The Husbandry and Care of Dendrobatid Frogs

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Dendrobatid frogs are studied primarily for the bioactive alkaloids found in their skin. Also known as poison-dart frogs, these animals accumulate toxic alkaloids from dietary sources. The function and uses of the many alkaloids, the alkaloid accumulation system, and the basic biology and physiology of the frogs themselves are of research interest. Here we overview the taxonomy of these frogs and some of the unique aspects of their natural biology and reproduction. We also describe the components of a successful laboratory housing system, including temperature, lighting, humidity, ventilation, nutrition, health considerations, and handling. A brief summary of dendrobatid research highlights is provided.

Dendrobatid frogs are unusual but fascinating laboratory animals. More commonly referred to as 'poison-arrow' or 'poison-dart' frogs, these unique animals are providing researchers with an intriguing array of biomedically important alkaloids. Although alkaloids are largely of plant origin, 'animal-origin' alkaloids are a large group of basic, nitrogen-ring compounds, renowned for their potent toxic as well as pharmacologic activities. Many alkaloids demonstrate unique anesthetic, analgesic, and cardiotonic activities of interest in biomedical research. Alkaloids have been isolated from certain families of amphibians, namely frogs, salamanders, and toads. Dendrobatid frogs readily accumulate alkaloids that are studied for their potential pharmacotherapeutic properties. Although poison-dart frogs are not commonly used research animals, interest in studying them may increase as we discover important properties of these pharmacologically active alkaloids (12, 32).

Although the majority of alkaloids isolated from amphibians are only mildly toxic, three species in the genus *Phyllobates* from western Colombia contain deadly alkaloids that rank them among the deadliest animals on earth for their size (2.5 to 4 cm from snout to vent; 9). The Choco Indians of the western Colombian rainforest traditionally poison their blow darts by rubbing the grooved tips across the backs of the world's most toxic species, the Golden Poison Frog (*Phyllobates terribilis*; 29). Remarkably, a dart thus treated retains its toxicity for as long as a year, truly earning these frogs their common name, poison-dart frogs. Despite common use of the phrase 'poison-arrow frogs,' there is no record of these toxins ever being used to poison arrows. The frogs themselves are unaffected by their own toxins, as is one predator, a snake (*Liophis epinephelus*; 29).

The purposes of this paper are to describe some practical aspects of the biology and care of dendrobatid frogs in the laboratory and to discuss research findings and applications associated with this interesting group of animals.

Taxonomy and Unique Properties

The family Dendrobatidae contains approximately 170 described species (3) and is divided into six genera (*Dendrobates*, *Epipedobates*, *Minyobates*, *Phyllobates*, *Aromabates*, and *Colstethus*). Dendrobatid frogs commonly used in the laboratory include the Green and Black Poison Frog (*Dendrobates auratus,* Fig. 1), Phantasmal Poison Frog *(Epipedobates tricolor),* Black-legged Poison Frog *(Phyllobates bicolor*), and Rocket Frog (*Colstethus talamancae*; 7). Some dendrobatids are brilliantly and conspicuously colored, a characteristic referred to as 'warning' (or aposematic) coloration. This characteristic is thought to have evolved in this diurnal family, as it has elsewhere in the animal kingdom, to serve a protective function: equally forewarning and deterring potential predators and sparing the lives of the frogs themselves (36).

Figure 1. Green and Black Poison Frog (*Dendrobates auratus*). Color in this species varies from green and black to blue and black. Copyright permission by Thomas Villegas.

Frogs of the genera *Dendrobates*, *Epipedobates, Minyobates,* and *Phyllobates* have specialized cutaneous glands that accumulate a variety of toxic lipophilic alkaloids, whereas the genera *Aromabates* and *Colstethus* lack these glands. In those genera accumulating alkaloids, they are released from the glands and serve primarily as a means of chemical defense to deter predation (12). Major alkaloids found in dendrobatid frogs include the highly toxic batrachotoxins, pumiliotoxins, allopumiliotoxins, and epibatidine and the less-toxic histrionicotoxins, decahydroquinolines, and various izidines (10, 11,14-16, 18, 37).

Biology, Reproduction, and Larval Development

Sexual dimorphism occurs in some species but, when present, is often subtle. For example, males in some species may be differentiated from females by the presence of a flat, bi-lobed terminal disc on the front forelimb digits (45), or males may be more slightly built than are the larger-framed females (34), or both. In other species, males

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Figure 2. Vocal throat pouch of a Granular Poison Frog (*Dendrobates granuliferus*). Copyright permission by C.V.D. Lingen.

