Husbandry and Care of Terrestrial Invertebrates (Chapter 36, ZOOKEEPING)

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Introduction

The invertebrate world is one of diversity. There are literally millions of invertebrate species, many of them terrestrial, so this one chapter is somewhat insufficient for a thorough discussion of this fascinating group of animals. Invertebrates fill many niches in terrestrial ecosystems; they are essential to these ecosystems and to the vertebrate taxa that share them. To maintain specimens in captivity, the keeper must understand how and where the animals fit into their own ecosystem and what they feed on in the wild—or, if that is not known, what their closest relatives feed on. The keeper should know the animals' social behavior (or lack of it) and life cycle, and also the animals' ancestry or origin if possible. Another essential point to remember is that terrestrial invertebrates are very small creatures (the largest tarantula only weighs as much as a small rat). They are also all ectothermic and therefore can suffer quickly from adverse conditions. Temperatures, humidity, light levels, and food availability are all factors that must be assessed, just as with vertebrates. Ensuring that the animals are kept contained is essential, and sometimes it is a challenge due to their size. Daily maintenance cannot be ignored simply because they are considered to be less advanced than vertebrates; even though they may not show stress as vertebrates often do, their size may put them at a disadvantage, especially with regard to water balance (smaller animals often dessicate more quickly).

Maintaining a consistent routine is the first step to keeping invertebrates. At certain times of their development, species such as caterpillars (larval butterflies or moths) deprived of food for just two or three hours cannot recover and ultimately die without developing into the adult form. Conversely, certain tarantula species have survived 100 days without water, or a year without food. Although this would not be done in zoos, it is a testament of the hardiness of some species. Researching the animals one is caring for is essential to understanding their husbandry. This chapter will concentrate on the species regularly kept in zoos and institutes. Most species are arthropods (possibly well over one million species, including insects, arachnids, and crustaceans), but some mollusks (e.g., snails) are also maintained. In many cases, groups will be generalized. Specific techniques will have to be obtained from the source of the animals if they are captive-bred through specific protocols. The husbandry of wild-caught specimens that have not been kept before must be learned through detailed data collection and trial and error. A few books on species' husbandry do exist, but they mostly specialize in the care of those species that are most often kept as pets (and which may be kept in zoos). With few exceptions (e.g., honeybees, silkworms, mealworms, and domestic crickets), invertebrates in captivity are maintained for public display. This is a relatively new field and thus information is very scattered and, for certain species, difficult to obtain. Maintaining good records and dispersing information to others in the field is essential if populations are going to be successfully kept for display, research, and education in the future.

After studying this chapter the reader will understand
- the general anatomical terminology, similarities, and differences among the varied taxa.
- how the anatomy, physiology, and behavior of terrestrial invertebrates affects the housing and feeding of these animals in a zoological setting.
- the best practices for the daily care, handling, housing, and transport of these animals.
- the general environmental requirements of these varied taxonomic groups; specifically, the availability of water and proper substrate.
- the unique requirements of certain species and the challenges they pose to keepers.

Orientation, taxonomy and general husbandry

No single system or method can describe the husbandry of invertebrates. To cover as much of the subject as possible, the chapter will use various examples. The two phyla covered in this chapter are the Arthropoda and the Mollusca. There are four subphyla of importance in the phylum Arthropoda and in this chapter: Chelicerata (spiders and scorpions), Crustacea (crabs), Hexapoda (insects), and Myriapoda (centipedes and millipedes). The arthropods are noted for having a chitonous exoskeleton, jointed appendages, compound eyes (in most species), and a segmented body.

The first step in husbandry of an animal is to identify it to species. If the animal has come from another

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Good Practice Tip: The main thing to remember with invertebrate husbandry is to be consistent. This includes placing props, food, and water at the same site, servicing the enclosures at the same time of each day, controlling fungal growth, and maintaining humidity at appropriate levels.

zoo, it will most likely be accompanied by proper identification and a protocol for care. This is a good start, but a protocol designed for Florida, with a high ambient temperature and humidity levels of 70% or more, may be different than a protocol designed in North Dakota. If possible, keepers should contact others who maintain the species to learn of any existing protocols and adapt them to the specifics of their own facility to create the best microhabitat for the animal. Invertebrates maybe difficult to acquire from captive sources, so often a keeper will need to develop original care protocols. After identifying the species, or at least its closest relatives, it is important to determine how to house, feed, and maintain it. When it is time to design an enclosure for a particular species, several basic questions must be addressed. The best way to begin is to find out where the species is from, including its natural climate, but especially its ecological niche microclimate, and specifically its preferred humidity. It is also important to know what else the species requires in its microhabitat.

