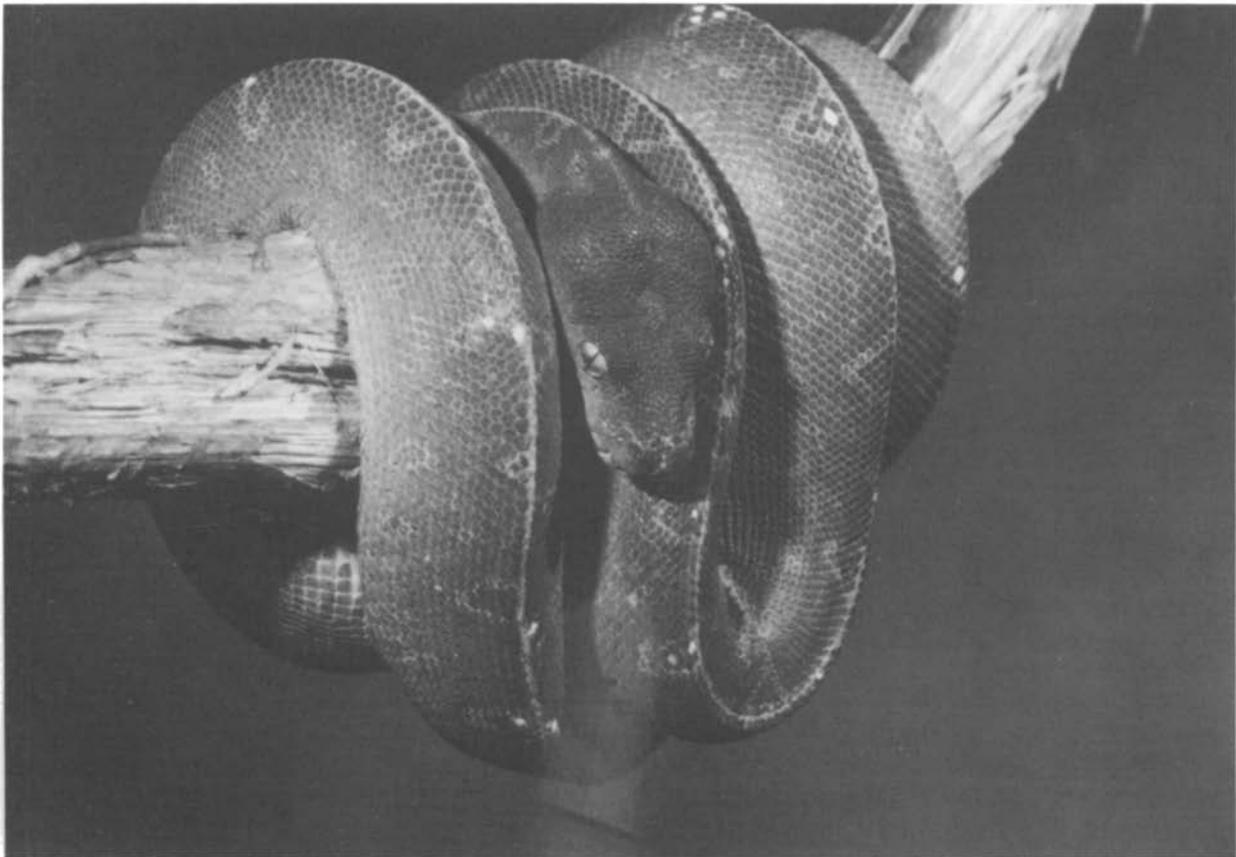


Recommendations for the Care of Amphibians and Reptiles in Academic Institutions

F. Harvey Pough



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On the cover: The green tree python (*Chondropython viridis*).
(Photo courtesy of F. Harvey Pough).

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F. Harvey Pough, Ph.D.

INTRODUCTION

Amphibians and reptiles differ in many respects from the mammals and birds most commonly used in biomedical research. These differences affect the physical and biological requirements of amphibians and reptiles in captivity. In this contribution, some basic biological characteristics of these animals are described that are relevant to their husbandry. My goal is to help members of institutional animal care and use committees appreciate the requirements of amphibians and reptiles in captivity, and to make suggestions that will be helpful in designing housing and providing day-to-day care.

I will focus on amphibians and reptiles used for research and teaching in colleges and universities. In the sense that amphibians and reptiles are exotic animals in a biomedical context, there are parallels between their use in academic settings and in zoos and aquariums. However, the facilities and resources available at colleges and universities are more limited than those of most zoos and aquariums. These recommendations address the limitations and opportunities of small-scale husbandry.

The husbandry practices suggested here are compatible with the Health Extension Act (PL-99-158), with the National Research Council's *Guide for the Care and Use of Laboratory Animals* (NRC, 1985) with the Canadian Council on Animal Care's *Guide to the Care and Use of Experimental Animals* (Canadian Council on Animal Care, 1980) and with the *Guidelines for Use of Live Amphibians and Reptiles in Field Research* (American Society of Ichthyologists and Herpetologists et al., 1987).

AMPHIBIANS AND REPTILES IN RESEARCH AND TEACHING

Understanding the husbandry requirements of amphibians and reptiles begins with understanding why these animals, rather than traditional biomedical species, are

being studied. Studies of amphibians and reptiles often have different perspectives and goals than those using traditional biomedical species. These differences are reflected in the housing and care that is appropriate for the animals. In addition, the physical and biological needs of amphibians and reptiles differ from those of mammals and birds, and are often more difficult to provide in an artificial setting. Both of these factors must be appreciated by investigators working with these animals, and by the individuals responsible for evaluating protocols and husbandry practices.

The Context of Study

Many studies of amphibians and reptiles have an organismal perspective. That is, the focus of study is the intact animal and the context is the species as it functions in its natural environment. This approach differs from the traditional biomedical use of mammals and birds to illustrate general biological phenomena or to serve as models of specific human diseases or genetic defects. In organismal research, behavior, ecology, physiology, and morphology are studied in the context of phylogenetic relationships and environmental specializations. Husbandry must consider the entire biology of an organism so that normal behavior, physiological response, and morphogenesis can be assured. Much research in organismal biology is currently directed to comparative studies that investigate the evolution of physiological, morphological, and behavioral characteristics by studying a series of species (see Brooks and McLennan, 1991; Harvey and Pagel, 1991; and Huey, 1987 for examples of this approach). Studies of this sort rely upon measuring the same phenomenon (e.g., thermoregulation, parental care, or feeding mechanics) in several species. Reviewers of protocols must understand that the study of multiple species of known phylogenetic relationship is an essential element of the comparative approach, and is not unnecessary duplication.

Practical Considerations

Providing environments suitable for amphibians and reptiles can be difficult. Domestic animals used in biomedical research have been bred to prosper under conditions

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that can easily be maintained in an animal room. Amphibians and reptiles, on the other hand, are wild animals, and the husbandry methods applied to them must take this into account. Housing, food, and care must match the physical and behavioral needs of each species. Carefully designed physical and biological environments are often needed, especially when the goal of husbandry is to facilitate studies of complex responses such as hormonal cycles, reproductive and social behavior, or water and temperature regulation. The welfare of the animals must have the highest priority in the design of animal rooms, cages, and cage furnishings. This effort must not be frustrated by the application of inappropriate standards based on domestic species.

Because most species of amphibians and reptiles are not available on short notice or from commercial breeding colonies, they are usually either collected from the wild by the investigators themselves, or obtained by gift from other researchers, zoos, or agencies such as the U.S. Fish and Wildlife Service. The availability of a species is likely to be affected by its seasonal activity cycle, the opportunity to collect in an exotic locality, and the provisions of national laws and international treaties. An investigator who plans to travel thousands of miles cannot predict in advance exactly how many individuals of which species will be collected. As a consequence of this uncertainty, investigators may have to submit protocols that include several taxa, only a few of which will actually be used. Furthermore, unusual species that have been successfully acclimated to laboratory conditions have a scientific value that transcends the project for which they were originally collected, and they may be kept indefinitely in expectation of further use. Animal care and use committees must understand these practical aspects of working with amphibians and reptiles and evaluate protocols accordingly.