Figure 3. Eggs of a Phantasmal Poison Frog (*Epipedobates tricolor*) on a leaf. Copyright permission by Tor Lindo.

alone may have enlarged or darkly colored throat pouches (24; Fig. 2). In the genus *Dendrobates,* the Green Poison Frog, Blue Poison Frog, and Dyeing Poison Frog (*D. auratus*, *D. azureus,* and *D. tinctorius,* respectively), sexual dimorphism develops at approximately 12 to 14 months of age (34).

The most reliable characteristic distinguishing adult males from females is vocalization: females of all genera are mute (45). In the wild, males secure their territories by using scent markings as well as by calls (22), and although intruding males receive warning vocalizations, chirps or different calls (or both) are used to attract receptive females. Calls vary from species to species and range from cricket-like chirps to long trills (20).

Courtship begins with the male's calls, and as the females approach, they display their interest in the male by tactile stimulation, including stroking, nudging, and even climbing on the males. In some species, the females may reject the males despite initial active courting. Although amplexus is absent in several species (*D. granuliferus*, *D. pumilio*, and others; 25), cephalic amplexus, a variation in which the male's forelimbs clasp the female's throat rather than her chest, occurs in *D. tricolor* and *P. terribilis* (29).

Eggs (4 to 20) are deposited on plants (Fig. 3) or hidden in areas close to water sources and are tended by one or the other parent, depending on species. Eggs may be checked, moved, or moistened with urine at regular intervals during the approximately 12-day period prior to hatching. Upon hatching, the tending parent positions itself above the brood and allows the tadpoles to climb upon its back (Fig. 4). In the wild, tadpoles are transported to a water source— small streams, ponds, or phytotelmata (water funnels, cups, or axils formed by bromeliad leaves)—with preferences being species-specific (5). The obligate oophagous species Granular Poison Frog (*D. granuliferus),* Harlequin Poison Frog *(D. histrionicus),* Lehmann's Poison Frog *(D. lehmani,* Fig. 5)*,* Strawberry Poison Frog *(D. pumilio*, Fig. 6)*,* and Splendid Poison Frog *(D. speciosus*) require phytotelmata (Fig. 7) in which to deposit and nurture their tadpoles (5). The females of these species carry individual tadpoles on their backs and deposit each in a separate axil. At least once a week, the female must back downward into each occupied axil; while the female remains in this position, the tadpole swims in ever more rapid circles until gaining enough momentum to wriggle upon the female's back (5, 45). This process is completed several times to encourage the deposition of unfertilized eggs for the tadpole to eat (5, 45). Tadpole morphology separates dendrobatids into two types of feeding habits: those bearing reduced labial denticles but having large horny (or heavy) beaks are carnivorous, whereas those with weaker beaks feed on algae and organic debris (34). Tadpoles feed for approximately 60 days (28).

Because males use olfactory cues to claim territory in captivity, moving an adult male to an enclosure previously occupied by another male may increase stress and diminish the likelihood of mating. It is also recommended that breeding pairs be housed separately to eliminate possible aggression between females should their mate breed with another female and care for her offspring (39, 40). A proven method to encourage breeding in captivity is to simulate a dry season followed by a wet season. Misting is discontinued or limited for 2 weeks to maintain a minimum of 70% relative humidity in the enclosure, with a concurrent reduction of feeding to twice weekly. The 'dry season' end is marked by the resumption of misting, either twice daily or daily depending upon needs, and a return to daily feeding. Another method is as simple as separating the male from the female for a period of 1 month.

Natural Habitat

Although some species of dendrobatids have disappeared from study areas, it remains unclear whether they are extinct (44). Because all species of poison-dart frogs are now regulated by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), the number of wild-caught frogs introduced into the pet trade has been curbed. Although this practice especially affected species with limited natural ranges, such as *D. azureus* of Surinam and *D. lehmanni* of Colombia, the greatest threat to the overall survival of the dendrobatids remains the deforestation of their habitat. Significant environmental changes, including pollution, over-use of fertilizers, increased ultraviolet levels from ozone depletion, and climatic changes carry additional concerns for their survival. Indeed, some populations in Panama have been lost due to deforestation and diseases such as fatal cutaneous chytridiomycosis (19).

