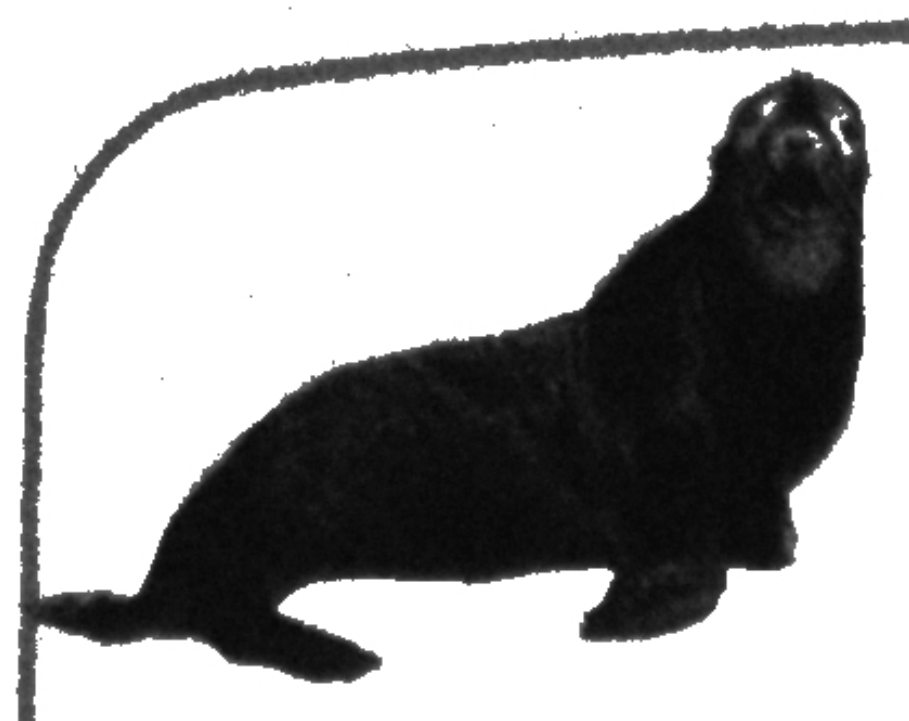

How Do We Know That Not All Mammals Are Endotherms?

Although traditional zoology states that all mammals are endotherms, there is at least one exception. The naked mole rat lives in complex tunnels in the grasslands of equatorial Africa (box figure 28.1). Scientists have been studying this species for years and have found out that they have no body fur, no subcutaneous fat, and no insulation, and they cannot regulate their body temperature via endothermy. Their body temperature fluctuates around 31° C; however, a certain degree of endothermy is achieved in a manner analogous to that of social insects.

BOX FIGURE 28.1 **Naked African Mole Rat.** *Heterocephalus glaber* in its tunnel.

Scientists have observed that these animals often move to their tunnel entrances where they bask in the sun. Because these animals do produce body heat by metabolic processes, they huddle together while sleeping to keep warm. The surrounding warm tunnel soil also provides some heat. These thermoregulatory mechanisms are similar to those of termites in their mounds. In addition, termites and mole rats have a social structure (called eusocial) that is similar to the hive societies of social insects. There is a single queen mole rat that only mates with a few dominant males. Workers dig the tunnels and gather food while soldiers protect the tunnels from predators such as snakes. Overall, the colony survives due to cooperation—a pair of mole rats on their own could not perform all of these functions needed to survive in the equatorial African grasslands.

of the cooler surroundings. Some bats also undergo daily torpor to conserve energy.

Some ectotherms can maintain fairly constant body temperatures. Among these are a number of reptiles that can maintain fairly constant body temperatures by changing position and location during the day to equalize heat gain and loss.

In general, ectotherms are more common in the tropics because they do not have to expend as much energy to maintain body temperature there, and they can devote more energy to food gathering and reproduction. Indeed, in the tropics, amphibians are far more abundant than mammals. Conversely, in moderate to cool environments, endotherms have a selective advantage and are more abundant. Their high metabolic rates and insulation allow them to occupy even the polar regions (e.g., polar bears). In fact, the efficient circulatory systems of birds and mammals can be thought of as adaptations to endothermy and a high metabolic rate.

Temperature Regulation in Invertebrates

As previously noted, environmental temperature is critical in limiting the distribution of all animals and in controlling metabolic reactions. Many invertebrates have relatively low metabolic rates and have no thermoregulatory mechanisms; thus, they passively conform to the temperature of their external environment. These invertebrates are termed **thermoconformers**.

Evidence indicates that some higher invertebrates can directly sense differences in environmental temperatures; however, specific receptors are either absent or unidentified. What zoologists do know is that many arthropods, such as insects, crustaceans, and the horseshoe crab (*Limulus*), can sense thermal variation. For example, ticks of warm-blooded vertebrates can sense the "warmth of a nearby meal" and drop on the vertebrate host.

