Human exploitation of amphibians: direct and indirect impacts

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HUMAN EXPLOITATION OF AMPHIBIANS

Direct and Indirect Impacts

JOHN B. JENSEN AND CARLOS D. CAMP

CENTRAL ISSUES

Humans have exploited wildlife since the beginning of measured time, using them as sources of food, clothing, weapons, and tools as well as in the practice of religion and medicine. The effects of these uses have varied with the degree of exploitation and resilience of the utilized species, with the most severe effect being extinction (e.g., the passenger pigeon). When compared to other vertebrate classes (e.g., reptiles, Gibbons et al. 2000), amphibians are not generally thought of as being a heavily exploited group. Regardless of the relative degree of impact from human use, conservation of amphibians worldwide requires knowledge of and attention to issues relating to their exploitation.

Throughout the world, amphibians are collected or raised for a variety of uses, including, but not limited to, food, pets, medicine, research and education, fish bait, and leather. We present examples of the various human uses of amphibians, emphasizing those uses and amphibian groups of greatest concern. We also provide information on the direct and indirect impacts this exploitation has had on amphibians and their environment, as well as provide suggestions for overcoming some of the related obstacles both amphibians and conservationists face. Many of the reported conditions and trends, such as the status of local populations and species, leading exporters/importers, and amphibian species most involved in a particular trade, are subject to change due to changing environmental, economic, and societal dynamics.

DIRECT IMPACTS

Amphibians as Food

Although certain large salamanders (e.g., Andrias in China and Japan) have been used locally as food (Fitzgerald 1989), frog legs are the primary form of amphibians used for human ingestion. There remains a large market for frog legs in the European Union (EU), Canada, and the United States. Frog legs are so popular in France that they are regularly served in school cafeterias (Patel 1993). In the 1990s, the countries of the European Community (now the EU) imported more than 6,000 metric tons of frog legs each year, with more than 80% going to Belgium, Luxembourg, and France (Hardouin 1995). Secondary markets occur in Asia, with six million *Hoplobatrachus rugulosus* (aptly named the Chinese edible frog) shipped from Thailand to Hong Kong in one year (Lau et al. 1997).

Historically, frog legs were locally collected and served as seasonal delicacies. Virtually any medium- to large-sized ranid has served as a potential source, with the edible frog (*Rana esculenta*), pool frog (*R. lessonae*), marsh frog (*R. ridibunda*), and agile frog (*R. dalmatina*) being the most popular in Europe. The resulting decline and subsequent protection of native European frogs have combined with the modern technology of packaging frozen foods to shift the source of legs to Asia. By 1981, India was the major supplier of frogs (e.g., *Euphlyctis hexadactylus* and *Hoplobatrachus tigerinus*) to the West for culinary purposes, exporting more than 4,000 tons in that year alone (Abdulali 1985). Concern for the inhumane killing of frogs and for the loss of natural controls of pestiferous insects, however, led India to ban the export of frogs in 1987. These concerns contributed to the listing of *Euphlyctis hexadactylus* and *Hoplobatrachus tigerinus* by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). (Supported by more than 150 signatory countries, CITES provides varying degrees of protection to certain species of wild plants and animals, depending on their biological status and the impact of their international trade.) Similar concerns have been expressed for Indonesia, which has replaced India as the primary exporter of frog legs. In 1990, the European Community imported nearly 5,000 tons of frog legs from Indonesia, primarily *Limnonectes blythii, L. cancrivorus, L. limnocharis,* and *L. macrodon*. At 20 to 50 individual frogs per kilogram, that translates into more than 100 million frogs per year (Patel 1993; Veith et al. 2000).

Before World War II, there was an active frogging industry in many regions of the United States, including Florida (American bullfrog, *Rana catesbeiana,* and pig frog, *R. grylio;* Enge 1993), Iowa (northern leopard frog, *R. pipiens;* Lannoo et al. 1994), and California (red-legged frog, *R. aurora;* Jennings and Hayes 1985). Culinary exploitation led to the decline of local populations, including the species-wide decline of the red-legged frog in California, eventually rendering commercial frogging economically infeasible. Although sport frogging still occurs, American restaurants, like their European counterparts, now procure their frog legs largely from Asia.

Most frog legs come from wild-caught frogs. In countries where collection and trade are banned, poaching continues to be a problem. Estimates place the annual illegal export from India in the tens of millions of frogs (Oza 1990). Unsustainable collection has had severe impacts on local populations of frogs. For example, large frogs have been extirpated from wetlands near villages in many parts of Java and Sumatra, where local farmers supplement their income by selling frogs to exporters (Veith et al. 2000).

