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Surveys

The Amphibian Extinction Crisis - what will it take to put the action into the Amphibian Conservation Action Plan?

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Abstract

The current mass extinction episode is most apparent in the amphibians. With approximately 7,000 species, amphibians are dependent on clean fresh water and damp habitats and are considered vulnerable to habitat loss (deforestation), changes in water or soil quality and the potential impacts of climate change, and in addition many species are suffering from an epidemic caused by a chytrid fungus. Because of their sensitivity and general dependence on both terrestrial and aquatic habitats they are often regarded as indicators of the health of the environment. The latest figures from the International Union for Conservation of Nature's (IUCN) Red List of Threatened Species™ show that there are nearly as many species of amphibians categorised as Threatened as those of Threatened birds and mammals put together, with an estimated 40% of amphibian species in danger of extinction. Furthermore, although amphibians have survived multiple previous global mass extinctions, in the last 20-40 years precipitous population declines have taken place on a scale not previously seen.

Although amphibian declines were first reported in the 1950s, the magnitude and global scope of the problem were only fully realised during discussions at the 1st World Congress of Herpetology in England in 1989. Shortly thereafter, the Declining Amphibian Populations Task Force (DAPTF) was established by the IUCN Species Survival Commission (SSC) to investigate the causes and severity of the declines. Many projects and publications were stimulated by the DAPTF and the results of these prompted the IUCN to conduct a global amphibian assessment in 2004.

IUCN SSC's Amphibian Conservation Action Plan (ACAP) was published in 2007, following an Amphibian Conservation Summit held in 2005. The ACAP identified the key issues that require attention in order to curb this crisis, and provided the framework for interventions. While there have been significant efforts in the last five years, the response to the crisis has not progressed across all areas of the action plan at a scale sufficient to halt the crisis. As a direct result, species continue to decline and go extinct.

Finding solutions to counter amphibian declines and extinctions is one of the greatest conservation challenges of the century, which comes with alarming and serious implications for the health of ecosystems globally. The Amphibian Survival Alliance (ASA), launched in June 2011, acts as a global partnership for amphibian conservation. It is in a pivotal position to implement the ACAP, acting to

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mobilise a motivated and effective consortium of organisations working together to stem the rapid losses of amphibian populations and species worldwide. The Alliance brings focus, coordination, and leadership in addressing one of the world's most serious extinction crises. Its goal is the restoration of all threatened native amphibian species to their natural roles and population levels in ecosystems worldwide. The recently formed Amphibian Survival Alliance will address the multiple ACAP issues with several new initiatives, including creating a web-based 'living' version of ACAP and driving the implementation of the ACAP themes in a more progressive and collaborative manner than ever before, thereby stemming the loss of an important part of the biological diversity of our planet.

Keywords: Amphibians, extinction crisis, amphibian conservation, Amphibian Conservation Action Plan, Amphibian Survival Alliance.

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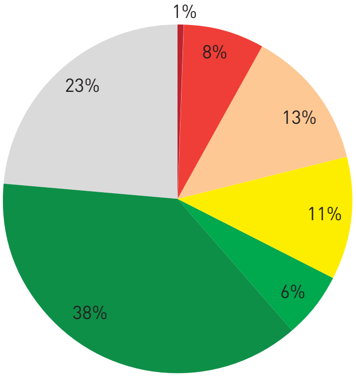
1. THE EXTENT OF THE AMPHIBIAN EXTINCTION CRISIS

The residents of the small city of Canterbury in Kent (UK) were unaware of the significance their city would have in relation to amphibian conservation when the largest international meeting of herpetologists took over their city in September 1989 for the First World Congress of Herpetology. As the biologists mingled in the various symposia and social events it became apparent that a common thread was emerging in their conversations: amphibian populations were in deep trouble. While authors of herpetological field guides had noted amphibian declines as early as the 1950s (e.g. Conant, 1958), it was only during the meeting in Canterbury that scientists realised the extent of the problem. Amphibians were in serious trouble across the globe.

Amphibians (frogs, toads, salamanders and caecilians) are usually encountered during the breeding season when they often produce loud breeding choruses or form aggregations at ponds, and in many cases very little is known about their non-breeding behaviour or movements. They are therefore difficult organisms to study at the population level. In the late 1980s, there were only a handful of long-term monitoring studies on amphibian populations; consequently at that time it was possible neither to quantify the extent of amphibian declines nor to discriminate them from natural population fluctuations. However, there was enough anecdotal information shared at the First World Congress of Herpetology to stimulate an investigation into the evidence of these declines (Rabb, 1990; Blaustein & Wake, 1990; Wake & Morowitz, 1990; Wake, 1991). This led to the formation of the Declining Amphibian Populations Task Force (DAPTF) by the International Union for Conservation of Nature Species Survival Commission (IUCN SSC) in late 1990 (Vial, 1991). The goal of the DAPTF was "to determine the nature, extent and causes of declines of amphibians throughout the world, and to promote means by which declines can be halted or reversed". The Task Force operated through a global network of some 108 regional and sub-regional working groups of professional herpetologists, who collected geographical data on amphibian declines and their causes (Heyer & Murphy, 2005). The DAPTF raised funds and distributed them in the form of seed grants to initiate research projects in key areas in over 49 countries resulting in 197 publications on amphibian declines in 15 years (T.R. Halliday, personal communication, 2012).

