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ZOO VIEW

Herpetological Review, 2015, 46(1), 119–134.

Studies on Non-venomous Colubrid Snakes and a Few Other Families in Zoos and Aquariums

> So general is the repugnance of mankind to the animals composing these classes, that their study has been overlooked, and they have usually been considered as beings which it was not only necessary but meritorious to destroy. A part of this vulgar prejudice is derived from education, and perhaps some of it may originate from the fact that several of them are furnished with venomous fangs, capable of causing intolerable sufferings and death. To the naturalist and physiologist, however; to those who study nature through her various modification of form and structure, they present some of the most interesting objects of contemplation. Their utility, either in diminishing various noxious animals, or in furnishing food themselves to others, has been lost sight of; and because they were cold to the touch, with a naked slimy skin without hair or feathers, they have been considered as loathsome and hideous, although their structure displays as much of the omnipotence and care of the Creator as can be seen in those which are considered to be the most gorgeous and beautiful of his animated beings.
>
> *Zoology of New-York or the New-York Fauna, Part III. Reptiles and Amphibia.* by James E. DeKay, 1842

This article is last in a four-part series on the history of snakes kept in zoos and aquariums. In each article, I focus on taxa that have been regularly displayed in zoos and aquariums. Certainly there are many other species that have been kept but in generally limited numbers. I would be remiss if I did not acknowledge the enormous contributions of our academic and museum colleagues over many centuries. Without their inspiration, guidance and assistance, we would not know what to call our animals or how these creatures live and die in the wild. Without knowing these facts, we would have been virtually helpless in maintaining them in captivity. Starting with lavishly illustrated books, cabinets of curiosities and operating theaters of anatomy, luminaries like Albertus Seba, Frederik Ruysch, Oleus Worm, Adam Oleareus, Konrad Gessner, and a host of others showed us the beauty and complexity of our natural world (Figs. 1, 2). Many biologists today have not had an opportunity to see these magnificent works of art and this is why I have included them in my articles.

Considerable advances on properly keeping and reproducing herps have been made by herpetoculturists in the private sector (Murphy and McCloud 2010a, b). Compare the behavioral observations in the first published herpetocultural book by Johann Matthäus (or Matthaeus) Bechstein in 1797 on captive care of reptiles (called Amphibians at that time) and amphibians entitled *Naturgeschichte; oder, Anleitung zur Kenntniss und Wartung der Säugethiere, Amphibien, Fische, Insecten und Würmer, welche man in der Stube halten kann [Natural History or Guide to Knowledge and Care of Mammals, Amphibians, Fishes, Insects and Worms which can be kept at Home]*. In it, he covered the European Grass Snake (*Coluber Natrix*, now *Natrix natrix;* Fig. 3) and here are a few quotes from that tome: "*Positive*

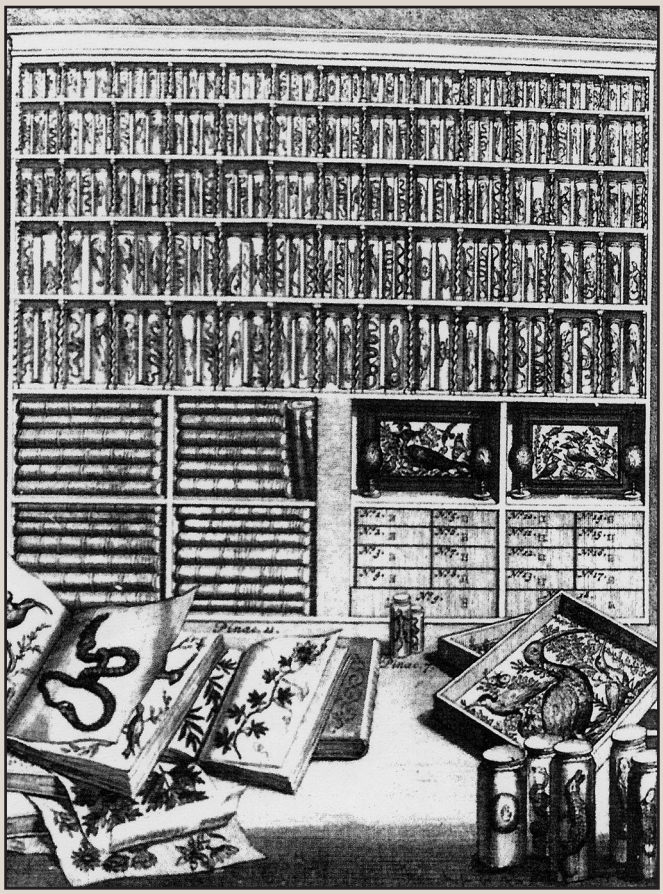

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Fig. 1. Upon death, zoo specimens should be cosmetically necropsied (if a necropsy is necessary), preserved, and placed in a scientific depository. Those lacking locality data can be used as study specimens. Illustration of cabinet of curiosities from Levinus Vincent's collection in 1704. In the 1660s, Robert Boyle published an article in *Philosophical Transactions* where he described using alcohol for fixing and preserving animal specimens. This important discovery revolutionized herpetological descriptions, for herpetologists and artists were able to scrutinize preserved materials and create detailed diagnostic drawings.

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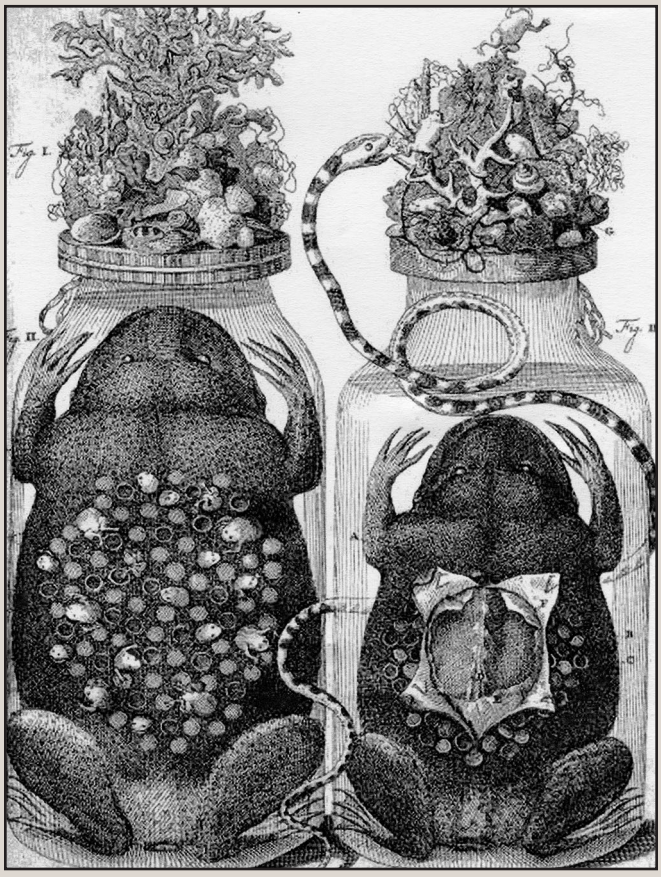

FIG. 2. Snake seems to be Dipsadidae, given New World *Pipa* in the jars. Could be a *Leptodeira* or (very skinny) *Imantodes* based on eating frogs, but is it attacking more diverse prey, including mollusks? Harry Greene suggests that it might be a composite dipsadid. Illustration from Frederik Ruysch's book on a natural history cabinet in 1710—*Frederici Ruischii ... Thesaurus animalium primus = / Het eerste cabinet der dieren / van Frederick Ruysch* ... Imprint: Amstelædami, apud J. Wolters.

Properties—These are certainly endearing animals which can be trained to dance with a stick and the pipe, and to play dead…My friend Mr D. Vognetz has a ringed snake which is so tame that she crawls up and down in the room like a domestic bird, often climbs up on him, crawling up the arms and into the bosom. But it does not easily approach anyone else. He puts it in his pocket, goes into the garden with it and as soon as he emits a loud whistle, similar to the tone with which at mating time they call their mates, it comes to him, crawls up on him, lets him put it in his pocket and remains there without moving until he takes it out again. Since these crawling amphibians often grow exceptionally large, this has provided opportunity for all kinds of fables." (translated from German in Heichler and Murphy 2004).