THE BIOLOGY OF AMPHIBIANS AND REPTILES

In order to design appropriate environments for amphibians and reptiles, one must have an appreciation for their unique biological characteristics. Some practices and materials that are suitable and desirable for the care of birds and mammals are unimportant or even deleterious for amphibians and reptiles. Conversely, considerations that have little relevance for birds and mammals can be crucial for successful husbandry of amphibians and reptiles. A large literature shows that husbandry practices that are appropriate for mammals are not suitable for amphibians and reptiles, but the pertinent references are scattered. Recent sources of general information about amphibians and reptiles include Bellairs (1969), National Academy of Sciences (1974), Harless and Morlock (1979), Stewart (1984a,b), Duellman and Trueb (1986), Halliday and Adler (1986), Seigel et al. (1987), Norris

and Jones (1987), and Pough et al. (1989) and the references therein.

Distinctive Characteristics

Two attributes of amphibians and reptiles underlie all aspects of their care: Ectothermy and diversity.

Ectothermy. Amphibians and reptiles are ectotherms, that is, they do not ordinarily generate enough metabolic heat to raise their body temperatures above the ambient temperature. However, ectotherms are not literally “cold blooded.” Under normal conditions, terrestrial ectotherms regulate body temperature by behavioral means, often at high levels and within narrow limits. Several important implications for their care follow from this aspect of their biology. Most importantly, they require environmental conditions quite different from those appropriate for birds and mammals.

Ectothermy is an energy-efficient mode of thermoregulation because metabolic energy is not used to warm the body. As a result, the resting metabolic rates, aerobic capacities, and overall energy needs of ectotherms are nearly an order of magnitude lower than those of endotherms (birds and mammals) of similar size (Figure 1).

The thermoregulatory mechanisms employed by amphibians and reptiles are by no means simple. Many ecto-

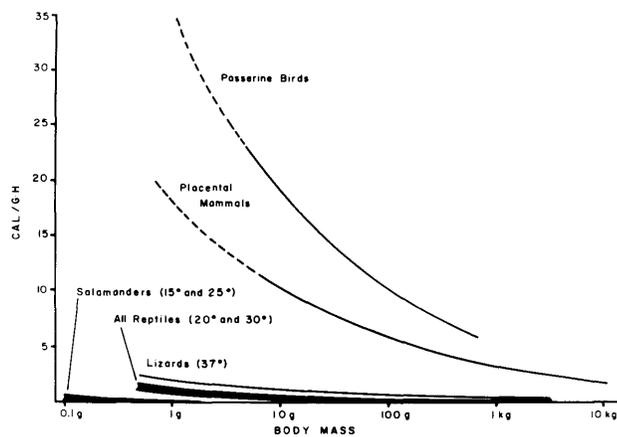


FIGURE 1 Resting metabolic rates of terrestrial vertebrates as a function of body size. Metabolic rates of salamanders are shown for 15°C and 25°C as the lower and upper limits of the darkened area, and data for all reptiles are shown at 20°C and 30°C. The metabolism-mass line for anurans falls within the “all reptiles” area, and the relation for non-passerine birds is similar to that for placental mammals. Dotted portions of the lines for birds and mammals show hypothetical extensions into body sizes below the minimum sizes of most adult birds and mammals. From Pough (1980), reprinted from *The American Naturalist* by permission of The University of Chicago Press. ©1980 by The University of Chicago Press.

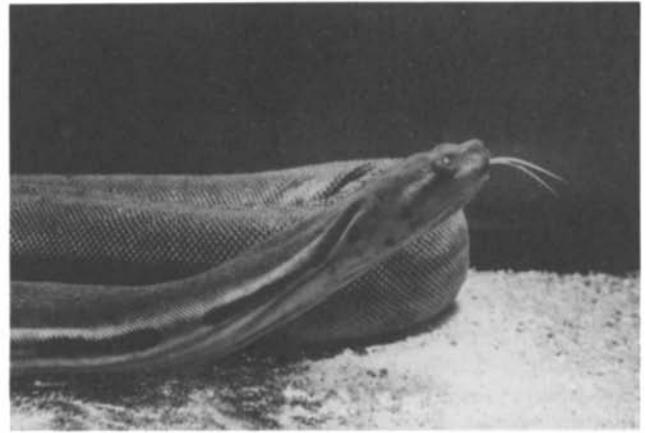
therms regulate their body temperatures during activity at levels that are similar to those of birds and mammals (35°C-42°C). The regulated temperature may change in response to internal and external conditions. Changes in thermoregulatory behavior include differences between daytime and nighttime temperature, elevation of body temperature following feeding, increase or decrease in body temperature during pregnancy, behavioral fever mediated by prostaglandin release during bacterial infection, and muscular thermogenesis during egg brooding (Hutchison et al., 1966; Regal, 1966, 1967; Lillywhite et al., 1973; Vaughn et al., 1974; Van Mierop and Barnard, 1976, 1978; Kluger, 1977, 1979; Hutchison and Erskine, 1981; Bartholomew, 1982; Beuchat, 1986; Sievert, 1989). Humane care of amphibians and reptiles requires conditions that facilitate their complex thermoregulatory responses.

Diversity. Living ectothermal tetrapods include nearly 4,000 species of amphibians and 6,000 species of reptiles. These 10,000 species display an enormous array of lifestyles, and it is this diversity that makes them attractive for research at the cellular or molecular level, as well as for studying organismal, ecological, and evolutionary questions (Deuchar, 1975; Greenberg et al., 1989; Pough, 1989; Elinson et al., 1990). For example, an investigator studying hormonal control of reproductive behavior can choose from some 3500 species of anurans (frogs and toads). Among these are species that retain an ancestral amphibian life cycle (terrestrial adults, aquatic eggs, and aquatic larvae); terrestrial species in which either males or females carry developing eggs and/or young on the back, in vocal pouches, and even in the stomach; species in which females feed their tadpoles unfertilized eggs; and species that give birth to live young, either with or without some form of matrotrophic contribution to the fetus. Moreover, anurans run the gamut

from totally aquatic frogs to species that live in deserts. Reptiles show still greater diversity in habitats and specializations. Because the ecological characteristics and husbandry requirements of the animals are so diverse, it is impossible to formulate specific guidelines for groups larger than a few species. In fact, broad application of specific guidelines would inhibit rather than promote humane care.

Sources of Information

The husbandry requirements of amphibians and reptiles in an academic setting are similar to those in zoos and aquariums (Gans and Van den Sande, 1976; Gans, 1979; Murphy and Campbell, 1987; Murphy and Chiszar, 1989), and research in zoos has been a fruitful source of information about amphibians and reptiles (Sajdak, 1983). Publications for herpetological hobbyists often provide useful guides for care of ectothermal vertebrates (e.g., Mattison, 1982, 1988; Obst et al., 1988; de Vosjoli, 1989, 1990a, b; and journals like *Lacerta*, *Reptile & Amphibian Magazine*, *Salamandra*, and *Vivarium*). *Herpetological Review*, published by the Society for the Study of Amphibians and Reptiles, has a section called "Herpetological Husbandry." The *International Zoo Yearbook* usually contains sections about amphibians and reptiles, and much of Volume 28 (1989) of this series was devoted to their care. Symposia, newsletters, and special publications of herpetological societies are also helpful sources of information (e.g., Bowler, 1977; Murphy and Armstrong, 1978; Ferner, 1979; Murphy and Collins, 1980; Gray and Bumgardner, 1984; Gray, 1985; Gowen, 1987, 1989; and the *Bulletin of the Association of Amphibian and Reptilian Veterinarians*). The professional staff at zoos and aquariums can often provide advice about the husbandry requirements of a particular species. Such advice may be



Examples of diversity: The Puerto Rican coquí (*Eleutherodactylus coqui*) (left) is an entirely terrestrial frog. It can pass its entire life without seeing a body of water larger than raindrops on a leaf. The elephant-trunk snake (*Acrochordus javanicus*) (right) is an aquatic species that never emerges from the water. (Photos courtesy of F. Harvey Pough)

particularly helpful in establishing breeding programs. Slavens (1989) publishes an annually-updated inventory of reptiles and amphibians in zoos and private collections; this volume can lead to an appropriate source of information about a particular species.

