ZOO VIEW

Herpetological Review, 2017, 48(2), 474–486.

History of Captive Management and Conservation Amphibian Programs Mostly in Zoos and Aquariums. Part II—Salamanders and Caecilians

"The belief that a salamander could pass through fire unscathed led to the idea that the animal passed through 'without stain.' Thus, the salamander came to symbolize enduring faith, courage, chastity, purity, virginity, and self-restraint. Salamanders became associated with the voice of God. During the eighteenth century, the word 'salamander' referred to a woman who lived chastely despite being surrounded by temptations."

—Marty Crump, 2015 *Eye of Newt and Toe of Frog, Adders Fork and Lizard's Leg.*

Of the Salamander

"But the greatest matter in the Salamander to be inquired after, is whether it can live and be nourished by and in the fire, or whether it can pass though the fire without any harm, or quench and put out the flame. Which opinions in the very relating and first hearing, do cross one another, for how can that either be nourished or live in the fire which quenches the flame being put into it?... Aristotle who never saw a Salamander himself but wrote thereof by hearsay, has given some color to this opinion, because he writes, the Salamander is an evidence that the bodies of some creatures are not wasted or consumed in the fire, for, as some say, it walks in the fire and extinguishes the flame…When the Salamander is provoked it emits a white matter liquor or humor, and it is an audacious and bold creature, standing to his adversary, and not fleeing the fight of a man; and even less, if it perceives that a man prosecutes and follows it to harm and kill it. The biting of it is very painful and deadly…That is, if a Salamander bites you, then betake you to a coffin and winding sheet. The *Rhatians* [ancient Alpine tribes conquered by the Romans in 15 B.C.] also do ordinarily affirm that when a man is bitten by a Salamander he has need of as many Physicians as the Salamander has spots. And *Arnoldus* [Bishop of Metz] says, that it has as many venoms and means of hurting as it has distinct colors. For when it once bites and fastens teeth, it never lets go, and being pulled off, it leaves the teeth behind, and then there never can be any remedy, and therefore it must be suffered to hang upon the wound until it falls off, either willingly or wearied or else compelled by the medicines that the wounded patient receives. For by this means only is the patient kept alive; yet this is always to be remembered, that the Salamander does not always bite, although provoked, for [Konrad] *Gesner* affirms that he having two of them, could never make them open their mouths by beating, nor that in all his life did he ever hear of any man bitten by them. And of this thing he not only accounts for the difference of time, where their rage sometimes shows itself by biting and sometime by not but also the difference of place and region, for that they bite in some countries, and not in others. When they have bitten, there follows a vehement pain and scab on the place, for the cure whereof there must be taken a decoction [Decoction is a method of extraction by boiling of dissolved chemicals from animal, herbal or plant material to extract the flavor or active principle] of Frogs, and the broth must be drunk, and the flesh applied to the fore; or else of the common remedies against the poison."

—Modified from *The Historie of Serpents* by Edward Topsell in 1608. Topsell was not a naturalist but relied on earlier authorities, most notably the *Historiae animalium* of the Swiss scholar Conrad Gessner.

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Introduction

There are about 700 described salamander species and 200 caecilians (AmphibiaWeb 2017). Salamanders are primarily concentrated in cooler northern temperate regions, with

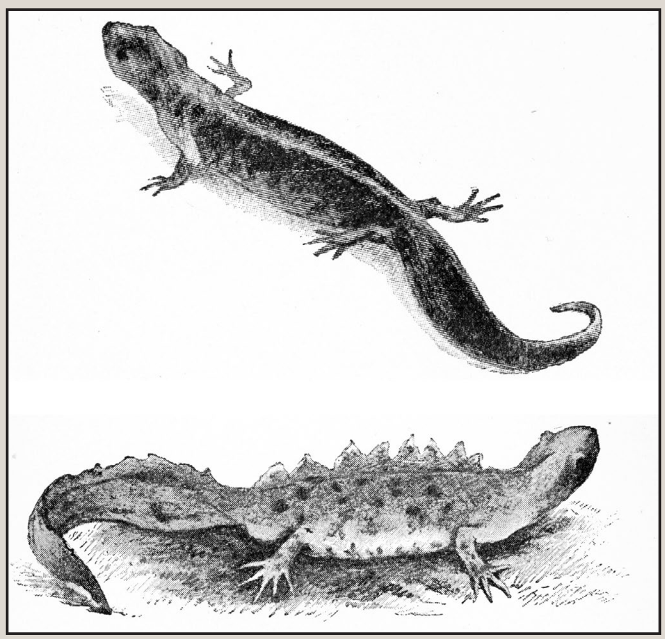


Fig. 1. Bateman's *The Vivarium*, 1897—This was the first book on herpetoculture in English. Female (top) and male Crested Newt (*Molge cristata*).

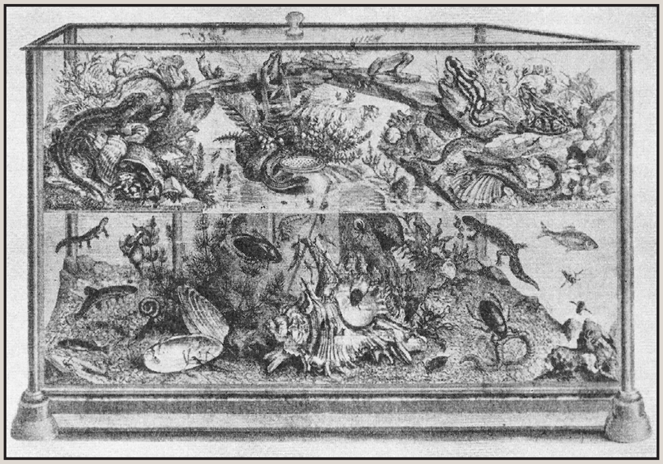


Fig. 2. Wilhelm Klingelhöffer packed his terrarium with newts, salamanders and suite of other animals in 1955–1959 in his encyclopedic *Terrarienkunde*. This work is the bible for herpetoculturists.

