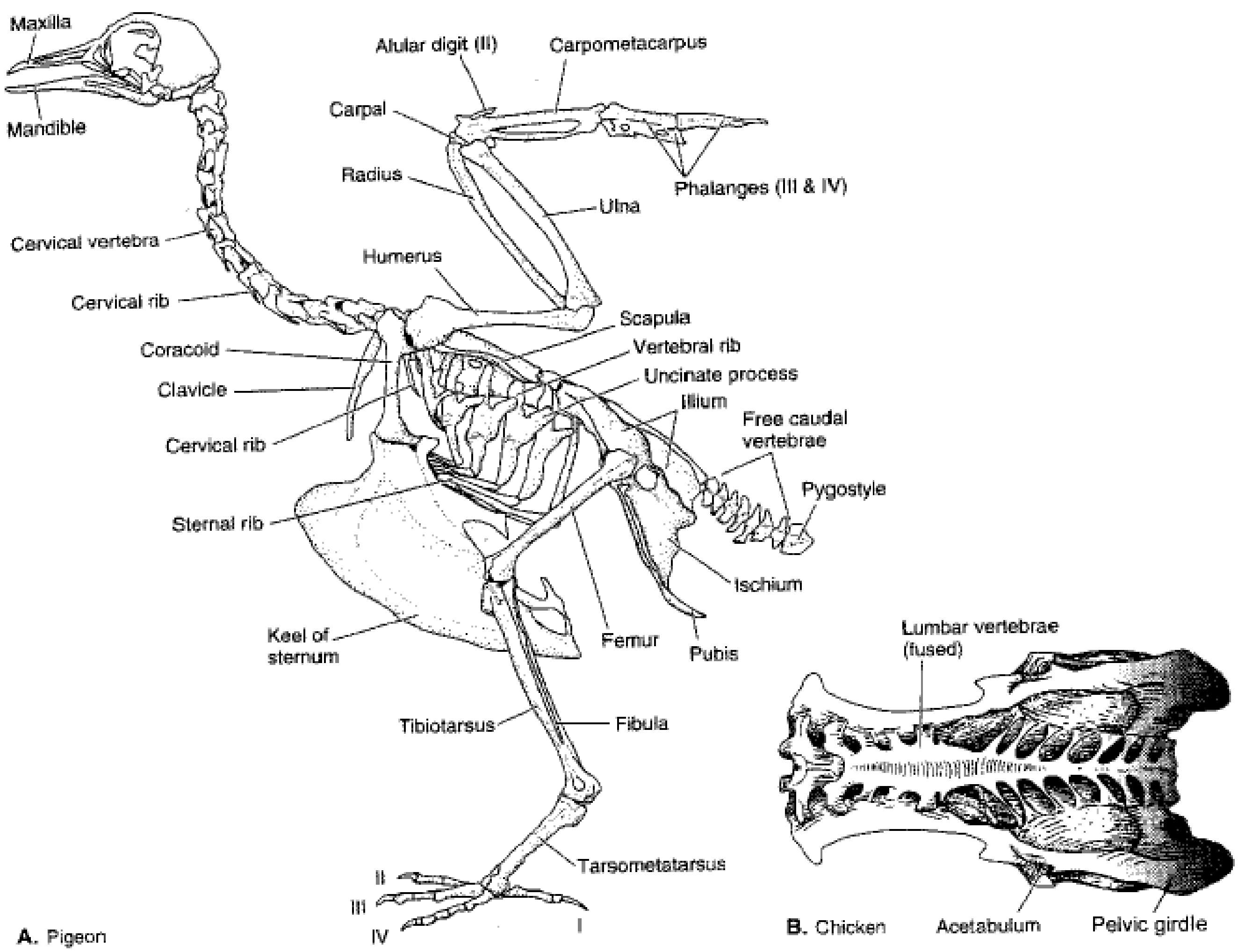
Be able to identify the following structures in snakes: **atlas, axis, thoracic vertebrae, ribs,** and **caudal vertebrae**.




Skeleton of a sea turtle.

# Aves

Be able to identify the following structures: **atlas, axis, cervical vertebrae, thoracic vertebrae, uncinate processes, ribs, lumbar vertebrae, sacral vertebrae, caudal vertebrae, pygostyle, scapula, foramen triosseum, coracoid, furcula, sternum, carina, femur, tibiotarsus, fibula, tarsometatarsus, phalanges, humerus, ulna, radius, carpometacarpus, phalanges, ilium, ischium,** and **pubis**.