The diversity exhibited by amphibians and reptiles presents problems for husbandry that are not encountered with domestic and laboratory birds and mammals. Husbandry conditions must match the needs of the species being kept. Three factors are essential to achieve that goal:

1. Knowledge of the natural history of each species, obtained from field observations or from the literature;
2. Duplication of the features of the animals' natural microhabitats that are crucial for normal behavior and physiological function; and
3. Awareness and sensitivity on the part of caretakers to the unique requirements of these animals and the ways in which they manifest ill-health.

GENERAL RECOMMENDATIONS FOR THE CARE OF ECTOTHERMAL VERTEBRATES

The following generalizations apply to the care of most amphibians and reptiles, but caution must be employed in their use. The taxonomic categories included are broad, and substantial variation exists within them. Some lizards, for example, are heliothermic and regulate their body temperatures between 38 and 42°C, whereas others live beneath the canopies of tropical forests with body temperatures that fluctuate between 25 and 30°C. Still others are nocturnal and active at body temperatures below 20°C. Similarly, some amphibians are entirely aquatic, whereas others may never see a body of water larger than a pool of raindrops on a leaf. While these guidelines emphasize the factors that are likely to be important for husbandry and point to general categories of problems and solutions, information about the ecology and physiology of the species being kept is indispensable.

The Physical Environment

Housing conditions must provide appropriate temperature, moisture, and light regimes. In general, these include visible and ultraviolet light controlled on a daily and seasonal cycle, water for drinking or bathing, and high relative humidity. High rates of air flow are not usually required in animal rooms housing amphibians and reptiles. Limiting the number of air changes per hour greatly simplifies the task of maintaining high humidities. In most cases the key to successful care of amphibians and reptiles lies in providing a gradient of conditions within the cage that allows animals to select combinations of environmental factors needed.

Temperature. The thermoregulatory requirements of amphibians and reptiles are different from those of birds and mammals and are more difficult to satisfy in captivity. As endotherms, birds and mammals have continuously high rates of metabolic heat production, and thermoregulation consists primarily of adjusting the insulating value of hair or feathers to equalize the rates of heat production and loss. Endotherms accomplish this regulation over a broad range of air temperatures. The radiative environments of the animal room and their cages normally have little significance.

In contrast, amphibians and reptiles balance heat uptake from the environment with heat loss to the environment (Tracy, 1976, 1982). Control of the radiant environment of the cage (in both the infrared and visible wavelengths) is especially important, because this is usually the major pathway of heat gain and loss. The thermoregulatory behaviors of many species, especially reptiles, are based on adjusting position, posture, and reflectivity in response to radiant flux. These animals may be unable to respond appropriately to a uniform temperature or to a substrate temperature gradient. Lizards can be confused by unnatural combinations of temperature and light intensity. For example, lizards controlled their body temperatures more effectively in gradients that provided the normal stimulus of bright light and heat at the same end of the gradient than they did in gradients that were uniformly lighted or in those that combined bright light with low temperatures (Sievert and Hutchison, 1991).

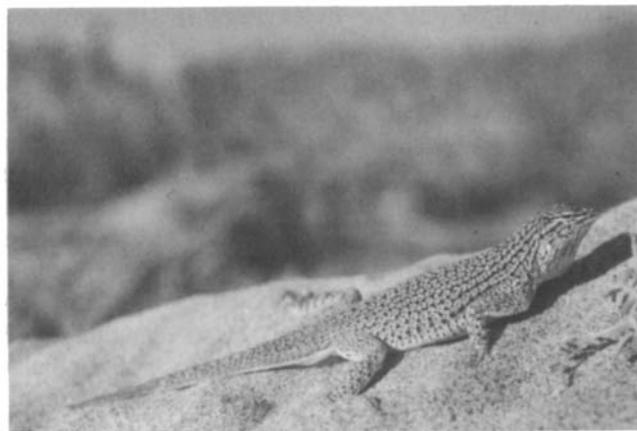
Photothermal gradients employing incandescent bulbs that produce both heat and light are probably the best choice for long-term care (Regal, 1980). These gradients must provide cool retreat sites as well as warm basking spots for the animals. Because the body temperatures that many species of lizards maintain during activity are only a few degrees below their lethal temperatures, overheating is a substantial risk if gradients are poorly designed. The cage must be large enough so that one end always remains cool, and cages that incorporate photothermal gradients should never be covered with solid lids that prevent the escape of heat. Shelters should be placed along the length of the gradient so that animals are not forced to choose between thermoregulation and security. In most cases, a variable temperature regime is necessary (Regal, 1967, 1971). Animals kept continuously at the warm body temperatures they select voluntarily during activity may show deleterious physiological changes (Licht, 1965). Transient exposure to high temperatures may suppress the immune system of reptiles (Elliott Jacobson, personal communication).

Choosing the range of temperatures that should be provided for a particular species requires information about its phylogenetic affinities and ecology. The thermoregulatory characteristics of groups of reptiles have been summarized (Avery, 1982). In particular, Ford (in press) suggests appropriate temperatures for snakes. In general, amphibians are less heliothermic than reptiles,

and the high rate of evaporative water loss characteristic of amphibian skin counteracts radiant heat uptake (Lillywhite, 1975; Tracy, 1976). Nonetheless, adult and larval amphibians bask in the sun or use temperature gradients to regulate body temperatures. A thermophilic response after feeding and behavioral fever mediated by prostaglandin E_1 have been reported for amphibians (Lillywhite et al., 1973; Hutchison and Erskine, 1981). Substrate temperature gradients produced by heating elements beneath the cage floor may be more effective than photothermal gradients, especially for nocturnal or secretive amphibians. The thermoregulatory characteristics of amphibians have been summarized (Brattstrom, 1979; Hutchison, in press), and information about salamanders can be found in Feder et al. (1982) and the references therein.

Water. A shallow container of water is appropriate for many amphibians and reptiles. However, some tropical species require daily spraying, and some desert reptiles never drink. Amphibians do not drink; terrestrial species absorb water through the skin and anurans have an area of skin in the pelvic region that is specialized for this function. Shallow water dishes, moist substrates, and spraying are appropriate for terrestrial amphibians. Chlorinated water should be avoided, especially for aquatic amphibians, and water bowls should be changed as often as practical because *Pseudomonas* populations increase rapidly in stagnant water (Elliott Jacobson, personal communication).

Humidity and Air Flow. Most amphibians and reptiles are much smaller than laboratory mice (Pough, 1980, 1983). An adult white mouse weighs about 20 g, while nearly 80 percent of the species of lizards and frogs and



Desert lizards like the Coachella Valley fringe-toed lizard (*Uma inornata*) live in regions where the average annual rainfall is less than 20 cm. One would expect animals from such habitats to be tolerant of dryness, but these lizards spend much of their time underground where humidity is close to saturation. In captivity even desert reptiles require high relative humidities. (Photo courtesy of F. Harvey Pough).

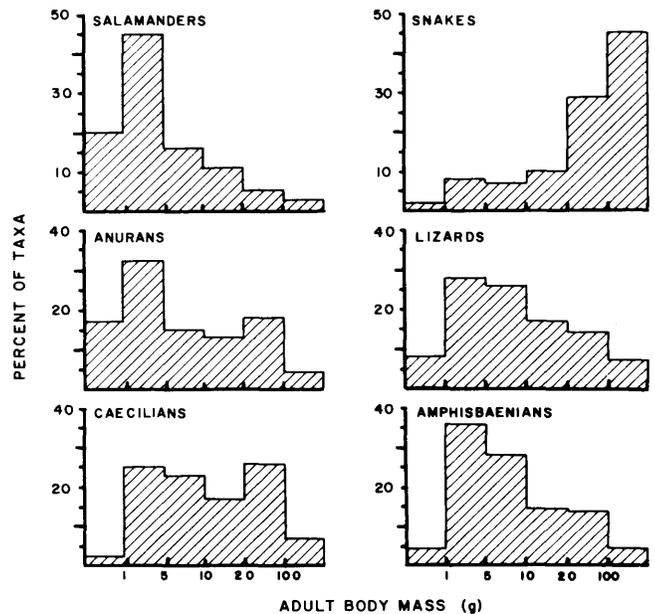


FIGURE 2 Adult body masses of amphibians and reptiles. The percentages of the total number of taxa surveyed with body masses in the ranges <1, 1–5, 5–10, 10–20, 20–100, and > 100 g are shown. Sample sizes: salamanders, $n = 198$; anurans, $n = 1,330$; caecilians, $n = 160$; snakes, $n = 1,592$; lizards, $n = 1,780$; amphisbaenians, $n = 110$. From Pough (1983), reprinted by permission of the Ohio State University Press.