Appalachia being a global biodiversity hotspot for salamanders, and caecilians are primarily a tropical group (Stuart et al. 2008). Salamanders are a highly imperiled group with nearly half being reported as threatened by the IUCN Redlist Authority, while 66% of caecilians were listed as data deficient, probably because they are so difficult to find and sample (Stuart et al. 2008). Stuart et al.'s comprehensive book *Globally Threatened Amphibian Species* provide an encyclopedic compendium of basic information about the conservation status of most of the world's salamanders and caecilians associated with the 2004 global amphibian assessment. Jean Raffaëlli, a French journalist and salamander enthusiast, wrote *Les Urodèles du monde* describing 850 species and subspecies of the salamanders with numerous personal observations from both the field and in captivity. He has personally kept about one-fourth of the world's salamanders in captivity and collaborated with the Urodèle group of French salamander hobbyists to compile their collective observations (Raffaëlli 2007). Raffaëlli's incredible book is in French, but another book covering salamanders of the Old World is written in English and cites many of Raffaëlli's observations on captivity and breeding (Sparreboom 2014). Michael Lannoo's edited volume *Amphibian Declines* has encyclopedic accounts of every US salamander species (Lannoo 2005). Notably, the Raffaëlli, Lannoo, and IUCN Redlist accounts are all available online at AmphibiaWeb (AmphibiaWeb 2017). Frank Indiviglio, who earlier worked at the New York Zoological Park, wrote a comprehensive book in 1997 called *Newts and Salamanders. Everything About Selection, Care, Nutrition, Diseases, Breeding, and Behavior* (Figs. 1, 2). An excellent resource, and a good source of general veterinary information on salamander medicine, was written by Eric Baitchman of Zoo New England and Tim Herman of the Toledo Zoo in *Fowler's Zoo and Wild Animal Medicine* (Baitchman and Herman 2017).

History

Although little known to the general public, salamanders are an exceedingly important group of animals (Fig. 3). They are standard laboratory animals for use in research on developmental biology. Hans Spemann's Nobel-prize-winning experiments in 1935 on embryonic induction, which first explained how spinal cords and eyes develop in vertebrate animals, were done with European newts. Salamanders are also critical links in the ecological food chains that sustain terrestrial animal communities. In most eastern North American forests, the total body mass of all Red-backed Salamanders exceeds the total body mass of all birds and about the same as all small mammals living in the same forest (Burton and Likens 1975), which implies the huge role that these rarely seen and mostly subterranean animals play. Because salamanders are so important, textbooks and handbooks recording their biology and distribution are crucial references for scientists.

In 1943, the most important book on the salamanders of North America was published, Sherman Bishop's *Handbook of Salamanders*. This is a 555-page review of the biology and distribution of 70 species (Bishop 1943). During that same year, an even more extensive book on salamander biology was issued in Japan. But being published at the height of World War II, it did not reach America until after the war when returning servicemen brought the first copies back late in 1949. The book is Ikio Sato's *Monograph of the Salamanders of Japan* [*Nihon-san Yubiru Sosetsu*] (Figs. 3–5). It is, proportionate to numbers of species covered, far more comprehensive than its American counterpart. The geographic coverage is Imperial Japan, thus encompassing present-day Japan plus Formosa (Taiwan), Korea, and part of what is now eastern Russia. Many Japanese and all of the Korean species are also native to China. Sato's book covers 24 species of salamanders in three families: Cryptobranchidae (the giant salamanders, native to China, Japan, and North America), Salamandridae (the newts, native to Europe, Asia, and North America), and the Hynobiidae (an ancient family of aquatic salamanders native to Asia, from western Siberia and Iran to China and Japan, and the only family of salamanders that is not native to North America).

Sato's book, however, had one significant drawback for many scientists: it was in Japanese. Not only that, Sato's book is written in an old form of Japanese that used now-obsolete Chinese characters and idioms that even most Japanese today cannot properly understand because the Japanese government ordered a linguistic reform in 1952. Therefore the valuable information in Sato's book has been largely inaccessible to scientists around the world and, in recent years, even to Japanese biologists. The original book was published by Nihon Shuppan in Osaka on March 30, 1943. However, this company's facilities, and many copies of Sato's book, were destroyed during American bombing in March and June of 1945. Sato died in August 1945 from radiation burns five days after the atomic bombing of Hiroshima. The late Richard C. Goris has translated the entire text into English, and Kraig Adler is currently editing the book, and this will soon be published by SSAR.

In his book *Herpetological History of the Zoo and Aquarium World*, Murphy (2007) described a fascinating story in the vignette entitled "Siebold's Giant Salamanders." There is a section on the history of giant salamanders in Japanese institutions and an extensive list of publications on this taxon.

Behavior

Salamanders have fascinating behaviors that are often challenging to study in the field, but their small size and the relative abundance of some species makes them good study organisms in captive situations, and this has led to a host of behavior studies. A classic study of anti-predator behavior in captive *Plethodon* describes how sticky secretions from salamander tails and the

Figs. 3, 4, 5. Three plates from Sato's book from left to right: *Andrias japonicas, Pachypalaminus boulengeri, Triturus pyrrhogaster*

ability to detach their tails (autotomy) completely frustrate snake predators and, in some cases, immobilizes them by these adhesive properties (Arnold 1982). Although aquatic-breeding salamanders have a variety of anti-predator behaviors, they can be particularly discerning about selecting fishless water bodies in which to lay their eggs (Kats and Sih 1992). Lungless salamanders of the genus *Plethodon* have also been shown in captive settings to aggressively defend territories from each other, with intruders being expelled in about three-fourths of cases (Jaeger et al. 1982). Aquatic salamanders like hellbenders have a very keen sense of "smell" and displayed foraging behaviors in response to a drop of earthworm extract with detectability limits somewhere between 1:75,609,800 and 1:151,219,600 (Kuppert 2013). Much behavior in amphibians can be linked to the hormones prolactin and gonadal steroids interacting to stimulate reproductive maturation development and behaviors; vasotocin has been connected to key reproductive behaviors, like clasping in newts, and corticosterone can suppress reproductive behavior (Moore et al. 2005). Captivity and handling of salamanders can be stressful, as evaluated through lethal sampling by measuring corticosterone as an indicator of stress levels (Beachy 1995). Handling of captive Ocoee Salamanders (*Desmognathus ocoee*) led to elevated corticosterone responses, and decreased testosterone levels in salamanders but did not affect courtship behavior and mating in the short term (Woodley and Lacy 2010). Davis and Maerz (2008) observed that captive mole salamanders held for 10 days had significantly fewer lymphocytes in relation to neutrophils and eosinophils, suggesting a stress response due to captive conditions.