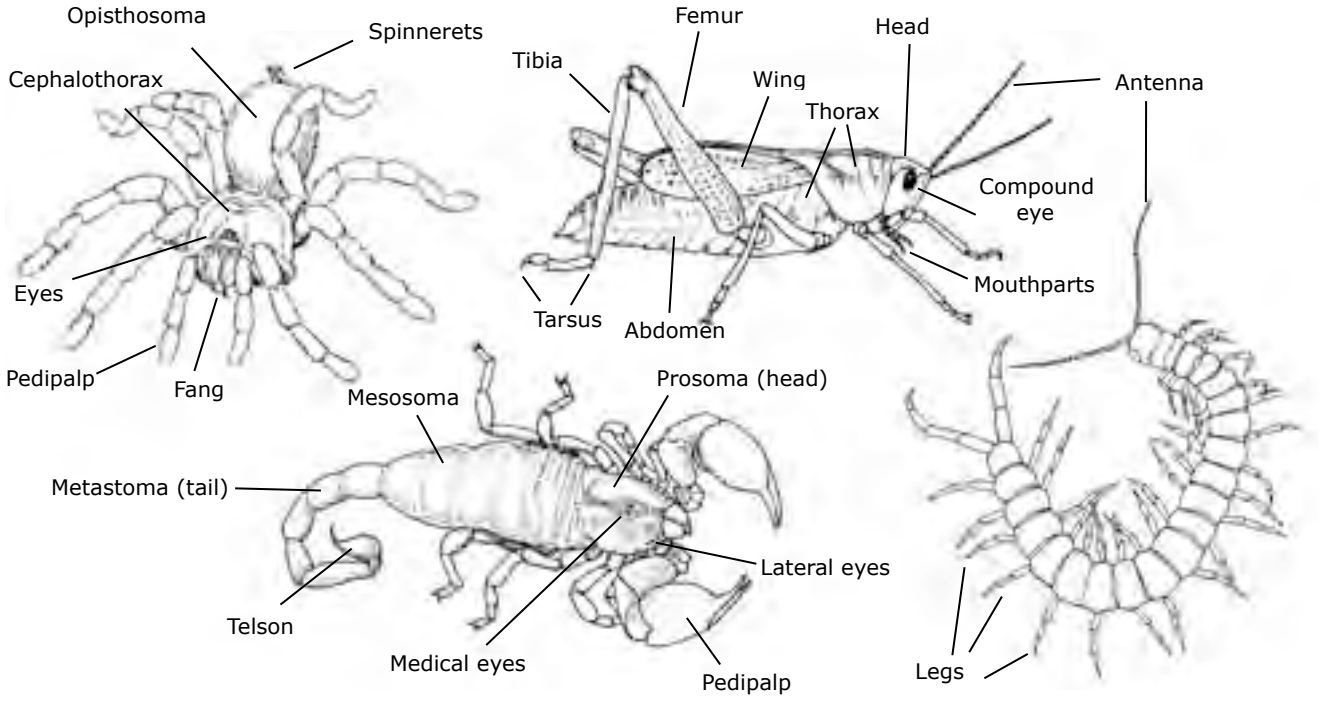
Crustaceans

Although most crustaceans are marine, they can be found in a broad array of habitats, including terrestrial environments. Almost all species have gills for respiration (some use highly modified structures, such as woodlice, order Isopoda, which use pleopods), but that doesn't mean that all are aquatic (for example, there are isopods adapted to desert habitats). However, the life histories of many terrestrial forms can be complicated, specifically with regards to reproduction, as many female crustaceans must return to the water to deposit their eggs, and the larvae may undergo various stages of development.

The most commonly displayed terrestrial crustaceans are land hermit crabs, various land crabs, and (most recently) certain highland forms of crabs (*Geosesarma* sp. from Indonesia, and *Eudaniella* sp. from the New World) found in rain forest areas of the world. For husbandry purposes, these groups can be divided into two broad categories. Most land crabs and all land hermit crabs depend on the ocean for at least part of their life cycle. These species tend to require some "hard" water (i.e., water with high mineral content, usually calcium and magnesium) or even brackish water (a mix of fresh and marine water) in captivity. The highland crabs (variously known as manicou crabs, mountain crabs, spring water crabs, and carnival crabs) are found well away from salt water and do not require any contact with a marine habitat. They do well with fresh nonchlorinated water sources. For all crustacean species, water quality and the control of microbes in the exhibit is important. Regular water changes and/or proper water filtration are required.

Most crustacean species maintained in captivity are found in tropical or subtropical areas. Knowing exactly where a species is found will help determine its temperature preferences. A good search through meteorological data would provide the keeper with seasonal temperatures and rainfall. Relative

Figure 36.1. Basic anatomical features of terrestrial invertebrates. Clockwise from upper left: spicier (subphylum Chelicerata), insect (subphylum Hexapoda), centipede (subphylum Myriapoda), scorpion (subphylum Chelicerata). Illustrations by Kate Woodle, www.katewoodleillustration.com.



humidity is also an important factor for some species. Knowing the chemistry of the substrate the animal lives on and whether the substrate drains, sheds, or holds water is also something to determine before building an environment for the animal. Knowing how the animal uses that substrate (whether it digs, sifts, etc.) is also important in deciding what depth of substrate to provide. Once these factors have been determined, the keeper can design the exhibit. When examining the environmental features, one should look at the moderate levels and not the extremes. The complete replication of an environment is impossible; therefore, all things need to be done in moderation.

To determine the size of the enclosure and its decor, knowing how the species uses its environment is essential. Species that live in leaf litter may spend their entire life moving from damp to dry sites within the litter. The opposite can be seen in the Caribbean land hermit crab (*Coenobita clypeatus*), whose adults can be found in trees, several meters off the ground. Knowing how and where the species use the habitat will help determine whether perching and live plants are possible or whether a sloped flat landscape is required. Also knowing whether the species is solitary (like the land hermit crab) or social (like the fiddler crab) will also help determine the size and shape of the exhibit.

Most terrestrial crustaceans are predominantly scavengers and detrivores. Dead leaves and wood are two important sources of nutrients for these animals. Some fruit, root vegetables, insects, and small amounts of animal protein (e.g., fish or shellfish) will be readily taken. However it is very easy to overfeed. These animals have to compete heavily for sufficient sources of protein and easily digestible carbohydrates in their natural environment. Dead leaves constitute a large portion of their food. For species such as fiddler crabs (*Uca* sp.) and the species found on mudflats, microbes sifted out of the wet silt are a major portion of their diet. It also must be remembered that the exoskeletons of crustaceans contain high amounts of calcium. It is therefore very important that calcium is available to these animals, usually in the form of cuttlebone.

Arachnids

Members of the class Arachnida are among the most popular species used in public display. They are in general hardy, longlived, and popular in displays. The most popular forms are the spiders (tarantulas, widows, and golden silk orb weavers), scorpions (emperor, desert hairy, and flat rock), whip spiders (Tanzanian, *Damon* sp.) and whip scorpions (American, *Mastigoproctus*; or Thai, *Typopeltes* sp.).

Tarantulas

There are approximately 900 species of tarantulas in the family Theraphosidae. All are predators, and all live in tropical to warm temperate areas. They differ, however, in what they need in the way of optimal temperatures, humidity requirements, and habitat. They also vary in the level of their aggression, the toxicity of their venom, and the presence or absence of urticating hair.

Tarantulas (also known as baboon spiders, earth tigers, or bird-eating spiders) can be found in habitats ranging from desert to rain forest. Desert species either burrow or find previously made shelters. Rain forest species are either terrestrial or arboreal. Forest-dwelling terrestrial species are often the same as desert species in their habits. Again, exhibit design should meet the needs of the species. Arboreal species need vertical hides, terrestrial species that hide require "caves" or ready-made burrows, and burrowers need substrate of a depth that allows them to dig. To ensure that a species can be seen, a tip would be to design its cage so that its prime hiding sites are at the front of the exhibit nearest the viewing area. Various substrates have been used over the years, including soils and mulches. Hatchling spiders can be kept in pill jars on vermiculite or perlite. As they mature and are moved into larger enclosures, they can be kept on peat moss or on a mixture of peat and sand, but sharp silica sands must not be used. Aged mulch can be a useful substrate for arboral species. The substrate and decor should be free of any pesticides, fungicides, preservatives, paints, or dyes, as chemicals of any form can be hazardous to the spiders' health.