The picture that emerged from the work stimulated by the DAPTF and other organisations and experts was not favourable for amphibians. Amphibian declines were reported as occurring as early as the 1950s in the USA, Puerto Rico and Australia (Conant, 1958; Czechura & Ingram, 1990; Kagarise-Sherman & Morton, 1993; Drost & Fellars, 1996; Burrowes *et al.,* 2004). There were many subsequent reports of rapid and severe amphibian declines from Central and South America (e.g. Pounds & Crump, 1994; Young *et al.*, 2001; Ron *et al.*, 2003) and most alarming were the reports of declines in seemingly pristine areas (e.g. Czechura & Ingram, 1990; Pounds & Crump, 1994; Ron *et al.*, 2003; Burrowes *et al.*, 2004; Gallant *et al.*, 2007). Statistical modelling by Pounds *et al.* (1997) demonstrated that the declines were more severe and widespread than had previously been thought, and as more and more papers were published, scientists became alarmed with the severity of the problem. In fact, using data from 936 amphibian populations across the globe, Houlahan *et al.* (2000) suggested that amphibian declines were a global phenomenon and Alford *et al.* (2001) demonstrated that the declines had been occurring at a global scale since 1990.

These studies highlighted the urgent need to identify formally those amphibian species that were declining and needed conservation attention. In 1996 the IUCN Red List of Threatened Species™ (Baillie & Groombridge, 1996) included only



Red List Category	Number of Species
Extinct	34
Extinct in the wild	1
Critically Endangered	455
Endangered	768
Vulnerable	670
Near Treatened	369
Least Concern	2236
Data Deficient	1382
Total Number of Species	**5915**

Figure 1. Summary of Red List categories for all amphibians. The percentage of species in each category is displayed on the pie chart (from Stuart *et al.* 2008)

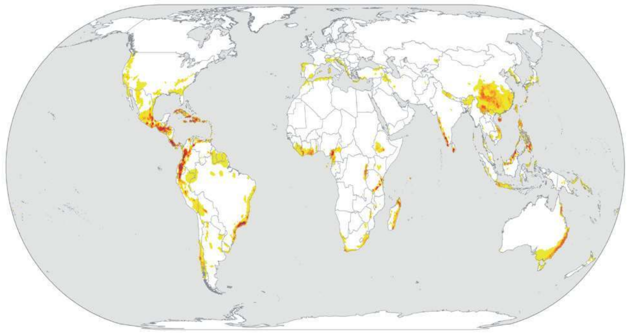


Figure 2. Richness map of Threatened amphibian species, with dark red colours corresponding to higher number of species (from Chanson *et al.*, 2008).

126 species of amphibians, and although by the year 2000 this number had increased (Hilton-Taylor *et al.*, 2000), there was still no comprehensive overview of the status of the planet's amphibians. Although some countries had initiated their own Red List assessments (e.g. Minter *et al.*, 2004), fewer than 1000 amphibian species had been assessed, which was not reflective of the amphibian species richness that was known at that time. Due to the severity and apparent global scope of amphibian declines, the IUCN, in partnership with Conservation International and Nature Serve, launched the Global Amphibian Assessment (GAA) initiative in 2001. The GAA was designed to help prevent further losses of amphibian populations and species by developing a complete picture of the conservation status and needs of all known species of amphibians (nearly 6000 species at the time, in contrast to the current total of approximately 7000 species[1]). This would be the first time that such an ambitious project assessing all species within the entire class of Amphibia had ever been carried out, and this very fact highlighted the severity and urgency of the problem.

The entire assessment took over three years to complete, and the process involved hosting 14 regional workshops and one global (caecilian workshop), with the participation of over 500 amphibian specialists in more than 60 countries. The GAA resulted in an in-depth look at the state of the world's amphibians – and it was a sobering scene (Stuart et al., 2008). While amphibian population declines were the main focus of DAPTF and the initial spark for conducting the GAA they had progressed into amphibian extinctions. The GAA assessed 5,915 amphibian species and categorised a third of these as Threatened with extinction[2] (Figure 1).

The only other vertebrate classes that have been comprehensively assessed as to conservation status are the mammals and the birds. While the data for birds (9917 species, 12% Threatened) and mammals (4853 species, 23% Threatened) paint a gloomy picture, it is considerably worse for amphibians (5915 species, 32% Threatened; see Table 1). Perhaps one of the most alarming areas is the Data Deficient category, with currently 1,615 species of amphibians in this category[3] (in contrast, birds are very well studied, with few species in the Data Deficient category; mammals less so, but still only have half as many Data Deficient species as amphibians). Organisms are placed in this category when they have been assessed against the IUCN Red List Categories and Criteria (2001) and the information available is inadequate to make either a direct or indirect assessment of their risk of extinction.

Consequently, the Data Deficient category contains many newly described species, or ones that are rare with very small ranges or are difficult to find. If global figures are extrapolated to the Data Deficient category, it suggests that at least a third of these species are also seriously threatened, thereby implying that nearly 40% of amphibian species are threatened with extinction (Table 1).

Although amphibians inhabit every continent in the world except Antarctica, their distributions are not uniform. The Neotropical Realm, which comprises Latin America and the Caribbean, contains nearly half of all amphibian species, most of which are endemic to this area (Chanson *et al.*, 2008). It is no surprise that this area also contains the largest proportion of threatened and extinct species considering the extent of recent land-use change. The global map of the distribution of Threatened amphibian species (Figure 2) shows that these species include insular systems, which are susceptible to habitat loss and disease (Chanson *et al.*, 2008) In addition, being less mobile than other taxa, many amphibians have very small distributions, making them more susceptible to extinction (Purvis *et al.*, 2000).

1 see www.amphibiaweb.org for an updated tally.
2 'Threatened with extinction' comprises the categories Critically Endangered, Endangered, and Vulnerable.
3 v. 2011.2 - www.redlist.org

Table 1.A comparison of Threatened categories for Amphibians, Birds and Mammals. 'Threatened with extinction' comprises the categories Critically Endangered, Endangered, and Vulnerable. Actual number of species in each category is in parentheses (based on data from Baillie *et al.*, 2004 and Stuart *et al.*, 2008).