Reproduction

Heinrich Rudolf Schinz has many exceptional drawings of amphibian reproduction (Figs. 6, 7). The elaborate courtship behaviors of *Plethodon* species have been well documented in captivity and involve chin tapping so that male pheromones can be transferred to female nasolabial grooves followed by tail straddling and spermatophore transfer (Marvin and Hutchison 2010). Not all courtship is successful at spermatophpore transfer, and male *Ambystoma* and *Plethodon* have been observed mimicking female behavior to duping rival males into wasting their spermatophores (Arnold 2010). In Red-backed Salamanders (*Plethodon cinereus*), a terrestrial species, several lines of evidence indicate that male fecal pellets contain chemosignals of interest to sexually receptive females (reviewed in Jaeger and Forester [1993] and Jaeger and Wise [1991]). Females were more interested in fecal pellets from males that fed on high-quality diets, suggesting that the fecal pellet is an honest signal of a male's ability to garner resources. It is not clear whether the fecal pellet chemosignals are signals per se, or simply cues of the male's diet. Similar to Red-backed Salamanders, archaic frogs (*Leiopelma hamiltoni)* inhabit home ranges and individuals distinguished between their own feces versus those from conspecifics (Lee and Waldman 2002). Robert Jaeger (pers. comm. to JBM) called it his "Sexy Feces Theory."

With all the studies of *Plethodon* salamander courtship in captivity, it is somewhat surprising that few published studies of the entire reproductive cycle of these creatures exist based on captive animals. The Toledo Zoo, however, has successfully bred the Black Mountain Dusky Salamander (*Desmognathus welteri*), the Cave Salamander (*Eurycea lucifuga*), the Four-toed Salamander (*Hemidactylium scutatum*), the Slimy Salamander (*Plethodon glutinosus*), and the Northern Red Salamander (*Pseudotriton ruber*) in captivity (Odum 2011). In 2005, the Galeana False Brook Salamander (*Pseudoeurycea galeanae*) reproduced at the San Antonio Zoo.

Kerbert (1904) described the first captive breeding of the Japanese Giant Salamander at the Amsterdam Zoo (Figs. 8, 9). Japanese Giant Salamanders were successfully bred at the Asa Zoological Park for the first time in 1979, and have been reliably bred in captivity ever since (Kuwabara et al. 2007). Staff of the Ron Goellner Center for Hellbender Conservation at the St. Louis Zoo have successfully bred state-listed Ozark Hellbenders (*Cryptobranchus alleganiensis bishopi*) as part of a unique naturalistic artificial stream-breeding setup (Ettling et al. 2013). The Nashville

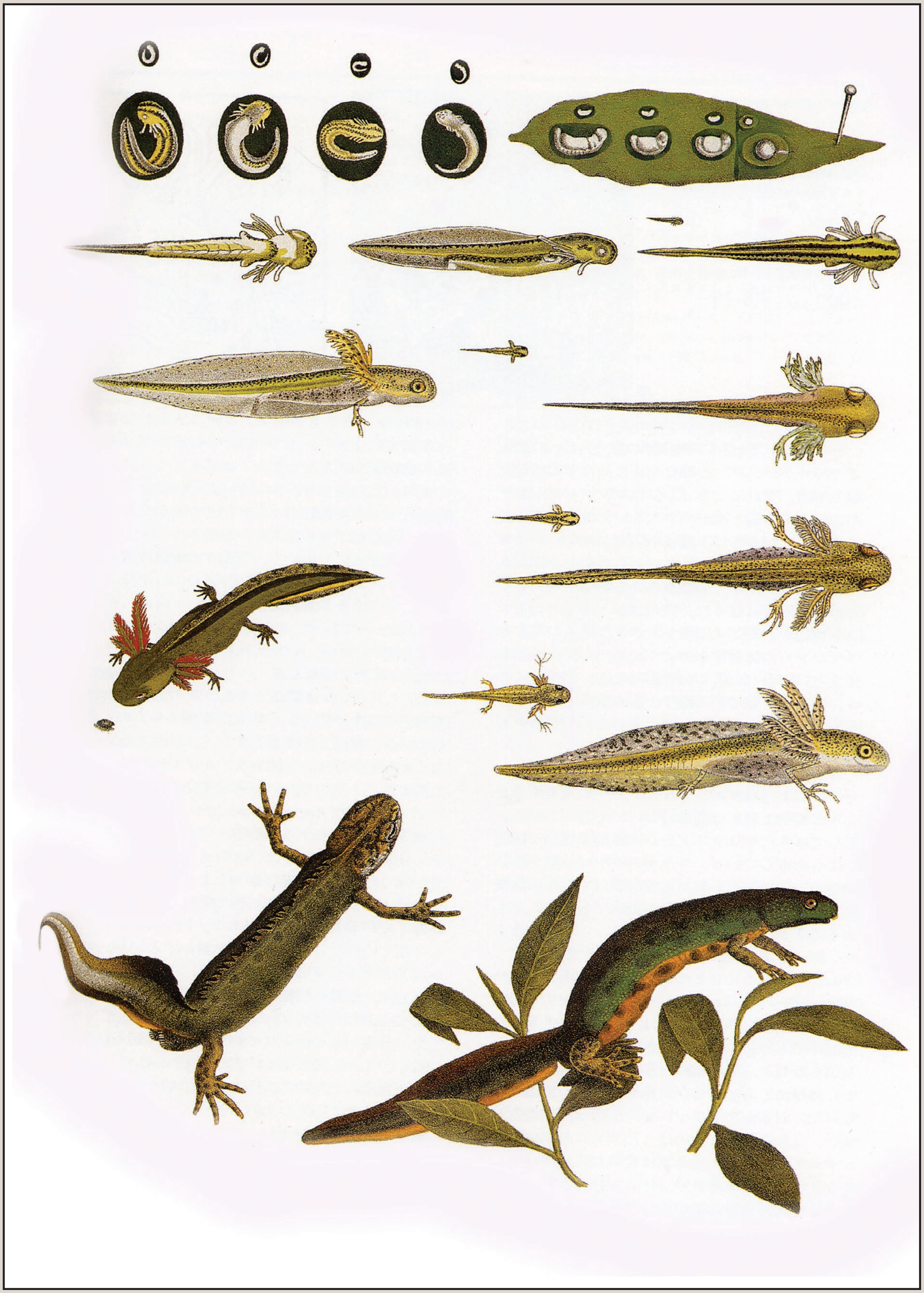


Fig. 6. Heinrich Rudolf Schinz, professor of natural history at University of Zürich, published detailed illustrations of amphibian reproduction in 1833. This *Triturus cristatus* drawing is from *Naturgeschichte Abbildugen der Reptilien.*