Laboratory Husbandry

It is recommended that new shipments of frogs be quarantined for at least 30 days (21). Quarantine housing should be enriched with hiding areas and plants, but it is best to keep the housing simple to allow visualization of daily food intake and to monitor health. Sterile housing setups have been found to be unsatisfactory, as amphibians so housed show increased rates of illness and death (6). Rat isolator cages make suitable containers for quarantine, short-term housing, and young dendrobatid frogs younger < 1 month or so of age. Initial cleaning and disinfection of quarantine cages and small tanks is accomplished using 10% hypochlorite or Nolvasan in dechlorinated

Figure 4. Blue Poison Frog (*Dendrobates azureus*) carrying tadpoles on her back. Copyright permission by David Doyle.

Figure 5. Lehmann's Poison Frog (*Dendrobates lehmanni*). Copyright permission by Thomas Villegas.

water, every 2 weeks as recommended by the National Aquarium in Baltimore, Md. Because plastic cages may absorb chemicals that later leach into the cage environment, special care must be used to rinse away all residues with dechlorinated water. Iodine-based disinfectants must be strictly avoided, because poison-dart frogs show extreme sensitivity to these agents (38). Water used for misting and as in-cage reservoirs must be dechlorinated as well.

Folded moistened paper towels may be used as temporary cage liners for quarantine housing, provided they are changed every other day, because they absorb organic wastes and disintegrate rapidly (43). Frogs housed on towels should be observed when feeding, because insects often stick to toweling and are difficult for the frogs to ingest (2). Environmental enrichment minimizes stress and need not be elaborate. Hollow coconut shells, Brazil nut pods, and small plastic flowerpots can provide hiding places. Small pieces of curved cork bark provide cover and serve as feeding platforms. A Petri dish may be added to hold dechlorinated water.

A more naturalistic enclosure can be designed by lining the microisolator with 1/2 in. of smooth-edged 'aquarium' gravel covered with moistened live moss. Live or true-to-life imitation plants provide both cover and habitat for climbing (Fig. 8). Care should be taken in selecting only specimens with smooth edges to minimize injuries to delicate skin. Recommended tropical plants include *Philodendron*, *Scindapsus aurea*, *Aglaonema commutatum, A. roebelini*, *Ficus*, bromeliads, and orchids (6, 45). We plant *S. aures,* commonly referred to as Marble Queen Pothos, in our laboratory tanks. This plant is one of the easiest to grow, readily available, extremely hardy and thrives under artificial light, resistant to many plant pests, and known for its longevity. In addition, it can be uprooted and cleaned without detriment, and its ability to vine provides natural hiding areas. We trim the plant to leave open areas close to the sides of the terrarium for animal observations and to allow the frogs room to hunt and catch their insect prey. To prevent contamination of the enclosure with fertilizers, pesticides, and other chemicals, live plant additions should be carefully uprooted, rinsed, and replanted in chemical-free soil (43).

More permanent housing can be constructed using a 10-gallon or larger aquarium. To streamline cleaning and prevent excess water accumulation, a false-floor grate and drain are recommended (2). Daily misting and weekly flushing of the tank appear to maintain a stable and healthy environment for these frogs. In general, to induce breeding, the environmental parameters must be within the desirable range for each species. In general, to induce breeding, the environmental parameters must be within the desirable range for each species.

We typically break down the tanks between studies, which last approximately 4 months each. For studies lasting longer than 6 months, our frogs are removed to replacement tanks set up approximately 1 month prior to use to allow the environment to stabilize and ensure that the plants are thriving. During the cleaning process, the plants, soil, false bottom, and accessories (e.g., feeding dishes, huts, hiding containers) are removed, and the tanks and accessories are cleaned with a 5 to 10% solution of household bleach, with a minimum contact time of 30 min (43). Cleaning should be followed by a dechlorinated water rinse to remove trace chlorine, and then tanks are allowed to air dry for 24 h.

Because several dendrobatid species are territorial, adequate terrarium space is an important consideration. In our experience, 465 cm^2 of floor space is adequate for each adult frog. Therefore, a 20-gallon terrarium can comfortably accommodate four to five adult frogs. The larger 20-gallon terrariums maintain more stable internal environments than do the 10-gallon tanks and can be moved about without breaking down the set-up. Because dendrobatids can squeeze through small gaps, all primary enclosures must be properly constructed and kept in good repair to prevent both injuries to their delicate skin and escape.