When I started in the zoo profession in the mid-1960s, I never imagined seeing the amazing numbers of amphibians and reptiles produced by the private community in the following decades. There are several pictures of enormous displays of these animals (Rieck et al. 2001). See Barker and Barker (2014) for a thorough discussion of the topic of the value of animals in captivity and the role that serious amateurs can play in conservation.

Where feasible, I have updated scientific names from those used by the authors in their publications, based on Uetz and Hošek (2014). I follow McDiarmid et al. (1999) for family arrangements.

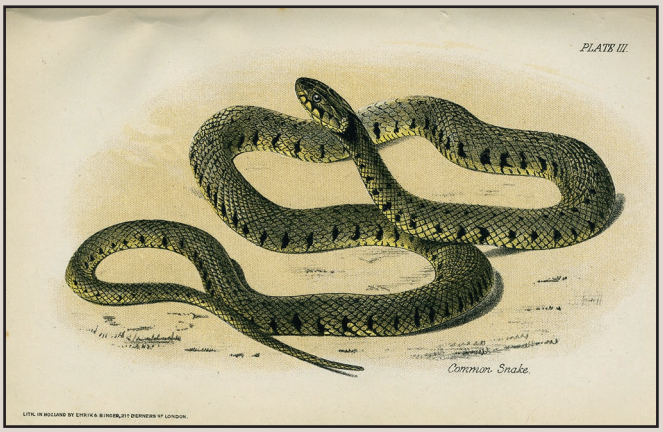

FIG. 3. Common Snake *Tropidonotus natrix* from *Our Reptiles and Batrachians* by M. C. Cooke, 1893. "Everybody shudders at the name of a snake. Very few possess courage enough to attempt staring one out of countenance, or staying to count the number of scales on its head."

TRAVELING THROUGH TIME

As every herpetologist knows, snakes have been the focus of attention of humans for centuries in both positive and negative ways. Brattstrom (1998) postulated that the circular Aesculapian Temple (Tholos) at Epidauros, Greece was likely an early snake pit between 360 and 320 BC. Wajid Ali Shah kept a large menagerie in Calcutta in the 1850s that included tortoises and a large enclosure containing thousands of snakes (Walker 2001). Rulers during this period often kept animals to impress their subjects and competitors. There were many early assemblages of captive snakes, as described in Murphy (2007). One which caught my attention was when Hernando Cortés and his band of soldiers arrived at the Aztec capital Tenochtitlan (now Mexico City) in 1519 and found the Aztec emperor Montezuma's royal menagerie which included snakes. There were over 300 animal keepers so I will remind my herpetological colleagues to continually complain to their bosses about being constantly shorthanded by stressing this factoid. To gain a picture of the relationship of humans and snakes, read Greene (1997), Morris and Morris (1965), and Stutesman (2005).

Arthur E. Brown from Philadelphia Zoo (see Conant 1957) described Marcy's Garter Snake, Trans-Pecos Ratsnake, Gray-banded Kingsnake, Short-tailed Snake, and others (1889, 1890, 1893, 1901a, 1901b, 1902a, 1902b, 1902c, 1903a, 1903b, 1905). Cover and Boyer (1988) bred the endangered and beautiful San Francisco Garter Snake (*Thamnophis sirtalis tetrataenia*) at Dallas and Ft. Worth Zoos. These illegally-collected snakes were confiscated from private persons by the US Fish & Wildlife Service for the purpose of providing captive-born neonates to other zoos to stress the species' precarious state in California and develop assurance colonies. We were told that plans were being considered to clear prime habitat proximal to the airport to be used for additional landing strips and should this become a reality, immediate action for intervention would be needed. The snakes proved to be prolific and many were distributed to institutions throughout the world. In 2005, the Eastern Plains Garter Snake (*Thamnophis radix radix*) reproduced at Cleveland Metroparks Zoo. The same year, the Exiled Garter Snake (*Thamnophis exsul*) produced a litter at San Antonio Zoo. Many years ago, curator Ray Pawley showed me a

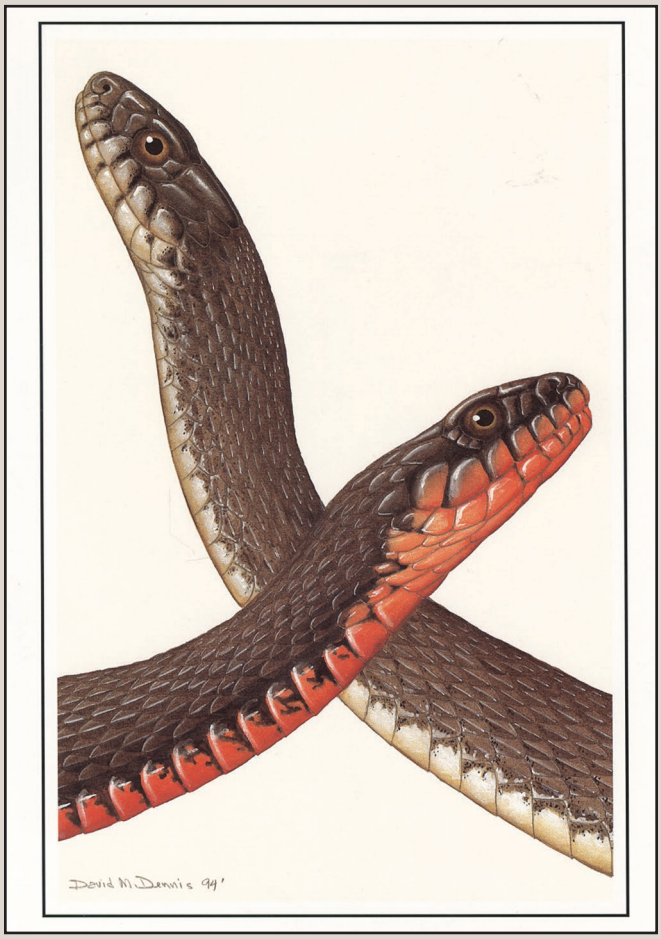

FIG. 4. Two endangered water snakes described by Roger Conant: Northern Copperbelly Water Snake (*Nerodia erythrogaster neglecta*) and Lake Erie Water Snake (*Nerodia sipedon insularum*). Reproduced from a watercolor by David M. Dennis in 1994 from the SSAR book *Captive Management and Conservation of Amphibians and Reptiles.*

FIG. 5. Eastern Garter Snake (*Thamnophis s. sirtalis*) in *The Natural History* by Mark Catesby in 1743.

unique and effective garter snake exhibit at Chicago Zoological Park. The enclosure was filled with human detritus often found strewn in wild areas and vacant lots in the city—rusty tin cans and bed springs, broken shards of glass, discarded food wrappers and newspapers, and junk of all types. Ray's message was simple—we are littering our world with our garbage! North American Queen Snakes (*Regina septemvittata*) produced 48 young between 1872 and 1880 at London Zoo (Coote 2001). Fox et al. (1961) described the morphological effects of low temperatures during the embryonic development of the garter snake, *Thamnophis elegans*. In 1942, Conant reported on young of Brazos Watersnake (*Natrix harteri*) as well as Southern Black Racer (*Coluber constrictor priapus*), and Texas Patchnose Snake (*Salvadora lineata*), and Arid Land Ribbon Snake (*Thamnophis proximus diabolicus*) and Aguanaval Watersnake (*Natrix erythrogaster alta*) (Conant 1965). Lederer (1949) published a lengthy study on the Viperine Snake (*Natrix maura*) and hybrid ratsnakes (Lederer 1950). Reichling (1974) reported upon a new record-size *Natrix erythrogaster flavigaster* x *neglecta*. Petzold bred the Indian Striped Snake (*Amphiesma stolata*) at Tierpark Berlin (Petzold and Stettler 1972) and reported observations on the breeding biology and keeping of *Tretanorhinus variabilis*, a water snake of Cuba (Petzold 1967). Roger Conant was the most prolific researcher on natricine snakes in the zoo community (Conant 1938, 1943a, 1943b, 1945, 1946, 1949, 1950, 1951, 1953, 1958, 1961, 1963, 1965, 1969, 1975; Conant et al. 1945). As a nonagenarian, Roger sent me a copy of his last paper in 2003 on the garter snakes of the *Thamnophis eques* complex from Mexico from data compiled in the 1960s—simply extraordinary productivity. His accomplishments were recognized in an SSAR volume in 1994 (Adler 1994; Fig. 4.) and other publications (Conant 1957, 1980, 1997; Conant and Collins 1991). It bears repeating that Roger was the only herpetologist who returned cloth shipping bags cleaned, pressed, and folded to me (Adler 2004). There are several other excellent references on garter snakes and water snakes (Rossman et al. 1996; Gibbons and Dorcas 2004, Fig. 5).