Amphibians as Pets

Amphibians have long been popular as pets. Many species are easy to maintain because they require very little space and food requirements are easy to satisfy. Many children growing up outside of urbanized areas have kept frogs, toads, and/or salamanders as pets, typically after catching them in nearby wetlands or forests. However, amphibians are not just for the younger generations anymore, and most are now purchased rather than caught by the pet owner.

Hobbyists are becoming increasingly interested in unique and, especially, brightly colored amphibians, often paying high prices for some species. This increased demand has created a significant market for amphibians in the pet trade, negatively affecting natural populations in some instances. For example, aided by changing economics and relaxation of border controls, trade in amphibians has become one of the most profitable businesses in the former U.S.S.R., placing Russia among the top world exporters of herptiles for terraria (Kuzmin 1996). Overcollection to support this trade has been implicated in the decline of several rare salamanders, including the Semirechensk salamander (*Ranodon sibiricus*), spotted salamander (*Salamandra salamandra*), and the banded newt (*Triturus vittatus*, Kuzmin 1996). Protected and rare amphibian species are not uncommon in the trade elsewhere. The Chinese giant salamander (*Andrias davidianus*), a protected species in China and listed on CITES Appendix I (species on Appendix 1 are threatened with extinction and cannot be legally traded internationally for commercial purposes), is regularly found in food and pet markets in southeastern Asia (Lau et al. 1997).

The poison-dart frogs (*Dendrobates* and *Phyllobates*) of Central and South America and Malagasy poison frogs (*Mantella*) of Madagascar are among the most sought-after pet amphibians worldwide. Most are brightly colored with interesting patterns, display elaborate courtships, and oviposit terrestrially (Zimmermann and Zimmermann 1994). *Dendrobates azureus*, perhaps the most desired dendrobatid in the pet trade, often sells for more than US $100 per individual. Between 1987 and 1993, nearly 16,000 dendrobatid frogs were reported in international trade, more than 80% of which were wild-caught. Most dendrobatid species are considered common within their native habitats. One museum biologist collected 7,600 *Dendrobates histrionicus* from a single population over a 4-year period without any obvious effects (Bringsøe 1992). Regardless, the habitats in which many of these species occur are rapidly being destroyed (Colwell 1994), and the added stress of collection may become a contributing threat to the future viability of their respective populations.

All species of *Dendrobates* and *Phyllobates* were listed on CITES Appendix II (species on Appendix II are those that may become threatened if their trade is not controlled; commercial trade of these species requires an export or re-export permit from the country of origin or re-export, respectively) in 1987, which subsequently increased the trade in then-unregulated *Mantella* spp., especially the Malagasy golden frog, *Mantella aurantiaca*. With a very restricted natural range (~3,000 km^2) that is threatened by rapidly increasing habitat destruction, the exploitation of this species for the pet trade may be a very significant threat (Zimmermann and Zimmermann 1994; Raxworthy and Nussbaum 2000). All *Mantella* spp. have since been added to CITES Appendix II, yet trade in wild-caught Malagasy golden frogs is increasing (UNEP World Conservation Monitoring Center 1998), with the United States responsible for 75% (>12,500 animals) of the imports. Other *Mantella* species, especially *Mantella cowani* and *Mantella viridis*, are also highly vulnerable to overcollection, with collectors reporting drastic reductions in the average daily harvest from previous years. Most *Mantella* spp. and dendrobatids are imported by Germany and the Netherlands; however, Japan and the United States are becoming increasingly involved in this particular trade (Gorzula 1996; CITES 2000).

Florida, long known as a center in the international pet trade, is one of few states in the United States that has monitored the impact of commerce on its native herpetofauna. From 1990 to 1992, 1,050 salamanders and 41,500 anurans were reported as being collected in Florida and sold in the pet trade. Some, such as southern leopard frogs (*Rana sphenocephala*) and southern toads (*Bufo terrestris*), were purchased as food for captive snakes. Destinations for these amphibians included most of the states and territories of the United States, as well as 16 other countries. States with high human-population densities, such as New York, California, and New Jersey, led the demand for Florida amphibians, and Germany was the largest foreign customer (Enge 1993). This trade is thought to be of minor importance, ranking ninth of 10 identified principal threats to South Florida herpetofauna (Wilson and Porras 1983). It may be a more significant threat in other areas, such as Louisiana, which has reported an annual harvest of at least 3 to 5 million herptiles, including 54,000 hylid treefrogs (Reptile and Amphibian Task Force 1992).

Amphibians in Education and Research

Amphibians, particularly frogs, have a historical connection with classroom education in Western countries. Many people have had their first, and sometimes only, exposure to amphibians through dissecting frogs in high school biology. Curricula in introductory biology, particularly at the secondary level, have traditionally included the study of the organs of the human body, a study often mandated by state-generated standards (e.g., Quality Core Curriculum in Georgia, U.S.A.). Relevant laboratory exercises have typically included animal dissection. The low cost and ready availability of grass frogs (*Rana pipiens* complex) and bullfrogs have made frog dissection a staple of many high school and introductory college curricula. A survey of Georgia high schools (Table 15.1) indicates that most use grass frogs for dissection.

