Improving the Impact of Amphibian Conservation

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Abstract

Enhancing efforts to conserve amphibians will help ameliorate a sixth mass extinction event. In this thesis, I analyse current perceptions of success in amphibian conservation, and review the quantity and content of conservation-related scientific studies with a view to improving conservation impact. Achieving and measuring success is dependent on the way success is defined. Perceptions of success among practitioners and scientists were predominantly associated with improving the status of target species and habitats; specifically stabilising or increasing population trajectories. However, respondents with fewer years of experience view the human dimensions of conservation – such as public education, engagement, and capacity building – to be increasingly more important in defining success. This may have repercussions for interdisciplinary conservation action in the future. Secondly, the availability of relevant literature is crucial for science-based and accountable decision-making. Amphibian research is not meeting conservation needs, particularly in terms of threatened species, prevalent threats such as habitat loss and fragmentation, and studies relevant to conservation management. Improving the impact of conservation action requires the effectiveness of interventions to be tested in diverse contexts. Evidence is unrepresentative geographically, with just 10% of all studies conducted in the tropics, and there is also a deficiency for threatened species. Available evidence is unrelated to the number of amphibian conservation scientists per country. Threat mitigation studies for certain stressors (pollution, exploitation, climate change) is very limited or non-existent, and education and engagement initiatives are poorly represented, restricting understanding of the social dynamics of amphibian conservation. This limits what can currently be deduced about effective conservation practice. An expert assessment of global evidence found that over half of conservation interventions are ineffective and/or harmful, or effectiveness is unknown due to limited evidence. My findings indicate clear directions for future conservation-related research: social aspects of amphibian conservation require greater attention; research should be made more relevant to conservation objectives, focusing on neglected species, threats and approaches to conservation practice; developing increased global collaboration and capacity building is crucial to addressing knowledge gaps, as is generating the necessary funding opportunities; and a culture of evidence-based conservation should be promoted. Improving amphibian conservation impact will require a paradigm shift to enhance interdisciplinary action, increase innovation, and enable this cause to be understood and supported globally by conservation agencies, policy-makers, and funding bodies. This can be achieved through targeted and coordinated action from existing global networks in amphibian conservation science and practice.

Declaration

All the work presented in this thesis is my own, with the following acknowledgements. The IUCN Red List data used were freely available from the IUCN website (www.iucnredlist.org), and I also thank Ariadne Angulo and Janet Scott from the IUCN Red List Authority for providing requested data on amphibian extinction risk, diversity, threat, habitat and distribution for all species from Red List version 2014.2. In addition: David Bickford contributed amphibian life history data (from Sodhi et al. 2008); Tatsuya Amano contributed data on the proportion of English speakers per country (from Amano & Sutherland 2013); the Institute for Economics and Peace provided Global Peace Index data (GPI 2014); the Central Intelligence Agency World Factbook provided data on Gross Domestic Product, country area, and human population per country (CIA 2014); evolutionary distinctiveness data for amphibians was provided by Isaac et al. (2012) in collaboration with the EDGE of Existence programme at the Zoological Society of London; the IUCN SSC Amphibian Specialist Group shared their membership data (ASG 2014); and the Conservation Evidence team at Cambridge provided me with a copy of "*Amphibian conservation: Global evidence for the effects of interventions*" (hereafter "Amphibian Synopsis"; Smith & Sutherland 2014) prior to general publication. All sources are fully acknowledged in the text. The ideas presented in this thesis were formulated in consultation with my supervisors: Richard Griffiths, Ben Collen, and Freya St. John. Additional support and supervision for specific chapters was kindly provided by William Sutherland, Rebecca Smith, Tatsuya Amano and Lynn Dicks. Advice on creating recommendations based on the results of this thesis was provided by the IUCN SSC Amphibian Specialist Group Secretariat and the Amphibian Survival Alliance. All the statistical analyses and writing are my own, with invaluable inputs from my supervisors. Specifically, I acknowledge the following inputs:

Chapter 1: I wrote the chapter with supervision from Richard Griffiths and Ben Collen.

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Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

Biodiversity crisis

A sixth mass extinction event since the origin of life of Earth is potentially unfolding (Barnosky et al. 2011). Current species extinction rates exceed normal background rates by two to three orders of magnitude (Pimm et al. 1995). Mass extinctions are defined by a loss of over 75% of estimated species (Jablonski 1994), and a perfect storm of threat processes acting in synergy is pushing much of global biodiversity ever closer to this threshold (Barnosky et al. 2011). Even prior to extinction, population declines and changing species community structures can have severe impacts upon ecosystem function (Ceballos & Ehrlich 2002; Gaston & Fuller 2008). Since biodiversity produces and embodies countless ecosystem services on which we depend (Mace et al. 2012), ameliorating current high extinction rates is crucial to our own survival. However, the brewing biodiversity crisis is an inherent aspect of the Anthropocene, which describes the now central role of humans in shaping ecology and geology (Corlett 2015). The Anthropocene will be characterised by the widespread defaunation of global ecosystems unless action can be taken to alleviate ongoing species declines, but current knowledge gaps in conservation science drastically hinder our capacity to respond (Dirzo et al. 2014). We must resolve these knowledge gaps, and embrace more effective approaches to conserve biodiversity as a matter of urgency. Although global distributions of species richness may concord across taxa, spatial patterns of rare and threatened taxa do not necessarily align (Grenyer et al. 2006), necessitating the adoption of taxon-specific strategies to ensure effective biodiversity conservation. Also, extinction filters induced by human activity have a non-random spread of impact across groups of related species; a species' extinction risk is influenced by multiple, interacting aspects of its biology, geography, adaptation to historical anthropogenic pressures, and the independent and synergistic nature of external threats (Balmford 1996; Brook et al. 2008; Cardillo et al. 2008). At multiple taxonomic levels (e.g. Class, Order, Family, Genus), certain species are more susceptible to extinction than others (Russell et al. 1998; Isaac et al. 2007, 2012).

Amphibian declines

Amphibians have been highlighted as a particularly vulnerable vertebrate Class, due to the narrow habitat preferences and small distributions of many species (Wake & Vredenburg 2008). Regional amphibian declines have been reported since the 1950s, and have been accelerating globally for several decades (Houlahan et al. 2000). The widespread nature of these observations was reported during the First World Congress of Herpetology in 1989

(Bishop et al. 2012). Since then, the global phenomenon of declining amphibian populations has been the subject of extensive research effort (Blaustein & Wake 1990; Alford & Richards 1999; Houlahan et al. 2000; Collins & Storfer 2003). Understanding of the fate befalling amphibians further crystallised in 2004 with the completion of the Global Amphibian Assessment, which classified the extinction risk of all described species at that time; almost 6000 species (Stuart et al. 2004). Thirty percent of species are currently known to be threatened with extinction (assessed as Critically Endangered, Endangered, or Vulnerable; IUCN 2014), although this could rise to 41% if Data Deficient species are threatened in the same proportion as data-sufficient species (Hoffmann et al. 2010). In fact, given that Data Deficient species are more likely to be threatened than data-sufficient species (Bland et al. 2014), even 41% is likely to be an underestimate of the proportion of threatened amphibians (Zippel & Mendelson 2008). Additionally, there are thought to be in the region of 3500 undescribed amphibian species (Giam et al. 2012), increasing the pool of species of unknown extinction risk. Amphibians are thought to be the most imperilled vertebrates (Hoffmann et al. 2010), and are therefore currently among the vanguard of the purported sixth mass extinction event (Wake & Vredenburg 2008; Barnosky et al. 2011). The current rate of amphibian extinctions has been estimated to exceed the background rate by between 200–2700 (Roelants et al. 2007) and 25,039–45,474 times (McCallum 2007).

Why are amphibians declining?

Amphibian declines have been attributed to a range of threats, many of which act synergistically (Sodhi et al. 2008). Habitat destruction and fragmentation is currently the leading cause of declines (Gardner et al. 2007); it is known to affect 65% of assessed amphibian species (4131 of 6353 species), and 92% of threatened species (1800 of 1956 species; IUCN 2014). Exponential human population growth since the turn of the 20th century has occurred largely in the subtropical and tropical ecoregions favoured by amphibians; many regions of the Earth supporting the richest assemblages of amphibians are currently undergoing the highest rates of landscape modification (Gallant et al. 2007). Amphibians get their moniker from the Greek term "*amphibios*", meaning a being with a double life, referring to the capacity of many amphibians to inhabit both terrestrial and aquatic ecological niches (Mishra et al. 2014). 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). Together with their multiple microhabitat requirements, this necessitates an integrated landscape approach to habitat management for amphibians (Lindenmayer et al. 2008).

Pollution affects 18% (1118) of assessed species, and 26% (505) of threatened species (IUCN 2014). 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 such as mercury (Bergeron et al. 2010), fungicides (McMahon et al. 2012), herbicides such as Roundup® (Jones et al. 2010) and atrazine (Hayes et al. 2002, 2006), insecticides (Rohr & Crumrine 2005), and fertilisers (Rouse et al. 1999). However, very 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) affect 16% (1006) of assessed species, and 30% (594) of threatened species (IUCN 2014). Invasive species, such as introduced predatory fish, have severe repercussions for aquatic communities (Adams 1999), and the impact of disease has been of burgeoning concern since it was conclusively linked to many enigmatic declines (Daszak et al. 1999, 2013). Ranaviruses cause mass mortality in multiple amphibian hosts (Gray et al. 2009), and the pathogenic fungus *Batrachochytrium dendrobatidis* can induce chytridiomycosis in susceptible species; a disease 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), as well as several species extinctions (e.g. Schloegel et al. 2006; Vredenburg et al. 2010). Fisher (2008) suggests chytridiomycosis could be the most destructive emergent infectious disease ever recorded, and the impact of chytridiomycosis on amphibians has been described as "*the most spectacular loss of vertebrate biodiversity due to disease in recorded history*" (Skerratt et al. 2007, p. 125).

Although climate change currently affects only 6% (399) of assessed species, and 13% (261) of threatened species, its impact is set to rise in the future (Araújo et al. 2006; Lawler et al. 2010). Amphibians are likely to be especially sensitive to climate change for several reasons, including their highly water-permeable skin and ectothermic life histories, leading to 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 due to climate change (IPCC 2007). Dry, open areas created by droughts can present barriers to migration, fragmenting amphibian habitat further and hindering dispersal (Dodd & Smith 2003). Climate change may also worsen the impact of disease (Pounds et al. 2006b; Bosch et al. 2007; Rohr et al. 2008) and environmental contamination (Blaustein et al. 2010).

Exploitation impacts 5% of assessed species, and 7% (140) of threatened species (IUCN 2014). Hundreds of amphibian species are harvested for subsistence and national/international trade for a wide variety of reasons (Carpenter et al. 2007). For example, many South-east Asian amphibian species are threatened by over-collection for food, traditional medicines, and the international pet trade (Rowley et al. 2010). Intensive Chinese giant salamander farming in China demonstrates how over-exploitation for human consumption can also heighten disease risks to wild populations, as outbreaks of Ranavirus infection in farms may be transferred to wild populations via effluent water (Cunningham et al. 2015). Across the board, synergisms between multiple drivers of extinction intensify the many stressors to amphibians, and are predicted to accelerate the rate of amphibian declines in the future (Sodhi et al. 2008; Hof et al. 2011).

Why are amphibians important?

Despite their unquestionable conservation need, amphibians have struggled to take centre stage as flagships of species preservation. A study by Clucas et al. (2008) of 759 issues of 10 conservation and nature magazines in the United States (1994-2006) revealed that amphibians have graced the front cover less than 1% of the time, making them the least publicised vertebrate taxon, behind mammals (39%), birds (17%), reptiles (4%), and fish (4%). Research in Switzerland rating the likeability of 27 indigenous species (including mammals, birds, reptiles, amphibians, and insects) among school and university students found the three most negatively appraised species to be amphibians (Schlegel & Rupf 2010). Given that the majority of funding raised by international non-governmental organisations in conservation goes to flagship species (Smith et al. 2012), it is clear that amphibians require a surge of goodwill to promote their status. However, human preferences for species are at least partly driven by perceived aesthetic virtues and the degree to which species are feared; the cuter and less frightening the better (Knight 2008). Amphibians have their loyal fans, as evidenced by a multitude of global initiatives seeking to protect them (e.g. Pavajeau et al. 2008; Isaac et al. 2012; Froglog 2013; ASA 2015b; ASG 2015). However, they have endured a mixed history in terms of their perceived value to humans.

Amphibians have frequently been associated with Biblical plagues, witchcraft and sorcery throughout human history, although their medicinal properties have also been embraced for thousands of years in global traditional remedies (Lazarus & Attila 1993). Amphibians continue to represent a pharmacopeia of medical opportunities. Their 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), indicating the vast potential of amphibian chemical ecology to improve human lives. Also, amphibians are frequently 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). They have often been cited as effective "bioindicators" of environmental change due to their permeable skin, potentially high rates of bioaccumulation of contaminants, 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; Rowe et al. 2003; Hopkins 2007).

Amphibians also 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 have profound repercussions, altering primary production, algal community structure, faunal food chains (from aquatic insects up to riparian predators), and reducing energy transfers between aquatic and terrestrial systems (Whiles et al. 2006). Additionally, given that larval and adult amphibians are frequently ecologically and functionally different, losing one species is akin to losing two species (Whiles et al. 2006). As a food source, the global consumption of amphibians is rampant, with combined estimates of imports and exports of frogs alone totalling in the region of 20,000 tonnes annually between 2000-2006 (Warkentin et al. 2009). They have also 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.

Global responses to amphibian declines

Amphibian declines have prompted the establishment of many initiatives designed to strengthen global conservation responses. Following the First World Congress of Herpetology in 1989, the Declining Amphibian Populations Task Force was formed by the International Union for Conservation of Nature Species Survival Commission (IUCN SSC) in 1990, with the goal of determining the nature, extent, and causes of global amphibian declines, and promoting means by which declines can be halted or reversed (Heyer & Murphy 2005; Bishop et al. 2012). Growing concern over the extent and severity of global amphibian declines prompted the IUCN Global Amphibian Assessment (GAA), which gathered data on all described amphibian species relating to their distribution, abundance, population trends, habitat associations, threats, and any conservation actions (Stuart et al. 2004). The results of the GAA heightened widespread concern for amphibians (Beebee & Griffiths 2005; Mendelson III et al. 2006; Halliday 2008; Zippel & Mendelson 2008), and was followed up in 2005 by the International Amphibian Conservation Summit, convened by the IUCN SSC and Conservation International (Moore & Church 2008). This led to the establishment of the IUCN SSC Amphibian Specialist Group (ASG 2015), and subsequent publication of the Amphibian Conservation Action Plan (ACAP) in 2007 (Gascon et al. 2007). Given the magnitude of threats that could not be mitigated in the short-term, including disease and rapid habitat destruction that overwhelmed existing *in situ* conservation capacity, 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 (AArk 2014), developing the "Year of Frog" campaign in 2008 to raise awareness of the plight of amphibians globally and stimulate conservation efforts (Pavajeau et al. 2008). The EDGE Amphibians project was launched by the Zoological Society of London in 2008 to develop conservation initiatives for Evolutionarily Distinct and Globally Endangered species neglected by conservation action, and has since developed several conservation programmes for high priority species, whilst building capacity among global amphibian conservationists through the EDGE Fellows initiative (Isaac et al. 2012; EDGE 2015). The ACAP also laid the foundations for a global umbrella organisation, the "Amphibian Survival Alliance" (ASA), to coordinate and facilitate global amphibian conservation programmes, whilst garnering and administering necessary funds (Mendelson et al. 2006). The ASA was formally established in 2011 (ASA 2015a).

How can we improve the impact of conservation efforts?

What are we aiming for?

Global conservation efforts are struggling to keep pace with demand. The Convention on Biological Diversity did not meet its 2010 targets (Butchart et al. 2010), which related to slowing the rate of decline of biodiversity at the global, regional and national level (Balmford et al. 2005), and also struggled to develop a complete set of indicators by which to assess progress (Walpole et al. 2009). However, before the impact of conservation can be assessed and improved, it is first essential to understand what we aim to achieve, since the framing of conservation shifts over time (Mace 2014). Delimiting two ends of this spectrum, some argue that a unifying goal should be the preservation of nature for its own sake, lest we risk reducing our ability to conserve what remains due to trade-offs and compromise (Child 2009a,b). Others assert that conservation must, at least partially, be justified in terms of natural resource management for human benefit (Adams et al. 2004; Fisher et al. 2009a; Roe et al. 2013; Davies et al. 2014), and that trade-offs between biodiversity conservation and human well-being are an integral reality of conservation action (McShane et al. 2011). A more intermediate stance purports that there are multiple valid viewpoints, constituting a plurality of belief systems in conservation (Sandbrook et al. 2011). Furthermore, these differing values need not be homogenised into one over-riding conservation dogma, but should be embraced so that conservation can be practiced in a variety of ways according to the motivations of different cultures and stakeholders (Robinson 2011). Establishing the aims of amphibian conservation scientists and practitioners is a logical first step in improving conservation impact.

What can science contribute to conservation?

Science can support ongoing conservation decision-making in a clear and transparent way (Murphy & Noon 2007). Conservation biology was established around the principle of addressing "*the biology of species, communities, and ecosystems that are perturbed, either directly or indirectly, by human activities or other agents*"; the central goal being to "*provide principles and tools for preserving biological diversity*" (Soulé 1985, p. 727). This landmark conceptualisation of the contribution of science to conservation founded a wide arena for academic endeavour, encompassing both natural and social sciences. Latterly, definitions of conservation science have broadened the remit of academic enquiry further, espousing the central goal of improving "*human well-being through the management of the environment*" (Kareiva & Marvier 2012, p. 962), and incorporating diverse disciplines such as sustainable development, economics, public policy, psychology, and public health. Approaches to conservation that tackle biodiversity conservation in conjunction with promoting human well-being are often advocated in the literature (Kapos et al. 2008; Black et al. 2011b; Redford et al. 2011a; Phillis et al. 2013), leading to trans-disciplinary approaches to conservation (Reyers et al. 2010). Our quest for greater and deeper understanding of the factors imperilling biodiversity (e.g. Stuart et al. 2010) must be balanced against the urgency of preserving what remains before all is lost (Knight et al. 2010). As stated by Shrader-Frechette (1996, p. 914) "*if knowing that we were correct were a necessary condition for acting, we could never act*". Even the most rigorous scientific approach may only support conservation action to the point where informed advocacy takes over (Murphy 1990), and operational conservation planning begins (Knight et al. 2006).

The role of conservation biology in averting global ecological disaster has been questioned. Is conservation biology just another branch of science confined to the corridors of academia (e.g. Whitten et al. 2001), or a boundary science, equally concerned with advancing scientific understanding and contributing to real-world conservation impacts (e.g. Cook et al. 2013)? Murphy (1990) asserted that research lacking direct application to conservation planning cannot be considered conservation biology. Additionally, a wholly biological view of solutions to conservation challenges may be insufficient to achieve success. Careful scientific conservation planning cannot eschew modification at the hands of on-the-ground realties, where social, political and economic considerations rule decision-making (Margules & Pressey 2000). Also, policy and behaviour change that supports scientific conservation recommendations does not occur in the absence of public interest (Clark & Wallace 1998; Balmford & Cowling 2006; Cowling & Wilhelm-Rechmann 2007; Phillis et al. 2013).

Conservation Evidence

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). A branch of conservation science that may lend itself to achieving a balance between objectivity and relevance to real world conservation management is evidence-based conservation. A unifying element of conservation practice is intervening in various circumstances with the goal of preserving the content and/or functionality of the natural world, without undesirable negative consequences (Fisher et al. 2009a). Whether these interventions actually work is of paramount relevance to whether conservation action will meet our intended goals. Evidence-based conservation research tests the outcomes of interventions to determine their effectiveness at achieving stated objectives related to biodiversity conservation (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 conservation evidence to support the practice of interventions has potential to enhance knowledge exchange, and establish a scientific basis for conservation action (Sutherland 2000; Pullin & Knight 2001; Sutherland et al. 2004). In the absence of an evidence-based approach, the natural world is subjected to well-meaning but potentially damaging experiments, that are rendered impossible to replicate, and, in the absence of evaluation, learn from (Pullin & Knight 2009; Haddaway & Pullin 2013). Evidence-based conservation currently favours quantitative approaches to testing the effect of interventions (e.g. Smith & Sutherland 2014), although increased input from qualitative research has been advocated (Adams & Sandbrook 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; Conservation Evidence 2015). Conservation Evidence manages a database of global evidence studies, and produce taxon- or issue-specific synopses that summarise evidence under relevant interventions types. These interventions are compiled by expert advisory boards to represent all practiced conservation interventions relevant to that taxon or issue (Conservation Evidence 2014, 2015). A synopsis of conservation evidence for amphibians was published in 2014, which is the first attempt to collate global evidence studies across this taxon (hereafter "Amphibian Synopsis"; Smith & Sutherland 2014). Synopses present summarised evidence, written in simple, non-technical language, from scientific studies and systematic reviews, to support decision-making associated with the practice of conservation interventions (Dicks et al. 2014a). This system of organising evidence to support decision-making is based on a similar hierarchy of information developed for evidence-based medicine (Haynes 2001, 2006). Figure 1.1 displays a schematic of this system, referred to as the 4'S' hierarchy of information organisation.

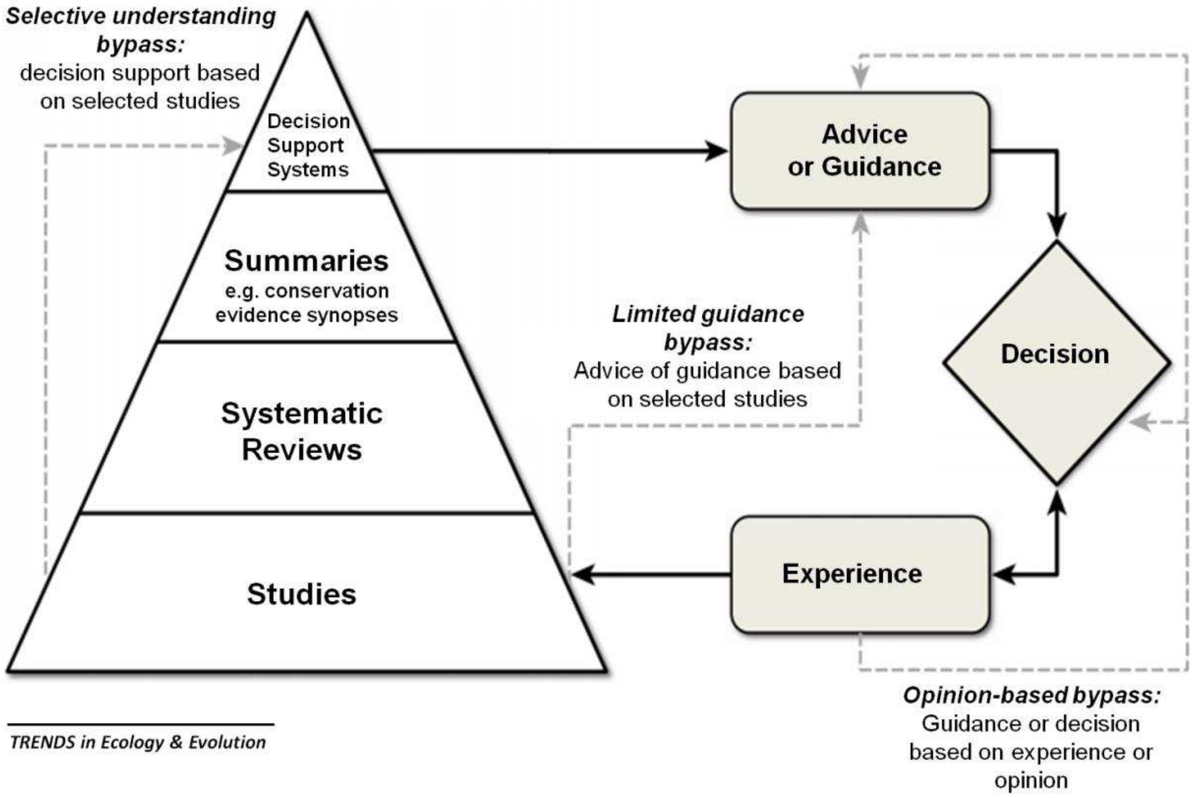


Figure 1.1. A framework for organising evidence for environmental decisions proposed by Dicks et al. (2014; reproduced with permission). The triangle on the left is a simplification of the ‘4S’ or ‘5S’ hierarchy proposed by Haynes (2001, 2006) in which summaries integrate evidence from studies and systematic reviews, and are used as the basis for information flowing into decision support systems. In this scheme, environmental decisions are based on the best-available evidence, combined with the expertise and local knowledge of the practitioner or policymaker (described by the ‘Experience’ box). Broken lines illustrate bypass routes currently taken to inform environmental decisions (Dicks et al 2014, p. 608).

The collation of evidence for these synopses follows a strict protocol (Figure 1.2). The studies and systematic reviews for the Amphibian Synopsis were drawn from a thorough literature search. Forty-eight journals, including 18 specialist amphibian journals and 30 conservation journals, were searched for evidence studies from their very first published issue up to the end of 2012. Additional information (including relevant grey literature) was included following consultation with the advisory board and over 100 additional advisors (Smith & Sutherland 2014). The criteria for inclusion of studies are as follows: they must detail an intervention that is relevant to conservation practice for amphibians; and the effects of the intervention must have been monitored quantitatively (Smith & Sutherland 2014). These criteria exclude studies that examine the effects of specific interventions without actually conducting them. For example, predictive modelling studies, and research examining species distributions in areas with long-standing management histories (correlative studies) were excluded. As stated by Smith & Sutherland (2014, p. 13) "*such studies can suggest that an intervention could be effective, but do not provide direct evidence of a causal relationship between the intervention and the observed biodiversity pattern*". Synopses are updated on an ongoing basis following widespread dissemination of evidence and continued consultation.

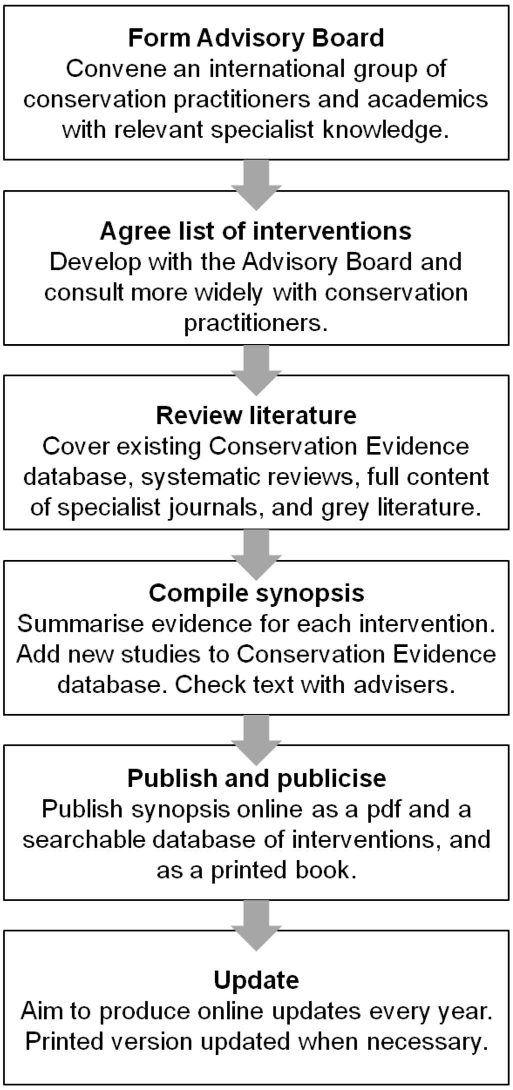


Figure 1.2. Flow chart illustrating the Conservation Evidence synopsis process. Reproduced with permission from Conservation Evidence (2014).

The Amphibian Synopsis collated 417 studies between 1971 and 2013, across 129 management actions attributed to 107 different conservation actions. The rate of evidence production has increased with time (Figure 1.3).

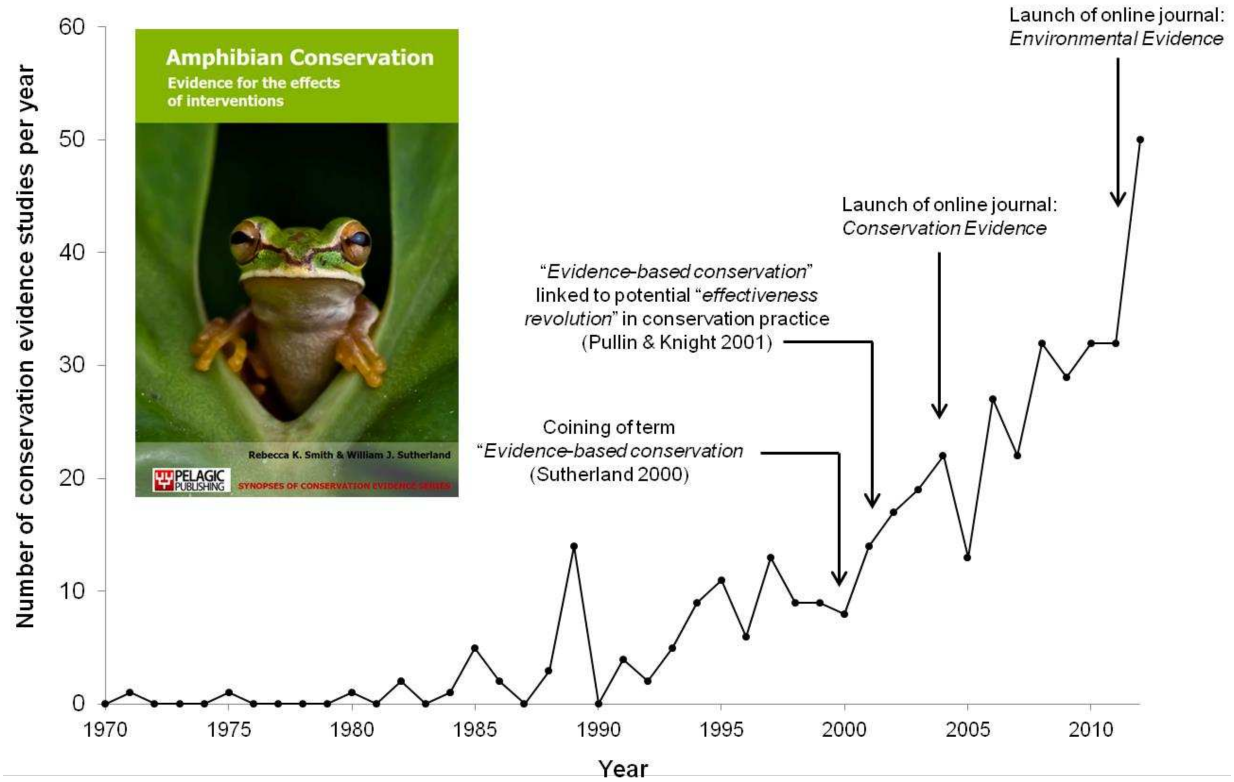


Figure 1.3. Annual rate of production of conservation evidence studies for amphibians collated in the Amphibian Synopsis: "*Amphibian Conservation: Evidence for the effects of interventions*" (Smith & Sutherland 2014).

In my thesis, I use the Amphibian Synopsis to assess the availability of conservation evidence studies for amphibians. I also investigate what the evidence can tell us about contemporary levels of intervention effectiveness in achieving the pre-stated objective of increasing healthy amphibian populations within their natural/*in situ* habitat (Appendix IV). Improving the impact of amphibian conservation will necessitate the practice of effective interventions. The Amphibian Synopsis is a timely resource that has potential to boost the effectiveness of conservation practice through evidence-based methods.

Aims of thesis

Exploring the central theme of evidence-based conservation, I ask four mutually reinforcing questions. These questions are all germane to improving the impact of amphibian conservation though building robust evidence frameworks for conservation practice:

i. *What is "success" in amphibian conservation?*
ii. *Are we meeting amphibian conservation research needs?*
iii. *What are the biases and trends in existing conservation evidence for amphibians?*
iv. *What works in amphibian conservation?*

What is "success" in amphibian conservation?

Once viewed as a crisis discipline in the hands of scientists (Soulé 1985), many now argue for a reformed concept of conservation science and practice that involves multiple stakeholders, diversified solutions, and promotes more positive attitudes and messages (Redford & Sanjayan 2003; Meine et al. 2006; Kareiva & Marvier 2012; Redford et al. 2012). Approaches to conservation practice have diversified over the years (Rands et al. 2010), leading to a proliferation of definitions of success (Mace 2014). Concepts of success may change with our understanding of conservation, leading to a plurality of viewpoints (Robinson 2011; Sandbrook et al. 2011). Greater and more frequent conservation successes must be achieved as a matter of urgency, but this may be difficult to enact as different definitions of success abound. Achieving conservation goals, as well as defining these goals, is largely a matter of human choice (Cowling & Wilhelm-Rechmann 2007). Different perceptions of success may therefore have great consequences for conservation goal-setting, related research agendas, the delivery of conservation practice, and the communication of programme achievements. As stated by Balmford and Cowling (2006, p.692) "*conservation is primarily not about biology but about people and the choices they make*". How we choose to view success has profound consequences for the routes we take in conserving the natural world.

To improve the impact of conservation efforts for amphibians, it is first necessary to find out how scientists and practitioners in amphibian conservation currently conceptualise "success". Chapter 2 is an assessment of the meaning of "success" in amphibian conservation, and the factors that influence these perceptions.

Are we meeting amphibian conservation research needs?

Published science frequently fails to meet the needs of conservation practice (Knight et al. 2008; Sunderland et al. 2009; Esler et al. 2010; Biggs et al. 2011a). Failure to achieve requisite collaboration between researchers and practitioners can lead to science and practice heading in different directions (Arlettaz et al. 2010). As stated by Cook et al. (2013, p. 669) "*conservation scientists wishing to produce management-relevant science must balance this goal with the imperative of demonstrating novelty and rigor in their science*". Practitioners regard research related to localised economic, societal and stakeholder conflicts as the most important to conservation action, and prefer species-specific studies over ecosystem-related research, as this provides the targeted information required for on-the-ground management (Braunisch et al. 2012). However, bespoke and localised conservation research questions may fail to meet the grade demanded in academia to enable funding success and career progression (Sutherland et al. 2011).

The disparity between what is produced and what is needed has led to questioning of the conservation literature's relevance (Milner-Gulland et al. 2009), so understanding the content of this literature can highlight future research directions that may redress the balance. The environmental sciences in general are subject to spatial and topic-related biases, with particular reference to knowledge gaps in poorer countries, especially the tropics where information need may be greatest (Karlsson et al. 2007; Yesson et al. 2007; Collen et al. 2008). This has led to a skewed understanding of both ecological processes and extinction risk (González-Suárez et al. 2012; Martin et al. 2012a). Mismatches between published science and the research needs of amphibian conservation practice have already been noted (Griffiths 2004), and amphibians are known to be poorly represented in the conservation literature (Griffiths & Dos Santos 2012). In order to fully comprehend research imbalances, the net must be cast wider to encompass the scientific literature as a whole, and not just research found in conservation journals. In Chapter 3, I assess the content of the scientific literature for amphibians to illuminate its inherent strengths and biases in addressing amphibian conservation research needs, and make recommendations for future research.

What are the biases and trends in amphibian conservation evidence?

The worsening biodiversity crisis drives a global necessity to improve the effectiveness of conservation action. Improving the performance of conservation interventions through the use of evidence-based approaches has been widely advocated (Pullin & Knight 2001; Sutherland et al. 2004; Cook et al. 2010). Conservation evidence research tests the effectiveness of interventions with the aim of improving the performance of conservation action through sharing practical experiences (Sutherland et al. 2012). Evidence-based conservation seeks to collect and synthesise appropriate research that informs decision-making in both practice and policy (Haddaway & Pullin 2013). However, conservation evidence research may currently be produced at a low level, with Fazey et al. (2004) commenting that just 12.6% of 547 studies published in three prominent conservation journals in 2001 (*Biological Conservation*, *Conservation Biology*, and *Biodiversity and Conservation*) tested the effectiveness of interventions. The Amphibian Synopsis (Smith & Sutherland 2014) enables the first assessment of evidence informing conservation practice for amphibians. Amphibian conservation evidence output has increased with time (Figure 1.3), but little is known of the global distribution and content of this information. Chapter 4 examines trends associated with the availability of conservation evidence for amphibians, and seeks to explain any inherent biases. This enables recommendations for increasing the output, relevance, and interdisciplinarity of conservation evidence, thus helping to meet amphibian conservation objectives.

What works in amphibian conservation?

In Chapter 5, I conduct an expert assessment of the evidence in the Amphibian Synopsis to investigate what it can currently tell us about the effectiveness of interventions. The first edition of the Amphibian Synopsis sought to include all interventions currently employed to conserve amphibians, including threat mitigation, species management, and public education and engagement actions. This is the first assessment of the effectiveness and side-effects of all interventions used in amphibian conservation. In the context of any evidence biases and trends revealed in Chapter 4, I make recommendations concerning future directions in evidence-based conservation practice for amphibians.

Chapter 2. What is "success" in amphibian conservation?

Abstract

Improving the impact of amphibian conservation means achieving more successful outcomes. This is a matter of urgency, both in terms of preserving biodiversity and the many services it provides, and building a foundation of hope that conservation successes can be increasingly realised. However, success is conceptualised in multiple ways depending on the desired outcome of a programme, which can vary according to numerous factors. Using a questionnaire, we evaluated variations in perceptions of success among scientists and practitioners working to conserve amphibians. When asked to provide personal definitions of success in conservation, our sample of 242 amphibian specialists noted combinations of four general success types: species and habitat improvements (84% of respondents); effective programme management (36%); outreach initiatives such as education and public engagement (25%); and science-based conservation (15%). Existing definitions of success were not rated equally; demonstrating stable or increasing population trajectories of target species through appropriate monitoring was most popular. Some aspects of a conservation programme were considered more significant than others in achieving success: reducing known threats was considered the most important, and capacity building was rated least important. Perceptions were influenced by factors such as level of experience (number of years working in conservation science and/or practice), professional affiliation, role, and country of residence. For example, more experienced conservation practitioners tended to associate success more with improvements to species and habitats, and less with education and engagement initiatives, relative to less experienced practitioners. The perceived importance of sustainable resource use, education and awareness initiatives, and capacity building all declined with increasing experience. Whilst science-based conservation was rated as important, as the number of programmes a respondent was involved in increased, this factor declined in importance, particularly amongst those from Less Economically Developed Countries. Success therefore means different things to different people. The plurality of viewpoints held by those shaping the direction of amphibian conservation, and the evolution of these perceptions, should be taken into account when assessing and building success.

Introduction

What does "success" mean in conservation? Despite an abundance of global efforts aiming to conserve biological diversity (Rands et al. 2010), conservation success is rarely defined, measured, and communicated by the stakeholders involved (Saterson et al. 2004), and may be a highly subjective concept (Zedler 2007). White et al. (2012) commented that one factor confounding the assessment of avian reintroductions was uncertainty in defining success, compounded by either widely differing definitions, or none at all. Conservation may be framed in multiple ways – from championing the existence value of nature, to maintaining ecosystem services for human well-being – which impacts how conservation success is measured (Mace 2014).

Abundant definitions of conservation success can be found in the literature. For example, *"conservation action might be considered successful if it slows down the human-induced rate of global biodiversity decline*" (Rodrigues 2006, p. 1051). It is also viewed as the achievement of stated project goals as indicated by appropriate evaluation (Kleiman et al. 2000; Saterson et al. 2004). In the context of species and population recovery, success is "*a reversal of declines and achievement of predefined targets relating to metrics of persistence such as abundance or density, range distribution, and genetic/phenotypic variability*" (Hutchings et al. 2012, p. 542), or "*maintaining multiple populations across the range of the species in representative ecological settings, with replicate populations in each setting*" (Redford et al. 2011b, p.2717, based on Redford et al. 2011a). This can include the long-term persistence of any reintroduced populations of a species (Soorae 2013). Ultimately, a conservation programme may aim to render a species self-sustaining in the wild as the definitive endpoint, thus permitting the reduction of conservation interventions over time (Redford et al. 2011a). Success can also be indicated through an official downgrading of extinction risk on the IUCN Red List of Threatened Species resulting from genuine status change (Butchart et al. 2004; Hoffmann et al. 2010; Young et al. 2014), thereby minimising the chance of species populations declining to extinction (Shea 1998). Success may also be viewed more pragmatically as any improvement relative to the counterfactual situation that would have arisen had no conservation action occurred (Ferraro 2009; Young et al. 2014).

Nature is increasingly valued in terms of how it can benefit people (Mace 2014). Concepts of success that encompass human welfare include "*increasing the likelihood of persistence of native ecosystems, habitats, species and/or populations in the wild without adverse effects on human well-being*" (Kapos et al. 2010, p. 76). It is reasoned that biodiversity conservation can directly link to poverty alleviation through improved environmental resource management (Adams et al. 2004; Roe et al. 2013). Frameworks for assessing socio-ecological systems have been developed to examine the impact of improved ecosystem services on human well-being (Carpenter et al. 2009; Ostrom 2009), providing anthropocentric measures of conservation success. These developments have been dubbed the "*new conservation*" promoting "*economic development, poverty alleviation, and* *corporate partnerships as surrogates or substitutes for endangered species listings, protected areas, and other mainstream conservation tools*" (Soulé 2013, p. 895), raising concerns that actual biodiversity conservation may be supplanted, or even lost entirely, in the process. However, ecosystem services are underpinned and/or actualised by biodiversity at every level, so benefits to people may only be maintained in the context of species and ecosystem preservation (Mace et al. 2012).

