

# 10

## Analysing Osteological and Other Faunal Remains

In some archaeological sites, the bones, shells, and other relatively robust remains of animals constitute one of the most completely preserved classes of macroscopic archaeological materials. Because they are often preserved better than plant remains, they have attracted considerable attention from archaeologists hoping to reconstruct the natural environments, hunting and herding behaviors, and dietary preferences of prehistoric people, and the season in which their settlements were located.

As with other chapters in this book, the limitations of an introduction require omission of many topics that would appear in a thorough reference. Although the osteological study of ancient humans has much in common with that of non-human mammals, in this chapter we will focus on comparing the latter with birds, and introduce only the most common types of fish and mollusc remains. The processes by which human remains accumulate in archaeological sites (often intentional interment) differ, in most but not all cases, from those responsible for the distribution of faunal remains. Research on human burials, furthermore, usually has quite different research goals than research on archaeological fauna. Human remains also entail ethical issues that are better dealt with in courses on physical anthropology. For detailed treatment of human remains see Brothwell (1981), Roberts and Manchester (1995), and Ubelaker (1989).

There are many labels attached to archaeologists who study the surviving evidence of an-

imals. Some texts refer to them as zooarchaeologists, others as archaeozoologists, still others as faunal osteologists, faunal osteo-archaeologists, or simply faunal analysts.

### Types of Faunal Remains

It is tempting to jump to the conclusion that an analysis of faunal remains is an analysis of bones. In fact, bones are only one of the categories of fossils that zooarchaeologists analyse. Although bones are often the best preserved and most obvious fossil evidence of animals with bony endoskeletons, it is sometimes also possible to detect and recover fragments of cartilage, skin and hair, muscle tissue, certain stomach contents, and coprolites (fossil feces), especially in sites that are waterlogged or very dry. Teeth may be preserved much more reliably than bone in typical site environments. In some sites the fragmented shells of birds' eggs may occur (Keepax, 1981). Meanwhile insects sometimes leave parts of their exoskeletons, parasites have left eggs, while snails and various sea animals leave shell, and some animals leave antler, hoof, or horn. Insects and worms may even leave distinctive traces of tunnelling or nests. Some archaeologists have attempted to identify pastoral sites on the basis of microscopic **phytoliths** and **spherulites** from plants that are deposited on sites in the animals' manure. A very productive line of research is to identify the mineral concretions called **otoliths** (ear-stones) from fish. This chapter, however, will emphasize the analysis of bone, teeth, otoliths, and mollusc shell.

## Taphonomy and Faunal Assemblages

As with other classes of archaeological remains, it is important to remember that the sets of fossils that archaeologists study are not equivalent to the sets of either bones or animals that existed in the past. Archaeologists do not directly study past populations of animals; instead they study modern samples of bones and bone fragments. Not only does this force us to pay attention to the quality and size of the sample (see chapter 4), but we must think about the ways in which our modern sample became a distorted remnant of the original past population. It is useful to view this as a sequence of selections that gradually reduced the large original population of living creatures to a sample of their remains.

**Taphonomy** is the study of the processes by which living animals in the biosphere are transformed and eventually become (through fossilization) part of the earth's rock or lithosphere (Efremov, 1940; Gifford, 1981; Lyman, 1994). Taphonomists try to strip away the "biases" in a fossil assemblage in the hope of reconstructing the structure of the population of animals at the time they died. By studying factors that concentrate or destroy bones in modern environments and in laboratories, they attempt to understand these biases. Taphonomy has much in common with the study of what Schiffer (1976; 1987) would call site-formation processes. Taphonomic research includes various kinds of geoarchaeological, analogical, and experimental work, including moving bones by water flow through a laboratory flume (e.g., Hanson, 1980), ethnoarchaeological observations of recent scavengers, hunters, and butchers (Binford, 1978; 1981; Brain, 1975; 1976; 1981), and experiments with bone trampling and dog consumption (Gifford, 1981; Payne and Munson, 1985). Taphonomic processes are the actions whose forces modify the physical characteristics and distribution of animal carcasses and tissues, while a taphonomic effect is the trace of such a process (Lyman, 1994: 35).

Modern zooarchaeologists now distinguish among a number of quite sets of fauna, only one of which is normally directly observable. Klein

and Cruz-Uribe (1984: 3), following Clark and Kietzke (1967), Meadow (1980) and others, propose the following distinctions.

1. The **life assemblage**: This is the living community of animals, a population from which the fossils are ultimately derived.

2. The **death assemblage**: This is the population of carcasses that results when members of the life assemblage die. Except when there is a catastrophic kill of the whole community, we would not expect the proportions of animals of various ages, sexes, and health status in this assemblage to be the same as in the life assemblage for the simple reason that death is not equally probable for animals of different age or health. This is the population whose size ( $N$ ) the Peterson estimator (chapter 5) estimates.

3. The **deposited assemblage**: This is the set of carcasses or body parts that are deposited on an archaeological site through the action of humans, non-human predators, and scavengers such as hyaenas, rats or owls, and other agents of bone-accumulation (e.g., water flow, gravity, erosion).

4. The **fossil assemblage**: This is a subset of the deposited assemblage, consisting of those animal parts that survive in the site's deposits until found by a modern researcher. Environmental conditions, such as pH of the surrounding sediments (see chapter 12), have a substantial effect on the character of this assemblage. In terms of sampling, this (or some spatial volume that encloses it) is the population that archaeologists sample (see chapter 4).

5. The **sample assemblage**: This is the portion of the fossil assemblage that was excavated or collected and then analyzed (in fact, the sample assemblage is sometimes only a portion of what was excavated). Archaeologists' field and laboratory methods have a great impact on the character and size of this sample.

At each stage from the life assemblage to the sample assemblage, the absolute number of bones and other animal remains decreases and, even more importantly, the distribution of remains by sex, age, body part, and health status changes. Both diseases and hunting behavior

select victims unequally; bone accumulators, including humans, preferentially bring certain animal parts to a location, and the work of scavengers and various natural agents (e.g., chemical leaching, erosion, trampling) destroys some kinds of bone more easily than others. Finally, the behavior of the modern researchers, including how carefully they excavated, inspected, or screened the sediments (Clason and Prummel, 1977; Payne, 1972a), affects the likelihood that certain kinds of bones in the fossil assemblage (and particularly very small ones) will get into the sample assemblage. As with archaeobotanical work, zooarchaeologists spend a great deal of time worrying about how to compensate for the effects of poor preservation, principally fragmentation, during the transition from the deposited assemblage to the fossil assemblage.

### Animal Taxonomy

Carl von Linné, an 18th-century anatomist, developed the basic structure of the taxonomic classification of organisms that biologists still use. All organisms are classified in a hierarchy with **kingdom** at the first level, down through the levels **phylum** (or division), **class**, **order**, **family**, and **genus** to **species** and sub-species. In the kingdom, Animalia (the other kingdoms are Protista and Plantae), Mammalia is a class of the phylum, Chordata (animals possessing a spinal chord). Because there is an evolutionary, that is, historical, basis for the hierarchy in this taxonomy (although von Linné was himself ignorant of the evolutionary history), the taxonomic relationships mimic relationships of descent. Animals descended from the same ancestor tend to share quite a few characteristics. This is very helpful to zooarchaeologists trying to identify animals on the basis of fragmentary evidence. Even when they do not have enough evidence to identify a fossil to species, often they can at least narrow down the possibilities to a given genus (plural, genera) or family because of these familial similarities. The taxonomic category to which we assign a particular animal or bone is called its **taxon** (plural, taxa), whether that is a species, genus or more general category.

### Mammalian Anatomy

Through common evolutionary descent, all mammals (members of the class, Mammalia) have largely the same skeletal anatomical parts, even though their skeletons vary in the total number of bones. For describing parts of skeletons, zooarchaeologists employ the same segmentation rules and analytical elements that zoologists use (see figure 10.1). In addition to the names for whole bones and teeth, there are also terms for their parts and various surfaces: **epiphysis** (bone end) and **diaphysis** (bone shaft or centrum), **proximal** and **distal** ends (toward or away from the body), **medial** and **lateral** position (near or away from the midline), **anterior** and **posterior** (roughly "front" and "rear"), **dorsal** (toward back) and **ventral** (toward stomach), and **buccal** (cheek-side) and **lingual** (tongue-side) for the mouth and teeth. But there are also names for groups of bones within the structure of the skeleton. Conventionally, biologists divide the skeleton into the **axial** (skull, vertebral column, ribs, and sternum) and **appendicular** parts. Appendicular includes the fore-limbs, hind-limbs, **pectoral girdle** (shoulder region), and **pelvic girdle** (hip region).

Although this is the basic system of segmentation rules that zooarchaeologists use, where we have some information about butchering practices, as in historical archaeology, it is sometimes useful to supplement it with the butchers' system of segmentation. For example, in recent times in England a butcher would subdivide a pig's carcass into such portions as loin, belly, shank, forehock, and gammon (Davis, 1987). Data organized by segments such as these is sometimes more informative about past butchering activity than those organized in the standard zoological manner.