	Amphibians (5915)	Mammals (4853)	Birds (9917)
Threatened with extinction	32% (1893)	23% (1101)	12% (1213)
Critically Endangered or Endangered	21%* (1242)	10.5% (162)	5.4% (179)
Data Deficient	23% (1382)	7.8% (380)	0.8% (78)
Extrapolated proportion of Threatened species+	39.5% (2336)	24.5% (1189)	12.3% (1220)

*Over 10% of amphibians in the Critically Endangered category are flagged as being "Possibly Extinct", i.e. they have not been seen in a long time despite targeted surveys and are suspected to be possibly extinct.
+This row was calculated by assuming that there is a similar proportion of Threatened species in the Data Deficient category as in the Class overall.

2. WHAT IS CAUSING AMPHIBIAN DECLINES?

Six major causes of amphibian declines were identified by Collins and Storfer (2003), which they categorised into two classes: Group 1 threats, of which we have a good understanding of the processes involved and which may have negatively affected amphibian populations for a long time, perhaps in some cases 100 years or more, and Group 2 threats, of which we have poor knowledge of the subtleties and interactions involved, and which have emerged in the last 30 years or less, and are in desperate need of further investigation. They are:

Group 1 threats:

- Habitat change (destruction and fragmentation);
- Alien invasive species;
- Over-exploitation/utilisation.

Group 2 threats:

- Emerging infectious diseases;
- Pesticides and environmental toxins;
- Global climate change (including UV radiation).

The extent to which each of these environmental factors is threatening the species exposed to it is illustrated in Figure 3. Each of the threats is briefly outlined below.

2.1 HABITAT CHANGE (DESTRUCTION AND FRAGMENTATION)

Many authors have documented how habitat change can cause amphibian declines and extinctions (Gallant *et al.*, 2007; Gardner *et al.*, 2007; Sodhi *et al.*, 2008; Hof *et al.*, 2011). Habitat loss is the major contributing factor to amphibian declines globally with an estimated 63% of all amphibian species affected, and

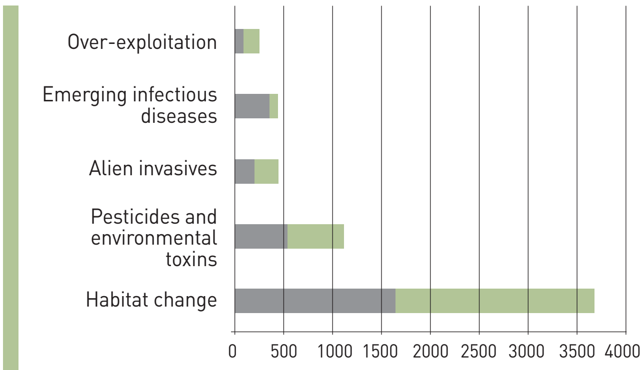


Figure 3. Total (grey+green) and threatened (grey) numbers of amphibian species that are affected by five of the six major environmental risks. N.B. Data were not available for determining how many amphibian species are threatened by Global climate change (including UV radiation). (From Chanson *et al.*, 2008).

as much as 87% of the Threatened species affected (Chanson *et al.*, 2008). Many amphibians require specific microhabitats with appropriate conditions of moisture, temperature, pH and sufficient refuges and food resources. These conditions are easily disrupted during even minor habitat modifications. The most common forms of habitat change are clearance for crops, logging, clear-cutting, urbanization and industrial development. Further, most of these processes are happening in tropical forests, where the majority of amphibian species are found (72%). The extent of the effects of habitat change can be difficult to determine as many amphibians spend most of their lives in one or two terrestrial environments and seasonally migrate to a different, usually aquatic environment, to breed. To disrupt the breeding migration would thereby cause a decline (see Becker *et al.*, 2007). Habitat change may affect one or more of the habitats necessary for completion of the life cycle, for example, the environment in which the amphibians spend most of their year (e.g. forests), a summer feeding habitat (e.g. grasslands), the water bodies in which they breed and are utilised by their larvae (e.g. ponds, lakes, streams), or the land that separates these different habitats (e.g. corridors). Most amphibians do not live in isolation in a single microhabitat and effective conservation will require an integrated landscape approach as outlined by Lindenmayer *et al.* (2008) and Lannoo (2012). In addition, since the beginning of the 20th century human populations have grown exponentially, with concomitant habitat alteration and destruction, and most of this change has occurred in tropical and subtropical ecoregions of high amphibian diversity and endemism (Gallant *et al.*, 2007).

2.2 ALIEN INVASIVE SPECIES

Humans have been deliberately or accidentally introducing animals all around the world for hundreds of years and in places like New Zealand they even formed 'Acclimatisation Societies' whose main mandate was to introduce 'innoxious' species (sometimes from the other side of the globe) to make the new colonised landscape feel more like home! There are many documented examples of how the introduction of alien species has negatively impacted local amphibian populations, and these can be broadly grouped into several categories: competition for food, space and resources; direct predation on adults and/or larvae; and vectors or reservoirs for disease and parasites. To a lesser extent some invasive species may actually hybridise with the native species, disrupting genetic integrity (e.g. *Xenopus gilli/X. laevis*; Picker, 1985). The list of particularly damaging invasive species includes fish (e.g. salmonids; Bradford, 1989; Bradford *et al*., 1993; Drost & Fellers, 1996; Jennings, 1996; Lannoo, 1996; Vredenburg, 2004; Knapp, 2005), the American bullfrog (*Lithobates catesbeianus*; Rosen & Schwalbe, 1995; Kiesecker & Blaustein, 1998; Mazzoni *et al*., 2003) and cane toads (*Rhinella marina*; see Shine, 2010 for review).