All stated husbandry and housing procedures have been adapted from recommendations established at the National Aquarium in Baltimore, Md., and all described procedures have been approved by the Animal Care and Use Committee for the National Institute of Diabetes and Digestive and Kidney Diseases. There are no standards available from the Association for the Assessment and Accreditation of Laboratory Animal Care, International, regarding the housing and care of these animals, because no controlled studies have been performed to assess the merit of various housing strategies, humidity levels, diet, sanitation and disinfection, and lighting on the health and reproduction of these species.

Temperature

The optimal temperature for maintaining and breeding dendrobatids is 21 to 27°C. However, species from higher altitudes favor temperatures at the lower end of the range, whereas most eggs and tadpoles thrive at the upper end. In the laboratory, the easiest way to maintain correct temperatures is to adjust the room settings to mimic those of their natural habitat. Optimal temperatures also may be maintained using an under-tank heating pad attached to cover approximately half of the tank base. The under-tank heating pad then is connected to an adjustable thermostat, with a sensor located just above the floor of the tank. Care should be taken to avoid tempera-

Figure 6. Strawberry Poison Frog (*Dendrobates pumilio*). Copyright permission by Mike Wallitis.

Figure 7. Phytotelmata (water-filled bromeliads). Copyright permission by Mike Wallitis.

tures above 32°C, because even short periods of high temperatures can be lethal to dendrobatids (2).

Lighting

Although a single light source is adequate, combinations of lights that more closely simulate the characteristics of the natural environment have been used with good success. A 40-W full-spectrum light (Vita-Lite, Duro-Test Lighting Inc., Philadelphia, Pa.) in conjunction with a 40-W ultraviolet light (Black Light, General Electric, Cleveland, Ohio) mounted approximately 8 cm above the top of the enclosure have been highly successful at the National Aquarium in Baltimore (6). All lights should be replaced every 6 to 12 months because their effectiveness decreases over time.

Because dendrobatids are diurnal, correct photoperiods play decisive roles in behavior and reproduction. An appropriate lightcycle is 12 h on and 12 h off. Timers with twilight transitions allow animals to adjust to a gradual onset of dusk and dawn and may serve to eliminate stress associated with sudden light changes.

Humidity and Ventilation

Maintaining the proper balance between humidity and ventilation can be a challenging endeavor. Relative humidity within enclosures should not drop below 70%; ideally it should be maintained between 80 and 90% to mimic the frog's natural habitat. Shallow containers, filled with dechlorinated water, add to the relative humidity. To conserve moisture and hold enclosures at 80 to 95% relative humidity, they may be covered with solid glass or Plexiglas sheets (6). Misting with dechlorinated water is also a practical means of maintaining proper humidity levels within the enclosure. Misting may be accomplished manually, by use of an automatic misting system, or by means of an ultrasonic humidifier. A misting schedule, from once or twice a day to once every third day, should be developed to suit the needs of each individual setup and sustain ideal humidity levels. Tank walls can be rinsed with dechlorinated water once a week.

Nutrition

Adult frogs capture insects and arthropod prey by sight and the use of their sticky protractible tongues, which are attached at the front of their mouths. In captivity the diet consists of 1- to 7-day-old crickets (*Acheta*) and wingless fruit flies (*Drosophila*) lightly dusted with multiple vitamins and minerals (Dendrocare, Black Jungle Terrarium Supply, Greenfield, Mass.) to supplement the insect's low calcium-to-phosphorous ratio (1). Other food sources include springtails (*Collembola*), ants, and termites. Alternatively, frogs can be force-fed using a 20-gauge animal-feeding needle (Popper and Sons, New Hyde Park, N.Y.) placed toward the back of the frog's mouth. The mixture, made by pureeing two young crickets or five to six fruit flies (dusted with multiple vitamins and minerals) combined with equal parts dechlorinated water is ingested readily and will provide adequate caloric intake until frogs are eating on their own. Larval dendrobatids (tadpoles) can be fed flake fishfood or powdered algae (*Chlorella* and *Spirulina*), contingent on whether they are carnivorous or herbivorous. However, the larvae of obligate oophagous species, including *D. histrionicus, D. lehmani, D. pumilio , D. granuliferus,* and *D. speciosus*, generally will not accept any alternative foods.