Bone and cartilage are the supporting tissues in vertebrate organisms. Bone is a living tissue that consists of cells and their products, blood vessels, and nerves. The inorganic materials that the cells deposit include calcium phosphate ( $\text{Ca}_3(\text{PO}_4)_2$ ), calcium carbonate ( $\text{CaCO}_3$ ), magnesium, fluorine, chlorine, and iron. These are the materials that sometimes survive in fossil assemblages long after the organism is dead

and most of the organic constituents have decayed away. In addition, the fossilization process itself deposits minerals while gradually converting the bone into a stone. Bone cells also deposit fibrous protein material, similar to that found in cartilage, of which collagen is very important. All red and many white blood cells are produced in the long bones. Cartilage is durable and generally more flexible than bone. It consists of cells in a matrix of protein, carbohydrates, and fibres.

Bone is formed by **ossification** over the lifetime of a vertebrate animal. Early in the animal's life, the "bones" are in fact composed entirely of cartilage. Ossification begins midway between the proximal and distal ends of the bone and later occurs at the two epiphyses. The bone-forming cells remain alive within the matrix materials that they secrete, and the first bone that they form is spongy (*cancellous*), but is later replaced by more compact bone tissue as concentric layers of bone are deposited on the inside surface of channels along the *periosteum* (outside of the bone). The channels thus become narrowed over time, forming canals through which lymph and blood vessels run. Once bone has stopped growing, the bone-forming cells occupy cavities in the bone, where they maintain the bone. The central cavity of long bones contains marrow (Lyman, 1994: 72-78).

Antler is an outgrowth of bone and is structurally similar to long bone. The outer cortex is compact and bone-like, but the inner part is similar to cancellous bone, rather than marrow-filled. Following seasonal growth, antler ossifies and is shed annually.

Horns, on the other hand, are instead an outgrowth of epithelial tissue, like skin. Horn is made up of a fibrous material, called keratin, also found in hooves and claws. The horn grows as keratin is laid down in layers over the horn-cores, which are protuberances of cancellous bone that project from the skull. Consequently, horns tend to have distinct layers of fibrous material that can flake off during burial. Rhinoceros horns do not have horn cores.

In common speech we tend to think of the teeth as part of the skeletal system, but they are actually part of the digestive tract and not bones

at all, having been formed from tooth "buds" formed in the epithelial tissue that lines the mouth. They are composed of dentine, enamel, and cementum, with a central nerve cavity. Elephant ivory is almost entirely dentine (the enamel only occurs on the tips of the tusks of young elephants).

### Axial Parts

The axial skeleton consists of the skull, vertebral column, ribs, and sternum.

The skull is constructed of the cranium, which protects the brain, and facial bones that shape and protect the eyes, nose, and mouth. Normally, in adults, only the mandible is movable, the *sutures* in the cranium being immovable joints. At the base or back of the skull, the *foramen magnum* is an opening that permits the spinal chord to enter. Near it, two bony projections called *occipital condyles* serve much as hinges on the *atlas* and *axis* at the top of the spinal column. With two condyles we can nod our heads up and down. The dome (*calvaria*) of the skull contains a frontal bone, left and right parietal bones, left and right temporal bones, an occipital bone, sphenoid bone, and ethmoid bone. The face includes two maxillae (upper mouth), a mandible (jaw), two zygomatic (cheek) bones, and two nasal bones, among others that are not visible.

The vertebral column consists of a stack of vertebrae (sg., vertebra), separated by intervertebral discs made of cartilage, that protect the spinal nerve and provide support for the animal's weight. Conventionally, we segment the vertebral column into cervical (neck), thoracic (upper back), lumbar (lower back), sacral (hip area), and caudal (tail) regions. Although they vary in detail, each vertebra has a body, on which the discs rest, and a vertebral arch, which encloses the spinal canal or foramen and is surrounded by processes that radiate out from it, including the transverse processes and the spine. The transverse processes are attachments for muscles and, in the thoracic vertebrae, ribs. Openings allow nerves to branch out from the spinal chord to various parts of the body.

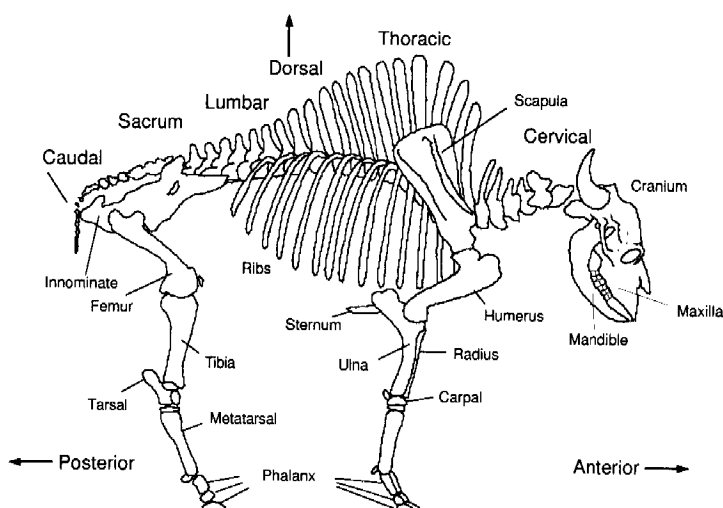


Figure 10.1. Right lateral view of the skeleton of a North American bison (*Bison bison*), to illustrate the major skeletal parts of ungulates (after Lyman, 1994:88). The fibula is hidden behind the tibia.

Given that the sternum and ribs function mainly as protection for the heart and lungs and to aid breathing, it is not surprising that they are important in mammals.

### Appendicular Parts

The pectoral girdle consists of the scapula (shoulder blade), which serves as a broad attachment for muscles, and sometimes the clavicle (collar bone) and coracoid (as in birds).

The forelimb consists of the humerus, radius, and ulna, carpals, metacarpals, phalanges, and sometimes sesamoids.

The pelvic girdle (innominate) consists of the two ilia, two ischia, and two pubis bones, all fused together and joined to the sacrum (fused sacral vertebrae) in the vertebral column. The males in some species also have a baculum (penis bone).

Each hindlimb consists of the femur (pl., femora), patella, tibia and fibula, tarsals, metatarsals, and phalanges.

### Teeth

Mammals typically replace their deciduous (primary) teeth only once, having to make do with their permanent teeth through their adult lives. Mammal teeth include incisors, canines, premolars, and molars.

A mammal's tooth consists of the crown, exposed above the gum, and the root. The surface on the crown that makes contact with its opposite during chewing is called the occlusal surface, which itself has one or more projections called cusps. Enamel covers most of the crown in most species, but is absent, for example, on the lingual side of rodents' and rabbits' incisors. It is generally the cusps that are most helpful in identifying the animal to which a tooth belonged.

### Anatomy of Birds

Birds belong to the class, Aves. Although the overall skeletal structure of birds is similar to that of mammals, and they have many bones in common, avian skeletons also have unique features and features they share with reptiles, especially the subclass Archosauria, which includes dinosaurs and crocodiles. Among these are features that allow them to run on their hind legs, leaving the forelimbs available for evolution into wings (figure 10.2). As a further aid to flight, the skeleton is lightened by pneumatization. This means that many bones are hollow and contain air sacs (Bellairs and Jenkin, 1960:243, 289-93). Most of the zoological literature on avian skeletons is old and widely scattered (e.g., Fürbringer, 1888; Shufeldt, 1909), but there are some recent guides for archaeologists working in western Europe and North America (Cohen and Serjeantson, 1986; Gilbert et al., 1981; Olsen, 1972).

The avian skull has several reptilian and other unusual features. In some birds there is a craniofacial joint that allows the upper jaw, and not only the lower one, to move relative to the braincase. To accommodate their eyes, birds usually have extremely large orbits that rarely form full circles (King and McLelland, 1984:46). Instead, there is a ring of 10 to 18 tiny, overlapping bones, *scleral ossicles*, to provide stiffer support for the eyeball (Bellairs and Jenkin, 1960:288). Birds' tongues actually have a skeleton, or *hyobranchial apparatus*. This apparatus allows birds to probe into narrow spaces for food. Birds, with only one *occipital condyle*, can turn their heads almost full-circle.

In the axial skeleton, there is much variation in the number of vertebrae but the actual number in each portion of the column is often uncertain because of widespread fusion of vertebrae and the difficulty of distinguishing cervical from thoracic vertebrae (King and McLelland, 1984:51). Thoracic, lumbar, sacral, and anterior caudal vertebrae are frequently fused, making the trunk very rigid to support birds in flight. The cervical vertebrae compensate by being generally more numerous and more mobile than in mammals. Unlike most vertebrates, the articular surfaces of the vertebrae are saddle-shaped, with the anterior surface concave in the transverse but convex in the dorso-ventral plane, and are arranged in a way that allows the anterior part of the neck to move mainly in a forward direction, and the middle part backward, so that the neck tends to be S-shaped (Bellairs and Jenkin, 1960:249; King and McLelland, 1984:52). All the cervical vertebrae except the atlas have ribs or vestiges of ribs, mainly fused with the vertebrae, but sometimes the last one or two vertebrae have long and movable ribs articulated with them. The thoracic ribs, as in some reptiles, have *uncinate processes*, small bones at an angle to the ribs that provide extra muscle attachment. In flying birds and penguins, the sternum usually has a pronounced keel (*carina*) that strengthens it with a cross-section like a steel girder and provides muscle attachments for large pectoral muscles. Finally, there are often five to eight free caudal vertebrae and up to ten fused elements that form an upturned rump-post, or *pygostyle*, for moving the bird's tail feathers.