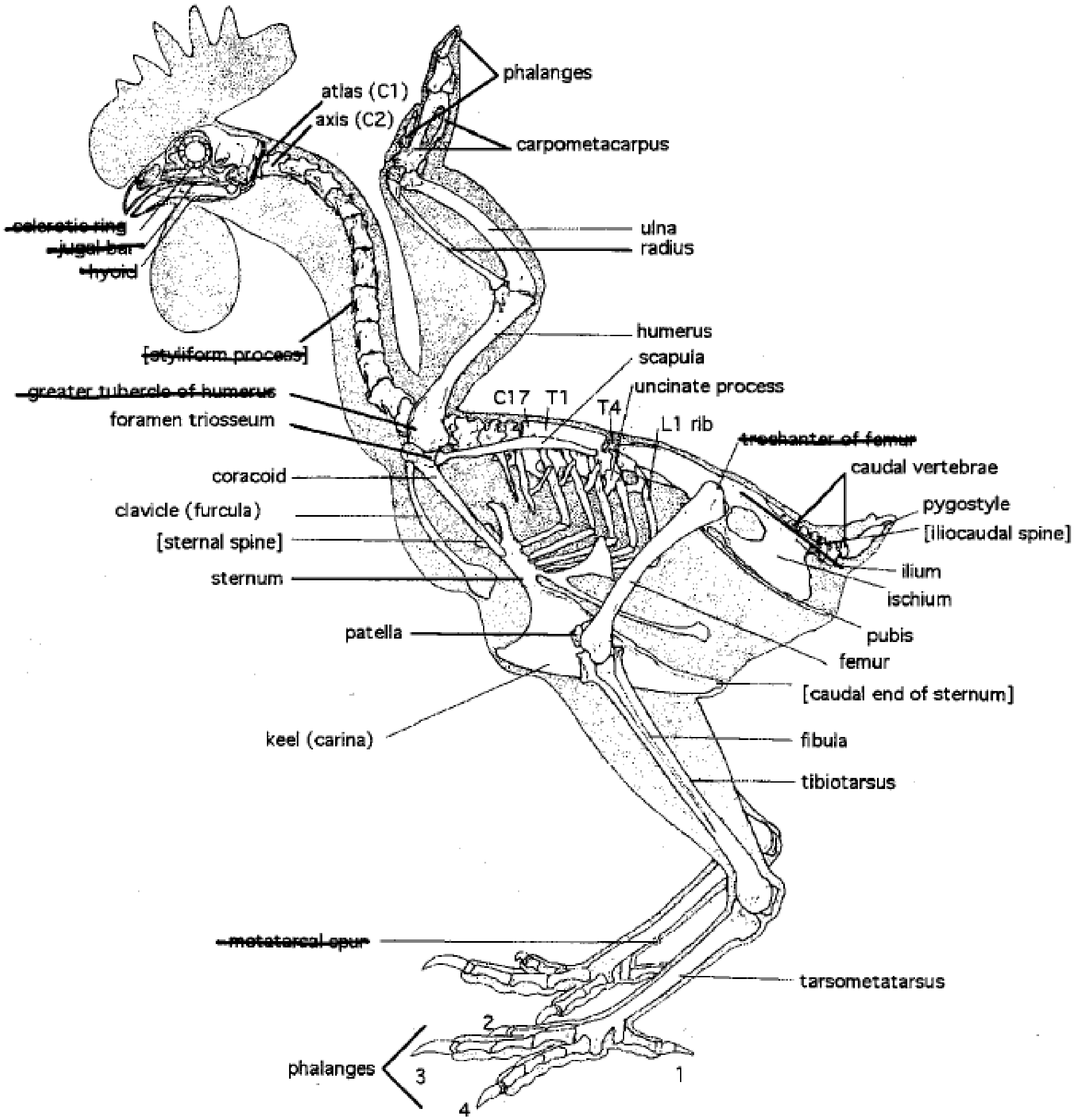



Figure 4-4. Skeleton of a bird (*Gallus* species).

**Mammals** (pp. 297-308)

Focus on the terms and bones identified on the figures in the notes below, and be able to identify the following vertebral structures (pp. 299-300): **spinous process, vertebral canal, centrum, odontoid process** (axis), **prezygapophysis, postzygapophysis, transverse process, transverse foramen** (cervical vertebrae), **hemal arch** (caudal vertebrae), **demifacet** (thoracic vertebrae), **articular facet** (thoracic vertebrae), **pleurapophysis** (lumbar vertebrae), **accessory process** (lumbar vertebrae), and **mamillary process** (lumbar vertebrae).

Be able to identify the following structures in cats: **atlas, axis, cervical vertebrae, thoracic vertebrae, lumbar vertebrae, sacral vertebrae, caudal vertebrae, scapula, humerus, radius, ulna, carpals, metacarpals, phalanges, ribs, femur, patella, tibia, fibula, tarsals, metatarsals, phalanges, sternum,** and **scapula**.