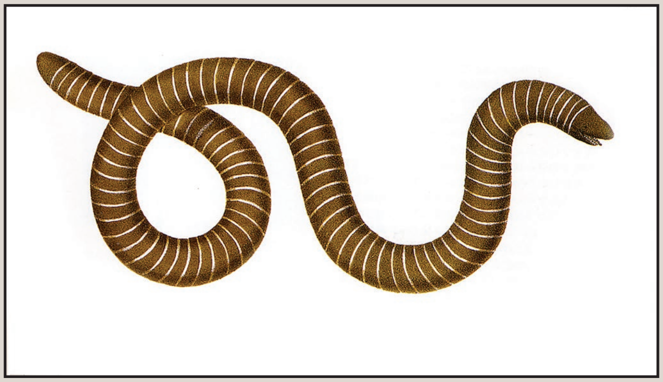
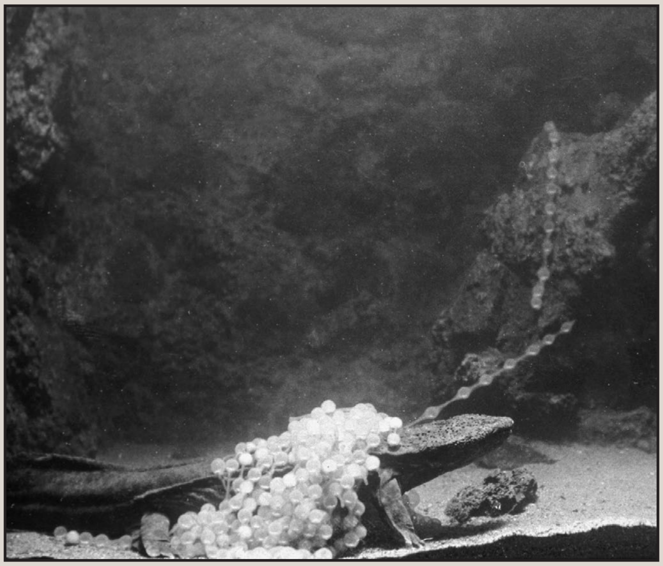


Fig. 7. *Siphonops annulatus* from Heinrich Rudolf Schinz's *Naturgeschichte Abbildugen der Reptilien* (1833).



COURTESY OF EUGÈNE BRUINS, NATURA ARTIS MAGISTRA ARCHIVES

Fig. 8. Male Japanese Giant Salamander (*Andrias japonicus*) guards eggs called "Rosenkranzschnüre" or "rose wreath strings" at Natura Artis Magistra. Undated photograph but probably taken around 1902. Reproduction occurred several times at Artis.

Zoo staff was successful in hatching an Eastern Hellbender (*Cryptobranchus alleganiensis alleganiensis*) by artificially fertilizing an egg for the first time using cryopreserved sperm (Grow and Ahmad 2015; Fig. 10). Pfaff and Vause (2002) prepared a note on the captive reproduction and growth of the Broad-striped Dwarf Siren (*Pseudobranchus s. striatus*) at the Riverbanks Zoo. A specimen of Lesser Siren (*Siren intermedia*) grazed on algae growth daily at Dallas Zoo. A Greater Siren (*Siren lacertina*) lived for nearly 15 years and a Mudpuppy (*Necturus punctatus*) for 5 yrs and 8 months at Cincinnati Zoo (Snider and Bowler 1992, Figs. 11, 12).

Newts of the genus *Neurergus* are popular in captivity and have an elaborate courtship display, with tail fanning followed by spermatophore deposition by the male. The female moves over the spermatophore and is "braked" by the male when her cloaca reaches the right position (Sparreboom et al. 2000). Female Striped Newts (*Notophthalmus viridescens*) held in captivity were found to effectively store viable sperm for up to six months after mating (Sever et al. 1996). Many years ago, JBM visited the London Zoo. The staff was excited about their Giant Panda, one of the few places where this creature was on display. When visitors entered Regent's Park, they were told by a volunteer that the lovable panda should not be missed. Herpetological Curator Dave Ball was proud of his *Triturus* breeding program. Dozens of enclosures harboring many species were on the Reptile Building roof and so many hours were spent watching these newts. When JBM returned home, he was asked by many zoo colleagues about the panda but he realized that he had totally forgotten about it. He insisted that newts are far more interesting than pandas anyway. At Berlin Tierpark, Freytag and Petzold (1978), and Rehák (1991) at the Prague Zoo, described the natural history and captive breeding in the Vietnamese Warty Newt (*Paramesotriton deloustali*). In 2004, Fire Salamanders (*Salamandra s. bernardezi*) and Fire-bellied Newts (*Cynops cyanurus*) reproduced at the Cincinnati Zoo. The Detroit Zoological Institute, Baltimore Zoo, Metro Toronto Zoo, and others have been involved in a broad-based captive breeding program to conserve the Emperor Newt (*Tylototriton shanjing*) with production of over 500 metamorphs. Anderson's Newt (*Echinotriton andersoni*) reproduced at the Buffalo Zoo in 2005. Wisniewski and Paull (1986) bred and reared the European Fire Salamander (*Salamandra salamandra*). Husbandry and reproduction of the Shangcheng Salamander (*Pachyhynobius shangchengensis*) in captivity was described by Pasmans et al. (2012). They noted their extremely efficient ability to convert food to body mass with a food conversion efficiency ratio of about 0.33.

COURTESY OF KRAIG ADLER

Fig. 9. Japanese Giant Salamander (*Andrias japonicus*) from a lithograph drawn from life by the Dutch natural history artist, A. Saagmans Mulder (from Philipp Franz de Siebold's "Fauna Japonica," Reptilia part 3, Leiden, 1838).