2.3 OVER-EXPLOITATION/UTILISATION

Amphibians are mainly harvested for food, medicine, use in research and teaching or the pet trade. A surprisingly huge number of frogs (hundreds of millions of individuals, Altherr *et al*., 2011; Warkentin *et al*., 2009) are consumed in the EU and USA every year. While more than 200 species of amphibians are consumed on a subsistence level or traded nationally or sub-nationally around the globe, approximately 20 species of the larger-bodied amphibians are regularly exported/imported for the food markets, most of these being wild-caught animals (Carpenter *et al*., 2007). However, the United States international trade is dominated by commercially bred bullfrogs *Lithobates catesbeianus*, with the overall trade of this species superseding trade of other highly traded frog species by several orders of magnitude (the US alone imported between 2,000-3,000 tonnes per annum of captive-bred bullfrogs from 2001-2009; Altherr *et al*., 2011). Unfortunately, similarly detailed trade and sourcing (captive bred, wild) information for other major markets is not readily available to determine whether this could be a pattern across importing countries. Although no large-scale declines have been attributed to collection for medicinal purposes, there have been reports of local population declines (Ye *et al*., 1993, cited in Carpenter *et al*., 2007). Many species of amphibians are collected for the pet trade, and in some countries such as Madagascar this represents a considerable financial income (Carpenter *et al*., 2007). In other amphibian-rich countries, the extent of amphibian collections for the pet trade is largely unknown (Pistoni & Toledo, 2010).

International trade of amphibians is regulated by the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)[4], an international agreement between governments whose goal is to ensure that international trade of species in the wild is not a threat to their persistence. Amphibians are also contemplated under CITES, where individual species or groups of species are listed under Appendices I–III, which accommodate varying levels of threat, with Appendix I addressing those species under the highest level of threat (CITES, 2012). Nevertheless, only a small fraction of amphibian species is listed under any of the Appendices, and most of the heavily traded amphibians in the US are not regulated by CITES (Schlaepfer *et al*., 2005). When taking into account extinction risk of species in trade as per the IUCN Red List of Threatened Species™, a UNEP-WCMC report found that of 134 species for which international trade was considered to be a major threat, 54 were Threatened, and 46 were listed in CITES; however, there were 29 species that were Threatened but not listed in CITES (UNEP-WCMC, 2007).

In addition, there are issues surrounding recording the species in trade. Because there is currently no way to capture this information using the Harmonized Commodity Description and Coding System (the World Customs Organization's international customs coding system), it is not possible to monitor individual species in trade across countries (Gerson, 2012), and the lack of trade and biological information precludes an accurate assessment of whether current trade levels are sustainable (Schlaepfer *et al*., 2005). Furthermore, taxonomic issues compound this matter further as there are cryptic species that could easily be assigned to a nominal species and go undetected even in countries that do keep such species records. Therefore, it is very likely that current CITES listings underrepresent the number of amphibian species in international trade.

2.4 EMERGING INFECTIOUS DISEASES

While many of the factors implicated in the declines (habitat change, overexploitation, invasive species, pesticides, environmental toxins and climate change) may act in synergy, amphibian biologists and conservationists were looking for the 'smoking gun' – a common causal factor for the extremely rapid amphibian declines and mass mortalities in multiple parts of the world. The DAPTF played an important role in identifying what first appeared to be the 'smoking gun', by establishing a subcommittee of scientists to focus on disease and pathology, the PWG (Pathology Working Group). The PWG connected the researchers involved with monitoring amphibian mass mortality incidents and helped arrange a week-long meeting at the University of Illinois for all the scientists concerned. At the meeting it was concluded that the organism implicated with the mass mortalities was the same in Australia and Central America and that it belonged to an ancient group of fungi, the Chytridiales. This organism belonged to an undescribed genus that had previously not been known to affect vertebrates. Berger *et al*. (1998) identified the pathogen and Longcore *et al*. (1999) described the species as *Batrachochytrium dendrobatidis*, the amphibian chytrid fungus, hereafter referred to as *Bd*. When the potential problem associated with the 'new' chytrid disease was identified, it was predicted to be "one of the most challenging threats to herpetological conservation in particular and wildlife conservation in general" (Cunningham, 1998). Fifteen years later, *Bd* is still considered to be one of the most severe threats faced by any vertebrate group (Fisher *et al*., 2012; Woodhams *et al*., 2011).

4 www.cites.org

Increasing evidence suggests that *Bd* may act as an epidemic disease and has been associated with numerous amphibian population declines around the globe (e.g. Lips, 1998; 1999; Ron & Merino-Viteri, 2000; Rollins-Smith *et al*., 2002a; 2002b; Lips *et al*., 2003; 2005; Burrowes *et al*., 2004; Bell *et al*., 2004; Lips *et al*., 2006; Skerratt *et al*., 2007; Crawford *et al*., 2010; but see Di Rosa *et al*., 2007). An unprecedented number of fungal diseases has recently been documented to cause severe declines in animals and plants and is beginning to be recognised as one of the most severe risks to biodiversity in general (Fisher *et al*., 2012). The biology of *Bd* is well suited to position this disease as a very serious threat to amphibians. The fungus has been demonstrated to hybridise into a hyper-virulent strain (*Bd*GPL, Farrer *et al*., 2011), it is easily spread around the globe by human activity and it is able to persist in the environment on non-susceptible species (and possibly even waterfowl; Garmyn *et al*., 2012), giving it the most potential, to cause dramatic amphibian extinctions.

2.5 PESTICIDES AND ENVIRONMENTAL TOXINS

Pollution with pesticides and environmental toxins is the second most significant threat to amphibians with nearly a fifth of all species affected and 29% of Threatened species affected (Chanson *et al.,* 2008). Amphibians have a uniquely permeable skin compared to other vertebrates and most species cannot easily control the movement of water across their external surface, making them particularly sensitive to any changes in water quality. Lethal, direct, sub-lethal and indirect effects have been reported for many environmental pollutants, such as heavy metals like mercury (Bergeron *et al*., 2010), pesticides (see review by Boone & Bridges, 2003; Groner & Relyea, 2011), herbicides such as Roundup® (Rohr & Crumrine, 2005; Jones *et al*., 2010; Relyea, 2011), fertilisers (see review by Rouse *et al*., 1999; Hatch *et al*., 2001) and endocrine disruptors (see review by Norris, 2011, and the many papers on atrazine, e.g. Hayes *et al*., 2012). In addition, predator-induced stress has been demonstrated to turn otherwise nonlethal levels of pesticide exposure into lethality for some species of amphibian larvae (Relyea & Mills, 2001; Relyea, 2003; 2004). The subtle and synergistic effects of many of these contaminants can be very difficult to determine.