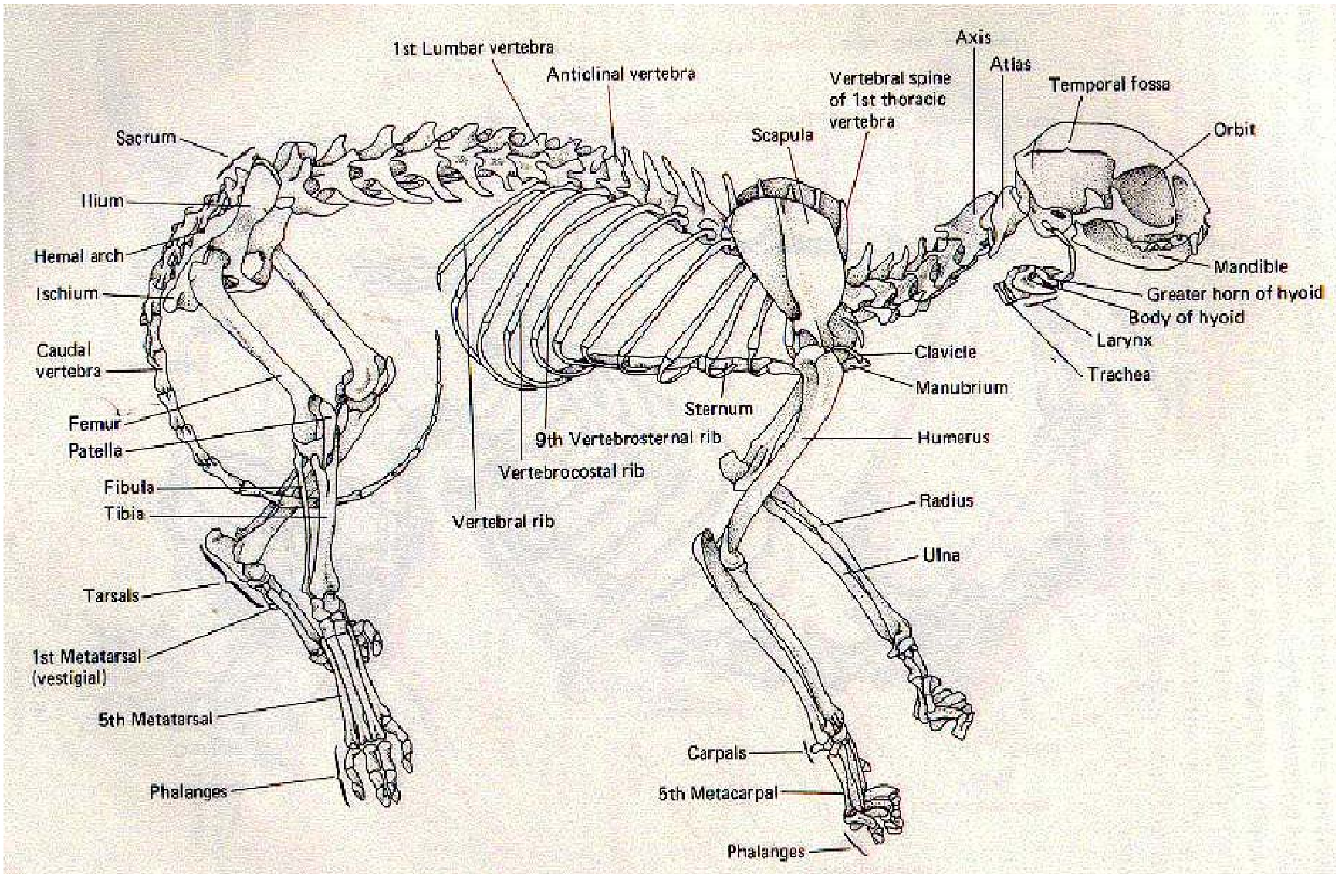
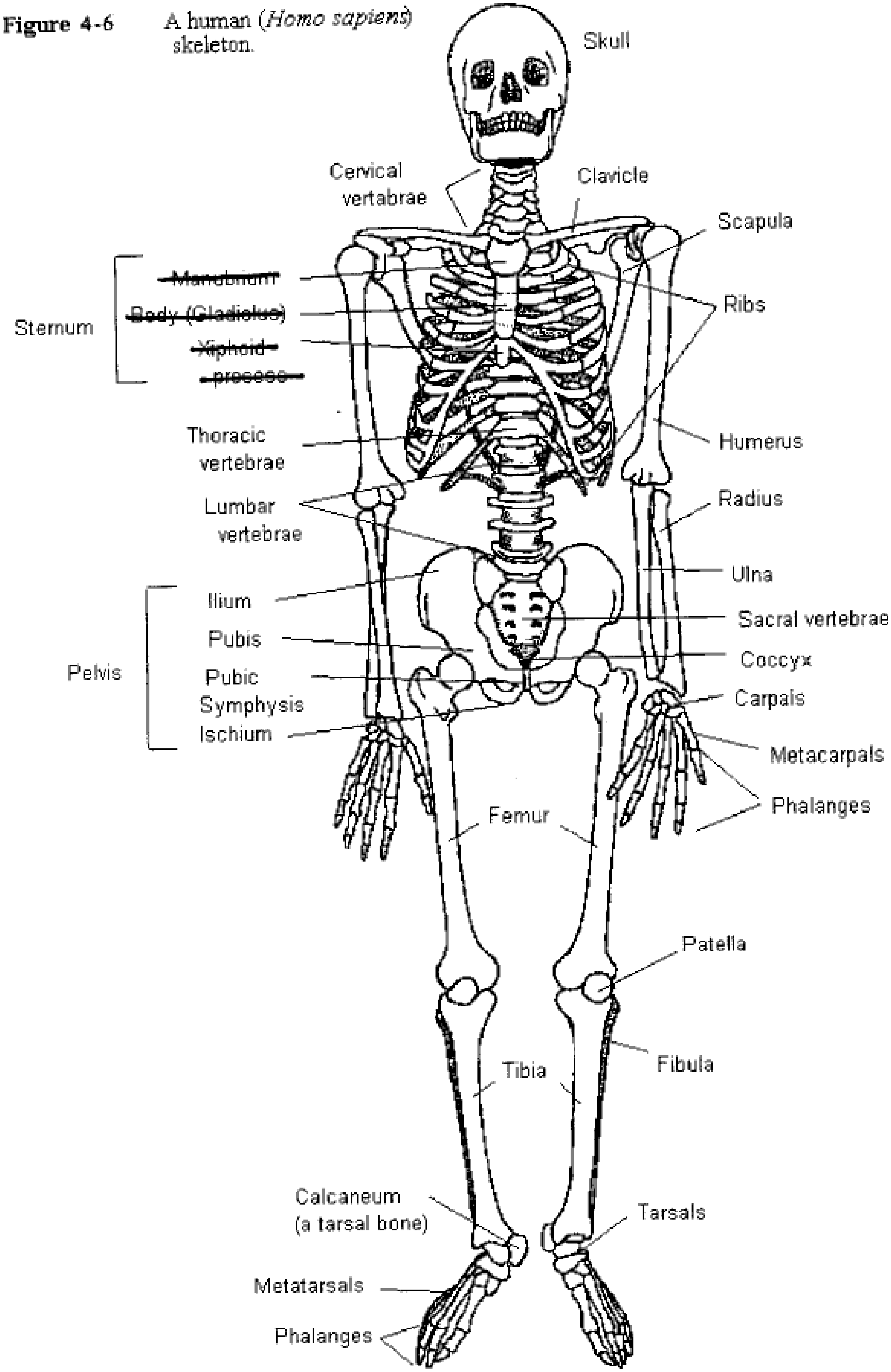



