Making amphibian conservation more effective

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SUMMARY

Amphibians face an extinction crisis. Hundreds of species may be lost as conservation scientists and practitioners struggle to identify remedies to poorly understood declines spanning several decades. Due to various life history characteristics and a range of drivers, amphibians continue to be especially hard-hit, more so than any other vertebrate group. In this special issue of *Conservation Evidence*, studies that report the effectiveness of amphibian conservation interventions are presented to add to the rapidly growing body of literature on this topic. We here summarise the current understanding of global amphibian declines to highlight the importance of applying evidence-based strategies to amphibian conservation.

Amphibian declines

Declines have affected an estimated 43% of amphibian species (Stuart *et al.* 2004) and have been accelerating globally for several decades (Blaustein & Wake 1990, Houlahan *et al.* 2000, Mendelson *et al.* 2006). Amphibians are particularly vulnerable due to the narrow habitat preferences and small distributions of many species (Wake & Vredenburg 2008). Thirty percent of species are currently known to be threatened with extinction (assessed as Critically Endangered, Endangered, or Vulnerable; IUCN 2014). This could rise to over 40% if Data Deficient species are threatened in the same proportion as data sufficient species (Hoffmann *et al.* 2010), and higher still given that Data Deficient species are more likely to be threatened than those that are data sufficient (Bland *et al.* 2014). Additionally, around 3,500 amphibian species remain to be described (Giam *et al.* 2012), more than tripling the pool of species of unknown extinction risk. Amphibians are thought to be the most imperilled vertebrates (Hoffmann *et al.* 2010). The current amphibian extinction rate has been estimated to exceed the background rate by least four orders of magnitude (McCallum 2007, Alroy 2015). Counteracting amphibian declines presents monumental challenges to conservation scientists and practitioners around the world (Catenazzi 2015).

Why are amphibians declining?

Amphibian declines have been attributed to a range of threats. Furthermore, synergies between multiple drivers of extinction are predicted to accelerate the rate of these declines in the future (Sodhi *et al.* 2008, Hof *et al.* 2011). Key stressors include:

- *Habitat destruction and fragmentation.* Regions of the Earth supporting the richest assemblages of amphibians are currently undergoing the highest rates of landscape modification (Gallant *et al.* 2007), making habitat destruction the leading cause of declines (Gardner *et al.* 2007). Many species depend on more than one terrestrial habitat and migrate to aquatic habitats for seasonal breeding, so changes compromising any of these habitats can disrupt a species' life cycle (Bishop *et al.* 2012).
- *Pollution.* The sensitivity of many amphibian species to environmental toxins may in part be attributed to their permeable skin and frequent reliance on aquatic systems (Bishop *et al.* 2012). Amphibians are affected by a range of chemical contaminants, including heavy metals (Bergeron *et al.* 2010), fungicides (McMahon *et al.* 2012), herbicides (Hayes *et al.* 2002), insecticides (Rohr & Crumrine 2005) and fertilisers (Rouse *et al.* 1999). However, little is known about the impact of most common chemical pollutants on amphibians, and this remains a poorly understood threat (Boone *et al.* 2007).
- *Invasive and other problematic species, including disease.* Invasive species, such as introduced predatory fish, can have severe repercussions for aquatic communities (Adams 1999). The impact of disease has been of burgeoning concern since it was conclusively linked to many unexplained declines (Daszak *et al.* 1999, 2000). Ranaviruses cause mass mortality in multiple amphibian hosts (Gray *et al.* 2009), and the pathogenic fungi *Batrachochytrium dendrobatidis* and *B. salamandrivorans* can induce chytridiomycosis in susceptible species. This disease has been implicated in the declines of over 200 frog, toad and salamander species since the 1990s (Lips *et al.* 2006, Fisher *et al.* 2009b, Kilpatrick *et al.* 2010, Martel *et al.* 2013), as well as several species extinctions (e.g. Schloegel *et al.* 2006, Vredenburg *et al.* 2010).
- *Climate change.* Amphibians are likely to be especially sensitive to continuing climate change (Araújo *et al.* 2006, Lawler *et al.* 2010). Many species possess physiological constraints to persistence in warmer and drier climate regimes (Blaustein *et al.* 1994). Freshwater ecosystems constitute a key component of most amphibian habitats, and are among the ecological systems most at risk (IPCC 2007). Dry, open areas created by droughts can present barriers to migration, further fragmenting amphibian habitat (Dodd & Smith 2003). Climate change may also worsen the impact of disease (Pounds *et al.* 2006, Bosch *et al.* 2007, Rohr *et al.* 2008) and environmental contamination (Blaustein *et al.* 2010).
- *Exploitation.* Hundreds of amphibian species are harvested for subsistence and national/international trade for food, traditional medicines, and the international pet trade (Carpenter *et al.* 2007, Rowley *et al.* 2010). Amphibian farming can exacerbate disease risks to wild populations through untreated effluent water (e.g. Cunningham *et al.* 2015).