The late John Werler was director of Houston Zoo for many years (Kawata and Murphy 2004). At Houston Zoo, common Diamondback Watersnakes (*Nerodia rhombifer*) were periodically obtained as living food snakes from a reptile dealer for the King Cobras—they were not frozen until used because Werler felt that the cobras deserved living prey; they were kept in a large enclosure in the rear section. In 1953, Roger Conant described a new taxon in honor of Werler (*Nerodia rhombifer werleri*) from Mexico and a few living ones were collected by him and kept on display to honor John. Just before Conant was to visit, a prankster in the herp department convinced a newly-hired keeper that he had fed all of this very rare subspecies to the cobras by using the ones in the holding enclosure. To continue the ruse, John contacted Roger and they both confronted this terrified keeper for many minutes about his sheer incompetence feeding off these priceless serpents until they both started laughing uproariously and admitted their nefarious deed—the poor keeper had a near-death experience. As an aside, I have collected the nominate form and experiencing them up close and personal is a miserable experience—multiple bites with flowing blood, unpleasant musk, and staggering amounts of metabolic by-products. See Werler and Dixon (2000) for an exhaustive treatment of Texas snakes, including natricines.

Kingsnakes and milksnakes (*Lampropeltis*) have been popular zoo ophidians due to their beauty and hardiness in captivity (Fig. 6). Beginning in the mid-1960s, we began to specialize in this group at Dallas Zoo. We reported on courtship and copulatory behavior in the Mexican Milk Snake (*Lampropeltis triangulum sinaloae*) by looking at three elements—Tactile-Chase, Tactile-

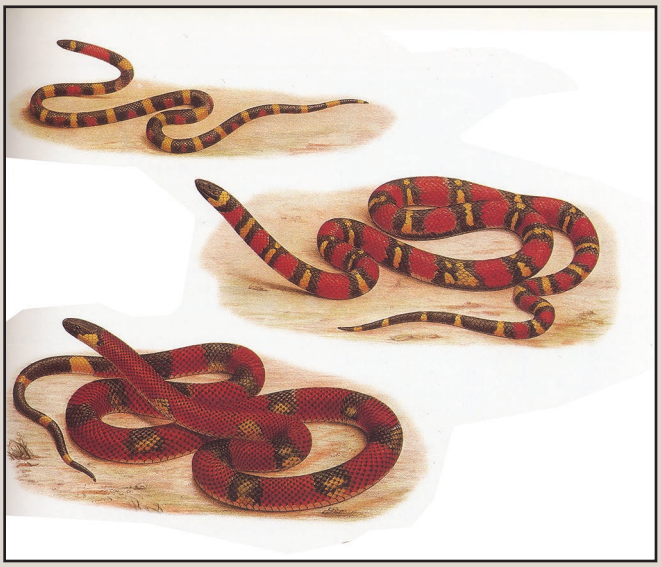

FIG. 6. Varieties of kingsnakes (*Coronella annulata*) from *Biologia Centrali Americana: Reptilia and Bathrachia* in 1885–1902 by Albert Günther—top to bottom—Yucatan, Mexico, Tehuantepec.

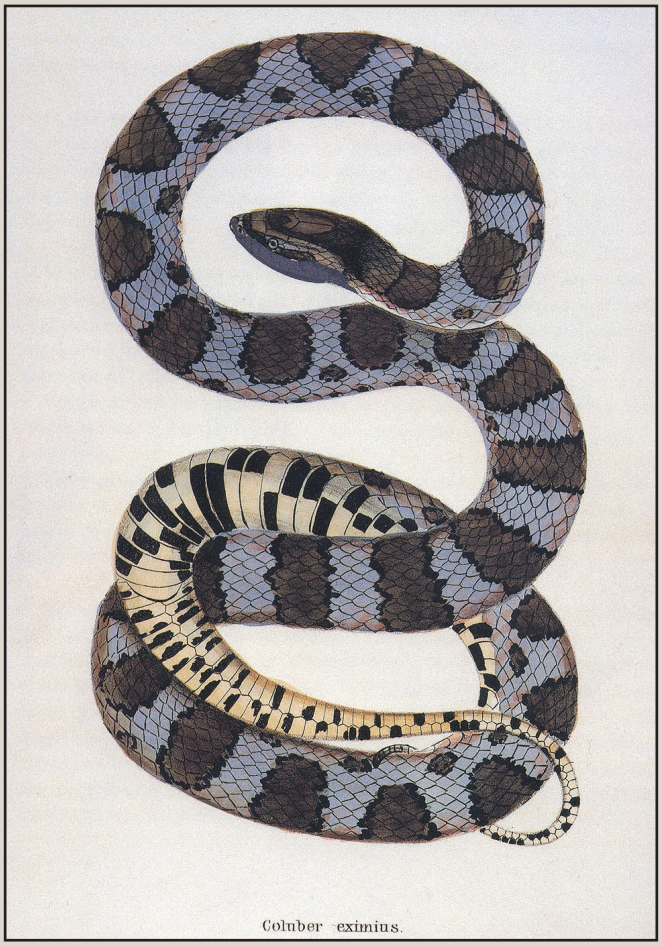

FIG. 7. John Edwards Holbrook published *North American Herpetology,* beginning in 1836, covering all herps found east of the Mississippi River at that time. Shown is Eastern Milksnake *(Lampropeltis t. triangulum*).

Alignment, and Intromission and Coitus—and by creating this new terminology for a generalized colubrid pattern (Gillingham et al. 1977). Murphy et al. (1978) provided an inventory of reproduction and social behavior in Gray-banded Kingsnakes (*L. alterna*). At San Antonio Zoo, Laszlo (1984) discussed reproduction in captives utilizing environmental parameters. After these snakes were cooled to as low as 9°C in the winter, successful reproduction did occur—in both the Tryon colonies (window left open in unheated room) and the Dallas Zoo group (hibernaculum) (Radcliffe et al. 1974; Murphy et al. 1978; Tryon 1984a). Tryon and Murphy (1982) investigated the reproductive biology of thirteen varieties of kingsnakes (species *mexicana, triangulum,* and *zonata*). Jon Campbell brought some beautiful milksnakes to our Zoo collected from Zapotitlan, Puebla, Mexico, found in desert terrain at 1500 m, and listed in our paper as *L. t.* ssp. Hugh Quinn (1983) later described these as *L. triangulum campbelli.* These snakes proved to be incredibly prolific. Hammack (1989) reproduced the Colombian Milk Snake (*L. t. andesiana*) at Dallas Zoo. Radcliffe and Murphy (1984) described precopulatory and related behaviors in captive kingsnakes and other reptiles. Paul Weldon presented kingsnake secretions to assess the ophiophage defensive response in a large number of crotaline snakes (Weldon and Burghardt 1979). In some cases, the defensive body bowing behavior exhibited by the pitvipers was dramatic as bodies were lifted in an inverted U-configuration with head and tail on the substrate and mid-body pressed to the top of the enclosures. Because it was reported in the literature, we assumed that the pitviper might use body blows directed to the kingsnake swabs but I did not notice this behavior. Later, Chiszar et al. (1993, pers. comm.) felt that this was a strategy used by the pitvipers to wedge themselves tightly into burrows to avoid being seized by the kingsnakes.

When private kingsnake breeders learned about the extent of our collection, many visited the Zoo but often focused only on kingsnakes even though we had a very diverse collection. Some particularly desirable forms which we were reproducing in numbers but were unavailable at that time in the private herpetocultural community were Jaliscan Milksnake (*L. t. arcifera*; these were actually Ruthven's Kingsnake [*L. ruthveni*]; R. Hansen, pers. comm.), Pueblan Milksnake (*L. triangulum campbelli*), and Colombian Milksnake (*L. t. andesiana*). We also had a group of snakes of the *L. mexicana* complex collected by Jon Campbell and Barry Armstrong (see Garstka 1982 for additional information). Fanciers begged us for some neonates but when I explained that zoo policy required that all propagules had to be offered first to AZA members and there was a very long waiting list, a few unscrupulous ones started calling my keepers at home to try and convince me to change my mind by doctoring records to eliminate hatchlings. It reminded me of the tulip craze in Holland during the 1630s. As the private sector became more proficient at breeding kingsnakes, we later decided to move on to other projects and sent most of them to other zoos.