**Figure 5-5**
Lateral view of the skeleton of the cat. *(From Walker,* A Study of the Cat.*)*

Be able to identify the following structures in humans: **atlas, axis, cervical vertebrae, thoracic vertebrae, ribs, lumbar vertebrae, sacral vertebrae, caudal vertebrae, coccyx, scapula, clavicle, sternum, illium, pubis, ischium, humerus, radius, ulna, carpals, metacarpals, phalanges, femur, patella, tibia, fibula, tarsals, metatarsals,** and **phalanges.**

Be able to identify the **epipubic bones** on the duck-billed platypus. What is their function?

**Figure 4-6** A human (*Homo sapiens*) skeleton.



# The Axial Skeleton

## Purpose:

Understand the basic components that comprise the axial and appendicular skeleton in Craniates
Understand the broad evolutionary forces shaping the these elements in a phylogenetic context
Learn structural differences between the represented classes of Craniates

## Introduction:

The post-cranial skeleton is comprised of both axial and appendicular elements. The axial skeleton includes the notochord, vertebral column, median fins, ribs and the sternum, while the appendicular skeleton includes the paired fins and limbs and the girdles to which they attach. The axial and appendicular elements of the body, together with the associated muscles work together to both support and move the craniate body. Due to very different forces at work in the water and on land, the craniate skeleton has undergone drastic changes to help facilitate this transition. In the next two chapters we will identify the key skeletal elements of these regions and the evolutionary forces that have shaped them over the course of craniate evolution.

## The Axial Skeleton:

The shape and arrangement of axial elements in craniates is closely linked to an animal's need to support itself. Aquatic craniates tend to have straighter spines in association with the support of hydrostatic buoyancy they receive from their surrounding aquatic medium. Terrestrial vertebrates encounter a greater effect of gravity and show a variety of modifications to their spine in order to support their weight while on land.