Abiotic conditions vary. Tarantulas require variation in temperature and humidity. Desert species should be kept drier, but their enclosures should have areas slightly higher in humidity that the spider can retreat to. Forest species require higher humidity, and there should always be a level of moisture within the substrate, but keepers should also ensure that there is an area that remains dry. Desert species require warm days and cool nights. They also often prefer warmer, damper summers (26-29 °C [79-84 °F]) and cooler, drier winters (15-18 °C [59-64 °F]). For the reproductive success of temperate and high-altitude species, seasonal change is essential. Forest species also need seasonal variation, but in some cases the level of humidity combined with the temperature is more critical. As far as lighting is concerned, no requirement has been found for tarantulas. Lighting should be determined by what works best for the exhibit. Obviously, planted exhibits would need more light. In general, however, tarantulas tend to be somewhat photophobic. Therefore, the display sites one wants them to spend the most time in should be made the darkest. All tarantula species should have a source of water. Newly hatched specimens can get moisture from damp substrate, but as the spider gets larger a water source should be provided. A small shallow dish is best. It can be left open, but this often becomes a magnet for crickets that drown in it. To prevent this, keepers place a sponge or pea gravel in the water container to give the crickets a surface to walk on.

Crickets are probably the most common food item for tarantulas, but they are not a complete diet. In the wild a tarantula may eat large insects, scorpions, other tarantulas, small frogs, lizards, snakes, and small mammals. They will even take small birds. In

captivity, cockroaches, caterpillars, stick insects, mice, and chicks can be used as food. Small specimens should be fed lightly twice a week. Older specimens can be fed once a week to once a month, depending on the amount of food given. A spider should always be observed before it is fed. If the spider has covered the entrance to its retreat with silk, one must not feed it. This action is often the precursor to moulting or egg laying; the spider will not feed and is at a weakened state at this time. Crickets finding a spider in this defenseless, freshly moulted condition can use it as food. Even a small wound on the leg while the spider is recovering can lead to excessive fluid loss and death.

Tarantulas are solitary to somewhat social in nature. Most specimens, especially females, never travel more than a meter away from their hide, as their food comes to them. A few New World species have developed what appears to be a symbiotic relationship with certain species of microhylid frogs. However, this relationship has never been maintained or displayed in captivity. Some tarantula species are capable of living in association with conspecifics. This is always risky, however, and there is no guarantee that the spiders will remain compatible over time.

Once the exhibit is set up, it should be disrupted as little as possible. Leftover and dead food or any rotting organic matter should be removed. Tarantulas make their shelters to last a lifetime; excessive cleaning and disruption creates unnecessary stress for them, and it will end up affecting their quality of life. With a New World spider, one should wear disposable gloves due to their urticating hairs, which can cause discomfort. Though some people handle tarantulas, it is not recommended. Some species will bite (with various reactions) and can be severely injured or killed in a fall. When a tarantula must be moved, the easiest method is to use a tube or a small container, such as a clear plastic cup. One should set the cup in front of the spider and then, using the lid, gently touch the abdomen and push the spider into the cup. PVC tubes are often used as hides for tarantulas. With both ends of the tube covered, it is easy to transport the spider for short periods with no danger to the spider or the handler.

Scorpions

Most scorpions are tropical to subtropical, and are found from deserts to rain forests. They may live in trees, under rocks, or in burrows. Some are social, while others are solitary. Ecosystems in the Middle East have been known to contain 25,000 scorpions per hectare (2.471 acres) of land. In captivity, many species are offered by dealers. The species recommended by the North American s Association of Zoos and Aquariums (AZA) Terrestrial Invertebrates Taxon Advisory Group (TITAG) is the African emperor scorpion (*Pandinus imperator*). Other species often displayed are the African flat rock scorpion (*Hadogenes* sp.) and the desert hairy scorpion (*Hadrurus arizonensis*) from the American southwest and Mexico; however, the diversity of habitat use by scorpions is by no way covered by these three species, of which only the emperor scorpion is consistently bred in captivity.

Each of these three highlighted species needs a different kind of substrate. The emperor scorpion is a communal forest dweller that digs its own burrows; it needs a substrate that can hold the burrows without collapsing and also maintain a relatively high humidity. Pure peat moss, potting soil, aged mulch, or a mixture of peat and sand are often used. In the wild, emperors spend much of their time below ground, but replicating this in captivity would make them difficult for zoo visitors to see, so the depth of their substrate is often reduced. For best viewing, a sheet of clear glass or acrylic can be placed over a shallow depression in the substrate. The emperor will hide under this as a form of security, even though it can be clearly seen from above. This works as long as ambient light levels are minimal.

The desert hairy scorpion is also a burrowing species. The harsh habitat it inhabits forces it as much as a meter (39 inches) underground for many months of the year. In the desert scrub the substrate is normally coarse sand. In captivity, a small amount of peat moss mixed with coarse sand helps to hold the sand in position. This species may spend long periods of time buried underground. The lower levels of its substrate should show some signs of humidity, while the upper layers should be dry. Again, a glass cover placed over a shallow depression in the substrate can be useful for exhibiting this species. The rock scorpions (*Hadogenes* sp.) are not burrowers. This African genus specializes in rocky habitats. They squeeze into cracks between rocks, or find flat rocks under which to dwell. They do not dwell outside the rocky outcrops. When housing them, it is best to have a shallow absorbent substrate. Aside from that, layers of rock set up as shelves will keep this species happy.

Scorpions as a whole are photophobic. They may come close to the surface to heat up, but they will always stay under cover. The best way to view them is in subdued light. One point of interest is that all scorpions have a waxy substance on their exoskeleton that reflects ultraviolet light. Many exhibits are designed to go dark at the push of a button and then use ultraviolet light to make the scorpion glow. This is a very dramatic method of display, but some reports state that prolonged exposure to ultraviolet light is dangerous to scorpions. It is best to spot clean these containments, removing leftovers, with minimal disturbance to the animals. No chemical product should be considered safe with these animals. If the exhibit glass needs cleaning, try to dry clean it first. If this does not work, use a small amount of water.

All scorpions are predators, and they will eat anything they can overpower. In most cases, the prey is half the scorpions size or less. Some species will take larger prey, using their venom to subdue it. In the wild, the prey can be ants, termites, beetles, cockroaches, spiders, or other scorpions; for larger

species it can also be small lizards, snakes, or other small vertebrates. Larger species tend to overpower their prey, using their strong claws (pedipalps) to grab and subdue it. Smaller species grasp the prey with their pedipalps, but these clawlike organs are not powerful enough to subdue the prey. The prey is then quickly dispatched with a sting. For scorpions in captivity, crickets are the main staple, though they are not considered a complete diet. To ensure that specimens are kept healthy, one should feed them a variety of food. Mealworms, mealworm beetles, cockroaches, and other insects can be used. Larger species will also take small mice. One must not feed larger live mice to large scorpions, as the mice can fight back and cause damage. Feeding a scorpion once a week is sufficient. If it starts to look fat, it may be about to moult or produce young. It must only be fed what it will eat in a short time period. Many scorpion species feed on other scorpion species as a normal part of their diet. In fact, many species are solitary and are socially compatible with other scorpions only when a female is receptive. On the other hand, species such as the emperor scorpion are social and live in family groups. Both the male and female emperor scorpion are known to feed their young for up to 18 months, and the offspring may live with their parents for three years. Reproduction involves ritualistic courtship, and females give birth to live offspring, which will remain on the female's back until they molt.