The mudpuppy (*Necturus maculosus*) has been considered to represent a "primitive tetrapod," and as such has been a subject for dissection in college laboratories focusing on vertebrate anatomy and evolution. The past importance of such courses to curricula organized around organismal themes (e.g., zoology) led to the dissection of large numbers of mudpuppies. In addition, amphibians (*Rana* or *Necturus*) have traditionally been used for classroom investigations of physiological phenomena, including neural, muscular, and renal function. Ranid and ambystomatid eggs have been common subjects of embryological studies.

Demand for amphibians for dissection and experimentation has been met by companies specializing in scientific products. All of the companies in a survey of 14 catalogs (Table 15.2) sell grass and/or bullfrogs for dissection, and most offer mudpuppies.

Table 15.1

Amphibians most commonly used for educational purposes in surveyed institutions in Georgia, U.S.A., in 2001

	Secondary Schools[a]			Colleges and Universities[b]		
Species	N	%	n/year	N	%	n/year
Rana pipiens complex	7	64	53	7	44	20
Rana catesbeiana	0	—	—	3	19	1
Hyla cinerea	0	—	—	1	6	<1
Rana egg masses	0	—	—	1	6	2
Necturus maculosus	1	9	1	8	50	3

Notes: Numbers are rounded to the nearest integer. N = number of schools using a species; % = percentage of sampled schools using a species; n/year = mean number of specimens used per year by all schools answering the respective surveys.

[a]Public school systems participating in the survey: Dodge County, Douglas County, Franklin County, Gwinnett County, Jackson County, Winder-Barrow.

[b]Colleges and universities participating in the survey: Armstrong State University, Berry College, Covenant College, Columbus State University, Emmanuel College, Georgia Institute of Technology, Georgia Southwestern College, Middle Georgia College, North Georgia College, Oglethorpe University, Piedmont College, Savannah State University, University of Georgia, Valdosta State University, Wesleyan College, West Georgia University.

We requested information from companies on the number of amphibians sold but were told that those data are confidential. Many companies also sell live specimens for observation and/or experimentation, although concerns have been expressed over the quality of the health of these specimens for research purposes (Gibbs et al. 1971). One company (Charles D. Sullivan, Tennessee) raises amphibians on its own farm. Most others, however, deal in wild-caught amphibians. Five companies (Finn, Frey, Nasco, Sargent-Welch, and Ward) publish statements claiming that their grass frogs are collected in a sustainable fashion. A large number of grass frogs (*Rana for-*

Table 15.2

Amphibian species provided (live and/or preserved) by U.S. biological suppliers[a] for educational purposes

Common Name (Scientific Name)	Number of Suppliers Offering the Species
True frogs (*Rana* spp.)	14
Grass frogs (*R. pipiens* complex)	14
American bullfrog (*R. catesbeiana*)	13
Eurasian common frog (*R. temporaria*)	1
Ranid eggs/larvae	10
Treefrogs (*Hyla* spp.)	3
Cope's gray treefrog (*H. chrysoscelis*)	1
Barking treefrog (*H. gratiosa*)	1
Green treefrog (*H. cinerea*)	1
Hylid eggs/larvae	1
Toads (*Bufo* spp.)	5
Cane toad (*B. marinus*)	4
American toad (*B. americanus*)	2
Fowler's toad (*B. fowleri*)	1
Oak toad (*B. quercicus*)	1
Toad eggs/larvae	2
African clawed frog (*Xenopus laevis*)	6
Eastern newt (*Notophthalmus viridescens*)	11
Mudpuppy (*Necturus maculosus*)	11
Mole salamanders (*Ambystoma* spp.)	9
Tiger salamander (*A. tigrinum*)	8
Spotted salamander (*A. maculatum*)	3
Mexican axolotl (*A. mexicanum*)	2
Ambystomatid eggs/larvae	4
Amphiumas (*Amphiuma tridactylum* or *A. means*)	5
Sirens (*Siren* sp.)	1

[a]Surveyed suppliers: American 3B Scientific, Berkshire Biological Supply, Blue Spruce Biological Supply, Carolina Biological Supply, Charles D. Sullivan, Connecticut Valley Biological Supply, Delta Biologicals, Flinn Scientific, Frey Scientific, Nasco Biologicals, Nebraska Scientific, Sargent-Welch, Southern Scientific, Ward Scientific.

reri) are collected from irrigation canals in agricultural areas of Mexico, although many are also collected in the northern United States. According to state-agency records, one collector reported taking more than 450 kg of northern leopard frogs from Wisconsin during the last 6 months of 2000.