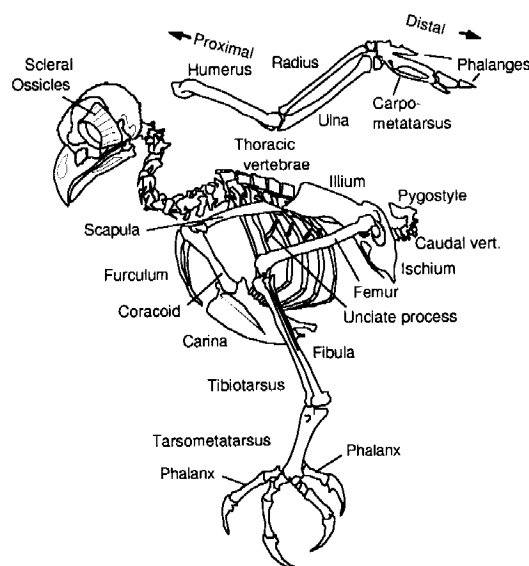


Figure 10.2. Avian skeletal elements illustrated with an owl, *Bubo bubo*, with wings and one leg removed, and, upper right, left wing of swift (*Micropus apus*)(redrawn after Bellairs and Jenkin, 1960).

The pectoral girdle and forelimbs are usually adapted for flying. The girdle is strong to deal with compression stresses during flight, and the coracoids and clavicles (often fused into a furculum or "wishbone") act as struts that hold the wings away from the sternum. The scapula is usually long. A bird's wings are supported mainly by the "arm" bones — the humerus, radius, and ulna — rather than the "hand" bones that are important in the wings of bats and pterosaurs (Bellairs and Jenkin, 1960:255). The proximal end of the humerus is flattened and has two prominent crests for muscle attachment. The ulna generally shows small knobs where quills of feathers are attached. Fusion of distal carpals with three of the metacarpals creates the compound structure known as the *carpometacarpus*.

The pelvic girdle and hindlimbs are similar to those of some dinosaurs. The sutures between pelvic bones tend to disappear, while the ilium is fused to the synsacrum, the whole thus becoming a rigid structure that carries the bird's weight when it is walking. In most birds the ilium and ischium do not meet ventrally in a symphysis. This makes the pelvic outlet more open, allowing the passage of hard-shelled eggs

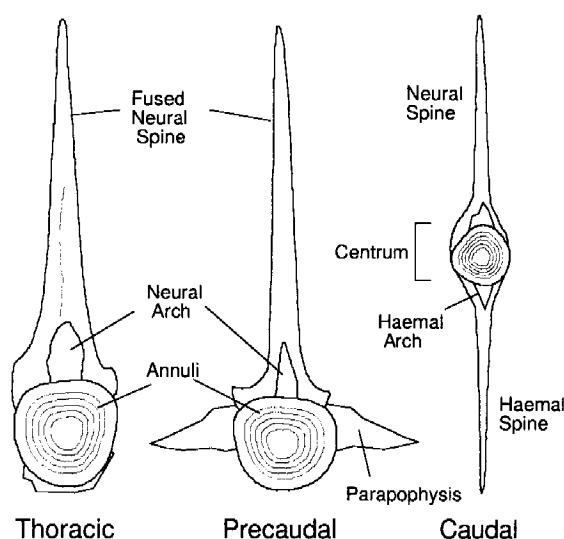


Figure 10.3. Generalized anterior view of thoracic, precaudal, and caudal vertebrae of bony fish.

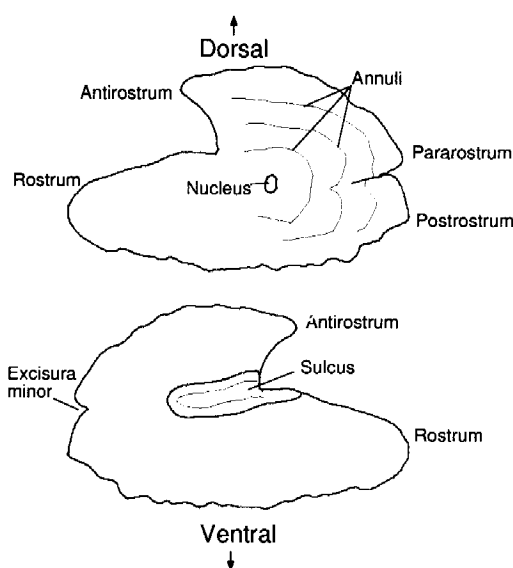


Figure 10.4. Anatomy of a sagittal otolith, in lateral (top) and medial (bottom) views (after Casteel, 1976:22).

in females. The *acetabulum*, into which the head of the femur fits, is completely perforated instead of a cup-like socket, and a facet on the ilium, above the acetabulum, prevents the femur from pushing through when there is weight upon it. The more distal parts of the hindlimb include the *tibiotarsus* (fusion of tibia with the proximal tarsal bones), with an anterior extension called the *cnemial process*, and fibula (usually much reduced in size), sometimes a patella, and a *tarsometatarsus* (fusion of distal tarsal bones with elongated metatarsals). Because the distal end of the last is made up of three fused metatarsals, it branches into three pulley-shaped processes called *trochleas* (Bellairs and Jenkin 1960: 263). Sometimes (as in fighting cocks) there is also a spur on the inner side of the tarsometatarsus. Birds vary considerably in the arrangement of their feet, most birds having four toes with three, four, and five phalanges but others having three or even two.

### Anatomy of Bony Fish

Unlike the skeletons of mammals, those of bony fish do not experience re-modelling or resorption; the bones simply keep growing throughout the fish's life. Like reptiles, fish continually

replace their teeth because they also have a life-long supply of tooth buds. The rate of fish's bone growth varies seasonally, resulting in distinct growth rings. As we will see below, this is extremely helpful in determining the fish's age at death and even the season in which it died. There are also many differences in skeletal anatomy, although many of the major classes of body part found in mammals and the terms for orientation can also be used for fish. The body parts of greatest importance to archaeologists are the otoliths (ear stones) and vertebrae, because these are more often preserved. In some contexts and with careful recovery, however, even scales can be very useful sources of data.

Fish vertebrae (figure 10.3) consist of a spool-shaped *centrum* to which a number of *spines* are attached. The concave face or faces of centra show annuli, or annual growth rings. Casteel (1976:77-78) recommends classifying fish vertebrae according to nine classes, extending posteriorly from the basioccipital, where the skull articulates with the spinal column. These are the proatlas, the atlas, the second vertebra, the Weberian vertebrae, the thoracic vertebrae, the precaudal vertebrae, the caudal vertebrae, the penultimate vertebra, and the ultimate verte-

bra. The spines are not always preserved in archaeological specimens, but can include the neural spine on the dorsal side of the centrum, parapophyses or transverse processes that extend laterally from the centrum, and two haemal spines (or ribs) flanking the centrum's ventral surface, which can sometimes be fused. The passage for the spinal cord is the neural arch. The ultimate vertebra has a urostyle at the posterior end, where it begins the fanning out of the tail.

Often more important than fish vertebrae as sources of archaeological evidence are **otoliths**, small concretions of calcium salts, principally calcium carbonate, that occur in the inner ear. They appear to be part of the animal's control over balance, or to help with depth perception or hearing (Casteel, 1976:17-18). The smallest otoliths are not very helpful for identification, but the larger ones, called statoliths, occur in three pairs. These are the *sagittae*, *asterisci*, and *lapilli*.

The outer face of most otoliths is flat or concave, sometimes with concentric rings or *annuli*, but with little relief, while the inner face is highly sculptured in ways that facilitate identification, sometimes to species level (figure 10.4). Both the sagitta and the asteriscus tend to show a groove, called a sulcus, extending roughly horizontally across the inner surface and often bordered by a ridge. Two protrusions, the anterior rostrum and the antirostrum, which juts out on the anterior dorsal edge, flank the anterior end of the sulcus.