Scorpions are quite diverse in their need for water. Forest species such as the emperor scorpion should have a source of moisture supplied regularly. Open water is not advised, as scorpions cannot swim, so pea gravel or a sponge is often placed in their open water containers. It is extremely important for a keeper to know the preferred habitat for a species. Too much exposure to water may be fatal to the scorpion. Desert species are very well adapted to living in areas with little water. For example, desert hairy scorpions allowed to walk over a water source can actually absorb too much water, and this can prove fatal. These scorpions are quite capable of procuring enough water from their food, and thus they should have very limited contact with water. It is therefore extremely important to research each species and know what range of humidity and moisture is normal for it.

Of the 1,500 species of scorpions, only a number of species in one family (Buthidae) are considered dangerous to humans (i.e., possessing venom of medical significance). The three species highlighted in this chapter are not considered highly venomous, and their stings range from a pinprick feeling to that of a bee sting. As some species can be deadly, one should always be careful when handling a species one does not know. The best way to move any unknown scorpion is to use a container that can be placed over it or in front of it, and then pushing the scorpion into the container using forceps or the container's lid. Scorpions can be picked up by grasping the last segment of the tail, preferably with forceps and not fingers. Large species can lift themselves up and use their claws in defense, and can draw blood with them.

Whip Scorpions

The whip scorpions are a small order (Thelyphonida) of arachnid that is becoming more popular. Unfortunately, most still come from the wild. Two species are found in the zoo world. The most common is known as the vinegaroon (*Mastigoproctus* sp.), from the southern region of North America, and the other is from Thailand (*Typopeltes* sp.). The latter species has been bred in captivity, but captive-born numbers are low. Most species tend to come from forests ranging from upper scrub and pine to humid forest. Although they look dangerous, they are harmless. Their one defense is their ability to spray acetic acid into the faces of their enemies. If the acid contacts the eyes, it will sting and perhaps cause temporary blindness. Whip scorpions have the same basic anatomy as other arachnids. They have eight legs, eight eyes, and two major body parts. They differ from scorpions in having a flagellum and not a tail ending with a venomous sting. The first pair of legs are antenniform (elongate with sensory organs). They cannot be used for walking, but have the same use as antennae in insects.

Whip scorpions are mainly terrestrial. Some may climb, but they prefer flat horizontal surfaces. Most of their time is spent underground in burrows. They are photophobic, so subdued lighting is preferred in a zoo display. A shallow substrate of a sand/peat mixture or a sterile cactus soil is fine. For viewing, place their shelter against the viewing glass or use a piece of glass over a depression in the substrate. The substrate should be dampened regularly, but should never get too wet. The lower levels of substrate should always contain some moisture, with the top staying dry. This will enable the whip scorpion to find the humidity level it desires. The diet for this group is similar to that of scorpions, but the food should be smaller. Whip scorpions can only physically overpower their prey, not having a stinger, so they are unable to take larger meals. They have been known to eat small spiders, scorpions, a variety of insects, small lizards, and snakes. Of course, whip scorpions should also be given a source of clean water.

When cleaning, it is best to disturb the animal's habitat as little as possible. Dead and refused food should be removed and surface fecal material cleaned up if possible. If the animal is held off display, one should let it burrow and not disturb or feed it if it fills in the entrances to its burrow. Covering of the burrow means the specimen is going to moult, aestivate, or have young. Disturbing it will only stress the animal. No precautions are required when handling these species, except to keep them away from the eyes. If a specimen is placed into a small container and sprays acetic acid within the container, it can be fatal to the animal. So one should ensure that the animal is not disturbed when contained, or it should be allowed to spray beforehand. Reproduction in the whip scorpion is similar to that in scorpions,

and the sexes should be kept separate except for breeding.

Whip Spiders
The whip spiders (order Amblipygi) are the closest relatives of the true spiders. They were once known as tailless whip scorpions, but the common name was changed to help avoid confusion. Whip spiders differ from true spiders in not having the ability to produce silk and in not having secondary reproductive organs on the pedipalps. They are tropical to subtropical and are photophobic and, for the most part, antisocial. Pairs with young will live together for some time, but this compatibility will break down over time.

Whip spiders are extremely vertically compressed (flattened). Like spiders they have two body parts, eight legs, and eight eyes. Their vision is poor but their first pair of legs are very long and antenniform. Most often they are found on vertical surfaces, and during the day they can be found in caves or wells. At night they venture out and may be seen on tree trunks or flat rock faces. Smaller species sometimes use rodent burrows as their residence. The species most often available is the Tanzanian whip spider (*Damon variegates*).

The substrate can be shallow, as they do not dig; peat moss or pea gravel can be used. Keeping the substrate damp will help maintain the high humidity they prefer. When properly set up, whip spiders will only visit the bottom of their displays when there is no comfortable vertical surface to sit on. They prefer vertical surfaces and are often positioned upside down. A single animal appears to do well on a surface that is 30 x 30 cm (one square foot) in size. Whip spiders prefer flat surfaces with a slight roughness, and tree bark (e.g., cork) or wood is fine. Rock can also be used, but its texture may cause the claws to wear down.

Whip spiders will keep the vertical surfaces they walk on clean by defecating at the bottom of their enclosures. One should clean the substrate periodically and wash any fecal matter from vertical surfaces with clean water. No chemicals of any sort should be used, unless it is planned to remove the animals and break the entire exhibit down. Once a whip scorpion is set up, it is best to not move it. Physical contact will increase stress and reduce longevity. As with scorpions and whip scorpions, subdued lighting is definitely preferred.

These animals are predators. Whereas a spider must eat its food as a liquid, whip spiders chew and masticate their prey. Only the hardest materials are left behind. The large raptor-like pedipalps are used to capture and subdue the prey. Whip spiders feed on any living thing of the appropriate size. This could include crickets, cockroaches, mealworms, moths, caterpillars, small lizards, or one another. In captivity they should be offered a variety of food, and fed twice per week.

These animals should also always have a dish of clean water. They are capable of going underwater when frightened, but one must ensure that they can maintain a grip so they can pull themselves out. It is best to put a sponge or gravel in the water container so they can drink without having to risk going in. Place the water container close to the vertical surface, as this will ensure that they can find it.