2.6 GLOBAL CLIMATE CHANGE (INCLUDING UV RADIATION)

It is well recognised that the altered global climate of the 21st century will present new and challenging threats for amphibians on many fronts. In response to changes in average temperatures and rainfall patterns, amphibians have already been reported to have altered their breeding phenology by shifting the timing of their breeding behaviour (Blaustein *et al*., 2003; Phillimore *et al.*, 2010). This has severe implications for the survival of their larvae due to snowmelt or desiccation. As highlighted in the previous section, amphibians have a sensitive permeable skin and are therefore very susceptible to changes in the amount and timing of rainfall and increasing dry periods. Furthermore, climate change has been documented to cause amphibian populations to expand their range to higher elevations, bringing species (and accompanying pathogens) into new habitats, with new competitive interactions (Raxworthy *et al*., 2008).

Coastal wetlands around the world are considered prime habitat for many species of amphibians and rising sea levels will inundate a lot of these wetlands thereby making them unsuitable to sustain amphibian populations. In addition, the increase in UV-B radiation caused by the decreasing levels of ozone in the atmosphere has been shown to be particularly damaging to amphibians in general and their eggs (Blaustein *et al*., 1994) and larvae in particular (reviewed in Blaustein *et al*., 1998; Blaustein & Belden, 2003). However, recent studies imply that UV-B radiation may not be a significant contributor to global amphibian declines (Vredenburg *et al*., 2010). Although many of these issues may seem insurmountable, Shoo *et al.* (2011) identified management actions from across the globe to help ameliorate the effects of global climate change on amphibian populations.

2.7 SYNERGISTIC EFFECTS

While all the factors listed above may play an independent role in amphibian declines and extinctions it has been reported that many may interact synergistically (e.g. Hof *et al*., 2011). For example, earlier studies found that habitat modification (Adams, 2000), chemical contaminants (Relyea & Mills, 2001), UV-B radiation (Kats *et al*., 2000), and disease (Kiesecker *et al*., 2001) work synergistically to exacerbate the negative effects of introduced species on native amphibians. Furthermore, pollution in the form of excess nitrogen and phosphorous has been shown to increase the number of snail intermediate hosts of a trematode parasite, thereby increasing the incidence of these parasites in their amphibian definitive host (Johnson & Chase, 2004; for a full review see Lannoo, 2008). As a further example of the extent of synergistic effects, a link has been made between El Niño Southern Oscillation (ENSO) events, causing decreased rainfall and therefore lower pond levels and shallower water for breeding, exposing amphibian embryos to greater amounts of UV-B radiation which may result in increased mortality due to an increase in fungal attack from a saprophytic fungus (Kiesecker *et al*., 2001; but see Vredenburg *et al*., 2010 for clarification on the role of UV-B radiation). There has been considerable debate on the synergistic effects of global climate change on disease (Pounds *et al*., 2006, Alford *et al*., 2007) and although climate change will obviously play an important role, more evidence is required to confirm a causal link (Rohr *et al*., 2008).

The causes of amphibian declines and extinctions are complex and multifactorial and differ between species and localities. Addressing these issues is undoubtedly one of the most challenging conservation problems of our times.

3. WHAT GLOBAL ACTIONS HAVE BEEN TAKEN TO STOP THE CRISIS?

3.1 THE EARLY RESPONSE

After the anecdotal reports of declining amphibian populations the scientific community responded rapidly with the formation of the DAPTF. One of the earlier problems with identifying amphibian declines was the lack of a consistent monitoring system, and the first output from the DAPTF was the publication of a standard amphibian monitoring handbook (Heyer *et al.*, 1994). This led to a network of DAPTF groups monitoring amphibians around the world in an easily comparative way and disseminating their results through the newsletter *FrogLog*. The DAPTF acted as the nerve centre for the worldwide effort and assisted in organising amphibian declines symposia (3rd World Congress of Herpetology in Prague, 1997), workshops (with NSF in 1998) and producing resolutions (Heyer & Murphy, 2005). Six working groups were formed under DAPTF to look at specific issues and procedures (Climatic and Atmospheric Working Group, Chemical Contaminants Working Group, Disease and Pathology Working Group, two Interdisciplinary Working Groups, and Monitoring Protocols Working Group) and a volunteer network was established of 108 regional and sub-regional Working Groups in 90 different countries. During the period 1990 – 2005 (the term of DAPTF), despite the lack of sufficient funding, extensive and focused research was conducted resulting in more than 750 papers published on amphibian declines and conservation (Ohmer & Bishop, 2011). Furthermore, several texts on amphibian declines were also published (e.g. Green, 1997; Lannoo, 1998; 2005; Linder *et al.*, 2003; Semlitsch, 2003) and many of these identified ways to address the continuing issue of declining amphibian populations.

In summary, despite substantial contributions from hundreds of biologists all over the world, amphibian species continued to decline, some to extinction.

3.2 THE POST-GAA RESPONSE

After the alarming GAA results were published concerted efforts were made to develop global-level initiatives to further address the amphibian extinction crisis.