While extant Agnathans do not possess calcified vertebrae as adults, all other adult vertebrates possess at least traces of vertebrae. The shape and components of vertebrae vary considerably among species and throughout regions of the body. In basal vertebrates such as sharks, the notochord persists and runs through the center of the vertebral column. In most other vertebrates, the notochord is replaced with disk-like vertebral bodies called **centra**. Successive vertebrae are joined together to form the vertebral column with articulations occurring at these centra. The shapes of the centra have functional implications for movement of the vertebral column (Fig. 4-1). Centra that are concave on both ends are termed **amphicoelous**. The strength of the vertebral column is considerably increased if the union between successive vertebrae resembles a ball and socket. One end of the vertebrae forms a bump that fits into the concavity of the adjacent vertebrae. If the anterior (cranial) surface of the centrum is concave, the centrum is **procoelous**; if the posterior end is concave, the centrum is **opisthocoelous**. If both surfaces of the centrum are flat it is termed **acoelous**. Birds display a unique centra shape teremed **heterocoelous**, where the ends are saddled-shaped.

In addition to the shape of the centra, the vertebral columns of some teleost fishes and most mammals have additional processes called **zygapophyses** that increase the resistance to twisting. These extend both backwards and forwards from the neural arches of the individual vertebrae. In this way, the posterior zygapophyses of one vertebra articulate with the anterior zygapophyses of the next posterior vertebrae in series within the vertebral column. Additional processes specific to certain classes of vertebrates will be discussed below as will the variations in both rib and sternum structure.

In most amniotes, individual vertebrae can be distinguished based on their position within the vertebral column. **Cervical** vertebrae are found in the neck, identifiable by the lateral transverse foramina; **thoracic** vertebrae have facets to support ribs; **lumbar** vertebrae support the lower back, have large transverse processes, and are rather robust in most mammals; **sacral** vertebrae help support the pelvis and are typically fused into a characteristic shape; and **caudal** vertebrae are found in the tail, identifiable by the presence of **hemal crests** or **processes** (the ancestral remnant of hemal arches, well developed in fish, many amphibians and reptiles) through which the caudal artery and vein pass into and through the caudal region. Additionally, the most anterior vertebra is slightly modified to articulate with the skull. It articulates at the position of the occipital condyles. The first vertebrae of amphibians and mammals articulates with **two** occipital condyles on the skull, while the first vertebrae of reptiles and birds articulates with a **single** occipital condyle.

### Jawless Fish (e.g., Lamprey)

The major postcranial modification of the earliest craniates that differed from their protochordate ancestor was the presence of a notochord running the length of the animal from head to tail. This can most clearly be seen in our preserved specimen of the lamprey. The notochord itself resembles the vertebral column and extends the length of the animal.

### Chondrichthyes (e.g., shark)

Chondrichthyans possess a notochord that runs the length of the vertebral column through its centra. They are the earliest examples of extant vertebrates with true, segmented vertebrae. **Their vertebral centra are amphicoelous.**

### Gnathostome Fishes (e.g., bowfin and perch)

Depending on the group, a notochord or its remnants may be present. In general, the early osteichthyans and non-teleost fishes possess a notochord. The vertebral column can be divided into trunk and tail vertebrae. The first vertebra is slightly modified for articulation with the skull. The trunk vertebrae are essentially identical, as are the caudal vertebrae. When ribs are present, they help transfer muscular force to the vertebral axis during lateral undulations while swimming. **Most fishes possess amphicoelous vertebral centra.**

### Amphibians (e.g., bullfrog (*Rana catesbeiana*), mudpuppy (*Necturus*))

Amphibians represent the earliest extant examples of the vertebrate transition to land. As they were no longer supported by hydrostatic buoyancy, their vertebral columns evolved a series of processes to help support their body mass. **In many species, the centra are now either procoelous or opisthocoelous**. **However, caecilians, a few frogs, and most salamanders retain the ancestral amphicoelous condition**. Amphibians have well-developed **prezygapophyses** and **postzygapophyses**.

Only dorsal ribs are found in the endoskeleton of tetrapods, corresponding to the dorsal ribs of osteichthyans. Ribs appear best developed in ancestral fossil amphibians, many caecilians and a few species of extant salamanders. In many frogs, including *Rana*, these ribs are fused to vertebrae, and at first glance, may look like enlarged transverse processes. Although a true, somewhat flexible neck was present in extinct amphibians, in extant forms it exists only as a single cervical vertebra, the **atlas**. The atlas articulates with the **two occipital condyles** of the skull, providing a strongly limited hinge-joint. This joint can be used to provide flexion between the cranium and body while leaping (frogs) or while feeding (especially in salamanders, which must elevate the upper jaw to feed). Typically, there is no differentiation between the **thoracic** and **lumbar vertebra**, in which case they are collectively called **thoracolumbar** vertebrae. The nature of the trunk vertebrae allows the spine to flex laterally, but is restricted from flexing dorsoventrally. The notochord or remnants of it are retained in caecilians, salamanders, and a few species of frogs.

## Reptiles (non-avian) (e.g., turtle, snake)

Corresponding to their greater dominance of the terrestrial environment, reptiles evolved stronger axial skeletons than early tetrapods and amphibians. Reptiles also evolved a greater regional differentiation of the vertebral column, and have more cervical vertebra and stronger sacral regions than amphibians.