Although amphibians, particularly grass frogs, are still used for educational purposes in many schools (Table 15.1), their use in dissection is declining. Ethical concerns over the use of animals have grown in recent years, and legal decisions in U.S. courts have forced schools in some states to offer nondissection alternatives to conscientious objectors. These concerns have grown concomitantly with the availability of computer-based dissection-simulation programs and a spreading technophilia among public educators. Together these factors have encouraged the movement away from traditional dissection and toward computer-based programs. This trend, however, has been slowed by cost considerations and traditional teacher preferences (Smith 1994).

A decline in the use of *Necturus* in colleges has paralleled the reorganization of college curricula, especially at the university level. Curricula for academic majors are becoming increasingly based on conceptual (e.g., evolutionary biology) rather than organismal (e.g., zoology) themes. In addition, studies of broad patterns of evolution are becoming reliant on genetic patterns rather than traditional morphological ones. As a result, many programs no longer require courses in comparative vertebrate anatomy, and the subsequent demand for *Necturus* is relatively small (Table 15.1).

Amphibians remain popular subjects for scientific studies of morphology, physiology, behavior, ecology, evolution, and systematics. Although amphibians are occasionally procured from supply houses, many of them are collected from wild populations. In studies dealing with characteristics of specific populations (e.g., studies of geographic variation), there may be no alternative. However, the need for statistically valid sample sizes may drive researchers or museum curators toward overcollection, which, in turn, may have the unintended consequence of threatening the population(s) in question. Although some believe that it may be underrated as a factor in local population declines (Hairston and Wiley 1993), the impact of scientific collecting on amphibian populations is unknown. The greatest threat would seem to be large collections from small or isolated populations (e.g., 177 specimens of a now extinct population of southern dusky salamanders, *Desmognathus auriculatus;* Dodd 1998) or involving species with relatively small ranges (e.g., 356 individuals of Tellico salamanders, *Plethodon aureolus,* from the type locality; Highton 1983). Conversely, several species, including certain *Desmognathus* spp. in the Appalachian Mountains, occur so densely that systematic attempts to remove them from study plots have succeeded only with great difficulty or not at all (Hairston 1986; Petranka and Murray 2001). The appearance of high density may itself invite overcollection, however, especially at times when a significant portion of the population is vulnerable (e.g., during breeding congregations).

Amphibians in Medicine

Humans have recognized the chemical properties of amphibians for thousands of years. Indigenous peoples of South America used extracts from the skins of the endemic brightly colored frogs, giving rise to such common names as poison dart frogs (Dendrobates). Amphibian products continue to be widely used in traditional medicine in many parts of the world and are used to treat such varied ailments as warts and heart disease (Anderson 1993).

The use of plants and animals in healing in Western cultures historically has been associated with the "black art" of divination (Shakespeare's "eye of newt and toe of frog . . ." in Act 4 of *Macbeth*) and, as such, they are regarded as evil. This attitude traveled to Africa during the reign of European colonial powers, which sought to replace the beliefs of indigenous peoples with Christianity, resulting in a decline in traditional medical practice there during the nineteenth century. There has been a recent revival of the use of traditional medicine, however, in conjunction with the recognition of the importance of native cultures (Marshall 1999). Amphibians have continued to be included in the traditional pharmacopoeia of many Asian cultures. Parts of certain amphibians, like the parts of other animals (e.g., gall bladders of bears), are believed to have medicinal and/or aphrodisiacal properties. The dried oviducts of *Rana chensinensis* and skins of bufonids, for example, are sold in China by traditional medicine companies, in drug stores, and in open markets (Yinfeng et al. 1997).

The use of amphibians in western medicine is much more recent. Since the 1940s, frogs from a variety of families have been successfully used to test for human pregnancy (Hansen 1960); the African clawed frog, *Xenopus laevis*, is commonly used. In addition, the integuments of amphibians produce a diversity of biologically active compounds (Erspamer 1994), which have only recently come under scrutiny for their pharmacological potential. Researchers have identified peptides from the skins of *Xenopus laevis* and *Litoria caerulea* that show promise as antibiotics, and alkaloids from other species (e.g., *Epipedobates*) demonstrate analgesic properties. The skins of plethodontid salamanders harbor resident microbial floras; some member bacteria produce compounds that exhibit antibacterial and antifungal activity (Austin 2000).

The effect of the medical use of amphibians on endemic populations is not known. The main sources of amphibians used in Chinese traditional medicine are from the wild. The use of amphibians in Western medicine is so new that it has probably had little effect on natural populations. However, should current research lead to the successful production of widely marketed compounds, the impact could be large.