95 percent of the salamanders have adult body masses smaller than 20 g (Figure 2). Indeed, 8 percent of lizards, 17 percent of frogs, and 20 percent of salamanders weigh less than 1 g as adults! These very small body sizes have important implications for husbandry (Pough, in press). In their natural environments, most amphibians and reptiles spend their time at the ground surface, under leaf litter, or in burrows. As a result they are exposed to microclimates (especially humidities and rates of air movement) that are very different from those perceived by large animals like humans. Even desert species spend much of their time in burrows or buried in loose sand. Relative humidity approaches saturation in these microhabitats, and the low humidities characteristic of heated and air-conditioned buildings can be stressful even for desert reptiles. Relative humidities should be maintained above 70 percent (preferably at 80 percent) for nearly all species of amphibians and reptiles. However, most reptiles develop skin lesions when they are kept on wet substrates for long periods.

Amphibians can often be kept in cages with lids to keep humidity high, but many reptiles require photothermal gradients. Putting a lid over a photothermal gradient quickly leads to lethal overheating of the animals inside. Instead, it is necessary to maintain high relative humidity in the entire animal room. Room air flow can be limited to a maximum of one or two changes per hour to maintain the humidities these animals require.

The large number of incandescent lights required in a room that houses 20 or 30 cages of lizards or snakes may produce more heat than the air-handling system can exhaust, especially when the number of air changes per hour is restricted to keep the relative humidity high. It is wise to incorporate thermostats to turn off the lights when room temperature approaches a level that is stressful for the least heat-tolerant species.

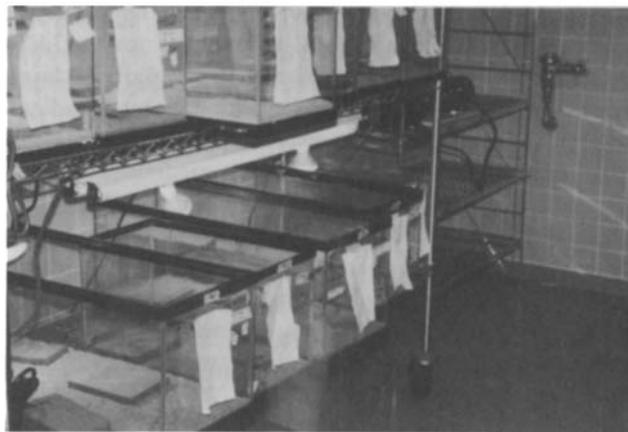
Light. Quality and quantity of light may both be important to amphibians and reptiles. An annual cycle of day length is usually critical, especially for breeding colonies. Windows or skylights that admit bright sunlight without overheating the room are ideal, but are rarely included in animal rooms. In lieu of natural daylight cycles, timers can be used to control photoperiod on an annual cycle.

The wavelengths of light provided to captive amphibians and reptiles also require attention, but little is known about the effects of different light intensities and of varying ratios of wavelengths. A trial-and-error approach has been adopted by zoos and individuals who maintain these animals, and this body of anecdote constitutes nearly all the information currently available for most species.

Providing the proper amount and quality of ultraviolet light is probably the most difficult aspect of lighting. Some species of amphibians and reptiles appear to require ultraviolet light for calcium metabolism, normal behavior, and reproduction (Cole and Townsend, 1977; Laszlo, 1969; Moehn, 1974; Townsend, 1979; Townsend and Cole, 1985; Regal, 1980). Middle-wavelength ultraviolet light (UVB) penetrates the epidermis and converts provitamin D_3 to previtamin D_3 . Synthesis of the active form of the vitamin (1,25-dihydroxyvitamin D_3) by birds and mammals has been studied, but the process is not well understood for amphibians and reptiles, some of which have as many as six types of provitamin D_3 in their skins (Holick, 1989a).

Some diurnal reptiles from open habitats have layers of melanin in the skin that block penetration of ultraviolet light (Porter, 1967). These animals might require higher intensities of light than do species with more translucent skins. Preliminary information from work at the National Zoo suggests that green iguanas (*Iguana iguana*) cannot use dietary vitamin D_3 , and must receive ultraviolet light for maintenance of blood levels of 1,25-dihydroxyvitamin D_3 (Mary Allen, personal communication). Similarly, birds and mammals synthesize two types of vitamin D_3 , and dietary 1,25-dihydroxyvitamin D_3 would not substitute for cutaneous synthesis of 24-dehydrovitamin D_3 (Holick, 1989b). However, several species of lizards have been raised successfully without ultraviolet light, in some cases for two or more generations, using dietary supplementation to provide vitamin D_3 (Larry Talent, personal communication; Gehrmann et al., 1991).

We do not know exactly what wavelengths of light are required for vitamin D_3 synthesis by amphibians and



Cages for desert lizards. An incandescent lamp at one end of each cage creates a temperature gradient, and black light and sunlamp fluorescent tubes provide ultraviolet radiation. (Photo courtesy of F. Harvey Pough).

reptiles, nor do we know whether the ratio of middle-wavelength (290 to 315nm) to long-wavelength (315 to 400nm) ultraviolet light (UVA) is important. Gehrmann (1987) presented information about the spectra of several bulbs used in animal husbandry. Broad-spectrum fluorescent bulbs such as Vita-Lite® (Duro-test) and Chroma 50® (General Electric) may be effective (Regal, 1980), although these lights, especially the Chroma 50 bulb, emit little energy in the middle-wavelength ultraviolet portion of the spectrum. (Note that, contrary to common misconception among hobbyists, Gro-Lux® bulbs do not emit much ultraviolet light, and they are not appropriate for UV supplementation, although they may be used in displays to support plant growth without harm to animals) (Roberts and Gehrmann, 1990). Fluorescent BL (black light) bulbs provide long-wavelength ultraviolet light (UVA). Bulbs designated BLB (black-light blue) have a filter that passes only ultraviolet wavelengths; they are more expensive than BL bulbs, but no more effective for animal husbandry. Neither a twelve-hour daily exposure to Vita-Lite® nor a half-hour exposure to a Sylvania BL bulb was sufficient for normal calcification of young chickens (Bernard et al., 1989), and the authors recommended that these bulbs not be used for captive animals.

Middle-wavelength ultraviolet light (UVB) is provided by fluorescent sunlamp bulbs of the sort sometimes used in treating psoriasis. In addition to the familiar tubular fluorescent sunlamps, self-ballasted reflector mushroom-type mercury lamps emit UVA and UVB radiation (William H. Gehrmann, personal communication). They are manufactured in 160 and 250 watt sizes by Philips Lighting Company and Iwaski Electric Company. National Biological Corporation (1532 Enterprise Parkway, Twinsburg, OH 44087) is a source of UVA and UVB bulbs. Middle-wavelength ultraviolet light can injure the eyes of animals and caretakers, and precautions should be

taken to limit exposure. Species of reptiles differ substantially in the UV exposure they require (Townsend and Cole, 1985; Gehrman, 1987), and a conservative approach is advised. Exposure periods of 30-45 minutes at a distance of 50 cm from a UVB lamp may be satisfactory for reptiles from open habitats (Moyle, 1989). UV irradiance at the midpoint of tubular bulbs is about twice as intense as irradiance at the ends (Gehrman, 1987). Breaking the daily UVB exposure into 10-15 minute periods at hourly intervals may help to ensure that all the individuals in a community cage have access to the light.