3.2.1 THE AMPHIBIAN CONSERVATION SUMMIT

The Summit was called because it was deemed to be "morally irresponsible to document amphibian declines and extinctions without also designing and promoting a response to this global crisis" (Gascon *et al.*, 2007, p.4). It was convened by the IUCN SSC and Conservation International in September 2005 in Washington and involved 78 amphibian specialists from around the globe. The overall goal of the Summit was to produce a comprehensive plan to respond to the on-going declines and extinctions of amphibian species by developing targeted actions to counter the different threats identified. In addition to novel threats such as emerging infectious diseases, pesticides and environmental toxins and global climate change, delegates also addressed the usual suspects such as habitat change, over-exploitation/utilisation and alien invasive species. The delegates acknowledged a poor understanding of the complex relationships among all the potential causal factors. A subset of the delegates also wrote white papers for each theme covered that formed the backbone of a comprehensive Amphibian Conservation Action Plan (ACAP) (Gascon *et al.*, 2007). In addition to producing the ACAP, the Summit recatalysed the constitution of the IUCN SSC Amphibian Specialist Group and, following a meeting in 2006 in Panama of the IUCN SSC Conservation Breeding Specialist Group and the World Association of Zoos and Aquaria, gave rise to the Amphibian Ark (AArk).

3.2.2 THE AMPHIBIAN CONSERVATION ACTION PLAN

The ACAP established the strategic elements of an initiative needed to address the global decline of amphibians, including a five-year budget. As the situation is constantly changing it was by necessity a 'living' document, reflecting the dynamic nature of amphibian declines and extinctions. In this form the ACAP could respond to new findings and evolve to keep up to date with current knowledge. As no single answer will prevent further losses of amphibian species, an interdisciplinary approach was used in the ACAP to design a response that was suited to the scale of the problem. The ACAP outlined priority action steps for amphibian conservation within eleven thematic areas: (1) identifying, prioritising and safe-guarding Key Biodiversity Areas; (2) freshwater resources and associated terrestrial landscapes; (3) climate change, biodiversity loss and amphibian declines; (4) emerging infectious diseases; (5) over-harvesting; (6) mitigating impacts of environmental contamination on amphibian population; (7) captive programmes; (8) reintroductions; (9) the continuing need for assessments: making the GAA an ongoing process; (10) systematics and conservation; (11) bioresource banking efforts in support of amphibian conservation.

3.2.3 THE IUCN SSC AMPHIBIAN SPECIALIST GROUP

At the Amphibian Conservation Summit in 2005 it was decided to merge the Global Amphibian Specialist Group (GASG), the DAPTF and the GAA into one entity committed to implementing a global strategy for amphibian conservation: the Amphibian Specialist Group (ASG). The ASG was established to ensure long-term sustainability of amphibian research and conservation by building on DAPTF's worldwide network of expert working groups and integrating them into the IUCN's global network of Specialist Groups. The ASG is recognised as a formal specialist group within the IUCN SSC, and as such houses the Amphibian Red List Authority, which has taken over stewardship of other amphibian assessment processes from the GAA coordinating team. The ASG supports development and dissemination of new tools and best practices for adoption and application by a network of local, national, and regional working groups. The ASG has been able to implement a range of conservation initiatives focused around habitat protection in partnership with local and international organisations.

During the last six years the ASG's direct conservation efforts have included:

- Supporting the creation of 14 new protected areas for amphibians in Latin America, Africa and Asia and the development of new community conservation areas.
- Protecting over 22,000 hectares of critical amphibian habitat, home to over 55 threatened or endemic species.
- Supporting dozens of species-oriented research projects in Africa, Asia, Latin America and North America through annual Seed Grant programs.

Capacity building, education and outreach are all integral parts of the ASG's approach to amphibian conservation. This is shown through a range of programs including:

- A partnership in Sulawesi with the Alliance for Tompotika Conservation, where local communities and children have been actively engaged in an educational campaign celebrating biodiversity.
- A training course for promising herpetology students in Colombia run in partnership with local NGO Fundación ProAves and Global Wildlife Conservation.
- A training course in Haiti run in partnership with Panos Caribbean to teach and train young journalists aged 12-18 in biodiversity conservation, amphibian protection, and conservation communication.
- Supporting the creation and implementation of 12 National and Regional Action Plans.
- Spearheading an initiative – the Search for Lost Frogs – that has supported 126 researchers to undertake expeditions in 21 countries resulting in 15 species rediscoveries to date. The Search for Lost Frogs generated over 700 news articles in 21 countries, bringing a message about the importance of amphibians to a broad audience.

3.2.4 THE AMPHIBIAN ARK

Ex situ conservation refers to "off-site" conservation and is usually conducted in the form of captive breeding programmes in zoological institutions. The AArk was formed in 2006 after the Amphibian Conservation Summit to specifically address the *ex situ* conservation components of the ACAP. The speed at which some species were disappearing, and the lack of a full understanding on how to abate some of the most acute threats that amphibians face, particularly those affected by Bd, meant that the only way to ensure the survival of some species was by buying time through captive breeding programmes. AArk began Conservation Needs Assessment Workshops in 2006 and has now evaluated 42% of the world's amphibian species for their conservation needs in 25 workshops across the globe[5]. AArk analyses suggest that over 360 species require captive breeding assistance, which when extrapolated to all Threatened and Data-Deficient species would result in about 950 species requiring captive populations. Unfortunately, the estimated global capacity for managing viable captive populations at the present time is only about 50 species. The AArk (and its partners) has also delivered 52 Ex Situ Conservation Training courses in 30 countries, and has trained over 1,725 students in amphibian biology, husbandry and conservation practices.

AArk has been particularly active in two campaigns, "2008 Year of the Frog" and "Frog Match Maker". "2008 Year of the Frog" involved many hundreds of zoos, aquaria, museums, universities, schools and other organisations. The main goal of the campaign was to generate public awareness and understanding of the amphibian extinction crisis and to ensure sustainability of survival assurance populations by creating funding for this conservation work. The money raised from the global campaign also helped to fund AArk's international coordination activities and regional initiatives such as assessment and husbandry workshops and coordination of activities within each region. While the campaign was successful in raising awareness and funds, one of the drawbacks of such a concentrated and focussed campaign seems to be that once the campaign has finished the general public assumes the problems have been solved. "Frog Match Maker" is attempting to find partners to fund 51 different amphibian conservation projects in 26 countries.