The centra shape of reptiles is highly variable and species dependant. All reptiles, and those tetrapods derived from them, have an **axis** (CV II) articulating with and posterior to the **atlas**, a feature lacking in extant amphibians. The joint between the atlas and **single occipital condyle** of the skull allows a rotational movement. A notochord or remnants of it persists in some species of reptiles such as the geckos.

Ribs are present in most of the vertebrae of reptiles. In addition to dorsal ribs, many reptiles (e.g. crocodilians) have a set of abdominal ribs called **gastralia** that are of dermal origin. Some reptilian ribs are strengthened by processes called **uncinate processes**. These are also found in birds (see the chicken skeleton). In turtles (Figure 4-3), the bony components of the carapace are simply large plates of **dermal bone** fused to the vertebrae and ribs. The clavicles and interclavicle (both dermal bone) are incorporated into the bony dermal plates of the plastron, and the **pectoral** and **pelvic girdles** are modified to fit within the shell. The turtle's **pectoral girdle** is actually inside its ribs!

## Aves

The axial skeleton of birds is highly modified to correspond with both flight and bipedal walking. The neck has become much longer and flexible and this allows for greater mobility of the head. The centra of avian cervical vertebra have unique saddle-shaped articulating surfaces, and are called **heterocoelous**. This arrangement allows for enhanced dorsoventral flexion while restricting lateral flexion when the neck is folded over in flight. The trunk vertebrae of birds are either thoracic or lumbar. Thoracic vertebrae have thoracic ribs attached, while the lumbar vertebrae lack ribs. Depending on the species a certain number of lumbar and thoracic vertebrae are fused; this fused region can include a single cervical vertebra. The last few lumbar vertebrae, the sacral vertebrae, and the first few caudal vertebrae are all fused as a single unit with the pelvis to form a **synsacrum**. These, in turn, are typically fused to the fused thoracolumbar vertebrae. This results in a rigid anchorage for the pelvis and hind limb. This is important for carriage of the weighty posterior portion of the bird in flight. The last few caudal vertebrae are fused to form a laterally compressed coccyx, usually termed the **pygostyle**; a dinosaurian feature.

**Uncinate processes**, a reptilian feature, project as flat spurs from the caudal border of each rib and overlap the next rib posterior to it. This arrangement strengthens the rib cage, provides more surface area for muscle attachment, and assures synchrony of movement of the ribs during respiration.

The **sternum** is well ossified and highly developed, in contrast to that of nonavian reptiles, and is a variable structure in birds. The sternum is the origin of flight muscles and thus has been modified accordingly. In strong fliers, (e.g. hummingbirds, pigeons), a flange-like process on the **sternum** called the **carina** or **keel**, may be deeper than the width of the sternum. In many flightless birds, (e.g. the ostrich), the **carina** is absent. Consequently, the size of the **carina** is a fair index of power in flight. Since the sternum of birds is large and supports the viscera, there is little development of the abdominal wall musculature or of the **pubis**. The **pubis** can be seen as a thin splint of bone passing from the acetabulum, the socket for the articulation of the femur, posteriorly along the ventral border of the ischium. The loss of strength resulting from the lack of a pelvic symphysis is partially compensated for by the strong fusion of the **ilia** along their dorsal borders with the rest of the **synsacrum**, and along their ventral borders the **ischia**. The sutures in these fused regions may not be visually apparent.

## Mammals

Because most mammals are active, agile creatures, their axial skeletons have evolved to be supportive, yet flexible. With almost no exception, all mammals have **seven cervical vertebrae**. The **atlas (CV I)** articulates with the **two occipital condyles** of the skull. The reptilian rotation-joint between skull and atlas is lost (in mammals it is mostly between the axis and atlas), restricting movement to a nodding motion (dorsoventral flexion) caused by the resulting hinge-joint. The **odontoid process** found on the axis of mammals and most other tetrapods articulates with the atlas and allows for the rotation-joint between it and the axis. Mammals posses all of the vertebrate types (i.e. cervical, thoracic, lumbar, sacral, and caudal). The thoracic vertebrae possess ribs, which articulate with via costal cartilages. The lumbar vertebrae have transverse processes that were embryonic ribs. The sacral vertebrae have fused to form the sacrum. In most mammals, the tail is rather modest in size, and has a myriad of functions that include locomotion, balance, behavioral, etc. In mammals, such as humans, where the tail is not present, the remaining caudal vertebrae have fused to form a **coccyx**.

# The Appendicular Skeleton

**Purpose:**

Understand the basic material that comprises the appendicular skeleton in Craniates
Understand the broad evolutionary forces shaping the appendicular skeleton in a phylogenetic context
Learn structural differences between the represented classes of Craniates

**Introduction:**

The skeletal elements of the appendicular region consist anteriorly of paired pectoral appendages (fins or limbs) and an associated pectoral girdle, and posteriorly of pelvic appendages and pelvic girdles in the hip region. In fishes, the pectoral appendages are usually small fins that aid in maneuverability and stability of the body. As vertebrates made the transition to land these fins evolved into limbs which were necessary for both body support and movement on land. The associated girdles of the shoulder and hip region, while small in fishes, are large supportive structures that help transfer body weight from the axial skeleton to the appendicular skeleton.

