Global Amphibian Declines: Perspectives From The United States And Beyond

Christine L. Densmore

United States Geological Survey, Leetown Science Center, National Fish Health Research Laboratory, 11649 Leetown Road, Kearneysville, WV 25430

Abstract:

Over recent decades, amphibians have experienced population declines, extirpations and species-level extinctions at an alarming rate. Numerous potential etiologies for amphibian declines have been postulated including climate and habitat degradation. Other potential anthropogenic causes including overexploitation and the frequent introductions of invasive predatory species have also been blamed for amphibian declines. Still other underlying factors may include infectious diseases caused by the chytrid fungus *Batrachochytrium dendrobatidis*, pathogenic viruses (*Ranavirus*), and other agents. It is nearly certain that more than one etiology is to blame for the majority of the global amphibian declines, and that these causal factors include some combination of climatological or physical habitat destabilization and infectious disease, most notably chytridiomycosis. Scientific research efforts are aimed at elucidating these etiologies on local, regional, and global scales that we might better understand and counteract the driving forces behind amphibian declines. Conservation efforts as outlined in the Amphibian Conservation Action Plan of 2005 are also being made to curtail losses and prevent further extinctions wherever possible.

Key words: amphibian, frog, decline, extinction, Chytridiomycosis, climate change

Introduction

While population declines and extirpations, and even occasional species extinctions, have been noted throughout modern history, perhaps none of these events have been more striking than the global scale declines of countless populations and species of amphibians during the past few decades. These declines are so substantial that some investigators have proclaimed them to be a hallmark of the sixth mass extinction event experienced on the planet (Wake and Vredenburg 2008). Recent data indicates that, of the approximately 6400 described species of amphibians around the world, roughly 2700 (43%) are in decline and 1800 (32%) are in danger of extinction; it is further estimated that an additional 160 species largely consisting of neotropical anurans have already become extinct (Sodhi et al. 2008). Evidence in support of these large-scale losses in amphibian biodiversity has been collected and disseminated by scientists from around the world, and this phenomenon is fundamentally uncontested. While declines are truly global, affecting all six continents that contain amphibian life, the losses are concentrated in neotropical areas of Central and South America and the Caribbean islands as well as tropical eastern Australia (Becker and Loyola 2008; Figure 1). Many causal relationships have become clearly established between one or more associated factors and amphibian population declines. In other instances, causes of declines remain quite enigmatic. In general terms, the most likely and frequently postulated causal factors can be assigned to one of four categories: habitat destruction, climate change, emerging infectious disease, or anthropogenic manipulation of biota.

Figure 1. Global distribution of amphibian declines. Nations shaded in grey (n=41) are those with 10 or more amphibian species listed as threatened or endangered. Nations shaded in dark grey (n=22) are those with 40 or more threatened or endangered amphibian species. Data obtained from the 2008 update to the Global Amphibian Assessment (http://www.iucnredlist.org/amphibians).

Habitat destruction and degradation

Anthropogenic changes in landscapes and land use have resulted in considerable loss of habitat for animal life around the globe. Not only does loss of viable habitat impair an individual's ability to feed, reproduce, and evade predators, but habitat fragmentation may adversely impact the population as a whole through physical isolation resulting in a bottleneck in genetic diversity. Deforestation and drainage of wetlands for agriculture or urban development are primary examples of these types of changes that have significant implications for habitat conservation (Cushman 2006). Deleterious impacts of these types of land use changes on amphibian species richness and biodiversity have been documented in different areas of the world (Becker et al. 2007, Hecnar and M'Closkey 1998). Even more concerning is the evidence suggesting that the regions of the world that support the greatest level of amphibian biodiversity are also the areas experiencing the highest degree of habitat destruction through land use change (Gallant et al. 2007). These changes are especially noteworthy in low latitude eco-regions including tropical rainforests, moist tropical forests, and temperate broadleaf forests. For example, the Atlantic Forest region of Southeastern Brazil and adjacent South American nations is one of the world's hot spots supporting a diversity assemblage of wildlife, yet this area is also losing considerable natural habitat through agricultural expansion and urban development (Morellato and Haddad 2000). Habitat split, the physical separation of habitats used by different life stages of a species, is one type of human-driven habitat destruction that is particularly detrimental to amphibians in the Atlantic Forest. Becker et al. (2007) found that habitat split was a significant cause of the diminished amphibian biodiversity in this region. Indeed, that study found that habitat split was the best (negative) predictor of leaf-litter amphibian species richness throughout the Atlantic Forest. Although destruction of the neotropical rainforest is perhaps the most recognized example of reduced amphibian habitat in the world, it is by no means the only location where such impacts occur. For example, Hecnar and M'Closkey (1998) observed that deforestation was the primary variable related to amphibian species richness in southwestern Ontario, Canada.