### Anatomy of Molluscs

Mollusc shells constitute the only invertebrate remains that archaeologists routinely collect, although analysis of archaeological insect remains is becoming more common. The major classes of molluscs (phylum mollusca) are the Monoplacophora, the Amphineura (including subclass Polyplacophora), the Gastropoda (including snails, slugs, limpets, and abalone), the Scaphopoda (including Dentalium or "tusk" shells), the Bivalvia or Pelecypoda ("bivalves" such as clams and oysters), and the Cephalopoda (including squid, octupi, nautilus, and extinct ammonites) (Wilbur and Yonge, 1964). Molluscs'

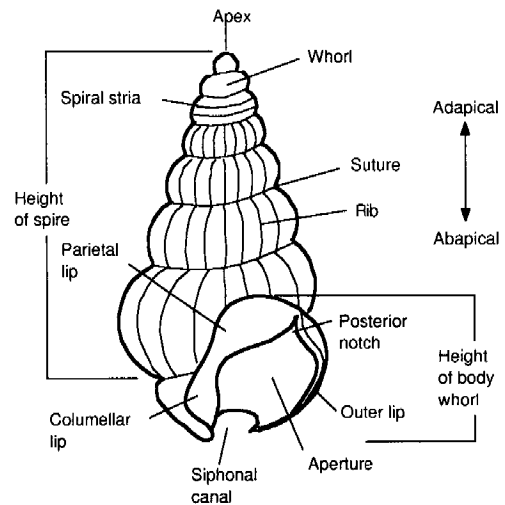


Figure 10.5. Anatomy of a helicone (after Fretter and Graham, 1962:56-66).

hard tissue occurs, if at all, in the form of one or more exoskeletons, or shells, formed from deposited calcium carbonate, that serve as external protection for the animal's soft, unsegmented body (Weselkov, 1987).

The shells occur in a number of major varieties (Fretter and Graham, 1962:49-82). Gastropods, for example, can have an overall helicoid (a long cone wound around a shorter cone) shape, but be described as ventricose, if each whorl bulges outward between sutures, flat-sided, if the whorls are flattened, or turreted, if the upper part of each whorl projects outward below the suture line. Other gastropods have shells shaped like simple cones. In bivalves the two shells are hinged, each valve a mirror-image of the other, and occur in a wide variety of symmetrical and asymmetrical shapes. Good introductions to shells include Wye (1991) and Claassen (1998).

As you would expect, the terminology for the parts of molluscs shells is quite different from that for skeletal elements.

As illustrated in figure 10.5, helicoid gastropod shells are oriented relative to the apex, vertically along the axis of the spiral, with apex at top. The coiling is normally upwards and clockwise (dextral) when viewed from the apex, but there are exceptions with sinistral coiling or



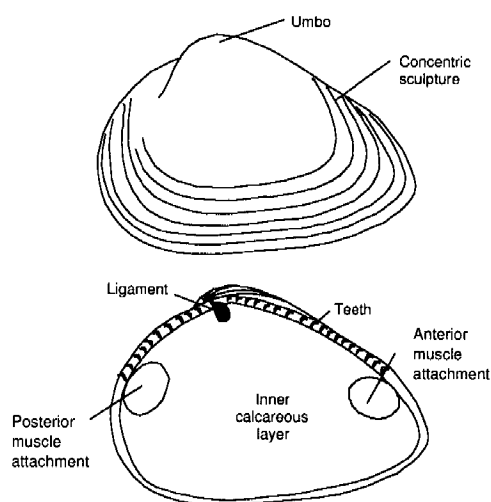


Figure 10.6. Anatomy of a bivalve shell (after Yonge and Thompson, 1976:147, 150), here the outer right valve (top) and inner left valve of *Nucula nucleus*.

with the spire extending downwards. In helicocones that lay new whorls so that they touch the central axis, a solid or hollow central pillar, called the *columella*, is visible in a broken shell. In hollow *columellae*, the lower opening is called the inferior *umbilicus*. The protoconch is the original shell, secreted while the animal is embryonic or larval, at the innermost part of the shell's helicocone. The mouth, or aperture, is near the bottom of the shell and its growing edge, or *peristome*, includes an outer lip, or *labrum*, away from the axis of the shell and inner columellar lip or *labium*, close to the shell's axis. Where part of the peristome lies over the previous whorl, it is called the *parietal lip*. An important attribute for identification is the angle of the outer lip relative to the shell's axis. Other features of the aperture can include the siphonal or anterior canal, which allows the gastropod to suck water into its mantle cavity, and which can be an elongated tube in some species. At the adapical (towards apex) end of the aperture there may be a posterior notch or canal, which facilitates the discharge of feces. The youngest (largest) whorl, forming one complete turn of the helicocone, is the *body whorl*; all other whorls combine to make the *spire*. The maximum diameter of the body whorl is known as its periphery. Tiny spiralling folds on the surface of the whorls are known as *striae*, while periodic thickenings of shell along the length of the helicocone are

ribs, which appear to intersect the striae. Where the ribs appear parallel to the axis of the shell, they are orthocline ribs. If their adapical ends are turned toward the direction of growth, they are prosocline, and if turned in the opposite direction, they are opisthocline. At the microscopic level, there are also tiny growth lines created by secretion along the peristome, which can be seasonal, allowing the age of the animal to be counted in the lines. In some species, there are long spines protruding from the ribs, or series of out-turned flanges, called *varices* (sg. *varix*), both of which originate in an out-turning of the outer lip. In some species, mature animals stop growth of the helicocone and instead secrete bosses (denticles or teeth) on the inside of the aperture. A *septum* (pl. *septa*) is an interior growth of shell, extending from the *columella*, to block off the uppermost whorls of the spire when the animal no longer occupies them (Fretter and Graham, 1962:50-66; Wye, 1991: 16)

Bivalve shells are oriented relative to the umbo (beak) and nearby ligament (hinge), inner and outer surfaces, anterior and posterior ends, and left and right valves (figure 10.6). The shell of a bivalve grows from the margin of the mantle, as in gastropods, but the mantle is divided into two symmetrically arranged lobes, from which shell growth must be identical to ensure that the margins of the two valves meet when the shell is closed. The mantles' margins have three parallel folds, of which the outer secretes the peristracum and outer calcareous layer of the shell, the middle has sensory functions, and the inner controls water flow into the mantle cavity. The shell itself has three major layers: the outer, horny periostracum, made of protein, the outer calcareous layer, consisting of calcium carbonate in a matrix of protein conchiolin, and the inner calcareous layer, which sometimes has the iridescent quality of mother-of-pearl. Along the bivalve's mid-line, an uncalcified, elastic ligament serves as a hinge. While the ligament is rarely preserved in fossil assemblages, hinge "teeth," ridges and grooves on either side of the ligament are often important attributes in bivalve identification. Each tooth fits into its corresponding groove or socket on the opposing valve. The teeth ensure that the two valves line up properly when the shell is closed, and that

they will not slip against one another (Yonge and Thompson, 1976:142-49).

As with fish, seasonal variations in temperature and food availability affect shell growth in many species of molluscs. For some, there may be no shell growth at all in winter (Davis, 1987:83-90). Molluscs accumulate shell when specialized parts of the mantle secrete an organic base, conchiolin, and inorganic salts of calcium around its growing edge. Later deposition of calcareous material thickens the shell over its whole inner surface. But shell deposition is not always constant. Some bivalves, for example, only secrete shell when the animal is submerged and the shell is open. In intertidal bivalves, such as the cockle, there is a new increment of shell at each high tide. Hundreds of these small increments, separated by thin dark lines, accumulate during each growing season (generally summer) and are separated by grooves, or "growth cessation rings," when only extremely thin increments, or none at all, are added to the shell. Some gastropods also show seasonal increments, representing either winter cessation of growth due to cold, or summer cessation to avoid dessication. As we will see later, these growth increments have important implications for the analysis of seasonality at archaeological sites.

### Identifying Taxa

One of the basic activities of the zooarchaeologist, although it is only a first step, is to try to identify the taxon to which a particular fossil belongs.

As we have seen, animals with similar evolutionary histories tend to have similarities in the presence and morphology of body parts. We can take advantage of this fact in our attempt to identify fossils. The first step is to determine to what skeletal part a particular fossil belongs. Once we have done this, we may be able to note morphological idiosyncracies that allow us to narrow down the taxonomic possibilities to a particular family, genus or species.

Although osteological reference books can be helpful for identifying the more common animals (e.g., Cornwall, 1964; Glass, 1973; Hall and Kelson, 1959; Olsen, 1972; Pales and Garcia, 1981; Pales and Lambert, 1971; Schmid, 1972;

Walker, 1985), a critical tool in faunal identification is a *reference collection*. This is a collection of modern skeletal elements, teeth, shell, and horn or antler from reliably identified specimens of known species, age, and sex (determined before or shortly after the animal's death). It is also useful for the reference material to show such information as the place and date of each animal's killing or capture, and its mass and other useful size measures (e.g., length or stature) at that time. Because most of the species of archaeological interest will have evolved only very slowly, the modern specimens should be a very good guide to most archaeological specimens, although evolutionary changes will be more important in very old assemblages. Since most of the collections in museums of natural history are neither complete enough nor formed with archaeologists in mind, it is usually necessary for zooarchaeologists to build up specialized reference collections. This may require hunting, trapping, fishing, finding cooperative zoos and butchers or slaughterhouses, making exchange arrangements with other reference collections, and scouring roadsides for road-kill or beaches for dead birds. Where you are unable to obtain whole animals, however, you need to make special arrangements to ensure you have accurate information about the sources of body parts.