## Jawless Fish (e.g., lamprey)

The extant jawless fishes (lamprey and hagfish) have no paired appendages. This was most probably the case for most groups of extinct jawless fishes. They also lack any girdles in the pectoral and pelvic regions.

## Chondrichthyans (e.g., shark)

The pectoral girdle and pelvic girdle of chondrichthyans are composed entirely of cartilage. The girdles are enlarged, extending dorsally and merging ventrally to form u-shaped bridges. The well-developed basal cartilages of the fins are not dermal, but the ceratotrichia are currently considered dermal derivatives. Make sure to examine the specimens in the lab to be able to identified the homologous elements of both girdles with that of other higher vertebrates.

## Osteichthyans (e.g., bowfin, perch)

As with the other portions of the skeleton in osteichthyans, the structure of the pectoral and pelvic girdles is also highly diverse. In this group we are most concerned with how these elements were beginning to change in order to support paired appendages. The endoskeletal cartilages remain as the point of appendage attachment. However, dermal elements have fused to the pectoral girdle to add support. Some of these bones form a connection with the skull and superficially appear as skull elements.

The structure on the fin itself deserves some attention, and is usually the basis for differentiating between taxonomic categories of osteichthyans. The fins of aquatic sarcopterygians are composed of a central axis of bone with branches, and are termed **crossopterygia**. This type of fin is muscular and fleshy. Evidence suggests that crossopterygia are the type of fin from which tetrapod limbs evolved. The first element of the crossopterygian fin is homologous to the humerus or femur (pectoral or pelvic girdle). The fins of actinopterygians (ray fins) are composed of a web of skin supported by horny or bony **rays** that are actually modified scales. The skeleton and flesh do not normally extend into the fin. In the derived actinopterygians, the fin base is narrow and the bony elements are much reduced.

## Amphibians

Both the bullfrog and *Necturus* represent tetrapods with fully developed limbs used to both support and move the body. The girdles of these animals still possess cartilaginous elements consistent with the ancestral condition. Prototypical tetrapod limbs are seen in *Necturus*. The forelimb consists of the **humerus, radius, ulna, carpals, metacarpals,** and **phalanges.** The hind limb consists of the **femur, tibia, fibula, tarsals, metatarsals,** and **phalanges.** The basic tetrapod foot is **pentadactyl** though *Necturus* has lost the first digit.

The limbs and girdles of *Rana* are highly modified for jumping. The paired bones of the forearm and lower hindlimb have fused to form single structures, the **radioulna** and **tibiofibula**, respectively. This fusion greatly strengthens the bones, an adaptation to absorb the shock of landing, leaping and swimming with propulsive kicks. The pectoral girdle of anurans includes the **dermal clavicle** and other elements. It too is strengthened to absorb the shock of landing. Within the pelvic girdle the **ilium** is greatly elongated. The caudal vertebrae are fused into a single unit that is a highly specialized coccyx, called an **urostyle**. This structure articulates with the rest of the spine at the sacroiliac joint, providing more length to the elements that act as levers during a jump. The hind limb is greatly elongated. Uniquely, two tarsal elements, ~~**the astragulus and calcaneum**~~, have enlarged to form a fourth functional segment to this tetrapod limb. (The **calcaneum** is the heel bone of most tetrapods). These bones, plus the very long **digits**, provide a long output lever arm, adding speed to the final movements in a leap (effectively acting like the arm of a catapult). Use the whole skeleton of the bullfrog to visualize these elements.

## Reptiles (non-avian)

Within the reptiles we see further specialization of the paired limbs and girdles as well as the loss of limbs in the snakes and among certain lizards. The limbs of lizards and *Sphenodon* (tuatara) are similar to basic amphibians in that the **clavicles** and **interclavicle** are usually well developed.

Crocodilians also have lost the clavicle, although the interclavicle is present. All snakes have completely lost the pectoral girdle and only some ancestral forms (several families including the Boids) retain the pelvic girdle and spur-like remnants of the femur. Most legless lizards (occurring in several independently derived lineages) retain both limb girdles.

Most extant reptilian species have a **sprawling** posture; the legs extend laterally and the lower legs bend vertically. This position, which is similar to a constant push-up position, requires complex limb girdles to support the heavy muscles necessary for even simple locomotion. Use the complete skeleton of the turtle to locate the bones of both girdles and the paired limbs.