It is possible to place a pair of whip spiders together as long as they are given sufficient food. The males have longer pedipalps than the females. It is not advisable to try more than one pair together. The young will remain on the female's back after hatching until their first shed. Groups of these species living together have been noted in captivity. In the wild, it is unusual to see more than whip spider at a time, but sometimes pairs are observed together, or a small group can be seen in a well or a cave where conditions are optimal. Handling and transporting these arachnids and all the others mentioned previously is basically the same. They should be placed in a small container that restricts their movement. They should be able to sit in a comfortable position but have cushioning above, below, and all around them. The animal must be protected from any jarring or shaking, as abdominal injuries are often fatal.

Other Arachnids
The orders Opiliones (harvestmen, daddy longlegs), and Solifugae (wind scorpions, camel spiders) have occasionally been used for displays. Opilionids can be maintained on dead insects for prolonged periods, and some are impressive in appearance; however, they are not available commercially. Solifugids are available through the pet trade, but there is little available information that explains how to maintain this order in captivity. Experimental trials on this group may help develop maintenance strategies for these animals, but none have yet been successful.

Insects
More species of insects are known than all other species of plants and animals put together. Insects make up 85% of all known animal species, and other invertebrates make up a further 12%. Described here are the insect species most commonly maintained in public displays.

Orthopteroids
Orthopteroids are part of a large group of insects from various orders that include the katydids, grasshoppers, cockroaches, mantids, and stick insects. Most have two pairs of wings, although there are species that cannot fly or have entirely lost their wings. They also have chewing mouthparts, characteristic of more primitive insects. Members of four orders are often kept for exhibit. They cover a large variety of shapes and sizes, and are found on every continent except Antarctica. In all there are over 36,000 species. They have competed with humans for crops in plague proportions; they use people's homes as shelters, and sometimes as food. Some have been recognized as symbols of luck, while

others have been used in competitions to fight to the death.

The cockroaches (order Blattodea) are well known for sharing residences with humans throughout the world. They are also part of the detrivore (organic decomposers) cycle from temperate zones to the tropics. A few feed on flowers and vegetation, but most specialize in consuming dead organic matter. Most are nocturnal by nature and vertically compressed, with cryptically-coloured bodies, usually brown in color, although green, black, and multicolored species are known. Most are considered semisocial, and some species, such as the wood roaches of Canada or the burrowing roaches of Australia, are classified as monogamous, with pairs mating for life. Several species have been kept for display. The most commonly kept are the American cockroach (*Periplenata americana*), the hissing cockroach (*Gromphadorhina portentosa*), Brazilian giant cockroaches (*Blaberus giganteus*) and the Cuban roaches (*Panchlora* sp.). All of these species are basically kept in the same manner. The main differences are their humidity requirements and the enclosures required for them. Food, substrate, temperature, and furniture are all similar.

Cockroaches in general should be maintained on a dry absorbent substrate, such as peat moss. Slight dampening will help keep the dust down, but if the substrate is too wet, fungus will proliferate and this could jeopardize the health of the animals. In the species previously mentioned, less than 2 cm (4/5 in.) of substrate is required. Juveniles will burrow and hide under the substrate if it is loose enough. Furniture requirements can be a variety of materials, depending on the environment being portrayed. American roaches are often displayed in household settings, while Brazilian giants and the Madagascan hissers tend to be depicted on dead wood or forest floor settings. The way an animal is displayed can tell the public a lot about the animals' habits. If cockroaches are being kept off display, a good medium to hold them on is cardboard egg cartons. This medium is absorbent and easily replaced if necessary. Cockroaches will basically eat any organic matter. Food can include carrot, sweet potato, banana, apple, orange, lettuce, kale, rabbit pellets, dog chow, cereals, any human foods, dead wood, dried leaves, or dried animals. The food should not be allowed to become moldy, but otherwise if it is organic it can be eaten. A source of water is important, but the water should not be an open source as the cockroaches may drown in it.

Cockroaches should be kept shaded as they do not like light. If the exhibit contains too many dark crevices, the specimens will disappear. The temperature should stay between 21 and 25 °C (between 70 and 77 °F). Temperatures that are too high appear to cause premature ejection of egg masses. Species such as American roaches and hissing roaches are quite capable of climbing glass, while others can fly; so one should ensure that the enclosures are properly and securely covered, with metal screen over ventilation openings, as cockroaches are quite capable of chewing through nylon or fiberglass screen.

Praying mantises (order Mantodea), although taxonomically close to the other insects mentioned here, are very different in behavior and morphology. They are solitary hunters that only come together for a short time to mate. When mating, at least in captivity, the female mantis often kills and consumes the male after fertilization. Compared to that of other orders, husbandry of praying mantises is relatively simple. All are ambush predators that will feed on anything that they can overpower. The smallest species make a meal of a house fly, while large species such as the Chinese mantis (*Tenodera sinensis*) have been known to capture and consume hummingbirds.

For best results, a praying mantis should be reared singly. A specimen does not need a large space. A young specimen will do well in a small plastic box 15 x 10 x 10 cm (6 x 4 x 4 in.) in size. As the mantises grow, they can be moved to larger containers. A large praying mantis could be kept in an aquarium 60 x 30 x 30 cm (24 x 12 x 12 in.) in size. Most species prefer being off the bottom, so perches should be placed both vertically and horizontally. If possible, do not place perches in a manner that will allow crickets to climb to the top of the container. The mantis can climb to the top by walking up the side, and this gives it a "safe" spot to allow it to moult without being disturbed. A freshly moulted mantis is defenseless and open to attack by feed insects such as crickets. Feeding the mantis is quite easy, and the larger the mantis the larger the prey should be. Flying insects are the preferred diet. Fruit flies, house flies, wax moths, and even honeybees can be fed to mantises. Crickets, grasshoppers, and beetles will also be taken if the mantis is hungry, but they are not what mantises prefer. The species with the heaviest raptorial forelegs are capable of taking the largest prey. For water, misting is the best method. All species prefer to drink droplets of water, and normally one spray of water a day is sufficient. Known rain forest species should also get an evening shower as well. On average, mantises are short-lived, with three to four months being the average, although occasionally they can reach six months or possibly a year. For breeding, one should use a young adult female and feed it very well before adding the male, and use a larger space than they are normally kept in, as this will give the male a greater chance to survive.