Effective conservation has been associated with different approaches and characteristics, including: the use of evidence-based conservation decision-making (Sutherland et al. 2004); a rapid and proactive response to conservation challenges (Martin et al. 2012c); and strengthening government involvement and relevant policy (e.g. Phillis et al. 2013). Community Based Conservation projects (as classified by Souto et al. 2014) associate success with supportive social processes that enhance the awareness, needs and values of local stakeholders and the general public (Clark & Wallace 1998; Mascia et al. 2003). In certain cases, an extension to this premise would be the development of appropriate sustainable livelihoods, and improving the welfare of local stakeholders (du Toit et al. 2004; Davies et al. 2014). Capacity building of local conservation practitioners and scientists is also widely emphasised – for example in the Convention on Biological Diversity Aichi Biodiversity Targets, under strategic goal E (CBD 2014). This can partly be achieved by promoting "social-learning institutions" that bring together local and international conservation practitioners and researchers, helping to strengthen local agencies to set and enact the conservation agenda (Knight & Cowling 2006; Smith et al. 2009). In this sense, it is perhaps not just the type of success that is important, but also how it is achieved. As discussed by Kleiman et al. (2000), a conservation programme may initially achieve its stated scientific goals, but do so with negative consequences for local support, inter-organisational relationships, or non-target species, creating long-term threats to sustained conservation success. Conversely, a programme may operate smoothly but fail to reach its goals.

Previous studies have recognised that success can come in different forms, dividing it into categories such as "ecological" (species and ecosystem benefits), "attitudinal" (positive perceptions of local people towards the conservation target), "behavioural" (influencing human behaviour relative to the conservation target) and "economic" (livelihood-related progress) (Brooks *et al.* 2006; Waylen *et al.* 2010). Sodhi et al. (2011) describe conservation successes at different spatial scales, recognising accomplishments at the micro-, meso- and macro-scale. Mace et al. (2007) sub-divide project achievements into four ascending levels (inputs, activities, outputs and impacts). Conservation programme success may be more accurately discerned from its outcomes and long-term ramifications than the details of its implementation (Kapos et al. 2009). This has led to the development of approaches that seek to assess the separate and combined impact of different programme components, such as activities linked to: species and site management; capacity building; government policy; education & awareness; sustainable resource use; and research (Kapos et al. 2008, 2009, 2010). These discrete components may be individually assessed, demonstrating not only their respective importance, but also their relevance as building blocks of overall success.

In this study we explore the perceptions of success held by amphibian conservation scientists and practitioners, examining ideas across the range of inputs, activities, outputs, outcomes and impacts associated with conservation action. Our aim is to investigate the range of views held about the nature of success in a conservation programme. Of specific interest is whether these views align with concepts of success found in the literature in terms of both general definitions, and also specific programme components that may act as pre-requisites for success. We investigate whether factors such as role, experience, institution-type, country, and involvement in conservation practice predict different viewpoints. Amphibians are an interesting case study taxon because they are a large and widespread group experiencing significant declines (Stuart et al. 2004). They are also the subject of concerted and long-term conservation efforts (e.g. Griffiths & Pavajeau 2008; Smith & Sutherland 2014; Young et al. 2014), and there is a substantial group of practitioners and scientists focusing on their conservation, for example through the IUCN SSC Amphibian Specialist Group (ASG 2015) and the Amphibian Survival Alliance (ASA 2015b).

Methods

Data collection

A questionnaire was developed to assess perceptions of success in conservation among members of the amphibian conservation science and practice community. Initial key informant interviews (Newing 2011) were conducted at the 2012 Amphibian Conservation Research Symposium with five delegates, chosen to represent a cross-section of amphibian conservation research and practice activities. Using the results of these discussions, a pilot questionnaire was developed and disseminated among delegates of the 15th African Amphibian Working Group meeting in Trento (2012) (16 completed questionnaires, plus additional feedback from other delegates). Pilot data were used to improve and refine questions included in the final questionnaire.

The questionnaire (Appendix I) was delivered to respondents in two formats: hard copies distributed at the 7th World Congress of Herpetology (7WCH), August 2012; and an identical online version (www.surveymonkey.com), which was available between August 2012 and February 2013. A link to the online questionnaire was sent to all members of the IUCN SSC Amphibian Specialist Group, and recipients were encouraged to circulate the questionnaire link to colleagues in amphibian conservation research and practice. A targeted sampling strategy was therefore employed, selecting potential respondents with relevant expertise at both 7WCH and via the ASG, with chain-referral sampling encouraged through dissemination among colleagues by existing respondents (Newing 2011) to maximise our sample size. Respondents were asked to provide details relating to five potential explanatory variables: institution (academic or non-academic); country where they are based; whether they consider themselves a conservation practitioner; number of years of experience in conservation science and/or practice; and number of conservation programmes with which they are currently involved (see Appendix II for full definitions). These explanatory variables were chosen to enable investigation of any existing differences in perceptions of definitions and pre-requisites of success between scientists and practitioners of varying geographic locations, institutions, experience levels, and conservation programme involvement.

Measuring perceptions of success

Perceptions of success in amphibian conservation were assessed in several ways. Respondents were requested to list up to five examples of "successful" and "unsuccessful" amphibian conservation programmes in order to investigate any level of consensus among the amphibian conservation science and practice community over the success of specific programmes, and provide potential case studies for subsequent evaluation. Respondents were then asked the open-ended question *'How do you perceive "success" in a conservation programme? Please write briefly about what success means to you in the context of a conservation programme'* (hereafter "open-ended question"). This question was not structured according to specific attributes of success in order to permit respondents to define success in their own terms. Therefore, any time-scale, level, and type of success could be noted, as determined by the views of the respondent. Answers were coded to permit quantitative assessment (Newing 2011). Finally, using a five point ordinal scale (1 = not important, to 5 = highly important, with 0 = not applicable) respondents were asked to score a series of statements describing aspects of perceived success in conservation that were derived from the literature. Statements were divided into two subsets: definitions of overall conservation programme success, hereafter "Definitions"; and specific activities or components of conservation success, hereafter "Components" (Appendix I; Table 2.1). The former included definitions outlined earlier in this article, and the latter were defined in Kapos et al. (2008, 2009, 2010) as: Species & Site Management; Sustainable Resource Use; Education & Awareness; Capacity Building; Research; and Government Policy. Definitions refer to programme outcomes linked to success, as noted in the literature, and Components relate to discrete programme areas that could comprise key pre-requisites for success. Respondents were then asked to pick the "top 3" statements from each subset (Definitions and Components) that they felt best described the achievement of "success", providing a measure of popularity for the statements. These statements of success were posed after the open-ended question, enabling respondents to record their initial perceptions of success without being influenced by concepts that followed in the Definitions and Components sections. Permission to conduct this study was granted through ethical reviews from the 7WCH and the University of Kent.

Data analysis

Data were analysed using R version 2.14.2 (R Core Team 2012) and all statistical and descriptive analysis preserved the anonymity of respondents. Answers to the open-ended question were coded by dividing each full answer into a series of segments. These ranged in length from partial sentences to entire paragraphs that noted discrete aspects of success (hereafter "points"; examples of point types provided in Appendix II). Each point was coded according to a defined list assembled post-data collection to ensure all aspects of success were captured consistently (Newing 2011). These codes were allocated to one of four major categories: (i.) "Species & Habitat" points described direct improvements in species populations and/or habitats resulting from *in situ* or *ex situ* conservation interventions; (ii.) "Programme Management" points related to general conservation programme structure and management, and/or the achievement of stated programme goals; (iii.) "Education & Engagement" points included public education and awareness activities, and/or local community/stakeholder support and involvement; and (iv.) "Research & Evaluation" points addressed species and habitat-related scientific research needs and/or the evaluation of programme outcomes through appropriate monitoring. For each respondent, the proportion of their responses across each of these four major categories was calculated by dividing the number of points made per category by the total number of points made by the respondent. For example, if a respondent made one point from each category in their open-ended response (four points in total), the proportion of points represented by each category would be 0.25 (e.g. "*I believe success means achieving stable populations of the target species* [Species & Habitat = 0.25], *raising long-term funding for all conservation objectives* [Programme Management = 0.25], *ensuring local communities are fully involved in all activities* [Education & Engagement = 0.25], *and that all actions are based on up-to-date scientific evidence* [Research & Evaluation = 0.25]).

The proportion of responses for each of the four main categories were modelled separately as a function of five discrete explanatory variables: Institution (Academic or Non-academic); Country (divided between: Less Economically Developed Countries (LEDCs, otherwise termed Developing Economies); and More Economically Developed Countries (MEDCs, otherwise termed Advanced Economies, as defined by the International Monetary Fund, IMF 2014); Conservation Practitioner (Yes or No); Experience (in years, encompassing conservation science and/or practice); and number of amphibian conservation programmes ongoing (see Appendix II). We modelled each variable and all two-way interactions using Generalised Linear Modelling (GLM) with binomial error structures. A quasi-binomial error distribution was employed when models were over-dispersed (Crawley 2007). Starting with two-way interactions, models were simplified by removing the least significant factor; the resulting model was compared to the previous one using an F-test (quasi-binomial distribution) or Chi-squared test (binomial distribution) before factor deletion. If the variance explained by the model before and after removal was significantly different, the interaction or variable was retained (Crawley 2007). The final model was accepted when only significant factors remained. Nagelkerke's R^2 was calculated for the final model to determine its explanatory power (Nagelkerke 1991).

To investigate perceptions of different Components of a conservation programme, importance scores given by respondents to Sustainable Resource Use, Education & Awareness, Capacity Building, Research, and Government Policy were also analysed using GLM. Per statement, each score was converted to a proportion of the maximum score (i.e. 5) and the same initial model structure and simplification was used as above. We did not include the Species & Site Management statement ("*Reducing known threats to improve the response of conservation target species to conservation interventions*") in this analysis because "*known threats*" could subsume aspects of the other Components, e.g. unsustainable resource use could clearly constitute a threat requiring management. Instead we focused on discrete areas that contribute to the management of species and habitats in a conservation programme.

Results

Questionnaire respondents

The questionnaire was answered to varying degrees of completeness by 355 respondents, which included 96 paper questionnaires from 7WCH and 259 online questionnaires. The

7WCH sample comprised a slightly higher proportion of respondents from academic institutions (7WCH = 60%; Online = 51%), and the online questionnaire attracted a greater proportion of respondents from LEDC countries (7WCH = 11%; Online = 30%). Overall, the questionnaire was answered by 89 LEDC-based respondents and 265 MEDC-based respondents (one respondent did not give their country of residence). The online questionnaire was completed by proportionally more conservation practitioners (7WCH = 38%; Online = 44%). The median years of experience were similar across the two samples: 6.5 years for the 7WCH questionnaire (interquartile range [IQR], 4-18.75; range = 0-45; n = 96); and 10 years for the online questionnaire (IQR, 6-20; range = 0-60; n = 259). The median number of conservation programmes per respondent was identical across the two groups: one programme for both the 7WCH sample of respondents (IQR, 0-3; range = 0-20; n = 96) and the online sample (IQR, 0-2; range = 0-15; n = 259).

Amphibian conservation programmes defined as "successful"

Of the 123 respondents who listed up to five "successful" amphibian conservation programmes, 60% of suggestions were species-specific (194 nominations for 81 different programmes) and 40% benefitted a range of species (128 nominations for 41 programmes). Thirty two percent of respondents (n = 62) asserted that there were no examples of successful amphibian conservation programmes. The listing of “successful” and “unsuccessful” species-specific programmes resulted in disagreement between respondents across overlapping examples. Out of 67 species-specific programmes from 25 countries, 37% listed as "successful" (receiving at least one nomination of success) were also listed as "unsuccessful" by other respondents. Figure 2.1 displays the results for all species-specific programmes receiving ≥3 nominations of success (22 programmes), 64% of which were also categorised as "unsuccessful" by other respondents.

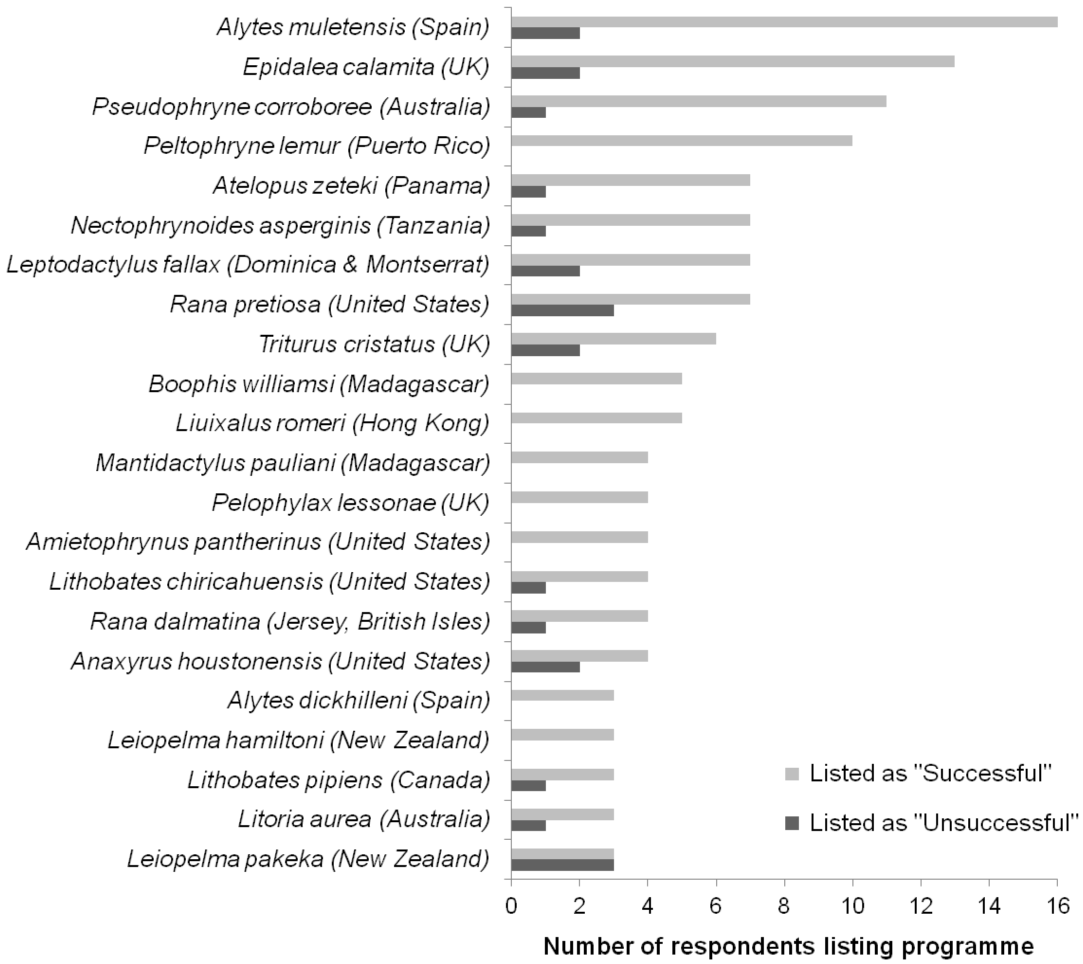


Figure 2.1. Examples of 'successful' species-specific conservation programmes for amphibians. All programmes receiving three or more nominations of success are included (*n* = 123 respondents).

Perceptions of success: Open-ended question

The number of discrete points describing success in amphibian conservation ranged from one to nine per respondent, with 242 respondents making a total of 579 points. Responses described 19 different types of success, which were allocated between four major categories relating to: Species & Habitat; Programme Management; Education & Engagement; and Research & Evaluation (see Appendix II for a detailed description of the types and categories of success, and numbers of points made). Species & Habitat improvements were mentioned by 84% of respondents (*n* = 203), Programme Management by 35% (*n* = 85), Education & Engagement by 24% (*n* = 59), and Research & Evaluation by 14% (*n* = 35).

Examining each major category in turn, 96% all Species & Habitat points (a total of 349 points from 203 respondents) referred to *in situ* species conservation (e.g. improvements in population numbers, persistence, security, genetic diversity, and health) and their habitats (e.g. improvements in condition, size, connectivity, and protection). The remaining 4% described *ex situ* conservation measures, whereby assurance colonies of species are maintained in captivity, especially in cases where *in situ* threats cannot currently be mitigated. *Ex situ* populations are maintained with the hope of potential reintroduction, and for study and awareness-raising. The majority (78%) of Programme Management points (113 points from 85 respondents) referred to effective programme development, structure, and/or ensuring sustained, long-term action. This included considerations such as the achievement of long-term funding, taking a multi-stakeholder approach, employing clear strategic planning, and effectively managing personnel. Specific styles of management, such as adaptive management and adopting a “learning programme” framework, were mentioned as important to success, and respondents also noted that there are different types/degrees/stages of success within a conservation programme depending on the context. The remaining 22% of Programme Management points asserted that success equals the achievement of pre-determined programme goals. Education & Engagement points (77 points from 59 respondents) described public education and awareness initiatives (57%), or the development of local support, sustainable livelihoods, and local community/stakeholder involvement (43%). Research & Evaluation points (40 points from 35 respondents) mentioned scientific research on species and habitat as being a crucial to successful conservation (63%), as well as the evaluation of programme outcomes through appropriate monitoring (37%).

Perceptions of success: Definitions and Components of success

When respondents were asked to select their 'top three' definitions of success from the statements provided, clear differences existed in popularity across the sample for both Definitions (Table 2.1a) and Components (Table 2.1b). The ranked order of popularity mirrored the mean assigned scores of importance. The highest scoring Definitions all related to improvements in population numbers and persistence of target species, habitats and ecosystems. The lowest scoring and least popular definitions included slowing (but not reversing) the rate of decline, and improving the official conservation status of a species through the IUCN Red List, or national government-level listing within a species range country. Statements associated with programme management, including the achievement of defined project goals and reduction in intensity of conservation actions over time, were of intermediate popularity and importance scores.

Table 2.1. Statements of success. Statements are ordered by the percentage of respondents choosing the statement as one of their 'Top 3' that best describe success in conservation (% Popularity). Mean scores of importance are out of a maximum of 5, from 1 = *Not important* to 5 = *Highly important* in describing conservation success. (a) General definitions of success (n = 245); (b) Components of a conservation programme (*n* = 235).

(a)	**Definitions of 'conservation success'**	**% Popularity**	**Mean importance score out of 5** (± 1 s.e.)
1	*Wild population of conservation target species is stable or increasing, as indicated by appropriate monitoring and evaluation* (e.g. Hutchings et al. 2012)	81	4.59 ± 0.04
2	*Increasing the likelihood of persistence of native ecosystems, habitats, species and/or populations in the wild without adverse effects on human well-being* (Kapos et al. 2010, p. 76)	72	4.47 ± 0.06
3	*Long-term persistence of reintroduced population(s) of conservation target species* (e.g. Soorae 2013)	47	4.15 ± 0.06
4	*Defined conservation project goals have been achieved through measurable indicators* (e.g. Saterson et al. 2004)	45	4.03 ± 0.06
5	*The reduction of the intensity of conservation actions over time as the outcomes of these actions have been effective, and become less significant to the survival of the species* (e.g. Redford et al. 2011a)	27	3.60 ± 0.08
6	*Conservation target species is declining at a slower rate than before conservation interventions were initiated* (e.g. Ferraro 2009)	12	3.50 ± 0.08
7	*The status of the conservation target species has been downgraded on the IUCN Red List of Threatened Species (e.g. from Critically Endangered to Endangered)* (e.g. Young et al. 2014)	12	3.19 ± 0.07
8	*The status of the conservation target species has been downgraded by national level government relevant to the range area*	6	2.98 ± 0.08

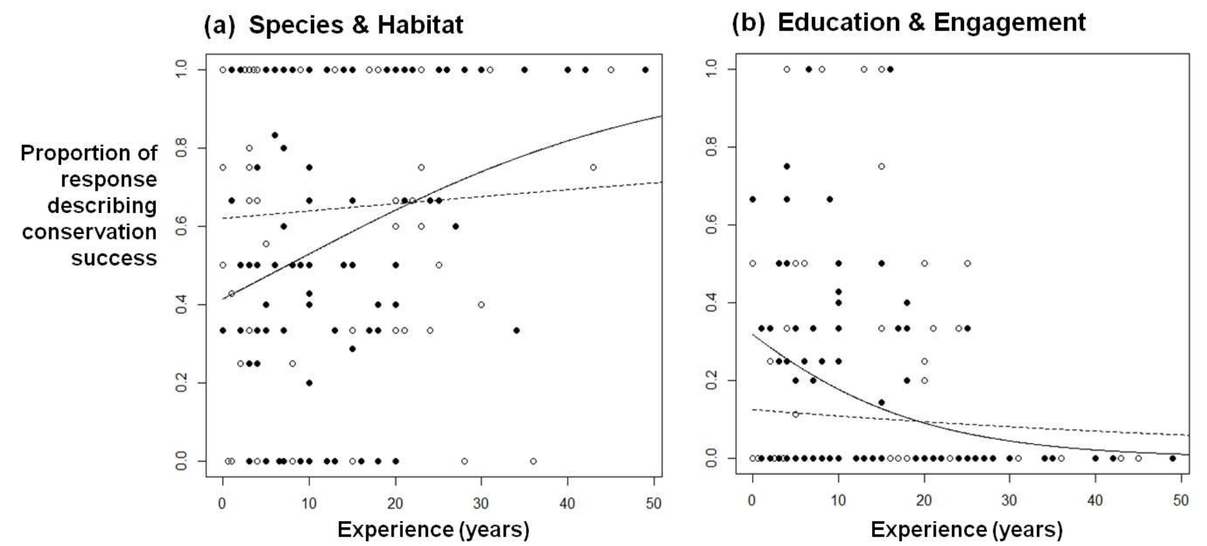
(b)	**Components of 'conservation success'** (e.g. Kapos et al. 2008, 2009, 2010)	**% 'Top 3' statement**	**Mean importance score out of 5** (± 1 s.e.)
1	***Species & Site Management:*** *Reducing known threats to improve the response of conservation target species to conservation interventions*	84	4.70 ± 0.04
2	***Research:*** *Applying appropriate research results to conservation practice*	53	4.51 ± 0.05
3	***Sustainable resource use:*** *Promoting sustainable resource use and minimising damaging practices by relevant stakeholders*	47	4.26 ± 0.06
4	***Education & Awareness:*** *Increasing support for the conservation of a species among appropriate target audience(s) through a communication, education and public awareness strategy*	46	4.30 ± 0.06
5	***Government Policy:*** *Implementing relevant policies and/or promoting legislation relevant to conservation aims*	38	4.18 ± 0.06
6	***Capacity Building:*** *Increasing the quality and/or quantity of conservation action(s) through appropriate capacity building (training of project staff)*	32	4.09 ± 0.07

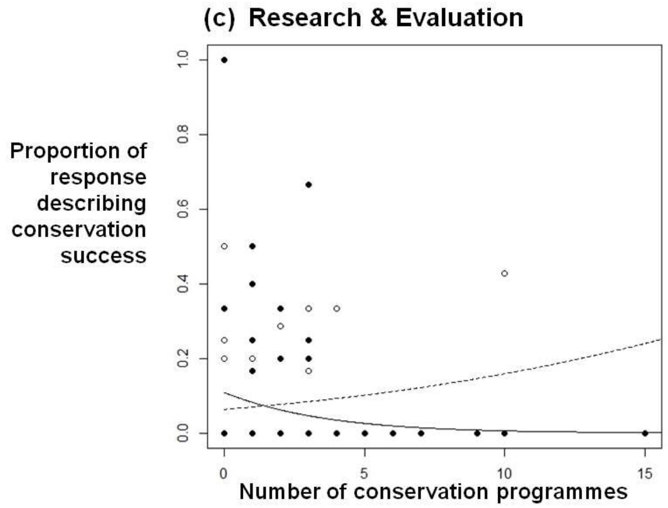
The most popular and high-scoring Component in achieving conservation programme success was Species & Site Management. The other Components all received mean importance scores of over 4 out of 5, with Government Policy and Capacity Building being the least popular and lowest scoring Components. Education & Awareness and Sustainable Resource Use were of intermediate popularity and importance scores, and Research was the second most popular statement overall, with the second highest mean importance score.

Predictors of success perceptions: Open-ended question

Species & Habitat

Overall, conservation practitioners believed species and habitat improvements to be proportionally less significant in defining conservation success than non-practitioners (GLM: $t = -2.811$, s.e. 0.297, $p = 0.00540$, df = 241, $R^2 = 0.0852$). Practitioners therefore made a greater proportion of their points in the other categories of Programme Management, Education & Awareness and Research & Evaluation. However, a significant interaction between the explanatory variables of Conservation Practitioner and Experience (GLM: $t = 1.996$, s.e. 0.0191, $p = 0.0471$, df = 241) suggests that conservation practitioners with more years of experience believe factors relating to Species & Habitat are proportionally more important than practitioners with fewer years of experience (Figure 2.2a). This model had an R^2 value 0.0852, so although the interaction between Practitioner and Experience was significant, the overall explanatory power of the model is low and there are likely to be other factors not tested in the model that contribute to the variance observed in the response variable.





(a) Species & Habitat: Interaction between conservation practitioners (solid circles, solid line) or non-practitioners (open circles, dashed line) and experience on the perceived importance of Species & Habitat measures to conservation success.

(b) Education & Engagement: Interaction between conservation practitioners (solid circles, solid line) or non-practitioners (open circles, dashed line) and the extent of their experience in amphibian research and/or conservation practice on the importance of Education & Engagement on perceived conservation success.

(c) Research & Evaluation: Interaction between the respondent's institution type – non-academic (solid circles, solid line) or academic (open circles, dashed line) – and the number of their ongoing conservation programmes on the importance of Research & Evaluation on perceived conservation success.

Figure 2.2. General perceptions of success in a conservation programme. The relationship between types of "success" noted by respondents and different explanatory variables (n = 242).

Education & Engagement

Conservation practitioners considered Education & Engagement to be more important in defining conservation success than non-practitioners (GLM: t = 3.000, s.e. 0.282, p = 0.003, df = 241). A significant interaction was found between the explanatory variables of Conservation Practitioner and Experience and the importance placed on Education & Engagement in defining success (GLM: t = -2.020, s.e. = 0.0302, p = 0.043, df = 241, R^2 = 0.107). This relationship suggests that as the number of years in practice increases, the less a practitioner believes Education & Engagement is related to conservation success (Figure 2.2b). This model had an R^2 value 0.107, so as with the previous model for Species & Habitat, the interaction between Practitioner and Experience was significant but the explanatory power of the model is low and there are likely to be other untested factors that contribute to the variance observed in the response variable.

Research & Evaluation

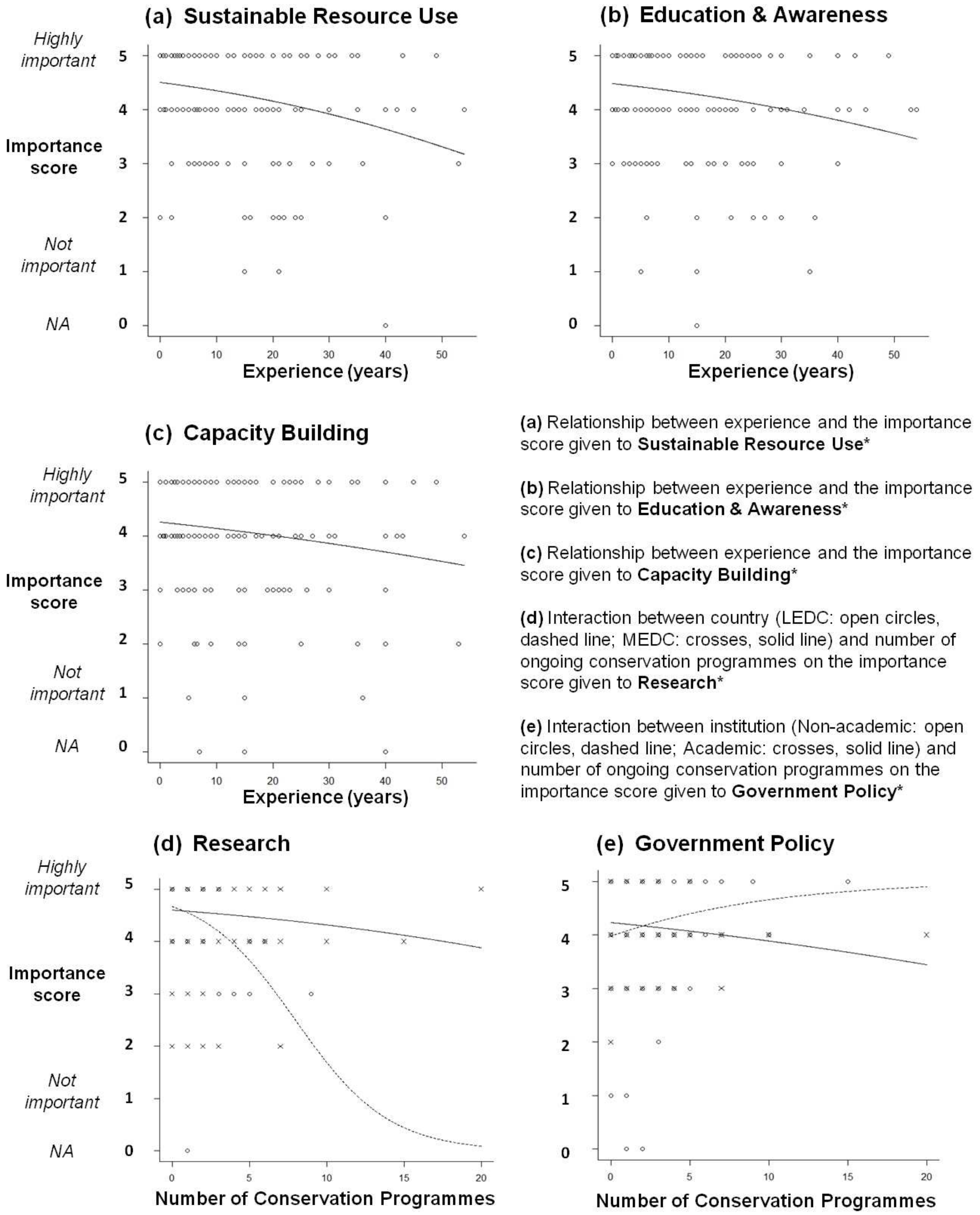
Overall, the proportion of points relating to Research & Evaluation was low. However, respondents based at academic institutions who are involved in more than one conservation programme made a greater proportion of points relating to research and evaluation than those based at non-academic institutions. The importance of Research & Evaluation increased with the number of conservation programmes for individuals from academic institutions, but decreased to zero for respondents based at non-academic institutions (GLM: $z = -2.030$, s.e. = 0.0201, $p = 0.043$, df = 241; Figure 2.2c). This model had an R^2 value 0.0607, so although the interaction between Institution and programme number was significant, a low explanatory power suggests that there are other factors not tested in the model that contribute to the variance observed in the response variable.

Programme Management

No significant relationships were found between any of the interactions or discrete explanatory variables and the proportion of programme management points made by respondents in defining conservation success.

Predictors of success perceptions: Components of success statements

Echoing modelling results for the open-ended question, scores for Components associated with investing in the human aspects of a conservation programme (namely Sustainable Resource Use, Education & Awareness and Capacity Building – i.e. the components most analogous to the open-ended question category "Education & Engagement") were negatively related to years of experience in all cases: Sustainable Resource Use (GLM: $t = -3.889$, s.e. 0.00791, $p = < 0.001$, df = 234, $R^2 = 0.103$); Education & Awareness (GLM: $t = -3.135$, s.e. 0.008, $p = 0.002$, df = 234, $R^2 = 0.0684$); and Capacity Building (GLM: $t = -2.330$, s.e. 0.008, $p = 0.021$, df = 234, $R^2 = 0.0380$) (See Figure 2.3a,b,c). For Research, a significant interaction was found between the explanatory variables of Country and Conservation Programmes. This suggests that, whilst across our sample the importance of Research declines as the number of conservation programmes per person increases, (GLM: t = -3.251, s.e. 0.102, $p = 0.001$, df = 234, $R^2 = 0.108$), this decline is particularly pronounced for those from Less Economically Developed Countries (GLM: t = 2.460, s.e. 0.110, $p = 0.015$, df = 234) (Figure 2.3d). In the case of Government Policy scores, a significant interaction was found between the explanatory variables of Institution and Conservation Programmes (t = 2.193, s.e. 0.078, $p = 0.029$, df = 234, $R^2 = 0.0355$). This suggests that as the number of conservation programmes per respondent increases, those from non-academic institutions score Government Policy more favourably than those from academic institutions; scores increased with programme number in the former, but declined in the latter (Figure 2.3e). Low R^2 values for all models suggest that other untested factors are responsible for contributing to the variance observed in the scores for each Component.



(a) Relationship between experience and the importance score given to **Sustainable Resource Use***

(b) Relationship between experience and the importance score given to **Education & Awareness***

(c) Relationship between experience and the importance score given to **Capacity Building***

(d) Interaction between country (LEDC: open circles, dashed line; MEDC: crosses, solid line) and number of ongoing conservation programmes on the importance score given to **Research***

(e) Interaction between institution (Non-academic: open circles, dashed line; Academic: crosses, solid line) and number of ongoing conservation programmes on the importance score given to **Government Policy***

Figure 2.3. Components of success in a conservation programme. The relationship between scores of importance for statements describing components of success and different explanatory variables (n = 235). ***See Table 2.1b for all statements.

Discussion

The results of our study indicate that conservation success is perceived and defined in a variety of ways, and that these perspectives are influenced by a respondent's background (i.e. number of years of experience), responsibilities (i.e. involvement in conservation practice), institution type, and the wealth of the country in which they are based.

Has success been achieved in amphibian conservation?

The variety of "successful" conservation programmes suggested was somewhat undermined by the fact that nearly a third of respondents stated there were no examples of successful amphibian conservation programmes. Over a third of species-specific examples listed as successful were also listed as unsuccessful by other respondents, rising to over two thirds when considering only the 22 most popular programmes. The Mallorcan midwife toad (*Alytes muletensis*) programme was most frequently cited as successful. This is a well-publicised and long-term conservation programme, in operation since 1985, that features both *in situ* and *ex situ* conservation interventions (Young et al. 2014). It commenced shortly after the species' discovery in 1979 (Mayol & Antoni 1980). The Mallorcan midwife toad is therefore, in amphibian terms, a high-profile species that enjoys the singular distinction of being the only amphibian downgraded on the IUCN Red List as a result of genuine status change following ongoing conservation actions (Hoffmann et al. 2010). The natterjack toad (*Epidalea (Bufo) calimata*) in the United Kingdom is the second most cited example of success. Improving upon downward populations trajectories in the 1970s, around 40 years of proactive conservation measures for the natterjack have achieved stable populations across its UK range, with occasional local extinctions approximately matched by successful translocations (Denton et al. 1997; Beebee 2014). However, these highest ranking examples of successful programmes each received two nominations for being "unsuccessful". Other high-ranking examples of "success" that were listed as "unsuccessful" are also the subject of lengthy and well-promoted conservation actions (e.g. Tanzanian Kihansi spray toad, Krajick 2006; Panamanian golden toad, Gagliardo et al. 2008; and Dominican mountain chicken frog, Tapley et al. 2014). It is clear that one person's perceived success can be another's perceived failure. However, these examples provide a barometer reading of where the amphibian conservation community currently tends to perceive successful action. The projects listed as “successful” provide a wide variety of case-studies, ranging from *ex situ* programmes tackling chytridiomycosis outbreaks (e.g. Kihansi spray toad and Panamanian golden toad), to long-term *in situ* population maintenance (e.g. natterjack toad), and combinations of the two (e.g. Mallorcan midwife toad and Dominican mountain chicken). The long-term, structured and sustained nature of these programmes is their chief commonality. This suggests efforts need to be well-organised and enduring to be perceived as successful, preferably achieving stable or increasing population trends for the target species. However, preventing imminent extinction in the face of significant threats, such as chytridiomycosis, is also associated with "success".

Our results illuminated a selection of amphibian conservation programmes that are associated with success, providing case studies that can be evaluated to assess programme activities and achievements linked to perceived success. Interpretation of the specific qualities of programmes that embody success is limited because no further details were requested from respondents to help determine why they considered these programmes successful. As such, further research should incorporate a variety of lines of questioning, including: specific factors of named conservation programmes that are believed to be associated with success; the time scale over which different types of success is perceived; the evidence respondents have used to determine the success of specific programmes; and the degree of certainty in assessing success.

General perceptions of success

Success in a conservation programme was perceived under four general categories: improvements in the status of species and habitats; effective programme management; the development of relevant education and public engagement initiatives; and ensuring programme actions are evaluated and supported by appropriate research (respectively mentioned by 84%, 35%, 24% and 14% of respondents). These results are worth considering when developing a conservation programme, as they provide guidelines (albeit from a snapshot in time) on increasing the likelihood of a project being deemed successful, both in terms of formulating programme aims and communicating achievements. Achieving an appropriate balance in acting and reporting on these different areas could help generate perceived – and hopefully therefore actual – success. These four elements work synergistically in their contributions to a programme's successes, but may also be examined independently. Accurately gauging success has been linked to the evaluation of outcomes rather than outputs and implementation (Kapos et al. 2009). However, outputs remain a prevalent method of determining success in conservation due to their relative ease of assessment (Jones 2012), and outputs have been shown to align fairly closely with outcome-based success rankings of projects (Howe & Milner-Gulland 2012). When tasked with defining success in our open-ended question, respondents cited notions that incorporated everything from specific activities and outputs, to long-term programme impacts. Success is therefore perceived on many levels, irrespective of accepted theory on how it should be evaluated.

The achievement of *in situ* improvements in the status of species and habitats is overwhelmingly central to perceived success in amphibian conservation, with *ex situ* measures only mentioned in conjunction with success by 12 of the 242 respondents. This result is particularly important in amphibian conservation, where *ex situ* conservation actions are advocated when it is impossible to mitigate threats, such as disease, *in situ* (Pessier 2008; Zippel et al. 2011; Scheele et al. 2014). The aforementioned case-studies of success include many examples where *ex situ* strategies are employed. However, *ex situ* measures, though crucial in some cases to avert imminent extinctions, may not be associated with long-term success unless captive individuals are sustainably restored to the wild.

Success achieved through effective programme management was chiefly perceived in the effective organisation of financial and human resources, and also in achieving pre-stated goals. Programme management unites all conservation activities under a leadership strategy and theory of change (Salafsky et al. 2002; Margoluis et al. 2009; Black & Groombridge 2010; Dietz et al. 2010; Salafsky 2011; Black et al. 2013). The high frequency of programme management attributes mentioned indicates that its significance is duly recognised by both scientists and practitioners. Black & Groombridge (2010) investigated organisational measures of success in business management, and adapted them to benefit strategy, leadership, resource supply, and team organisation in conservation. Effective leadership and management techniques are increasingly championed in conservation, particularly as programmes become more interdisciplinary (Black & Copsey 2014; Pooley et al. 2014). The sustained mobilisation of financial and technical resources (Kleiman et al. 2000; McCarthy et al. 2012), effective programme management and leadership (Williams et al. 2007; Black et al. 2011a), and use of adaptive management and organisational learning (Clark et al. 1989; Clark 1996) have all been associated with success in conservation. The implementation strategy of a conservation programme is, after all, as crucial to its operational success as any of its component actions (Knight et al. 2006).

Education and engagement is viewed as paramount in conservation endeavours that seek to unite biodiversity conservation with improvements in local welfare and livelihoods (Sayer & Wells 2004; Davies et al. 2014; Souto et al. 2014). Embracing the twin-goals of biodiversity conservation and poverty alleviation is critical to sustaining projects in countries where species richness is inversely related to economic development, and these goals have great potential to be mutually reinforcing (Roe et al. 2013). Furthermore, the nature of engagement is key. Prescriptive approaches used by international conservation organisations can undermine local support, particularly if local people do not have central roles in project steering and management, and if local institutions are not strengthened in the process (Rodríguez et al. 2007). Commenting on conservation in developing countries, Rodríguez et al. (2007, p. 756) state that "*locally produced strategies and agendas, implemented by strong local institutions and individuals are key to success*". In our sample, outreach initiatives were only mentioned by one in four respondents when defining conservation success in the open-ended question. Although education and awareness initiatives have been employed (e.g. Lin et al. 2008; Pavajeau et al. 2008; Froglog 2013), amphibian conservation has not been historically linked to development projects encompassing livelihood provisions. However, this situation is changing (e.g. Bride et al. 2008; Lin et al. 2008), especially given evolving tendencies of biodiversity conservation funding bodies to support projects that also benefit people. For example, the UK Darwin Initiative (DI; currently predominantly funded by the Department for International Development (DI 2014)) supports numerous long-term programmes that benefit amphibians, and follows the Organization for Economic Cooperation and Development's Development Assistance Criteria for evaluating development assistance when monitoring success (Cunningham & King 2013). Conservation efforts cannot be sustained without integral local involvement, support and leadership (Smith et al. 2009). Finding ways for a programme to benefit people, in conjunction with appropriate trade-offs, will be increasingly vital in many conservation contexts (Fisher et al. 2009a).

Finally, research and evaluation was predominantly related to success in terms of supporting conservation interventions through appropriate scientific studies. Additionally, respondents felt that programmes should be evaluated to monitor progress. Improving the impact of conservation has been linked to the promotion of evidence-based conservation decision-making (e.g. Sutherland et al. 2004; Pullin & Knight 2011) and the regular evaluation of outcomes (Salafsky & Margoluis 2003; Ferraro & Pattanayak 2006; Margoluis et al. 2009; Dietz et al. 2010; Bottrill & Pressey 2012; CMP 2014; FOS 2014). Despite being the least-mentioned aspect of conservation success of the four categories, research and evaluation is instrumental in achieving verifiable improvements in species and habitats. Furthermore, when research was rated against other components of a conservation programme, it was second only to species and site management, indicating that it is of key concern in amphibian conservation (Table 2.1b). Ongoing programme evaluation is crucial, as the effects of conservation interventions can occur over protracted time periods, and often outside of specific project funding timescales (Kapos et al. 2008). The evaluation of intermediate-level criteria for success may therefore enable a project to progress more effectively towards its ultimate goals. Given that a conservation programme may not achieve its final objectives for many decades, Margoluis & Salafsky (1998) reason that conservation success should be defined in a stepwise fashion over short, medium and long-term timeframes. Employing a logical structure in project design and indicator evaluation, a programme's theory of change can be followed in a graduated fashion from activities through to long-term impacts (Salafsky et al. 2008; Margoluis et al. 2009), enabling an objective assessment of whether it has achieved its desired outcomes and impacts. Additionally, measures of success may need to be the subject of ongoing negotiation by all relevant stakeholders throughout the lifespan of the programme, rather than something prescribed *ex-ante* by donor organisations (Sayer & Wells 2004).