Amphibians as Bait

One needs only to visit a tackle or fishing store to understand the connection between sport fishing and amphibians. Many types of lures are colored and shaped to resemble frogs, and a variety of soft-plastic artificial baits are designed to mimic salamanders. However, despite the large numbers of amphibian-mimicking lures, live frogs and salamanders are relatively uncommon as commercial baits. Meronek et al. (1997) conducted surveys of the bait industry in the north-central region of the United States and found that amphibians were of minor importance and value when compared to fishes, earthworms, grubs, leeches, mayflies, and crickets. In certain regions of the country, however, the bait trade in amphibians is noteworthy and a potential conservation concern.

Most state wildlife agencies do not require permits specific to amphibian bait-collection or sale and only a few require a fishing license. Data on the number of animals collected and sold are, therefore, scanty, making evaluation of the trade's impact difficult.

Although sirens, amphiumas, and other amphibians turn up occasionally in the bait trade, ranid frogs, salamanders of the genus *Desmognathus,* and eastern tiger salamanders (*Ambystoma t. tigrinum*) are the groups most often involved. Bait trade involving amphibians may not be limited to the United States, but we are unaware of published information pertaining to this in other countries.

Although "farms" exist as commercial sources of ranid frogs, most if not all of these frogs are destined for biological supply houses and research institutions rather than bait shops (Gibbs et al. 1971). Meronek et al. (1997) revealed that 100% of the frogs sold in the north-central United States were harvested from the wild. Most frogs destined for the bait trade are hand-captured in and around wetlands. Large hibernating aggregations are often targeted, frogs being sometimes taken from under the ice. Most of the bait trade involving frogs occurs in the midwestern and north-central United States, where some states have established harvest seasons, size restrictions, and bag limits (Levell 1997). During 1998 and 1999, an estimated 250,000 frogs were reported taken from the wild in Minnesota (license-sales report to the Minnesota Department of Natural Resources), but these data include frogs taken for purposes other than for bait. Exploitation of frogs specifically for bait is thought to be of minor conservation concern, and any noted declines are more frequently attributed to habitat loss and invasive species.

Salamanders of the genus *Desmognathus* are commonly sold and used for bait in portions of the southeastern United States, particularly in Appalachian regions. They are used primarily for catching various species of centrarchid and temperate bass. Bait salamanders in this part of the country are colloquially known as "spring lizards," presumably because of their preference for spring-fed aquatic habitats and their gross resemblance to lizards. Spring lizards are less regulated than frogs; licenses or permits, bag limits, seasons, and size limits are not established in most states in which they are traded. Jensen and Waters (1999) interviewed the owners and inventoried the bait boxes of shops in northern Georgia that sold spring lizards. One bait-shop owner reported purchasing approximately 1,400 spring lizards per year from collectors. The salamanders were then sold to customers for US $4 to $6 a dozen. This trade is seasonal, and only a small proportion of bait shops in the region sell spring lizards. Approximately 95% of the 1,026 salamanders inventoried in the study were either seal salamanders (*Desmognathus monticola*) or black-bellied salamanders (*D. quadramaculatus*), but this is likely a result of what species are available at the collection sites rather than selective harvesting. Five other species, including three additional *Desmognathus* spp., made up the remaining salamanders encountered, none of which are considered rare or protected species in Georgia. *Desmognathus* spp. are abundant in the areas where the spring lizard trade is prominent. One study conducted in western North Carolina estimated the density of a local *Desmognathus* population to be 14,366 individuals per hectare (Petranka and Murray 2001). Although heavily collected local populations may experience short-term declines, the overall abundance of *Desmognathus* spp. and the limited extent of their trade would suggest that this group is not likely to be significantly affected by current levels of collection as bait.

Like spring lizards, "waterdogs" found in the bait trade are not what their name would suggest. The term waterdog correctly refers to salamanders of the genus *Necturus;* but those typically marketed as such for bait are actually the gilled, larval stage of the eastern tiger salamander. Waterdogs are primarily used to catch various species of centrarchid bass, mostly in the southwestern United States. They are obtained by seining from three primary sources: (1) natural populations from local wetlands; (2) natural populations from wetlands in distant states and then imported; and (3) introduced populations established as brood stock in local wetlands (Collins et al. 1988). Introduced populations of waterdogs in the southwestern United States are rarely composed of local subspecies, creating concern because of the negative impacts of alien introductions on endemic ecosystems.

Because the waterdog trade is not well regulated in most states where it occurs, few data are available on the numbers involved and their effect on natural populations. One dated study revealed that 2,440,000 waterdogs were sold as bait in the Lower Colorado River basin in one year (1968), and this total well exceeded the volume of bait-fish sales (Espinoza et al. 1970). A bait dealer recently interviewed by personnel with the California Game and Fish Commission indicated that he annually sells approximately 120,000 waterdogs, representing 15% of his total sales. Tiger salamanders remain quite common in most of the states from which they are harvested. Biologists in those states where the species is of conservation concern implicate nonnative fish introductions, wetland loss, deforestation, and possibly acid rain as more significant threats (Petranka 1998; Lannoo and Phillips, in press).