Tryon and Hulsey (1976) noted reproduction in captive Nelson's Kingsnakes (*Lampropeltis triangulum nelsoni*) at Ft. Worth Zoo. At this Zoo, Ronald Markel worked in the herpetological department. He told me that he was planning an ambitious project illustrating as many milksnakes and kingsnakes in color as possible and he succeeded by locating them all at zoos and other places (1990). Herman (1979a, b) bred the Jaliscan Milksnake (*L. t. arcifera*; again, these were actually *L. ruthveni,* as noted above) and Scarlet Kingsnake (*L. t. elapsoides*) at Zoo Atlanta. Kardon (1979) noted breeding in three

Mexican milksnake subspecies (*L. t. polyzona, L. t. nelson,* and *L. t. sinaloae*) at San Antonio Zoo. Korinek (1997) bred Campbell's Milksnake (*L. t. campbelli*) in the terrarium of Olomouc Zoo. In 2004, five Eastern Milksnakes (*L. t. triangulum*) hatched at the Detroit Zoological Institute (Fig. 7). Tryon and Murphy (1982) and Tryon (1984b) described multiple egg clutches in a single reproductive season; this phenomenon is now known to occur in a number of *Lampropeltis* taxa.

Roger Conant (1934) recorded reproduction in the Black Kingsnake (*Lampropeltis getula nigra*) and discussed milksnakes of the Atlantic Coastal Plain (1943a). Hosono (1982) bred the Florida Kingsnake (*L. getula floridana*) at the Kyoto Municipal Zoo in Japan. Mulder et al. (1979) from Audubon Zoo surgically removed retained eggs from a kingsnake (*L. getula*). Tryon and Carl (1980) reproduced the Mole Kingsnake, *L. calligaster rhombomaculata.*

Zweifel (1980) described techniques for maintaining a colony of *L. getula* at the American Museum of Natural History in New York to study inheritance of color pattern. Shaw (1956, 1959) described two-headed California Kingsnakes (*L. g. californiae*) at San Diego Zoo by name: Dudley-Duplex, Dudley-Duplex II, and Nip-and-Tuck. This Zoo has owned several of these snakes over the years and the first one lived over six and one-half years. Boyer and Baldwin (1997) devised a simple method of preventing self-inflicted injury when feeding a dicephalic California Kingsnake by using a collar around one head (pictured in Murphy 2007). Groves (1964) and Groves and Groves (1972) described swallowing of shed skin by *L. getula.*

Ratsnakes are also popular zoo exhibits. I use the term "ratsnakes" in an historical sense, inclusive of both Old and New World representatives that we now know are not closely related (Utiger et al. 2002). Herrmann (1998) reported on husbandry and reproduction in the Black and Yellow Ratsnake (*Spilotes pullatus*) at Cologne Zoo (Fig. 7). At Ft. Worth Zoo, Campbell (1972) bred the Trans-Pecos Ratsnake (*Bogertophis subocularis*) and Tryon (1976) reported on courtship behavior and second-generation reproduction. Brecke et al. (1976) documented reproduction and social behavior in the Baird's Ratsnake (*Pantherophis bairdi*) at Dallas Zoo, and Dathe and Dedekind (1985) at Tierpark Berlin. Tremper (1981) propagated the Neotropical Ratsnake (*Pseudelaphe f. flavirufa*) at Chaffee Zoo. Engelmann (1984) explained egg-laying behavior of the Yellow Ratsnake (*Pantherophis obsoletus*) at Leipzig Zoo. Retired Detroit Zoo curator Jim Langhammer (pers. comm.) had many snakes at Indiana University during our college years including Ludwig, a large female Yellow Ratsnake: "She was about 5 feet long and totally trustworthy around strangers. Ludwig's dimensions were too small to allow her being on the ground among foot traffic but she was often handled by strangers. I often walked Jordan Halls with her settled quietly around my neck. Many strangers would ask directions/questions of me without ever seeing the snake. To my recollection she never struck at anyone. One indication of her gentleness was her intense fondness for large chicken eggs. She ALWAYS began at the blunt end of an egg. If you held it with the blunt end in your palm, she would work to expose that blunt end but never bit the hand in the process. Once engulfed, she would move it down about 10 inches and then crush the egg against her vertebrae before swallowing it further."

Frolov and Kudryavtsev (1985) and Kudryavtsev and Frolov (1984) kept and bred Russian Ratsnakes (*Elaphe s. schrencki*) at Moscow Zoo. Mamet (1989) outlined the reproductive biology of ratsnakes of the *longissima*-complex from Southern Azerbaijan

FIG. 8. Baron Georges Cuvier published *Le règne animal…* in 1836–1839. Illustration is Aesculapian Snake *(Elaphe longissima*).

FIG. 9. Yellow and Black Ratsnake (*Spilotes pullatus*) from *Biologia Centrali Americana: Reptilia and Batrachia* in 1885–1902 by Albert Günther. This beautiful and active snake is not often seen in zoo collections.

(Fig. 8). Mamet and Kudryavtsev (1997a) propagated the Mandarin Ratsnake (*E. mandarina*) and Mamet and Kudryavtsev (1997b) provided notes on the reproductive biology of the Asiatic Ratsnake (*Elaphe persica*) at the Moscow Zoo. At Tula Exotarium in Russia, Ryabov (1997) reported upon high productivity in the Radiated Ratsnake (*E. radiata*), natural history, keeping, and breeding the Persian Ratsnake (*E. persica*) (2001), and Ryabov and Popovskaya (2000) provided some comparative data on the breeding of four subspecies of the Stripe-tailed Ratsnake (*Elaphe taeniura*). "This is from Stan Grumbeck who told me that Moellendorf's Ratsnakes (*Orthriophis moellendorffi*) are notably different than the norm in that their eggs feel much more like turtle eggs and that the young do not slit the eggs upon hatching but rather burst or break through the shells" (William Lamar,

FIG. 10. Ferruginous Thrushes (*Turdus rufus*) defending nest from attacking Black Ratsnake (*Pantherophis obsoletus*) from John James Audubon's *Birds of America* from 1827–1830.

FIG. 11. Bull Snake (*Pituophis melanoleucus*) from *United States Exploring Expedition, Vol. 29. Herpetology* in 1858 by Charles Frédéric Girard.

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pers. comm.). Frank Groves described eggs and young (1957) and albinism (1965) of the Corn Snake (*Pantherophis guttatus*) at the Baltimore Zoo. Lederer (1950) discussed hybridization in ratsnakes. Barnard et al. (1979) from Zoo Atlanta followed growth and food consumption in the Corn Snake. Orangutans and gorillas are afraid of Black Ratsnakes (Murphy et al. 2014, Fig. 12). Clarke (1973) recorded longevity in a Great Plains Ratsnake (*Pantherophis guttatus emoryi*). Dowling (1959a) noted egg-eating adaptations in the Chinese Ratsnake, *Elaphe carinata*. During the 1970s, political relationships with China were tense so virtually no herpetofauna from the region was being imported into the US. When relations improved, a few reptile dealers began to bring in some ratsnakes such as *Elaphe dione, E. schrenckii, E. carinata, E. bimaculata,* and *Orthriophis moellendorffi*. Some of these were sent to zoos but after a few weeks, there was unacceptable mortality. Upon necropsy, it was discovered that gall bladders had been removed for the medicinal market and the surgical site stitched so expertly that it was virtually impossible to notice. Two references on ratsnakes are especially helpful: Schulz 1996 and Rhodes 2008.