Natural History and Conservation

Many salamanders are threatened but even as the natural history of temperate species has been comparatively well studied, tropical species remain poorly understood (Gratwicke et al. 2015). Even in the US, numerous detailed natural history studies of individual species have not translated into a clear understanding of conservation threats, but in Appalachia climate change, pollution, residential development, energy production and mining, and invasive species and disease are thought to be the top threats to salamanders (Gratwicke 2008, Fig. 13).

Climate change is projected to be a significant threat to Appalachian salamanders that require relatively cool, moist microclimates (Milanovich et al. 2010), and to cave salamanders that dependent on subterranean aquifers (Loáiciga et al. 2000). Climate change has been linked to a 12-year decline of the Aquatic Spring Salamander (*Gyrinophilus porphyriticus*) in New Hampshire (Lowe 2012), and another study of museum specimens

Fig. 10. *Cryptobranchus alleganiensis* from Baron Georges Cuvier's *le règne animal....*'Disciples edition' between 1836–1849. See text for study on olfaction.

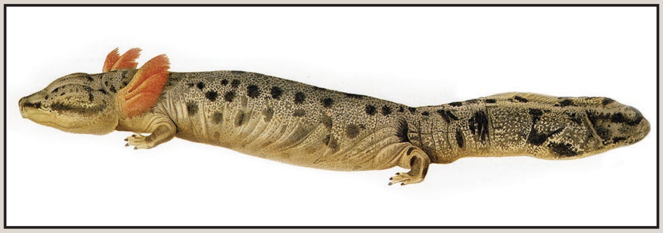


Fig. 11. *Necturus maculosus* from Baron Georges Cuvier's *le règne animal....*'Disciples edition' between 1836–1849.

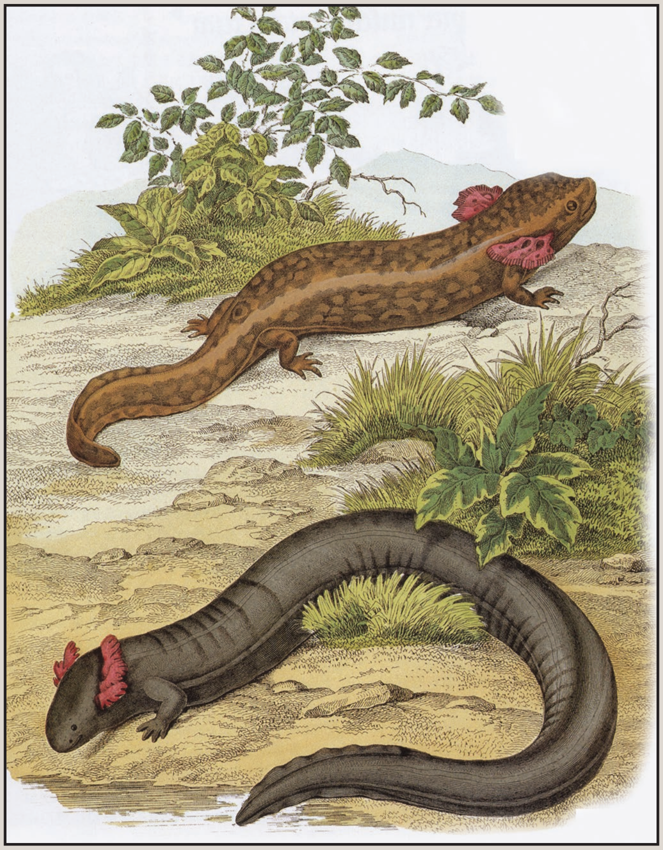


Fig. 12. *Necturus maculosus* and *Siren lacertina* from C. Hoffman's *Das Buch der Welt*...in 1842–1872.

noted increased body size of Red-backed Salamanders (*Plethodon cinereus*) associated with climate change (McCarthy et al. 2017), but in other cases the effects have been less clear-cut. At the Smithsonian's National Zoological Park, a climate change-related experiment investigated the effects of projected increases in stream temperature fluctuations on hellbender immune systems, but found that they were quite resilient and in fact, immune response was somewhat improved in systems with rapid temperature fluctuations (Terrell et al. 2013). Another experiment investigating the effects of warmer climates on intraspecific interactions between the mountain-top endemic Shenandoah Salamander (*Plethodon shenandoah*) and Red-backed Salamanders (*P. cinereus*) found that *P. shenandoah* were able to outcompete *P. cinereus* even under warmer conditions (Dallalio 2013).

Road kill is a huge source of mortality for mole salamanders and their relatives with annual breeding migrations (Gibbs and Shriver 2005). The Toronto Zoo has championed the Ontario Road Ecology Group; the latter worked with civil engineers to prioritize underpass placement sites for new roads by modeling hotspots for species vulnerable to road kill, including Spotted Salamanders (Gunson et al. 2009). Other groups have trained volunteer "salamander crossing brigades" deployed during migration season to help salamanders safely cross roads as part of their citizen conservation efforts (Thelen 2013; Grow and Ahmad 2015).

Salamanders can contract and die from chytridiomycosis caused by the pathogen *Batrachochytrium dendrobatidis* (*Bd*) in laboratory conditions, but there are few documented cases of mortality caused by this pathogen in the wild (Baitchman and Herman 2017). Surveys of *Bd* in wild salamanders have revealed low prevalence and loads not associated with clinical disease (Gratwicke et al. 2011; Muletz et al. 2014; Bales et al. 2015), but declines have been noted in the neotropics (Cheng et al. 2011). A related species of the fungus, *Batrachochytrium salamandrivorans* (*Bsal*), has been associated with major salamander declines in Europe (Martel et al. 2014), and potential risks to native US salamanders led to successful calls for moratorium on the trade in pet salamanders in the US where the fungus has not yet been detected in wild salamanders (Gray et al. 2015; USFWS 2016). Ranaviruses can also affect salamanders and they have been associated with mortality events in the wild (e.g., Bollinger et al. 1999) and in captivity, including on a Chinese Giant Salamander farm in China (Geng et al. 2011).

Salamanders can, if cared for properly, live for a very long time in captivity (Maruska 1994). The Cincinnati Zoo under Director Ed Maruska has nearly 60 salamander longevity records (Snider and Bowler 1992). The following species all have lived for 20 years or more in captivity—Eastern Tiger Salamander (*Ambystoma tigrinum*), Japanese Giant Salamander (*Andrias japonicus*), Black Mountain Salamander (*Desmognathus welteri*), Northern Slimy Salamander (*Plethodon glutinosus*), Red Salamander (*Pseudotriton ruber*), and Japanese Fire-bellied Newt (*Cynops pyrrhogaster*) (Snider and Bowler 1992, Fig. 14).