Snakes may normally satisfy their vitamin D₃ requirements from their diet of whole animals (Ford, in press). Reptiles from forests, and amphibians in general, are probably more sensitive to UV light than are desert reptiles, and UVB bulbs are probably not appropriate for these animals. Early signs of UVB toxicity include failure to eat, lethargy, diminished activity, and a gray or smoky skin color that turns progressively darker (William Gehrman, personal communication). All of these symptoms appear to be reversible when exposure ceases. Considering the potential risk posed by UVB bulbs to reptiles and their caretakers, a combination of broad-spectrum fluorescent bulbs and long-wavelength (UVA) bulbs is probably the most practical starting point for husbandry of a species with unknown requirements (Townsend and Cole, 1985). The bulbs should be as close as possible to the tops of the cages, preferably within 15-20 cm of the animals. However, if symptoms of vitamin D₃ deficiency are observed, it may be wise to consider providing a source of UVB radiation.

Because glass does not transmit middle-wavelength ultraviolet light and greatly attenuates longer wavelengths, it should not be used for cage tops. Wire mesh and some acrylic plastics and fluoroplastics transmit short-wavelength ultraviolet light and are suitable for cage tops (Gehrman, 1987).

The ultraviolet output of fluorescent bulbs decreases substantially after a few hundred to a few thousand hours of use. Unfortunately, this change is not apparent to the human eye, and can be easily overlooked until the animals' health is affected. Manufacturers can provide information about the useful life of their bulbs, and a regular schedule of changing bulbs will ensure that the animals are receiving ultraviolet light (Townsend and Cole, 1985).

The Biological Environment

Most amphibians and reptiles are secretive. They live in close association with their structural microenvironments, and subtle cues—scent, texture, contact—are important aspects of their behavior. Animals of this sort do not thrive in barren steel cages or in plastic boxes filled with wood shavings; their husbandry requires housing that combines the animals' need for environmental cues with



Dart-poison frogs (*Colostethus*) deposit eggs in folded leaves. The eggs are attended by a parent during development. When the eggs hatch, the tadpoles are transported to water on the back of the adult frog. (Photo courtesy of F. Harvey Pough).

effective care and sanitation. Providing hiding places is of paramount importance for nearly all species.

Cage Furnishings. Cage and aquarium props (e.g., branches, rocks, and substrate) should complement the normal lifestyle of the animal. A varied cage environment may be necessary for normal behavior; for example, the thermoregulatory and foraging behaviors of *Lacerta vivipara* break down in the absence of spatial diversity (Roger A. Avery, personal communication). Many species of amphibians and reptiles require materials that duplicate their natural settings for breeding. Terrestrial frogs such as *Eleutherodactylus*, *Dendrobates*, and *Colostethus* breed in captivity when they are given suitable nest sites. In nature these species deposit their eggs in smooth-surfaced fallen leaves, which should be included in the cage. Nearly all animals require a hiding place; opaque plastic boxes with small entrance holes make good retreat sites, and have the merit of being easily cleaned. Thigmotaxic stimuli may be nearly as important as the darkness that opaque shelters provide. Cobras used transparent plastic boxes as regularly as they used opaque boxes for hiding places when the two kinds were tested sequentially. However, in simultaneous presentations, the snakes always chose the opaque box (Chiszar et al., 1987). It can be advantageous to be able to see an animal when it is in its retreat, and some situations may warrant the use of transparent shelters.

Amphibians and reptiles often ingest bedding material with food, and cage substrates should be chosen with this possibility in mind. Several substrates commonly used for bird and mammal cages are harmful for amphibians and reptiles. Appropriate substrates keep the animal dry, such as newspaper, indoor-outdoor carpet, sand (only for species that normally live in sand), gravel (smooth particles that are fine enough to pass through the digestive

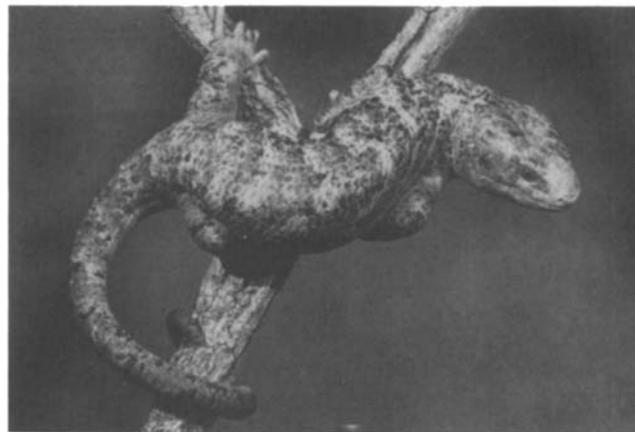
tract), crushed oyster shells (especially good for tortoises, large lizards, and snakes), hardwood mulch and bark chips, and peat and sphagnum moss. Materials that swell when they are swallowed, such as ground corn cobs, kitty litter, the pine shavings used in rodent cages, and cocoa shells, should not be used (Demeter, 1989). Cedar shavings have neurotoxic properties and should not be used (Elliott Jacobson, personal communication). Aspen shavings (Animal Bedding #2, American Excelsior Co., Arlington, TX) have proven satisfactory for snakes (Ford, in press).

Many animals press their snouts against the walls of their cage as they explore, and rough or sharp surfaces may injure them.

Behavioral Interactions. Many amphibians and reptiles are territorial in the field, and in captivity often form dominance hierarchies. Initially the establishment of these dominant-subordinate relationships is likely to involve fighting and the risk of injury, especially because the loser is unable to leave the cage. After hierarchies have stabilized, low-ranking individuals may be excluded from feeding, basking, or retreat sites (Regal, 1971). Aggressive behavior often waxes and wanes seasonally. For example, courtship can lead to injury of a female that rejects a male's advances but is unable to escape from him. Caretakers must be alert to subtle departures from normal behavior that indicate incipient problems, as well as to the appearance of wounds and new scars.

Caretakers must also be aware of the sensory worlds of the animals and the stimuli that are important to them. For example, it is stressful for a plethodontid salamander to be moved into a cage that bears the scent of another individual, or to have pheromones from another salamander deposited on its body during handling (Jaeger, in press). Ovarian development of female lizards (*Anolis carolinensis*) has been reported to be accelerated by the sight of male lizards giving courtship displays, and retarded by watching aggressive interactions between males (Crews, 1975).

Social interactions may be important components of the biology of some amphibians and reptiles. Crocodylians appear to be the most social reptiles, and parental care for young after hatching is probably universal among crocodylians (Lang, 1987). Sibling groups of young crocodylians remain with one or both parents for extended periods—as long as 24 months for the American alligator (Garrick and Lang, 1977; Hutton, 1989). Young American alligators spend the day together, basking on land or moving back and forth between land and water. At night the individuals disperse to forage, reassembling in the morning (Deitz, 1979 (quoted in Lang, 1987)). Vocalizations by juveniles and adults assist in maintaining these groups, and a distress call from a juvenile brings an adult to the rescue. Juvenile and adult crocodylians may continue to associate in social groups, sometimes segregated by age and sex. These social interactions have



The Solomon Islands prehensile-tailed skink (*Corucia zebrata*) benefits from having branches in the cage to climb. (Photo courtesy of F. Harvey Pough).

implications for management (Lang, 1987), and the behavioral consequences of raising and maintaining crocodylians in isolation have not been studied. The possibility that behavioral imprinting of juveniles occurs during their association with their parents should be considered in husbandry programs.

Some lizards and snakes employ communal defecation, hiding, or egg-laying sites. Several lizards and a few snakes remain with their eggs, and prolonged association between mother and offspring has been reported for the Solomon Islands prehensile-tailed skink, *Corucia zebrata* (John Groves, personal communication). Parental care by some species of frogs extends to association between an adult and its tadpoles or hatchlings (see Duellman and Trueb (1986) for examples). I suspect that social interactions are more widespread among amphibians and reptiles than we currently realize, and in some cases may be components of successful husbandry.

Food. The type of food and the rate of feeding should, at a minimum, ensure normal growth or maintenance of weight. (The nutritional requirements of breeding animals may be different from those only being maintained.) The low metabolic rates and high conversion efficiencies of ectotherms means that overfeeding of captive animals is more common than underfeeding. The food requirements of amphibians and reptiles vary widely; some species require nearly daily feeding, whereas others do best on three, two, or even one feeding per week. Very large snakes may benefit from still longer intervals between meals. In general, if a healthy animal that has adjusted to captivity does not accept food soon after it is offered, the food should be removed and the animal allowed to fast until the next feeding time. In salamanders, crocodylians, snakes, and lizards emaciation is first visible as concavity at the base of the tail and prominence of the lateral processes of the caudal vertebrae. The pelvic girdle of emaciated frogs is clearly outlined. While turtles

exhibit fewer conspicuous signs of emaciation, with experience it becomes easy to recognize a turtle that feels too light for its size.