At Memphis Zoo, Steven Reichling has embarked on a long-term study of the Louisiana Pine Snake (*Pituophis melanoleucus ruthveni*) (1986, 1988a, 1989, 1990a, 1990b, 2008) and the Black Pine Snake (*P. m. lodingi*) in 1981—both taxa are at risk. At Cheyenne Mountain Zoological Park, Connors (1986) described a captive breeding of the Great Basin Gopher Snake (*P. catenifer deserticola*). Charles Shaw and Sheldon Campbell from San Diego Zoo described male combat, courtship behavior and reproduction, feeding, defense, and many other aspects of the Gopher Snake (*Pituophis catenifer*) in their book *Snakes of the American West* (1974, Fig. 11). This is an excellent reference for all the snakes in this area. Shaw (1951) described male combat in American colubrid snakes with remarks on combat in other colubrid and elapid snakes. From the same Zoo, Jeffrey Lemm (2006) has published a field guide to herps of the San Diego region. Chiszar et al. (1989) showed that Bull Snakes (*Pituophis melanoleucus*) discriminated between thermally different rodent carcasses. An adult at Dallas Zoo regularly pinned as many as four live mice at the same time during feeding bouts; the one it was swallowing had been constricted and was dead, the second was being constricted by the first third of the body, the third and fourth were being pressed against the side of the enclosure with such force that they were gasping. I never could answer the question of how a snake could deal with multiple prey items.

At Zoo Atlanta and other institutions, neonates of the Eastern Indigo Snake (*Drymarchon couperi*) were maintained for a captive head-start program (Speake and Smith 1987; Wines 2014). Gravid females were collected in the wild, eggs were hatched, and females released at site of capture. This is an excellent model for a collaborative project; it involved U.S. Fish and Wildlife Service, The Alabama Natural Heritage Program, Alabama Department of Conservation and Natural Resources, Georgia Department of Natural Resources, Zoo Atlanta, The Orianne Society, and the U.S. Forest Service. The researchers examined reproductive ecology, captive propagation, juvenile ecology and restocking potential, including optimal egg incubation temperature, and the effects of diet on growth of hatchlings. After necropsying many indigo snakes, pathologist John Roberts (pers. comm.) was adamant in insisting that these snakes need a predominantly bird diet rather than rodent diet. Serum chemistry values were analyzed for two specimens at Sacramento Zoo (Drew 1994). Hellmuth et al. (2012) used operant conditioning and desensitization to facilitate veterinary care with this taxon at National Zoological Park in Washington, DC. Groves (1960) bred the Eastern Indigo Snake (*D. couperi*) at the Baltimore Zoo.

Some species are rarely kept in zoos and aquariums and thus are poorly studied. There are many reasons why certain taxa do not make their way to zoos and aquariums—availability, specialized food needs, non-attractiveness or other lack of visitor appeal, inability to adapt to captivity, size, secretiveness, poor temperament, lack of managed captive management

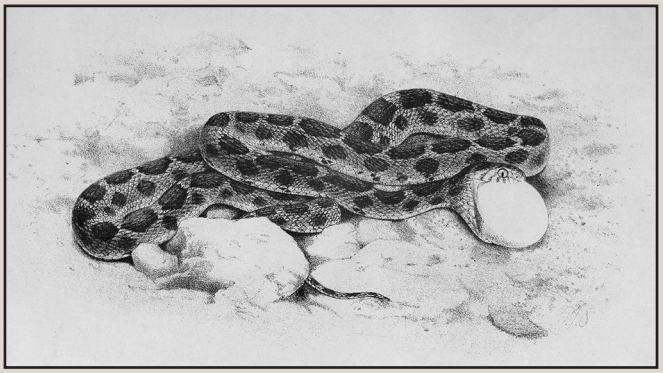

FIG. 12. John Anderson published *Zoology of Egypt* in 1898. Some of the finest drawings of reptiles ever produced were by P. J. Smit and John Green in this book. Pictured is Egg-eating Snake *(Dasypeltis scabra).*

FIG. 13. Andrew Smith published *Illustrations of the Zoology of South Africa* in 1838–1839. Mole Snake (*Pseudaspis cana*) (top and bottom), Green Bush Snake (*Philothamnus semivariegatus*) (middle).

program, lack of space and, of course, curatorial preferences. Cahill (1971) provided observations on a captive Beak-Nosed Snake (*Scaphiophis albopunctatus*) at the University of Ife Zoo in Nigeria. Simmons (1977) reproduced the Chinese Red Snake (*Dinodon rufozonatum*) and Campbell and Murphy (1984) outlined reproduction in five species of Paraguayan colubrids housed at the Fort Worth Zoo—racers (*Liophis*), false cobras (*Hydrodynastes*), green racers (*Philodryas*). At Houston Zoo, Freed (1989) documented delayed fertilization in the African Egg-eating Snake (*Dasypeltis scabra*), a species rarely kept in zoos because of the need for a steady supply of suitably-sized eggs (Fig. 12). Shaw (1961) published photographs of an egg-eating snake swallowing an egg. Boycott (1990) described copulation and parturition in the Mole Snake (*Pseudaspis cana*) at Transvaal Snake Park (Fig. 13). Dathe and Dedekind explained care and breeding of Horseshoe Snakes (*Coluber hippocrepis*) (1988), and Madagascar Hog-nosed Snakes (1996) in the Berlin Tierpark. Campbell and Murphy (1977) described reproductive biology of two colubrid snake species from the Malagasy Republic, Madagascar Hog-nosed Snakes *Leioheterodon madagascariensis* and *Madagascariophis colubrina.*

At Dallas Zoo and a few others, the Southern Hognose Snake (*Heterodon simus*) was maintained but the Eastern Hognose Snake (*Heterodon platirhinos*) was rarely exhibited. This was because the former usually fed on rodents whereas the latter almost always restricted its diet to toads or occasionally frogs, difficult to find during winter. In one case, a beautiful orange-phase Eastern Hognose was on display at another facility but the supply of toads disappeared. In desperation, the caretaker offered a large horned frog (*Ceratophrys*). The battle was epic with the frog trying to swallow the snake for many minutes; at the end, the snake prevailed. The South American Hognose Snakes (*Xenodon dorbignyi, X. pulcher*) are now showing up in zoo collections, due to attractive coloring and hardiness in captivity.

One of the most spectacular snakes in our collection at Dallas Zoo was the Filetail Ground Snake (*Sonora aemula*) from northwestern Mexico. Our specimen, about a foot long, had a brilliant red body with a black head and whitish collar. It lived in a gallon jar with a moist paper towel and small water dish and fed on small insects. The snake remained visible most of the time and always caught the eye of our visitors. Many years ago, we held an open-house tour of the reptile building, complete with wine and cheese in the lobby, for an ASIH meeting held in Fort Worth. While we were enjoying the repast, one of our attending herpetological or ichthyological colleagues slipped into the rear section, opened the jar, stole the snake, and replaced the cover—the snake was never recovered.

At Dallas Zoo and Zoo Atlanta where I started my career, we had several snakes with foul tempers. The most notorious were Wagler's Snake (*Xenodon merremi*), Jackson's Twig Snake (*Thrasops jacksoni*), sipo (*Chironius* sp.), Indian Ratsnake (*Ptyas mucosa*), rear-fanged Mangrove Snake (*Boiga dendrophila*), tropical racer (*Masticodryas*), and several US watersnakes (*Nerodia*). Curator Joe Laszlo at San Antonio Zoo had a few examples of keelback snakes, genus *Helicops,* comprising about 16 species. Although small, they were incredibly skillful at biting and left tiny teeth marks. Joe invited visiting herpetologists to touch the tail without being bitten—these snakes swapped ends so quickly that few were able to avoid being bitten even though forewarned. These episodes helped pass the time for us during my visits. I strongly recommend that all of these noxious creatures be excluded from future collection plans.