Global responses to amphibian declines

Growing concern over the extent and severity of global amphibian declines prompted the International Union for

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Conservation of Nature (IUCN) Global Amphibian Assessment (GAA), which gathered data on all 6,000 described amphibian species relating to distribution, abundance, population trends, habitat associations, threats, and conservation actions, and classified species by extinction risk (Stuart *et al.* 2004). The GAA was followed up in 2005 by the International Amphibian Conservation Summit (Moore & Church 2008). This led to the establishment of the IUCN Species Survival Commission Amphibian Specialist Group, and publication of the Amphibian Conservation Action Plan (ACAP) (Gascon *et al.* 2007), which has recently been updated (ASG 2015). Given the magnitude of threats that could not be mitigated in the short-term, the ACAP recommended the establishment of captive assurance colonies for species most at risk (Mendelson *et al.* 2007). The Amphibian Ark was formed in 2006 to unite the *ex situ* conservation community and implement the captive programme components of the ACAP. ACAP also laid the foundations for an umbrella organisation, the Amphibian Survival Alliance (ASA), which was established in 2011 to coordinate and facilitate global amphibian conservation programmes, whilst garnering and administering necessary funds (Mendelson *et al.* 2006). Together these initiatives offer a framework and support network for coordinated global amphibian conservation.

Why are amphibians important?

The value of amphibians to humans is not widely perceived, despite presenting many compelling reasons for their conservation:

- *Human medicine.* Amphibian skin secretions contain novel analgesic, wound-healing, and antimicrobial properties (active against bacteria, viruses, protozoa and fungi), and substances that may treat cancerous tumours, arrhythmia, diabetes, and immunosuppression (Gomes *et al.* 2007). Additionally, amphibians are used as model organisms in laboratory research, with prominent roles in our understanding of the physiology of musculoskeletal, cardiovascular, renal, respiratory, endocrine, reproductive, and sensory systems, including work that has resulted in several Nobel prizes (Burggren & Warburton 2007).
- *Ecosystem services.* Amphibians have diverse and significant roles in ecosystem services, from soil bioturbation and nutrient cycling to pest control and ecosystem engineering (Hocking & Babbitt 2014). Evidence suggests that the loss of amphibians from stream ecosystems can alter primary production, algal community structure, faunal food chains (from aquatic insects up to riparian predators), and reduce energy transfers between aquatic and terrestrial systems (Whiles *et al.* 2006).
- *Indicator species.* Amphibians have frequently been cited as effective "bioindicators" of global environmental change due to their permeable skin, potentially high rates of contaminant bioaccumulation, climate-sensitive breeding cycles, and the fact that many species are reliant upon both terrestrial and aquatic habitats during their life cycle (Dunson *et al.* 1992, Hopkins 2007). However, the reliability of amphibians as definitive bioindicators remains under investigation, and carefully chosen species are probably best employed as part of a context-dependent suite of indicators (Sewell & Griffiths 2009, Kerby *et al.* 2010).
- *Human nutrition***.** As a food source, the global consumption of amphibians is widespread, with thousands of tonnes of frogs being traded internationally each year (Warkentin *et al.* 2009). France and the USA currently import the largest amount of frogs, from Asia (mostly Indonesia) and South America (Ecuador and Brazil) respectively (Warkentin *et al.* 2009).
- *Culture.* Amphibians have played rich and varied roles in culture, from ancient folklore to the modern day (Lazarus & Attila 1993, Hocking & Babbitt 2014). Our world would be a lesser place without them.