# Aves

The avian skeletal system is an ideal example of functional anatomy and adaptation. All birds are bipedal and winged. The pectoral girdle of birds includes a narrow, bladelike **scapula** parallel to the vertebral column and a stout **coracoid** bone extending to the **sternum** and stabilizing the pectoral girdle. The scapula and coracoid together form the **glenoid fossa** for articulation of the head of the humerus. The elongate scapula is a dinosaurian feature. The well-developed **clavicles** are fused midventrally to form a **furcula** or wishbone. (The furcula has been found recently in some nonavian dinosaurs, such as *Velociraptor*.) In passerine birds (song birds) the furcula is flexible and acts as a spring during wingbeats, adding power from elastic recoil to the beats and aiding in pumping air through the bird's complicated respiratory system as well. The scapula, coracoid, and furcula form the walls of the important **foramen triosseum** in the avian shoulder. Important tendons used for flight pass through the foramen triosseum.

Wings are characterized by a reduction and fusion of the distal elements. You should take time to look at a bird and bat wing to see how the elements of the bird wing have become reduced, while the opposite is true of the bat. The stout humerus fits into the shallow glenoid fossa. In the folded wing, the radius is dorsomedial to the ulna. The **ulna** also may be identified by the **olecranon process**, which forms the distal apex of the elbow. The wrist is greatly reduced, and the hand and digits fused and reduced. Two carpal bones are distinct, while the other carpal elements have fused with the metacarpal elements to form a single, harp-shaped **carpometacarpus**. The half-moon shape of the proximal carpals is a dinosaurian feature that allows flexibility for flapping. Apparently, only the **phalanges** of only the first, second, and third digits remain. The exact number of these digits is disputed and may represent the second, third, and fourth digits.

The bones of the wing, along with the other bones of the skeleton have had to reduce their density while maintaining their strength. This has been accomplished through a reduction in marrow and bone and their replacement with internal struts and ridges along stress lines. Additionally air sacs run throughout many of the long bones of the bird. These **pneumatic channels** are in direct communication with respiratory passageways and potentially increase respiratory capacity while reducing, or perhaps redistributing body weight. These **pneumatic bones** make possible an increase in bone size for greater muscle attachment without a coincident increase in mass. As a generalization, the more efficient flying birds have many pneumatic bones, whereas flightless birds have few. **Pneumatic bones** in birds are an ancestral feature; the bones of many nonavian dinosaurs share the same morphology despite the fact that they did not fly. Take care to look at some of these pneumatic bones in the lab. Notice those that belong to flyers and compare them to those of non-flying species such as the chicken.

Due to the bipedal stance of birds, their pelvic girdles have evolved into extremely strong structures. The legs and girdle support all the body weight. Notice how the pelvic bones are all strongly united. The pelvic limb skeleton of a bird consists of a **femur, fibula, tibiotarsus, tarsometatarsus,** and the **phalanges**. Birds do not possess the distinct, separate tarsal bones that characterize other tetrapods. The major region of hindlimb flexion in birds is between tarsal elements, or intratarsal, and not proximal to the tarsals as in most tetrapods. This same condition, called the **mesocrusal ankle**, was also present in nonavian dinosaurs. An additional feature shared by birds and dinosaurs is the **bipedal, parasagittal stance**. The **patella** rests on the anterior surface of the knee joint. Most of the features of the avian hindlimb are shared with their nonavian dinosaur ancestors. Additionally, the fenestrate acetabulum of the pelvic girdle is dinosaurian.

# Mammals

The appendicular skeleton in mammals reflects the new position of the limbs in relation to the body. The dermal **clavicles** persist in most mammals, but may be reduced to a mere sliver of bone for muscle attachment in cursorial (running) species. This condition is present in the cat where the clavicle has been reduced to a vestigial piece of bone. Consequently, this allows free rotation of the **scapula** and increases the stride length. Increasing the length of the scapula can increase stride length in cursorial mammals as well. The reptilian interclavicle and coracoid remain only in monotremes.

The pelvic girdle of mammals is of similar composition to that of reptiles, although its proportions may differ. In contrast to extant reptiles, mammal limbs typically do not spread out in a sprawl, but are **parasagittal**, positioned directly under the body, perpendicular to the ground. Many marsupialshave an extra set of bones attached to the pelvis, termed **epipubic bones**. These unusual, dermally derived bones have the dual functions of supporting the **marsupium** (brood pouch) and muscles associated with the **femur**. You can see these bones on the skeleton of the platypus.

The basic vertebrate limb evolved as the first amphibian like fish left the warm seas for the new dry land. It is called the pentadactyl limb, from the Greek *penta* for five because it ends in five digits or phalanges. Though the fore and hind limbs are basically the same they have different names for the various bones. The lower part of both limbs consists of a pair of bones running parallel to each other. The Forearm consisting of the Ulna and Radius and the Shin consisting of the Fibula and Tibia. This arrangement allows for greater flexibility and stronger turning/twisting movements than a single bone would. This is not remarkable in some mammals which only use their limbs for walking on, but for those who use their limbs, particularly the fore limbs, for grasping, climbing and or digging it is of great value and has contributed greatly to the diversity of mammals.