3.2.5 AMPHIBIAN CONSERVATION MINI-SUMMIT AND THE AMPHIBIAN SURVIVAL ALLIANCE

Although there have been some important gains since the Summit it became evident that little progress had been made in relation to the huge scale of the crisis. In 2006 many of the Summit participants issued a call to form an Amphibian Survival Alliance (ASA) to undertake full implementation of the ACAP (Mendelson *et al.*, 2006). Therefore, Simon Stuart, as new SSC Chair, convened an Amphibian Mini-Summit in 2009 in London at which various parties committed to form the Amphibian Survival Alliance to combat amphibian declines and extinctions at a higher level than ever before. The participants also prioritised attention to two actions in the ACAP: stopping extinctions of species threatened by land use change or commercial use; and stopping the spread and reversing the impact of the amphibian chytrid fungus. In addition to these two priorities, the ASA also embraced expanding *ex situ* rescue operations as a priority issue to secure the persistence of amphibian species. The ASA is now operational, with two staff, and a secretariat provided for the time being by the European Association of Zoos and Aquaria (EAZA). However, it now needs to bring more organisations and institutions into the Alliance, and more importantly, become instrumental in making resources and funds available to galvanise amphibian conservation. Most conservation organisations are still not addressing this crisis, although the class Amphibia represents by far

5 A detailed five-year AArk report is available for download at: www.amphibianark.org/AArk-5-year-report.pdf.

the most dramatic example of vertebrate extinctions taking place in our time (Wake & Vredenburg, 2008).

4. FUTURE PERSPECTIVES

Although a framework was set-up in the past to allow passive networking between individuals working on amphibian declines, there was no motivating driver that stimulated coordination and networking. The ASA was established to provide a powerful driving force to ensure efficient and effective coordination and collaboration between the main themes of amphibian conservation. The ASA will put in place a global strategy that will implicitly connect with other communities, scientific or otherwise, outside of amphibian specialists. Towards this goal, the ASA will turn the ACAP into a virtual, web-based, 'living' document. As described above, the ACAP is divided into eleven themes and these have been expanded and remodeled into *action statements* by the ASA to form 15 Action Working Groups (AWGs). The ASA will recruit members for each AWG (some of whom are likely to be external specialists, e.g. epidemiologists, climate change researchers, molecular biologists, etc.) and the members will select a chair (or co-chairs) to coordinate the group. As the AWGs become populated with members, the ASA will facilitate and stimulate productive interactions between the different AWGs. In addition, where necessary (e.g. captive breeding, disease mitigation and research), regional centres for the working groups will be established, with coordination and support through ASA, as conservation activities such as these should remain in affected countries whenever possible. To support the AWGs and many of the new amphibian conservation initiatives, the ASA is engaging with the business sector and will shortly be releasing an amphibian conservation business plan.

Amphibian conservation has thus far been, naturally, very much focused around the amphibians themselves, and the experts, aware of the magnitude of the crisis, have made huge efforts to try to revert it. However, in spite of some attempts to create awareness, a large audience is still unaware of the amphibian crisis and its implications, and even some large organisations dedicated to biodiversity conservation have not embraced the amphibian cause. If we keep trying to save amphibians in isolation it will continue to be an uphill struggle, so it is very important to capitalise on the fact that amphibian conservation touches on many aspects of environmental conservation, and therefore provides numerous opportunities to unite efforts across sectors. By our own count, amphibian conservation can contribute to 15 of the 20 targets of the revised and updated Strategic Plan for Biodiversity 2011- 2020 (Aichi Biodiversity Targets), that the Convention on Biological Diversity (CBD) subscribed countries agreed upon (CBD, 2012).

Safeguarding the terrestrial and freshwater habitats that amphibians use is the cornerstone of amphibian conservation strategies: without this, all other conservation efforts are futile. Habitat destruction and degradation has a negative effect on two out of every three amphibian species across the world. It also has a negative effect on many other types of animals and plants, and this immediately provides an opportunity to reach out beyond the amphibian community – a quick look at the sites identified by the Alliance for Zero Extinction highlights that in many cases, sites of conservation importance for amphibians are also important for many other different types of plants and animals. Organisations that are involved with the conservation of other taxonomic groups with significantly more access to resources, either because of the charismatic species involved or because of the utilitarian nature of the taxonomic group (e.g. game and hunting, see Lannoo, 2012), have been natural allies in the conservation of specific sites, and therefore, the amphibians in those sites. Partnerships with such organisations have the potential to scale up habitat protection for amphibians to a truly global scale by integrating amphibians into conservation planning and implementation. In this regard the ASG has had some success working with bird-oriented conservation organisations in its efforts to set aside habitat that is important for amphibians (e.g. American Bird Conservancy or Fundación Pro Aves). Similar efforts should be explored with other groups that have more resonance with people. Over 400 Threatened amphibian species are still entirely unprotected throughout their geographic ranges (Rodrígues *et al.*, 2004), and many of these live at a single site, making their risk of extinction especially high – but also offering the opportunity to complement existing protected area networks with small reserves, which in turn could improve the habitat connectivity among protected areas or serve as stepping stones for habitat restoration. This is something that also requires us to bear in mind the potential effects of climate change and to develop ties with those institutions and organisations working on the topic to ensure that amphibians are also considered in their efforts and benefit from their initiatives.