The role of conservation evidence

Conservation actions must become more effective if we are to arrest and reverse species declines. Conservation biology can walk a fine line between maintaining scientific objectivity (Lackey 2007) and more value-led approaches that permit advocacy (Chan 2008) and benefit practical conservation decision-making (Barry & Oelschlaeger 1996). Evidence-based conservation science can achieve a balance between objectivity and relevance to real world conservation management. A unifying element of conservation practice is intervening with the goal of preserving the content and/or functionality of the natural world without undesirable negative consequences (Fisher *et al.* 2009a). Evidence-based conservation research can determine the effectiveness of specific interventions at achieving stated objectives (Pullin & Knight 2001, Sutherland *et al.* 2004, 2012). The premise of evidence-based conservation is to increase understanding of the consequences of interventions to inform future decision-making via the synthesis of varied information sources (Haddaway & Pullin 2013). Ongoing aggregation and dissemination of such evidence has potential to enhance knowledge exchange and establish a scientific basis for conservation action (Pullin & Knight 2001, Sutherland *et al.* 2004). In the absence of an evidence-based approach to conservation practice, the natural world is subjected to well-meaning but potentially damaging experiments that are impossible to replicate and cannot appropriately inform future action (Pullin & Knight 2009, Haddaway & Pullin 2013).

The Conservation Evidence initiative at the University of Cambridge launched in 2004 with the aim of determining the effectiveness of global conservation interventions, and providing an open access journal for the publication of such studies (Sutherland *et al.* 2012). A synopsis of conservation evidence for amphibians was published in 2014, which includes 417 studies that provide evidence for one or more interventions, and is the first attempt to gather global evidence studies for this taxon (Smith & Sutherland 2014). Evidence has so far been collated across 129 amphibian conservation interventions, permitting 98 of them to undergo an expert assessment of their effectiveness and side-effects (Smith *et al.* 2015).

This special issue is a timely contribution to boosting the amount of available conservation evidence for amphibians. The five studies across three continents that follow offer excellent case-studies, discussing a range of approaches to amphibian conservation, from captive rearing and reintroduction to invasive species control and legal site protection. López-Torres *et al.* (2015) document the relocation of 403 cave dwelling frogs (*Eleutherodactylus cooki*) in Puerto Rico to both natural and artificially constructed habitats. The beneficial role of captive facilities in supporting amphibian conservation is highlighted by Stiles *et al.* (2015), who report on a head-starting initiative for crawfish frogs (*Lithobates areolatus*) in the USA. This project reintroduced over 10,000 tadpoles during a three-year period, with survivorship to metamorphosis of captive-reared tadpoles vastly exceeding that of wild tadpoles. Two studies in this issue examine how active management of invasive or dominant species can successfully boost amphibian populations. Bruni *et al.* (2015) show that the exclusion of non-native crayfish from