Amphibians in the Leather Trade

Although not typically thought of as sources of leather, frogs have recently begun to be used for fashion purposes. The species involved are usually large with thick hides and include Asian (*Limnonectes macrodon, Bufo melanostictus,* and *Kaloula pulchra*) and

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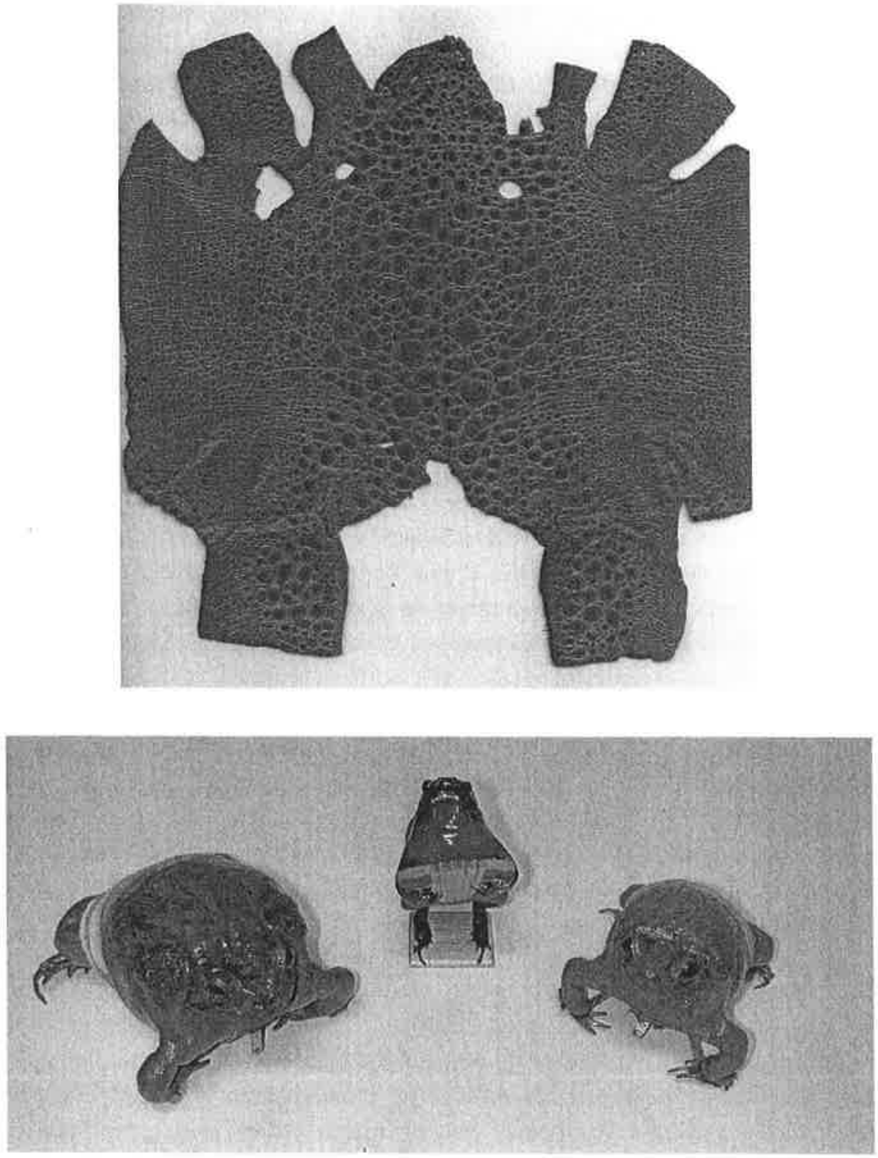

Figure 15.1. Cane toad (*Bufo marinus*) hide (a) prepared for use in various curios (b). (Photo by Barry Baker, U.S. Fish and Wildlife Service)

North American (American bullfrog) species (Fitzgerald 1989). A cottage industry has arisen in Australia that deals in novelty items made from the hides of the cane toad (*Bufo marinus*) (Figure 15.1). The cane toad is an exotic species that has caused severe ecological problems in Australia, from feeding on small wildlife to poisoning predators. Because of its effects on native species, including indigenous amphibians, the destruction of this species for its leather, at least in Australia, is probably helpful to amphibian conservation. It could have negative impacts, however, if this species were to be purposefully introduced into other countries to farm it for its leather. The potential impacts on other species involved in the leather trade are largely unknown, but are probably insignificant relative to those caused by their exploitation for other purposes.