Ex-Situ Conservation of Salamanders

Amphibian Ark reports that about 30 salamander species are collectively being maintained for ex-situ conservation or research purposes in 28 institutions in eight countries (AArk 2017). Alan Pessier reviews captive management of amphibians with reintroduction goals—taking strategies to quarantine collections intended for release from cosmopolitan collections to prevent new disease, noting the role of salamanders in bait trade in spreading diseases in the US (Pessier 2008; Pessier and Mendelson 2010).

Fig. 13. Illustration in Gotthilf Heinrich von Schubert's *Naturgeschichte des Thierreichs. . .*, published in 1869. There are several nice herpetofaunal drawings in this series.

Given the extensive zoo history and appeal of giant salamanders, salamanders in the family Cryptobranchidae are probably the most popular group of salamanders in zoos and aquaria and all species and subspecies are currently in some form of captive conservation effort. They are represented by the Cryptobranchid Interest Group in the American Association of Zoos and Aquariums (Grow and Ahmad 2015). The Chinese Giant salamander (*Andrias davidianus*) is a class II protected species and listed as critically endangered in the Chinese red book of amphibians and reptiles, and yet is commercially raised as a luxury food worth US $200–450 per kg in China (Wang et al. 2004). The result has been the creation of the largest commercial salamander breeding operation anywhere in the world. In the Shaanxi Province, farms produced about 500 tons of salamanders worth about 1 billion CNY, and in Liuba County, where there are more than 700 farms, this is believed to be the main economic industry (Cunningham et al. 2016). Farms pay little attention to genetic stock, hold animals in high densities (where they are prone to diseases like ranavirus outbreaks), and are required to release 13% of captive-bred offspring into the wild as a conservation measure (Geng et al. 2011; Cunningham et al. 2016). Despite the supposed high numbers of released animals, and six established giant salamander reserves in the wild, poaching with hooks, poison, and electrofishing is rampant (Wang et al. 2004). While the farming of this species could have benefits to local populations, a clearer understanding of the effects of the industry on wild populations is urgently needed (Cunningham et al. 2016).

We have already covered the extensive efforts for Japanese Giant Salamanders, but in the US, our own giant salamander, the hellbender is declining rapidly and is represented in 41 zoos and aquaria (Species 360 2017). The causes of hellbender declines are unclear, but the harvesting of hellbenders for the pet trade was found to be a significant factor in the decline of Ozark Hellbenders (Nickerson and Briggler 2007). Head-starting hellbenders for release is a subject of much active research ranging from designing coolers with chiller and aeration systems (Kenison et al. 2016), to conditioning captive-reared hellbenders to develop a flight response to trout scent by pairing trout scents with hellbender stress secretions in exposure trials prior to reintroduction (Crane and Mathis 2011). Genetic research in head-started populations showed that a single clutch can have multiple parents (Unger and Williams 2015) but concerns exist about genetically swamping wild

Fig. 14. *Cynops pyrrhogaster* from *Honzozusetsu* by Shunzan Takagi around 1852. Thousands were collected for the pet trade.

Fig. 15. *Proteus anguinus* from Baron Georges Cuvier's *le règne animal*....'Disciples edition' between 1836–1849.

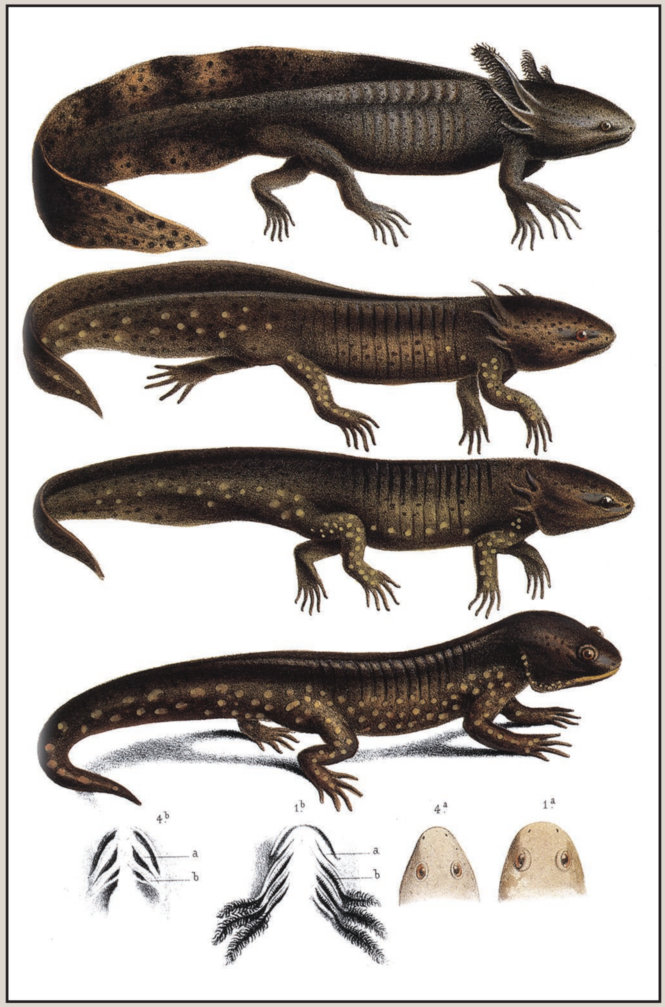


Fig. 16. *Ambystoma mexicanum* from *Nouvelles archives du Muséum d'histoire naturelle de Paris 1865–1908.*

hellbender populations with reduced numbers of genotypes (Jensen 2013). The poor establishment of released animals in the wild indicates that much work remains to be done (Boerner 2014).