Further research examining success definitions and measures should incorporate a time-bound context, providing an opportunity for respondents to differentiate between short-, medium- and long-term success. Although some respondents automatically differentiated types of success over different time-scales, it would be useful to encourage respondents to think about success over a selection of defined time periods. The purpose of the open-ended question was to give respondents an opportunity to outline success in their own terms. However, this reduces the level of certainty associated with answers because the question may be interpreted in a variety of ways. Hence, further research could take a structured approach to enable specific attributes and stages of success to be delimited, such as time-scales, values and beliefs, attitudes, and motivations, in addition to the level of certainty associated with different answers. A variety of survey methods, including interview and questionnaire-based approaches, could be employed to further understand how values relevant to conservation success are formed, accounting for a wider range of factors that may drive human decision-making related to these perceptions (e.g. Fishbein & Ajzen 2010).

Conservation must succeed in a complex world where failure is commonplace and should be openly acknowledged (Game et al. 2014) to capitalise on important learning opportunities (Beier 2007; Hobbs 2009). Recognising and managing failure is a key concern in many other fields, including medicine, where learning from mistakes is considered central to improving performance (Bosk 2003; Edmondson 2004; Fischer et al. 2006; Greenberg 2009) and discussing errors. and how to overcome them, can save lives (Kohn et al. 2000). An honest approach to failure may illuminate common problems, and reporting errors can encourage wholesale change at the organisational level and beyond (Jeffs et al. 2012). Admitting to failings should therefore not be misconstrued as an indication of weakness, but rather a necessary aspect of adaptive management and organisational learning (Edmondson 2004; Biggs et al. 2011b). Failure can also help refine effective approaches, explore new frontiers through trial and error, and identify novel strategic directions (Edmondson 2011). Failure is therefore not necessarily the inverse of success, but can be a crucial part of a journey towards success. Future research should aim to outline understanding of the role of failure in conservation and how to harness its potential to help engineer success.

Definitions and Components of success

Definitions of success from the literature were favoured if they related to stable or increasing populations of the target species in the wild. The definition that linked persistence of the target species to human well-being, though popular and high-scoring, came second to a definition that considered only the target species. This may suggest that a biocentric attitude to amphibian conservation currently prevails over more anthropocentric viewpoints. This may be attributed to a predominance of natural sciences training among our respondents, which can lead to approaches to conservation that focus more on species and habitats, and less on people (Pooley et al. 2014). Conversely, the definition referring to counterfactual improvements indicated through slower declines was considerably less popular, indicating that declines must be halted or reversed before success is broadly perceived. Effective species and site management through the reduction of known threats was the most popular component in achieving conservation success. Clearly, such achievements may pivot on programme-appropriate advances in the other areas, such as sustainable local resource use, education and awareness, advantageous government policy, research-led actions, and capacity building. However, if species and site management is failing, success is less likely to be perceived overall. This is a highly intuitive outcome from our study, but one worth reinforcing: programmes must be able to demonstrate clear improvements to the *in situ* population status of target species and habitats in order for success to be widely perceived.

IUCN extinction risk categories, and their derived Red List Indices, are commonly used to track conservation progress (Sachs et al. 2009; Butchart et al. 2010; Hoffmann et al. 2010; Hutchings et al. 2012; Young et al. 2014). However, in our study, definitions about improvements in a species' official conservation status, as indicated by local government categorisations and IUCN extinction risk, were decidedly unpopular. This signifies a degree of mistrust in threatened species lists as a means of signifying conservation success. Many changes to species listings reflect increased knowledge in taxonomy and distribution, rather than genuine changes in conservation status (Possingham et al. 2002). Additionally, whilst the IUCN Red List is the most authoritative and comprehensive global information source on the extinction risk of species (Rodrigues et al. 2006), keeping species assessments up-to-date is a colossal challenge, with assessments becoming out of date after 10 years according to IUCN regulations (Rondinini et al. 2014). This means that the majority of amphibians (assessed in 2004) are currently up for reassessment. The last assessment of circa 6000 species took three years, and involved over 520 experts and 16 workshops (Stuart et al. 2004). With these reservations in mind, it is perhaps unsurprising that the IUCN Red List is not the preferred indicator of conservation success among our respondents, and it is also not designed for this purpose (Possingham et al. 2002). That said, it is rated above national level lists in its ability to communicate status change, indicating that the rigorous assessment approach of IUCN is generally favoured over country-based systems that vary according to the location.

Just under half of the respondents chose the achievement of stated goals as one of their preferred definitions of success. This suggests that success can be gauged in the comprehensive execution of a programme's strategic plan, which may contradict emerging notions of the importance of adaptive management and flexible targets in conservation programmes (Sayer & Wells 2004; Dietz et al. 2010). Adaptive management should seek to improve understanding of how a system works, enabling improvements in the ability to make future decisions (Sutherland 2006). This is important in conservation, but setting and achieving appropriate goals does allow managers to chart progress (Kleiman et al. 2000). Defining success through a reduced need for management interventions (Redford et al. 2011a) was chosen by fewer than a third of respondents, indicating that success is appraised more through stable or increasing target populations than through the reduced need for management. It may currently be difficult to imagine future scenarios where management action can be cut back. Just as slowing declines is perhaps too defeatist a definition of success, ceasing management action may be regarded as overly optimistic.

Predictors of different perceptions

The number of years of experience in amphibian research and/or conservation practice is a key factor in predicting perceptions of success among our respondents. Practitioners with more years of experience placed greater emphasis on species and habitat improvements in the open-ended question, whereas those with fewer years of experience placed relatively more emphasis on outreach initiatives such as public education and engagement. Across all respondents, years of experience also influenced the importance attributed to human components of conservation. Scores for education and awareness, sustainable resource use and capacity building were all negatively associated with experience. An increasing number of years of professional experience is often linked to hierarchical ascendance, which may draw perceptions of overall success away from programme components, and towards over-arching goals. The over-riding goal of conservation, in the traditional sense, is the effective management of target species and habitats (Murphy 1990), and those with more experience may regard true success in terms of this outcome. Additionally, what each of us regards as "success" may simply reflect our own personal interests and worldviews in conservation (Sandbrook et al. 2011). Conservation biology only emerged as a distinct discipline thirty years ago (Soulé 1985), and conservation science is multifaceted and ever-evolving (Kareiva & Marvier 2012). We are still learning how to develop effective conservation programmes, and how to frame the objectives of conservation (Mace 2014). Perceptions of success are developing concurrently with our understanding of conservation as a whole, leading to different theories of success being embraced by a range of interested parties across different generations. As the ethos of conservation changes, this is reflected in the amount of interdisciplinary training that conservation scientists and practitioners receive, which may include increased exposure to the "human dimensions" of conservation (Newing 2010).

As the number of conservation programmes per respondent increased, those from academic institutions placed greater emphasis on research and evaluation, which contrasts with respondents from non-academic institutions. At academic institutions, it makes sense that respondents involved in multiple conservation programmes should emphasise research when defining success; their academic career progression depends substantially on publishing (Sutherland et al. 2011). Similarly, respondents based at non-academic institutions will have different responsibilities, and publishing may be less of a priority (Arlettaz et al. 2010). However, the importance of research declined rapidly with increasing programme number for respondents (scientists and practitioners) from LEDCs. This may highlight a fundamental schism in priorities across the global wealth divide. Wealthier countries view research-based decision-making as fundamental to success, whereas countries with less well-funded research bodies may prioritise other actions out of socio-economic necessity (Sayer & Wells 2004; Karlsson et al. 2007; Sunderland et al. 2009). Finally, scores of importance for Government Policy also depended on the number of conservation programmes per respondent. The importance of Government Policy was positively correlated with programme number for respondents from non-academic institutions, with a slight negative correlation for those based at academic institutions. The significance of policy and legislation to ongoing conservation success is germane to the legal enforcement and support of conservation objectives (Rands et al. 2010), but again may be further removed from the priorities of those based at academic institutions due to differences in remit between academics and non-academics (Arlettaz et al. 2010).

Questionnaire respondents

As we applied non-probabilistic sampling strategies, there is a general potential for bias related to an over-representation of respondents with especially strongly-held viewpoints (e.g. Bowen et al. 2009). The questionnaire sample was skewed towards respondents from MEDCs. Although the online questionnaire was disseminated widely throughout the amphibian conservation and research community, it was prepared in English, which may have discouraged non-English speakers. However, this sample may still be representative in terms of global amphibian research and conservation expertise. In their assessment of global amphibian taxonomic expertise, Rodrigues et al. (2010) found expertise to be concentrated in economically wealthy but biodiversity-poorer countries in North America and Europe, with many developed country experts also working abroad in more biodiversity-rich countries. IUCN SSC Amphibian Specialist Group membership, which provides the most accurate proxy of amphibian conservation expertise per country, currently reports a mean number of members per MEDC of 9 (± 3.67, 1.s.e., $n = 27$) whilst the mean number per LEDC is 4 (± 0.76, 1.s.e., n= 59) (ASG 2014). This lower representation of amphibian specialists in LEDCs would contribute to a reduced proportional questionnaire response rate, and may also impact other areas of interest, such as conservation programme number, development, collaboration, and research output. If we disproportionately captured rich country viewpoints, then this is in part representative of the currently unequal distribution of amphibian conservation expertise globally. However, the ASG reports 240 MEDC members across 27 countries, and 260 LEDC members across 59 countries. More research is therefore necessary to better understand the viewpoints of amphibian conservationists in LEDCs.

Conclusion

The variety of notions of success is perhaps partially an artefact of the difficulty of objectively assessing conservation impacts (Mace et al. 2007). This means that initial attempts to assess conservation projects focussed on monitoring inputs and outputs (e.g. Miller et al. 2004) rather than outcomes and impacts, which can be more difficult to evaluate. Achieving funding and securing collaborators (inputs) and/or looking at goals achieved (outputs) may become incorporated into concepts of success because they are easily measured, rather than because they are determinants of long-term positive change. Conservation success can only be fully understood when a wide variety of programme data are evaluated, such as ecological, geographic, socioeconomic, demographic, political and institutional measures (Ferraro & Pattanayak 2006). Gathering and analysing such data present serious logistical, financial and analytical challenges in terms of mobilising cooperative cross-disciplinary expertise and obtaining meaningful results (Ferraro & Pattanayak 2006; Jones 2012). However, the effective management of species and ecosystems demands an interdisciplinary understanding of social-ecological systems (Mascia et al. 2003; Adams 2007; St. John et al. 2014), which would improve our ability to evaluate and understand successful approaches in conservation. Also, understanding how success is perceived by a broad range of relevant stakeholders is crucial from the outset; a "one size fits all" definition of success will not satisfy diverse audiences. Soulé (2014) expressed concern that proponents of an entirely humanitarian approach to conservation believe preserving nature for its own sake to be a "*dysfunctional, antihuman anachronism*" (p. 895). Perspectives in amphibian conservation may increasingly be embracing anthropocentric concepts, concordant with a general transition in the framing of conservation as a discipline (Mace 2014), although this need not be cause for apprehension. Ultimately, conservation programmes should take a pluralistic and pragmatic approach, adopting multiple goals according to their context, and seeking effective action that is sustainable ecologically, culturally, socially, economically and politically (Robinson 2011).

Success is a value interpretation (Büscher 2014), which is shaped by an individual's worldview (Jones 2012). Since worldviews may be influenced by everything from a person's experiences and geographic location, to the latest theories on what constitutes success, it is intuitive that conservation should be appraised in a wide variety of ways. Furthermore, competition for funding drives conservation scientists and practitioners to formulate diverse success stories, in part because "*the cycle of success is actively guarded – renewal of funding is contingent on success…Few have ever been rewarded for anything other than success*" (Redford & Taber 2000, p1568), which may obscure our understanding of success in conservation. Publicised success stories may inform our perceptions, whether or not these "successes" are objectively sound. The propagation of optimistic conservation messages is crucial in myriad ways to the future of conservation efforts (Beever 2000; Webb 2005; Swaisgood & Sheppard 2010; Garnett & Lindenmayer 2011), but so too is learning from our mistakes (Redford & Taber 2000; Adams et al. 2002; Knight 2006), as only this will lead to improved understanding of the true nature of success in conservation, and how it can be realised, sustained and replicated. Understanding failure in conservation, and how to learn from it, is just as important as understanding success. Conservation must develop new strategies to acknowledge, manage, and navigate failure to improve the effectiveness of conservation action, taking guidance and inspiration from other fields actively engaged in failure management. Further research should investigate perceptions of failure to aid the development of strategies to identify and overcome mistakes in the future. As we move forward, we must continue to learn from unsuccessful approaches, and adopt a sufficiently broad and informed view of achieving success in conservation that represents the diverse skill-sets and perspectives being absorbed by conservation science and practice.

Chapter 3: Are we meeting amphibian conservation research needs?

Abstract

Scientific literature supports the conservation of natural resources in many ways, providing information on threats, conservation management, and the abundance of species. Research into the systematics, biology and ecology of species can also inform conservation strategies, whilst studies that make use of species (e.g. for medical research) further increase our understanding of the value of biodiversity to humans. It is therefore important to understand the content of the literature, not least to enable recommendations for future research. We assessed all literature published on a sample of 600 amphibians between 1970 and 2013, stratified by IUCN extinction risk category. One hundred and five species lacked any publications, including 18% of threatened (CR, EN, VU species), 10% of non-threatened (NT and LC species), and 31% of data deficient species. Despite increasing steadily since the mid-1980s, conservation-related research constituted just 12% of the 3485 studies published: 1% on species abundance and monitoring, 8% on threats, and 3% on conservation management. A low proportion of species, especially threatened species, had any studies relating to threats as documented by the IUCN Red List (between 0% and 30% of species depending on the threat). Threats such as exploitation, pollution, and habitat destruction and fragmentation (the leading cause of amphibian declines) were particularly overlooked in research, whilst invasive species (including disease) was the most studied threat. Eighty-four percent of threatened species lacked research on threats, conservation-management, and abundance, versus 74% of non-threatened species. Non-threatened species were the subject of significantly more threat and conservation-management studies. Publications on issues relevant to the conservation of amphibians were associated with authors from non-academic institutions within range countries of the species, indicating that in-country collaborative conservation science is crucial to boosting conservation-related research in the future.

Introduction

Scientific studies form the basis of science-led conservation (Dicks et al. 2014a), providing crucial evidence to support conservation interventions (Sutherland et al. 2004), and systematic conservation planning (Margules & Pressey 2000). Science also provides fundamental information on the natural history and ecology of target species (Arnold 2003; McCallum & McCallum 2006), their abundance in the wild (Nichols & Williams 2006), and the processes that threaten them (e.g. Smith et al. 2006; Gardner et al. 2007). Accurate and up-to-date knowledge of taxonomy and systematics provides an essential classification framework for research and conservation (Minton 2005), and enables prioritisation measures based on phylogenetic relatedness (Isaac et al. 2007, 2012). Even research that makes use of species as model organisms in laboratory research and pharmacology studies can further demonstrate the many services provided by biodiversity to humans (Burggren & Warburton 2007; Gomes et al. 2007). A balanced and thorough understanding of the natural world, as documented in the scientific literature, underpins attempts to stem biodiversity loss (Brooke et al. 2014).

However, a great number of biases are perceived in published studies, including those related to taxonomy, extinction risk status, research topic, geographic location, ecological systems and species "charisma" (Clark & May 2002; Báldi & McCollin 2003; Lawler et al. 2006; Rodrigues 2007; Wilson et al. 2011). Historical factors can also lead to taxonomic and topic-related biases in cases where long-standing research traditions result in "*more giants upon whose shoulders one can stand*" (Shine & Bonnet 2000, p.221), broadening the knowledge gap between well-known and neglected areas. Biases may trickle down through the peer-review process across generations, as increased data availability begets continued high levels of research attention (Schipper et al. 2008; González-Suárez et al. 2012). Additionally, there is a "research-implementation gap", whereby conservation science seldom meets the needs of practice, or delivers real-world action (Anonymous 2007; Knight et al. 2008; Sunderland et al. 2009; Pietri et al. 2013). The differing roles and responsibilities of scientists and practitioners can present significant challenges to the development of research that improves conservation implementation (Arlettaz et al. 2010). This situation has led to questioning of the content and relevance of the conservation literature (Milner-Gulland et al. 2009; Griffiths & Dos Santos 2012), necessitating efforts to understand the biases inherent in published studies, particularly those that impede conservation action.

Interest in amphibian conservation has been mounting as experts anticipate an unprecedented extinction crisis (Beebee & Griffiths 2005; Wake & Vredenburg 2008). Amphibian declines have attracted growing concern globally (Stuart et al. 2004), with extinction rates accelerating at orders of magnitude above background levels (McCallum 2007). However, amphibians are the least prevalent vertebrate taxon featured in leading conservation journals (Griffiths & Dos Santos 2012). Their appearance in publications has been found to warrant greater concealment behind theoretical frameworks than is the case for mammals and birds (Bonnet et al. 2002), indicating lesser interest in their research. However, conservation objective-setting and action should be underpinned by the best available science (Kinnaird & Timothy 2001; Pullin & Knight 2001; Stewart et al. 2005), subject to peer-reviewed publication as assurance of quality (Tear et al. 2005). Amphibians need this research now more than ever.

Previous cross-taxonomic research into the content of the conservation literature has focused on characteristics of literature published in leading conservation journals (e.g. Clark & May 2002; Fazey et al. 2005a,b; Campbell 2007; Milner-Gulland et al. 2009; Griffiths & Dos Santos 2012), but much information relevant to conservation can be found in non-conservation journals. For example, less than 20% of all studies included in the evidence synopsis "*Amphibian Conservation: Global evidence for the effects of interventions*" (Smith & Sutherland 2014) were found in journals concerned with conservation and environmental management, and of these just 7% were found in the leading conservation publications scrutinised by these previous studies (e.g. *Animal Conservation*, *Biodiversity and Conservation*, *Biological Conservation*, *Conservation Biology*, and *Oryx*). Our study is an unrestricted assessment of the amphibian literature (i.e. including all journals), investigating the extent of biases in the availability of conservation-related research. We specifically assess how the literature has changed over time, whether IUCN extinction risk status influences the amount and type of studies available, and whether the literature is responding to information needs required to improve conservation efforts for amphibians. We also examine conservation-related publications to determine correlates of their authorship to find ways of promoting the production of relevant research in the future.

Methods

Bibliometric data collection

A list of 600 amphibian species was compiled, sampling 100 species from each of the IUCN Red List categories at random (IUCN 2014): Critically Endangered (CR); Endangered (EN); Vulnerable (VU); Near Threatened (NT); Least Conservation (LC); and Data Deficient (DD). Risk status was drawn from the 2014 IUCN update (IUCN 2014). A proportionally representative sample was not taken from each category because this would have resulted in highly imbalanced subsets across the six different categories, resulting in a pronounced bias towards NT and LC species. An equal number of species per category was randomly sampled to enable a more balanced assessment of how IUCN extinction risk status is related to research output. Although the IUCN Red List is regularly updated and species categories change over time, the rate of this change is typically slow. Hoffmann et al. (2010) showed of the 5489 mammal species reassessed in 2008, only 193 changed category from their previous assessment in 1996. We therefore assessed peer-reviewed scientific literature available to support conservation management of amphibian species in their current (2014) risk categories. Furthermore, although we recognise that globally non-threatened species may be nationally or regionally threatened, not all countries have national threatened species lists (Collen et al. 2008). This study therefore considers global extinction risk level and employs the IUCN Red List because it is the best and most complete standardised assessment of extinction risk at the global scale (Lamoreux et al. 2003; Rodrigues et al. 2006). We quantified the variation and content in species' research effort published between January 1970 and December 2013 by assessing peer-reviewed literature listed in Thomson Reuters' Web of Science© (WoS) database for the 600 species in our sample. The WoS database of publications is described as comprehensive but not all-inclusive, covering over 12,000 top tier international and regional journals in all areas of the natural sciences, social sciences, and arts and humanities (Testa 2012). Although the majority of journals are in English, foreign language publications are included where appropriate, and WoS journal lists are regularly updated to reflect the dynamics of global research developments (Testa 2012). WoS therefore does not cover the grey literature, and our study focuses only on peer-reviewed research in order to better understand global research production, at least in terms of publically available records of conducted research. We recognise the value of the grey literature, but its explicit analysis is beyond the scope of our study.

Each species' scientific binomial and any synonyms were entered as search terms into the "Topic" field, which includes title, abstract, keywords and Keywords Plus (index terms created from significant, frequently occurring words in the titles of an article's cited references). Scientific species names adhere to those used by the IUCN Red List, but WoS searches included all relevant synonyms recorded by Amphibian Species of the World (Frost 2014). A database was compiled in Microsoft Access to include all relevant publications listed by WoS for each species. Publication relevance was confirmed by reading the abstract of each article and, if necessary, the full publication, filtering out any duplications in the WoS database and any publications that did not directly mention the species in question. Where more than one species from our sample was the focus, the paper was recorded once for each of the study species. For each relevant publication, information was collected on a number of bibliometric aspects, which were developed in consultation with researchers investigating correlates of research effort on different mammal species (Brooke et al. 2014), in addition to authorship correlates of the conservation impact of research (Campbell 2007; Milner-Gulland et al. 2009) (Table 3.1). Categories and sub-categories of research were developed *a priori* based on previous studies (e.g. Fazey et al. 2005b; Griffiths & Dos Santos 2012), and refined during data collection to best describe the assessed literature. All studies accessed through WoS were included in the database, so any missing research categories reflect areas of zero research availability.

Table 3.1. Bibliometric data collected. Information was collected for all publications on our sample of 600 species between January 1970 and December 2013.

Bibliometric data type	Categories and sub-categories of research
Research Category	▪ **General;** sub-categories = (i) Taxonomy & systematics; (ii) General species biology & ecology ▪ **Use;** sub-categories = (i) Amphibians as model organisms in laboratory research; (ii) Studies into skin secretions: potential pharmaceutical and other useful properties ▪ **Abundance*;** sub-categories = (i) Species monitoring; (ii) Papers on declines/localised extinctions ▪ **Threat*;** sub-categories = studies investigating, without mitigation, the following threats: (i) Habitat destruction & fragmentation; (ii) Pollution; (iii) Invasive & other problematic species; (vi) Exploitation; and (v) Climate change ▪ **Conservation-management*;** sub-categories = (i) Conservation prioritisation, assessments and recommendations; (ii) Species & habitat protection, restoration & management; (iii) Conservation Action Plans; (iv) *Ex situ* actions (including captive breeding/husbandry & genome resource banking); (v) Conservation evidence (investigating the effect of interventions). ***Abundance**, **Threat** and **Conservation-management** were also grouped together under the over-arching category of "**Conservation-related**" publications for certain analyses
Year	Year of publication
Impact Factor	Latest Journal Impact Factor as provided by Thomson Reuters' Web of Science©
Institution of First Author	Recorded as: *Academic; NGO; Government Agency; International Government Agency (e.g. IUCN); Zoos & Aquaria.* Also recorded whether the institution is located in a range country of the species
Country of First Author	Country recorded as location of first author's primary institution
Co-Authors	Total number of co-authors
Institution of Co-Authors	Institution of co-authors recorded as for first author. Also recorded whether the institution is located in a range country of the species

Data Analysis

Descriptive bibliometric analyses were conducted to determine research effort across IUCN extinction risk categories. Following IUCN convention (e.g. Hoffmann et al. 2010), species classified as Critically Endangered (CR), Endangered (EN) and Vulnerable (VU) were grouped as "Threatened", while Near Threatened (NT) and Least Concern (LC) species were grouped as "Non-threatened ", with Data Deficient (DD) species treated separately. This grouping permitted a clear distinction between research output on Threatened versus Non-threatened species, although further studies could evaluate categories separately to determine whether a particular level of extinction risk impacts research interest. Research type was considered under the broad headings of General, Use, Abundance, Threats, and Conservation-management (see Table 3.1). Following a study by Lawler et al. (2006), publications that investigated processes that produced, sustained or threatened biodiversity in the face of anthropogenic disturbance were considered the most relevant to conservation, hence publications under the categories of Threat and Conservation-management were grouped as "Conservation-related". The category of Abundance was also included under Conservation-related publications because monitoring and evidence of declines, in the context of adaptive conservation management, is crucial to conservation efforts (McDonald-Madden et al. 2001; Keith et al. 2011; Martin et al. 2012c). Separating Conservation-related publications into the sub-categories of Abundance, Threat and Conservation-management permitted a more detailed assessment of the evidence-base for different monitoring methods, threat types and conservation actions.

Kruskal-Wallis (KW) testing was used to identify whether there were significant differences between number of publications for Threatened, Non-threatened and Data Deficient species. *Post-hoc* multiple comparison testing was used to determine which of the pair-wise comparisons were responsible for any overall difference detected using the Kruskal-Wallis test (as in Brooke et al. 2014).

Generalised Linear Modelling (GLM) was used to compare the research output (number of papers) for Threatened and Non-threatened species under the research sub-categories of Threat and Conservation-management (see Table 3.1 for sub-categories). The response variable was the number of publications per species, and the two-way categorical explanatory variable was Threatened or Non-threatened. Absence of model overdispersion meant that a Poisson error distribution was used in all cases (Crawley 2007). Nagelkerke's R^2 was calculated to determine each model's explanatory power (Nagelkerke 1991). Although we look to the literature for conservation-related research that may support the implementation of conservation initiatives, we make no overt assumptions about the practical value of individual publications to conservation efforts, as this is not within the scope of our study.

To investigate whether different categories of research are associated with publication in journals of different mean Impact Factor, all publications that appeared in journals with a 2014 Impact Factor were sub-sampled from our dataset, looking at papers published between 2009 and 2013 to better reflect current ISI (Institute for Scientific Information) Journal Impact Factor (JIF) figures. Impact Factor was taken from the Journal Citation

Reports® (ISI 2014). Journal Impact Factor was used rather than the five-year Impact Factor because this allowed inclusion of a greater number of journals in our analyses. In order to investigate differences in mean Impact Factor between research categories, we compared log-transformed Impact Factors for the categories of General, Use and Conservation-related using ANOVA testing, with a *post-hoc* Tukey test to elucidate differences between the categories. We also categorised publications according to journal subject area to investigate the spread of information across journal disciplines, including: Conservation (conservation biology and environmental/wildlife management); Threats (specialist disease, climate change and environmental contamination journals); Herpetology (journals restricted to the study of amphibians and reptiles); Ecology; and General (including topics such as general biological sciences, zoology, and veterinary science).

Our analysis of authorship factors related to Conservation-related publishing builds on previous research investigating the relationship between research type and conservation impact (Campbell 2007; Milner-Gulland et al. 2009), which was used to guide our selection of potential variables explaining conservation-related research output. GLM was used to explore the relationship between whether a publication was Conservation-related, a binomial variable (1 = Conservation-related, 0 = not Conservation-related), and six explanatory variables relating to authorship. The sample of articles was split into two groups of countries based on current standardised differences in economic development (IMF 2014). Articles (both Conservation-related and otherwise) were divided between those with first authors from Less Economically Developed Countries (LEDCs; otherwise termed Developing Economies by IMF); and those with first authors from More Economically Developed Countries (MEDCs; otherwise termed Advanced Economies by IMF) (IMF 2014). GLMs with a binomial error distribution were constructed for both MEDC and LEDC samples. Of the six authorship explanatory variables, two related to the publication's first author: i) the institution type of the first author (academic or non-academic institution), and ii) the location of the first author's institution at the time of publication in relation to a country that includes at least part of the focal species' distribution range (inside or outside of a species' “range country”). A further four explanatory variables related to co-authors: presence (Yes or No) of at least one co-author from any of the following: i) academic institutions within a focal species' range country; ii) academic institutions outside a species' range country; iii) non-academic institutions within a focal species' range country; iv) non-academic institutions outside a species' range country. Analysis was restricted to a sample of articles published between January 2000 and December 2013. Nearly 80% of Conservation-related articles in our sample were published since 2000, and this also meant that a recent standardised indicator for the wealth of countries could be used (i.e. Advanced or Developing Economies based on

IMF 2014). Models were checked for multicollinearity by calculating Variance Inflation Factors (VIF) for each constituent set of variables. VIFs were uniformly low (<1.5) suggesting that collinearity was unlikely to be significantly affecting these models (Brooke et al. 2014). Models were also checked for overdispersion, but this did not occur in either MEDC or LEDC models. Models were simplified by removing the least significant factor, and testing models before and after removal for significant increases in deviance using Chi-squared tests (Crawley 2007). If there was a significant increase in model deviance upon removal of a factor, the factor was retained in the model. Nagelkerke's R^2 was calculated for the final models to determine their explanatory power (Nagelkerke 1991). All analyses were conducted using R version 3.0.0 (R Core Team 2013). We also examined the proportion of species in our sample across different global regions (UN 2014) relative to the proportion of first authors based in species' range countries within that region, for both Conservation-related and General/Use research.

Results

Extinction risk

A total of 3485 publications published between January 1970 and December 2013 were recorded across the sample of 600 species. The percentages of publications attributed to our research categories were as follows: General - 80%; Use - 8%, Abundance - 1%; Threat - 8%; and Conservation-management - 3%. The number of publications per species ranged from zero (for 105 species) to 336 (for *Pelophylax* (formerly *Rana*) *perezi;* which is Least Concern and native to France, Spain and Portugal). Eighteen percent of Threatened species (54 of 300 species) had no publications, versus 10% of Non-threatened species (20 of 200) and 31% of DD species (31 of 100). Threatened, Non-threatened and DD species were found to have significantly different levels of research effort (Kruskal-Wallis test: H = 44.709, df = 2, p = <0.001). Median publication number per species was two for Threatened species (interquartile range [IQR], 1-4; range = 0-59; n = 300), three for Non-threatened species (IQR, 1-8; range = 0-336; n = 200) and one for DD species (IQR, 0-2; range = 0-9; n = 100). The number of publications for Non-threatened species was significantly higher than for Threatened (KW: $p < 0.05$) and DD species (KW: $p < 0.05$). Threatened species also had significantly more publications than DD species (KW: $p < 0.05$).

General publications (n = 2781) were fairly equally split between the sub-categories of taxonomy & systematics (44%, n = 1212) and species biology & ecology (56%, n = 1569). However, this ratio was influenced by IUCN extinction risk status; the proportion of publications on taxonomy & systematics was higher for the Threatened (54%, 544 of 1002

General publications across 300 species) and Data Deficient species (84%, 132 of 158 General publications across 100 species) than for Non-threatened species (33%, 536 of 1621 General publications across 200 species). There were 278 Use publications; 11% featured Threatened species, 88% Non-Threatened species, and 1% DD species. Conservation-related publications are considered below.

Conservation-related publications

There were 426 Conservation-related publications in total. Eighty-four percent of Threatened (252 of 300), 74% of Non-threatened (148 of 200) and 97% of Data deficient (97 of 100) species lacked Conservation-related research. Abundance was the least prevalent research category, with 51 publications split between 26 species (16 Threatened; 10 Non-threatened). Of these 51 publications, 65% described declines and the remainder reported monitoring techniques and results. There were 285 Threat publications, relating to 70 species (31 Threatened; 37 Non-threatened; 2 Data Deficient). Species-specific threats documented by the IUCN Red List (IUCN 2014) did not form the subject of Threat publications in the majority of cases. Figure 3.1 contrasts the proportion of IUCN Red Listed amphibian species affected by five major threat categories (Figure 3.1a) with the proportion of species from our sample where IUCN-documented threat types were addressed in the literature (Figure 3.1b). The percentage of species from our sample of 600 that lacked even a single publication addressing a documented major threat type (as classified by IUCN 2014) was: Habitat destruction & fragmentation - 97% of species; Pollution - 93%; Invasive species & disease - 77%; Exploitation - 97%; and Climate change - 91%.

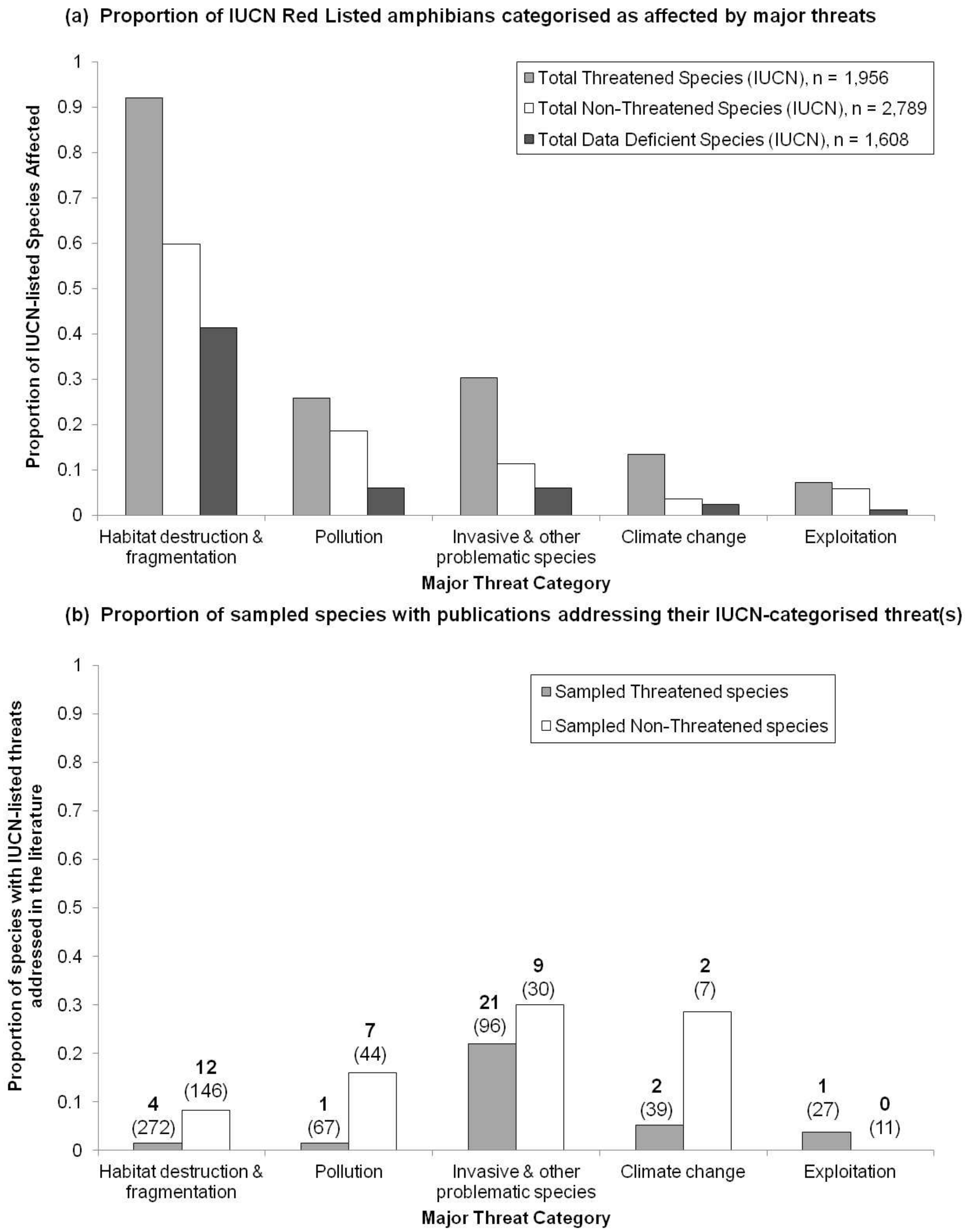


Figure 3.1. Publications on IUCN-classified threats: (a) Proportion of IUCN Red Listed amphibian species (IUCN 2014) affected by major threat types; (b) Proportion of sampled species with IUCN-categorised threats addressed in the literature; numbers in bold above columns are the total number of species from our sample that have studies on the threat (numbers in parentheses are the total species in our sample affected by the threat). Data Deficient species had no threat studies and are not included in Figure 3.1b.

Research effort (as indicated by mean publication number per species) on Threat types differed between Threatened and Non-threatened species (Figure 3.2). When each research sub-category for Threat was independently compared for Threatened and Non-threatened species (excluding DD species due to the negligible publication output of Threat research), differences were found in several cases. Non-threatened species had a significantly higher number of papers on the following topics: Habitat destruction and fragmentation (GLM: z = -4.139, SE 0.424, p = <0.001, df = 499, R^2 = 0.121); Pollution (GLM: z = -5.480, SE 0.717, p = <0.001, df = 499, R^2 = 0.274); Invasive species & disease (GLM: z = -6.574, SE 0.101, p = <0.001, df = 499, R^2 = 0.112); and Climate change (GLM: z = -5.514, SE 0.407, p = <0.001, df = 499, R^2 = 0.143).

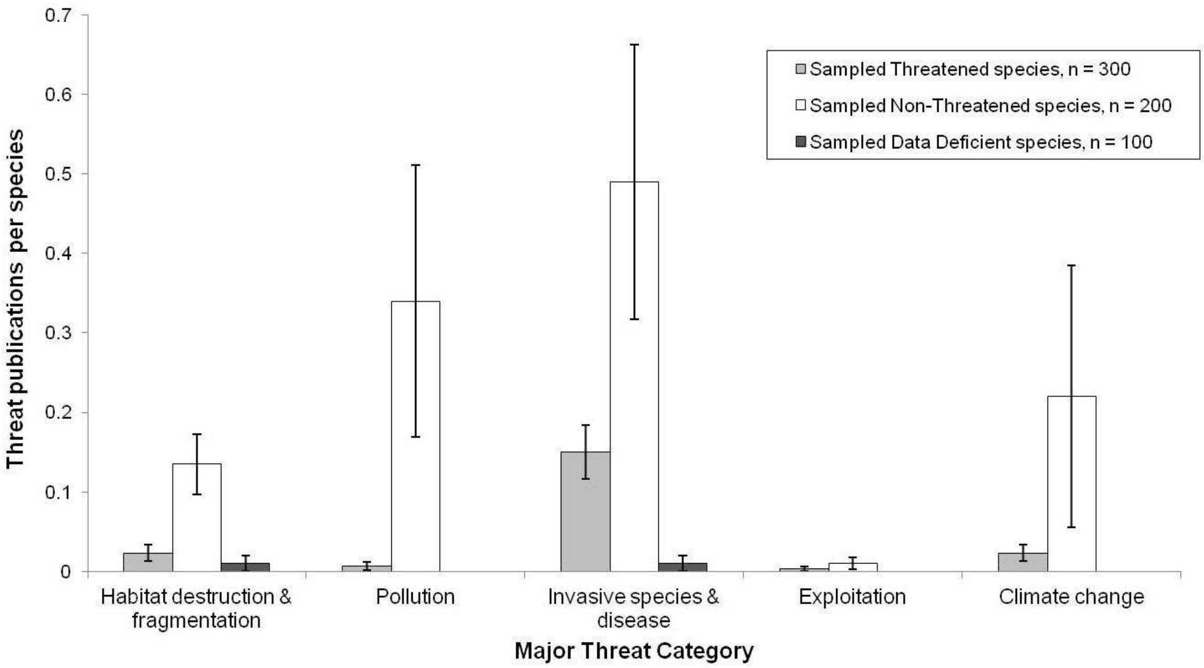


Figure 3.2. Number of Threat publications per species. Publication rate calculated by dividing overall number of publications for Threatened, Non-threatened and Data Deficient species per research sub-category by the number of species in these samples. Publications on multiple threats (5 articles) were counted once for each constituent major threat type. Standard errors bars (± 1 s.e.) displayed.

There were 90 Conservation-management publications relating to 50 species (18 Threatened; 31 Non-threatened; 1 Data Deficient). Output varied according to different sub-categories of Conservation-management research (Figure 3.3). There were no publications on education, public engagement, sustainable use, or conservation programme evaluation, so these topics are not reflected in our results. When each research sub-category for Conservation-management was independently compared for Threatened and Non-threatened species (excluding DD species due to the negligible publication output of Conservation-management research), significant differences were found in several cases. Non-threatened species were associated with higher research output in the following Conservation-management sub-categories: Conservation prioritisation, assessments &

recommendations (GLM: z = -2.171, SE 0.271, p = 0.030, df = 499, R^2 = 0.0208); and *Ex situ* actions (GLM: z = -3.070, SE 0.563, p = 0.002, df = 499, R^2 = 0.0890). There was a complete lack of publications for Threatened species in the sub-categories of Species/habitat protection, restoration & management (n = 5 papers for Non-threatened species) and Conservation evidence (n = 8 papers for Non-threatened species). There were no publications under Conservation Action Plans for Non-threatened species (n = 2 papers for Threatened species). Low R^2 values in all GLMs suggest that other untested factors contribute to explaining the variance observed in the number of papers in different Threat and Conservation-management research categories.