It is then necessary to deflesh the animals (sometimes dissecting them to study their anatomy first), and there are several ways to accomplish this messy and smelly task (Anderson, 1965; Casteel, 1976:8-16; Hangay and Dingley, 1985:326-65; Hildebrand, 1968). A common method is a combination of defleshing manually, simmering the partly defleshed specimen just below boiling, often with some detergent or enzyme in the water (Ossian, 1970), and maceration (allowing the partly defleshed specimen to rot in the water). This is fairly slow and is best accomplished under a fume hood to evacuate the steam and very unpleasant odors that result. Safe disposal of water containing rotted tissue and enzymes can also be a problem, and simple disposal down the drain may violate health-and-safety regulations or municipal law. Dermestid beetles will clean articulated specimens quite well, but this method is even slower and the beetle colonies require careful

maintenance. Another, available only at coastal laboratories, is to place eviscerated specimens in perforated containers in the intertidal zone of the sea, where marine isopods will deflesh them fairly quickly (Casteel, 1976). Nested screens should be used to capture the disarticulated remains from all these methods, to avoid losing the smallest elements, and when these are clean and dry they need to be labelled accurately by species, sex, age, and specimen number and stored safely where you can easily retrieve them. This may require thousands of plastic or other insect-proof and rodent-proof boxes of various sizes, considerable shelving, and good climate control (see chapter 7). Ideally, you will want enough specimens of each taxon to represent not only various ages and both sexes, but other within-species variations in size and shape.

Shape differences among taxa can be subtle and only differ from within-taxon variation by degree (Davis, 1987:37-38). Often they may allow us to differentiate by genus but not species. We can attempt to separate these taxa by making careful measurements of skeletal parts and calculating ratios between them. In cases of rather similar taxa, we often find that animals in a population consisting of one species will show the same or closely similar ratio between two measurements, while groups of animals of different species will tend to differ in these ratios. This is a matter of **allometry**, the scaling of body parts in animals. If we are to depend on such measurements to distinguish taxa, however, we must be careful to be very consistent in the way we make them. Angela von den Driesch (1976) provides one guide to the measurement of mammals and birds from parts of the Old World. The use of such ratios, often presented graphically in a scatterplot, can help us make subtle distinctions between elements of such closely related taxa as sheep and goats (Davis, 1987:33; Payne, 1968) or horses, donkeys, and onagers. In the most difficult cases, we may now use DNA analyses to distinguish these species as long as DNA is reasonably well preserved (Loreille et al., 1997).

Not all variation in size and shape is due to interspecific difference. Bones are modified over the life of an animal, but especially in its youth.

As you would expect, we can use some of the changes that occur in the development of the skeleton to determine the age at which a particular animal died. In addition, some parts of the skeleton may show *sexual dimorphism* (patterned differences between males and females). When this happens, and the sexually diagnostic parts are preserved, we can identify both the age and the sex of the animal from which the bones came.

### Determining Sex

Some parts of the skeleton, such as the pelvic girdle, and teeth or antlers that are used in sexual display, vary by sex in their size and shape. For example, in equids (horses), the males usually have large canine teeth, while females usually either lack canines or have only vestigial ones, while in both cervids and bovids, females usually either lack horns or antlers or have ones that are different in shape from those on males. The pelvis frequently shows differences related to birthing. In most mammals, males' bones tend, on average, to be larger and more robust than the same bones in females of the same age, and males often have greater overall body size. There are exceptions, however, as in hares (the doe is larger than the buck). Castration of males, furthermore, slows epiphyseal fusion and allows more longitudinal growth. Sometimes bones that are good indicators of sex are those that support the extra weight of the male animal's large horns or antlers, as these may well exaggerate the sexual dimorphism. One must be careful, however, not to confuse size differences due to sex with those due to age. Comparing fused epiphyses, for example, controls for age (Klein and Cruz-Urbe, 1984:40). Using size as an indirect measure of sex works well in species with strong sexual dimorphism, such as goats, cattle, and seals, but in some species there is too much overlap between the size distributions of males and females for us to determine the sex of any but the most extreme cases in the sample assemblage. Even when we cannot be certain about each individual bone element, however, it may still be possible to recognize assemblages that show, for example, predominant culling of males.

## Age at Death

There are several sources of evidence for determining the age-at-death of animals from which we have bones or teeth (Iscan, 1989).

One is fusion of the epiphyses. As we have seen, bone formation begins in the mid-shaft and two epiphyses, and the epiphyses remain separated from the shaft by a layer of cartilage for quite some time. Eventually, however, ossification proceeds to the point that they become fused to the shaft, and the time when this tends to occur in modern animals is known. Bones with unfused epiphyses therefore belong to young animals, while fused ones belong to adults. We can often be more precise than this in that, for some bones, the two epiphyses fuse at different times. For example, often the distal epiphysis of the humerus fuses before the proximal one. As long as we know the ages at which fusion occurs in modern animals of the same species, we can use the ordinal scales (unfused, one epiphysis fused, both fused) to estimate age in months. This leaves us with a coarse, indirect measure of age, not always as precise as we would like (Davis, 1987:39; Klein and Cruz-Uribe, 1984:43), and we must keep in mind that unfused epiphyses are less likely than fused ones to survive centuries of burial.

Teeth provide a more precise indirect scale of age. As horse-traders have known for centuries, patterns of dental eruption and tooth wear are excellent clues to an animal's age (Hillson, 1986:176-223). Deciduous teeth are replaced on a schedule that is known in modern animals, so it is often possible to determine the age of young animals very precisely as long as their mandibles or maxillae are preserved to show the stage of tooth eruption (Deniz and Payne, 1982). Clearly, young animals should also show very little wear on the occlusal surfaces of their teeth (apart from any post-depositional wear), while old animals may show quite a lot of wear. Although tooth wear depends on a number of factors besides age, including the amount of grit and acid in the diet, it is possible to make a rough aging scale based on tooth wear (figure 10.7; e.g., Klein and Cruz-Uribe, 1984; Spinage, 1973). Where we can assume that the usual cause of

death of the animal was seasonal (as in a seasonal kill site), we may be fortunate that the degree of wear in a particular tooth (say, a molar) clusters into groups that probably represent annual age-grades. In other words, teeth with almost no wear come from animals in their first year, the cluster with slightly more wear from animals one to two years old, and so on (Klein and Cruz-Uribe, 1984:45). Aging on the basis of tooth eruption and wear works much better when whole rows of teeth are available; single teeth are more difficult.

In some herbivorous animals, with high-crowned teeth whose growth stops early in life, tooth wear results in ever-diminishing crown height, as measured from the top of the root. For example, Spinage (1972) has found an exponential decrease in the crown height of zebra teeth.

An alternative is to count the growth increments (*annuli*) in mammal tooth cementum (Morris, 1972; 1978), much the way dendrochronologists count tree rings. Fortunately for zooarchaeologists and wildlife biologists, the rate of deposition of secondary dentine in the pulp cavity and of cementum on the roots varies by season in many mammals. Cementum is the concentric tissue that mineralizes collagen fiber onto the tooth's root to hold the tooth in place. Consequently, it grows throughout a mammal's life and, in thin section and polarized light, shows discrete, alternating translucent and opaque bands that we can count to determine the animal's age at death. In many species and environments, there is a strong correlation between the number of these bands and the known age of animals. Because the pulp cavity fills with dentine fairly early in an animal's life, however, zooarchaeologists focus on the cementum *annuli*, as viewed in stained thin-sections. The method does have some problems, as the deposit of cementum is not uniform in thickness, some cementum may be resorbed during life or lost through abrasion, and "secondary bands" may be mistaken for true annuli (Klein and Cruz-Uribe, 1984:44-45). In many cases, the method is more useful for estimating the season in which the animal died, rather than its actual age at death (see below).

Age period (years)	About 17-25			25-35			33-45			About 45 +		
Molar number	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3
Wear pattern			Dentine <i>not</i> exposed. There may be slight enamel polishing							<div>Any greater degree of wear than in the previous columns</div> <div>NB. Very unequal wear sometimes occurs in the later stages</div>		
	Or											
	Or											

Figure 10.7. Chart for estimating the age of humans on the basis of molar wear (Brothwell, 1981:72).

Most determinations of age depend, however, on metrics (ratio-scale measurements). Not only are there gross differences in size among animals of the same sex and species but different ages, but there may also be differences in the ratios of one measurement to another (i.e., differences in shape). As already mentioned, the study of the relationships between these measurements and animals' age, sex, and weight, is called **allometry**. It is also possible to use these measures on teeth to quantify tooth wear (Klein and Cruz-Urbe, 1984:46-55).

In fish, thanks to the characteristic of constant bone growth, often rather simple allometric relationships will result in accurate estimates of the fish's size (Casteel, 1976:93-123), which is in turn a function of its age. In addition, incremental, seasonally varying bone growth results in annular rings, or *annuli*. These are quite detectable on the anterior and posterior surfaces of the centra of fish vertebrae (figure 10.3) and we can simply count them, like tree rings, to determine age in years, as has been recognized for more than two centuries (Casteel, 1976:78-83). *Annuli* also occur on fish otoliths and scales (Casteel, 1976:31-35, 65-71).