Handling and Restraint

Most if not all poison-dart frogs raised in captivity are nonpoisonous. However, some wild-caught frogs have retained as much as 22% of the toxin even after 6 years in captivity, so all frogs should be considered potentially toxic (17). Although the toxins typically must enter the bloodstream to become active, it is good practice for handlers to wear gloves to prevent accidental exposure via abraded or lacerated skin.

Powder-free gloves rinsed in dechlorinated water prevent trauma to the frog's delicate skin and limit the transfer of potential pathogens. Gloves should be rinsed thoroughly or changed when moving from tank to tank. To hand-catch, it is best to maneuver the frog into a corner of the enclosure. While one hand will suffice to capture, the second is held above the first to maintain gentle control and to prevent hopping. Once it's captured, lift the frog, allowing the feet to extend behind and the head to emerge between the thumbs and forefinger. The second hand then is placed below the first as a cradle. For transport, frogs are often placed in small plastic cups.

Collection of Toxin

Glanular secretions can be collected by four different methods: 1) chemical extraction from whole-skin samples (35), 2) injection of noradrenaline (30), 3) surface electrical stimulation (SES; 41); and 4) transcutaneous amphibian stimulation (TAS; 23). The preferred methods of extraction are SES or TAS, because multiple samples can be collected every 2 to 4 weeks. However, not all species or individual dendrobatid frogs respond to SES or TAS (8).

Health

Reports of diseases in dendrobatid frogs are uncommon. Intestinal

Figure 8. A planted section of a terrarium. Copyright permission by Patrick Nabors.

Figure 9. Phantasmal Poison Frog (*Epipedobates tricolor*). Copyright permission by Tor Lindo.

protozoa such as *Zelleriella* sp., *Nyctotheroides* sp., and retortamonad, trichomonad, and diplomonad flagellates often colonize these frogs but may not be pathogenic. *Trypanosoma* sp. has been identified in a blood smear from *D. auratus* (33). Dendrobatid frogs have proven susceptible to a fatal cutaneous chytridiomycosis caused by *Batrachochytrium dendrobatidis* (31). *Xenopus laevis* and *X. tropicalis* can be asymptomatically infected with chytridiomycosis, therefore dendrobatids should not be housed in the same room with these species because this chytridiomycete fungus is highly contagious. Spindly Leg Syndrome (SLS) is seen in *D. pumilio,* as well as in other species, and although the specific cause is uncertain, low microenvironmental temperatures and inadequate diets with attendant deficits in the eggs fed to tadpoles have been implicated. Clinical signs of stress or sickness in dendrobatid frogs often are not noted. Fecal examinations should be performed every 6 months to detect the presence of intestinal parasites. Stressed or sick frogs with heavy loads of intestinal protozoa can be treated with fenbendazole at 100 mg/kg twice, 10 days apart, with or followed by metronidazole at 10 mg/kg once daily for 5 days (33). One recommendation for health monitoring is to weigh frogs on a weekly or biweekly basis; those losing weight should be observed closely for other signs of illness. Underweight frogs may be force-fed and treated for any underlying disease. Frogs that are maintained in a healthy environment have an average life span of 7 to 10 years (4).

Regulations and Shipping

Poison-dart frogs are regulated by the CITES. When wild-caught frogs are desired, one should contact the U.S. Fish and Wildlife Service to obtain the proper permits to import and house these frogs. Frogs should be shipped in separate Styrofoam containers under controlled conditions to prevent losses from heat or cold. Placement of moistened moss in the container provides humidity during shipping. Heat or cold gel packs can be placed on one side of the container to stabilize the internal temperature. Care should be taken to prevent direct contact of the frog with the heat or cold gel packs to prevent thermal injury. Wild-caught frogs should not be shipped in the same container with other species, to avoid accidental death due to release of toxic alkaloids.

Dendrobatid Research

Alkaloids, nitrogen-containing organic compounds, once were thought to be entirely of plant origin, and of the 10,000-plus that have been characterized, several well-known examples include morphine, yohimbine, caffeine, cocaine, nicotine, and strychnine. Over the past 40 years, approximately 30 dendrobatid species, and many dendrobatid populations in Central and South America as well, have been studied. In excess of 500 alkaloids have since been isolated from dendrobatid epidermal glands and have been partially or completely characterized. Interestingly, of these alkaloids, only three are known to occur also in plants (8).