I have always been intrigued by snake patterns and colors, especially since many from various parts of the world are similar. One of the most striking combinations are a coralsnake-mimic coloring anteriorly and a unicolored part posteriorly in the colubrid Neckband Snake, *Scaphiodontophis annulatus* (Fig. 14). At Dallas Zoo in the 1970s, an adult was obtained which fed well in captivity on a diet of anoles and skinks, which were swallowed alive at astounding speed. The snake often rested

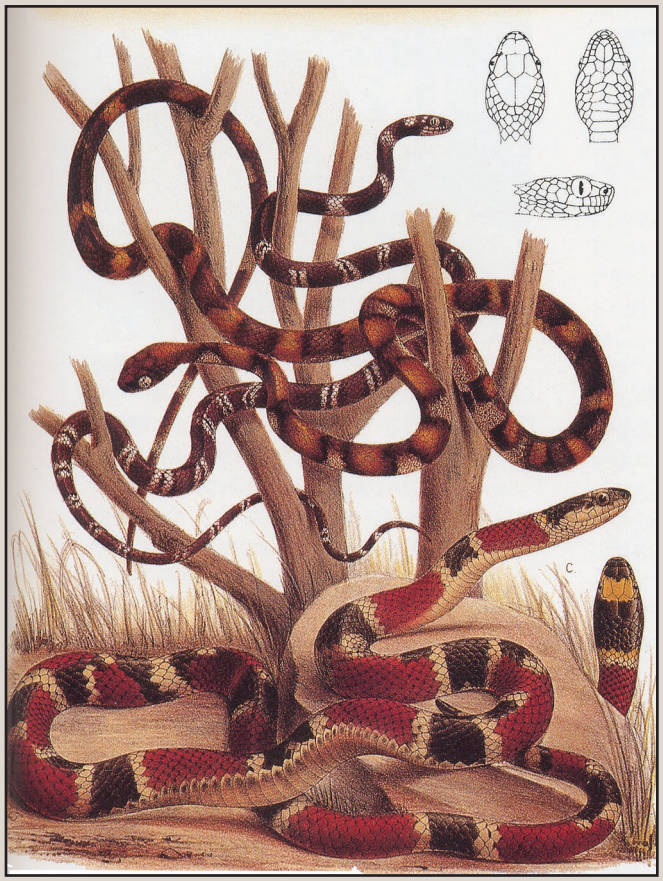

FIG. 14. *Mesopeltis dimidiatus* (above) and *Henicognathus venustissimus* from *Biologia Centrali Americana: Reptilia and Batrachia* in 1885–1902 by Albert Günther. *Henicognathus* is now *Scaphiodontophis*; the congener *S. annulatus* (Neckband Snake) was maintained at Dallas Zoo.

with the anterior portion of the body elevated. I decided to test the snake's reactions to potential predators or their scents—European Ferret, Gray Fox, skunk, raptor feathers, and humans. The snake remained motionless rather than thrashing the body as was described in a paper by Henderson (1984). The tail of this species is exceedingly long and breaks easily (likely in response to predators) but this did not happen in our specimen.

Coachwhips (*Coluber flagellum*) and Racers (*C. constrictor*) are rarely kept in zoo collections as they are snappy, nervous, and flighty. In fact, an adult male Racer was the only snake in my career to have aggressively attacked me without provocation. I encountered this male courting a female in the wild during high school and this suitor likely wanted privacy. I retreated and the snake continued to pursue me, wildly striking.

During my college years, I had a perverse streak which, some would say, lasts even to this day. I had captured an adult black-phase Coachwhip in Florida. For my speech class, I gave a riveting presentation in dulcet tones on snakes, using some of my calm live captives as examples. Admittedly, many of the students were apprehensive but fascinated. I finished by talking about the exceptional speed, aggressiveness, and toxicity of black mambas and slowly opened the cloth bag containing my black-phase Coachwhip, which promptly exploded from the bag and shot off the stage into the crowd. There was complete pandemonium as the students rushed toward the exits, scattering chairs in their way—within minutes, I was standing alone in the room. The professor, who bolted as well and peeked around the open door frame to see if the snake had been secured, thought it was hilarious and gave me an A+ for the class. He said that it was one of the few presentations that was not dreadfully boring!

Husbandry and Medical Management

In my earlier papers and books, I listed many titles dealing with these subjects. There is a comprehensive new book that must be on the bookshelf of every person maintaining live herpetofauna—Petzold's *The Lives of Captive Reptiles*. This wonderful compilation, translated into English by Heichler and Murphy (2008), includes aspects of reproduction, development, nutrition, history of zoos, relevance of terrarium observations, and conservation programs in zoos and private terraria. See Peeling's review (2009) for details.

Campden-Main from the Louisiana Purchase Zoo in Monroe wrote a paper on the care of newborn snakes (Campden-Main and Campden-Main 1982). Banks (1985) observed feeding and sloughing in a collection of captive snakes. Greene (1983) collected data from a number of serpents in zoos to strengthen his analysis of the dietary correlates of the origin and radiation of snakes. These data are helpful when considering suitable prey items. Bloxam and Tonge (1986) appraised the breeding program for reptiles at the Jersey Zoo. William Gehrmann discussed lighting requirements in several papers (1971, 1987, 1994). Murphy and Campbell (1987a) provided selected references applicable to the maintenance of snakes in captivity and a book chapter on captive maintenance the same year (Murphy and Campbell 1987b).

Susan Barnard from Zoo Atlanta and her associates have published a number of papers on parasitism in snakes. Camin and associates (1948, 1953, 1964) documented the ravages caused by the snake mite (*Ophionyssus natricis*) in captive reptile collections. Da Paixão Sevá et al. (2011) described occurrence and molecular diagnosis of *Cryptosporidium serpentis* in captive kingsnakes and ratsnakes in São Paulo, Brazil.

Lloyd at the Roger Williams Park Zoo in Rhode Island published three papers on ophidian paramyxovirus and reptilian dystocias (Lloyd and Flanagan 1991; Lloyd 1990, 1992). Reichling (1988b) discussed treatment of dystocia in snakes. Ungureanu et al. (1972) identified hemorrhagic septicemia in snakes in captivity at Zoological Garden of Bucharest. At Philadelphia Zoo, Aronson (1929) described spontaneous tuberculosis (*Mycobacterium thamnopheos*) in garter snakes. Adamy (1966) investigated the therapy of salmonellosis. Mitch Bush and associates from the Smithsonian National Zoological Park published papers on the use of antibiotics in snakes (1976), biological half-life of Gentamicin in Gopher Snakes (1978), and blood collection and injection techniques in snakes (1978). At the same zoo, Nichols and Lamirande (1994) used methohexital sodium as an anesthetic for colubrid snakes. Hilf et al. (1989) investigated pharmacokinetics of Gentamicin and Piperacillin in blood pythons and Hilf et al. (1990) did a comparative study of upper airway flora in healthy boid snakes and snakes with pneumonia at Pittsburgh Zoo. Velayan and Ambu (1991) studied bacterial infections in reptiles at the National Zoo, Malaysia. Flanagan and Harwell (1983) from Houston Zoo discussed pathobiology and management of chronic regurgitation in snakes. At Baltimore Zoo, Cranfield and Graczyk (1995) expanded information on ophidian cryptosporidiosis. Ippen (1980) described mycosis in snakes. Garner et

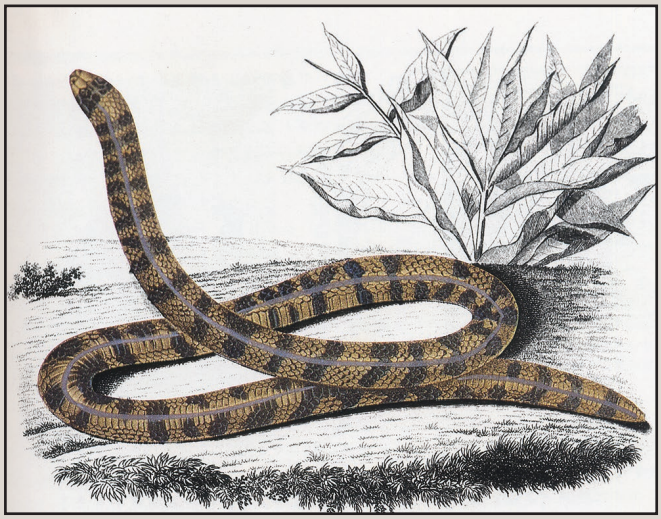

FIG. 15. Coral Pipe Snake (*Anilius scytale*) from *Dictionnaire universel d'histoire naturelle* by Alcide D'Orbigny in 1838–1849.

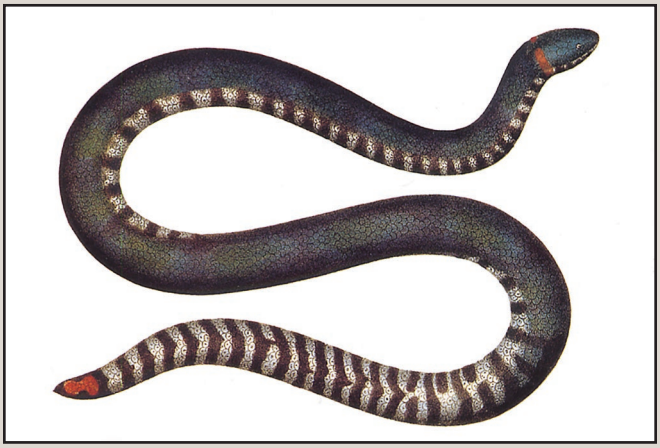

FIG. 16. Illustration of Red-tailed Pipe Snake *Cylindrophis ruffus* from Heinrich Rudolf Schinz, curator of the natural history society of Zürich and author of many important zoological works between 1824 and 1852. Modified image from *Naturgeschichte und Abbildungen der Reptilien* (1833–1834).

al. (1995) diagnosed vertebral chondrosarcoma in a Corn Snake (*Pantherophis guttatus*). Zachiesche et al. (1988) diagnosed lymphoid leukemia with presence of type C virus particles in a Yellow Ratsnake (*P. obsoletus*).