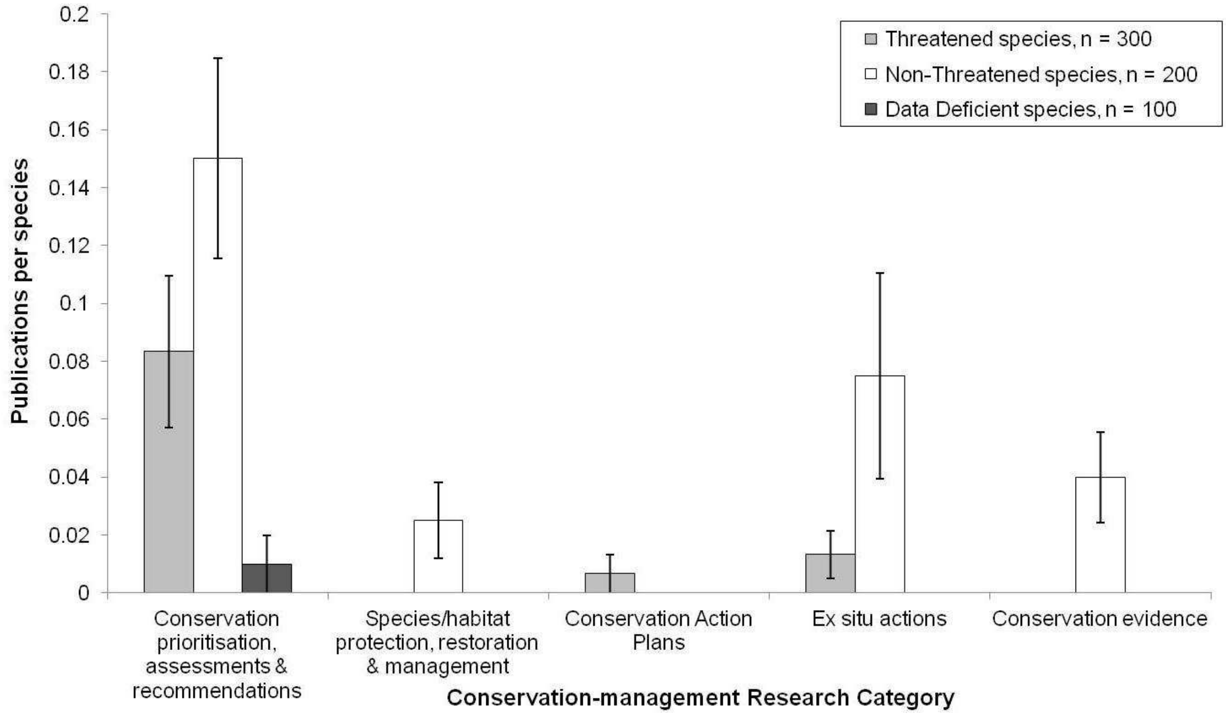


Figure 3.3. Number of Conservation-management publications per species. Publication rate calculated by dividing overall number of publications for Threatened, Non-threatened and Data Deficient species per research sub-category by the number of species in these samples. Standard errors bars (± 1 s.e.) displayed.

Temporal trends

There was an increasing trend in annual publication rate across Non-threatened, Threatened and DD species from 1970 to 2013, although publication rate peaked in 2007 for Non-threatened species (when total publication number also peaked) and 2010 for Threatened and DD species (Figure 3.4).

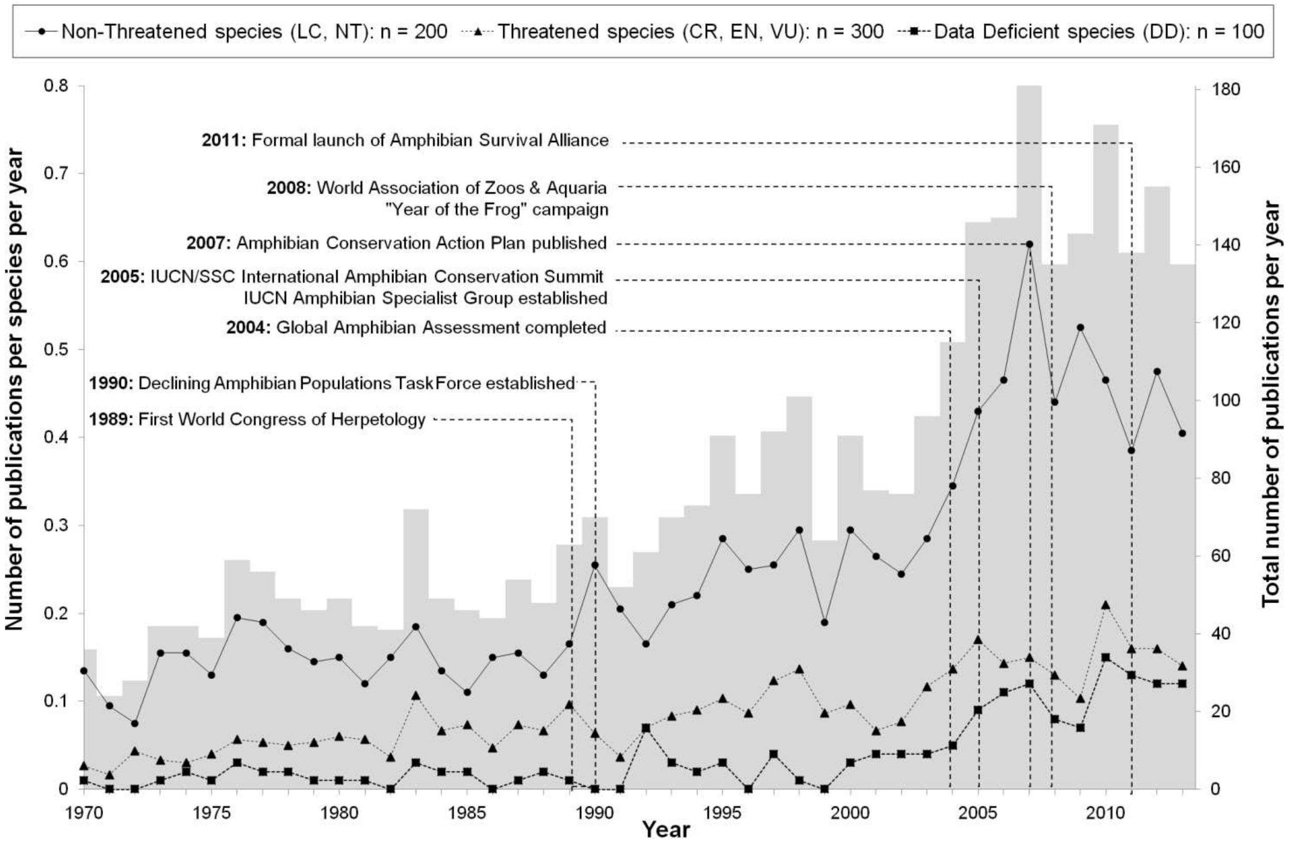


Figure 3.4. Annual publication rate for sampled species. Annotated with notable events in global amphibian conservation. Number of publications per year for Threatened , Non-threatened and Data Deficient species are displayed as line graphs against the primary axis. Total number of publications per year across the sample of 600 species is displayed as a grey bar chart against the secondary axis.

Rates of publication in all research categories increased from 1970, with General publications peaking in 2007 and Conservation-related publications peaking in 2013 (Figure 3.5a). Use publications peaked in 2012, and studies into skin secretions (investigating potential pharmaceuticals and other useful properties) steadily increased from 2002, superseding model organism research in 2007 to become the majority sub-category of Use research. Research effort on different major threat categories varied according to the threat (Figure 3.5b), with publications on invasive and other problematic species (which includes disease) being most prevalent. Of the 153 publications investigating invasive and other problematic species, 58% focused on the fungal pathogen *Batrachochytrium dendrobatidis*. Pollution had the second highest publication rate, with a total of 62 publications. Of the 42 publications on Climate change, 79% focussed on the detrimental impact of UV-B radiation on amphibians. Habitat destruction and fragmentation received a low level of research attention, with just 36 publications overall. Exploitation, represented by just three publications, was by far the least researched threat topic.

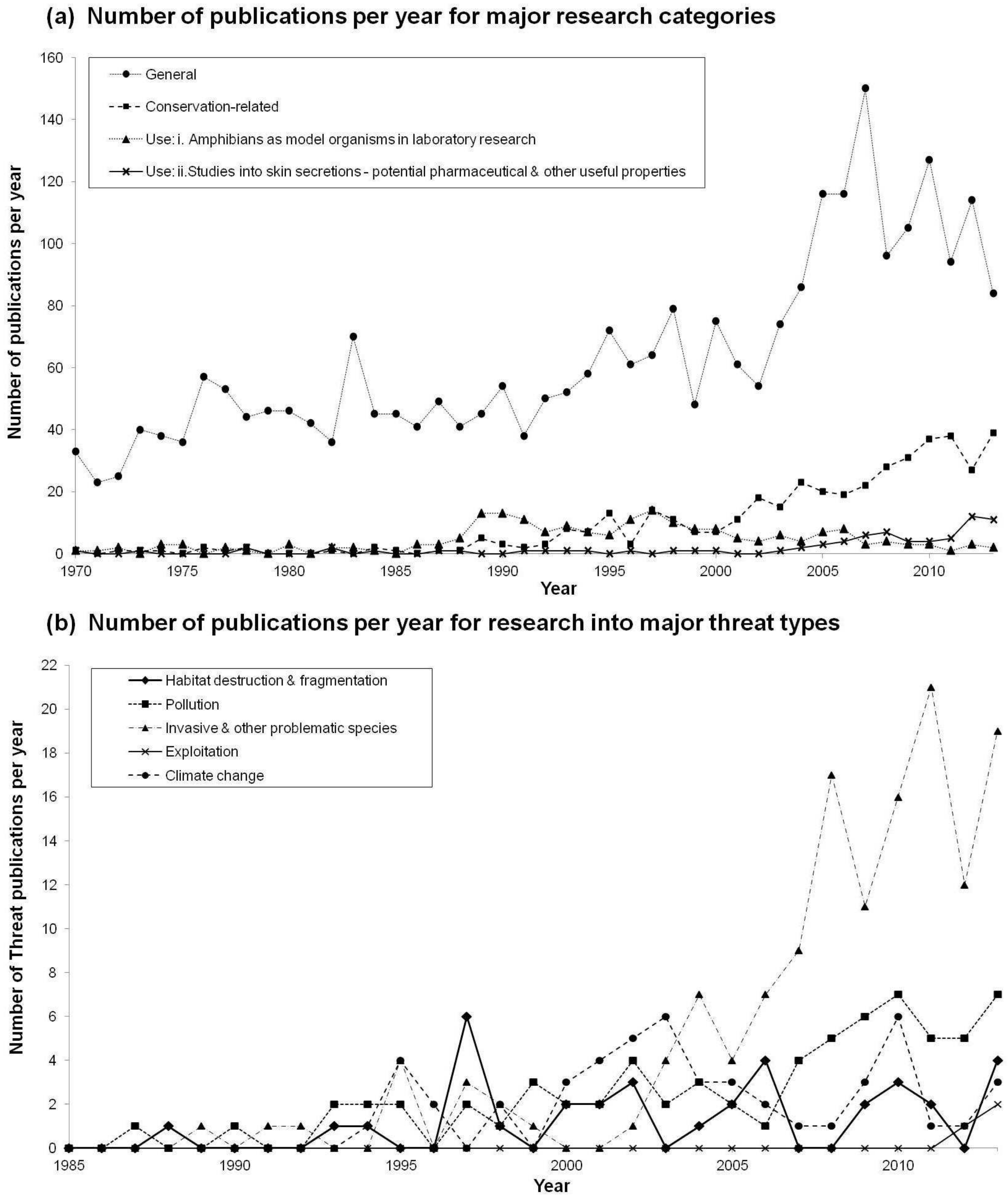


Figure 3.5. Annual publication rates for different research topics. Temporal trends for: (a) research categories of General, Use and Conservation-related; and (b) different major threat types.

Journal Impact Factor and subject area

Our dataset included 696 journals, with Impact Factors ranging from 0 to 42.4. General amphibian publications were featured in 549 of these journals, Use articles in 129 journals, and Conservation-related articles in 144 journals. When considering only articles appearing in journals with ISI registered JIF between 2009 and 2013, a significant difference ($F_{2,598}$ = 28.19, p = <0.001) was found between the JIF of articles for General (mean = 1.400, ±

0.104, 1 s.e., n = 414), Conservation-related (mean = 2.203, ± 0.170, 1 s.e., n = 146) and Use (mean = 2.469, ± 0.270, 1 s.e., n = 41). A *post-hoc* analysis using Tukey's multiple comparisons test revealed that JIFs associated with Use and Conservation-related publications were significantly higher than those for General (p = <0.001 in both cases), but mean impact factors for Use and Conservation-related publications were not significantly different from each other (p = 0.650). Also, a greater proportion of Conservation-related publications are found in higher impact journals than General and Use publications. Seven percent of Conservation-related studies (31 of 426 publications) were found in journals with a JIF of 5 or more, versus 3% of General studies (73 of 2783 publications) and 4% of Use studies (12 of 276 publications).

Conservation-related publications appear in journals from a variety of different subject areas: Conservation (18% of articles), Threats (e.g. journals on disease, climate change and environmental contamination; 20%), Herpetology (16%), and Ecology (13%) contain the majority of the Conservation-related articles. However, 34% of articles appear in General journals, which include biological sciences, zoology, and veterinary science. Abundance publications were found in 33 journals, Threat publications in 104 journals, and Conservation-management publications in 39 journals.

Authorship correlates of "Conservation-related" publications

Between 2000 and 2013, 44% Conservation-related publications on species occurring in LEDCs (40 of 91 studies) were carried out by first authors based in a country that includes at least part of the focal species' distribution range (hereafter "species range country"). However, 54% of these publications (49 of 91 studies) had a first author from an MEDC outside of the species' range, only 29% of which (14 studies) included a range-country co-author. For species occurring in at least one MEDC, 93% of 257 Conservation-related publications had an MEDC range-country first author, and 89% included at least one range-country co-author. Incidentally, examining co-authorship for all research published between 2000-2013 (both Conservation-related and otherwise), for publications on species found in LEDCs with a non-range country MEDC first author (n = 451), there was no corresponding author from a species range country in 76% of cases (345 studies).

Relative to the regional distribution of species from our sample, the proportion of first authors from Europe and North & Central America was disproportionately high, and very low in Africa, including both Conservation-related and General/Use research (Figure 3.6). Of the 404 publications on African species, only 25% had first authors based at institutions within species' range countries. Sixty-nine percent of research carried out on species from Africa was conducted by first authors from Europe and North & Central America (chiefly the United States and Canada). The region with the second lowest level of first authorship from species range countries was South America (48% of 665 publications), where 46% of the research was published by first authors from Europe and North & Central America. Of the remaining regions, first authors were based in species range countries to the following degrees: 82% (*n* = 162) for Australasia; 73% (*n* = 1150) for North & Central America; 73% (*n* = 568) for Europe; and 65% (*n* = 519) for Asia. All preceding summary percentages were corrected for species from multiple regions. The top ten countries in our sample for Conservation-related research first authorship were: the United States (163 publications); Spain (29); Australia (23); Portugal (15); Germany (13); New Zealand (13); United Kingdom (12); Italy (11); South Africa (10); and US-territory Puerto Rico (7).

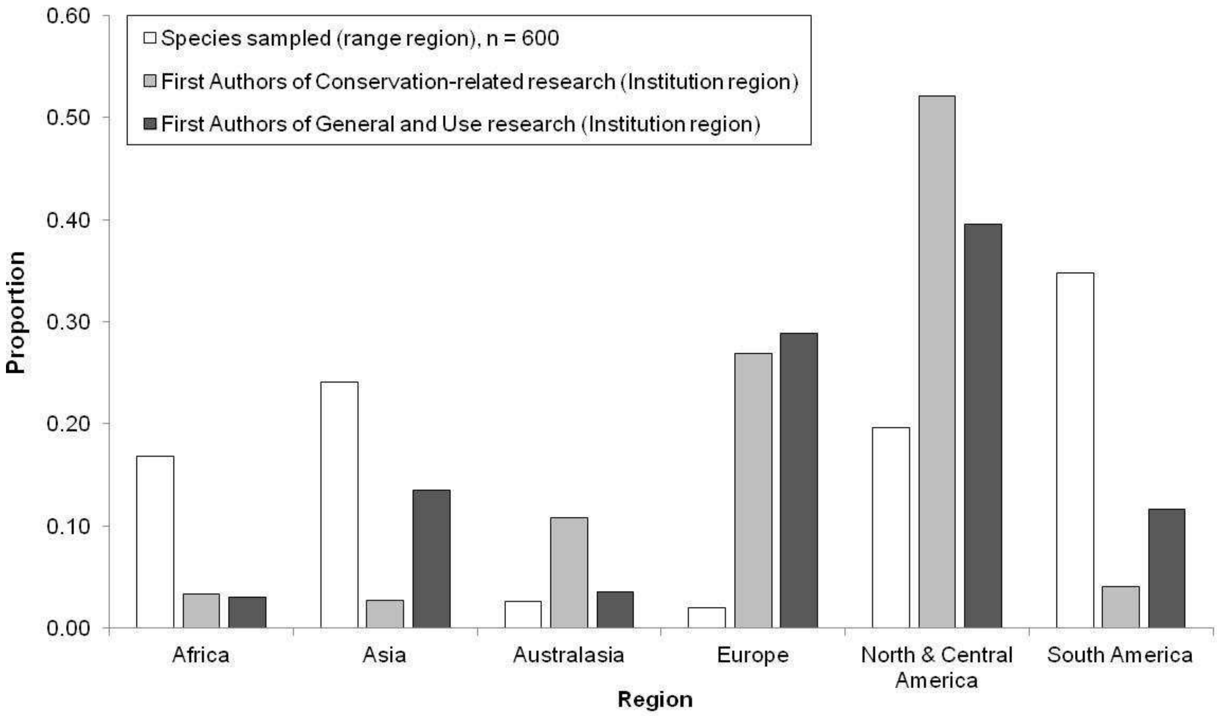


Figure 3.6. Regional distribution of first author institutions relative to sampled species. Total research output for different regions: Africa (*n* = 106 publications); Asia (*n* = 421); Australasia (*n* = 156); Europe (*n* = 998); North & Central America (*n* = 1435); South America (n =369). Species from more than one region were counted once for each region of occurrence.

For studies published between January 2000 and December 2013, we analysed Conservation-related publications separately for Advanced (MEDC) and Developing (LEDC) Economy countries (IMF 2014) to investigate how authorship affects conservation publication output in different economic settings. Within LEDC countries, the results suggest that Conservation-related publications are associated with co-authors from institutions that are based in a species range country (Table 3.2a), whether from non-academic ($p < 0.001$)

or academic (p <0.05) institutions. Collaborators from academic institutions not within a species' range country were also significantly associated with Conservation-related publications (p <0.05), but no first author factors were significant. Within MEDC countries, Conservation-related publications were associated with range-country first authors (Table 3.2b). The number of Conservation-related publications was significantly higher when first authors were based at non-academic institutions ($p < 0.001$). Publications were also more likely to be Conservation-related when they included co-authors from non-academic institutions, either based in a species range country ($p < 0.01$) or outside a species range country ($p < 0.05$). Conservation-related publications were also significantly higher when publications included co-authors from academic institutions within a focal species' range country ($p < 0.001$). In both MEDCs and LEDCs, collaboration with individuals in non-academic institutions and those within a species' range country increases the likelihood that research will be more conservation-focused. The R^2 values for both models were low (see Table 3.2). Although a series of authorship variables were significant in explaining variance associated with whether publications were conservation-related, it is apparent that other untested factors also contribute to the observed variance.

Table 3.2. Minimal adequate GLM for authorship correlates of Conservation-related publications (2000-2013) from first authors in Developing Economies (LEDC) and Advanced (MEDC) Economies. Based on 539 publications for Developing Economies (39 of these Conservation-related) and 1267 publications for Advanced Economies (296 of these Conservation-related). A "species range country" includes at least part of the species' distribution. * *$p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.* R^2 (LEDC model) = 0.0863; R^2 (MEDC model) = 0.136.

(a) Publications with First Authors based in Countries with Developing Economies (df = 538)			
	Estimate	**Std. Error**	**z value**
(Intercept)	-4.091	0.576	-7.101***
One or more Co-Author(s) from Non-Academic Institution within species range country	2.172	0.515	4.222***
One or more Co-Author(s) from Academic Institution within species range country	1.355	0.543	2.497*
One or more Co-Author(s) from Academic Institution outside species range country	0.785	0.395	1.989*
(b) Publications with First Authors based in Countries with Advanced Economies (df = 1266)			
	Estimate	**Std. Error**	**z value**
(Intercept)	-2.300	0.153	-15.065***
First Author from Non-Academic Institution	0.745	0.245	3.045**
First Author from Range Country	0.834	0.188	4.430***
One or more Co-Author(s) from Non-Academic Institution within species range country	0.644	0.203	3.181**
One or more Co-Author(s) from Non-Academic Institution outside species range country	1.136	0.464	2.446*
One or more Co-Author(s) from Academic Institution within species range country	0.590	0.175	3.371***

Discussion

Extinction risk

The fact that non-threatened amphibians received more research attention than threatened species concurs with similar findings across a range of taxa (e.g. Lawler at al 2006; Stein et al. 2002), including fish (Azevedo et al. 2010), corals (Fisher et al. 2011), birds (Brito & Oprea 2009), carnivores (Brooke et al. 2014), and felids (Brodie 2009). However, the relationship between extinction risk and research effort is not always so clear. Similarly, a study of the PanTHERIA database (a large mammalian life-history dataset; Jones et al. 2009) found more entries per species for non-threatened species (González-Suárez et al. 2012). However, a study of Southern African vertebrates in the Zoological Records Database (1994 to 2008) found more entries for threatened large mammals (body mass ≥2 kg) than lower risk species within this category, although the reverse was true for small mammals (<2 kg) (Trimble & Van Aarde 2010). Research attention can also be contingent on factors such as perceived species charisma and general popularity (Wilson et al. 2011), although amphibians are not widely subject to charisma-based special attention (e.g. Dreitz 2006). Issues associated with the study of threatened species may preclude wider research attention, as stated by Wilson et al. (2011, p. 411): "*Common species may be studied because they are abundant and easier to collect, while the study of endangered species has many practical limitations and special ethical concerns*". Wilson et al. (2007) also found a tendency for researchers to focus on species with ranges close to their own physical location, implying that logistical issues also can influence research choices. The relationship between extinction risk and the allocation of research and conservation resources has been argued across a spectrum of strategies. These include: prioritising the most threatened species (Sagoff 1996; Dunn 2002; Brito & Oprea 2009; Brodie 2009); opting for triage solutions that focus on moderately threatened species where there is a good chance of conservation success (McIntye et al. 1992; Bottrill et al. 2008); and recognising the value of common species by understanding and maintaining their vital functions in ecosystems (Gaston & Fuller 2008; Gaston 2010). Information is therefore also required to help conserve less threatened species; although a lack of research attention on threatened species is worrying if amphibian declines and extinctions are to be prevented using science-based conservation in the future.

Conservation-related research

The vast majority of Threatened, Non-threatened and Data Deficient species in our sample lacked any conservation-related research, with Threatened and Data Deficient species left particularly wanting. Non-threatened species were the subject of significantly more studies into all major threat types except exploitation, which accounted for just two publications across our sample (one Threatened species and one Non-threatened species). Contrasting known threat types for species (as recorded by IUCN 2014) with the presence of studies in the literature, habitat destruction and fragmentation remains one of the most overlooked threats, and invasive and other problematic species (including disease) the most studied. Low levels of research effort on habitat change may signify a presumption that we already understand the associated ecological mechanisms of this threat. Gardner et al. (2007) challenged this assumption for amphibians and reptiles and found it inaccurate, concluding that habitat change demands considerably more research attention, particularly in the tropics. Improving our understanding of the leading cause of amphibian declines is therefore a research priority for the future. Within the general conservation literature, Fazey et al. (2005b) also noted the apparent lack of research attention on the loss of native habitat, finding that 54% of habitat studies published in the journals of *Conservation Biology*, *Biological Conservation*, and *Biodiversity & Conservation* focused on undisturbed habitat. Certain biomes and threats are known to be under-represented in the literature (Lawler et al. 2006), and priority conservation sites can be similarly neglected (e.g. Fisher et al. 2011). Research may instead focus on conservation problems that are easier to study (McNie 2007), or species with desirable qualities, such as a large range size (Brooke et al. 2014). Additionally, scientists may prefer to study novel or "enigmatic" stressors that enable a high scientific output, versus more logistically and methodologically challenging research areas, such as habitat change (Gardner et al. 2007). In fact, research priorities may be driven by a host of factors, including personal preference, and socio-political, cultural and economic societal values (Shine 1994; Wilson et al. 2011; Brooke et al. 2014).

Threat research was more abundant than Conservation-management research, which was also found to be the case in the general conservation literature (Fazey et al. 2005b). The low level of "Conservation-management" publications for amphibians is somewhat disquieting considering their vast conservation need. Non-threatened species received more research attention in conservation management than Threatened species. Conservation evidence, a much-emphasised research priority to improve the performance of conservation practice (Pullin & Knight 2001, 2009; Sutherland et al. 2004; Cook et al. 2010), was completely lacking for Threatened species, and only represented by eight studies on Non-threatened species. The disparity between research production and action is apparent in many areas of conservation practice (see Esler et al. 2010), including conservation planning (Knight et al. 2008), resource management (Shackleton et al. 2009), ecosystem management (McNie 2007), endangered species management (Stinchcombe & Moyle 2002; Griffiths 2004) and restoration ecology (Higgs 2005). This could, in part, be influenced by reward structures for research in academia (Agrawal & Ostrom 2006; Pooley et al. 2014). The majority of conservation researchers are focused on aspects of performance unlinked to practical applications for their career progression, such as the impact factor of the journals in which they publish (Arlettaz et al. 2010). There are insufficient rewards available for participating in research and action that would improve the status of threatened species (Chapron & Arlettaz 2008). The mismatch between science and practice is a major obstacle to effective conservation (Milner-Gulland et al. 2009; Memmott et al. 2010), and certainly impacts amphibians (Griffiths 2004; Griffiths & Halliday 2004). Realigning research priorities with the needs of practitioners, and the species and habitats they are attempting to manage, is crucial if researchers are to provide the information required to arrest or reverse species declines.

Temporal trends

The rate of research output from 1970 to 2013 has undergone clear increases across all extinction risk categories and major research types. This echoes a previously documented explosion in biodiversity-related research since the 1990s, which occurred in conjunction with increased rates of collaboration (Liu et al. 2011). Peaks in publication number coincided with several significant events in global amphibian conservation and awareness, all occurring between 2004 and 2011. These included: the completion of the IUCN Red List Global Amphibian Assessment (GAA) in 2004 (Stuart et al. 2004); the 2005 IUCN/SSC International Amphibian Conservation Summit, concurrent establishment of the IUCN SSC Amphibian Specialist Group, and subsequent publication of the Amphibian Conservation Action Plan (ACAP) in 2007 (Gascon et al. 2007; ASG 2015); the World Association of Zoos and Aquaria "Year of the Frog" campaign (Pavajeau et al. 2008); and the formation of the Amphibian Survival Alliance in 2011 (ASA 2015a). These events not only provided new sources of information, as was the case with the GAA and ACAP, but also put amphibians firmly on the world conservation agenda, stimulating funding opportunities for their study and conservation.

Conservation-related research in amphibians has steadily increased since the mid-1980s, in conjunction with the formal initiation of conservation biology as a distinct research discipline (Soulé 1985). It has continued to rise in the context of mounting global attention on the predicament of amphibians worldwide (Blaustein & Wake 1990; Houlahan et al. 2000; Mendelson III et al. 2006; Halliday 2008; Bishop et al. 2012; Wake 2012). The number of publications categorised by this study as ‘General’ have declined in number since 2007, potentially lessening in rate following the huge injection of research interest leading up to GAA and release of the first amphibian phylogeny supertrees (Frost et al. 2006; Roelants et al. 2007). The steady climb in the number of studies making use of amphibians for human benefit encompasses not only the well-established role of amphibians as model organisms (Burggren & Warburton 2007), but also, increasingly, research into skin secretions seeking pharmaceutical and other useful properties (20 species from our sample; 76 publications). Amphibian skin secretions present valuable research opportunities along a range of medicinal avenues, including peptides that could lead to the development of novel antibiotics (e.g. Li et al. 2007), analgesics (e.g. Zhu et al. 2014) and wound-healing products (e.g. Liu et al. 2014). The potential of amphibians to enrich human medicine could provide a persuasive rationale for increasing their conservation attention, although it could also pose a threat if exploitation is not effectively regulated.

The number of publications on different threats has fluctuated depending on the topic. The IUCN has documented known threat types for 6353 amphibian species (IUCN 2014), currently placing the order of threat-prevalence as: habitat destruction and fragmentation (65% of assessed species); pollution (18%); invasive and other problematic species (16%); climate change (6%); and exploitation (5%). This order of prevalence was not altogether reflected in current levels of research effort in our sample. Exploitation was the least studied threat, and pollution was the second-most studied threat, but research interest was not in proportion to prevalence for other major threats. Publications on invasive and other problematic species have increased steeply, becoming the leading threat research topic, following the establishment of a causal link between "enigmatic" global amphibian declines and the fungal pathogen *Batrachochytrium dendrobatidis* (Daszak et al. 1999; Berger et al. 2009), with Ranaviruses also threatening many species (Gray et al. 2009). Research into climate change, the third most-studied threat, has been boosted by interest in the potential link between amphibian declines and harmful UV-B radiation (Blaustein et al. 1994), although disease has since been exposed as the reason behind many formerly unexplained declines (Smith et al. 2006). Habitat destruction and fragmentation, despite being the most prevalent threat to amphibian species globally (Stuart et al. 2004; Bishop et al. 2012), has received a comparatively low level of attention, and is the second least-studied threat. A review of the amphibian decline and conservation literature between 1990 and 2009 also found this to be the case, with invasive species and disease accounting for 40% of studies, and habitat loss and fragmentation constituting just 15% (Ohmer & Bishop 2011). It seems threat research is not altogether guided by research needs of species, suggesting a potentially worrying trend of overlooking the leading cause of amphibian declines in favour of examining indirect or "enigmatic" population declines in areas of less disturbed habitat (Gardner et al. 2007). Disease research is crucial to better understand the substantial impact of this threat upon amphibians, particularly if it is exacerbated by climate change (Pounds et al. 2006a; Bosch et al. 2007). However, with almost two-thirds of amphibians affected by habitat destruction and fragmentation, more research on this threat is a clear priority for the future.

Journal Impact Factor and subject area

JIF is calculated by dividing the number of current citations of items published in the previous two years by the total number of articles and reviews published in that same time span for each journal (Wallin 2005). Since the prestige of a journal is often closely linked to its JIF (Sutherland et al. 2011), journals may seek to maximise their JIF by selecting articles that will yield the most citations over the two-year period relevant to the calculation of this metric (Van Leeuwen et al. 2003). Although a weak positive correlation between societal impact and JIF in was found in bee conservation (Sutherland et al. 2011), journals may reject research relevant to a more limited audience in favour of interdisciplinary, globally-focused studies with rapid citation rates (Wallin 2005). This could conceivably work against the publication of bespoke, localised conservation-relevant information. Overall, JIF must be viewed with caution when interpreting the quality and influence of research (Hecht et al. 1995; Leeuwen et al. 1999), especially when comparing research areas with markedly different citation half lives (the number of years from present day in which 50% of total citations accrue for journals within that field) (Kokko & Sutherland 1999). Although the interpretation of JIF may be open to criticism, it does communicate a broad pecking order for journals and the studies they contain (Van Leeuwen et al. 2003). JIF is widely used by scientists and funders to assess the quality of publications and researchers (Sutherland et al. 2011).

Given the importance of JIF for academic career progression (Wallin 2005; Arlettaz et al. 2010), it is encouraging to see that Conservation-related amphibian research was associated with a high JIF relative to other amphibian research areas. General research (taxonomy, systematics, biology and ecology) is found in a much wider range of journals, and some of its constituent subject areas are typically higher impact than others, for example evolutionary biology and ecology (Urbina-Cardona 2008). However, our findings indicate that the proportion of Conservation-related studies found in high impact journals (JIF ≥ 5) is greater than for the categories of General and Use. Although there may be many factors that discourage Conservation-related research, JIF should not necessarily be one of them. More citable conservation-relevant study types may be over-selected in certain journals, presenting barriers to the publication of highly specific and management-orientated research. However, information relevant to the conservation of amphibians is published in a wide variety of journals, in terms of both the number of titles and their subject area. Had this study followed previous research (e.g. Campbell 2007; Milner-Gulland et al. 2009; Griffiths & Dos Santos 2012), and considered only the leading conservation journals of *Animal Conservation*, *Biological Conservation*, *Conservation Biology*, *Biodiversity Conservation*, and *Oryx*, only 13% of Conservation-related articles from our dataset would have been captured. Even the more inclusive approach of Lawler et al. (2006), which examined 14 leading conservation journals, would only have yielded 16% of the Conservation-related publications from our dataset. The wide range of journals accepting Conservation-related research should encourage such publications. In cases where researchers wish to share findings of direct relevance to conservation management, the journal *Conservation Evidence* (www.conservationevidence.com) offers a rapid route for the peer-reviewed publication of research, monitoring results and case studies on the effects of conservation interventions (Sutherland et al. 2012). Publishing research that may be of use to conservation practitioners offers potential for a societal impact that should be duly valued (Chapron & Arlettaz 2008; Knight et al. 2008; Sutherland et al. 2011).

Authorship correlates of "Conservation-related" publications

We found the production of conservation-related research between 2000 and 2013 to be positively correlated with collaboration with individuals from non-academic institutions, and those within a species' range country, in both countries with advanced and developing economies. Conservation-related research in countries with advanced economies was also linked to having a first author based at a non-academic institution within the species' range-country. Practical implementation of conservation research has previously been related to the presence of co-authors from non-academic institutions, and range-country support, particularly from local NGO and government partners (Campbell 2007; Milner-Gulland et al. 2009). These authorship factors therefore predict both the real-world application of conservation-related research and, for amphibians at least, its existence in the first place. Publishing is thought to help increase the credibility of conservation recommendations, but is only part of a suite of dissemination approaches by research projects with links to conservation implementation (Milner-Gulland et al. 2009). Although we did not examine the conservation impact of individual publications in our sample, the high rate of range country involvement (whether through first-authorship or co-authorship), and collaboration with non-academic institutions, potentially signifies real-world conservation impact, albeit of a limited number of studies given global species' needs.

Regional patterns of first authorship reveal, unsurprisingly, a disproportionately high output from Europe, North & Central America and Australasia, which is in line with the conservation and environmental sciences literature (Fazey et al. 2005a; Karlsson et al. 2007) and research production in general (May 1997). These regions contain countries that are associated with a very high scientific output, including the United States, United Kingdom and Australia (May 1997). The United States was particularly dominant in terms of conservation-research; nearly half of all the Conservation-related publications in our sample (199 of 426 publications; 47%) have first authors from institutions in the United States. North America has a strong community of professional herpetologists (Gardner et al. 2007), and the United States is a consistent front-runner in research, producing over a third of global scientific output (May 1997). This prominence extends to biodiversity research and conservation science (Fazey et al. 2005a; Liu et al. 2011).

The low rate of first authorship of conservation studies by researchers in developing countries indicates reliance on assistance from people in wealthier countries to facilitate publication. However, in instances where research was carried out by a first author from the developed world without co-authors from a species' range country (76% of cases), valuable opportunities for collaboration and capacity building in publishing have been missed. Over ten years ago, the then Secretary-General of the United Nations, Kofi Annan, challenged all countries to work together to help rectify the great inequalities in scientific output between the developed and developing world (Annan 2003). An unbalanced distribution of scientific activity has serious repercussions for our understanding of global issues in ecology and environmental management (González-Suárez et al. 2012; Martin et al. 2012a). However, this pattern is slowing changing. Despite the ongoing dominance of Europe and North America, rates of increase of scientific output are actually higher in some developing countries, such as China and Latin America, than in Canada and the United States (Holmgren & Schnitzer 2004). In terms of conservation research, a lack of monitoring of biodiversity in the tropics remains a concern (Collen et al. 2008), and scientific output in much of Africa and Asia requires a considerable boost (Fazey et al. 2005a). Furthermore, in countries where biodiversity and endemic species counts are highest but research conditions are challenging (in terms of political, economic and environmental factors), research may struggle to progress beyond routine, descriptive and survey-driven studies, as scientists labour to document their vast national natural heritage (Shine 1994; Barnard 1995; Young et al. 2001). It has also been asserted that the ecology and conservation grey literature in the tropics vastly exceeds the peer-reviewed published literature (Corlett 2011), impeding a balanced evaluation of ongoing research. Additionally, language presents a considerable barrier to publication, with English language journals representing over 80% of the scientific literature (Montgomery 2004). Research capacity in developing countries needs to be expanded, through collaboration between international institutions and host-country agencies, to build the conservation evidence-base required to protect so many species.

Conclusion

The abiding rationale of conservation science is to provide a rigorous basis for conservation action (Milner-Gulland et al. 2009). Conservation research should therefore support management-related research priorities relevant to conservation practice (Murphy 1990). Our study suggests that conservation-related research on amphibians occurs at a low level, and currently does not prioritise research on threatened species. Although certain threats, such as disease, are the subject of intense investigation, other significant threats, such as habitat destruction and fragmentation, are largely overlooked in the literature. Research related to conservation-management – particularly conservation evidence studies – is also insufficient. Conservation research production is presently outpaced by demand. However, a trend towards increased collaboration with non-academic institutions within the range countries of species will hopefully spell greater research output in tune with conservation needs, and increased implementation of research findings in the future. Continued and heightened international and multidisciplinary collaboration is required to develop the capacity of conservation scientists and practitioners to meet amphibian conservation research needs globally. Also, rewarding academics for research that enables societal engagement and implementation of conservation action could boost the production of conservation-relevant publications (Knight et al. 2008). This will help build the evidence-based action required to mitigate the impending amphibian extinction crisis.

Chapter 4. What are the biases and trends in amphibian conservation evidence?

Abstract

Widespread use of evidence-based conservation practice has the potential to bring about dramatic improvements in the effectiveness of conservation efforts. Threatened and declining amphibians are in great need of effective conservation action based on sound evidence. We investigated the availability of studies on the effectiveness of interventions in a recently published synopsis of global conservation evidence for amphibians. A total of 417 studies provided evidence for one or more interventions, and indicated a number of biases. Evidence was not widely available for all interventions, and studies were mainly conducted in temperate regions. The mitigation of some threats received more focus than others. For example, interventions tackling habitat destruction/fragmentation and invasive species/disease were relatively well-studied. The impact of interventions targeting pollution, exploitation, and climate change received little or no research attention, and few education and engagement-related interventions were studied. Research output can be affected by numerous factors, including geographical location, and species characteristics. The number of studies per country was positively related to a country's wealth and proportion of English language speakers. Evidence availability was not related to a country's IUCN SSC Amphibian Specialist Group membership, suggesting the number of experts involved in amphibian conservation does not always align with research interest in amphibian conservation interventions. Results also indicated that species were more likely to be the subject of conservation intervention studies if they were Non-threatened (all interventions) or Extinct in the Wild (captive breeding studies), and more evolutionarily distinct. Species with a reproductive mode where eggs are laid that hatch into larvae are more likely to be studied than species without free-living larvae. As the majority of amphibian larvae develop in wetlands, this indicates a propensity for research focusing on wetland species rather than those with terrestrial or arboreal breeding strategies. These findings highlight several important knowledge gaps. We urge anyone involved in amphibian conservation science, both directly or as a collaborator, to engage in monitoring interventions and publishing subsequent results. Our study suggests that research entailing global collaboration and capacity building efforts, particularly focused in the tropics, will benefit the availability of representative evidence to support amphibian conservation.

Introduction

Evidence-based practice has been advocated for over a decade as an essential prerequisite for increasing the effectiveness of conservation interventions (Pullin & Knight 2001; Fazey et al. 2004; Keene & Pullin 2011; Segan et al. 2011). Basing conservation decision-making on scientific evidence can enable greater accountability, the development of more appropriate methods, and a reduction in the use of ineffective or harmful practices (Sutherland et al. 2004; Pullin & Knight 2009). Methods for applying evidence-based practice to conservation are largely based on frameworks employed by medicine and public health, where the introduction of this approach has brought about an "effectiveness revolution" since the 1970s (Stevens & Milne 1997), and evidence-based clinical practice is now routine (Graham et al. 2011).

The prevailing purpose of conservation biology is to improve the practice of conservation management (Meffe et al. 2006; Milner-Gulland et al. 2009). However, a "research implementation gap" (Knight et al. 2006, 2008) or "great divide" (Anonymous 2007) has been widely perceived between the studies produced by conservation scientists and the research needs of conservation practitioners (Balmford & Cowling 2006; Milner-Gulland et al. 2009; Braunisch et al. 2012). The lack of appropriate conservation evidence studies has been attributed to a variety of factors. Studies may be low in relevance to conservation practice due to differing research priorities of conservation scientists, practitioners and policy-makers (McNie 2007; Shanley & López 2009; Arlettaz et al. 2010). Highly specific conservation research can be seen as too narrow and insufficiently citable to attract serious research effort from conservation scientists based at academic institutions (Laurance et al. 2012), where research is often graded by Impact Factor (Sutherland et al. 2011) rather than relevance to a conservation problem. Reductionist study designs (Pullin et al. 2009) and low levels of interdisciplinary research can render the real-world application of research findings challenging (Sunderland et al. 2009). Equally, conservation practitioners may find the primary literature inaccessible in terms of availability, content and the time commitment required to regularly process and assimilate the latest findings (Pullin & Knight 2005; Laurance et al. 2012; Milner-Gulland et al. 2012; Walsh et al. 2014). Journals that are not open access may be particularly unattainable in developing countries and outside of academia (Gossa et al. 2014). Also, a slow turn-around in publishing has repercussions for the utility of peer-reviewed science in conservation practice (Meffe 2001; Kareiva et al. 2002). Furthermore, a general lack of sharing experiences from the field has been partially attributed to unwillingness to publish failures (Redford & Taber 2000; Knight 2006), and a tendency for practitioners not to publish their findings (Pullin & Knight 2003; Sutherland et al. 2004), in large part due to time constraints associated with their roles (Pullin & Knight 2005). A continuum exists between scientists and practitioners in conservation (Gossa et al. 2014), with many conservation practitioners having a high level of science training (Courter 2012). However, differences in agenda and work remit may still bring about a mismatch between available science and the needs of practitioners, creating an ongoing impediment to science-based conservation practice (Arlettaz et al. 2010). In addition to an under-developed "fail-safe" culture in conservation (Redford & Taber 2000; Knight 2006), an evidence-based approach may be more difficult to develop in conservation than in medicine and public health because of marked differences in funding and study-complexity across these two areas; medicine benefits from more financial support and fewer challenges associated with the necessary controlled studies that form the basis of evidence-based approaches (Fazey et al. 2004).