In molluscs, similarly, we can sometimes depend on constant but seasonally varying accretion of shell as a source of information on age. This is discussed more fully below, in connection with seasonality.

In many species for which it is possible to estimate age fairly precisely and sample size is fairly large, we can construct *mortality profiles* that show how the probability of death varies with age and compare such profiles. We will return to the interpretation of age profiles below (pp. 204-205).

### Seasonality

Faunal remains are among the archaeologist's best evidence for the season or seasons during which an archaeological site was formed and used.

On sites that contain large samples of cervid (deer) remains, zooarchaeologists can take advantage of the fact that deer shed their antlers annually to try and estimate the season in which the cervid remains were deposited. One of the classic studies of site seasonality used the presence of shed antlers of red deer, most easily collected in April, to conclude that the Mesolithic site, Star Carr (Clark, 1954:119-22) was a campsite occupied in winter and early spring. Subsequent authors have noted that shed antler can be curated, while other evidence points to use of the site in summer and probably other seasons as well (Andresen et al., 1981).

Some authors have tried to use evidence of migratory birds to show that a site was occupied during the season when the birds are expected to have been present. As Muñiz (1998) shows,

birds' phenology (behavior relative to climate and season) can change along with climate, food availability, and other factors, while birds vary substantially in their reliability as seasonal indicators. For example, birds whose modern breeding grounds were glaciated during the Ice Age must have had quite different migratory habits in the Pleistocene. However, careful consideration of these factors and combining the bird evidence with other evidence for seasonality can still be useful.

Marine molluscs have provided one of the best sources for seasonality of shell middens and other sites that contain significant numbers of these fossils (Deith, 1985). One way in which some molluscs can inform us about season is through size. Molluscs increase fairly steadily in size as they age, and in some areas the largest age-class is likely to be molluscs less than a year old, the "young of the year" (Russo, 1998). Where we know the approximate time of year that clams, oysters, and scallops of a given taxon began their lives, and the rate of shell growth, we can use size measurements to estimate the age of a mollusc in months and add this to its probable "birthdate" to arrive at an approximate season of death. Better still, we can often rely on the fact that in some species of bivalve, increments of shell growth are separated by bands of little or no shell growth during winter or summer. For example, in quahogs (a kind of clam), Quitmyer et al. (1985) found that they could identify six different seasonal phases of shell growth depending on the thickness of the outer increment and whether it was translucent or opaque.

Mammal teeth are also a source of evidence for seasonality. For mammals born in a brief and predictable season, such as spring, we can use dental patterns to age the teeth closely enough to determine season of death. As Moore (1998) points out, this works best when we have sets of teeth representing all the ages we would expect in the population at one time (i.e., animals born one year apart). It is also difficult to use eruption and wear patterns unless a large sample, with many fairly complete sets of teeth, is available. The increments in tooth cementum are more generally useful. They are not only associated

with age in years, but also with season of death (Bourque et al., 1978). The nature of the outermost cementum band, unless it has been abraded away, will often provide evidence in thin-section for the season of death (Miracle and O'Brien, 1998; Lieberman and Meadow, 1992; Lieberman, 1998).

A special case of bone allometry also provides evidence for season of death in sites where fetal bones are well preserved. Miracle and O'Brien (1998) used both percentage of fetal remains and the lengths of fetal long bones to show that pregnant deer were killed at Badanj in late winter and early spring.

### Paleoecology

Faunal remains are among the sources that archaeologists and paleontologists have used in the attempt to reconstruct extinct ecologies. In the more extreme cases, such as the change from the Pleistocene to Holocene in Europe, there may be substantial replacement of cold-climate fauna by temperate-climate fauna (Butzer, 1971:258-62).

One attempt to reconstruct changes in a site's environment on the basis of faunal remains depended on the alternation of fallow deer and gazelle hunted by humans in Kebara cave at Mount Carmel, Israel (Davis, 1977). Although the deer preferred woodland and the gazelle more open habitats, cultural preferences will have made the distribution of their remains at best a distorted reflection of their abundance in the environment. Rodents, however, may sometimes provide a more representative picture of the environment around cave sites (Tchernov, 1968). Owls may have sampled the rodent population in their hunting range and, after eating their prey, disgorged rodent bones in the cave. Changes in the relative frequencies of rodents that, in modern ecologies, prefer wetter or drier climates can then contribute to reconstruction of climatic changes within the cave's catchment area.

Land snails are often very sensitive indicators of ecological conditions, and archaeologists have taken advantage of their sometimes "fussy" requirements to reconstruct the environments

in which their shells were deposited (Butzer, 1971:265-66; Evans, 1972; Thomas, 1985). Some of the factors that influence the distribution and abundance of land snails are water availability, temperature, soil pH, and calcium levels (Evans, 1972). The abundance of food (snails can be herbivores, carnivores, omnivores, or detritivores) may rarely limit snails' distribution simply because there is almost never a shortage of the foods they consider acceptable, but the quality of food may sometimes influence that distribution (Thomas, 1985:136-37). Generally, analysts combine various taxa of snails into groups based on their supposed ecological niches. For example, British zooarchaeologists group taxa into habitat-groups: "shade-loving," "open-country," "marshland," and "catholic" (able to live in a variety of habitats). Like plant taxa (see chap. 11), snails tend to occur in associations of several taxa, and it is always better to look at whole assemblages of taxa rather than placing too much emphasis on individual taxa that are supposed to be indicators of a particular kind of habitat (Thomas, 1985:140-44). For information on the extraction, identification, and analysis of snails see Evans (1972) and Preece (1981).

Insect remains can also be instructive about the habitats around a site, and even the microhabitats within it. Like snails, insects can be very particular about their environments. Where conditions permit their preservation, parts of insects' exoskeletons can then be used in an attempt to reconstruct those environments (Kenward, 1975; 1976). Kenward (1985) shows how insect assemblages can be used to distinguish indoor from outdoor archaeological contexts, which would be very valuable in cases where architecture is not very substantial or it is uncertain whether certain walled spaces were roofed rooms or open courtyards. He cautions, however, that we must take into account the mechanisms that could transport "outdoor" insects into buildings, such as wind and predation by birds. Some archaeologists have attempted to use the fossils of insect pests that infest grain to identify probable grain-storage facilities even where no plant remains are preserved.

## Biostratigraphy

Biostratigraphy is a paleontological technique for the relative chronology of deposits that depends on the sets of fossils found in them and the assumption that these fossils reflect the paleoecology of a particular time and place (Butzer, 1971:261-66). In archaeology, this technique is rarely used except on Paleolithic sites for two reasons. First, other dating techniques are usually available, including relative dating by artifact typology and absolute dating by radiocarbon assay, that can date the deposits more precisely. Second, cultural effects make it unlikely that the fossil assemblage bears very close resemblance to the life assemblage.

Yet for assemblages too old for radiocarbon dating to be applicable and without the volcanic ash layers that allow dating by the potassium-argon method, biostratigraphy is a useful method of relative dating. It operates on the assumption that the fossil assemblages reflect the appearance, spread, and eventual extinction of various species. A given geological deposit will contain a set of fossils that is a sample of the species that existed at that location at the time it was deposited. Deposits below and above it may show quite different combinations of taxa, as some species are added to or subtracted from the set through speciation and extinction. When two columns of deposits from different rock outcrops show similar sequences of fossil sets, then, we can correlate them to determine which deposits are approximately contemporary.

In one archaeological application of the method, Eitan Tchernov (1990) attempts to redate the Paleolithic deposits at 'Ubeidiya, Israel, to about 1.4 million years ago on the basis of similarities in the spectrum of fauna to deposits in Europe, Russia, and Olduvai Gorge, and the lack of faunal taxa from known earlier and later deposits.

## Domestication of Animals

A research area that has attracted zooarchaeologists is the investigation of early animal domestication. Although archaeologists are mainly interested in the human behaviors involved in the shift from an economy based on

hunting and gathering to one based mainly on herding and agriculture, quite often they rely on physical, evolutionary changes in the plants and animals that are associated with domestication as indirect evidence of these behaviors.

In the Old World, zooarchaeological research on domestication has tended to focus on the first domesticates: dogs, goats, cattle, and pigs, while in the New World it has focussed on dogs, guinea pigs, and llamas. But some animals, such as the camel (Köhler-Rollefson, 1981), were added quite late to the repertoire of domestic animals.

Domestication can be difficult to identify or even to define (Bökönyi, 1969; 1989). Generations of animals can show physical changes as they are domesticated, including changes in size, crowding of teeth and, in some animals, loss of horns or change in their shape. Some authors suggest that such changes may not appear until many generations after the domesticatory relationship between humans and animals began (Bökönyi, 1989: 25). We cannot expect domestic animals to be consistently distinguishable from wild ones (Ducos, 1989). Although many animals decreased in size over the course of domestication (Meadow, 1989:86-87), size changes can also occur in other situations, such as isolation on islands or changes in mean annual temperature (Bökönyi, 1989:25; Davis, 1981; Meadow, 1989:87). Tooth crowding in dogs and pigs, and hornlessness in sheep, seem to be rather reliable indications of domestication, but it is not clear how long it takes for these changes to evolve.