Some stick and leaf insects (order Phasmatodea) are possibly the most displayed insect species in North American zoos. The Macleay's spectre's (*Extatosoma tiaratum*) only competition may be the Madagascan hissing cockroach, but the Macleay's spectre is much more impressive in appearance. Stick and leaf insects are superb exhibit animals and educational tools. Some are the longest insects in the world. Many are sexually dimorphic, but some are parthenogenic with female-only populations produced from one individual, and colonies that may last for years. Some are winged, others totally flightless,

and their ability to "disappear" in the environment has given them their ghostly name, the phasmids; yet a few specimens display aposematic (warning) coloration. Although all stick insects are similar in their husbandry needs, there are also differences. Some are generalist feeders, while others require specific foods. Some stay in branches to hide, while others retire to cracks or under rocks for the day. Good references are available through groups such as the Phasmid Study Group in the UK (www.phasmid-study-group .org). One stick insect species that is recommended to keepers by the AZA Terrestrial Invertebrate Taxon Advisory Group (TITAG) is the Peruvian firestick (*Oreophoetes peruana*). This is the one available stick insect with warning colors of red and yellow on black. Although not a large insect (6-9 cm/ 2.53.5m), its striking colors always make an impression on the visitor. The species is also unique in that it requires ferns as a food source. Stick insects are often displayed in large numbers and make an impressive display. However, one should make sure that enough space is available; otherwise accidental cannibalism may occur. If limbs are lost, the number of animals in the enclosure should be reduced. Limb problems may also occur if the humidity is kept too low as well. If this is the case, pieces of old sheds will remain attached at the legs. If limbs are lost in the earlier stages of development, they can regrow, but adults that lose limbs will not grow replacements.

For all species the need for good browse is essential, especially during the early life stages. Favorite plant species for generalist feeders are raspberry, bramble, rose, white oak, leather leaf viburnum, and ficus. For many Australian species, eucalyptus can be added. Mango leaves are also taken by many stick and leaf insects, but that plant appears difficult to maintain in northern climates, so it is not recommended as a key food source. Generalists include some of the favorite species including Macleay's spectres, thorny devils (*Eurycantha calcarata*), Annam sticks (*Medauroidea extradentatum*), and Malayan wood nymphs (*Heteroptera dilatata*). When offering food, one should keep the leaves on branches, place the branches in a container of water, and block any access to the water; otherwise the insects can drown. Ensure that the branches are long enough to support them. Stick insects prefer to hang upside down from the branches, and enough space must be given to allow for this. It is sometimes difficult to get newly hatched juveniles to eat. Raising the humidity helps, but newly hatched "sticks" prefer to feed at sites that have already been chewed, so to get them started they should be placed on the same food plant with older specimens. If a young insect is the first specimen in the collection, one should tear (not cut) a piece out of a leaf and offer it to the insect. Changing the species of plant offered as food can sometimes cause problems in a collection. For example, losses may be as great as 50% when a species is moved from bramble or raspberry to any of the fig species. Once converted, the insects appear to be fine. Changing from a hard leaf to a soft leaf tends to lead to fewer problems, but problems still can occur. A gradual change is best. It is not usually advisable to feed stick insects on potted plants; they will use the pot as a place to lay their eggs. This leads to problems later when the plant is moved elsewhere to "rest" and regenerate, as babies may end up hatching in the wrong place. Potted plants should only be used if the soil is covered or if the plant is large enough and the stick insects are in low enough numbers not to cause major damage. Reproduction is relatively straightforward as long as males are present with the females, except in parthenogenic species. Finally, when working with stick insects, keepers should be extremely careful when exchanging food. Newly hatched stick insects tend to sit on branches and often get overlooked and discarded with the refuse. Also, keepers should always know how many insects are supposed to be in the container and count them before discarding any old and refused food.

Grasshoppers and katydids (order Orthoptera) have species with different requirements, some of which are very specific. Grasshoppers include the locusts, and their infamy dates back to biblical times, as swarms of locusts and grasshoppers can destroy large tracts of farmed crops. Despite that, a few species are maintained for display, whereas some species, such as the desert and migratory locusts, may only be kept in labs under strict quarantine. The species that appears to be most popular for displays is the eastern lubber grasshopper (*Romalea microptera*). This is a colorful (aposomatic) nonflying species that is hardy and reliable as a display and as an educational tool for children. The species can be maintained in front-opening screened insect cages at least 40 x 40 x 60 cm (16 x 16 x 24 in.) in size, at a temperature of 23-30 °C (73-86 °F). These grasshoppers are diurnal and enjoy basking under a hot spot as do many reptiles. In the wild they will eat a wide variety of foods including some that are quite noxious to poisonous, and they are capable of using these chemicals after they are ingested. In captivity they can be fed kale, sliced apple, carrot, and sweet potato. The food is best presented to them hanging from hooks, as grasshoppers tend to like vertical surfaces to sit on. The food should be replaced approximately three times a week, or more often if it gets consumed faster. Shallow dishes of dry rolled oats, bee pollen, and bran can also be used. It is a good idea to not use lettuce unless it is 100% organic, as the pesticides used on farms often target grasshoppers, and residue appears to be on lettuce quite often. As for watering, most species tend to get enough moisture from the food they eat. A light misting is recommended for forest species. Eggs are laid in the substrate (females have an ovipositor), and adults die shortly after mating.

Katydids have diverse life histories. Among them there are herbivores, frugivores, food specialists, carnivores, and omnivores. Most katydids live in trees and bushes, but some like grasslands. Their eggs can be laid in the ground or in trees, in dead or living plants, or sometimes on the edges of leaves. Some katydids can also inflict an extremely painful

bite. They differ from grasshoppers by having longer antennae. In general katydids prefer an arboreal habitat, so tall enclosures are best suited for them, similar to those used for grasshoppers. Most katydids are solitary by nature and nocturnal, but a few appear to be semisocial and will hide together in small groups. Green katydids tend to hide on leaves in the open while many of the large brown forms find cracks or hollow logs to hide in during the day. They tend to come from moister habitats than most grasshoppers, so twice daily misting is recommended. Food will depend on the species kept. Most, even carnivores, will chew on sliced apple or cucumber. Some can be fed the same as grasshoppers, while others may need crickets or pollen added to their diet, and keepers should always keep their food fresh. The reproduction of katydids is similar to that of grasshoppers. Some katydids can live more than a year, so they can make good exhibit specimens. However, keepers should note that the adults are capable of flight, and that all have extremely good jumping abilities.

True Bugs (Order Hemiptera)
The true bugs most often displayed are the aquatic forms such as giant predacious water bugs, back swimmers, and water striders. Two terrestrial species predominate the captive displays. These are the large milkweed bug (*Oncopeltus fasciatus*) and the two-spotted assassin bug (*Platymeris biguttatus*). The first of these is an herbivore and the second a predator. As in all true bugs, the mouthparts in both these species have been modified to form a long, jointed tube capable of penetrating the protective skin layer of a plant or of prey. Both species require enclosed containers, as the adults are capable of flight. Increasing the surface area to walk on will allow for a greater concentration of specimens living together. The species are often found just above the substrate, so a thin cover of substrate is all that is required. For optimal activity, the temperature should remain between 23-26 °C (73-79 °F), although the large milkweed bug is capable of surviving in much cooler temperatures.