INDIRECT IMPACTS

Removing amphibians from the wild to support various human needs and uses can obviously have direct impacts on the "donor" populations. Some of the more insidious, and perhaps wider reaching results of this trade are those in which other forms of wildlife, including other amphibians, are indirectly affected. Amphibians are both predators of prey and prey of predators. In the simplest sense, reductions of amphibian populations can result in an overabundance of those species' prey and leave their predators with a more limited food supply. For example, the decline of frogs in both India and Indonesia has been blamed for exploding insect populations and, subsequently, an increased necessity for insecticides (Barfield 1986; Fitzgerald 1989). In some areas, amphibians likely constitute most of the vertebrate biomass (Burton and Likens 1975; Petranka and Murray 2001), and predators that specialize on amphibians would certainly be affected by their reductions.

Perhaps the most troubling indirect impact of amphibian trade is the establishment of amphibian populations outside of their natural ranges. Intentional establishment is often pursued to provide new sources of food, bait, or other products in an effort to further commerce. Releases of unwanted pet, laboratory, or leftover bait amphibians, as well as escapees from commercial farms, have led to many unintentionally established populations. Exotic populations of amphibians have consequently caused great stress to native wildlife in many regions of the world (see Chapter 9, this volume). American bullfrogs, for example, have become established in Europe as a consequence of the trade of their tadpoles as pets, and they have been intentionally introduced to many areas of the world as a reliable food source (Stumpel 1992; Hardouin 1995). Cane toads have been introduced into several countries, including Australia and the United States. Many of these introductions have negatively affected certain native wildlife species that now have to contend with a new predator or a new competitor, or both (Collins et al. 1988; Lannoo et al. 1994). In addition, invasive species represent a significant threat to endemic species through the spread of exotic diseases (Chapter 9, this volume).

Another significant concern pertinent to introduced amphibians involves the genetic disruption they may cause through contamination of the gene pools of locally adapted ecotypes, intergradation with native conspecifics, or even hybridization with similar species. The latter is cause for concern with the California tiger salamander (*Ambystoma californiense*). Although the greatest threat to this federally endangered species is loss of habitat, hybridization with the eastern tiger salamander, which was introduced to support the waterdog bait trade, compounds the vulnerability of this highly restricted taxon (U.S. Fish and Wildlife Service 2000). In response to this issue, the state of California recently enacted controversial legislation prohibiting the sale and use of waterdogs as bait.

Certain techniques used for collecting commercially valuable amphibians add yet another concern. Bait-salamander collectors in the southeastern United States employ at least two different environmentally damaging practices to increase their catch. Small stream channels are occasionally diverted to expose streambeds and allow easier capture of salamanders sheltered under rocks. Similar to cyanide used to force tropical reef fishes out from crevices and cavities (Schrope 2000), liquid bleach poured into streams is used to drive salamanders (spring lizards) from under rocks (Jensen and Waters 1999). Clearly, these destructive collecting techniques are capable of having significant negative effects on the viability of associated aquatic flora and fauna, including declining species such as the hellbender (*Cryptobranchus alleganiensis*).

POTENTIAL SOLUTIONS

In a market economy, when demand outstrips supply, the resulting imbalance is correctable by either lowering demand or increasing supply. There is both precedent and opportunity for the first option. Modern concerns for the humane treatment of animals were effectively used in a campaign ("Lasst den Fröschen ihre Schenkel!" or "Let the frogs keep their legs!") to significantly cut the consumption of frog legs in Germany (Oza 1990). Similar campaigns expressing ecological and ethical concerns in regions where amphibians are heavily consumed might further reduce the demand for dead amphibians. Because of the long association of frog legs and French cuisine, obvious target areas would be regions of French historical culture in western Europe, Canada, and the United States. Other likely target areas are countries that use amphibians for traditional medicine (e.g., China) or as laboratory-dissection animals (the United States and other countries). An effective campaign needs to seek to educate (1) government officials, whose understanding of the need for wild frogs (e.g., for insect control) could translate into tighter restrictions on trade; (2) venders, both at the wholesale and retail levels; and (3) the consumers themselves. The opportunity for reducing demand for laboratory frogs is great because dissection is already in decline. Computer-simulated dissections are as effective as actual dissection in teaching the fundamentals of anatomy (Strauss and Kinzie 1994) and offer viable options to traditional dissection. The decline in dissection needs to be accelerated by focusing on changing the attitudes of teachers and procuring adequate funding for computer-based programs—and educating teachers in their use. This could be accomplished effectively during teacher training as part of science methods courses, which are required curricula in teacher education.