The foods that can be provided to amphibians and reptiles in captivity rarely resemble their natural diets, and the nutritional requirements of amphibians and reptiles are poorly understood. A varied diet is likely to be more nutritious and more readily accepted than a diet consisting of only one kind of food. Providing balanced nutrition for amphibians and reptiles is challenging, and a variety of opinions can be found in the literature. The following paragraphs emphasize points of agreement, but the references should be consulted for additional information and dissenting views.

Vitamins and Minerals. The routine use of supplementary vitamins and calcium is often advised for amphibians and reptiles (Campbell and Busack, 1979; Allen et al., 1986; de Vosjoli, 1990a; Staton et al., 1990), but generalizations about the quantities needed are difficult to formulate. Studies of lizards have revealed substantial interspecific and geographic variation in vitamin and mineral requirements, and the symptoms of vitamin deficiency or excess are similarly variable (Larry Talent, personal communication). Many multivitamin supplements don't state nutrient levels on their labels. Using a product without knowing whether it has, for example, 5000 or 50,000 IU of vitamin A per gram is dangerous (Mary Allen, personal communication).

As with UVB supplementation, we remain largely at a trial-and-error stage, and a conservative approach to vitamin supplementation is probably the best starting point for a species with unknown requirements. Selective supplementation of particular nutrients is preferable to a shotgun approach. For example, a calcium:phosphorus ratio of 1.5:1 promotes normal bone growth.

Food items can be dusted with a vitamin-mineral mixture just before they are offered to the animals; uneaten items should be removed from the cage. Most insects have low levels of calcium, and dusting them with a calcium:phosphorus mixture that adjusts the ratio is desirable. D-Ca-Fos® (Fort Dodge Labs, Fort Dodge, IA 50501) is a finely powdered mixture of vitamin D, calcium and phosphorus that can be applied to insects as small as fruit flies and pinhead crickets. Beta-carotene and vitamins C and E may also be beneficial, but excessive vitamin and mineral supplementation can cause problems (de Vosjoli 1990a). Feeding a balanced diet is preferable to supplementing an inadequate one.

The diets of anurans can be supplemented by putting slow-moving insects, such as mealworms and wax moth larvae in shallow dishes with powdered vitamins and minerals. When the frogs catch the insects, some of the powder adheres to their tongues and is ingested with the prey. Many lizards will eat a mixture of dry vitamin and mineral powders and fine silica sand from a dish (Larry Talent, personal communication).

Live Food. Many amphibians and reptiles respond to movement and will ignore even their favorite prey if it is motionless. Live food is required for these animals, and husbandry of amphibians and reptiles often requires maintaining colonies of insects as well.

Insects. Diets that alternate different kinds of live food are desirable, and a diet consisting solely of mealworms is notoriously unsatisfactory (e.g., Demeter, 1989). A combination of crickets (*Acheta*), mealworms (*Tenebrio* larvae), flour beetle larvae (*Tribolium*) and wax moth (*Galleria*) or fly larvae (*Sarcophaga*) is suitable for insectivorous lizards and amphibians. Roaches (*Blaberus*), king mealworms (*Zoophobias*), and fruit flies (*Drosophila*) are also standard food items for captive amphibians and reptiles. The insects must be healthy and well-fed if they are to be nutritious food. Insects that are not eaten promptly should be removed from cages, because they may attack the animals. Suggested diets and instructions for care of insects and other invertebrates are available in *The Encyclopedia of Live Foods* (Masters, 1975), the *Carolina Arthropods Manual* (Anonymous, 1982), and *The Right Way to Feed Insect-eating Lizards* (de Vosjoli, 1990a). Mary Allen (National Zoo) recommends monkey chow and dog kibble as a stock cricket diet.

The material in the gut of insects is an important source of nutrients for amphibians and reptiles, and insects can be nutrient-loaded to increase their food value. A high-calcium diet for crickets (Cricket diet #39-390) is available from Ziegler Bros., Inc. (PO Box 95, Gardners, PA 17325). This diet is intended for calcium-loading crickets before they are fed to amphibians and reptiles; it is not suitable for rearing crickets. The gastrointestinal tracts of crickets contained detectable quantities of calcium and phosphorus after 48 hours on the high-calcium diet (see Allen and Oftedahl, 1989 for details and suggestions).

Birds and Mammals. Mice, rats, and hatchling chickens or quail should be euthanized by an approved method that does not leave a toxic chemical residue before they are fed to captive amphibians and reptiles. Asphyxiation with carbon dioxide is a satisfactory method of killing animals for this purpose.

Prepared Diets. Although many amphibians and reptiles have narrow dietary preferences, some species can be trained to accept prepared foods that incorporate vitamin and mineral supplements. Good candidates for such dietary shifts are lizards and snakes that rely on scent to identify food. Skinks (*Eumeces*, *Chalcides*, and many other genera), tegus and dwarf tegus (*Tupinambis* and *Callopistes*), monitor lizards (*Varanus*), and natricine snakes (*Thamnophis*, *Nerodia*, and related genera) will often learn to accept canned cat and dog food. The odor of a fish-based food is sometimes particularly attractive, even to species that never see a fish in their natural state. Dietary shifts can be facilitated by introducing them gradually, a time-honored technique among reptile keepers

(Weldon et al., in press). For example, a lizard that eats mice can initially be given mice with progressively more cat food spread on the fur, then cat food in a dish garnished with portions of a mouse carcass, and finally plain cat food. Not all of the commercial foods for reptiles and amphibians that are sold in pet stores provide a well-balanced diet, and advice about specific products should be sought from a qualified source. Many of the major zoos now have nutritionists who can provide helpful information.

Herbivorous Reptiles. Many species of reptiles include some plant material in their diets. The most specialized of these are folivores (leaf-eaters). Prominent in this group are large lizards such as chuckwallas (*Sauromalus*), green iguanas (*Iguana*), ground iguanas (*Cyclura*), the Galapagos marine and land iguanas (*Amblyrhynchus* and *Conolophus*), Fijian iguanas (*Brachylophus*), mastigures (*Uromastyx*), the East Indian water lizard (*Hydrosaurus*), and the green sea turtle (*Chelonia mydas*). These species rely on fermentative digestion and show characteristic morphological and physiological specializations of the gut (Iverson, 1982; McBee and McBee, 1982; Troyer, 1983, 1984a; Bjorndal, 1985; Bjorndal and Bolten, 1990). Food particle size, the ratio of fruit to foliage, and the ratio of plant to animal material can affect digestibility and the assimilation of energy and nutrients by herbivorous reptiles (Bjorndal, 1989, 1991; Bjorndal et al. 1990).

Nutritionally complete diets for herbivorous reptiles are commercially available. Ziegler Bros., Inc. (PO Box 95, Gardners, PA 17325) makes 15 percent and 25 percent crude protein meal-type diets for iguanas, and a variation of that diet in small pellets for desert tortoises. Marion Zoological (Marion, Kansas) makes an extruded diet of very small diameter for herbivorous reptiles. A mixture of 10 parts by weight of leafy greens to one part soaked dry dog food is a good alternative. The dog food should be soaked just enough to soften it because excess water can leach out nutrients (Mary Allen, personal communication). Chopped alfalfa hay is also accepted by tortoises, especially when it is mixed with greens.