Alkaloid profiles from different dendrobatid species, and even profiles from different populations of the same species, vary widely. It appears that these differences are related to the abundance and nature of alkaloid-containing insects and arthropods in the frog's diet. And of course, the presence of specific types of insects in the diet greatly depends on localized habitat (14). Wild-caught frogs show a decline in amount of toxin when held in captivity (17, 29). Moreover, when raised in captivity on a controlled diet of fruit flies and crickets, adult dendrobatids do not contain detectable alkaloids. A variety of studies have been undertaken to explore this lack in captive-raised frogs and include changing their enclosure environments, stressing, and feeding specific alkaloid precursors (8). All of these strategies failed, but when the frogs were fed the alkaloids themselves, they readily accumulated unchanged in the epidermal glands.

Indeed, it now appears that most if not all dendrobatid alkaloids come directly from dietary sources. Representatives of eight alkaloid classes are now known to occur in ants and are putative sources for > 100 dendrobatid alkaloids. Likewise, a representative of one class of alkaloids identified in beetles is the putative source for several others. The alkaloid class of spiropyrrolizidines, known to occur in millipedes, is now suspected as the source for five frog alkaloids. Histrionicotoxin, gephyrotoxins, and indolizidine are classes of alkaloids thought to have arisen in ants. Therefore, nearly half of the 500 described alkaloids isolated from dendrobatids have a suspected insect or arthropod source. The remainder remains under scrutiny and whether dietary sources, symbiotic soil microorganisms, or undiscovered precursors will emerge to account for them is left to the future (18).

Recent experiments indicated that a specific enzyme, which converts pumiliotoxin to an allopumiliotoxin by hydroxylation, has evolved in the genus *Dendrobates*. This enzyme appears to be genus-specific, as frogs in the genera *Epipedobates* and *Phyllobates* were unable to make the conversion (13). This finding differs starkly from those of previous studies, in which the various alkaloids fed to dendrobatid frogs remained unchanged and simply accumulated in the cutaneous glands.

Alkaloids have now been isolated from the skin of frogs and toads in other amphibian families as well. These include the genera *Pseudophryne* (family Myobatrachidae), *Mantella* (family Ranidae), and *Melanophryniscus* (family Bufonidae; 11, 15). It appears that the system controlling the accumulation of alkaloids is widely distributed in nature and is merely overexpressed in certain amphibian lineages, including the dendrobatids. The nature of the system controlling accumulation, the specific sources of the alkaloids themselves, and the varied spectrum and differing functions of the biologically active alkaloids remain important physiological and ecological questions.

Several alkaloids isolated from frogs are proving useful in biomedical research. The batrachotoxins from poison-dart frogs have been used by laboratories worldwide to characterize the voltage-dependent sodium channels generating action potentials in nerves and to study muscle contractions. The pumiliotoxins and allopumiliotoxins act through interactions with sodium channels and have cardiac stimulant properties. Histrionicotxoins are useful as probes to study neuromuscular function via nicotinic receptor blockade. Because the amphibian indolizidine alkaloids are noncompetitive blockers of sodium ion influx through nicotinic receptor channels in muscle and nerve ganglia, they are potentially useful in neurophysiological applications (27). Epidatidine, isolated from the Ecuadorian frog *E. tricolor* (Fig. 9), has provided the basis for a novel class of analgesic drugs that act via neuronal nicotinic acetylcholine receptors. This compound recently has been synthesized into a potent nontoxic, nonaddictive analgesic that lacks the side effects of opiates (26). New studies also have examined the use of alkaloids as muscle relaxants, heart stimulants, heart regulators, and anesthetics. Unfortunately, research on these alkaloids is limited because frogs in captivity, or that have been bred in captivity, lose their toxic secretions.

In addition, dendrobatids have proved useful in behavioral research (39) and may be good models of sex–role reversal (42), noted when the male's parental care level becomes so extensive that potential mating males are rare to the number of receptive females. In the future, dendrobatid alkaloids may provide investigators with heretofore unknown data inspiring the development of new drugs with anesthetic, analgesic, myotonic, or other useful properties and may suggest novel applications of previously identified compounds. A deepened understanding of the toxin-accumulation system is of ongoing evolutionary and physiological interest.

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