Cultural roots run deep, however, and educational campaigns may not be able to eliminate the demand for amphibians. The other option is to increase supply by captive-rearing species in high demand as pets or by farming food species agriculturally, thereby taking pressure off the wild populations. The increased availability of captive-reared tomato frogs (*Dyscophus antongilii*), for example, has apparently satiated the commercial demand for this CITES Appendix I-listed species (Fitzgerald 1989). Attempts at commercial raniculture for food have been less successful, because of problems associated with the control of bacterial disease and the need to provide live, moving prey. In addition, special techniques and facilities are required for managing each life-cycle stage, from hatching eggs to the maintaining brood stock (Lutz and Avery 1999). Even so, the potential for growth in this industry is large, particularly in tropical countries where suitable climatic conditions are coupled with the need for opportunities for economic development (Hardouin 1995). The bullfrog is currently farmed as "minilivestock" in the United States and has been imported into Brazil, Java, and the Philippines for this purpose (Hardouin 1995). Frog-farming operations are not without potentially negative side effects for wild amphibians, however. Unless only native species are farmed, there is the potential for introducing exotic species with all of their attendant difficulties (see Chapter 9, this volume). In addition, cultured frogs are a potential source of disease for their wild counterparts.

A continuing problem for trade officials attempting to enforce national and international law in the frog legs trade is the difficulty in correctly identifying species from frozen legs. With a number of countries allowing both the legal export of some species and farming of others, correct identification is essential to effective law enforcement. Although biochemical techniques (e.g., tests for allozymes) have been tried experimentally, a quick and inexpensive test is needed (Veith et al. 2000).

Governments should more effectively monitor the effects of potential overcollecting of amphibians in their respective principalities. Above a certain threshold number of animals, collectors should be licensed and required to report numbers taken, as is done for certain game species. Studies of population dynamics are still needed for many species so that agencies can determine sustainable collection numbers. However, regulations intended to set these sustainable levels should not wait on this biological information if, in the interim, the use may prove to be unsustainable. Sustainable-use policies should err on the side of caution and be amended later if necessary. Furthermore, government agencies should be more considerate of the importance of amphibians, enact necessary regulations and laws, and enforce them equally to those relating to other wildlife.

Companies seeking to exploit amphibians for pharmacological purposes should do so in a sustainable manner. In addition, should any companies reap large profits from marketing amphibian-generated compounds, those companies should consider "giving something back" and donate part of their proceeds for amphibian conservation.

Care should be taken within the scientific community to avoid overcollecting populations. Morphological studies should seek first to use museum specimens when feasible. With the development of biochemical techniques for studying variation and evolution, efforts to use regenerating body parts (e.g., tail tips of salamanders) in lieu of killing animals should be made. A system of banks that store tissues, similar to how museums store specimens, would eliminate the need for collecting specimens over and over from the same localities for new studies. Some museums (e.g., National Museum of Natural History, Smithsonian Institution) already have limited holdings of such material. In addition, journals that publish studies of wild-caught amphibians should require evidence from the authors that large collections from local populations do not irreparably harm those populations. There is precedent in behavioral journals, which routinely require authors to provide evidence that subject animals were treated according to ethical standards (e.g., author's instructions for journals such as *Animal Behaviour*).

To prevent the problems caused by the introduction of alien species, those who acquire living amphibians for pets or educational/research purposes should avoid releasing them into the wild. Educating the animal-using public on this issue is critical. To this end, Partners in Amphibian and Reptile Conservation (PARC) has developed a brochure outlining the dangers posed by invasive species. The intent is for supply houses and pet stores to include the brochure with every order of living amphibians. The brochure, *Please . . . Don't turn it loose!*, is available through the Arizona Game and Fish Department, Phoenix, AZ, and www.parcplace.org.

ACKNOWLEDGMENTS

We would like to thank the following people for providing information relative to this chapter: David Bechler, Kurt Buhlmann, Bruce Bury, Jan Caldwell, Chellu Chetty, Rod Christian, Jim Collins, Cris Cook, Steve Corn, F. Corotto, Mark Davis, Kay Dejno, Harold Dundee, Sharon Epperson, Dennis Ferraro, Tony Gamble, Tom Gehl, Christine Geist, Chris Hall, Robert Hay, Susan Healey, Robert Herrington, Kathy Hill, Craig Hoover, Sheila Hughes, Christopher Jones, Richard King, David Leonard, Sue Lieberman, Chuck Loeffler, Mitchell Lockhart, Chis McAllister, Chris McGrath, Grace McLaughlin, C Miller, Mark Mills, Paul Moler, John Moriarty, William Nelson, Jennifer Nolan, Marc Pline, Jamie Reaser, Kenneth Relyea, B. Rhoades, Bryan Rogers, Tara Seay, Brad Shaffer, Carol Smith, Cheryl Sniker, Kristina Sorensen, Mike Sredl, G. Stanton, Dirk Stevenson, Leigh Touchton, Art Tyson, Jerry Wenger, and J. Yearwood.