The specializations of folivorous reptiles extend beyond morphology and physiology to include behavior and ecology, and these phenomena must be considered in husbandry. Like all folivores, reptiles are selective about the species and the parts of plants they eat. Juvenile iguanas choose leaves with low fiber and high protein content, and they accelerate digestion by maintaining body temperatures higher than those of adults (Troyer, 1984b, 1987). Social behavior probably also contributes to folivory for iguanas. Newly hatched green iguanas spend a short time in the tropical forest canopy where adult iguanas live before returning to the forest-edge vegetation where they remain during their growth as juveniles. Apparently this brief association of hatchlings with adults facilitates the transfer of the gut symbionts responsible for fermentative digestion of plant matter

(Troyer, 1982, 1984c). Thus, juvenile folivores hatched in captivity and isolated from sources of normal symbionts probably do not have their species' typical complement of fermentative microorganisms. Although these individuals may grow and prosper on diets that do not require fermentation of plant cell walls, their digestive physiology is probably not typical of free-ranging individuals. This observation has important implications for laboratory studies that assume their subjects to be in a normal physiological state, and for husbandry programs that rear juveniles for release. In situations when digestive physiology is important, husbandry of folivorous reptiles should probably include a method of inoculating hatchlings with the species' typical gut symbionts. This may be a matter of substantial applied significance, because many folivorous species of reptiles are threatened or endangered, and captive breeding programs for some of them are planned or in progress (Bjorndal, 1981; Burghardt and Rand, 1982; Miller, 1987; IUCN, 1989; Swingland and Klemens, 1989).

Housing and Sanitation. Housing conditions should inhibit the presence and spread of disease. However, sanitation protocols should not frequently disturb the animals nor require complete removal of feces because many ectothermal vertebrates use pheromones, including constituents of feces, for intraspecific communication. Snakes kept in clean cages spend more time attempting to escape than do individuals in cages where a small amount of fecal matter is left each time the cage is cleaned (Chiszar et al., 1980). Similarly, plethodontid salamanders mark their cages with pheromones in their feces, and salamanders in freshly cleaned cages make more attempts to escape than do salamanders in cages they have marked with their own scent (Jaeger, 1986 and references therein). Thus, excessive cleaning or sterilization of cages can be deleterious to the well-being of the animals. The human nose is the most appropriate guide to cleanliness: No odor of waste products should be perceptible in the air of a room housing ectothermal animals. Application of this criterion is practical and effective because unsanitary conditions are readily detected when the number of changes of room air per hour is limited to maintain the high relative humidities amphibians and reptiles require.

Through-flow aquatic systems are less likely to spread pathogens than are recirculating systems. Chlorine should be removed from incoming water, which should be heated or cooled to the appropriate temperature before it is introduced to the animals' tanks. If a recirculating water system is necessary, each tank should have a self-contained system to minimize the chances of cross-contamination. A sterilization process may be a desirable component of recirculating aquatic systems.

Separate quarantine facilities are highly desirable for amphibians and reptiles, and newly arrived animals should be kept in cages isolated from long-term stock for at least

90 days (Elliott Jacobson, personal communication). Checks for parasites should be routine. These tests contribute to the health of the caretakers as well as to the welfare of the animals.

MARKING INDIVIDUALS

The ability to recognize individuals is critical to many studies, and methods of marking amphibians and reptiles were reviewed by Ferner (1979). In many instances individual variations in pattern allow even large numbers of animals to be distinguished without artificial marks. When this is not possible, several techniques can be employed, depending on whether long-term or short-term marks are needed. Clipping off portions of toes or scales has traditionally been used to mark individuals, but toe clipping in particular is painful and may affect locomotor ability, especially for arboreal species. Furthermore, some individuals regenerate the clipped toes or lose additional toes in fights. Freeze-branding appears to produce a mark that lasts one or two seasons. Passive integrated transponders (PIT tags) have been used successfully to mark amphibians and reptiles, and this appears to be the best method of permanently marking species that are large enough to accommodate the tag (Camper and Dixon, 1988).

BREEDING

The reproductive cycles of amphibians and reptiles are closely linked to their physical and biological environments, and effective breeding programs employ manipulation of these factors (e.g., Crews and Garrick, 1980). Case-studies are published in the newsletters and symposia of herpetological societies, the *International Zoo Yearbook*, and hobbyist literature. As with most other aspects of herpetological husbandry, we are at the stage of trial and error, and investigators should seek information about the species of interest to them from those publications and from the staffs of zoos and aquaria, many of which have successful breeding programs for several species.

Some generalizations will provide a starting point for establishing breeding programs. For example, manipulating temperature, humidity, and photoperiod on an annual cycle has been effective for many species. A period of 1 to 4 months of low temperature stimulates breeding for a variety of reptiles and amphibians, including some tropical species. This method has been applied successfully to snakes (e.g., Scheidt, 1984; Tryon and Whitehead, 1988), as well as to lizards, turtles, and amphibians. Animals must be allowed to fast before they are cooled, and a gradual reduction in temperature over a period of days is preferable to an abrupt change. Environmental temperatures can be lowered to 10°C for species from temperate zones, whereas warmer temperatures (18°C-

20°C) are appropriate for tropical species. Most animals do not become torpid under these conditions, but emerge from their hiding places during the day and retreat at night. A short photoperiod is more natural than continuous darkness, and a daily temperature cycle may be desirable. Dehydration is a risk in environmental chambers that regulate temperature by passing air over refrigerating coils. The cages must prevent excessive water loss without allowing the continuous contact with wet substrates that is likely to produce skin lesions. As the end of the cool period approaches, the photoperiod should be lengthened and the temperature gradually increased. Animals undergoing this treatment are not in any sense in cold storage or suspended animation, and water dishes should be cleaned and refilled daily.

Seasons in some habitats, particularly in the tropics, are distinguished more clearly by rainfall patterns than by temperature cycles. Animals from these habitats may be induced to breed by simulated rain showers. This method was used by the Metropolitan Toronto Zoo to breed Puerto Rican crested toads (*Peltophryne lemur*) (Paine et al., 1989). The breeding schedule is keyed to environmental conditions in the toads' natural habitat. In December, which corresponds to the late part of the rainy season in Puerto Rico, feeding is increased, and females receive newborn mice dusted with vitamin D₃ and calcium supplements. In late January, when the dry season is beginning, the toads are put into a cage that has been filled with a water-soaked mixture of peat and sphagnum mosses. Ambient temperature is about 22°C, and the relative humidity is 50 to 70 percent. The toads burrow into the substrate, which dries slowly during the next month. A shallow water dish in the cage allows the toads to rehydrate when they emerge from the substrate at night. The toads are dug out of the moss and fed weekly. Feeding ceases at about the time the moss dries completely. The toads are kept for another month in the dry substrate, and checked regularly to see that they remain hydrated.

At the end of 60 days of dryness, a time that corresponds to the usual onset of the Puerto Rican rainy season, water is added gradually for two days until the moss is saturated with water, and the air temperature is raised to 27°C. On the morning of the third day, the males are transferred to tanks of water in which cultures of algae have been established. A spray of water simulates rainfall, and tape recorded mating calls of the toads are played to both sexes. The males are left in the breeding tanks for two days before the females are added. The presence of a group of toads appears to contribute to the formation of amplexing pairs, and amplexus normally begins very soon after the females are introduced. The simulated rainfall and recordings of mating calls are continued for another three or four days.

The Toronto Zoo's program illustrates the effectiveness of techniques that initiate the physiological changes associated with breeding by manipulating the physical

and biological conditions that stimulate breeding in nature. Another approach is to administer exogenous hormones to initiate reproduction. This method has been widely used by embryologists to induce breeding by amphibians (e.g., Rugh, 1962; National Academy of Sciences, 1974), and the process is so simple that amphibian reproduction kits can be purchased from biological supply houses. Pituitary glands from amphibians or human chorionic gonadotropin have traditionally been employed for this purpose, but Goncharov et al. (1989) advocated the use of synthetic analogues of luteinizing hormone-releasing hormone. Caution in the use of these techniques may be desirable, because larvae produced by the administration of exogenous hormones might differ in morphology, growth rate, behavior, or viability from those obtained from breedings that result from endogenous endocrine cycles. An extensive literature of life-history studies testifies to the importance of maternal effects that are controlled by environmental variables such as temperature and energy intake during vitellogenesis (e.g., Kaplan, 1987). These interactions might be affected by interruption of normal reproductive cycles, and if exogenous hormones are to be employed, their use should be coordinated with the breeding cycle so that hormones are administered after gametes have matured (Goncharov et al., 1989).