One of the most intriguing and threatened groups of salamanders are the many species of depigmented cave-dwelling salamanders with vestigial eyes. They inhabit caves in limestone areas around the world, and have been isolated for long periods of time leading to high levels of endemism. Those in South Texas are particularly threatened by contamination and depletion of aquifers (Chippindale and Price 2005), and new environmental-DNA sampling methods are shedding further light on their distribution in inaccessible cave systems (Vörös et al. 2017). The zoological community has made great progress in understanding the needs of these unusual creatures and Amphibian Ark notes active programs for Salado Salamanders (*Eurycea chisholmensis*), San Marcos Salamanders (*Eurycea nana*), Texas Salamanders (*Eurycea neotenes*), Texas Blind Salamanders (*Eurycea rathbuni*), Barton Springs Salamanders (*Eurycea sosorum*), Grotto Salamanders (*Eurycea spelaea*), Jollyville Plateau Salamanders (*Eurycea tonkawae*), Georgia Blind Salamanders *Eurycea wallacei*, and Olms (*Proteus anguinus*) (Fig. 15; AArk 2017). In some cases like the Barton's Spring Salamander (*Eurycea sosorum*), the species is listed as endangered, and ex-situ rearing is part of the USFWS recovery plan (USFWS 2005) and funding is provided for research on husbandry issues. The San Marcos Aquatic Resources Center found that the optimal temperature for breeding and rearing was 18°C (Crow et al. 2016), while threatened San Marcos Salamanders (*Eurycea nana*) breed readily in captivity (Najvar et al. 2007). Roberts et al. (1995) duplicated the conditions found in nature to stimulate the Comal Springs Salamander (*Eurycea neotenes*) to breed at the Dallas Aquarium. They used a clear plastic tube, filled with rocks, with a continuous water flow from the bottom as these aquatic salamanders were found near spring upwellings (Fries 2002). In any conservation breeding facility, management and documentation of pedigree is essential to maintain genetic diversity in small populations (Ralls and Ballou 1986). Several tools are available to maintain captive studbooks, and these have recently been adapted

Fig. 17. *Ambystoma mexicana* from Baron Georges Cuvier's *le règne animal….*'Disciples edition' between 1836–1849.

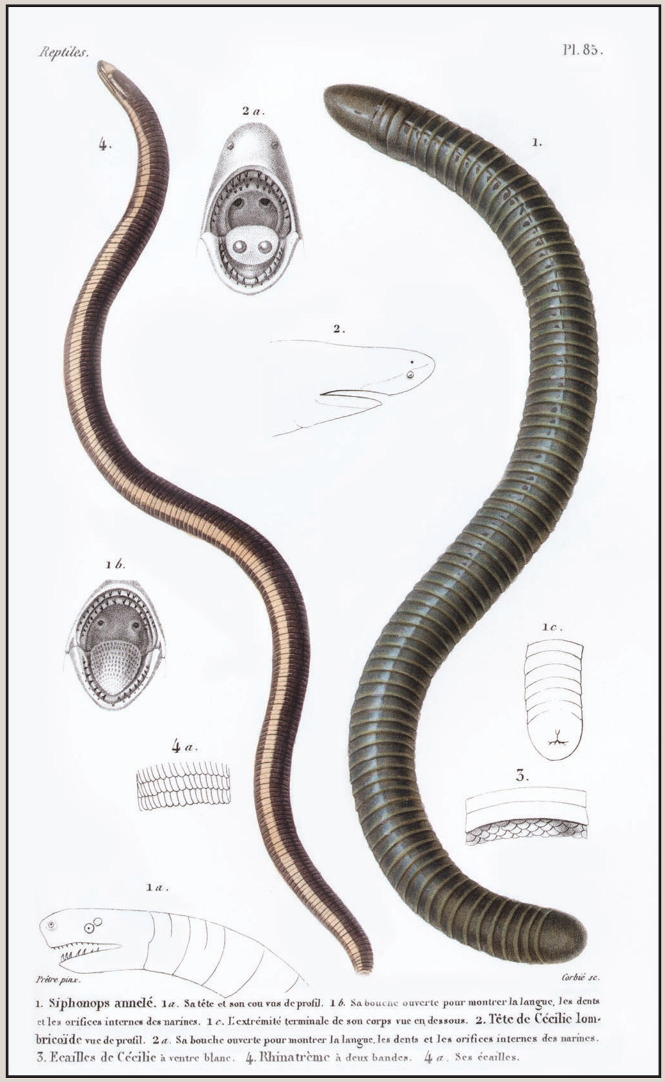


Fig. 18. Caecilians from *Erpétologie générale* by A. M. C. Duméril, G. Bibron, and A. Duméril, 1854.

to animals managed in groups using the Texas Blind Cave Salamander (*Eurycea rathbuni*) studbook as an example (Jiménez-Mena et al. 2016).

Many years ago, JBM and the late Ray Ashton traveled throughout the southeastern US in search of Mudpuppies (*Necturus*). He was working on several papers to identify their ranges and diagnostic characters using electrophoretic analysis and documenting reproduction in the wild so he enlisted the assistance of many southerners. When he asked about the places where mudpuppies could be found, he was met with blank stares. Only later, we realized that these amphibians were only called "waterdawgs," "spring lizards", or "fish bait" (Fig. 11).

Loss of Longleaf Pine habitats in the southeastern U.S. through fire suppression and habitat modification have resulted in drastic declines and subsequent listing of both species of flatwoods salamanders (*Ambystoma cingulatum* and *A. bishopi*) under the Endangered Species Act (Department of the Interior Fish and Wildlife Service 2009; Pauly et al. 2012). Captive populations of these animals have been established but not yet bred in captivity, although recent natural history observations of diets and breeding in nature may help to inform those efforts (Jones et al. 2012; Gorman et al. 2014).

The paedomorphic ambystomids of Mexico are often microendemic to a particular lake or lake system and are also popular in zoo conservation programs. They tend to be highly endangered because of their restricted distribution to habitats that are being rapidly modified, they make good exhibit animals and are relatively easy to care for. They have been promoted for conservation action due to their phylogenetic distinctiveness (Zoological Society of London 2017). While they seldom metamorphose in nature, treatment with thyroid hormones can induce metamorphosis (Brandon 1976). Axolotls (Figs. 16, 17) are a classic example, as they are widely used as lab animals for research into issues such as limb regeneration (Kragl et al. 2009), yet urban development, pollution, and introduced species from the surrounding suburbs of Mexico City have decimated the native habitat at Lake Xochimilco (Bride et al. 2008). Bride et al (2008) describe a project engaging three zoos and aquariums in Mexico, Canada, and the UK to launch Axolotls as a flagship conservation species for the area as part of a Darwin Initiative grant, and active habitat restoration work is underway (Valiente et al. 2010). Other species involved in ex-situ conservation programs include the Lake Patzcuaro Salamander (*Ambystoma dumerili*) and Taylor's Salamander (*A. taylori*) (AArk 2017). Africam Safari staff is working on surveying Mexico's Lake Alchichica for the endemic and critically endangered *A. taylori* (Grow and Ahmad 2015).