Since amphibians are dependent upon both suitable terrestrial and freshwater habitats to survive, they provide us with an opportunity for cost-effective conservation that integrates these two realms. Amphibian distributional data can be used to identify watersheds that are biologically connected, and also to connect the conservation management unit (reserves) with the water management units (river basins). The water sector is an important constituency with which to build synergies, as water management and provision is one of the key issues that everybody agrees is essential both for a healthy environment and opportunities for development. Stronger bonds with the Inland Waters program of the CBD and the Ramsar Convention on Wetlands are not only possible, but desirable. In addition, it would be important to work with the Conventions to ensure that they emphasise the role of amphibians as indicators of the health of wetlands, much more than they have done until now.

Amphibian populations are influenced by numerous factors both in terrestrial and in freshwater habitats (Wells, 2007). As stated above, their specific biological needs force us to integrate the management of these two realms. It is well documented that pollution in the form of chemical contaminants, including substances that are used in agriculture, is partially responsible for the decline of many amphibian populations (Chanson *et al*., 2008). As food production intensifies, not only will the water demand for agriculture rise in many parts of the world, but so will the amount of chemicals used. In addition, water will also be in high demand for energy production, and it will be very important that against these demands we all ensure that the water supply to the environment is sufficient to keep ecosystems functioning and providing vital environmental services. It is in this regard that amphibians can be used as a general indicator of the state of biodiversity. There are already reports of amphibian declines due to lack of access to water (McMenamin *et al*., 2008), and based on our current knowledge of amphibian biology we can forecast declines of populations in areas where pesticides and fertilisers are overused (and conversely, we can expect healthier amphibian communities where the use of these substances is limited and better regulated). Setting monitoring programs that allow us to compare the population and richness trends of amphibians in intact forests with those near commodity production plots could provide an early warning system for the potential effects of such chemical substances on other living beings and to guide policy to regulate these substances.

There are, of course, some aspects that will need to be dealt with mostly within the amphibian expert community, but even here there is room for more collaboration. While the chytridiomycosis epidemic has opened a whole new field of research – the fungus is interesting in itself, being the only known species within a large group of fungi that interacts with vertebrates – it is important to focus the research towards practical recommendations that help to manage the disease (Woodhams *et al*., 2011) and to pursue greater understanding of how the spread of the pathogen can be stopped. Prophylactic or remedial treatments of the disease and protocols for reintroduction of captive bred individuals into their natural environment are among the top priorities; there have been several reports of individuals of some species in captivity and in the wild healing or tolerating the infection (e.g. Bishop *et al*., 2009; Shaw *et al*., 2010; and see Woodhams *et al*., 2011 for more detail). This requires a thorough integration of captive breeding efforts with *in situ* conservation in order to undertake field trials that allow us to explore systematically different ideas to mitigate, if not cure, the disease, and to follow recommendations for reintroduction. This in turn relies on additional local capacity building so that captive breeding efforts can take place as close as possible to the original ranges of the species being bred. Even here there is room to collaborate with sectors beyond the amphibian community. For example, emerging infectious diseases caused by fungi are now recognised as a threat to food security and, after the emergence of the chytrid fungus on amphibians and the white-nose fungal syndrome in bats, fungal diseases are now seen as a general global threat to animal health and thus have a substantial negative impact on biodiversity (Fisher *et al*., 2012). Chytridiomycosis has been put forward as a model disease to understand the spread and persistence of other fungal pathogens in particular, and of emerging infectious wildlife diseases in general (e.g. Rachowicz *et al*., 2005; Briggs *et al*., 2010; Heitman, 2011).

The ASA is in the planning stages of a Global Amphibian Chytrid Summit. Although a smaller symposium on the amphibian chytrid fungus was organized by Partners in Amphibian and Reptile Conservation (PARC) and US Fish and Wildlife Service in 2007, it focused mainly on the USA, and perhaps occurred too early in the piece to determine how to "turn science into action". We have learned an enormous amount about the disease since then, and major advances in the science (particularly following recent field trials, e.g. the Kihansi Spray toad reintroduction) will provide us with the knowledge to devise a global approach. Besides presenting a 'state of the nation' report on how this disease may be impacting amphibians directly and indirectly, the summit would provide the forum for researchers to share unpublished data and specifically advise stakeholders (e.g. land-managers and conservation practitioners) how to tackle the threat of chytrids to wild amphibian populations – translating the science into action on the ground.

5. CONCLUDING REMARKS

It is essential that we engage more with communities beyond the amphibian research and conservation community in order to ensure that amphibians become embedded in broader conservation efforts. Amphibian conservation has been underfunded for many years – this is probably the most conspicuous factor responsible for the limited progress to stop the crisis so far. Amphibians in the US receive only one quarter of the Endangered Species Act (ESA) funding that other vertebrate classes do. Over 80% of the amphibians considered at risk remain unlisted under the ESA (Gratwicke *et al*., 2012), and it is very likely that a similar scenario occurs in many other countries. Conservation resources are scarce and "amphibian" does not seem to be a keyword that appeals to donors supporting environmental conservation. The huge diversity of amphibians and their ecological requirements, however, justify that amphibian conservationists should be actively engaged with many communities concerned about biodiversity, freshwater resources, forests and certification, pharmaceuticals and bio-mimicry, protected area management, epidemiologists and mycologists, veterinarians, reforestation, REDD+, climate change, ecosystem services and sustainability, toxicology and agriculture, etc.. We need to keep educating others on the role of amphibians as barometers of ecosystem health, and to insert amphibians as a necessary component of broader environmental issues. And we need to keep binding the amphibian conservation community together to be able to present a united and coherent front to all of these audiences, which may facilitate dialogue and access to resources.

The success of the ASA initiatives will depend upon a paradigm shift in the scale of the responses and an unprecedented level of collaboration and coordination from stakeholders from many different sectors. If the scale of our response remains the same as it has been over the last 20 years, then we will witness the amphibian crisis turning into "the amphibian catastrophe" (Stuart, 2012).

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