Both these species are quite capable of living without water, although they have been known to drink if the opportunity arises. They suck food and water through their proboscis. The large milkweed bug can be fed on milkweed plants; it especially favors the pods and seeds. Stored dried seed is fine. In laboratories a strain of this species has been developed that feeds on shelled sunflower seed. This form is nontoxic, unlike the milkweed-feeding wild types that use the toxins within milkweed to become toxic themselves. Two-spotted assassin bugs can be maintained on a diet of crickets. The more they are fed, the greater the number can be maintained together, as less cannibalism will occur. Both species also display aposematic coloration. The bright orange and black color of the large milkweed bug is a warning to predators of its noxious, poisonous nature. The two-spotted assassin warns of its venomous bite, which is extremely painful and can be lethal to people if an allergic reaction (anaphylaxis) occurs. The two-spotted assassin is also capable of "spitting" venom, which is very painful if it hits a person in the eye.

Beetles (Order Coleoptera)
The beetles are the largest order of animals in the world. There are approximately 10 times more species of beetles than of vertebrates. The diversity in their life history is just as broad. There are carnivores, herbivores, carrion feeders, aquatic dwellers, desert dwellers, fossorial species, and arboreal species. Some are adaptable to living among humans while others suffer due to human activity. The methods of care for the beetles are just as diverse. Certain species kept in captivity require specific diets to survive, whereas others are generalists. The most important and popular species in North American institutions are the scarab beetles. Temperatures for all should be maintained between 20-25 °C (68-77 °F).

Several species of scarabs are regularly maintained in collections. This large family contains the dung beetles, the flower beetles, and the giant rhinoceros beetles. As larvae all feed on decomposing plant matter, while adults become sap, fruit, or leaf feeders. One popular species is the yellowbellied chafer (*Pachnoda flaviventris*). Another species recommended as a species to be maintained by the AZA Terrestrial Invertebrate Taxon Advisory Group (TITAG) is the Atlas beetle (*Chalcosoma atlas*). Although quite different in size, these species have similar husbandry requirements. As adults, they both need to be able to move off of the substrate. Adults live on branches or any surface above ground at a temperature of 23-26 °C (73-79 °F). It is possible to keep an individual in a small space (30 x 15 x 20 cm, or 11.8 x 5.9 x 7.9 in.), but if there is more than a single animal a space of 60 x 40 x 20-40 cm (23.6 x 15.8 x 7.9-15.8 in.) is required. The base should be covered with a 10 cm (4 in.)-deep mixture of manure, dead leaves (oak, beech, or mixed deciduous), and soft (moist) rotting hardwood. In chafers the manure can be sterile commercial cattle or sheep manure, but for larger species such as Atlas beetles fresh cattle, zebra, or rhino manure results in higher production rates. Zoos are lucky in having such material readily available. Larval chafer beetles can be maintained in crowded conditions with 50 to 80 within an 80 x 40 x 15 cm (31.5 x 15.8 x 5.9 in.) space. Larger species, however, need to be given more space or cannibalism will occur, and usually only two to four larvae can be maintained within the same space. The medium should be changed when a high proportion is made up of larval frass (insect feces) or the medium looks very consistent in nature. Metamorphosis may take place after four months (in chafers), or after three years (in some of the larger rhinoceros beetles). Adults live from three to six months. All of the adults feed on soft fruit. The chafers and some other small species also feed on fresh leaves, and in captivity kale is often fed. The species contained within the scarabs are among the most unusual and colourful species of beetles.

The last species of beetle that should be considered is the American burying beetle, *Nicrophorus*

americana. This endangered species is one of the SSP species of the AZA, and a complete protocol for their care is available. Adults are set up in pairs for captive breeding. They are given a deep substrate of loose damp soil, and they feed on insects or pieces of meat. For breeding, the pair is given a carcass of appropriate size. Working together, the pair buries the carcass, and once underground the carcass becomes a nursery for baby beetles. The female (and rarely the male) takes care of the brood until it disperses into the soil to pupate. This program has been underway for several years and self-perpetuating wild populations now exist from the captive born stock.

Myriapods

Although centipedes and millipedes are not as obvious in the environment as butterflies or grasshoppers, they can and do make interesting exhibit animals under the right conditions, and they can live several years. Keepers should be aware that many species are nocturnal or semifossorial, and that many of these animals like to hide, and thus present challenges to display similar to those presented by scorpions. Centipedes are carnivorous and can consume a wide variety of prey (including crickets, earthworms, mealworms, and even small mice), but keepers should refrain from overfeeding them as it will shorten their lifespan; usually once or twice a week is sufficient. They must also be kept singly, except for reproductive purposes, as they will feed on other centipedes. Water can be provided by misting, but larger species will also use a shallow water dish, and keepers should ensure that their substrate (usually a soil mix) does not become too dry (especially for forest dwellers), as dessication is a concern. Some species are found in arid climates, but they shelter in moist microclimates during the day, such as underground and under large rocks. Most species are nocturnal, but a reverse light schedule can be used to enable viewing during the daytime. Enclosures must be secure, with metal screening used for ventilation, as the larger species have been known to chew through weaker materials such as fiberglass and plastic. Species from the genus *Scolopendra* are most commonly exhibited, with the South American *S. gigantea* relatively popular in zoos and among private hobbyists due to its larger size (up to 30 cm [12 in. long]) and its red body with yellow legs. They are quite fast and aggressive, with powerful venom, and should not be handled without tools. The females are known to protect their eggs.

Millipedes are herbivorous, consuming decaying plant material in the wild, but they can feed on produce such as lettuce, vegetables, and fruit in captivity. They can be fed ad libitum, with the food presented in a dish for ease of presentation and removal, and uneaten food removed daily; they may also require an additional source of calcium. Most species require sufficiently moist substrate (usually a soil mix) and higher humidity, but keepers should provide sufficient ventilation to prevent mold growth. Millipedes can be kept in groups with both males and females present; they lay their eggs in the substrate. The adults are usually dark-colored (black or brown, although some species can be bright orange), and the juveniles are usually white with few segments and legs, although additional segments and legs are added with growth. Most species are slow-moving and nocturnal, but again they can be displayed with a reverse lighting schedule. They are not aggressive, often coiling up when threatened, but they do possess paired glands on each segment that emit a noxious fluid mix of chemicals as an antipredator defense. Because of this, keepers should take care to wash their hands after handling them and prevent the fluids from contacting their eyes and mouth. The giant African millipede (*Archispirostreptus gigas*) is the most commonly exhibited species, which can reach up to 28 cm (11 in.) in length. Keepers should note that this millipede will burrow, and should account for its behavior when designing its enclosure.