Conservation practitioners have been found to base decision-making on a variety of evidence sources (Cook et al. 2012), but scientific evidence often lags behind reliance on experience, colleague advice and grey literature (Pullin et al. 2004; Cook et al. 2010). Practitioners are often comfortable basing their decisions on experience (Pullin & Knight 2005), and experience-based decision-making can complement evidence-based approaches to management (Hockings et al. 2009). However, it can also compromise accountability, knowledge development, and assurance of effectiveness in conservation (Keene & Pullin 2011). Access to appropriate information remains a key concern for conservation practitioners and policy-makers (Pullin & Knight 2005; Young & Van Aarde 2011; Bayliss et al. 2012; Matzek et al. 2014). Adapting methods employed to collate evidence in clinical practice (e.g. Haynes 2001; Dicenso et al. 2009; Windish 2012) can lead to conservation evidence being organised in a more accessible manner; Dicks et al. (2014) have adapted a 4'S' hierarchical system used in medicine to improve the flow of evidence to conservation practitioners (see Figure 1.1, Chapter 1). This comprises, in ascending order: "studies" (primary research); "systematic reviews" (see Pullin & Stewart 2006); "summaries" (of both studies and systematic reviews); and decision support "systems". Summaries are akin to Clinical Practice Guidelines (Graham et al. 2011) and Clinical Evidence (http://www.clinicalevidence.com), which is an online database of systematic overviews assessing benefits and harms of medical treatments published by the British Medical Journal Group (2015). Similarly, Conservation Evidence synopses (www.conservationevidence.com) bring together relevant studies and systematic reviews to address key issues in conservation practice and policymaking. Benefits of this approach include assembling all available evidence concisely in nontechnical language to help inform practitioners and policymakers who may have insufficient time and resources to access the primary literature directly (Dicks et al. 2014a). Summaries also clearly indicate where gaps in knowledge exist, helping to prioritise future research (Dicks et al. 2014b).

A taxon that would certainly benefit from an injection of effective conservation practice is the Amphibia. In 2004, the Global Amphibian Assessment found that at least 43% of amphibian species were experiencing population declines, with a third threatened with extinction, making them the most imperilled vertebrate group; a further quarter were classified as Data Deficient (Stuart et al. 2004). Amphibians are experiencing a global extinction crisis (Alford & Richards 1999; Alford 2011; Wake 2012), and the importance of conservation action to avert the mass extinction of species has been widely advocated (Wake 1998; Beebee & Griffiths 2005; Mendelson III et al. 2006). However, amphibian conservation research has also been found to lack alignment with the needs of conservation practice (Griffiths 2004). The first synopsis of global evidence studies for all interventions used in amphibian conservation was recently published: "*Amphibian conservation: Global evidence for the effects of interventions*" (hereafter "Amphibian Synopsis"; Smith & Sutherland 2014). This includes interventions linked to *in situ* threat mitigation, species management (such as captive breeding and translocation), and public education and engagement initiatives. Smith & Sutherland (2014) define evidence as studies that examine the effects of conservation interventions on native wild amphibians. As stated in Chapter 1, the criteria for inclusion of studies are as follows: they must detail an intervention that is relevant to conservation practice for amphibians; and the effects of the intervention must have been monitored quantitatively (Smith & Sutherland 2014). These criteria exclude studies that examine the effects of specific interventions without actually conducting them. For example, predictive modelling studies, and research examining species distributions in areas with long-standing management histories (correlative studies) were excluded.

Existing information on global biodiversity is known to be unequally distributed, both geographically and taxonomically (Sachs et al. 2009; Butchart et al. 2010; Martin et al. 2012a), leading to a distorted scientific understanding of biodiversity (Boakes et al. 2010). Data is especially lacking in the species-rich tropics (Yesson et al. 2007; Collen et al. 2008; Feeley & Silman 2011). Conservation evidence research for amphibians exists at a low level – out of a sample of 600 species (sampling 100 species from each IUCN extinction risk category between 1970 and 2013), only seven species (all Non-threatened) appeared in conservation evidence research, which included eight publications out of a total of 3485 (Chapter 3). It is likely that amphibian conservation evidence availability suffers from spatial-and species-level heterogeneity, as was the case for wild insect pollinators (Dicks et al. 2013).

A study by Amano & Sutherland (2013) elucidated four key barriers to the availability of records in biodiversity databases relating to wealth, language, geographic location and a county's and security (i.e. its peacefulness and stability). The number of records was found to be positively correlated with Gross Domestic Product (GDP) per capita, proportion of English language speakers, proximity to the country hosting the database, and high security levels. Wealth is known to positively correlate with ecological information availability (Martin et al. 2012a) and research impact (King 2004), and a low level of security can have negative repercussions for conservation activities (Kanyamibwa 1998; Rotshuizen & Smith 2013). English is the predominant language of science publishing (Montgomery 2004), disadvantaging non-English speakers (Karlsson et al. 2007; Gossa et al. 2014). To determine whether these factors are associated with any biases in conservation evidence availability for amphibians, we assessed the studies summarised in the Amphibian Synopsis (Smith & Sutherland 2014). We focused on three potential barriers to the availability of conservation evidence discussed above, namely: GDP per capita (as an indicator of the wealth of nations); language; and security. We also investigated the spatial variation in amphibian conservation expertise to determine whether countries with a high number of amphibian conservation scientists were associated with more evidence studies.

In addition to spatial biases, the process of choosing species for study can also be non-random (Clark & May 2002), and may reflect the interests of society rather than species diversity (Wilson et al. 2011). Methodological challenges associated with the study of certain species can result in scientists choosing easier research subjects (Pawar 2011), as well as species that are more abundant (Lawler et al. 2006). We therefore tested whether conservation evidence is representative in terms of geographical spread, and also species characteristics such as extinction risk status, evolutionary distinctiveness, and life history traits. We also assessed the Impact Factor and subject area of journals containing evidence. Our overarching aim is to clarify the spatial-level, species-level and bibliometric biases and trends associated with amphibian conservation evidence publishing, and identify future directions for conservation evidence-based research.

Methods

Data

The recently published Amphibian Synopsis (Smith & Sutherland 2014) collates evidence for all conservation interventions relevant to amphibians, and includes publications dating between 1971 and 2013 (see Chapter 1 for full details). Evidence included in the synopsis was gathered according to an established protocol under the headings of 107 interventions, which were determined though consultation with an expert advisory board (Smith & Sutherland 2014). The synopsis was converted into a database, detailing all summarised information on the conservation interventions (including species details, spatial details, and summarised results of evidence studies), which was compiled in Microsoft Excel to facilitate its assessment.

The latest available Journal Impact Factors were obtained from the Institute for Scientific Information (ISI). The Journal Impact Factor (JIF) was used rather than the five-year Impact Factor because this allowed inclusion of a greater number of journals in our analyses (ISI 2014). We collected information on the land area, population, and Gross Domestic Product per capita at purchasing power parity exchange rates (GDP) of each country from the World Factbook (CIA 2014). More detailed measures of wealth, such as the national budget for conservation activities and environmental research, might be a better predictor of conservation evidence output, but we could not obtain such information at a global scale and thus used the GDP per capita instead. Data for the proportion of English speakers was contributed by Amano & Sutherland (2013) from a 2012 dataset. The Global Peace Index (GPI) score was used to quantify a nation's level of security. GPI comprises 23 indicators, which gauge three broad themes: the level of safety and security in society (10 indicators), the extent of domestic or international conflict (five), and the degree of militarisation (eight), with appropriate data being collated by Institute for Economics and Peace (GPI 2014). Lower GPI scores signify higher 'peacefulness' and therefore greater security. In order to focus on the density of scientists directly involved in amphibian conservation, we used IUCN SSC Amphibian Specialist Group (ASG) membership as our proxy of expertise. The ASG is a global network of experts whose aim is to improve the practice of conservation through scientific guidance (ASG 2015). ASG membership per country was obtained directly from the ASG (ASG 2014), with figures taken as total members resident in each country. Species richness per country (number of native, extant species) and the extinction risk status for each species was obtained from the IUCN Red List database (IUCN 2014). An amphibian phylogenetic tree and Evolutionary Distinctiveness (ED) scores calculated for 4310 of the species were acquired from Isaac et al. (2012). The ED score was calculated for each species by dividing the total phylogenetic diversity of a clade amongst its members (for methodology, see: Isaac et al. 2007, 2012). Life history variables were taken from a database developed by Sodhi et al. (2008) that details life history information for 5718 species. "Habit" describes the general ecological location of the species when not breeding and "Spawn Site" refers to breeding location. "Reproductive Mode" describes whether the species produces eggs that are laid and hatch into a free-living larvae "Oviparous-Larvae", laid and hatch into miniature adults "Oviparous-Direct Development", or undergo development within the parent "Viviparous & Ovoviviparous".

Analyses

A set of analyses were performed to determine patterns of publication and research effort. Research was assigned to broad threat categories and additional actions based on the system employed by the Amphibian Synopsis (as with the IUCN Red List, the Amphibian Synopsis follows Salafsky et al. (2008) for threat categorisation). Interventions mitigating different threat types were assigned to the following major threat headings: habitat destruction and fragmentation; invasive and other problematic species (which includes disease); pollution; exploitation (specific to use of the species); and climate change. Two additional categories of evidence were included for: species management interventions (*in situ and ex situ*); and actions relating to education and engagement. For evidence published in a journal with a registered Impact Factor in 2014, a Spearman's Rank correlation test was used to investigate the relationship between the number of publications per journal and that journal's Impact Factor. We evaluated biases and trends in the available evidence for amphibian conservation interventions using spatial-level and species-level analyses.

Spatial-level analysis

A series of three spatial analyses were conducted using the following response variables: total number of evidence studies per country; number of evidence studies per square kilometre of each country; and number of evidence studies per native, extant species in each country (i.e. species richness). In each case, we tested the relationship between the response variable and four explanatory variables: GDP per capita; the proportion of English speakers; GPI; and number of ASG members per million human population. Species richness per country was included as an additional explanatory variable for two of the response variables: total number of evidence studies per country; and number of evidence studies per country area. Country area was also included as an explanatory variable for the following response variables: total number of evidence studies per country; and number of evidence studies per species richness.

To avoid multicollinearity among the explanatory variables, we first estimated pair-wise Spearman's rank correlation coefficients between the explanatory variables and confirmed that correlations for all the combinations were low ($|r| < 0.620$); the strongest being between GDP per capita and GPI ($r = -0.6189$). To investigate the effect of spatial autocorrelation, Moran's *I* was calculated for the residuals from the full models, using the package *ncf* (Bjørnstad 2005) in R. The calculated Moran's *I* was small (|Moran's *I*| < 0.3) up to the first 14,500 km, indicating no more than a weak spatial autocorrelation. Thus, we did not consider spatial autocorrelation explicitly in the subsequent models.

Species-level analysis

For the species-level analyses, we first tested the relationship between presence or absence of evidence studies for each species and the following five explanatory variables: ED score; IUCN extinction risk status; and the three life history descriptors, i.e. Habit, Spawn Site, and Reproductive Mode. In a separate analysis looking at only species with evidence, we tested the relationship between number of evidence studies and the same five explanatory variables. ED was a continuous variable between 3.407 and 190.674 million years of evolutionary history (Isaac et al. 2012). IUCN risk status was converted into a four-way categorical variable comprising the levels: Non-threatened (Near Threatened and Least Concern species); Threatened (Critically Endangered, Endangered and Vulnerable species); Extinct (including both Extinct and Extinct in the Wild species); and Data Deficient. Habit was a four-way categorical variable, including Aquatic, Aquatic-terrestrial, Terrestrial and Arboreal (Sodhi et al. 2008). Spawn Site was a five-way categorical variable including Aquatic, Aquatic-terrestrial, Terrestrial, Arboreal/Phytotelm and Parent (Sodhi et al. 2008). Reproductive Mode was a three-way categorical variable including Oviparous-Larvae, Oviparous-Direct Development, and Viviparous & Ovoviviparous (Sodhi et al. 2008). For all categorical variables, the reference categories for modelling were standardised as the sub-category containing the most species, and were therefore as follows: Non-threatened (IUCN extinction risk status); Terrestrial (Habit); Aquatic (Spawn Site); and Oviparous-Larvae (Reproductive Mode). Since related species cannot be assumed to be independent data points, we need to account for phylogenetic relatedness in model residuals. However, such phylogenetic models cannot easily be implemented with non-normally distributed data, as is the case in the analyses here. We therefore decided to use Generalised Linear Mixed Models (GLMMs) with binomial distribution (presence or absence of evidence studies) and negative binomial distribution (number of evidence studies), and taxonomic Family was used as a random factor to account for, at least to some degree, phylogenetic relatedness. The GLMMs were implemented using the package glmmADMB (Skaug et al. 2014).

To account for model selection uncertainty, we adopted a multi-model inference approach based on the Akaike Information Criteria (AICc) (Burnham & Anderson 2002). First, we generated a candidate set of models with all possible parameter subsets, which were then fitted to the data and ranked by ΔAICc values, or the difference between each model's AICc and $AICc_{min}$, that of the "best" model (Appendix III). We calculated Akaike weights (w_i) for each model as an indicator of relative support and summed these across the candidate set to find the 95%-confidence set (Johnson & Omland 2004). Model averaged coefficients (weighted by w_i) and their 85% confidence intervals (as advised by Arnold 2010) were also calculated across the 95% set. If the 85% confidence interval did overlap with zero, we did not consider the effect to be statistically significant; although clear trends in the data may still remain apparent. All analyses were conducted in R 3.0.0 (R Core Team 2013); General Linear Models were fitted with a negative binomial distribution using the MASS package (Venables & Ripley 2002). Model averaging was conducted using the package MuMIn (Bartoń 2012).

Results

Description of the evidence

The Amphibian Synopsis (Smith & Sutherland 2014) includes 417 studies published between 1971 to 2013. Research was conducted in 44 countries and was relevant to 204 species. Evidence ($n = 417$) came from six major sources: journals (76%); conservation and government reports (8%); newsletters (7%); conference proceedings (4%); research theses (3%); and book chapters (2%). A total of 125 journals were included, both international and regional, with 76 of these having a registered Impact Factor, ranging from 0.278 to 38.597. Of the evidence published in these 76 journals (211 studies), there was no relationship between a journal's Impact Factor and the number of evidence studies it contained (Spearman's rank correlation coefficient, ρ = -0.0609, $p = 0.6112$, $n = 76$; Figure 4.1). However, over 90% of evidence studies were published in journals with Impact Factors of less than 4, and median Impact Factor of the studies was 1.734 (interquartile range [IQR] 0.915-2.766; range = 0.279-38.597; $n = 211$).

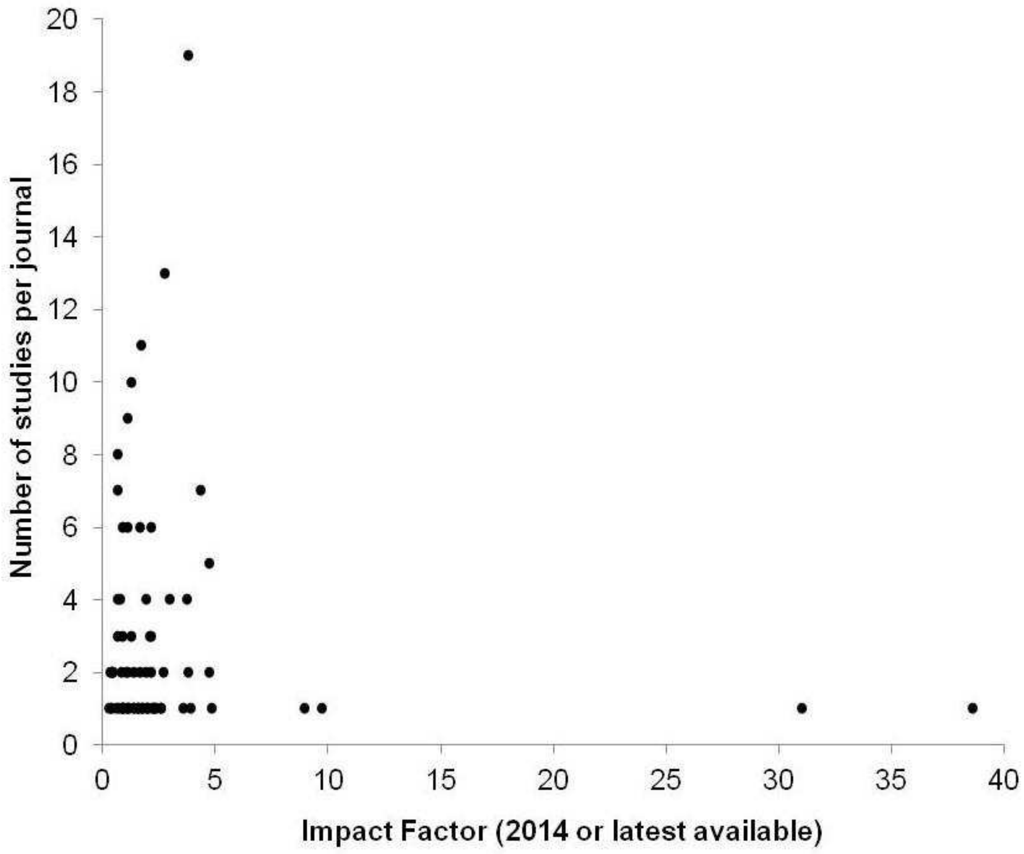


Figure 4.1. Relationship between latest available Impact Factor and number of conservation evidence studies. Including 76 journals with a registered ISI Journal Impact Factor (2014 or latest available). Journals included 211 studies (1971-2013).

The journals containing the most evidence studies included in the synopsis were: *Biological Conservation* (19 studies); *Forest Ecology and Management* (13); *Herpetological Review* (12); *Diseases of Aquatic Organisms* (11); *International Zoo Yearbook* (10); and *Wetlands* (10). Across all evidence in journals, both with and without an Impact Factor ($n = 317$), 24% of studies were published in journals focused on conservation and management, 22% in ecology journals, 24% in specialised herpetology journals and 5% in journals focusing on threats (such as disease or environmental contamination). The remaining 25% of articles were published in journals with more general topics such as biological sciences, zoology and veterinary science.

The 417 evidence studies were spread across 76 interventions (an additional 31 interventions lacked evidence), and covered a range of different threat mitigation methods, approaches to species management, and public education and engagement initiatives. Almost a third of studies (128 in total) were relevant to more than one conservation intervention. Research into the mitigation of specific threats was most common ($n = 402$ studies) and comprised studies tackling habitat destruction and fragmentation (321 studies), invasive and other problematic species (70 studies), pollution (8 studies) and exploitation (3 studies). Although interventions were proposed that may help mitigate the effects of climate change, no studies were found that specifically tested interventions in relation to climate change events and/or processes, so it is currently impossible to determine how effective interventions may be in response to changing climates. Other studies tested the effects of species management strategies rather than specific threats. These included *in situ* translocation (59 studies), and *ex situ* interventions (149 studies), such as captive breeding and release of animals, and cryopreservation of gametes. A further 32 studies tackled five interventions linked to education and engagement activities, including awareness-raising and education programmes (11 studies), engaging volunteers to collect amphibian data (8 studies), paying farmers to cover the costs of conservation measures (5 studies), and engaging landowners and other volunteers to manage land for amphibians (8 studies). A sixth intervention under this category – "use amphibians sustainably" – had no supporting evidence studies in the synopsis. The average number of studies per intervention and the number of interventions per category varied across the different types of threat mitigation, species management, and education and engagement actions (Figure 4.2). The number of different types of interventions practiced was highest for mitigating habitat destruction and fragmentation. Evidence per intervention was highest for species management strategies.

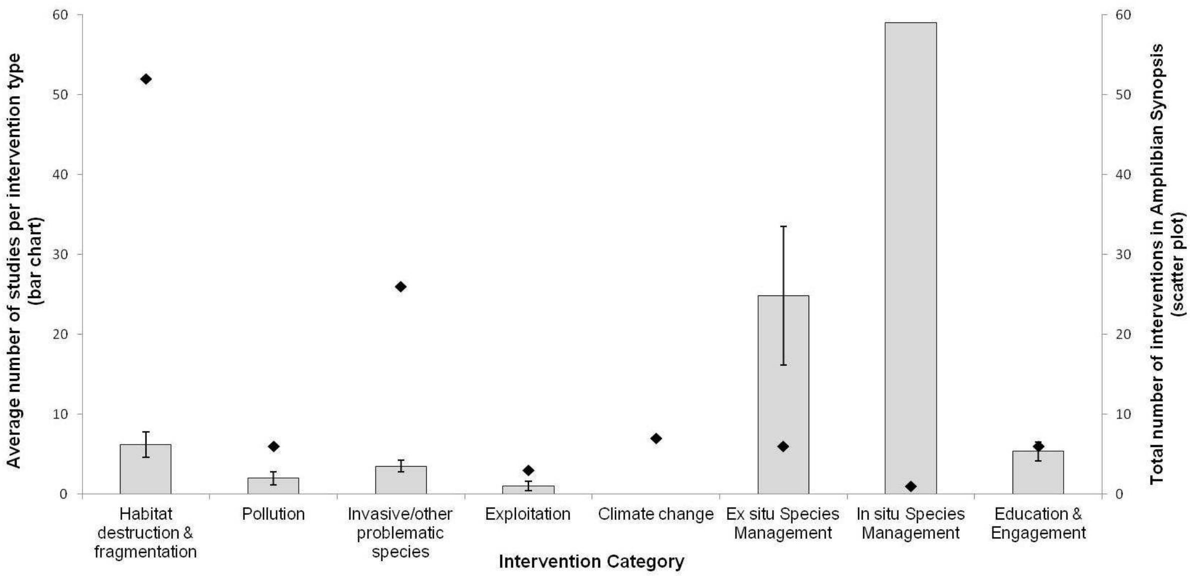


Figure 4.2. Summary of studies included in the Amphibian Synopsis, displaying average number of studies per intervention across different intervention categories (grey bars with standard errors against the primary y-axis) and total number of interventions per category (scatter plot against the secondary y-axis).

Geographic spread of evidence

Conservation evidence studies were unequally distributed globally, with the majority of countries having no studies (Figure 4.3a). The number of studies in most cases did not align with ASG membership density, global patterns of species richness, or a country's proportion of threatened species (Figure 4.3b,c,d). Eighty-six countries had at least one registered member of the ASG. The top ten countries for membership are currently: United States (99); Colombia (33); Australia (25); India (22); Germany (18); United Kingdom (18); Brazil (16); China (16); Peru (16); and Spain (13). Only 35 (41%) countries with ASG members had conservation evidence studies. The distribution of evidence studies per species was concentrated in North America, parts of Western Europe, Australia and New Zealand. Many countries with the highest amphibian species richness had very low levels of evidence, or none at all.

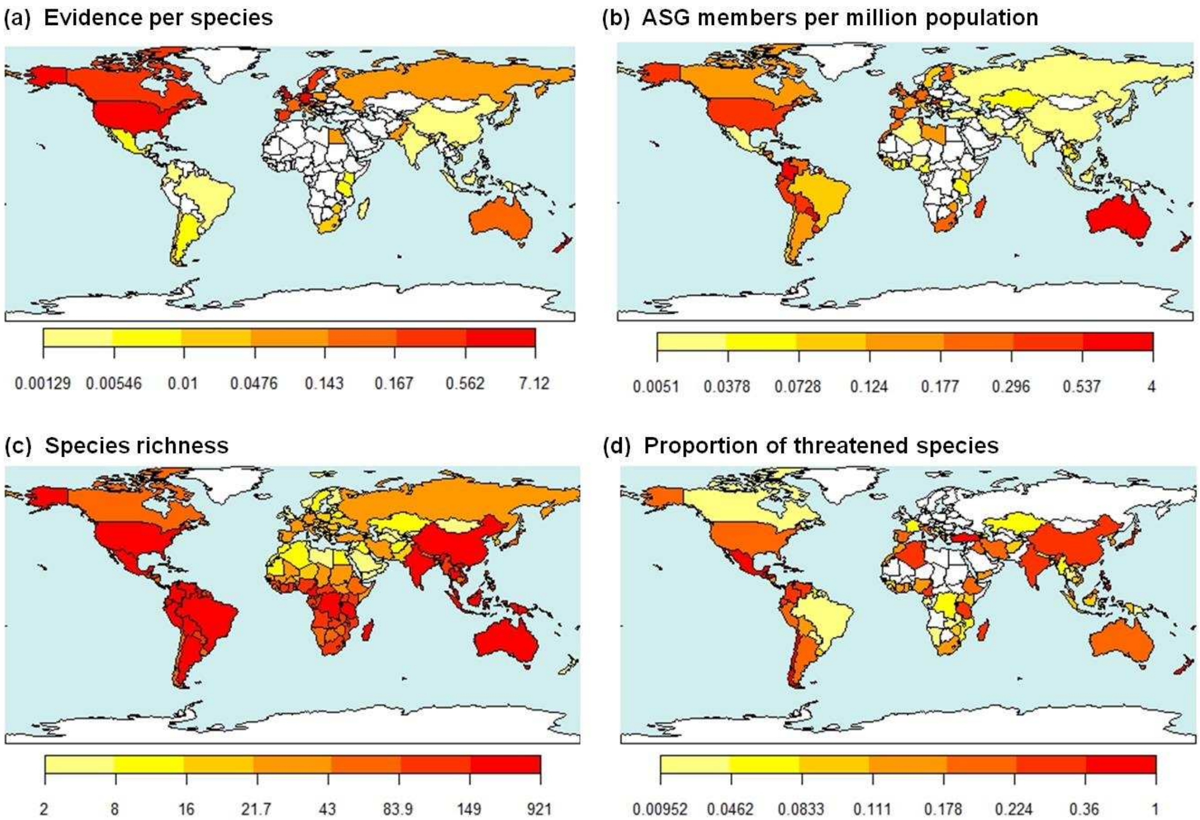


Figure 4.3. Maps showing the spatial variations in data: (a) Evidence per species – the number of conservation evidence studies on species per country divided by that country's species richness; (b) ASG members per million people – the number of IUCN SSC Amphibian Specialist Group Members per country divided by that country's population; (c) Species richness – the number of native, extant species; and (d) Proportion of threatened species – the proportion of a country's species currently in IUCN categories of Critically Endangered, Endangered or Vulnerable. Where values are zero, countries are shown in white.

Spatial-level analyses

Modelling results aligned across all three response variables of total number of evidence studies in each country, number of evidence studies per area in each country, and number of evidence studies per species in each country. Both GDP per capita and proportion of English speakers was positively correlated with all three response variables (Table 4.1a,b,c; Figure 4.4). GPI (a lower GPI equals greater security) is moderately correlated with GDP (r = -0.619), so although it did not emerge as an important variable in our analyses, it is still possible that GPI may explain some variation in conservation evidence output among countries.

Table 4.1. Spatial-level analyses. Model-averaged coefficients and 85% confidence intervals based on Generalised Linear Models with negative binomial distributions. Coefficients with 85% confidence intervals (CI) not overlapping zero were considered significant, and are presented in bold. *n* = 78.

(a) Total number of evidence studies in each country

	Coefficients	85% CI	
Intercept	-0.202	-0.529	0.125
GDP per capita	**1.137**	**0.675**	**1.598**
Proportion of English speakers	**0.705**	**0.422**	**0.988**
Global Peace Index	-0.068	-0.330	0.194
ASG members per million	0.045	-0.129	0.220
Amphibian species richness	0.008	-0.122	0.139
Country area	**1.027**	**0.740**	**1.314**

(b) Number of evidence studies per area in each country

	Coefficients	85% CI	
Intercept	-12.463	-12.819	-12.107
GDP per capita	**0.947**	**0.198**	**1.696**
Proportion of English speakers	**0.770**	**0.419**	**1.122**
Global Peace Index	-0.427	-1.032	0.177
ASG members per million	0.132	-0.180	0.444
Amphibian species richness	-0.059	-0.284	0.166

(c) Number of evidence studies per species in each country

	Coefficients	85% CI	
Intercept	-3.732	-4.103	-3.361
GDP per capita	**1.424**	**0.931**	**1.918**
Proportion of English speakers	**1.075**	**0.746**	**1.404**
Global Peace Index	-0.044	-0.301	0.212
ASG members per million	0.010	-0.128	0.149
Country area	0.294	-0.158	0.746

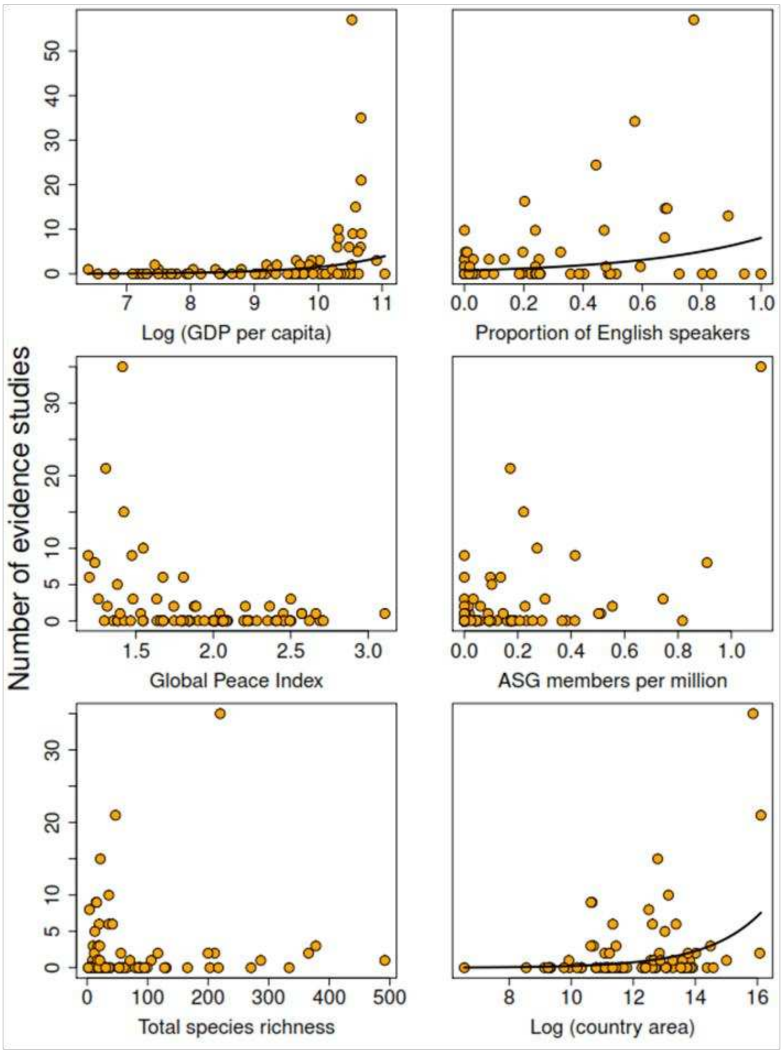


Figure 4.4. Spatial-level analyses scatter plots showing the relationship between total number of evidence studies and: GDP per capita; the proportion of English speakers; GPI; ASG members per million people; total species richness per country; and country area. Regression lines were based on the model-averaged coefficients and shown only for explanatory variables with 85% confidence intervals not overlapping zero. One outlier (United States with 181 evidence studies) is not shown in these figures. Scatter plots for number of evidence studies per square kilometre and number of evidence studies per species against explanatory variables are provided in the Appendix III, together with all modelling results.

Species-level analyses

Table 4.2 details the species-level model averaging results. Species with a high ED score had a greater quantity of evidence studies (Figure 4.5). Relative to Non-threatened species, amphibians that were Extinct in the Wild were significantly more likely to have evidence and Threatened species were significantly less likely to have evidence (Figure 4.6a). Species with an Oviparous-Larvae reproductive mode had proportionally more evidence than species with either an Oviparous-Direct Development or Viviparous/Ovoviviparous reproductive mode (Figure 4.6d). Habit and spawn site did not explain a significant amount of the variation in our models. However, species with at least a partially aquatic life history habit had a higher proportional representation in the Amphibian Synopsis (Figure 4.6b), and species that spawn in arboreal or phytotelm sites were the least proportionately represented group for spawn site (Figure 4.6c). For species with evidence studies, no explanatory variables were significantly associated with the amount of evidence (Table 4.3).

Table 4.2. Species-level analysis – Presence/absence of evidence (all species). Model-averaged coefficients and 85% confidence intervals based on Generalised Linear Mixed Models with binomial distributions and family as a random factor. IUCN Risk Status – Non threatened / Habit – Terrestrial / Spawn – Aquatic / Reproductive mode – Oviparous-Larvae were used as reference categories. Coefficients with 85% confidence intervals (CI) not overlapping zero were considered significant, and are presented in bold. *n* = 4125.

Presence/Absence of Evidence Studies	Estimate	85% CI	
Intercept	-3.702	-4.206	-3.198
ED score	**0.024**	**0.014**	**0.033**
IUCN Risk Status – Data Deficient	0.292	-1.244	1.827
IUCN Risk Status – Extinct/Extinct in the Wild	**4.791**	**2.461**	**7.122**
IUCN Risk Status – Threatened	**-0.569**	**-0.835**	**-0.303**
Habit – Aquatic	-0.016	-0.183	0.152
Habit – Aquatic -terrestrial	<0.0001	-0.082	0.082
Habit – Arboreal	0.012	-0.122	0.145
Spawn – Aquatic & terrestrial	0.562	-0.317	1.441
Spawn – Arboreal / Phytotelms	-1.017	-2.076	0.042
Spawn – Parent	0.714	-0.377	1.805
Spawn – Terrestrial	-0.009	-0.553	0.535
Reproductive mode – Oviparous-Direct Development	**-0.789**	**-1.479**	**-0.100**
Reproductive mode – Viviparous/Ovoviviparous	**-1.778**	**-3.538**	**-0.018**

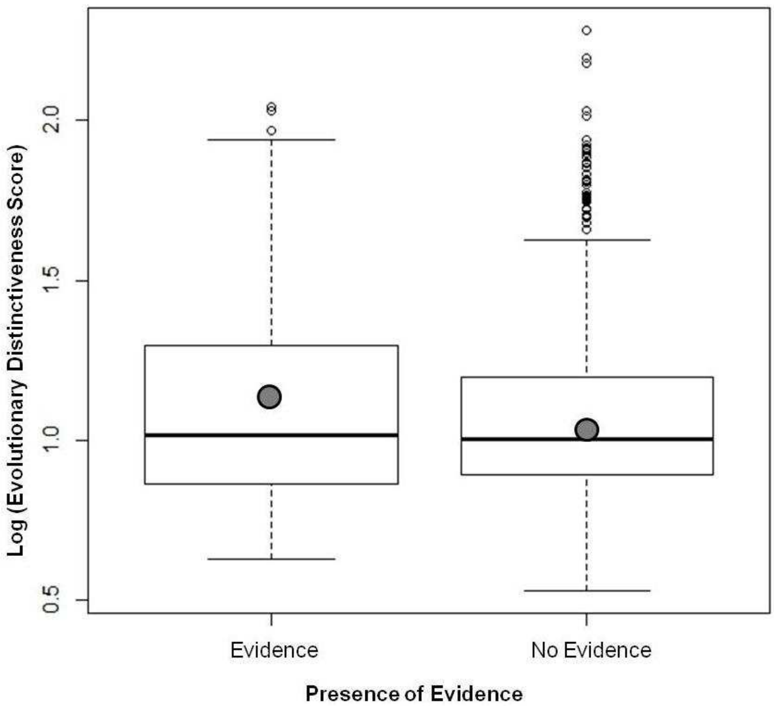


Figure 4.5. Box plots of logged Evolutionary Distinctiveness (ED) scores for species with evidence (*n* = 204) and with no evidence (*n* = 4106). Mean ED scores are shown as grey markers within the box plots.

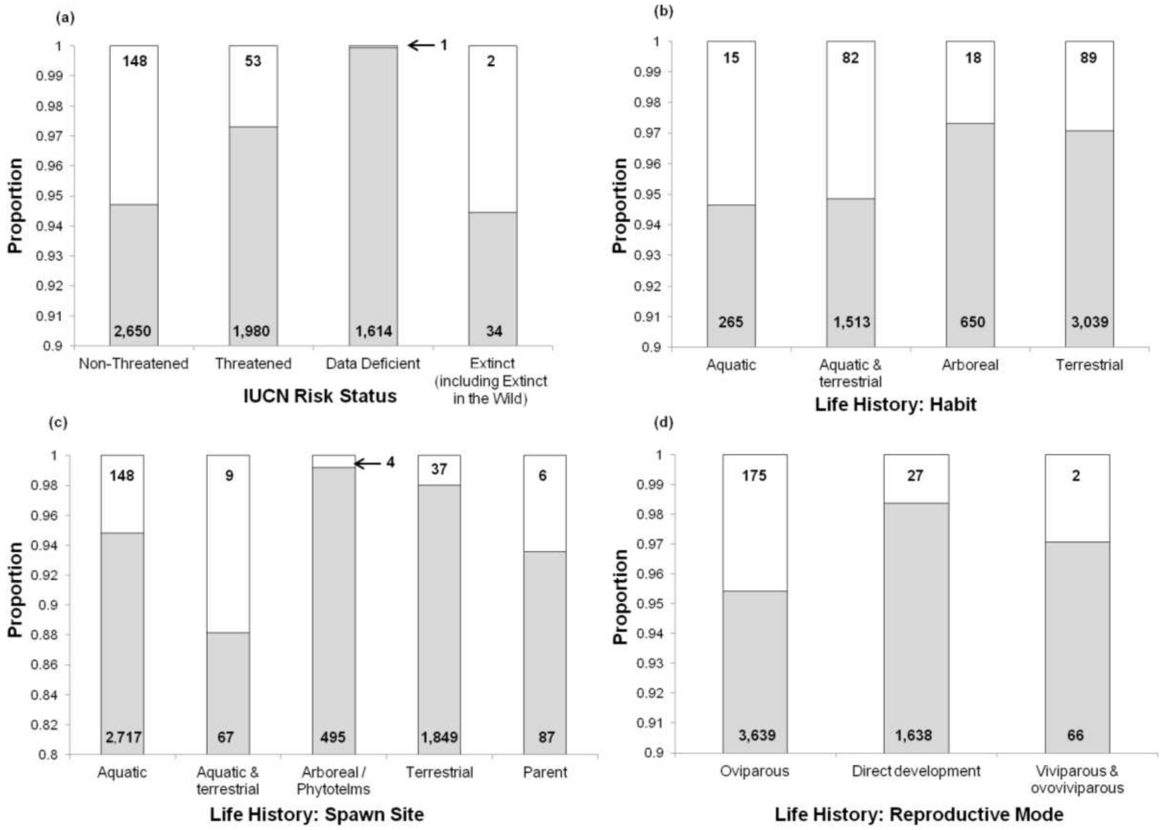


Figure 4.6. Proportions of species with evidence (white) and with no evidence (grey) in different categories, for: (a) IUCN extinction risk status; (b) life history habit; (c) life history spawn site; and (d) life history reproductive mode. Note that the y-axis does not start at zero and actual numbers of species are written in the relevant parts of the bars.

Table 4.3. Species-level analysis – Amount of evidence per species (only species with evidence). Model-averaged coefficients and 85% confidence intervals based on Generalised Linear Mixed Models with negative binomial distributions and family as a random factor. IUCN Risk Status – Non threatened / Habit – Terrestrial / Spawn – Aquatic / Reproductive mode – Oviparous (Larvae) were used as reference categories. Coefficients with 85% confidence intervals (CI) not overlapping zero were considered significant. *n* = 199.

Number of Evidence Studies (for Species with Evidence)	Estimate	85% CI	
Intercept	0.578	-0.085	1.241
ED score	<-0.001	-0.003	0.003
IUCN Risk Status – Data Deficient	-0.227	-1.414	0.960
IUCN Risk Status – Extinct	-0.055	-0.638	0.528
IUCN Risk Status – Threatened	-0.124	-0.414	0.166
Habit – Aquatic	-0.016	-0.162	0.130
Habit – Aquatic & terrestrial	-0.012	-0.114	0.089
Habit – Arboreal	-0.014	-0.159	0.132
Spawn – Aquatic-terrestrial	-0.006	-0.104	0.093
Spawn – Arboreal / Phytotelms	-0.017	-0.224	0.190
Spawn – Parent	0.005	-0.115	0.125
Spawn – Terrestrial	-0.010	-0.117	0.097
Reproductive mode – Oviparous-Direct Development	-0.024	-0.203	0.154
Reproductive mode – Viviparous/Ovoviviparous	-0.091	-0.646	0.464

Discussion

Description of the evidence

Assessment of the number of studies in the Amphibian Synopsis indicates that conservation evidence is not as widely available for amphibians as it is for other vertebrate taxa covered by existing evidence synopses (available through Conservation Evidence 2015). There were 417 studies examining the effectiveness of 129 actions across 107 intervention types for amphibians; for comparison, the same synopsis approach found 1240 such studies for birds spread across 457 interventions (Williams et al. 2012). The mammal synopsis is currently underway, but over 100 studies have been collated across 78 interventions for bats alone (Berthinussen et al. 2013). Taxonomic biases in vertebrate study levels are well-known, especially favouring bird and mammal research (e.g. Bonnet et al. 2002). However, a greater proportion of amphibians are currently threatened with extinction than other vertebrate taxa (Hoffmann et al. 2010; IUCN 2015), so it is crucial to stimulate the publication of much-needed conservation evidence for amphibians.