Although some zooarchaeologists are interested in tracing the origins and spread of domesticated animals (e.g., Bökönyi, 1974), others are more interested in explaining the beginnings of a mutualistic relationship between humans and animals, which must begin with describing a shift from the hunting of wild animals, to nearly complete dependence on domesticated ones, with a transitional phase that could include management of wild herds. This cannot depend on genetic changes, but sometimes pathologies, including evidence for tethering animals, can supplement anomalous mortality profiles (be-low) as evidence for herd management.

## Taxonomic Abundance — Menu Preference

Commonly zooarchaeologists try to reconstruct the dietary choices of hunters and herders. This means trying to quantify the relative "importance" of different species on the menu, as well as preferences for animals of particular sex or age in some cases. We will leave the latter for another section and concentrate here on the choice of species.

One of the things that archaeologists have noticed for some time is that prehistoric hunters and farmers sometimes changed their subsistence strategies substantially, particularly from narrow niches (hunting mainly one or two species) to broad ones (hunting, collecting, and raising a wide range of food resources), as well as shifting their emphasis from, say, gazelle to deer or wild animals to domesticated ones. In general, although changes in environment are often factors in such shifts, this kind of research focusses on diet and, as such, should focus on the amount of the resource (typically amount of meat, but potentially also hides, etc.), and not necessarily the number of animals killed, although these two measures are related. We would not want to assume a focus on rabbits, because of their greater number among the bone counts or estimated individuals, when in fact the diet of the people who created a site was dominated by, say, bison. A single bison would produce more meat than 100 rabbits.

As we saw in chapter 5, the appropriate way to quantify faunal remains when we are interested in the relative importance of taxa is to use an estimator that provides unbiased estimates of proportions. When we are interested in the proportions of different types of animals in the deposited assemblage, then, it would be useful to use a quantification approach that accounts for bone fragmentation (*f*) and the number of bones in whole animals (*s*). When we are interested in the proportions in the death assemblage, and the size and quality of our sample warrants it, we might base the proportions on the Peterson estimator. In some instances, we might have to quantify the remains by mass, sorting elements into age classes so that reasonable transformations to meat mass are possible.



In addition, an examination of niche breadth can employ measurements of diversity, such as the Expected Species index,  $s(m)$ .

We cannot assume that the remains of animals we find on archaeological sites are a simple reflection of diet. Not only can some of the skeletal remains belong to pests or pertain to non-human bone accumulators, or fail to be preserved, but humans themselves can bring animals and animal parts to sites for many purposes other than for food. Some of these purposes may be utilitarian — bringing hides for clothing or antler for tool-making, for example — while others could be ideological. Among the latter we might include skulls, whose food value is limited to the brain, but which can nonetheless have symbolic value. In Western culture, for example, mounting heads and antler racks of game is for social display and symbolizes status and mastery over nature. In other cultures, furthermore, there can be taboos requiring the remains of food animals to be buried off-site (e.g., Tooker, 1964:64, 67).

### Elemental Abundance — Choice of Cut

Interpreting dietary choices is often confounded by the fact that neither hunters nor herders typically deposit entire skeletons on site, where they can become part of the deposited assemblage. Instead, they often only deposit those bones associated with selected cuts of meat, or attached to pelts that they use for clothing or bedding.

When humans and other bone accumulators kill, butcher, and consume an animal, they can alter the distribution of bones in the deposited assemblage both by selective transport of body parts and by selective destruction of bone. Hunters who make a kill at some distance from their camp or village will often butcher the animal, if it is large, on the spot, taking the most valued cuts (e.g., upper limbs, pelvic girdle) back to their settlement and abandoning the parts that have low meat/bone ratios (e.g., axial skeleton, lower limbs) unless these have value for reasons other than nutrition (Perkins and Daly, 1968). For example, parts of the lower limbs may still be attached to highly valued pelts (which can also be used as “bags” for carrying the meat back

to camp), while skulls can be saved as trophies or religious items, and antler saved for tool production. In such cases, we would find some body parts missing from the settlement site, and others missing from the kill site.

Binford (1978:72-74; 1981) and others have attempted to understand the distribution of body parts by quantifying their value with “utility indices.” Binford introduced the “general utility index” (GUI) as a measure of each bone part’s usefulness for meat, marrow, and grease, and “modified general utility index” (MGUI), which makes allowance for less useful elements that were probably attached to parts of higher value. Binford used patterns in the MGUI values for different skeletal parts in an attempt to infer transport of more useful body parts and to distinguish between kill sites and transported sites of hominids and other carnivores in an attempt to infer whether hominids were responsible for bone accumulations.

Other researchers have since adopted utility indices (e.g., Lyman, 1992; Lyman et al., 1992), with Metcalfe and Jones (1988) providing a simpler way of calculating what they describe as a meat utility index (MUI):

$$MUI = g - d$$

where  $g$  is the gross mass of the body part, and  $d$  is the dry bone mass of the part. In effect it measures the amount of tissue expected on the bone. This measure has the effect of giving high scores to bones that would have a large mass of tissue on them, such as *femora*, even if they might have lower ratio of  $g/d$  and be more difficult to transport (Ringrose, 1993a: 146). Ringrose instead proposes indices based on  $g/d$ ,  $(g-d)/d$ , or  $(g-d)/g$ , with preference for the last. Although he has a point, there could be some cases where a large joint of meat was preferable to many small pieces of meat with higher  $g/d$  ratios.

The most serious potential problem with utility indices, once again, is differential preservation. Binford’s MGUI values are inversely correlated with volume density, and the patterns that he describes as a “bulk utility strategy” are equally explicable by differences in the probability of bone survival (Lyman, 1985; 1992; Grayson, 1989).

In cases where we are more interested in explaining the differential distribution of elements, rather than taxonomic abundance, utility indices, although not without problems, are a helpful approach if the preservation issue is also addressed.

We must be wary of assuming automatically that the selective transport of body parts for food, often called the "schlepp effect," is universal, however. In some societies, in fact, the killed animal's spirit is thanked and its unused remains are given ritual disposal not unlike that accorded deceased humans. We should also not assume that any discrepancies between body parts in their abundance must have resulted from selection between the death assemblage and the deposited assemblage. Since some body parts are more durable than others, post-depositional selection also contributes to such discrepancies (Lyman, 1985; 1992).

### Butchering Practices

In some cases, butchering of food animals is among the taphonomic effects that we can recognize.

Along with the elemental evidence we have just considered, cutmarks on bone have been studied as evidence for butchery since the 1970s (Aird, 1985; Noe-Nygaard, 1977). When analysed systematically, cutmarks may help us identify butchery traditions and reconstruct whether the butchers were preparing meat for immediate consumption or to preserve it for storage through smoking, drying, or salting (Maltby, 1985).

### Mortality Profiles — Hunting Strategies and Herd Management

In sample assemblages that are sufficiently large, fairly well preserved and with sufficient evidence for sexing and aging a large proportion of specimens, we can sometimes get some insights into the sex-age structure of the death assemblage.

One of the most common applications of this approach is to infer hunting strategies from mortality profiles. Some authors have inferred that proportions of young animals much higher

than their expected proportion in living herds indicates a kind of hunting that borders on herd management, and may even indicate early attempts at domestication. For example, Perkins' (1973) claim that sheep bones from very early Neolithic deposits at Zawi Chemi Shanidar were from domesticated sheep depends solely on an elevated proportion of immature animals.

Payne (1973), meanwhile, attempts to determine whether, in a sample assemblage of sheep and goat bones at Asvan Kale, different kill-off patterns reflected different herd-management practices (meat production, milk production, wool production). The approach is based on the idea that herders will kill off (cull) unproductive animals, such as males when milk is the desired resource, or animals that produce too little relative to the cost of maintaining them. Most dairy herders will cull males in their first few months, while a meat-producing strategy might keep them until they are about a year old to reach optimum weight and a wool-producing one might keep some of them even longer for their wool. Payne recognizes that there are numerous reasons why herders might select a "non-optimal" strategy, and both depositional and post-depositional selection could mimic herders' selection.

Even where taphonomic problems and sampling bias are minimal, and you can assume that the sample assemblage is representative of the death assemblage, this kind of analysis requires care. It is easy to confuse evidence for animal behaviour (ethology) with evidence for human exploitation. Baker and Brothwell (1980:19) have noted that claims for herd-management strategies are often unconvincing. An apparent shift toward younger animals is insufficient to demonstrate a transition from hunting to herding, while a shift toward more adults does not necessarily demonstrate milk or wool production. For example, Smith and Horwitz (1984) claim that high percentages of adult goats in the Early Bronze Age of the southern Levant indicates a shift from meat to milk products, but Payne (1973) shows that the survivorship curves for females can be identical in meat-, milk-, and wool-oriented herds. It is the treatment of males

that varies. In addition, milk, meat, and wool can be complementary in a mixed pastoral strategy. Some analysts also make the assumption that males and unproductive females will be culled at the point where the ratio of feed consumed to animal weight gained begins to rise. Prehistoric farmers and pastoralists, however, may not have relied on feed, and, where climate was unpredictable, may have kept males longer than optimal as a hedge against drought.