The nutritional status of a female reptile during oogenesis or pregnancy and the environment in which eggs are reared can affect characteristics of the clutch and of the offspring. In laboratory studies of viviparous and oviparous snakes the ratio of clutch mass (eggs or embryos) to female body mass remained constant under different feeding regimes, with the result that absolute reproductive effort (grams of offspring per female) was proportional to energy intake (Ford and Siegel, 1989; 1991). That is, females that were well fed during oogenesis produced larger litters than did females that received less food. In these experiments, only the number of offspring responded to maternal nutritional status, but in some species of reptiles the size and viability of the offspring might be affected. Viviparity has evolved at least 45 times among lizards, and another 35 times among snakes (Blackburn, 1982, 1985). Modes of fetal nutrition among viviparous reptiles encompass a spectrum from lecithotrophy (nutrients deposited in the yolk during vitellogenesis) to matrotrophy (nutrients supplied throughout development via a placenta). The skink *Mabuya heathi*, a Brazilian lizard, exhibits a nearly mammalian level of matrotrophy (Blackburn et al., 1984). The newly ovulated egg is only 1 mm in diameter, and placental transport accounts for more than 99 percent of the dry mass of the fetus at birth. Another skink, *Chalcides chalcides*, a species that is used in biological studies, may also rely primarily on matrotrophy during embryonic development: the ova of *C. chalcides* are less than 3 mm in diameter at ovulation (Blackburn et al., 1984). For these skinks, and for other reptiles with high levels of maternal input to

the fetus, the nutrition of a female during embryonic development may influence the size and viability of the young she produces.

Temperature is an important factor in the embryonic development of reptiles. Normal morphogenesis is limited to a narrow range of egg temperatures for some species of reptiles, whereas others tolerate ranges as large as 10°C (Packard and Packard, 1988). Temperatures outside those ranges may be lethal to the embryos, or may produce hatchlings with abnormal skeletons, scale patterns, or pigmentation (Vinegar, 1973), as well as differences in post-hatching survival (Whitehead et al., 1990). Snakes hatched from eggs that had been incubated at intermediate temperatures performed better in several behavioral tests than hatchlings from higher and lower incubation temperatures (Burger, 1989, 1990), and alligators from eggs incubated at intermediate temperatures grew faster and survived better than those from higher or lower temperatures (Joanen et al., 1987). Temperature-dependent sex determination has been demonstrated for species in seven families of turtles, for crocodylians, and for a few lizards (summarized by Paukstis and Janzen, 1990).

The wetness of the substrate on which reptile eggs are incubated affects the length of the incubation period and the size and robustness of the hatchlings (Packard and Packard, 1988). The same phenomenon has been demonstrated for one species of frog (Taigen et al., 1984). The largest and most vigorous turtle hatchlings are usually produced by incubating eggs in wet substrates (water potentials of -100 to -200 kPa) at the lowest tolerable temperatures (Gary C. Packard, personal communication). However, this advice must be modified for species that display temperature-dependent sex determination to avoid producing hatchlings of only one sex. As a rule of thumb, temperatures that produce incubation periods similar to those observed in the field are likely to be satisfactory (Miller, 1987). Unlike the eggs of birds, reptile eggs should not be turned during development.

ENVIRONMENTAL CONDITIONS AND MEDICAL CARE

A discussion of the veterinary requirements of amphibians and reptiles is beyond the scope of this review, but the importance of environmental conditions, particularly temperature during illness and following surgery should be noted. The role of temperature in reptilian health management was reviewed by Mader (1985, 1991). Fishes, amphibians, and reptiles maintain elevated body temperatures when they are injected with pathogens, and this behavioral fever is associated with increased survival compared to animals that are prevented from raising their temperatures (Vaughn et al., 1974; Kluger, 1977, 1979). The immune response of reptiles is temperature-sensitive (Evans and Cowles, 1959; Evans, 1963; Cohen, 1971;

Elkan, 1976), and antibiotic therapy also may be most effective at high temperatures (Mader et al., 1985). Because behavioral fever is a normal response of reptiles and amphibians to endogenous pyrogens, it may be desirable to allow the animals to control their febrile response during antibiotic treatment and following surgery by keeping them in thermal gradients so they can warm themselves several degrees above their normal activity temperatures.

HEALTH PRECAUTIONS FOR RELEASE OF ANIMALS

The release of amphibians and reptiles that have been held in captivity is potentially damaging to the health and the genetic composition of wild populations. It should be prohibited in almost all cases. Cross-contamination of animals with pathogens is nearly unavoidable in captivity, and amphibians and reptiles that are obtained from dealers have been exposed to a wide range of microorganisms that they would not encounter in their natural habitats. If these animals are released, the pathogens they carry can spread to the wild population with potentially disastrous results. From 1987 to 1990 an outbreak of upper respiratory distress syndrome (an infection by *Pasturella testudinis* and *Mycoplasma* spp.) reduced the population of desert tortoises at the Desert Tortoise Natural Area in California from an estimated 1000 individuals to 30 survivors. The outbreak may be associated, at least in part, with the release of captive tortoises by well-meaning individuals (Elliott Jacobson, personal communication).

Even in the absence of disease, the introduction of individuals from a distant part of a species' range can change the genetic composition of local populations, and exotic species may establish populations that compete with native species. A recent summary lists more than 20 exotic species of reptiles and amphibians that have become established in the United States (Conant and Collins, 1991).

Under some circumstances the release of animals does not pose a risk, or the risk can be justified. If animals are rigorously isolated from any contact with other species while they are in captivity and are returned to their sites of capture, no harm is likely to result. Work with threatened or endangered species may require the release of animals after they have been in captivity. In this case, the animals should be kept isolated from other species, and from individuals of other populations of their own species. They should be thoroughly screened for parasites and pathogens before they are released. Institutional animal care and use committees must be alert to the dangers associated with releasing animals. Committee members must expand their view of animal welfare to consider impacts on wild, as well as on captive populations. Unfortunately, the only possible option for



Large lizards like the tegu (*Tupinambis nigropunctatus*) require cautious handling. They protect themselves by biting, scratching, and whipping with the tail. (Photo courtesy of F. Harvey Pough).

animals that do not meet the criteria for release may be euthanasia.

HEALTH PRECAUTIONS FOR ANIMAL CARETAKERS

Most amphibians and reptiles pose no greater risks for caretakers than do birds and mammals. Normal precautions include washing the hands after working with the animals or their feces. A dust mask should be worn when cages containing dry fecal material are cleaned. *Salmonella* is frequently associated with reptiles, and its presence should be assumed unless several cultures of fresh feces have given negative results.

Some amphibians have potent skin toxins, and a few species can be dangerous to humans (e.g., *Phyllobates terribilis*; see Myers et al., 1978). Venomous snakes are potentially dangerous to caretakers, as are the two species of venomous lizards (the gila monster and Mexican beaded lizard, *Heloderma suspectum* and *Heloderma horridum*). Dangerously venomous snakes are not limited to vipers, elapids, and sea snakes; many colubrid snakes are venomous and some of these can be dangerously toxic to an animal as large as a human. Gans (1978, appendix 2) lists more than 40 species of venomous colubrids.

Husbandry of dangerously venomous snakes is a specialized activity involving legal and ethical responsibilities that are beyond the scope of these general recommendations. Most research programs do not require venomous snakes, and they should not be kept in an academic institution without a compelling reason to do so. Gans and Taub (1978) discuss the precautions that are necessary for housing venomous snakes, as well as the daunting legal implications of keeping these potentially dangerous animals.

SUMMARY

Successful husbandry of amphibians and reptiles must be based on an understanding of the ways in which they function as intact organisms. That is, one must know what physical and biological factors are important to them, how they interact with their environments, and how they exhibit signs of good or poor health. While the same principle applies to the care of a laboratory mouse, amphibians and reptiles are sufficiently different from mammals that our intuitive sense of what makes a suitable environment is not a satisfactory guide. Standards based on mammalian husbandry are likely to be detrimental to amphibians and reptiles. Intuition must be replaced by an understanding of the unique characteristics of ectothermal vertebrates and how these characteristics affect husbandry. Amphibians and reptiles are wild animals and we must adapt our laboratory techniques to their needs; we cannot expect them to adjust their biology to suit our convenience.

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