Many arthropods have unique mechanisms for surviving temperature extremes. For example, temperate-zone insects avoid freezing by reducing the water content in their tissues as winter approaches. Other insects can produce glycerol or other glycoproteins that act as an antifreeze. Some moths and bumblebees warm up prior to flight by shivering contractions of their thoracic flight muscles. Most large, flying insects have evolved a mechanism to prevent overheating during flight; hemolymph circulating through the flight muscles carries heat from the thorax to the abdomen, which gets rid of the heat—much as coolant circulating through an automobile engine passes through the radiator. Certain cicadas (*Diceroprocta apache*) that live in the Sonoran Desert have independently evolved the complete repertoire of evaporative cooling mechanisms that vertebrates use. When threatened with overheating, these cicadas extract water from their hemolymph and transport it through large ducts to the surface of the body, where it passes through sweat pores and evaporates. In other words, these insects can sweat.

Body posture and orientation of the wings to the sun can markedly affect the body temperature of basking insects. For example, perching dragonflies and butterflies can regulate their radiation heat gain by postural adjustments.

Many endothermic insects (such as bumblebees, honeybees, and some moths) have a countercurrent heat exchanger (*see figures 28.4 and 28.5*) that helps maintain a high temperature in the thorax, where the insect's flight muscles are located. This mechanism allows the insect to control heat gain and loss by regulating the amount of blood flowing through the heat exchanger. By allowing blood to flow through the heat exchanger or diverting it to other blood vessels in the body, the insect can alter the rate of heat loss as its physiological stage or environmental conditions change. For example, if an insect is flying in very hot weather, it runs the risk of overheating due to the large amount of work done by the flight muscles. Thus, the countercurrent heat exchanger can be "shut down" to allow the heat produced in the muscles to be lost from the thorax to the abdomen and then to the environment.

Chapter 15 provided a good example of how honeybees regulate their own body temperature and the temperature of their hive.

To prevent overheating, many ground-dwelling arthropods (*Tenebrio* beetles, locusts, scorpions) raise their bodies as high off the ground as possible to minimize heat gain from the ground. Some caterpillars and locusts orient with reference to both the sun and wind to vary both radiation heat gain and convective heat loss. Some desert-dwelling beetles can exude waxes from thousands of tiny pores on the cuticle. These "wax blooms" prevent dehydration and also are an extra barrier against the desert sun.

Color has a significant effect on thermoregulation, as 50% of the radiant energy from the sun is in the visible spectrum. A black surface reflects less radiant energy than a white surface. Thus, many black beetles may be more active earlier in the day because they absorb more radiation and heat faster. Conversely, white beetles are more active in the hotter parts of the day because they absorb less heat.

The previous examples of invertebrate temperature regulation give clues to how thermoregulation may have evolved in vertebrates. The endothermic temperature regulation of active insects apparently evolved because locomotion produced sufficient metabolic heat that thermoregulatory strategies could evolve. An increased metabolism associated with greater mobility could well have preceded the evolution of thermoregulation in vertebrates.

Temperature Regulation in Fishes

The temperature of the surrounding water determines the body temperature of most fishes. Fishes that live in extremely cold water have "antifreeze" materials in their blood. Polyalcohols (e.g., sorbitol, glycerol) or water-soluble peptides and glycopeptides lower the freezing point of blood plasma and other body fluids. These fishes also have proteins or protein-sugar compounds that stunt the growth of ice crystals that begin to form. These adaptations enable these fishes to stay flexible and swim freely in a supercooled state (i.e., at a temperature below the normal freezing temperature of a solution; −2° C [28° F]).

Some active fishes maintain a core temperature significantly above the temperature of the water. Bluefin tuna, swordfish, and the great white shark have major blood vessels just under the skin. Branches deliver blood to the deeper, powerful, red swimming muscles, where smaller vessels are arranged in a countercurrent heat exchanger called the **rete mirabile** ("miraculous net") (figure 28.4). The heat that these red muscles generate is not lost because it is transferred in the rete mirabile from venous blood passing outward to cold arterial blood passing inward from the body surface. This arrangement of blood vessels enhances vigorous activity by keeping the swimming muscles several degrees warmer than the tissue near the surface of the fish. This system has been adaptive for these fishes. Their muscular contractions can have four times as much power as those of similar muscles in fishes with cooler bodies. Thus, they can swim faster and range more widely through various depths in search of prey than can other predatory fishes more limited to given water depths and temperatures.

Temperature Regulation in Amphibians and Reptiles

Animals, such as amphibians and reptiles, that have air rather than water as a surrounding medium face marked daily and seasonal temperature changes. Most of these animals are ectotherms. They derive heat from their environment, and their body temperatures vary with external temperatures.

Most amphibians have difficulty in controlling body heat because they produce little of it metabolically and rapidly lose most of it from their body surfaces. However, as previously noted, behavioral adaptations enable them to maintain their body temperature within a homeostatic range most of the time. Amphibians have an additional thermoregulatory problem because they must exchange oxygen and carbon dioxide across the skin surface, and this moisture layer acts as a natural evaporative cooling system. This problem of heat loss through evaporation limits the