A Few Snake Families Rarely Kept in Zoos

Acrochordidae—Dunn et al. (1987) were successful in exhibiting and breeding the Arafura File Snake *(Acrochordus arafurae*) at Melbourne Zoo. Banks (1989) described skin lesions in *Acrochordus* and *Erpeton,* perhaps caused by excessively bright lighting. Our captives did not have skin lesions, which may be due in part to the presence of aquatic snails in their aquaria or relatively high pH (above 7.2). The snails were often on the heads and bodies of the snakes; algae growth did not occur and there were no shedding problems including eye caps. Curator Louis Pistoia told me that an adult Java Wart Snake (*A. javanicus*) refused food for slightly over four years in the Columbus Zoo collection. Dowling (1960) described feeding habits at Bronx Zoo. In the 1970s, *A. javanicus* was imported in small numbers to the US. The snakes were poor feeders on living fishes at Dallas Zoo until the water temperature was raised to 85°F (30°C) or slightly higher. Dubach et al. (1997) described parthenogenesis in the Arafura File Snake at Chicago Zoological Park.

Aniliidae—The only living zoo examples of Coral Cylinder Snake (*Anilius scytale*) I have seen were a few in collections in South America. This is likely due to specialized dietary requirements: amphisbaenians, caecilians, and snakes. Defensive tail display has been observed at Instituto Butantan (Sawaya 2010, Fig. 15).

Cylindrophiidae—The only living representatives of this group I have seen in zoo collections were a few Red-tailed Pipe Snakes (*Cylindrophis ruffus*) years ago at the Oklahoma City Zoo (Fig. 16). When I asked if the snakes ever displayed the characteristic tail-raising defensive behavior, the caretakers said that the snakes did briefly at first but quickly habituated to captivity.

Leptotyphlopidae—The only living example during my early career was a large snake called Giant Blind Snake (*Leptotyphlops maximus*) from Mexico at Dallas Zoo. The snake had been confiscated by US Fish and Wildlife Service and was given that technical name on the manifest[1]. The feeding behavior corresponded to the description by Kley (2001), known as mandibular raking. Ants, eggs, and larvae were literally sucked up like a vacuum cleaner; I have never seen a snake go into a feeding frenzy quite like this. In the beginning, we fed this snake Carpenter ants collected from nests on Zoo grounds. When fire ants arrived in Dallas, all carpenter ants disappeared and we were unable to find some to feed the snake. In desperation, I tried to collect fire ants to substitute but I regretted that plan immediately after multiple encounters with their defensive behavior. When I offered them to the snake, known as an ant specialist, it immediately went into convulsions. Amazingly, the ants had penetrated the interstitial skin between the scales and

[1]In this shipment, approximately 2000 tarantulas, each in its own small plastic bag, were included. Most were the Red-legged Tarantula but several other types were present as well. The wildlife inspector was worried that the arachnids would dehydrate and suffocate so he asked me to help him transfer the animals to larger containers with air holes and include a damp paper towel for moisture. One of the primary defenses is to flick urticating hairs (bristles), which are extremely irritating, especially to those persons with severe allergies. We had several tarantulas in the Dallas Zoo collection that I handled for demonstrations with no negative reactions but, as these tarantulas were unpacked, the hairs literally coated the room and after several hours of handling the creatures, my whole body began to itch and the result was excruciating. For two days, I soaked in the bathtub at home with Epsom salts added to the water to lessen the pain and diminish swelling, cursing the inspector who seemed to have no negative reaction and was amused by my plight. When I called in sick to the Zoo to explain the circumstances, my boss was quite skeptical. All of the confiscated tarantulas were donated to a university researcher a few days later. Also in this shipment were about three dozen adult spiny-tailed iguanas (*Ctenosaura pectinata* and *C. similis*). We did not have suitable holding space in the reptile building so the lizards were released in the rear section of the spacious aquarium, an antiquated Art Deco concrete structure in Fair Park. They immediately scaled the rough concrete walls and ran around the wide tops of the large cement aquaria, often basking under the display lights. We fed them several times a week and they would descend like ravenous wolves from all directions and snatch vegetables and dog food from the metal trays placed on the floor. They lived for years but avoided the water in the tanks, unlike Green Iguanas, which dive into water to escape predators.

COURTESY OF SMITHSONIAN INSTITUTION LIBRARIES, WASHINGTON, DC

FIG. 17. Illustration of snake hall (Schlagen-Zaal) at Natura Artis Magistra in Amsterdam from *De Dierentuin van het Koninklijk Zoölogisch Genootschap te Amsterdam* by Hermann Schlegel in 1872.

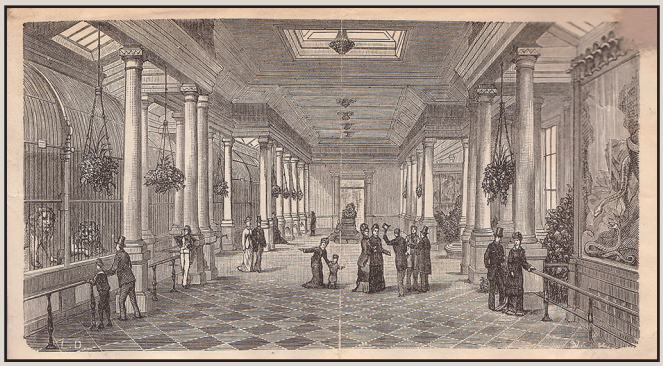

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FIG. 18. Title page from *Promenade au jardin zoologique d'Anvers par Eugéne Gens* by Eugéne Gens in 1861.

were attached to the snake's body. I immediately put the snake under running water and eventually the ants released their grip. Later, the snake laid three infertile eggs but did not coil around the clutch as mentioned in the literature about some blindsnakes.

Typhlopidae—I have never seen an exhibit of blind snakes (scolecophidians) in a zoo. These snakes are the most basal form for a visitor to compare against advanced snakes (caenophidians), but absence from collections is almost certainly due to difficulty in finding enough food throughout the year and the secretive nature of the animals. We found what we believed to be an adult Flowerpot Snake *Rhamphotyphlops* (now *Indotyphlops*) *braminus* in a pile of mulch outside the back door of the reptile building at the National Zoological Park in Washington DC. I asked the horticulturist who had delivered the pile and she said that the material had been ground into small pieces from branches trimmed from a standing dead tree on Zoo property and almost immediately brought to the building in the bed of a pickup truck. It may have traveled from flower pots delivered to the Zoo but she did not believe that this was the case as there were no pots anywhere near the tree. This invasive species is known from Massachusetts and Florida. My plan was to preserve the snake as a voucher specimen for certain identification but it wriggled through my fingers and catapulted into the adjacent outdoor alligator exhibit, never to be seen again.

Uropeltidae—In the April 2011 issue of Zoo's Print, the magazine of the Zoo Outreach Organization, the list of reptiles assessed during the Conservation Assessment and Management Plan (CAMP) workshop in Western Ghats, India in March 2011 included 20 species of shield-tail snakes (*Uropeltis*). The collected data are being analyzed to determine the conservation needs for reptiles throughout India and will be published in a future IUCN Red List.

Xenopeltidae—McGeorge (1997) bred the Sunbeam Snake *(Xenopeltis unicolor)* at Chester Zoo.

SUMMARY

During the past few decades, there has been an increasingly vocal group of animal rights advocates calling for a ban against keeping live animals in captivity. They claim that animal welfare issues are ignored and the captives live unenriched and unfulfilled lives. Concurrently, there have been objections to collecting and euthanizing animals for scientific research collections. Both of these views are misguided, for if this happened we would not be able to add very much to our current understanding of snake biology.