Conservation evidence for amphibians is found in a variety of sources, and distributed widely among journals, both in terms of Impact Factor and subject area. Evidence for amphibians is not restricted to journals that focus on herpetology and conservation issues, but is also found in ecology, threat, and general biological sciences literature. Furthermore, 24% of the evidence collated was found in sources other than journals, including books, research theses, and grey literature. Conservation evidence can reach a selection of specialist audiences, and searches for evidence must therefore take in the broadest range of data sources possible, as advocated by Pullin & Stewart (2006) in their guidelines for systematic reviews. Journal Impact Factor is not prioritised by practitioners when choosing evidence to support conservation decision-making; relevance of scientific studies is a key concern, with some commenting that higher Impact Factor journals may be too disconnected from practice (Gossa et al. 2014). Our findings indicate that conservation evidence research for amphibians tends to be found in lower impact journals, but research broaching real-world conservation problems can still be high impact and welcomed by strong journals (as emphasised in Laurance et al. 2012). Researchers and practitioners wishing to share findings of direct relevance to conservation management also have a series of options for swift publication. One example is the journal *Conservation Evidence* (www.conservationevidence.com), which offers a rapid route for the peer-reviewed publication of research, monitoring results and case studies on the effects of conservation interventions (Sutherland et al. 2012). A second online journal, *Environmental Evidence*, "*facilitates rapid publication of systematic reviews and evidence syntheses on the effectiveness of environmental management interventions and on the impact of human activities on the environment*" (Environmental Evidence 2015). Publishing evidence can therefore take a variety of routes, enabling researchers to achieve impact both in terms of citation and wider benefits to species and ecosystems (Sutherland et al. 2011).

There is a clear bias in the spread of evidence and methods for different intervention categories. Twenty-nine percent of interventions lacked any evidence, echoing assertions that many conservation interventions proceed unevaluated (Pullin et al. 2004). Interventions mitigating the effects of habitat destruction and fragmentation had the most evidence overall, and the greatest number of interventions. Habitat alteration is the leading cause of amphibian declines (Cushman 2006; Gardner et al. 2007), with 65% of assessed species currently known to be affected to some level, and 92% of Threatened species (IUCN 2014). The mitigation of threats imposed by invasive and other problematic species received the second highest amount of evidence. This threat affects 16% of assessed amphibian species, and 30% of Threatened species (IUCN 2014), and encompasses disease, which has experienced a surge in research interest in recent years (Gardner et al. 2007; Ohmer & Bishop 2011) following the linkage of emerging infectious diseases with global amphibian declines (Daszak et al. 1999; Skerratt et al. 2007). However, other threat types are greatly overlooked. The second most prevalent threat to amphibians is pollution (at least 18% of assessed amphibian species affected; 26% of Threatened species; IUCN 2014), but this topic had a very low level of evidence and mitigation interventions. Exploitation (affecting 5% of assessed species; 7% of Threatened species; IUCN 2014) similarly lacks evidence (Smith & Sutherland 2014). Climate change (currently affecting 6% of assessed species; 13% of Threatened species; IUCN 2014) is of increasing concern (Pounds & Crump 1994; Araújo et al. 2006), especially looking to the future where it could become a lead cause of declines (Corn 2007). Climate change also exacerbates the impact of other threats, such as disease (Pounds et al. 2006a; Bosch et al. 2007) and habitat availability (D'Amen et al. 2011). No evidence was found that tested interventions in the context of climate change events and ongoing processes. Amphibian life history is extremely sensitive to temperature and precipitation fluctuations (Corn 2007), not least in relation to breeding cycles (Blaustein et al. 2001). Interventions that can mitigate the effects of climate change are available, such as the installation of microclimate and microhabitat refuges, enhancement and restoration of breeding sites, and manipulation of hydroperiod or water levels at breeding sites (Shoo et al. 2011), all of which are listed as interventions in the Amphibian Synopsis (Smith & Sutherland 2014). Studies are required to test the effectiveness of these interventions in the context of real-world ongoing climate change. The overall pattern of research interest is therefore not developing entirely in a manner that represents the prevalence, or perceived future severity, of major threat types.

Only six education and engagement interventions were included in the synopsis, suggesting a currently low level of approaches to amphibian conservation that encompass human-related activities. Evidence relating to interventions that include social activities, such as the sustainable use of amphibians, non-harmful land management practices, livelihood development, and participatory conservation (e.g. Gonwouo & Rodel 2008; Rabemananjara et al. 2008; Bride et al. 2008; Randrianavelona et al. 2010), is presently not widely available, and therefore was largely missing from the synopsis. Amphibians must survive in increasingly human-altered landscapes (Gallant et al. 2007; Hamer & McDonnell 2008), so conservation actions that involve engagement with people are crucial as we move forward. Conservation interventions that include and involve people are therefore an important future direction in evidence research.

Geographic spread of evidence

The global spread of evidence is uneven and largely concentrated in North America (US and Canada), western Europe, Australia and New Zealand. With the exception of the aforementioned areas, evidence per species does not correspond to the density of ASG members. This is particularly true of the tropics, and highly speciose countries are especially lacking in conservation evidence. Under half of the eighty-seven countries with ASG members have conservation evidence studies (41%), and the region of South America, with its relatively high number of ASG members, exhibits a particular mismatch between ASG membership and conservation evidence production. Africa, mainland Asia and South-east Asia are lacking in both ASG members and conservation evidence. This information is valuable to the ASG for two main reasons. Firstly it highlights obvious gaps in membership, but also areas where a culture of conservation evidence publishing could be encouraged and supported through international collaboration within the ASG. Amphibian-related expertise is not necessarily lacking in many tropical countries (see also Rodrigues et al. 2010), but conservation evidence gathering as standard research practice or movement must be promoted globally to represent diversity in both species and ecosystems.

Spatial-level variation in evidence

Multiple socio-political drivers associated with spatial variation in ecological information have been tested by previous research (Amano & Sutherland 2013). We found the proportion of English speakers and GDP per capita to be key variables correlated with the distribution of conservation evidence studies for amphibians. This is not surprising, and highlights key impediments to the production and/or availability of evidence. Developing countries have been found to be disproportionately missing from published environmental science, both in terms of knowledge production and general scientific study (Karlsson et al. 2007). The location of ecological research is positively associated with the wealth of countries, leading to a distorted understanding of global biodiversity (Martin et al. 2012a). Wealth inevitably affects budgetary provisions for science and conservation, and is positively associated with both the production (May 1997) and citation intensity (King 2004) of research. However, the rate of publishing in many developing countries is increasing, and South America has achieved a superior ratio of publications to national research and development expenditure than the United States (Holmgren & Schnitzer 2004). Science in developing countries remains under-represented (Karlsson et al. 2007), which is contrary to the spirit of scientific objectivity, and also counterproductive in terms of global development (Annan 2003). There is also a "brain drain" of researchers leaving the developing world for opportunities in wealthier countries (Sunderland et al. 2009), potentially further lowering levels of environmental science expertise in poorer countries. Also, conservation research conducted in developing countries may frequently be authored by foreign researchers, especially from developed countries, and these articles often fail to include a co-author from the study country (Milner-Gulland et al. 2009; Chapter 3). Of the thirty-seven conservation evidence studies in the Amphibian Synopsis that took place in a developing country, 80% included at least one author from that country, and this was a first author in 65% of studies. Therefore conservation evidence for amphibians in poorer countries, though low in output, is largely led by, or in collaboration with, developing country scientists and practitioners.

English is the common language of science communication, which has repercussions for publishing in countries with a low proportion of English-speakers (Montgomery 2004). Sunderland et al. (2009, p. 550) note that the "*domination of the English language as the scientific medium for dissemination constrains many researchers and field practitioners and also hinders the impact of any published paper in the authors' country of origin*". Various solutions to the combined obstacles of wealth and language to environmental science publishing have been suggested, including writing workshops for developing world scientists, as practiced by the conservation journal *Oryx* (Milner-Gulland et al. 2009). Karlsson et al. (2007) suggest a multi-pronged approach incorporating: increased collaboration between developed and developing countries; capacity building; reducing publication costs and increasing opportunities for open access publishing; and working with the "gatekeepers of science" (journal editors are often from developed, temperate countries) to ensure publishing becomes more representative of global ecology and biodiversity. Conservation evidence publishing requires this degree of encouragement to increase the global representation of research. After all, conservation challenges rarely have universal solutions, and accounting for diverse ecological and cultural contexts will demand information from across the globe (Segan et al. 2011).

As is the case in regression-based studies, our results can only demonstrate associations between variables and do not necessarily prove that these highlighted factors drive the distribution of conservation evidence research. However, our findings are in alignment with research examining drivers of spatial variations in biodiversity data (Amano & Sutherland 2013), as well as documented barriers to publishing linked to wealth and English language ability (e.g. Karlsson et al. 2007; Gossa et al. 2014). It is possible that the Amphibian Synopsis failed to collate some sources of conservation evidence due to the search protocol employed, particularly evidence not published in English, and from the tropics where information may more frequently be found in inaccessible grey literature (Corlett 2011). Additionally, practitioners worldwide may not publish evidence on the effects of conservation interventions that they use, or monitor these effects in the first place (Sutherland et al. 2004). Only information sources that were accessible could be included in the synopsis, and a lack of evidence in certain areas and regions is likely to reflect current biases in research available (Smith & Sutherland 2014). Any relevant evidence studies that have genuinely been missed can be incorporated into updates of this evolving resource by contacting Conservation Evidence (2015).

Future studies investigating barriers to conservation evidence research output at the global scale should be conducted to elucidate more detailed factors linked to human decision-making. For example, it would be beneficial to survey members of the Amphibian Specialist Group to investigate attitudes towards evidence-based research and additional variables that may encourage or impede the output of conservation evidence. This would enable the development of improved strategies to promote conservation evidence production and dissemination in the long-term tailored to the needs of end-users.

Species-level variation in evidence

Given the spatial unevenness of evidence, it would be preferable if the choice of species for evidence studies were dictated by conservation need; for example species that are rapidly declining, threatened, and/or evolutionarily distinct. It would also benefit conservation practice if evidence were at least representative of diverse amphibian life histories. Firstly, species with evidence were associated with greater evolutionary distinctiveness (ED). Given that taxonomic family was used as a random variable to account for within-family differences between our explanatory variables, it appears that, within each family, species with higher

ED tend to be studied more. Higher levels of evolutionary distinctiveness have previously been associated with greater levels of conservation attention in both mammals and amphibians (Sitas et al. 2009), potentially due to novel species characters and functions (Isaac et al. 2007; Collen et al. 2011). Specifically, Critically Endangered amphibian species are more likely to be the recipients of conservation effort if they are well-known and evolutionarily distinct (Sitas et al. 2009). The conservation of high-ED species has been encouraged as a means of preserving evolutionary diversity and maintaining the branch structure of the 'Tree of Life' (Isaac et al. 2007, 2012), so it is encouraging that ED is a significant factor in explaining variation in conservation evidence production. Investing in evolutionary history and maximising such distinctiveness can help provide biological systems with more options to respond to a changing world, at both the species and community level (Collen et al. 2011; Redding et al. 2015). However, the tendency for evidence research to focus more on non-threatened than threatened species indicates that EDGE (Evolutionary Distinct and Globally Endangered; Isaac et al. 2012) species are likely to be under-represented. Of the 799 EDGE species currently recognised, only 27 (3%) appear in the Amphibian Synopsis (EDGE 2015). These include 11 in the top 100 EDGE species. High ranking examples from the top 10 EDGE amphibians in the synopsis include *Leiopelma archeyi*, *Andrias davidianus*, *Ambystoma andersoni* and *Ambystoma mexicanum* (EDGE 2015). Encouraging more conservation evidence for EDGE species is also advisable.

The tendency for threatened species to appear less in evidence studies than non-threatened species is a common theme in biodiversity research (Lawler et al. 2006; Stein et al. 2011). Less threatened species are more abundant, and not subject to the same degree of research restrictions (Wilson et al. 2011). However, it must be noted that globally non-threatened species can still be regionally threatened and protected by national legislation. Also, it is important to conserve non-threatened species – essentially keeping "common" species common – as they perform a variety of important functions in ecosystems and are therefore worthy of conservation attention (Gaston & Fuller 2008). Species that are Extinct in the Wild were more likely to have conservation evidence studies than non-threatened species. This may be accounted for by the fact that the only two amphibian species currently categorised as Extinct in the Wild on the IUCN Red List are present in the Amphibian Synopsis, namely the Wyoming toad (*Anaxyrus baxteri*) from the United States, and Tanzania's Kihansi spray toad (*Nectophrynoides asperginis*) (IUCN 2015). Both species have been affected by multiple threats, including the fungal pathogen *Batrachochytrium dendrobatidis*, and are the subject of *ex situ* conservation attention to avert their absolute extinction (Hammerson 2004; Lee et al. 2006). These species are unusual cases, but do indicate a global willingness to avert amphibian extinctions through captive measures; an effort championed by the Amphibian Ark, especially for species with threats that cannot currently be mitigated (Zippel et al. 2011).

Finally, species with conservation evidence were more likely to have a reproductive mode featuring egg laying with free-living larvae, rather than laying eggs that undergo direct development or internal development within the parent. Ninety-one percent of species that have free-living larvae are associated with aquatic larval development (data from Sodhi et al. 2008), suggesting a bias towards research into interventions for wetland-related species and interventions. This could reflect the dominant reproductive strategy of the temperate species over-represented in the Amphibian Synopsis, or a heightened level of conservation interest in wetland areas and species. However, it is important to evaluate these life history biases to ensure species with more terrestrial and arboreal habits, as well as diverse reproductive behaviours, are not neglected.

Conclusion

Biases in the subject area and distribution of conservation evidence studies have repercussions for the global practice of conservation. In order to ensure we are doing more good than harm, conservation must be based on evidence testing the effectiveness of the interventions employed (Pullin & Knight 2009). We therefore urge conservation scientists and practitioners to work together globally to develop and publish appropriate research that tests the effectiveness of conservation interventions. Conservation scientists are increasingly taking note of the need to generate research questions relevant to practice and policy (e.g. Sutherland & Woodroof 2009; Memmott et al. 2010; Hulme 2011; Milner-Gulland et al. 2012; Sutherland et al. 2014). Co-production of knowledge through the collaboration of scientists and practitioners is seen as the most effective means of generating useful knowledge for the sustainable management of ecosystems (Roux et al. 2006). Also, bilateral information exchange between scientists and practitioners is essential in developing conservation research projects relevant to practice (Braunisch et al. 2012). International collaborations fostering increased levels of conservation evidence research in countries that are rich in species but poor in resources will be crucial to developing our understanding of how to conserve global biodiversity effectively. We hope that the impact of amphibian conservation can benefit greatly from increased use of evidence-based conservation practice.

Chapter 5. What works in amphibian conservation?

Abstract

Determining what works in amphibian conservation is a crucial aspect of preventing extinctions and arresting or reversing declines within this highly threatened taxon. Evidence-based conservation approaches can ensure that effective interventions are used, alert attention to ineffective and harmful actions, and identify important knowledge gaps. We conducted an expert assessment of evidence collated in a recent synopsis for an exhaustive survey of amphibian conservation interventions, including 129 actions across 107 intervention types. Actions were taken for threat mitigation (78%), *in situ* and *ex situ* species management (17%), and education and engagement (5%), and 417 studies provided evidence for one or more actions. Thirty-one interventions had no supporting evidence, and of the 98 assessed actions with evidence, 44% were assessed as effective, 32% as ineffective and/or harmful, and 24% were of unknown effectiveness (due to limited evidence). Knowledge gaps were apparent throughout the synopsis, and evidence was heavily skewed towards studies in the United States, Western Europe, and Australia, with fewer than 10% of studies based in the tropics. This limits conclusions concerning the effectiveness of amphibian conservation on a global basis. Interventions associated with the creation and restoration of ponds and wetlands are currently among the most beneficial actions for appropriate amphibian species, and *in situ* species management involving translocations is more effective than *ex situ* management that includes releasing captive-bred individuals. However, more evidence is required to understand different methods used in conservation interventions, and the performance of interventions across different species and geographical locations. We urge conservation scientists and practitioners to ensure the effects of interventions are monitored, and that results are published and disseminated to inform others. We also summarise other recommendations for developing an evidence-based future for amphibian conservation.

Introduction

Amphibians face an extinction crisis (Zippel & Mendelson 2008). Hundreds of species may be lost as conservation scientists and practitioners struggle to identify remedies to poorly understood declines spanning several decades (Blaustein & Wake 1990; Houlahan et al. 2000; Mendelson III et al. 2006), which currently affect an estimated 43% of species (Stuart et al. 2004). The IUCN Red List currently categorises 518 amphibian species as Critically Endangered, representing eight percent of all species, as compared to 213 bird species (2%), 213 mammals (4%), and 174 reptile species (4%) (IUCN 2015). However, the number of amphibian species in this threat category is likely to be an underestimation, as 1614 species (25% of all species) are currently Data Deficient, versus 62 bird species (0.6%), 799 mammal species (14%), and 811 reptile species (18%) (IUCN 2015), and Data Deficient species are more likely to be assessed as threatened than non-threatened (Bland et al. 2014). Additionally, 34 amphibian species are classified as Extinct, two as Extinct in the Wild (IUCN 2015), and a further 111 are flagged as possibly extinct pending exhaustive surveys to confirm their disappearance (IUCN 2014). The Global Amphibian Assessment estimated that between nine and 122 amphibian species have become extinct since 1980, at which point 231 species were categorised as Critically Endangered (Stuart et al. 2004). The situation appears to be worsening in conjunction with improvements in our knowledge of the status and trends of amphibians, and the current extinction rate is estimated at up to 25,000–45,000 times the background rate (McCallum 2007). There has never been a greater urgency to develop effective conservation strategies for amphibians.

Practical conservation efforts are compromised by a lack of documented evidence (Sutherland 2006), and an over-reliance on untested experience-driven management actions that may prove to be ineffective or harmful (Pullin & Knight 2001; Pullin et al. 2004; Sutherland et al. 2004). Practitioners use a variety of information sources to guide their decision-making, and relevant empirical evidence is valued highly despite being less accessible than experience-based information and synthesised evidence sources such as databases, management plans and legislation (Cook et al. 2012). In a study of wetland management in England, experience-based knowledge, such as common sense, personal experience and colleague opinion, constituted 77% of the information used to guide 61 management actions, whereas primary scientific literature accounted for just 2% (Sutherland et al. 2004). A study examining conservation management actions across 1000 protected areas in Australia found that about 60% of decisions relied on experience-based information, and that insufficient evidence is a common obstacle to the assessment of actions by practitioners (Cook et al. 2010). Evidence-based approaches can give way to local expert knowledge and "rules of thumb" in situations where a lack of relevant information is accessible (MacMillan & Marshall 2006). As stated by Fazey et al. (2004, p. 190), the conservation literature is "*voluminous, has little coherence and is of varying quality*", and is frequently of low relevance to conservation practice (Knight et al. 2008; Esler et al. 2010; Arlettaz et al. 2010). It has also been associated with costly journal subscriptions, which may especially preclude access for interested parties in developing countries (Sunderland et al. 2009), who are more reliant on open-access resources (Fuller et al. 2014; Gossa et al. 2014).

Evidence-based conservation may be described as "*the practice of accumulating, reviewing and disseminating evidence with the aim of formulating appropriate management strategies*" (Sutherland 2006, p. 599). There is a great need to compile evidence in a way that is accessible to practitioners and policy-makers, facilitating cost-effective decision-making (Segan et al. 2011). Systematic reviews have become an established pathway for the scientific guidance of practice (Pullin & Stewart 2006), and form a vital second tier above scientific studies in the '4S' information hierarchy of evidence for environmental management decisions (Dicks et al. 2014a; see Figure 1.1, Chapter 1). Summaries constitute the next tier up in this hierarchy, and collate studies and systematic reviews into simple, non-technical language that can be readily accessed by practitioners who lack time to synthesise the primary literature. They can be organised into collections of synopses, which are crucial elements of an evidence-based framework, providing foci for the narrative compilation of evidence across a range of possible management options (Dicks et al. 2014b). Synopses of conservation evidence on management interventions are currently available for several taxa, including wild bees (Dicks et al. 2010), birds (Williams et al. 2012), bats (Berthinussen et al. 2013), and amphibians (Smith & Sutherland 2014), in addition to a variety of general conservation issues (Conservation Evidence 2015). Synopses allow for the continual updating and cumulative re-evaluation of evidence, highlighting areas of uncertainty and knowledge gaps on a cyclical basis (Dicks et al. 2014b). They can be more adaptable than systematic reviews, especially in cases where reviews are framed too broadly to be of use to on-the-ground managers (Cook et al. 2013b). Improved access to summarised scientific information can influence perceptions of interventions among practitioners. In a study of 92 conservation managers, appraisal of summarised evidence on interventions designed to reduce bird predation (see Williams et al. 2012) resulted in participants stating that they would be more likely to implement effective actions, and less likely to use ineffective interventions (Walsh et al. 2014). This result echoes the impact of evidence on medical practitioners, who have been found to change decisions about treatments, prescribe more effective treatments, learn new information, and recall prior knowledge in response to the availability of relevant evidence (Lucas et al. 2004; McGowan et al. 2008).

Combining evidence synopses with expert evaluation has been proposed as a transparent and versatile means of incorporating evidence into environmental decisions (Dicks et al. 2014b). Expert judgement is often used in conservation to resolve complex problems and determine extrapolations when resources are restricted and insufficient empirical evidence renders uncertainty high (Burgman et al. 2011a; Martin et al. 2012b). In this study we assembled a panel of experts to assess evidence collated for amphibians (Smith & Sutherland 2014) to determine the effectiveness of each conservation intervention. We aim to identify the most effective interventions for the conservation management of amphibians based on available evidence, in addition to any knowledge gaps. This represents the first attempt to assess the effectiveness of conservation interventions for amphibians.

Methods

A database of conservation evidence was developed using the recently published Amphibian Synopsis (Smith & Sutherland 2014), which compiles studies that examine the effects of conservation interventions on amphibians. Evidence included in the synopsis was gathered according to an established protocol under the headings of 107 interventions, which were deemed by an expert advisory board to include all conservation actions currently used to conserve amphibians (Smith & Sutherland 2014). Of these, 31 interventions had no supporting evidence in the synopsis and were therefore not included in the expert assessment process. Of the 76 interventions with evidence studies, five were made up of a total of 27 sub-categories to enable the sub-division of evidence between different habitats or species/taxa (see Smith & Sutherland 2014). Therefore, a total of 98 actions were included in the expert assessment, including 71 interventions without sub-categories, and 27 sub-categorisations of the remaining five interventions. Because evidence was reviewed separately for these sub-categories, they were treated as independent interventions in all analyses.

Expert elicitation process

The Delphi method is an expert elicitation process that can provide estimates, scores or opinions in situations where high levels of uncertainty or a lack of data preclude the attainment of absolute answers (MacMillan & Marshall 2006; Rowe & Wright 2011). As such, it can be used to convert evidence into a useable format for conservation practice (Sutherland 2006). Successive rounds of scoring by an expert panel, where experts are able to review the estimates and justifications of other panel members, allows a panel to move towards a consensus opinion based on their combined knowledge (Sutherland 2006). Group estimates are usually more accurate than reliance on the best-regarded expert in a group (Burgman et al. 2011a), and the structured design of the Delphi method, combined with panel anonymity, can ameliorate certain biases associated with expert judgement (see Martin et al. 2012). We used an e-Delphi approach (Hasson & Keeney 2011) to assess the effectiveness of conservation interventions summarised in the Amphibian Synopsis, which is the only resource to have systematically collated evidence for all amphibian conservation actions (Smith & Sutherland 2014). The Delphi process employed was developed using guidance (Conservation Evidence 2015) and previous research (Walsh et al. 2014), and entailed four rounds, which are summarised in Figure 5.1.

An expert panel was recruited by inviting a diverse selection of potential participants, representing a wide variety of expertise in global amphibian conservation. Our sample was stratified to represent as many global regions, conservation-related skill-sets, and institution types as possible, as well as a range of experience levels. Sampling encompassed experts with experience in both *in situ* and *ex situ* conservation actions, and global and regional conservation planning, based at academic institutions, zoological collections, non-governmental organisations, and government agencies. Due to the importance of seeking interventions to mitigate global disease risks for amphibians, which are still very much in development (Scheele et al. 2014), a sub-panel of amphibian disease specialists was recruited to focus only on interventions concerned with disease mitigation, and was tasked with providing perspectives from the amphibian disease literature. We initially approached 70 experts, 15 of whom were suggested by a person-to-person cascade approach, permitting a degree of snowball sampling (Rowe & Wright 2011). A group of about 10 experts is considered sufficient for a Delphi panel (Crance 1987). However, we chose to increase the size of the panel to incorporate the views of experts with the widest possible knowledge of the interventions under assessment. This helped to reduce subjective motivational biases related to the context of the expert, personal beliefs, and agendas (Burgman et al. 2011b; Martin et al. 2012b). A wide base of experience was important to ensure the best possible assessment of evidence across a varied selection of interventions.

The Amphibian Synopsis was converted into an online questionnaire; designed and conducted using the online survey tool Qualtrics (Qualtrics 2014), which enabled the interventions to be presented to panel members in a randomised order so that each intervention could be considered independently. In Round 1 we asked the expert panel to review the evidence in the synopsis for each intervention, and provide scores out of 100 for: (1) effectiveness; (2) the level of certainty associated with the effectiveness score; and (3) side-effects of each intervention (using the guidance in Table 5.2). “Effectiveness” was defined as "*increasing healthy amphibian populations within their natural/*in situ *habitat*" (Smith & Sutherland 2014), and panel members were reminded in each round to base their scores for each intervention on its potential to deliver this outcome. “Certainty” was defined as an assessment of evidence quality in relation to a number of factors, including: the number of studies; the global and methodological coverage and wider applicability of these studies; the similarity of results across different studies; and the robustness of the experimental designs (e.g. randomised, replicated, controlled experiments with a large sample size will tend to give more dependable results than, for example, a single before-and-after comparison). “Side-effects” relate to whether an intervention has negative impacts on any amphibian populations, in terms of numbers and/or health. Panel members were asked to provide justifications for their scores, which could be summarised and shared with fellow panel members in subsequent rounds, and to only base their scores on the evidence available in the synopsis. We requested that any additional sources of evidence familiar to the panel were noted so this information could be reviewed for inclusion in future updated synopses.

In Round 2, the same experts were asked to review Round 1 results, amend scores as they saw fit, and provide any justifications. Each intervention was placed into a category of effectiveness based on its median scores from the panel, and these scoring thresholds were shared with the panel in Round 3 (Table 5.1). Subsequently, panel members were asked to object to any interventions they perceived to be incorrectly assigned to an effectiveness category. Categories of effectiveness were based on the approach used by Clinical Evidence (www.clinicalevidence.com), which is an online database of systematic overviews assessing benefits and harms of medical treatments published by the British Medical Journal Group. Score thresholds (Table 5.1) were provided by Conservation Evidence (2015). Interventions with three or more objections were rescored in Round 4 following the review of any additional comments from the panel, resulting in final categories for all interventions. The anonymity of the panel members was preserved throughout the process to maximise objectivity of the panel's perception of comments from fellow panel members (Sutherland 2006). Guidance information for the expert assessment is detailed in Appendix IV.

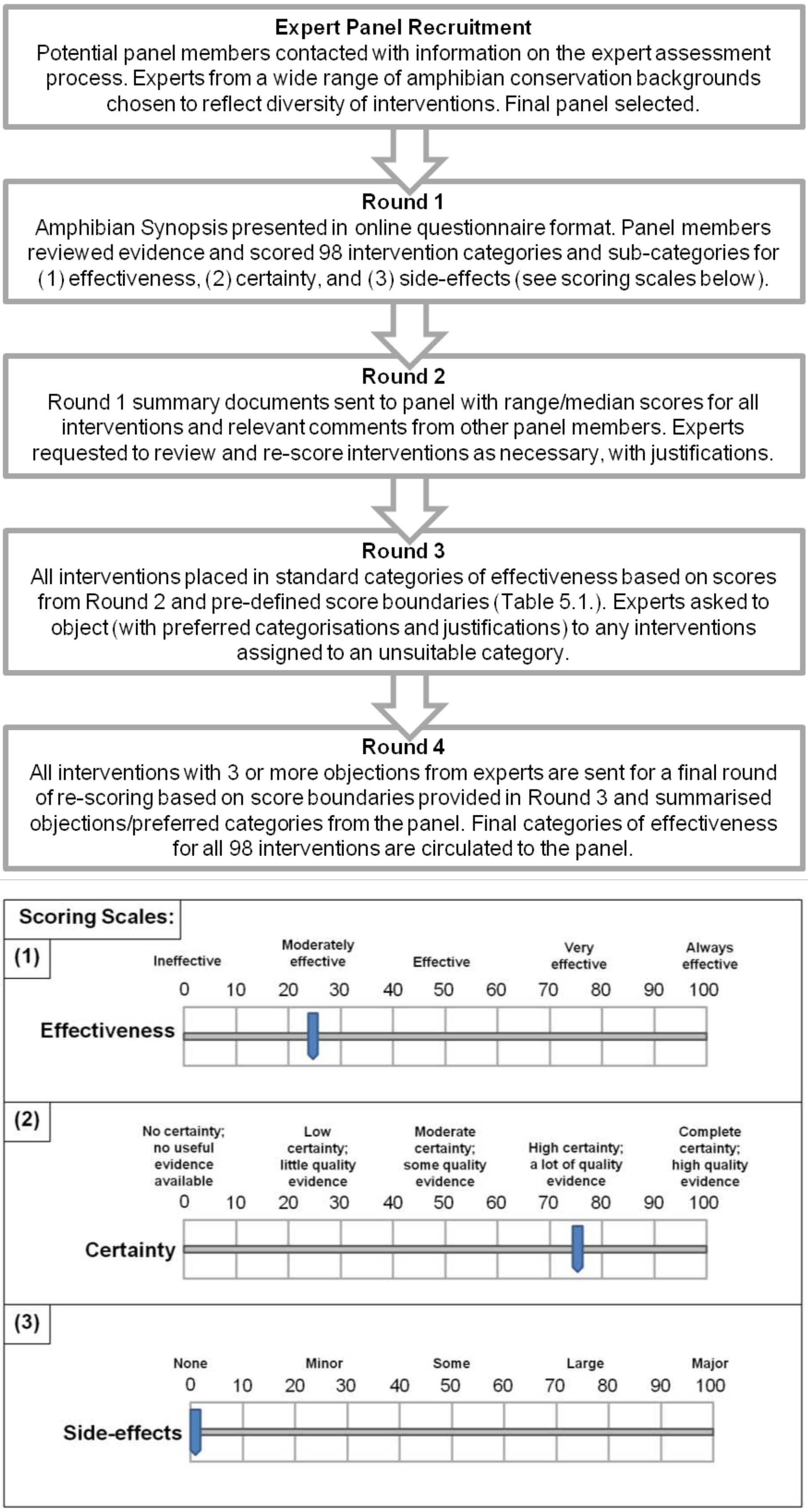


Figure 5.1. Summary of Delphi process and scoring scale used in the expert assessment of the Amphibian Synopsis. Panel members were asked to score each intervention for effectiveness, certainty and side-effects out of 100, with help from guidance notes (Appendix IV) and the score calibrations shown in this figure.

Table 5.1. Descriptions of categories of effectiveness. Score thresholds provided by Conservation Evidence 2015.

Category	Description	Score thresholds (out of 100)
Beneficial	Effectiveness has been demonstrated by clear evidence. Expectation of harms is small compared with the benefits	Effectiveness: >60 Certainty: >60 Side-effects: <20
Likely to be beneficial	Effectiveness is less well established than for those listed under 'beneficial' **OR** There is clear evidence of medium effectiveness	Effectiveness: ≥40 Certainty: 40-60 Side-effects: <20 **OR** Effectiveness: 40-60 Certainty: >40 Side-effects: <20
Trade-off between benefit and harms	Interventions for which practitioners must weigh up the beneficial and harmful effects according to individual circumstances and priorities	Effectiveness: ≥40 Certainty: >40 Side-effects: ≥20
Unknown effectiveness	Currently insufficient data or data of inadequate quality	Effectiveness: Any Certainty: <40 Side-effects: Any
Unlikely to be beneficial	Lack of effectiveness is less well established than for those listed under 'likely to be ineffective or harmful'	Effectiveness: <40 Certainty: 40-60 Side-effects: <20
Likely to be ineffective or harmful	Ineffectiveness or harmfulness has been demonstrated by clear evidence	Effectiveness: <40 Certainty: >60 Side-effects: Any **OR** Effectiveness: <40 Certainty: Any Side-effects: ≥20

Analyses

Descriptive bibliometric analyses were performed to determine patterns of publication and research effort. Research was assigned to three broad categories: Threat Mitigation, Species Management, and Education & Engagement. The same threat classification was employed as the Amphibian Synopsis, which was based on the IUCN Red List, and follows Salafsky et al. (2008). Interventions mitigating different threat types were assigned to the following major headings: (i) habitat destruction and fragmentation; (ii) invasive and other problematic species (which includes disease); (iii) pollution; (iv) exploitation (specific to use of the species); and (v) climate change. Species Management interventions were sub-divided between *in situ and ex situ* actions, and interventions relating to Education & Engagement were divided between education initiatives (including awareness-raising) and active involvement (engagement) of the public (see Table 5.2). Kruskal-Wallis (KW) tests were used to ascertain whether significant differences existed between the number of evidence studies for Threat Mitigation, Species Management, and Education & Engagement. *Post-hoc* multiple comparison testing in R was used to determine which of the pair-wise comparisons were responsible for any overall difference detected using the Kruskal-Wallis test.

Generalised Linear Modelling (GLM) was used to examine the relationship between the amount of evidence in the Amphibian Synopsis per intervention and the panel's median scores per intervention for effectiveness, certainty and side-effects. The response variable in each case was the median score (out of 100) converted into a proportion between 0 and 1, and the explanatory variable was the number of evidence studies per intervention. Each GLM was modelled using a quasibinomial error distribution, since all models were found to be overdispersed (Crawley 2007). GLM was also used to examine the relationship between the median effectiveness score per intervention (the response variable, converted into a proportion between 0 and 1) and the median certainty score (the explanatory variable). Again, the variables were modelled using a binomial error distribution, and a quasibinomial error distribution was used when the model was found to be overdispersed. Nagelkerke's R^2 was calculated to determine each model's explanatory power (Nagelkerke 1991). All analyses were conducted using R version 3.0.0 (R Core Team 2013).

Results

Expert Panel

Our final expert panel comprised 30 experts, and 22 completed all four rounds of the Delphi process, including: nine academics, eight from NGOs, three from zoos, one from a government agency, and one from an intergovernmental agency. The amphibian disease sub-panel comprised three amphibian disease specialists from academic institutions, all of whom completed four rounds. Experts were from 15 countries, including Belgium, Cameroon, China, Finland, India, Kenya, Mexico, New Zealand, Peru, Portugal, Romania, Russia, South Africa, United Kingdom, and the United States. The main panel that assessed all 98 actions included nine experts from Less Economically Developed Countries (LEDCs) and 15 from More Economically Developed Countries (MEDCs; as defined by IMF 2014). However, the majority of panel members from all countries have substantial international experience in amphibian conservation, and provided crucial insights on the global practice of conservation interventions throughout the expert assessment.

Summary of Amphibian Synopsis and Expert Assessment

Interventions in the synopsis fall under three overarching categories: actions designed to mitigate specific threats (Threat Mitigation); species management techniques divisible between *in* situ and *ex situ* strategies (Species Management); and approaches to education and public engagement (Education & Engagement) (Table 5.2). Of the 98 actions with evidence included in the assessment, Threat Mitigation was the most frequently represented category, accounting for 402 evidence studies across 71 actions. Species Management accounted for 208 studies and 22 actions, whilst Education & Engagement featured in 32 studies across five interventions. The median number of studies per intervention in the expert assessment was: four (interquartile range [IQR], 1-7; range = 1-35; $n = 71$) for Threat Mitigation; six (IQR, 4-11.75; range = 1-35; $n = 22$) for Species Management; and six (IQR, 5-7; range = 5-8 ; $n = 5$) for Education & Engagement. Threat Mitigation, Species Management, and Education & Engagement interventions did not have the same level of research effort (KW, H = 7.692, df = 2, $p = 0.0214$). The number of publications per intervention was significantly higher for Species Management than Threat Mitigation (KW: $p < 0.05$), but there was no significant difference between the number of publications for Education & Engagement and Threat Mitigation or Species Management actions. Habitat restoration/creation and *ex situ* species management were the sections of the synopsis with the greatest number of evidence studies, and climate change/severe weather was the least studied section.

The number of studies per action ranged between one study (for 22 of the actions) and 35 studies (install culverts or tunnels as road crossings; and breed frogs in captivity). Studies were unequally distributed globally, with some countries producing substantially more studies than others (Figure 5.2). The evidence studies apply to 44 countries in total, with the United States producing the greatest number (181 studies), followed by the United Kingdom (57 studies) and Australia (35 studies). Only two countries – the United Kingdom and New Zealand – had conservation evidence studies that featured all of their native amphibian species, though both have low diversity (Figure 5.2). Native species studied within the United States (43 in total, with additional subspecies) were the most abundant in the synopsis.

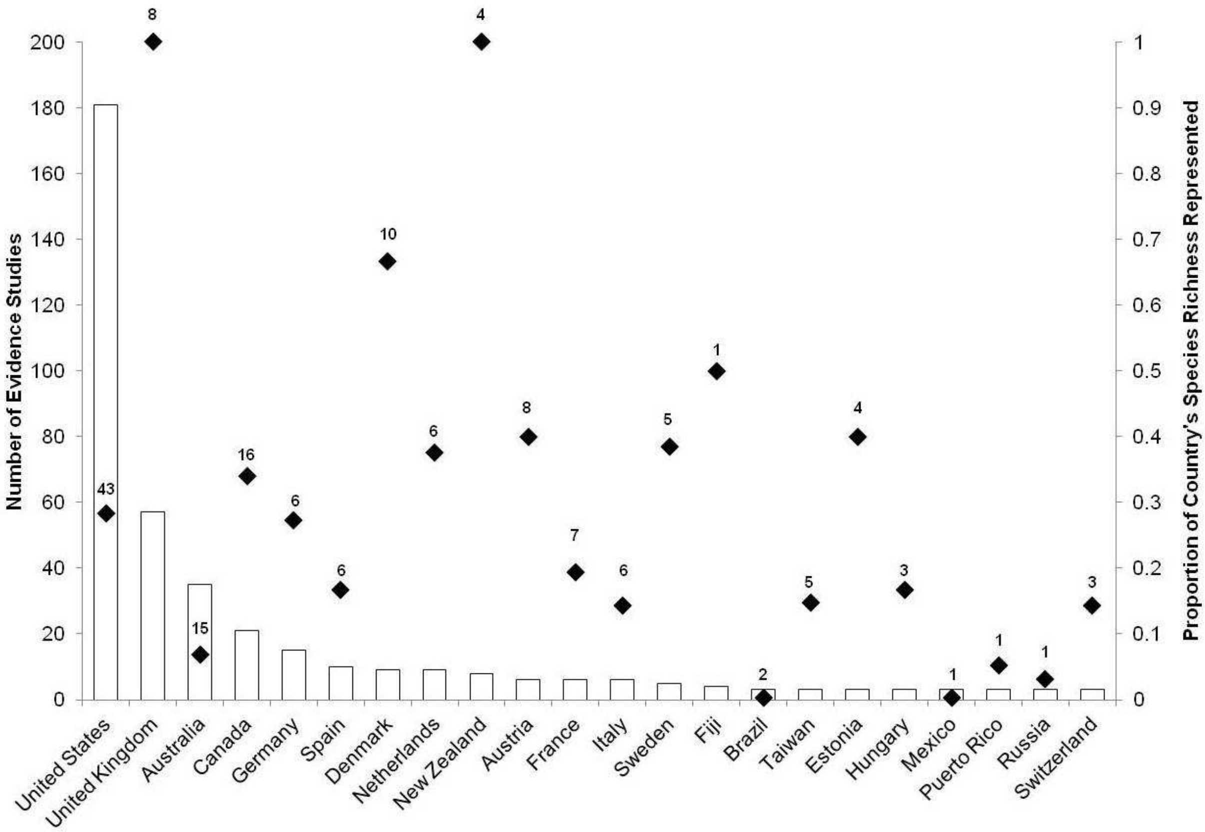


Figure 5.2. Top countries for conservation evidence. Number of evidence studies relevant to each country is displayed as bar against the primary axis (all countries with ≥3 studies included). The proportion of each country's species richness represented in these evidence studies is displayed as a scatter plot against the secondary axis. The total number of native species featured in the evidence studies is displayed above each marker.

Table 5.2. Summary of interventions in the Amphibian Synopsis.