Many terrestrial neotropical salamanders can be quite rare, reducing the probability that we will be able to find enough founders to attempt viable captive breeding efforts (Gratwicke et al. 2015). Nonetheless, the staff of the Toledo Zoo, who have made excellent progress in the captive care and breeding of many *Plethodon* species native to the US, for the first time have obtained founding populations of several species of Guatemalan salamanders and have now successfully bred the Northern Banana Salamander (*Bolitoglossa rufescens*) (Odum 2011) and Conant's Mushroom-tongue Salamander *(B. conanti*) (AmphibiaWeb 2017).

In Europe, a successful project involving the Sardinian Brook Salamander (*Euproctus platycephalus*) has resulted from private breeders who jointly developed a comprehensive set of husbandry guidelines that has become a model for all captive programs (Browne et al. 2011; Tapley et al. 2015). A second species, the critically endangered Montseny Brook Newt (*Calotriton arnoldi*), is the focus of a captive breeding effort run by the Catalonian government that began in 2007 (Valbuena-Ureña et al. 2014). Reproduction has been successful and reintroductions have started (AArk 2017).

In the Middle East, successful captive breeding of the Yellow-spotted Mountain Newt (*Neurergus derjugini*) and the Loristan Newt (*N. kaiseri*) has been accomplished using husbandry methods developed in collaboration with private breeders (Browne et al. 2011). A captive breeding facility for the conservation of *N. derjugini* at Razi University, Kermanshah, Iran, found that survival was improved and cannibalism reduced when animals were held at lower densities with higher food availability (Vaissi and Sharifi 2016).

Finally, it should be noted that Lauren Augustine of the Smithsonian's National Zoo created the Foundation for the Conservation of Salamanders (https://www.fcsal.org/) to raise awareness about salamander conservation. She and her team of zoo professionals across the US raise funds through engaging educational activities and events, such as the sale of reusable chopsticks. Each year small grants are awarded for salamander research and conservation.

Caecilians

Particularly vulgar traits are attributed to the secretive caecilians, possible owing to their body shape and coloration. Their vernacular name *Tapalcua* is a polite rendition of *Tapalculo*, which in turn is derived from a Spanish phrase that describes almost unspeakable acts thought to be performed by these animals. Briefly, there is a widely held belief that caecilians will spring out of the ground and enter the lower body orifices of unsuspecting people who are answering the call of nature. The fact that caecilians may be found in rotting vegetation does not help.

—Jon Campbell, *Amphibians and Reptiles of Northern Guatemala, the Yucatan, and Belize* (Campbell 1999)

Caecilians have been largely ignored in zoo and aquarium collections, and thus information on captive requirements is sparse (Fig. 18). In the wild, they are often difficult to find and the conservation status of most species is unknown (Gower and Wilkinson 2005). Many years ago, an animal dealer included a specimen of an unknown caecilian in a large shipment of reptiles consigned to Dallas Zoo. The dealer thought it was a primitive fish. Our tentative identification was that it belonged to the genus *Dermophis*. When Professor Edward H. Taylor, author of the enormous tome *Caecilians of the World: A Taxonomic Review*, was visiting from the University of Kansas, JBM asked if he could enlighten us as to its identity. Taylor agreed that it was, in fact, a *Dermophis*, but added excitedly that it was certainly an undescribed species, somewhat similar to *D. mexicanus*. Since no locality data had come with the animal, he asked if we could contact the dealer; we did but the dealer had no idea where it had been found. Ed was bitterly disappointed and the caecilian remained unnamed. Wright and Minott (1999) identified individual captive Mexican caecilians. The main reference for this group is Wake (1994). Murphy et al. (1977) documented coitus in caecilians (*Typhlonectes compressicauda*) for the first time at the Fort Worth Zoo.

Some kinds of caecilians have been successfully maintained and bred in captivity, and Parkinson (2004) gives an account of the care and captive breeding of the Rubber Eel (*Typhlonectes natans*). Growth rates and von Bertalanffy growth functions were calculated for *Ichthyophis* in captivity, with females attaining larger maximum sizes (Kupfer et al. 2004); this sort of study would be almost impossible to do in the wild. Burger et al. (2007) examined the effects of phototaxis and thigmotaxis on microhabitat selection in species of the genus *Ichthyophis* at Dallas and Oklahoma City zoos.

Caecilians have been shown to be vulnerable to myxozoan infections of *Cystodiscus axonis*, like frogs and salamanders, and it is possible that these are diseases associated with captivity (Hartigan et al. 2016). It is known that caecilians are also susceptible to *Bd* as captive *Typlonectes* and *Geotrypetes seraphini* have died from clinical infections, and were cleared from infection using both a heat-treatment approach and itraconozole treatments (Churgin et al. 2013; Gower et. al. 2013; Rendle et al. 2015). Surveys of wild caecilians showed about one fourth of those surveyed from more than six species were *Bd* positive, but had low-level symptoms. (Gower et. al 2013).

One of the most spectacular examples is the São Tomé Caecilian or cobra bobo (*Schistometopum thomense*). Butch Brodie kept a group in his lab at the University of Texas at Arlington, and these brilliant yellow amphibians were dazzling. This live-bearing taxon is found on São Tomé Island (Republic of São Tomé and Principé, Gulf of Guinea, West Africa). Since it is so unique and secretive, it might be possible to display these burrowers between two panes of glass filled with soil—a setup commonly known as "Ant Farms." To see some photos, consult Nussbaum and Pfrender (1998). Probably the most fascinating habit of some types of caecilians is their extended parental care of offspring that involves feeding on the mother's skin (Wilkinson et. al. 2008). A study of the Ringed Caecilian (*Siphonops annulatus*) showed the sexual maturation of males and females in captivity, but those authors were unable to determine the environmental cues to trigger breeding, and they were unsucessful in breeding them in captivity (Gomes et al. 2013).

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