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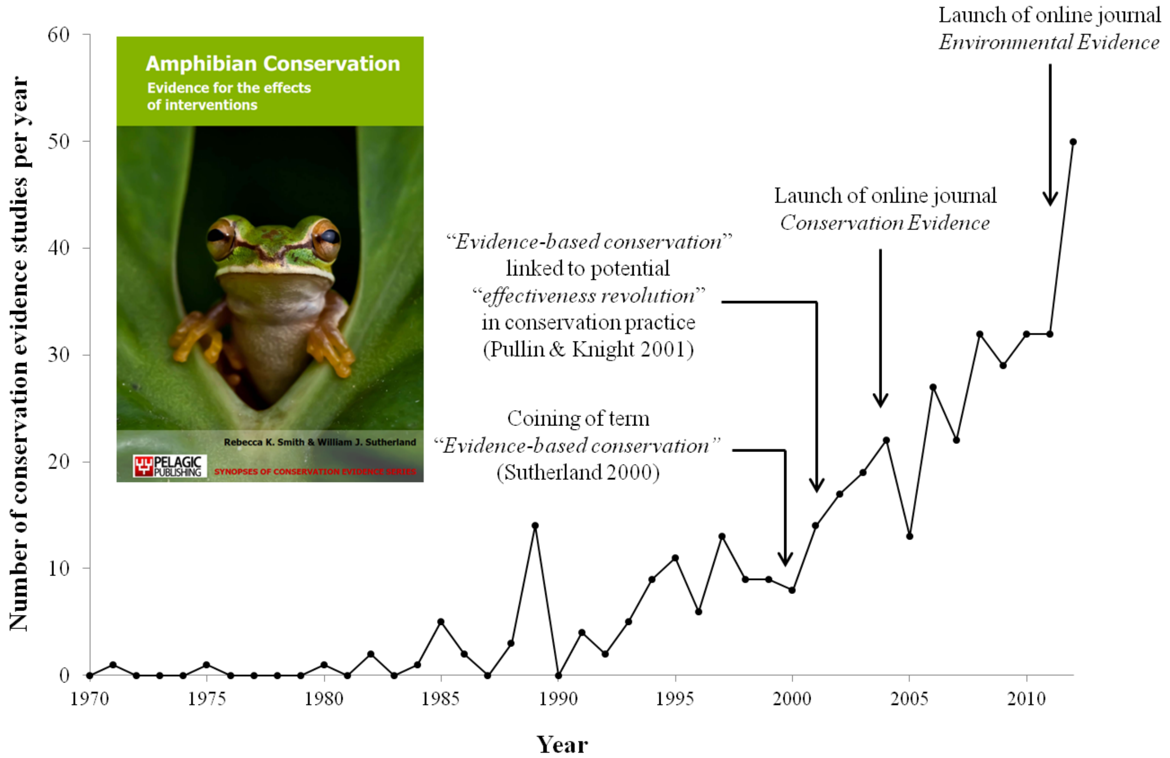

Figure 1. Annual rate of production of conservation evidence studies for amphibians collated in the Amphibian Synopsis: "*Amphibian Conservation: Evidence for the effects of interventions*" (Smith & Sutherland 2014).

newly constructed ponds in Italy allowed native amphibians, particularly newts, to thrive and reproduce. However, these amphibian communities collapsed following the introduction non-native crayfish and other invasive species. Similarly de Villiers *et al.* (2015) show that removal of African clawed frogs (*Xenopus laevis*) from ponds allowed endangered Cape platanna (*Xenopus gilli*) populations to increase. Interestingly, the role of protected areas in conserving amphibians is brought into question by Fog & Wederkinch (2015), who show that although protection of ponds may have delayed extinction of fire-bellied toad (*Bombina bombina*) populations in Denmark, ponds protected in isolation and with insufficient active management performed no better than those in unprotected areas. However ponds protected as part of a larger area did show improved persistence of *Bombina*. Together these five studies illustrate the varied and flexible approaches to amphibian conservation that are currently being conducted, informing attempts to mitgate declines around the world.

Conservation Evidence has received very few amphibian studies to date (Spooner *et al.* 2015), although the overall amount of amphibian evidence is increasing (Figure 1). We hope that the studies included here will inspire the production and dissemination of significantly more conservation evidence for amphibians. We urge you to share your experiences through research that tests the effectiveness of interventions in diverse contexts, including actions related to threat mitigation, species management, and human behaviour change through education and engagement. The strongest evidence comes from randomised, replicated, controlled trials with paired sites and before and after monitoring (Smith & Sutherland 2014).

We strongly encourage publications describing both successful and unsuccessful measures since all additional information can help inform future conservation efforts. Through working together, sharing experiences, learning from successes and failures, and embracing a culture of evidence-based practice, we can help amphibian conservation to flourish in the future.

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