Intervention Type	Sub-Sections of Amphibian Synopsis	Interventions with Evidence / Total Interventions	Total Evidence Studies
Threat Mitigation:			
Habitat destruction & fragmentation	2. Threat: Residential and commercial development	1 / 3	4
	3. Threat: Agriculture (*Habitat destruction*)	5 / 8	14
	4. Threat: Energy production & mining	1 / 1	2
	5. Threat: Transportation and service corridors	6 / 6	55
	6. Threat: Biological resource use (*Logging*)	8 / 8	46
	7. Threat: Human intrusions & disturbance	0 / 1	0
	8. Threat: Natural system modifications	4 / 4	32
	12. Habitat protection	3 / 3	7
	13. Habitat restoration and creation	12 / 18	161
Pollution	10. Threat: Pollution	4 / 6	8
Invasive/other problem species	9. Threat: Invasive alien & other problematic species:		
	Invasive alien species	9 / 12	29
	Control competing native species	1 / 2	1
	Disease	10 / 12	40
Exploitation	6. Threat: Biological resource use *Amphibian species exploitation*	2 / 3	3
Climate change	11. Threat: Climate change and severe weather	0 / 7	0
Species Management:			
In situ	14. Species management *Translocations*	1 / 1	59
Ex situ	*Captive breeding/re-introduction*	6 / 6	149
Education & Engagement:			
Education	15. Education & awareness raising: *Education*	2 / 2	11
Engagement	3. Threat: Agriculture: *Land owner engagement*	2 / 2	13
	6. Threat: Biological resource use *Use amphibians sustainably*	0 / 1	0
	15. Education & awareness raising *Engagement – citizen science*	1 / 1	8

Experts tended to rate actions as increasingly more effective as evidence studies increased in number. Assessments of certainty and side-effects also increased with study number.

There was a positive relationship between the number of evidence studies per assessed action (Figure 5.3a,b,c) and the experts' median scores for: effectiveness (GLM: t = 2.775, s.e. 0.0131, p = 0.00663, df = 97, R^2 = 0.772); certainty (GLM: t = 7.940, s.e. 0.00801, p = < 0.001, df = 97, R^2 = 0.982); and side-effects (GLM: t = 2.139, s.e. 0.00188, p = 0.0350, df = 97, R^2 = 0.663). High R^2 values for these models suggest that the number of evidence studies explains a high proportion of the variance in scores for effectiveness, certainty and side-effects. There was also a positive relationship between the median scores for effectiveness and certainty (Figure 5.3d; GLM: t = 6.214, s.e. 0.00541, p < 0.001, df = 97, R^2 = 0.997). A high R^2 value for this model indicates that the variance observed in effectiveness scores is largely explained by associated certainty scores.

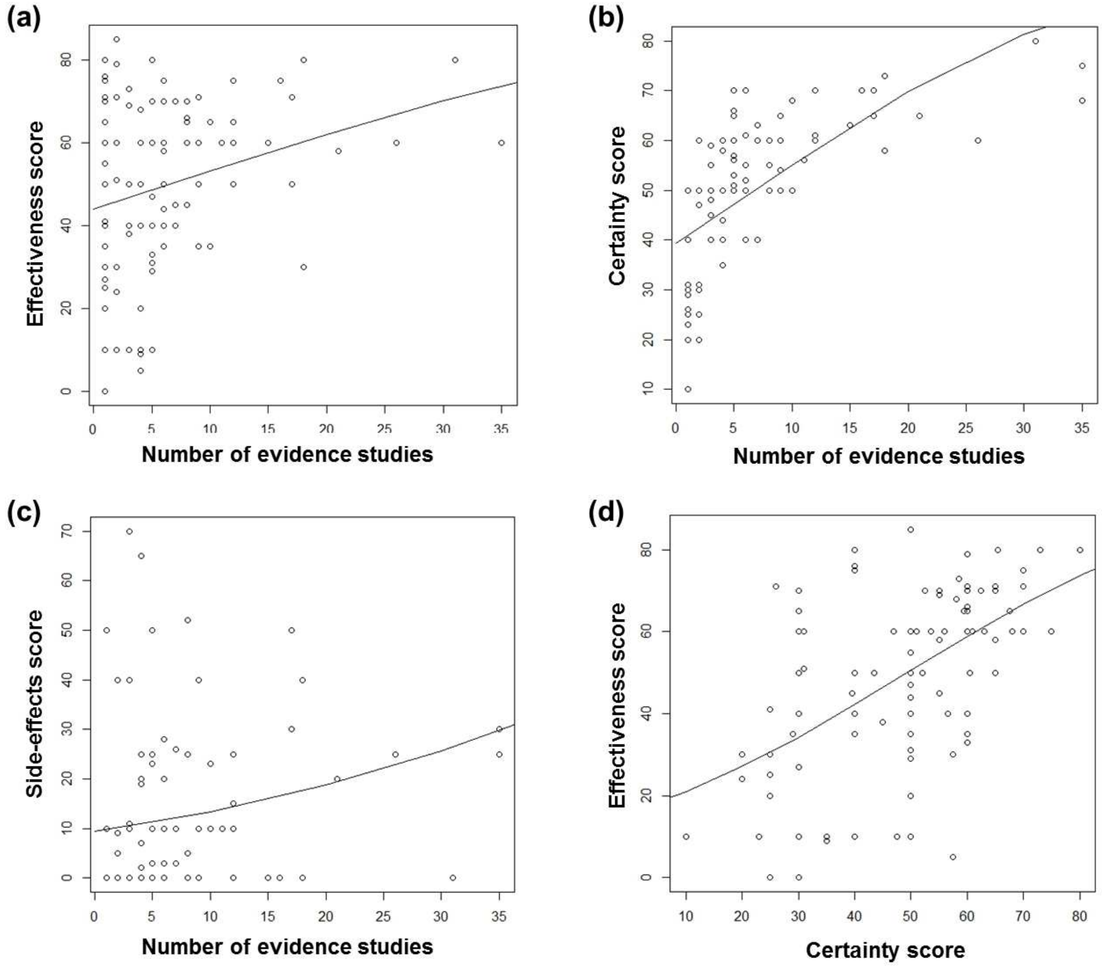


Figure 5.3. Relationships between the number of evidence studies and the median scores per intervention for (a) effectiveness, (b) certainty, and (c) side-effects. Figure 5.3(d) shows the relationship between the median certainty score and the median effectiveness score per intervention.

Categories of effectiveness

Forty-four percent of the 98 interventions were effective to some degree in the absence of significant negative side-effects, and could be categorised as "Beneficial" (10% of interventions) or "Likely to be beneficial" (34%). Thirty-two percent were assessed as ineffective and/or associated with substantial negative side-effects, and placed in the categories of "Unlikely to be beneficial" (6%), "Likely to be ineffective or harmful" (7%) or "Trade-offs between benefits and harms" (18%). The remaining 24% were considered to be of "Unknown effectiveness" based on a paucity of good-quality evidence. Therefore, out of 129 actions (including 27 sub-categories and 102 full interventions, 31 of which had no evidence), 43 (33%) may be assessed as likely to be effective. The rest (67%) were ineffective, associated with harmful side-effects or had insufficient evidence.

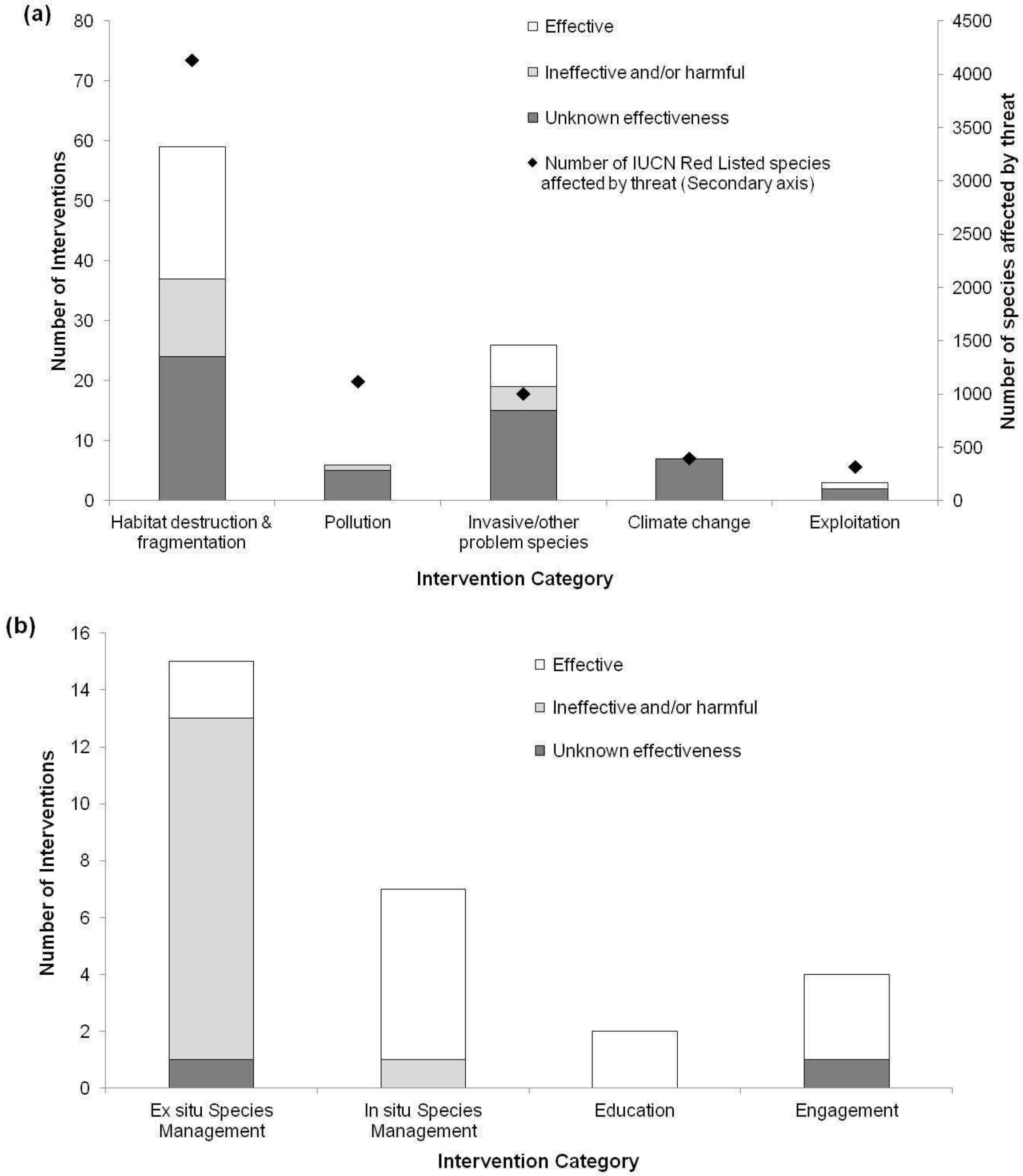


Figure 5.4. Stacked column charts summarising the results of the expert assessment: (a) Threat Mitigation interventions (*n* = 101); and (b) Species Management (*n* = 22) and Education & Engagement interventions (*n* = 6). Each bar displays the number of interventions under each category against the primary axis. The number of interventions in different effectiveness categories are

displayed within each bar: **Effective** includes interventions in the categories of "Beneficial" and "Likely to be beneficial"; **Ineffective and/or harmful** includes "Trade-off between benefit and harms", "Unlikely to be beneficial" and "Likely to be ineffective or harmful"; and **Unknown effectiveness** includes "Unknown effectiveness" and interventions with no evidence. See Table 5.1 for definitions of categories and score boundaries. A scatter plot against the secondary axis in Figure 5.4(a) shows the number of IUCN Red Listed species (IUCN 2014) affected by at least one threat from each threat category.

Fifty-three of 101 Threat Mitigation actions are of unknown effectiveness (including 30 with no evidence), and a further 18 were considered to be ineffective or harmful (Figure 5.4a). Actions tackling habitat destruction and fragmentation were the most numerous, both in overall number, and in the number assessed as effective. No mitigation interventions for pollution and climate change were assessed as effective (climate change interventions lacked evidence altogether). The number of actions per threat tended to be proportional to the number of amphibian species affected by each threat category (IUCN 2014), with two important exceptions. Pollution had the second fewest interventions despite being the second most prevalent threat, and invasive/other problem species has the second highest number of interventions despite being the third most prevalent threat. Furthermore, the geographic spread of evidence for threat mitigation interventions is highly uneven, and aligns poorly with the proportion of species affected by these threats globally (Figure 5.5).

For Species Management, two of 15 *ex situ* interventions (13%) were assessed as "Likely to be beneficial". Eighty percent of *ex situ* species management actions were considered ineffective or potentially harmful, 67% of which were categorised under "Trade-offs between benefits and harms". However, six out of seven (86%) *in situ* actions (all related to species translocations) were assessed as "Likely to be beneficial". All Education & Engagement interventions with evidence were assessed as "Likely to be beneficial", but the intervention "use amphibians sustainably" lacks evidence in the synopsis.

Table 5.3 displays the interventions assessed most favourably ("Beneficial"; Table 5.3a) and least favourably ("Likely to be ineffective or harmful"; Table 5.3b). In both cases, most of these actions tackle habitat destruction and fragmentation. Interventions relating to the creation and maintenance of ponds and the restoration of wetlands were most frequently assigned to the category of "Beneficial" based on a total of 105 evidence studies (Table 5.3a). Pond creation evidence in the context of frogs, natterjack toads, and salamanders/newts evidence comprised 53 studies from 14 countries, including the United States, Canada, Australia, ten European nations and China. Furthermore, pond creation for toads, green toads and great crested newts was assessed as "Likely to be beneficial". The majority of the 39 species that benefitted from pond creation in the sub-categorisations deemed "Beneficial" were not globally threatened, although two Vulnerable species (the Oregon spotted frog (*Rana pretiosa*) and Italian agile frog (*Rana latastei*)) survived in new ponds (*Rana latastei* also bred), and one Critically Endangered species from China (the Chinhai salamander, *Echinotriton chinhaiensis*) also survived and bred in constructed ponds. A fifth threatened species, Australia's Vulnerable Green and golden bell frog (*Litoria aurea*), only survived in created ponds if translocated individuals did not succumb to chytridiomycosis. Wetland creation and restoration evidence came from five countries, namely the United States, Canada, Australia, Kenya and Taiwan, and all of the 20 species mentioned in the synopsis were not globally threatened. Replanting vegetation was another habitat restoration intervention assessed as "Beneficial", and was based on studies in the United States, Canada, Australia and Spain. These studies covered a variety of vegetation types, including tree and shrub planting and grass reseeding. Out of five possible interventions for mitigating the impact of fish predation on amphibians, drying out ponds was the only option assessed as "Beneficial", with all evidence collected in the United States or Europe. By contrast, assessment of the other four options was mixed: remove or control fish using the board-spectrum piscicide rotenone ("Trade-offs between benefits and harms"); remove or control fish by catching ("Likely to be beneficial"); exclude fish with barriers ("Unknown effectiveness"); and encourage aquatic plant growth as refuge against fish predation (no evidence).

All interventions categorised as "Likely to be ineffective or harmful" relate to mitigating habitat destruction and fragmentation, except for the release of captive-bred Green and golden bell frogs in Australia (Table 5.3b). The lowest median effectiveness scores were associated with interventions that use fire and herbicides to manage vegetation, as well as the release of captive bred Green and golden bell frogs (*L. aurea*) from Australia into their native habitat. Evidence studies for the use of prescribed fire regimes in habitat management were conducted principally in the United States, but there were also two studies from Australia and Argentina. Herbicide studies were all conducted in the United States and Canada.

Table 5.3. (a). Interventions assessed as "Beneficial" based on median scores out of 100 for effectiveness, certainty and side-effects from the expert assessment.

Intervention	Effectiveness	Certainty	Side-effects	Studies	Intervention Type
8.4. Regulate water levels	70	65	10	5	Habitat destruction & fragmentation
9.4. Remove or control fish by drying out ponds	80	65.5	2.5	5	Invasive/other problematic species
13.1. Replant vegetation	70	62.5	2.5	7	Habitat destruction & fragmentation
13.8. Create ponds	80	80	0	31	Habitat destruction & fragmentation
13.8.1. Frogs	75	70	0	12	
13.8.3. Natterjack toads	75	70	10	6	
13.8.5. Salamanders	70	65	0	5	
13.10. Create wetlands	75	70	0	16	Habitat destruction & fragmentation
13.12. Restore wetlands	80	73	0	18	Habitat destruction & fragmentation
13.13. Deepen, de-silt or re-profile ponds	71	65	0	9	Habitat destruction & fragmentation

Table 5.3. (b). Interventions assessed as "Likely to be ineffective or harmful" based on median scores out of 100 for effectiveness, certainty and side-effects from the expert assessment.

Intervention	Effectiveness	Certainty	Side-effects	Studies	Intervention Type
3.9. Exclude domestic animals or wild hogs by fencing	31	50	25	5	Habitat destruction & fragmentation
6.5. Thin trees within forests	35	60	40	9	Habitat destruction & fragmentation
6.6. Harvest groups of trees instead of clearcutting	32.5	60	22.5	5	Habitat destruction & fragmentation
8.1.1. Use prescribed fire or modifications to burning regime: Forests	30	57.5	40	18	Habitat destruction & fragmentation
8.1.2. Grassland	10	40	70	3	
8.2. Use herbicides to control mid-storey or ground vegetation	10	50	50	5	Habitat destruction & fragmentation
14.6.2. Release captive-bred individuals: Green and golden bell frog	20	50	20	4	*Ex situ* Species Management

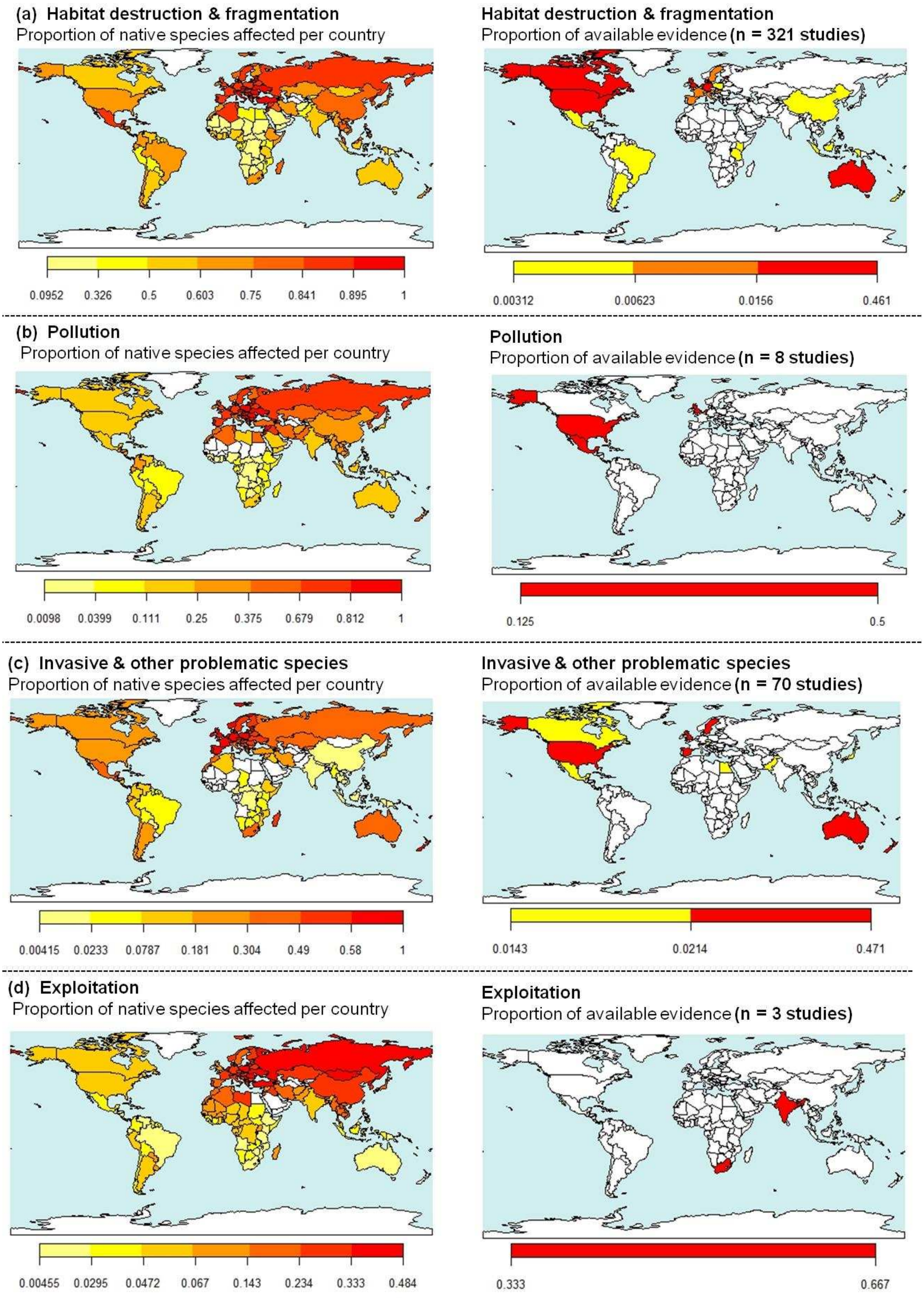


Figure 5.5. Maps showing spatial variation in the proportion of a country's species affected by a threat category and the proportion of available evidence on mitigation interventions for that threat category in the Amphibian Synopsis. Maps for climate change are not shown – no evidence existed to support interventions for mitigating this threat. Where values are zero, countries are shown in white.

Discussion

Gaps in the evidence

Out of 129 conservation actions listed in the synopsis, 43% are of unknown effectiveness, including 24% without a single evidence study. Therefore, approaching half of all conservation actions conducted for amphibians lack the requisite evidence base to inform practice. Only a third of the conservation actions listed in the synopsis were assessed as beneficial or likely to be beneficial in the absence of significant negative side-effects. Of the 98 assessed interventions with evidence, this rises to 43% that are beneficial or likely to be beneficial. Either way, our results suggest that management actions may frequently run the risk of not benefiting wild amphibian populations. These results must be interpreted against the backdrop of a general dearth of evidence for amphibian conservation interventions, which must be rectified before confident conclusions can be drawn about the effectiveness of many conservation interventions. The small number of interventions and low levels of evidence for the mitigation of threats such as pollution, climate change and exploitation must be addressed. Education and engagement initiatives are also poorly represented given their significance in engineering a supportive environment for conservation efforts (Froglog 2013).

The global imbalance of evidence is of primary concern, as literature is currently highly skewed towards a small number of countries (see also Chapter 4). The geographic spread of evidence for threat mitigation interventions is poorly aligned with threat prevalence, and we know very little about how to mitigate threats in the tropics. In fact, the top five countries where conservation evidence studies are conducted (in descending order: United States, United Kingdom, Australia, Canada, Germany) account for 73% of all studies, and 43% alone are based in the United States. The United States is a world leader in scientific output (May 1997) and publication citation rate (King 2004), and has a high gross expenditure on Research & Development (May 1998). It is therefore unsurprising that the US dominates the production of conservation evidence for amphibians. However, a number of embedded factors encourage science-based conservation management in the United States, particularly through government agency involvement. There is a legal obligation for conservation managers to justify actions using evidence under the US Endangered Species Act (ESA) (Pullin & Knight 2003), and a general requirement for Unites States agencies to set goals and provide evidence of their performance (Zients 2010; Keene & Pullin 2011). Although concerns have been raised that ESA funding for amphibian conservation is currently insufficient (Gratwicke et al. 2012), 41% of the 32 species currently listed as Threatened or Endangered by the ESA (USFWS 2015) currently appear in the Amphibian

Synopsis. Government agencies produce technology transfer documents providing details of evidence to support management interventions. For example, the Pacific Northwest Research Station of the US Forest Service publish a newsletter that disseminates science-based support for management actions (Science Findings 2015); tackling topics such as "*Engineering a future for amphibians under a changing climate*" (Science Findings 2011). Also, the US Geological Survey has a subgroup called the Amphibian Research and Monitoring Initiative (ARMI), and one of their central objectives is to "*Provide essential scientific information to support effective management actions to arrest or reverse declines*" (ARMI 2015). These few examples indicate a favourable infrastructure for evidence-based amphibian conservation in the United States, and could provide instructive frameworks for promoting evidence production in other countries.

More evidence enables more confident assessments

Sutherland et al. (2011) found a positive correlation between the number of evidence studies that address the effectiveness of an intervention and the certainty of knowledge score, which was suggested to be an asymptotic relationship of diminishing returns on research investment as the number of publications increases. We found a similar relationship between number of evidence studies and the median certainty score, but also a positive correlation between the number of studies and scores for both effectiveness and side-effects. As the evidence base increases, more information is available to understand the performance of an intervention in different contexts, leading to greater understanding of effectiveness and/or negative consequences. The positive relationship demonstrated between median certainty and effectiveness scores has also been observed elsewhere (Walsh et al. 2014), and may be related to a tendency of conservation programmes to publish positive outcomes (Spooner et al. 2015). However, learning from unsuccessful conservation approaches is an essential aspect of improving the effectiveness of conservation (Redford & Taber 2000).

Low median numbers of studies across all intervention types limit what can be deduced about the performance of interventions in diverse contexts. The intervention with the joint highest level of evidence (35 studies) was "install culverts or tunnels as road crossings for amphibians" which was assessed as "Trade-offs between benefits and harms" (median scores: effectiveness = 60; certainty = 75; side-effects = 25). This provides an informative case-study of how increasing evidence availability for an intervention does not only increase certainty with regard to effectiveness, but also improves our understanding of the relative merits of different methods. For example, collated evidence supported the following methods to increase the effectiveness of tunnels: the presence of barrier fencing to guide animals into tunnels; wider tunnel diameter; shorter tunnel length; and natural substrate along the tunnel floor. Negative impacts of tunnels were associated with vertical entry chutes, which caused a high mortality of common toads. Also the use of aluminium, zinc, copper and lead in tunnel construction was associated with dangerously high metal concentrations in the condensation that accumulated within the tunnel; 134–124,500 times higher than recommended for protecting freshwater aquatic life (see references in Smith & Sutherland 2014, p. 35-46). More evidence needs to be accrued for all interventions to improve the reliability of future assessments, representing an appropriate range of geographical, social, and methodological contexts.

What can we say about what works in amphibian conservation?

A full summary of the expert assessment of conservation interventions for amphibians can be found in Smith et al. (2015; and see Appendix V). An increased number of effective actions across all intervention types would be beneficial, but some important messages have emerged regarding promising courses of action. *In situ* species management actions (species translocations) are more frequently assessed as effective than *ex situ* actions (breeding amphibians in captivity and releasing captive bred or head-started individuals). Evidence therefore currently supports translocation efforts over actions that take individuals into captivity, with the important proviso that inadequate evidence may confound a direct comparison of *in situ* and *ex situ* species management. Evidence on *ex situ* interventions such as captive breeding often focuses on whether successful reproduction/rearing was achieved, but not whether populations were sustainably re-established in the wild. However, evidence for reintroduction of captive bred individuals into the wild is available, and results were largely dependent on the species involved. For example, the release of captive bred Green and golden bell frogs (*Litoria aurea*) in Australia between 1998 and 2007 was associated with limited survivorship, as individuals frequently succumbed to chytridiomycosis or predation by non-native fish (White & Pyke 2008). Unless threats in the wild can be mitigated, both reintroduction and translocation programmes are likely to be ineffective. Our panel raised a number of concerns about *ex situ* actions, including side-effects such as high mortality rates (e.g. *Litoria aurea*), the risk of spreading disease to wild populations post-release in the event of insufficient biosecurity (Walker et al. 2008 – an issue that is also relevant to translocations), as well as reduced fitness of captive individuals (Kraaijeveld-Smit et al. 2006; King et al. 2011; Antwis et al. 2014), and genetic adaptation to captive conditions over multiple generations (Williams & Hoffman 2009). As concluded by Bloxam & Tonge (1995; p. 643) in their assessment of the suitability of amphibians for captive-release programmes: "*reintroduction of captive-bred individuals is not always the answer but it is an important tool when all else may fail*". Successful reintroductions were noted for several species; a total of 25 studies examining the results of releases of captive-bred individuals reported the establishment of breeding populations for 10 out of 17 species (59%). Even so, evidence for the effectiveness of translocations is more positive; 43 studies found that 23 out of 30 species (78%) established breeding populations. Our results therefore indicate higher effectiveness of species translocations than releases of captive bred individuals; a finding which is also supported by existing reviews. Griffiths & Pavajeau (2008) evaluated literature on 58 species in captive breeding and reintroduction programmes (from 1970-2006), and found that 13 out of 58 reintroduced species (22%) established self-sustaining populations. Examining translocation literature from 1991 to 2006, Germano & Bishop (2009) found that over 50% of 38 amphibian translocation programmes had reliable evidence of a substantial addition of new recruits to the adult population resulting from breeding at the translocation site.

Examining examples from either end of the effectiveness category continuum (i.e. "Beneficial" and "Likely to be ineffective or harmful") illustrates some promising future directions in amphibian conservation, as well as some challenges. Firstly, the creation, maintenance and restoration of ponds and wetlands clearly benefits amphibians in locations where evidence has been collected. However, evidence is overwhelmingly skewed towards case studies in the United States, Canada, Europe and Australia, rendering impossible any confident global generalisations. Furthermore, common species appear to benefit the most in all cases, so further research is required to test these interventions for rare and threatened species. Pond and wetland creation is advocated widely as a wildlife conservation strategy for many other species in addition to amphibians, and is promoted in numerous management guidance documents and initiatives (e.g. IWWR 2002; Baker et al. 2011; Million Ponds Project 2012) . As a note of caution, however, constructed wetlands that receive treated waste water have been associated with development abnormalities in amphibians (Ruiz et al. 2010), so the effectiveness of these interventions can be compromised by additional threats. This example also highlights that interventions must be carefully monitored to ensure they are performing as intended, and to alert managers to further issues in need of mitigation. Ponds and wetlands are crucial to the majority of amphibians in terms of life history habit, spawning, and larval development, but is important to remember that almost a third of amphibian species have breeding strategies that are not associated with wetlands (data from Sodhi et al. 2008). Interventions for the conservation of terrestrial and arboreal species that do not require water bodies in order to breed must also be investigated to represent the needs of amphibians globally.

Prescribed fire is considered a beneficial management tool for the maintenance and restoration of fire-adapted ecosystems (e.g. Southern United States pine forests, Carter &

Foster 2004). Prescribed burning is recommended in habitat management guidelines for amphibians in the United States, under the belief that it aids declining species by improving habitat conditions and reducing fuel supplies for unplanned wild fires (Bailey et al. 2006). However, these guidelines also state that "*excessive or poorly planned fire can do more harm than good…before you strike a match, consult a qualified prescribed fire specialist*" (Bailey et al. 2006, p. 14). Evidence in the Amphibian Synopsis suggests that this intervention is largely ineffective, but that seasonal timing of fires can influence impact on amphibians. For example, springtime burns have greater negative consequences for salamander abundance in the United States than autumn/winter burns (Brodman 2010). Also, amphibian populations may need to recover between burns, as abundance increases with time after burns (Langford et al. 2007), and certain burn cycles are more conducive to increased numbers of amphibians than others (Hannah & Smith 1995). In an additional study suggested by the panel, the abundance of species following a prescribed burn may vary according to their requirement for open habitat (Ashton & Knipps 2011). The evidence therefore suggests that this intervention has the capacity to be beneficial or harmful depending on methodology and species. In the case of forests, only five of 18 studies compared different fire frequencies (2-7 year cycles) or burn seasons. If such management details can alter the overall outcome, it is erroneous to compare across studies that vary in these details (Smith et al. 2014). Studies comparing different burn methodologies are therefore required to ascertain the true effectiveness of this intervention.

All studies investigating the impact of herbicides in controlling mid-storey or ground vegetation took place in the United States and Canada, with uniformly ineffective or negative consequences for species. In most cases, species abundance did not change before and after treatments. However, capture rates of the southern toad (*Bufo terrestris*) in understory removal plots were significantly lower than in control plots in one US study (Litt et al. 2001), and a second study in Canada indicated that Wood frogs (*Rana sylvatica*) were significantly less abundant in 20-30 year-old stands that had been managed by planting and herbicide treatment, compared to those that had been left to regenerate naturally (Thompson et al. 2008). Bailey et al. (2006) in "*Habitat Management Guidelines for Amphibians and Reptiles of the Southeastern United States*" state that herbicides can help achieve many habitat management objectives, and can be especially effective when combined with prescribed fire, but that chemicals must be used with caution. Baker et al. (2011) in the "*Amphibian Habitat Management Handbook*" recommend using a glyphosate- or triclopyr-based herbicide to treat stumps during scrub clearance to prevent regrowth, and use foliar spraying to remove small saplings during habitat restoration. Again, more evidence is required to build a detailed picture of the consequences of this intervention, although our existing assessment of the evidence suggests it is both ineffective in increasing amphibian numbers and potentially harmful.

In summary, interventions currently assessed as "Beneficial" and "Likely to be ineffective or harmful" still need to be tested in a greater variety of geographic and species contexts. Comparative effectiveness research that investigates different methodologies and interventions for the same threat would also help strengthen our understanding of what works in amphibian conservation (Smith et al. 2014).

Interpreting categories of effectiveness - caveats and limitations

A series of caveats and limitations must be considered when interpreting categories of effectiveness assigned by the expert panel. Most importantly, categories are based only on the evidence in the synopsis, and must be interpreted through examination of this evidence. Panel members were asked to incorporate any geographic and species biases in the spread of evidence into their certainty scores, reducing certainty in cases where evidence coverage was insufficient to enable global generalisation (as in Dicks et al. 2014). Given that evidence in the synopsis is heavily skewed towards a few countries, many interventions have a limited geographic scope. Studies are concentrated in temperate regions, so extrapolating the effects of interventions to the tropics can be misleading when insufficient evidence exists. Categories of effectiveness should not be decoupled from their supporting evidence, perhaps especially in these early days of collating conservation evidence for amphibians, since relevant studies are low in number (e.g. Spooner et al. 2015). A positive, negative or unknown assessment of effectiveness should not discourage evidence studies in diverse contexts to build a detailed picture of an intervention (Smith et al. 2014). Interventions can be associated with winners and losers in terms of species, and conservation problems generally demand bespoke solutions adapted to the setting (Segan et al. 2011). Also, isolating the effect of different interventions can be challenging because they may act synergistically (Fazey et al. 2004). In any case, accumulating more supporting evidence testing the effects of interventions in varied locations, and on a diversity of species, will enable greater understanding of where and how interventions can be effective. Every effort should be made to rectify this imbalance to advance the use of evidence-based conservation worldwide.

Several panel members claimed that a substantial amount of evidence had been missed from the synopsis, particularly studies not published in English. However, when panel members provided details of studies that had been missed, the majority (81% of the 98 extra studies recommended, not all of which tested the effects of interventions) comprised research conducted in the United States, Canada, Western Europe or Australia, and indicated that prominent studies from other countries had not been excluded. The uneven distribution of evidence most probably reflects true gaps in research effort. It can be tempting to think that research into threats can inform our knowledge of the likely impact of interventions. For example, certain herbicides are harmful to amphibian populations (e.g. Atrazine: Hayes et al. 2006), so restricting their use is advisable. However, evidence from studies that specifically test the effects of interventions is favoured, because it demonstrates what actually happens when conservation management intervenes, rather than what is expected given an observed correlation (Dicks et al. 2014b). The Amphibian Synopsis only includes evidence that tests the effects of interventions (Smith & Sutherland 2014), which is the kind of research required to inform the practice of these actions.

Evidence is not all equal in terms of quality and relevance (Pullin & Knight 2005; Haddaway & Pullin 2013; Adams & Sandbrook 2013). Panel members commented that many studies provided limited inference, and there was a mix of scales, both spatial and in terms of individuals versus populations. Careful study design is critical to ensure evidence is of high quality and allows for clear conclusions about the effectiveness of interventions. There were also cases where evidence for an intervention did not cover effects on *in situ* native species, such as actions aimed at minimising disease transmission. Our sub-panel on amphibian disease strongly advocated that the precautionary principle be applied (e.g. Myers 1993) due to the substantial risks associated with this threat (Daszak et al. 1999), which also applies to translocating and/or reintroducing species. The risk of spreading disease through the reintroduction of species from captive-breeding programmes (e.g. Walker et al. 2008), or translocating pathogens along with their host organism (Cunningham 1996), is of great concern, especially when screening cannot always detect the presence of disease in live amphibians (e.g. St-Amour & Lesbarrères 2007). The expert panel therefore advised that interventions designed to minimise the spread of disease (e.g. sterilize equipment when moving between amphibian sites, and the use of appropriate gloves to handle amphibians) should be carried out as standard practice, in spite of both of these interventions being placed in the category of "Unknown effectiveness". Additional studies on methodologies for minimising exposure of amphibians to potentially harmful pathogens during field studies (Phillott et al. 2010), and the effectiveness of disinfectants against major disease-causing pathogens such as Ranavirus (Bryan et al. 2009) and *Batrachochytrium dendrobatidis* (Webb et al. 2007) were cited by panel members in support of these approaches.

Finally, although we attempted to reduce any biases in our expert assessment approach by using a structured and anonymous elicitation method with appropriate facilitation (Burgman et al. 2011a; Gregory et al. 2012; Martin et al. 2012b), it is probable that panel members provided some judgements based on their existing values (e.g. Donlan et al. 2010) or knowledge (e.g. Sutherland et al. 2011b). We asked panel members to base assessments only on the evidence in the synopsis, but we appreciate that this is a difficult task for experts who have wide research and practice-based experience of the interventions under consideration. However, our expert panel did reach consensus on the categories of effectiveness, and it is hoped that future synopses will draw upon increasingly large bodies of evidence to enable ever more rigorous appraisal of the interventions.

Recommendations for increasing the output and use of conservation evidence

Instilling a culture of evidence-based conservation will require a widespread change in attitude such that documenting practices and evaluating effectiveness becomes an integral aspect of any conservation project (Sutherland et al. 2004; Pullin & Knight 2005). Many recommendations have been made to promote this strategy. Increasing bilateral communication between scientists and practitioners would enable the co-production of knowledge through collaboration (Roux et al. 2006; Lauber et al. 2011; Braunisch et al. 2012), bridging the research-implementation gap. The promotion of interdisciplinarity could enhance the breadth and success of conservation initiatives (Campbell 2005), and incorporating evidence-based requirements into relevant policy would help propel cultural norms of reliance on experience-based practice towards approaches shaped by evidence (Pullin & Knight 2001; Sutherland et al. 2004). Encouraging the widespread dissemination of conservation research (Sutherland et al. 2004; Milner-Gulland et al. 2009) could facilitate the transfer of science to practice (e.g. Science Findings 2011). Establishing a professional reward structure for academics that recognises the real-world impact of research would also allow scientists to become more heavily involved in practice (Sutherland et al. 2011). Finally, making evidence sources more accessible through review and dissemination units, centralised databases of studies, and open-access publishing would also remove crucial obstacles to evidence-based conservation (Huettmann 2005; Pullin & Knight 2005; Sutherland et al. 2012; Fuller et al. 2014).

Conclusion

An assessment of publications over the first ten years (2004-2014) of the online, open-access journal *Conservation Evidence* revealed a low level of amphibian-related studies (Spooner et al. 2015). This agrees with our assessment of evidence in the Amphibian Synopsis. More conservation evidence is required across the board, even in cases where interventions have been categorised as "Beneficial" or "Likely to be ineffective or harmful". Globally representative evidence is particularly needed for all interventions that tackle threats, especially pollution, climate change and exploitation. Also, threats often act synergistically (Blaustein & Kiesecker 2002; Sodhi et al. 2008; Hof et al. 2011), so holistic conservation planning is required where combinations of interventions are tested. More studies that test the effects of education and engagement actions on wild amphibian populations are also recommended. Comparative research that tests the effects of different interventions for the same threat in the same context would highlight the best and most cost-effective management options (Smith et al. 2014). Given the varied conservation requirements of thousands of species affected by threats and declines, a greater diversity of interventions are required. Although interventions in the synopsis were compiled by an expert advisory board to reflect all actions used in amphibian conservation (Smith & Sutherland 2014), these actions are unlikely to be representative of the challenges facing all species in all locations. Solution scanning offers a means of identifying future management options, as already applied to major marine conservation problems (Jacquet et al. 2011), and the preservation of ecosystem services (Sutherland et al. 2014). We urge the amphibian conservation and research community to collaborate in developing potential solutions and publishing conservation evidence studies, as this could help generate an effectiveness revolution in amphibian conservation.

Chapter 6. Conclusions

In this chapter, I review the main findings of my thesis, and highlight limitations and emerging opportunities. I also provide specific recommendations to key initiatives coordinating global responses to the amphibian extinction crisis.

Summary of research findings

In this thesis I addressed four key questions germane to improving the impact of amphibian conservation:

i. What is "success" in amphibian conservation?
ii. Are we meeting amphibian conservation research needs?
iii. What are the biases and trends in existing conservation evidence for amphibians?
iv. What works in amphibian conservation?

What is "success" in amphibian conservation?

Understanding perceptions of success is a logical first step in improving the impact of conservation efforts. Conservation is a value-led discipline (Meine & Meffe 1996; Chan 2008), and a diverse range of viewpoints are held concerning its priorities and practice (Robinson 2011; Sandbrook et al. 2011). The framing of conservation has shifted over the last fifty years, as notions based on protecting nature for itself increasingly evolve to embrace benefits to humans in the context of safeguarding the environment; this has implications for defining and measuring success (Mace 2014). Following an assessment in Chapter 2 of the views of scientists and practitioners working to conserve amphibians, I conclude that success in amphibian conservation is subject to value plurality. Overall, a biocentric view of success prevails that is largely defined in terms of achieving stable or increasing population trends of target species. However, amphibian conservation scientists and practitioners earlier on in their careers mentioned more human dimensions of conservation as being integral to their success perceptions. Moving forward, I recommend that amphibian projects should not lose sight of objectives related to maintaining *in situ* amphibian populations; the future of hundreds, if not thousands, of amphibian species depends on successes in this area. However, these objectives must be achieved in the context of omnipresent and growing human populations, and must therefore embrace social aspects of conservation where relevant, such as awareness-raising, public engagement and capacity building. Since the formal establishment of conservation biology as a distinct research discipline in 1985 (Soulé 1985), the human population has increased from an estimated 4.9 billion to over 7.3 billion (UN 2013). Global population density is set to continue rising, and is expected to reach at least 8.9 billion by 2050 (Cohen 2003), peaking between 9.6-12.3 billion beyond 2100 (Lutz et al. 2001; Gerland et al. 2014). Humans are becoming an ever stronger influence on the world's systems, defining a mooted Anthropocene epoch characterised by human impacts that rival natural processes in shaping the Earth's ecology and geology (Corlett 2015). Human population growth has manifold repercussions for conservation efforts. Areas with high levels of threatened biodiversity are associated with higher population growth rates than the global average (Cincotta et al. 2000). Burgeoning human populations can accelerate threats such as habitat loss (Jha & Bawa 2006; Wittemyer et al. 2008), and therefore also species declines and extinctions (McKee et al. 2003). Ensuring that conservation efforts are inclusive of relevant human issues will help create sustainable action in areas where the ranges of amphibians and people overlap.