Contamination with xenobiotic agents is another major form of habitat degradation globally affecting a variety of amphibians. Some unique physiological features of amphibians including their reliance on both aquatic and terrestrial environments and their permeable skin make them especially at risk to the effects of chemical effluent and by-products from agriculture, industry, and other sources. A number of lethal and sublethal effects of chemical contaminants have

been documented in amphibians, including endocrine disruption, reproductive and developmental impairments, and immunomodulation (Blaustein et al. 2003). While many studies establishing causal relationships between xenobiotics and amphibian diseases are controlled laboratory experiments, there are also field based studies and observations that support population level impacts based on effects of contaminants. For instance, Kirk (1988) reported a mortality event affecting Western spotted frogs (*Rana pretiosa*) in Oregon (U.S.A.) following the treatment of forest habitat with the pesticide 1,1,1-trichloro-2,2-bis-(p-chlorophenyl) ethane (DDT). Vonesh and Buck (2007) demonstrated that gray tree frogs (*Hyla chrysoscelis*) had reduced oviposition and altered oviposition site selection in association with the insecticide, carbaryl. Endocrine disruption of the hypothalamo-pituitary-interrenal (HPI) axis was noted among wild mudpuppies (*Necturus maculosus*) exposed to chlorinated hydrocarbons in the St. Lawrence and Ottawa rivers in Canada (Gendron et al. 1997).

Climate Change

The complex climatological processes currently occurring that affect changes to air and water temperatures, precipitation patterns, humidity levels, cloud cover, and other weather-related phenomena are most certainly affecting habitat fitness for living organisms. There is widespread scientific belief that climate change has a major role in amphibian declines, yet there is less concordance concerning the precise extent and nature of this relationship (Pounds 2001). Suitability of habitat for amphibians largely depends upon both temperature and moisture, two environmental factors directly impacted by climate change. Some investigators have noted a relationship between extended periods (i.e. one or more years) of unusually warm temperatures and amphibian declines following. This phenomenon has been observed to occur with Harlequin frogs (*Atelopus* sp.) in South America (Pounds et al. 2006) as well as with various other anuran species in tropical Queensland, Australia (Laurance 2008). Pounds et al. (2006, 1999) also observed that reduced frequency of dry-season mist in warmer years was associated with the disappearance of two species of anurans as well as other population shifts of birds, reptiles, and amphibians. Increased exposure to ultraviolet radiation is yet another possible effect of global change, mediated through either ozone depletion or decreased water depth associated with increased temperatures and decreased moisture levels. Through multiple field studies as reviewed by Blaustein et al. (1998), ultraviolet radiation has a wide variety of potential effects on amphibians depending on species and life stage. These effects may include reproductive impairment, developmental malformations, decreased growth, immunomodulatory and behavioral changes, and ocular damage. In addition, it is theorized that the greatest impacts of climate change on amphibian populations may occur indirectly in synergism with other causal factors such as infectious disease (Burrowes et al. 2004, Pounds 2001); this phenomenon is broadly referred to as the "climate-linked epidemic hypothesis" (Pounds et al. 2006).

Emerging Infectious Diseases

Certainly the most widespread and devastating infectious disease known to affect wild amphibian species is chytridiomycosis. The causative pathogen is *Batrachochytrium dendrobatidis* (Bd), a chytrid fungus of moist and aquatic environments that affects anuran and caudate amphibians with the greatest impacts on post-metamorphic anurans. This fungus is keratinophilic, affecting

the skin, which compromises its function and integrity. Chytridiomycosis is highly lethal among amphibians and may spread rapidly through a population. The disease was first noted in the mid 1990's in Panama and Australia (Berger et al. 1998). It has been reported, often in association with population declines and extirpations, in many other countries including nations of North, Central, and South America, Africa, and Europe (Weldon et al. 2004). LaMarca et al. (2005) documented Bd among several of the neotropical *Atelopus* species experiencing population declines and extirpations; chytridiomycosis is believed to potentially be the underlying cause for these and other declines of amphibians from undisturbed habitats. That amphibians are widely and severely impacted by chytridiomycosis is well established among the scientific community; however, the potential role of climate change as a driving factor in the spread of Bd remains controversial (Pounds et al. 2006, Lips et al. 2008).

Though not to the same degree as Bd, there are other infectious disease agents also associated with amphibian population declines. The ranaviruses (Family Iridoviridae, genus *Ranavirus*) are highly pathogenic to various amphibian species. Ranaviruses tend to impact pre- and peri-metamorphic life stages the hardest, producing systemic disease often accompanied by high mortality. Throughout North America, ranaviruses have impacted populations of anuran tadpoles and metamorphs with mortality rates sometimes >90% (Green et al. 2002, Greer et al. 2005). Likewise, die-offs of tiger and spotted salamanders (*Ambystoma tigrinum*, *A. maculatum*) in the United States have been attributed to the *Ambystoma tigrinum* virus (ATV), another species of ranavirus (Docherty et al. 2003, Jancovich et al. 1997). Other infectious agents that have been noted to cause epizootics or otherwise impact wild amphibian populations include the water mold *Saprolegnia* sp. and the trematode *Ribeiroia ondatrae* (Daszak et al. 2003).