Mortality profiles can provide useful information, but you should keep Payne's caveats in mind if you plan to interpret culling patterns.

### Paleopathology

Evidence for disease, trauma, and genetics in the faunal remains from archaeological sites has great potential.

Although the literature on human paleopathology is much larger, key publications on the paleopathology of animals include Baker and Brothwell (1980) and Siegel (1976).

Evidence for trauma in animal bones can be informative about hunting methods and the handling of livestock (Baker and Brothwell, 1980:82). In addition to healed and unhealed fractures, there may even be flint fragments, embedded projectile points, or holes of distinct shape that suggest what weapon was used to dispatch an animal. Statistical anomalies in the distribution of trauma, both among taxa and among body parts, can help to reveal the causes of injury, including poor treatment of domestic stock and overcrowding of livestock (Baker and Brothwell, 1980:93-94).

Some kinds of disease and trauma in faunal remains can provide clues that herds were being managed. Paleopathological study can also show exostoses or neoplasia (abnormal growth) that might result from tethering or hobbling, and osteoarthritis of joints that can result from the stress of traction in draught animals, such as oxen and horses (Baker and Brothwell, 1980:97, 114-115). In general, herds belonging to sedentary people tend to be more prone to disease than are wild animals and the herds of nomads,

and a marked increase in pathology is probably a good indication that animals were being confined (Meadow, 1989:85), as we would expect during the first stages of domestication.

Smith and Horwitz claim that radiographic evidence of osteoporosis in the metacarpals of older sheep and goats are evidence of calcium depletion through prolonged milking. If they are right, then this provides evidence for early dairying. It is also possible that diverting milk for human consumption could have been a factor in the rapid size diminishment of early domestic animals (Meadow, 1989:86).

The treatment that people gave to the carcasses of animals that died of disease, furthermore, can suggest aspects of their ideology.

Faunal paleopathology is particularly important given the clues it can provide to the nature of human interactions with animals in the past, including domestication, and given the fact that some human diseases probably have their origins in these early interactions. One of the likely outcomes of the sedentism that accompanied the development of Neolithic food production was the proliferation of diverse pathogens and vectors that found new niches and ease of transmission among the clustered populations of humans, their livestock, and various animal pests that the villages attracted (Brothwell, 1969). Not only were some of the animal pests likely disease vectors, but the close association between humans and their herds, both probably occupying the same dwellings in some cases, provided additional pathways for disease transmission. Tuberculosis, for example, is probably a bacillus that humans first contracted from their cattle (Francis, 1947). Consequently, the study of diseases in the animals from ancient settlements has direct relevance to the history of disease in humans.

Recently, the potential of DNA analysis to solve difficult identification problems has created some excitement. As it turns out, fragments of DNA are quite often preserved in osteological remains even after millennia of burial. Sometimes even the DNA of infectious diseases can be preserved in ancient tissues.

### Trace Elements, Isotopes, and Diet

Sometimes the osteological remains are not the best evidence for the relative importance of meat, fish, and plant foods in a prehistoric community's diet. The chemistry of associated human bones can sometimes be important in this context. The most common approaches have been to study variations in the ratios of carbon isotopes and variations in trace elements that are thought not too susceptible to post-depositional (diagenetic) alteration.

Osteological remains can provide evidence for the diets of deceased humans or animals in the isotopic ratios of their carbon atoms. The ratio of  $^{13}\text{C}$  to  $^{12}\text{C}$  in living plants and animals varies because the synthetic pathways in some plants act slightly differently on these two carbon isotopes when they absorb carbon dioxide from the atmosphere. This slight favoring of one isotope over the other is called *fractionation*, and the two groups of plants distinguished by their synthetic pathways are called C3 and C4 plants. The former include trees, shrubs, and temperate grasses, while the latter includes tropical grasses, such as maize. Generally the C3 plants are more depleted in  $^{13}\text{C}$  than are C4 plants.

Consequently, we would expect humans or animals that eat exclusively C4 plants to be less depleted in  $^{13}\text{C}$  than ones that eat exclusively C3 plants. In fact, things are more complicated because fractionation is not identical for all kinds of animal tissues and fractionation varies with trophic level. "Secondary fractionation" in animals and humans results in herbivore bone collagen that is less depleted in  $^{13}\text{C}$  than the plants the animals ate. For example, in laboratory mice, bone collagen shows 0.3 to 0.4% less  $^{13}\text{C}$  depletion than the plant foods they were fed. Furthermore, secondary fractionation leads to different isotopic ratios in different kinds of tissue in the same individual. The herbivores' protein and lipids are less depleted in  $^{13}\text{C}$  than the collagen, and the bone apatite is even less depleted (figure 10.8). Carnivores, whose muscle tissue and collagen derives carbon from the herbivores' meat, but whose bone apatite derives it from the herbivores' meat and lipids, show still less depletion of  $^{13}\text{C}$ . In herbivores the difference in  $^{13}\text{C}$  depletion between collagen and bone apatite is

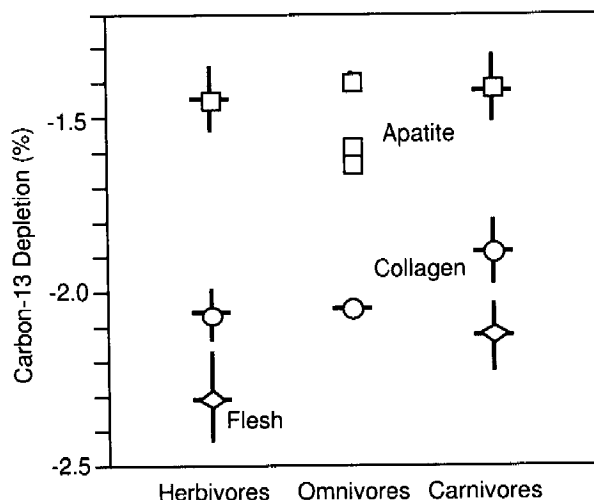


Figure 10.8. Examples of carbon-13 depletion ( $\delta^{13}\text{C}$  values) for bone apatite (squares), collagen (circles), and flesh (diamonds) from southern African fauna (after Lee-Thorp et al., 1989:592).

much greater, on average, than in carnivores. This difference could, in principle, help us distinguish primarily vegetarian humans from substantially carnivorous ones but, oddly, omnivorous humans can show a smaller difference between collagen and apatite than carnivores (Lee-Thorp et al., 1989).

In addition, populations whose diet consists mainly of marine animals, such as salmon and molluscs, will have carbon isotopic ratios that differ from populations with terrestrial diets (Chisholm et al., 1982; Hobson and Collier, 1984; Tauber, 1981). Even though marine animals consume C3 plants, their tissues are enriched in  $^{13}\text{C}$  relative to terrestrial herbivores.

Researchers have taken advantage of carbon isotopic differences to identify the introduction of maize into the diets of people inhabiting more northerly biomes, where C3 plants are found. This allows identification of early maize agriculture even in sites with poor plant preservation, as long as human bone is well preserved (van der Merwe and Vogel, 1978; Vogel and van der Merwe, 1977). They have also used it to identify heavy dependence on fish or marine mammals in coastal communities.

Carbon-isotope analyses such as these require fairly well preserved bone less than about

100,000 years old, and careful chemical removal of diagenetic carbonates (e.g., carbonates deposited from ground water while the bone was buried).

In some instances, trace element chemistry may also provide clues to prehistoric diet, although we must be very careful about diagenetic effects during burial that can alter bones' chemical compositions (Hancock et al., 1989; Price et al., 1992; Sandford, 1992). Some authors, for example, have used barium/strontium ratios to assess the degree of dependence on marine resources (Burton and Price, 1992). Strontium is also thought to be depleted in the bones of carnivores, and Sillen (1981), for example, attempted to use strontium levels and strontium/calcium ratios to detect changes in the dietary dependence on meat at Hayonim Cave, Israel. However, Tuross et al. (1989) have shown that strontium levels increase with time in buried bone, and that repeated washing of the samples does not completely remove this diagenetic strontium, some of which is locked into the bone apatite during recrystallization. Future use of strontium levels to infer dietary changes must take these effects into account.

## Conclusion

The physical traces of animals present a rich source of evidence for archaeologists. Taphonomic processes that affect the distribution of this evidence require careful attention, and the identification and analysis of bones and other remains requires specialized training and access to a large comparative collection. The faunal remains can tell us a great deal about environment, diet, hunting, food production, seasonality, tool use, and the use of animals for traction, transportation, or non-food resources. Human remains, meanwhile, can also provide indirect evidence for their diet.

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