In reading my four-part series on snakes kept in zoos and aquariums through centuries (Murphy 2014a, b, c; this paper), it should be apparent that many important scientific studies have been generated and replicated in that environment. In fact, many of the questions posed could not have been investigated in the wild. For example, how would we have known that some pythons incubate egg clutches to increase temperatures by twitching? What behaviors are apparent when males court females? What are the communication channels? Which snakes lay eggs and which ones give birth to living young? Does parthenogenesis happen?

What do hemipenes look like and how do they work? Former curator Herndon Dowling at New York Zoological Society published several important studies on the morphology of these structures (1959b, 1959c, 1967; Dowling and Savage 1960). Observations on living Ottoman Vipers (*Vipera xanthina*) at Dallas Zoo documented usage (Murphy and Barker 1980). Dowling also published a paper on zoo record-keeping (Dowling and Gilboa 1966), a critical component for documenting interesting animals doing interesting things.

Because snakes are essentially living tubes without limbs, how do they move and how do snakes find and dispatch their prey? Or swallow prey much larger than themselves? Being ectothermic, how can they digest meals and live and prosper in a world of changing climatic conditions? Several researchers

COURTESY OF KRAIG ADLER

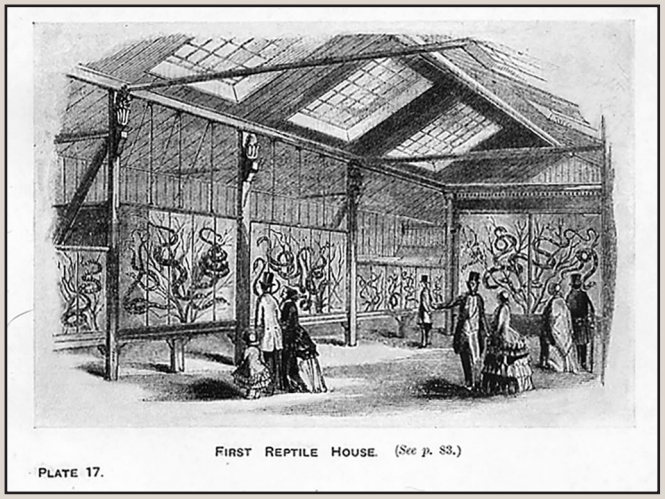

FIG. 19. Illustration of London Zoo reptile building. The beginning of an article from *The Illustrated London News* on 2 June 1849 reads as follows: "The new reptile house in the Gardens of the Zoological Society in the Regent's Park will ultimately form one of the most instructive, as it is the most novel and original feature in this delightful institution. The collection already contained in it is so unexpectedly brilliant, considering the small number of reptiles previously exhibited in the Menagerie, that we cannot but anticipate the most important results in the study of this singularly interesting division of the animal kingdom."

COURTESY OF ROBERT MENDYK

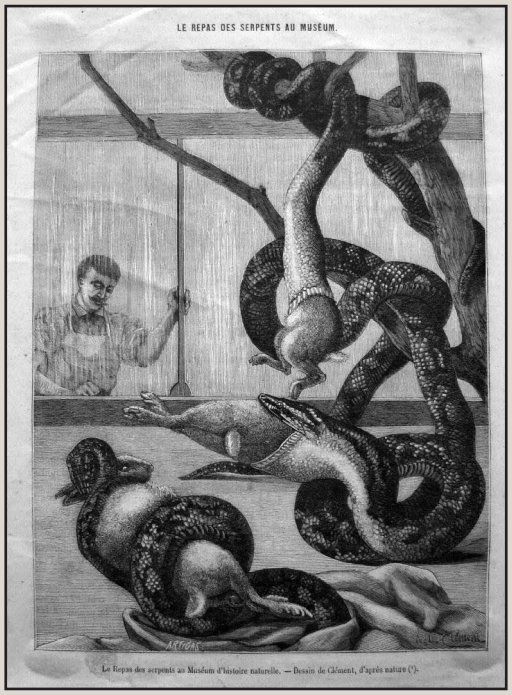

FIG. 20. How did this keeper feed these snakes (probably Reticulated Pythons, *Malayopython reticulatus*) in the same enclosure without them grabing and constricting each other? Possibly that is the reason he is holding a broom. Illustration called "The Meal of Serpents in Museum d' histoire Naturelle" from *Magasin pittoresque* to the 56th année, sér. II, tome VI, p. 241, 1888. The Menagerie Jardin des Plantes is part of the museum, located in Paris (see Murphy 2009a, b for history).

have published important studies that should be consulted: David Chiszar, David Cundall, Alexandra Duefel, Carl Gans, Frances Irish, Ken Kardong, Hamidreza Marvi and associates at Zoo Atlanta, Hobart Smith, Steve Secor, and others.

How can some live underground, others above ground, some in water, and others high in trees? What structural modifications are needed to do this? Harvey Lillywhite (2014) tells us how.

How do serpents defend themselves against predators (Greene 1997)? And against humans who want to chop them into tiny bits? Since human ophiophobia is a real phenomenon (Burghardt et al. 2009), why do we so-called intelligent beings want to wear their skins if ophidians frighten us and many are collected in unsustainable numbers for the fashion industry? When I ask some visitors and acquaintances who hate and fear snakes and other reptiles why they are wearing cobra shoes, python handbags, lizard hatbands, croc wallets and belts, and other reptilian accoutrements, they are clueless and find my question irrelevant and/or offensive. When I say that the fashion industry is responsible for millions of reptile deaths annually, there exists an enormous illegal black market worldwide, reptiles may be brutally dispatched by being skinned alive but cannot scream in pain, and many populations are seriously endangered, they often are completely indifferent. When I suggest that it would be interesting to study these fashion statements as possible subliminal expressions of dominance over a fallen enemy, they simply shrug their shoulders and view me as a lunatic. Would natural selection favoring ugly or nondescript skins be an advantage to survival? Probably not as I have seen plenty of artificially-colored reptile skin products in department stores and boutiques and most are garish, offending my aesthetic sense.

Most humans will never encounter a living snake in the wild. So would they miss seeing their stunning beauty and remarkable morphology unless they visited a zoo or aquarium? At the London Zoo, visitors were asked to rank their favorite exhibits; two of the three most popular were the aquarium and reptile house (Balmford et al. 1996; Balmford 2000). The message here is snakes may be fearful and unsettling but humans are fascinated with them nonetheless and a zoo visit must almost always include seeing them. One day outside a zoo reptile building, I sat on a bench next to an older female visitor who was waiting for her family to exit. I asked why she did not go into the place to see the snakes with her relatives as these creatures were well worth seeing. I was told in no uncertain terms that she could not even tolerate listening to the word "snake" much less view serpents. Even seeing a picture of one would send her to the sick bed for several days. Her family's daily task was to review incoming printed materials to intercept any snake images and remove them. Our interaction was quickly finished, especially since I did not feel like calling the paramedic squad that day should she see an ophidian. She was fortunate that I was not wearing my favorite ball python T-shirt showing a wide range of color morphs coiled together.

These are not questions generated by me. Rather, these are some of the intriguing enquiries over the past centuries explored and answered by our predecessors and we owe them a huge debt of gratitude. And it must be remembered that virtually none of this would have happened without zoos, aquariums, academic institutions, and museums (Figs. 17–20).

Acknowledgments.—This contribution is dedicated to Charles C. (Chuck) Carpenter and his then-graduate student James C. Gillingham from University of Oklahoma in Norman. Beginning in 1975,

we began a collaborative effort to study the behaviors of reptiles in the Dallas Zoo collection—two rattlesnake species, Madagascan Tree Boa, Blue-tongue Skink, Angle-headed Dragon, Gillen's Monitor, Death Adder, Fiji Island Iguana, and kingsnakes. About a decade later, Chuck published a paper on dominance of snakes (Carpenter 1984), based in part on observations at Dallas Zoo. We all learned an important lesson as we spent hours trying to document their lives—under carefully controlled conditions, animals tend to do as they damn well please!

For various courtesies, I thank Kraig Adler, Judith Block, Kristen Bullard, John Edwards, Matt Evans, Kevin de Queiroz, Harry Greene, Robert Hansen, William Lamar, Jim Langhammer, Joe Mendelson, Polly Lasker, Roy McDiarmid, Robert Mendyk, Matt Neff, Leslie Overstreet, Ray Pawley, Chad Peeling, Clyde Peeling, and George Zug.

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