Terrestrial Snails and Slugs (Class Gastropoda)

The European striped slug (*Limax maximus*), the banana slug (*Ariolimax columbianus*), the European garden snail (*Cepaea nemoralis*), the Roman snails (*Helix* sp.) and various giant land snails are often displayed because of their impressive size or bright colors (the giant land snails are not displayed in the United States, due to various regulations). They represent a large important taxa not often displayed. The unique mouthparts (rasping radula) and mode of locomotion make these species great educational tools. They can be maintained in enclosed plastic or glass containers with dampened substrate and no need for extra light. Only the tropical giant snails require warmer temperatures (25 °C/ 77 °F). Most gastropods are nocturnal, but if the substrate is moist and the light is not overly strong, they can be stimulated to move during the day.

Moisture should be offered through the food or by regular misting. Water in an open dish is not to be used, as the animals may enter and drown. As for food, these species are detritivores and herbivores. Lettuce, sliced yams, carrots, and apples can be placed with dead deciduous tree leaves and rotting wood. For a calcium source, cuttlebone works well (slugs require calcium too). This ensures proper shell growth and is required for metabolic purposes. Occasionally a protein source should be offered. In the wild this would be provided by carrion or fecal material. In captivity, a small amount of mouse chow or dog kibble could be used.

Reproduction is possible in captivity with these species. Some are hermaphrodites (in which the individuals have both male and female reproductive organs), so that any two animals could breed, while in other species male and females are separate. In the giant snails, an appropriate diet and warm humid conditions are all that are required for successful reproduction. Temperate species may reproduce in their first year, but a seasonal cooling is required to be continually successful. Eggs are laid under cover or buried in the substrate. The eggs hatch within a few weeks to a few months (some eggs laid in the fall may not hatch until the next spring). Young can be treated as the adults, but they are extremely

sensitive to desiccation and overwatering. Their growth is very quick as long as the appropriate food and water is available. The food must be plentiful, but rapid fungal growth must be avoided.

Enclosures, Tools and Transportation
Most of the species considered and discussed in this chapter will require relatively modest enclosures, typically constructed of glass and transparent acrylic (plastic) for optimal viewing and ease of cleaning. Glass may be preferable over acrylic, due to its greater resistance to scratching (a concern when cleaning), but it is also heavier than acrylic and can break if struck or dropped, whereas acrylic is impact-resistant. All enclosures must be ventilated, but openings must be screened (preferably with metal screening that cannot be chewed through) to prevent escape. Keeper access for husbandry efforts must be considered when choosing or designing an enclosure, and keepers should be able to access the enclosure without fear of escape or harmful interaction with the species within. There are many possible designs, including the use of commercial aquaria (especially for "holding" areas where aesthetics are not important) and even commercially available reptile/invertebrate enclosures with integrated screened openings. Exhibits may also be designed and constructed in-house by the facility's staff using materials such as fiberglass and gunnite and possibly incorporating intricate water features for certain species such as crabs. Other animals can be kept and displayed in quite large and unique exhibits such as the leafcutter ant exhibit at the Cincinnati Zoo, where lengths of acrylic tubes traveling throughout the World of the Insect exhibit building allow the ants to forage for leaves and return to their nest.

Tools used in invertebrate husbandry usually consist of forceps used for the feeding of prey to certain species, small scoops to remove fecal material and uneaten food from the enclosure substrate, variously sized plastic cups used to capture and move species that cannot be "free-handed" due to venom or delicacy of the invertebrate, and spray bottles used to mist enclosures. Tools used with invertebrates must be cleaned after use and stored so that they are accessible and free from damage.

Transportation needs are usually quite modest for most species discussed in this chapter, many of which can be moved in simple clear plastic cups ("deli cups") with snap-on lids. Moisture, perching, and cushioning needs should be addressed within these plastic containers, with moistened paper towels often used, and small twigs placed within for perching if necessary. These plastic containers are then placed within expanded polystyrene (Styrofoam®) boxes for insulation, and materials such as crumpled newspaper can be placed among the plastic containers for additional cushioning. Small ventilation holes in the cups can be created with a hot soldering iron tip or a punch, but the keeper should ensure that no sharp edges are present. If ventilation openings are needed in the larger shipping container they should be screened to prevent escape, and the lids on individual plastic containers can be taped to prevent their separation from the containers during transport.

Veterinary Care
Very little is known about the veterinary requirements of invertebrates, and invertebrate medicine is still in its infancy. The small size of invertebrates makes pathology difficult, as does the fact that their tissue begins to autolyze (break down and liquefy) soon after they die, leaving little for the pathologist to work with. Also, with only their chitonous exoskeletons to support them, little can be done to treat their wounds. Research has been done on commercially important species such as the honeybee (*Apis* sp.), and on some pest species; indeed, much invertebrate veterinary care is based on treatments used for bees. Little has been done with spiders and insects. In 2009 work was begun with millipedes; nematodes once thought to be part of their normal gut fauna were eliminated with positive health effects.

Conservation and Research
As invertebrates are basically the workhorses of the environment, their presence in a zoo should serve as the perfect tool for education about the importance of conservation and the delicacy of many ecosystems. Terrestrial invertebrates are harmed by the same forces that are problematic for vertebrates: habitat loss, introduction of alien species, and pollution. Many populations, especially of island species, exist in limited areas, and modest environmental pressure can cause rapid population declines. Zoos in general do not participate in terrestrial invertebrate conservation very often. One genus of spider (*Brachypelma* sp.), a species of beetle (*Nicrophorus americana*), a genus of snails (*Partula* sp.), and a few species of butterflies are currently the subjects of conservation initiatives at zoos in North America, but with increased awareness of the needs of terrestrial "microfauna," further efforts will be required.

Summary
Even with an enormous diversity of species in four different subphylums, terrestrial invertebrates share many husbandry needs and can serve as wonderful exhibit specimens. Many zoos incorporate at least a few invertebrate exhibits into their collections, and some devote significant resources to their display. Simple displays can have great impact on people unaccustomed to viewing "exotic" species, and even local species can be fascinating when viewed up close. Not all keepers will have entomological backgrounds or will view the task of invertebrate care as desirable as that of caring for some of the vertebrate taxa, but if they devote enough time to research and preparation, they will often find the fascinating behavior and lifestyles of their invertebrate charges as enjoyable as their public visitors do. Many invertebrate species may look "otherworldly," yet may respond as a vertebrate would to environmental cues such as food and shelter. Their sheer numbers and diversity suggest that more species may be exhibited at zoos in the near future, and one hopes that zookeepers and zoo visitors will continue to be fascinated by them.