Anthropogenic manipulation of biota

Direct human-related impacts on animal populations and species through hunting, harvesting, and other processes have been substantial throughout history. These types of manipulations are affecting amphibians around the world, potentially playing a significant role in their declines. Over-exploitation through the harvesting of wild-caught amphibians for food, the exotic pet trade, the laboratory animal trade, bait, medicinal and other uses is an ongoing concern in some parts of the world, particularly the main amphibian exporter nations like China and Indonesia (Gascon et al. 2007, Warkentin et al. 2009). The global trade market for frog legs for food has expanded over the past few decades, averaging approximately 5000 to 10,000 tons per year since 1995 (Warkentin et al. 2009). Overall, there is little international regulatory authority in the commercial amphibian trade. Furthermore, though overharvesting historically has been associated with significant amphibian population declines, there are few data available to assess the current effects of harvest on population levels (Collins and Storfer 2003; Gascon et al. 2007). As such, it is difficult to evaluate the present impact of this market on global declines, but clearly a need for such data is evident.

Human-driven introductions of new species, whether accidental or intentional, often have serious ramifications for the habitat's existing occupants. Introduction of invasive predatory species is another potential cause for declining amphibian populations, which can adversely affect species richness and

drive populations toward extinction (Hecnar and M'Closkey 1997). An example of this phenomenon is the severe decline and extirpation of mountain yellow-legged frogs (*Rana muscosa*) within the Sierra Nevada Mountains of the western United States following stocking of local waters with non-native trout (Knapp and Matthews 2000). Gillespie (2001) reported a similar occurrence in southern Australia when spotted tree frog (*Litoria spenceri*) declines followed introductions of brown and rainbow trout (*Salmo trutta*, *Oncorhynchus mykiss*). Salmonid fish, however, are not the only predators of concern. Other species such as bass (*Micropterus* sp.), smaller predatory fish that consume eggs or larvae (e.g. – mosquitofish, *Gambusia*), predatory invertebrates like the crayfish (*Procambarus clarkii*), and even amphibians themselves like the highly invasive and ravenous bullfrog (*Lithobates catesbieana*) have all been implicated in amphibian declines due to predation (Kats and Ferrer 2003). Invasive species' impacts on amphibians are not limited to predation; they may also spread infectious diseases like chytridiomycosis or out-compete amphibians in their niche (Hecnar and M'Closkey 1997).

Responding to the crisis

In the most basic terms, the scientific community is responding to this crisis in amphibian biodiversity through a combination of research, monitoring, conservation efforts, and public awareness. These responses are occurring through a number of venues and organizations worldwide including governmental agencies; universities and other institutions of higher learning; and other local, national, and international organizations with a dedicated interest in wildlife conservation. Perhaps the largest and most unified of these responses is represented by the development of the Amphibian Conservation Action Plan (ACAP) as an outcome of the 2005 Amphibian Conservation Summit, co-sponsored by a number of key international conservation-based organizations (Gascon et al. 2007). This summit, in turn, was a response to the findings reported in the 2004 Global Amphibian Assessment (GAA) that highlighted the critical state of worldwide declines, extirpations and extinctions of amphibians. The ACAP is a document providing recommendations for governments, businesses, civil society, and the scientific community to outline and organize a swift and effective response to the amphibian declines. It calls on the scientific community and the global community at large to participate in remediation through a four-part approach including: 1. Promoting continued research to expand our understanding of the causes of decline with additional focus on the interactive effects of the multiple stressors involved; 2. Continuing to follow and document amphibian diversity worldwide, largely through frequent periodic updates to the GAA; 3. Developing conservation programs to protect key sites, provide for reintroductions of species, and control over-harvesting; and 4. Providing critical response capability to immediate crises including the development of a large scale captive assurance program (the Amphibian Ark). Since its development, the ACAP, as implemented by the Amphibian Specialists Group that was formed for this management role, has made progress on each of these fronts and continues to work towards enhancing our understanding of the crisis and alleviating its effects.

Conclusions

It is certain that the causal factors outlined here have all contributed to the overall global decline of amphibian species. It also is

extremely likely that, in many instances, two or more of these factors interact to create the population declines, extirpations, and extinctions experienced around the world. While some of these factors are easily identified and controlled, others are less easily managed or reversed and may even remain somewhat enigmatic. Still, the scientific community has made great strides in recent years to better define the scope and nature of the crisis and to begin coordinated efforts to mitigate its effects.

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