Biodiversity supports human well-being in multiple ways (Costanza et al. 1997; Balmford et al. 2002; Smith et al. 2013), and amphibians provide numerous services to humans through their manifold roles in maintaining healthy ecosystems, indicating environmental change, and important contributions to our medicines, food and culture (e.g. Davic & Welsh 2004; Mohneke & Rödel 2009; Rubbo et al. 2011; Bowatte et al. 2013; Hocking & Babbitt 2014; Chapter 1). Education and awareness initiatives can support conservation imperatives by affirming poorly-publicised links between the conservation of amphibians and human well-being. In many contexts, conservation practice can be strengthened by increased linkage of the needs of biodiversity and people, encompassing the impact of conservation of human well-being (Adams et al. 2004; Newing 2010; Roe et al. 2013; Davies et al. 2014; Milner-Gulland et al. 2014). Emerging notions of success in amphibian conservation are starting to encompass social aspects, as evidenced by 24% of respondents who partly defined success in terms of appropriate education and engagement initiatives (Chapter 2). Accounting for the human dimensions of conservation programmes should be encouraged by amphibian conservation initiatives to ensure efforts do not flounder in the long-term context of population growth, and the mounting pressures this exerts upon natural systems.

Are we meeting amphibian conservation research needs?

In Chapter 3 I found that there are relatively few scientific publications to support amphibian conservation decision-making, particularly for threatened species, and those classified as Data Deficient. The majority of species affected by the most frequently-cited threats are not represented in scientific studies addressing these threat processes. In terms of research quantity, the most well-studied threat is disease, but there is little information on other threats such as habitat destruction and fragmentation, and exploitation. Although threats are increasingly being documented and described, conservation management research remains uncommon for the vast majority of species. For example, there were only eight conservation evidence publications out of 3485 publications across 600 species, which described interventions for seven non-threatened species. Therefore, 99% of sampled species appeared in no conservation evidence studies, indicating that they are either not subject to conservation interventions, or the subject of untested or unpublicised interventions.

Research is more likely to be conservation-related if it involves authors based in countries where target species are native, especially if publications include authors from non-academic institutions. My results indicate that the input of conservation scientists and practitioners based at conservation NGOs, government agencies and zoos facilitates the delivery of publications relevant to conservation. This supports the notion that multidisciplinary collaboration is key to the production of research relevant to conservation practice (e.g. Braunisch et al. 2012; Laurance et al. 2012; Moon et al. 2014; Pooley et al. 2014). That said, over half of all conservation-related publications on species from Less Economically Developed Countries between 2000 and 2013 had a first-author residing in a More Economically Developed Country outside of the species range (49 of 91 studies), and over 70% of these papers (39 studies) lacked an LEDC co-author. The overwhelming majority of amphibian species are found in developing countries (Gallant et al. 2007), so the need for in-country conservation expertise in LEDCs is extremely high. However, there are challenges associated with conservation-relevant research in LEDCs, especially in the tropics. In areas where species richness is high but research is underfunded, scientists may struggle to describe species and address substantial knowledge gaps in basic biology and ecology (Barnard 1995). Conservation management research often stems from fundamental baseline information in taxonomy, species distribution and ecology; and these topics often constitute the main biodiversity research priorities for developing countries (e.g. Young et al. 2001). Collaborations across the global wealth divide are required to increase the production of both baseline and conservation-relevant research (Sunderland et al. 2009), and develop essential expertise (Annan 2003; Karlsson et al. 2007). However, this must be achieved in the context of in-country leadership in developing research agendas and conservation strategies, implemented by strengthened local institutions, to improve the chance of long-term successful outcomes (Rodríguez et al. 2007; Smith et al. 2009).

A wide variety of journals publish conservation-relevant information (144 journals from the sample in Chapter 3), and specialist journals such as *Conservation Evidence* and *Environmental Evidence* offer rapid routes to the peer-reviewed publication of findings relevant to evidence-based conservation practice. Also, mean Journal Impact Factor of conservation-related studies was higher than for grouped systematics, taxonomy, biology and ecology publications, and not significantly different from research making use of amphibians as model organisms and in pharmaceutical research. Conservation research can certainly achieve competitive Journal Impact Factors (Laurance et al. 2012), but research relevant to practice would benefit from being recognised by academic institutions in terms of its on-the-ground impact on improving the status of species and ecosystems, providing incentives for researchers to publish such studies (Chapron & Arlettaz 2008; Sutherland et al. 2011). Relevant research may also be encouraged through the development of multidisciplinary collaborations to ensure the production of appropriate scientific guidance to improve the effectiveness of conservation action (Reyers et al. 2010; Cook et al. 2013a).

What are the biases and trends in existing conservation evidence for amphibians?

Promoting the practice of evidence-based conservation can increase the impact of conservation by improving the performance of interventions through increased knowledge-sharing (Pullin & Knight 2001; Sutherland et al. 2004). In Chapters 4 and 5, I conducted linked assessments of the evidence collated in the Amphibian Synopsis (Smith & Sutherland 2014). The Amphibian Synopsis became a focal point of my research because it is the most thorough and complete assessment of global conservation evidence studies for amphibians, and will also be a regularly updated resource (Smith & Sutherland 2014; Chapter 1). Hence, the results of my assessments can steer the collation and promotion of conservation evidence for amphibians in the future. In Chapter 4, I found that the spread of evidence studies is unrepresentative in terms of geography, species characteristics (including IUCN extinction risk status, life history traits, and evolutionary distinctiveness), and intervention type. Identifying these gaps in knowledge can inform research needs in amphibian conservation evidence. Priority areas for future research include more studies on: interventions in the tropics; threatened species; amphibians with non-aquatic reproductive strategies; and interventions that mitigate pollution, climate change and exploitation. An increased quantity of evidence is required across the board to improve conservation decision-making, so documenting the effects of interventions should become a routine element of conservation practice (Sutherland et al. 2004), and should be promoted by funders of conservation initiatives as an important condition of any grant, and encouraged in the assessment of the impact of academic institutions.

Discrepancy exists between the availability of general conservation-related information (Chapter 3) and specific conservation evidence research (Chapters 4 and 5) for certain threats. For example, pollution was the second most studied threat in Chapter 3, but had a very low level of conservation evidence in the Amphibian Synopsis. Conversely, habitat destruction and fragmentation was relatively poorly-studied as a threat, but received the most research attention in terms of conservation evidence. Methodological considerations play an important role in determining what researchers study (Pawar 2011), and topics with faster publication turnaround may be favoured as researchers seek to maximise their publication record (Arlettaz et al. 2010). For example, studies of long-term habitat change may be confounded by practical and logistical challenges, whereas novel stressors or threats that allow rapid assessment through reductionist experimental approaches can be more appealing to researchers in need of publications (Gardner et al. 2007). Hence, studying the dynamics of habitat destruction may be less straight-forward than, for example, charting pond colonisation. Likewise, assessing the pollutants of a water body may be more achievable than developing systems to mitigate environmental contaminants that manifest positive results in the short-term. A fundamental disjunct exists between the publication drivers of academics and the information needs of conservation practitioners, which impacts the alignment of research and conservation management goals (Arlettaz et al. 2010). Researchers and journals are rewarded for high impact research that may be widely cited (Kokko & Sutherland 1999; Wallin 2005; Sutherland et al. 2011), while practitioners require targeted information to facilitate management (Braunisch et al. 2012; Gossa et al. 2014). Providing incentives within academia that recognise the real-world impact of research would help generate the reward structure necessary to encourage science relevant to conservation practice (Chapron & Arlettaz 2008; Knight et al. 2008; Shanley & López 2009; Sutherland et al. 2011).

The number of evidence studies per country is positively correlated with GDP per capita and the proportion of English speakers. Actions that support conservation science publication in poorer countries would help to balance a currently skewed spatial representation across the environmental sciences (Yesson et al. 2007; González-Suárez et al. 2012; Martin et al. 2012a; Amano & Sutherland 2013). Options for addressing this imbalance include: supporting developing world scientists to publish their research through collaboration; writing workshops; capacity building; affirmative action across relevant journals; and open access publishing (Karlsson et al. 2007; Milner-Gulland et al. 2009; Sunderland et al. 2009; Fuller et al. 2014). These actions may be driven and incentivised by global networks devoted to amphibian conservation science, such as the IUCN SSC Amphibian Specialist Group (ASG). I found that the number of amphibian conservation evidence studies per country is not correlated with a country's ASG membership. Evidence-based conservation, though intuitive and central to the earliest justifications of conservation biology (Soulé 1985), has only been widely publicised since its inception as a distinct research discipline less than fifteen years ago (Pullin & Knight 2001). The journal *Conservation Evidence* was launched in 2004 (Smith et al. 2014), and in its first 10 years published 264 papers on 439 different conservation interventions, conducted for multiple taxa across 35 countries (Spooner et al. 2015). The number of conservation evidence publications collated per year in the Amphibian Synopsis underwent an almost four-fold increase between 2001 (14 publications) and 2012 (50 publications; see Figure 1.3, Chapter 1). Extensive dissemination of evidence summaries (translated into a range of languages) through networks such as the ASG would boost awareness of information relevant to conservation practice, and may help stimulate the production of relevant and representative studies. Promoting this branch of research in line with current amphibian conservation needs would raise awareness of evidence-based conservation decision-making as a tool for improving the impact of conservation actions.

What works in amphibian conservation?

Increasing the effectiveness of interventions is key to improving the impact of conservation action (Pullin & Knight 2009). In Chapter 5, I conducted an expert assessment of the effectiveness and side-effects of interventions currently practiced in amphibian conservation. The information biases illuminated in Chapter 4, coupled with few studies in many cases, limit what can currently be deduced about what works in amphibian conservation. Effectiveness categories assigned to different interventions predominantly apply to temperate countries. Interventions associated with the maintenance, restoration and construction of wetlands tended to benefit amphibians. The use of prescribed fire or herbicides to control understory vegetation was associated with negative side-effects and lower effectiveness. All interventions relating to education and public engagement initiatives were assessed as "Likely to be beneficial", despite little information linked to improved status of *in situ* amphibian populations. The effectiveness of *in situ* and *ex situ* species management approaches tended to depend on the species in question, but translocations were generally more effective than releases of captive-bred individuals in establishing sustainable populations in the wild. However, all interventions would benefit from increased levels of evidence, covering a greater number of species and geographical contexts. Effectiveness, certainty and side-effects scores were all positively related to the number of evidence studies per intervention, suggesting that increased information enables more confident and thorough assessments of interventions, and that evidence demonstrating effectiveness is perhaps more prevalent than evidence detailing failures. I also showed that conservation evidence for amphibians currently includes few approaches and studies that account for socio-political processes relevant to the long-term effectiveness of interventions. Conservation evidence collection should continually evolve to meet the needs of practitioners, and many interventions will have societal repercussions that require assessment. The interventions we practice are informed by our values (Adams & Sandbrook 2013), and approaches to collecting conservation evidence that incorporate social data will enhance understanding of the real-world applicability of interventions in diverse social contexts (Mathevet & Mauchamp 2005; Sutherland et al. 2005). As conservation science training at all levels becomes more interdisciplinary, bridges will increasingly be built between natural and social science approaches to conservation research and practice (Newing 2010). Solution scanning, which employs systematic expert elicitation methods to develop novel conservation interventions, can help to update approaches to conservation and direct future evidence-based research (Sutherland et al. 2014). Evidence-based conservation addresses a much-needed element of knowledge, in that it actively encourages the publication of unsuccessful results (Spooner et al. 2015), and therefore promotes a "fail-safe" culture that is often under-represented in conservation research (Redford & Taber 2000; Knight 2009).

Limitations and future prospects

Success and the assessment of interventions

A range of notions associated with success are presented in Chapter 2, although the effectiveness of interventions were assessed in Chapter 5 in terms of whether they increased healthy amphibian populations within their natural/*in situ* habitat. This measure of effectiveness concurs with the predominant view of success among the questionnaire sample in Chapter 2. However, this may be subject to two criticisms. Firstly, amphibian populations can fluctuate stochastically, and therefore growing population size in the short-term may not necessarily lead to overall improvements in population status (Pechmann et al. 1991; Pechmann & Wilbur 1994). Secondly, given the various ways of appraising success, only considering benefits to species may be seen as reductionist and insufficient. An intervention may increase amphibian numbers in the short-term, but may also be associated with socio-political conflicts that render long-term practice of an intervention impossible and/or ineffective. Currently, the Amphibian Synopsis only summarises quantitative evidence (Smith & Sutherland 2014), which can overlook local indigenous knowledge relevant to conservation practice (Adams & Sandbrook 2013). Adams & Sandbrook (2013) suggested a change in terminology from "evidence-based" conservation to "evidence-informed" conservation to ensure the broadest range of evidence types (both quantitative and qualitative) are reflected in decision-making, because evidence studies can be misused. Haddaway & Pullin (2013) countered that evidence-based conservation enables better understanding of the consequences of conservation interventions, and that this will always be preferable to bias and ignorance. However, they agree that evidence-based approaches may have limitations when applied to complex socio-economic contexts. Although frameworks developed for evidence-based medicine are useful in building similar approaches in conservation (Pullin & Knight 2001; Sutherland et al. 2004; Dicks et al. 2014a), medicine and conservation differ in several significant ways. Evidence-based medicine chiefly concentrates on the health of a single species with a global distribution, whereas conservation interventions tackle many thousands of species with restricted ranges (Fazey et al. 2004). In comparison to medicine, conservation management has more hotly contested aims, less financial support, greater challenges associated with evidence study design, and outcomes that may be difficult to define and measure (Fazey et al. 2004). Evidence-based conservation must therefore take inspiration from evidence-based medicine, but also evolve to find appropriate methods of rigorously assessing interventions across a range of relevant success criteria, evaluating both ecological and social data (see St. John et al. 2014).

Representing diverse viewpoints

A drawback of the approach used in Chapter 2 was that the questionnaire was prepared solely in English. Although it was widely disseminated via the ASG, reaching more respondents in LEDCs (n = 260) than MEDCs (n = 240), the majority of LEDC recipients may have been discouraged from completing the questionnaire due to language barriers. Future attempts to understand global perspectives in amphibian conservation should ensure that language barriers are removed wherever possible. One recommendation would be to work with the ASG Regional Chairs to disseminate language-appropriate versions of any questionnaires in order to more accurately represent global viewpoints. Additionally, the Advisory Board of the Amphibian Synopsis, who led the consultation process establishing a list of conservation interventions for amphibians (see Figure 6.2), comprises experts based in Europe (n = 4), the United States (n = 3), Australia (n = 1), and New Zealand (n = 1). The Advisory Board members were recruited because of their considerable global experience in amphibian conservation; its members represent global networks such as the Amphibian Survival Alliance (ASA), Amphibian Ark, ASG, and the World Congress of Herpetology Executive Committee. The list of interventions was also developed in cooperation with a wide range of conservation practitioners drawn from these global networks. However, the Advisory Board would benefit from increased global representation, encouraging more regional champions of the conservation-evidence approach. Increasing the number of experts with social science skills would also be advantageous to future updates of the Amphibian Synopsis, informing robust study design to guide the assessment of interventions from a social perspective.

Collating research from multiple sources

The Amphibian Synopsis collated information according to a search protocol detailed in Chapter 1. This included searching every issue of 48 specialist conservation and herpetology journals, as well as including evidence studies based on advice from over 100 expert advisors globally. In addition to published journal articles, evidence included conservation and government reports, newsletter articles, conference proceedings, unpublished research theses, and book chapters. During the expert assessment of the Amphibian Synopsis, our panel expressed concern that evidence not published in English may be missing from the Synopsis. In particular, grey literature is thought to be a repository of insufficiently utilised information relevant to tropical ecology and the conservation (Corlett 2011). However, when asked to suggest missing evidence, our panel (representing 15 countries) only suggested studies published in English, the vast majority of which were conducted in the United States, Canada, Western Europe, or Australia. This suggests that the Amphibian Synopsis does provide an accurate picture of the currently skewed distribution of evidence studies. Chapter 4 demonstrated that the proportion of English language speakers per country is positively correlated with the number of conservation evidence studies conducted in that country. English is the dominant language of science publishing (Montgomery 2004), and results from Chapter 3 also indicate that very few non-English language journals contain conservation-related research. From 2000-2013, only 3% of conservation-related publications from our sample (10 of 335 publications) were found in non-English language journals, which included two journals from Spain, one from Italy and one from France. In order to increase the representation of evidence studies prepared in diverse languages, evidence collation must increasingly be drawn from global collaborations. This will necessitate raising awareness of the need to collate and disseminate conservation evidence, and encouraging scientists and practitioners worldwide to contribute and/or publish research that tests the effectiveness of conservation interventions for amphibians. Translating summaries of Amphibian Synopsis key messages (see Appendix V) for widespread dissemination would further raise global awareness of this initiative. Conservation evidence production and dissemination could be encouraged through the ASG and ASA, and their various communication platforms, including a shared website (www.amphibians.org) and newsletter "Froglog" (e.g. Smith 2013, 2014).

Expert Assessment

Although a rigorous expert elicitation technique was employed in Chapter 5 to ameliorate the impact of incomplete information and uncertainty, it is difficult to assess the low levels of information for many interventions. Few interventions had sufficient evidence to establish the relative merits of different methodologies, and research testing different approaches to mitigating the same threat in the same context is generally absent (Smith et al. 2014). This currently limits the scope of evidence to aid cost-effective decision-making in conservation practice. Low evidence levels also mean that the effectiveness categories of most interventions cannot be confidently extrapolated to a wide range of geographical scenarios. Additionally, conservation practice is implicitly value-laden (Noss 2007), and cultural norms can affect the interpretation of evidence (Pullin & Knight 2005). Evidence can therefore be misused or misinterpreted, and can vary in reliability, as it may be gathered according to socially-influenced notions of conservation practice, which can exclude important stakeholder perspectives (Adams & Sandbrook 2013). Recruitment for the expert panel was stratified by specialist area, experience level, and geographical location in order to maximise the number perspectives. However, social science perspectives were still under-represented. Although many members of our panel are involved in a range of conservation projects involving multiple stakeholders, none were experts in social science. Given that interventions related to public education and engagement are also poorly represented among current amphibian conservation interventions, there is clearly a need to bring social science perspectives into future expert assessments of updated Amphibian Synopses. This could be achieved by inviting experts with social science skills onto the Advisory Board of the Amphibian Synopsis.

Recommendations to improve global amphibian conservation impact

Increasing Conservation Evidence

The Amphibian Conservation Action Plan (Gascon et al. 2007) was updated in 2015, and new priority actions were established across 12 thematic working groups, including: Habitat Protection; Climate Change; Infectious Diseases; Trade and Policy (including over-harvesting of amphibians); Ecotoxicology; Captive Breeding; Reintroductions; Taxonomy and Systematics; Genome Resources; Species Conservation Strategies; Surveys and Monitoring; and Communication and Education (ASG 2015). As a direct result of the research in this thesis, and my role as a Programme Officer in the ASG Secretariat, developing and improving the evidence-base for amphibian conservation interventions is now a priority action of the Species Conservation Strategies Working Group (SCSWG). This will enable the ASG to support the collation of conservation evidence in collaboration with the Conservation Evidence initiative (Conservation Evidence 2015) at multiple stages of the synopsis development process (Figure 6.1). A conservation evidence sub-group will be formed within the SCSWG to: (1) recruit willing ASG members to promote the publication and dissemination of conservation evidence across the ASG, by region and/or specialist topic; (2) assist the Conservation Evidence team at Cambridge University (www.ConservationEvidence.com) to regularly update the Amphibian Synopsis by contributing appropriate studies from ASG members and their colleagues; and (3) support the development of conservation evidence research projects on a regional basis, especially in the tropics (ASG SCSWG 2015). Also, conservation evidence summaries, translated into several languages, can be hosted on the joint ASA-ASG website (www.amphibians.org) to help disseminate current information and build further support moving forward.

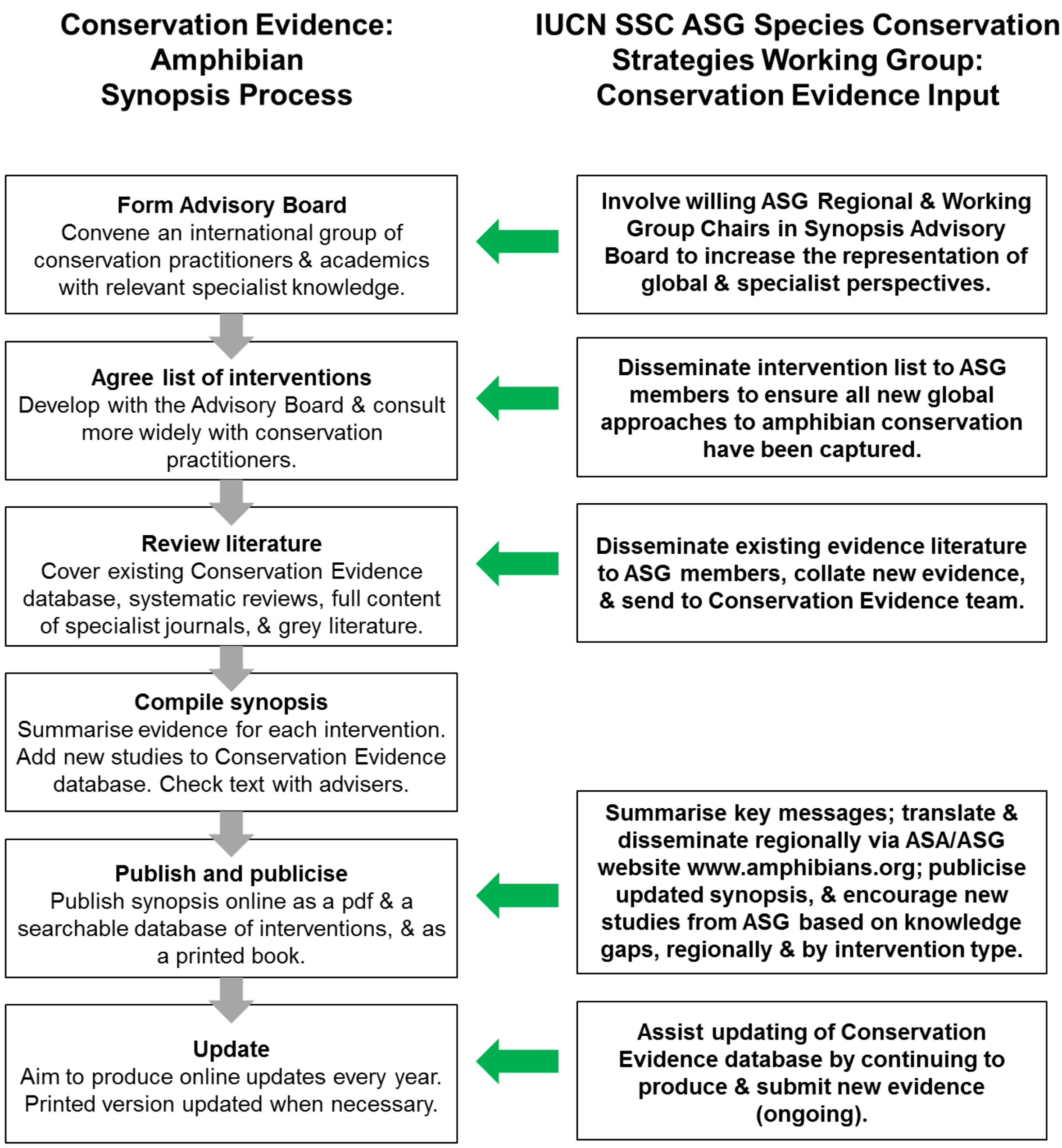


Figure 6.1. Schematic showing how input from the Amphibian Specialist Group can facilitate the update of future Conservation Evidence Amphibian Synopses.

Building capacity to address global knowledge gaps and conservation needs

There are substantial spatial inequalities in conservation-relevant information for amphibians. The aim of the ASG is to provide the scientific foundation to inform effective amphibian conservation action around the world (ASG 2015). The ASG supports and mobilises a global network of members to develop capacity, and improve coordination and integration, in order to achieve shared, strategic amphibian conservation goals (ASG 2015). Where feasible, the ASG should aim to recruit members from under-represented countries, perhaps specifically targeting countries with low/no membership in relation to their species richness (Figure 6.2a,b). Countries with a high proportion of threatened species, and particularly threatened endemics, will especially require enhanced in-country action to mitigate impending extinctions (Figure 6.2c,d). Membership recruitment and management is within the remit of the ASG Regional Groups Chairs (Figure 6.3; ASG *pers. comm.*), who should be provided with strategic guidance where appropriate. Supportive international collaborations should also be fostered to promote capacity building, publishing, and conservation action where needed, especially in the tropics. Complementing any strategic approach, amphibian conservation activities should also take advantage of positive opportunities where conditions are conducive to advancing conservation research and practice agendas (e.g. Cowling et al. 2010; Moon et al. 2014) as this will help develop much-needed progress through capitalising on "lower hanging fruit".

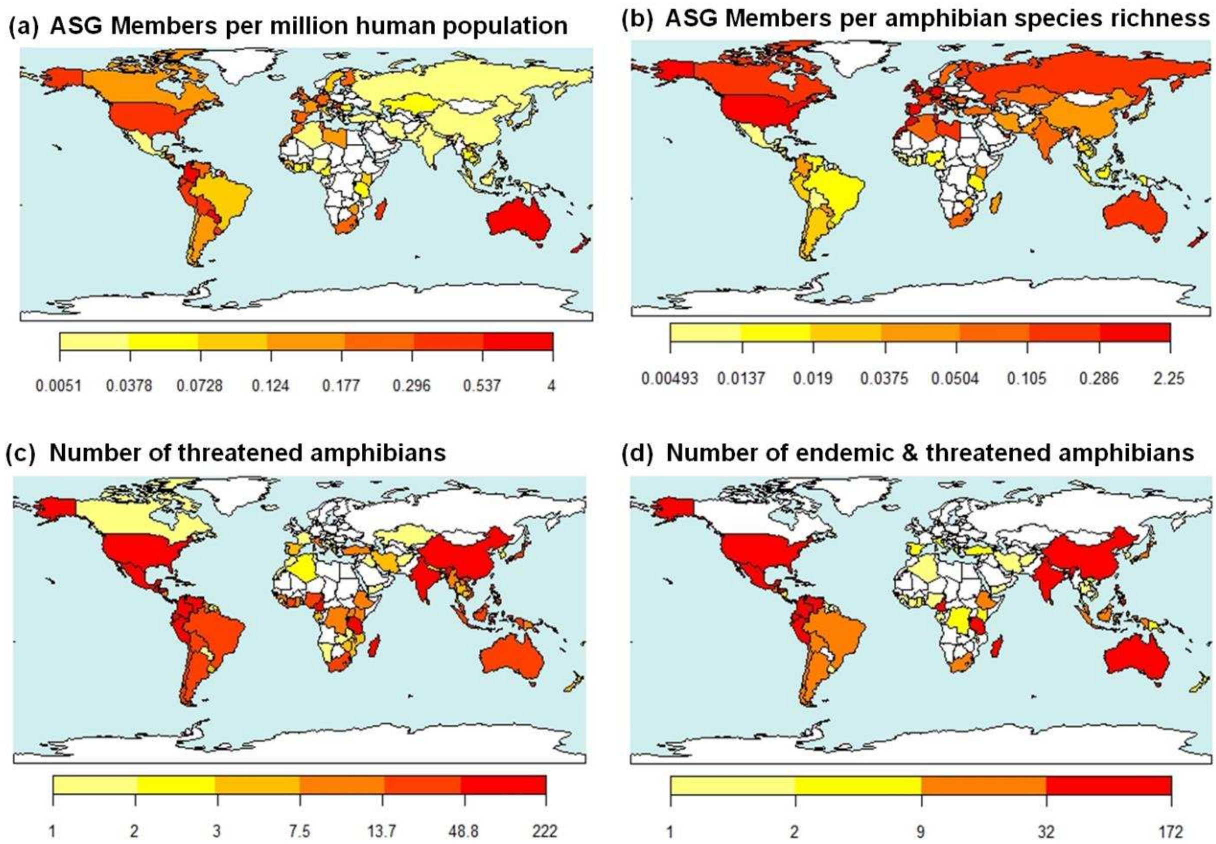


Figure 6.2. Global distribution of ASG members and threatened species. ASG members scaled by: (a) human population per country; and (b) species richness (native, extant species). Map (c) displays numbers of threatened species per country, and map (d) displays numbers of threatened endemic species per country, indicating areas where membership could specifically be boosted and supported to protect species from extinction. Where values are zero, countries are shown in white.

The ASG plans to develop two prominent initiatives to achieve the goal of increasing amphibian conservation science capacity: the ASG Mentorship programme and ASG/ASA Youth programme (ASG Strategic Plan 2015; Figure 6.3). The ASG Mentorship programme is intended to promote capacity building in amphibian research and conservation by matching early-career ASG members with established experts who can supervise projects relevant to amphibian conservation. The ASG/ASA Youth programme targets an even earlier stage in an amphibian enthusiast's life, increasing awareness and interest among future generations of amphibian conservationists through the development of outreach initiatives in schools. Both programmes are intended to be implemented by the ASG Regional Groups, building amphibian conservation communities and networks on a regional basis, as appropriate to local contexts. This is intended as a "bottom-up" approach to encourage ownership of regional activities. In addition to within-region mentorship and capacity building, I would encourage increased levels of international collaboration between developed and developing countries to help source valuable funds and training opportunities for amphibian conservation scientists and practitioners. ASG Regional Groups vary in geographic scope, ranging from single countries (e.g. the United States) to larger areas (e.g. West/Central Africa, or Mainland South-east Asia). Regional Groups can include both members based in the region, and those who conduct research there, which can lead to a combination of members from developed and developing countries within the same Regional Group. Members from wealthier countries should continue to be actively encouraged, on a regional basis, to help generate funding opportunities and publishing support through collaboration with in-region members from developing countries.

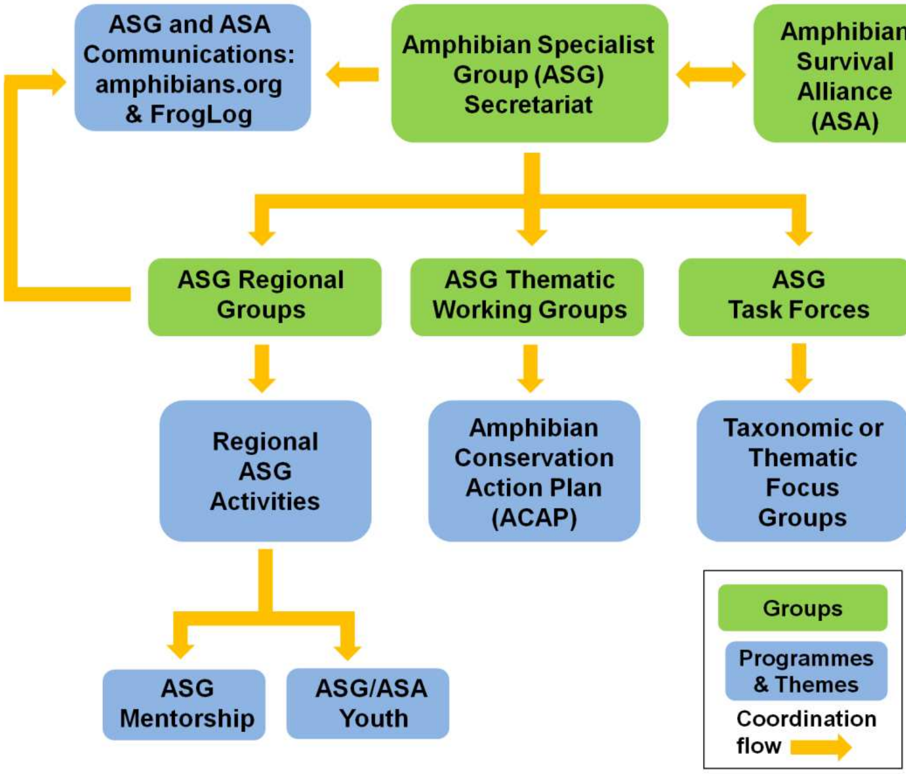


Figure 6.3. Groups and activities coordinated by the IUCN SSC Amphibian Specialist Group, in partnership with the Amphibian Survival Alliance.

The role of ASA is to provide an umbrella organisation for amphibian conservation, coordinating global strategies and fundraising. These actions are reinforced by relevant science from the ASG and embedded Amphibian Red List Authority (Figure 6.4). ASG and ASA are linked agencies, with ASG providing scientific guidance to ASA, and ASA supporting amphibian conservation science imperatives led by ASG, whilst also raising funds and generating awareness globally. The aims of ASA are far-reaching, from preventing amphibian extinctions, to addressing broader biodiversity conservation issues in the context of improving the quality of people's lives (ASA 2015b). Encouraging collaboration across the ASA's 100+ member organisations could facilitate capacity building exchanges for amphibian conservation scientists and practitioners. Mentorship that provides early-career members with training opportunities, both nationally and abroad, would benefit global capacity building efforts. This network of organisations can improve information sharing appropriate to advancing global conservation efforts. ASA has a critical role in developing all-important funding opportunities to drive conservation efforts forward, which is a central aspect of its mandate. Providing seed grants and opportunities for long-term project funding will be vital to improving the impact of worldwide conservation efforts for amphibians. Ensuring that these funding opportunities promote the documentation and publication of conservation evidence will also encourage the development of an evidence-based culture in amphibian conservation.

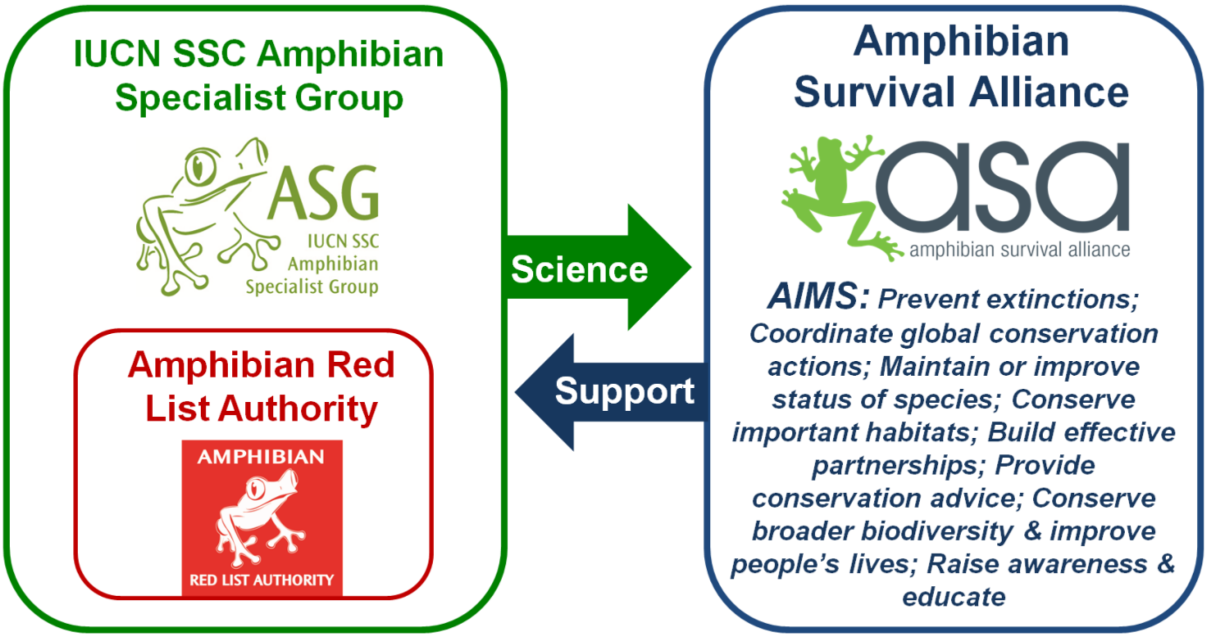


Figure 6.4. Role of Amphibian Survival Alliance in supporting the IUCN SSC Amphibian Specialist Group and global amphibian conservation initiatives.

In 2014, I co-organised the Amphibian Conservation Research Symposium (ACRS), and have since become a member of the ACRS Steering Committee, developing this symposium in collaboration with the ASG and ASA. ACRS fills an important niche in the amphibian conference circuit, as it is the only meeting to focus entirely on research linked to conservation practice (ACRS 2015). ACRS has considerable potential to help promote information needs in amphibian conservation and encourage the publication and dissemination of conservation evidence research. In 2015, ACRS launched the capacity building initiative "Future Leaders of Amphibian Conservation". This funds conservation scientists and practitioners from developing countries to attend ACRS to present their work, and participate in training courses, enabling them to make supportive contacts in amphibian conservation. Capacity building will continue to be a fundamental element of improving the impact of amphibian conservation, and therefore investing globally in amphibian conservationists is essential. Following four years in the United Kingdom (2012-2015), ACRS 2016 will be held in South Africa, and ACRS 2017 is planned to take place in New Zealand. The new regional-touring model for ACRS will bring the conference closer to many amphibian conservation scientists and practitioners, ensuring a greater catchment for global expertise. Ongoing fund-raising by ASA and ASG will continue to develop the Future Leaders of Amphibian Conservation programme, and raise awareness of this initiative to promote amphibian conservation opportunities globally. In addition, fund-raising to develop a proposed ASG Seed Grant programme would provide essential start-up support for new initiatives developed by Future Leaders of Amphibian Conservation.

Evaluating success in amphibian conservation

Another priority action of the ASG Species Conservation Strategy Working Group is to assess existing amphibian species Action Plan successes and failures, and analyse possible causation. Ensuring that the evaluation of success and failure is inclusive of multiple outcome types will be crucial in adequately appraising Action Plan efforts. Measures of success should reflect emerging views in amphibian conservation, including improvements to species and habitats while incorporating appropriate achievements in other areas. Programme aspects such as public education and engagement should be assessed, as well as relevant capacity building efforts. The use and production of scientific research promoting effective conservation action, and the ongoing evaluation and adaptive management of the Action Plan's strategic objectives, also require assessment. Learning opportunities from failed attempts at species conservation should be actively communicated to promote future innovation.

Concluding remarks

Improving conservation impact will require multidisciplinary collaboration and commitment, both nationally and internationally. Although the challenges are immense, this thesis highlights clear future directions for uniting conservation science and practice to improve the prognosis for amphibians. Promoting the development of relevant scientific research to facilitate effective conservation practice will enhance our ability to respond to the amphibian extinction crisis. Funding opportunities must be developed to incentivise the exploration of conservation-related questions, particularly in developing countries. Funding agencies should also engage in promoting evidence-based conservation as a condition of awarded grants, as this will help encourage a culture of evidence-based conservation practice. The proportion of effective conservation interventions for amphibians can grow as a result of collaboration between scientists and practitioners internationally, helping to: devise and test new interventions; learn from previous failures; and encourage capacity building at every turn. Fundamentally, it will be crucial to engineer a paradigm shift in amphibian conservation.

Amphibians are becoming synonymous with the study of declines and extinction in the conservation literature, with few emerging messages of hope. Global amphibian conservation networks should continue to focus on encouraging amphibian conservation efforts and interventions in the face of ongoing threats, whilst developing pragmatic approaches to implementing actions that are inclusive of the social dimensions of conservation.

Amphibian conservation must not be viewed as a lost cause, but rather an under-developed area of conservation that has huge potential to achieve more successful outcomes in the future. Reframing the mission of amphibian conservation to seek out multifaceted routes to success, supported by appropriate conservation evidence and necessary funding opportunities, will help improve the impact of amphibian conservation. Growing the number of successes globally will require international collaboration. Fortunately, global networks and initiatives such as ASG, ASA and the Amphibian Ark are in place to help promote these objectives, and raise awareness of the importance of amphibian conservation efforts. These groups must build a strong foundation of hope. No efforts to date have been wasted, even in the case of unsuccessful actions, as all provide valuable lessons that can be shared. The future of amphibian conservation is not in monitoring the demise of this taxon, but in recruiting diverse supporters and collaborators to develop new ways forward to maintain diversity, minimise extinctions, and, wherever possible, arrest and reverse declines. This must not be a world that we take from the amphibians, but one that we share with them for our mutual benefit.

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APPENDIX I. Questionnaire (Ch. 2)

DICE University of Kent   ZSL LIVING CONSERVATION

I am based at the Durrell Institute of Conservation & Ecology and the Institute of Zoology and am investigating the relationship between science and practice in conservation. For any further information, please contact: **helen.meredith@zsl.org**

1. What is your name? (Including title) ………………………………………………………………….

2. What is your nationality? ……………………………………………………………………………........

3. Who is your employer? ……………………………………………………………………………………

4. What is your job title? …………………………………………………………………………………...

5. Which of the following best applies to you? (Tick more than one option if necessary)

☐ Amphibian scientist / researcher

☐ Amphibian conservation practitioner

☐ Scientist / researcher (other) – please specify subject area……………………..……………….……..

☐ Conservation practitioner – please specify taxa / location(s)

……………………………………………………………………………………………………….……..

☐ Other – (please specify any role that links you to amphibian conservation / research)

……………………………………………………………………………………………………….……..

6. How many years have you worked in *amphibian* research / conservation practice?

…………………………………………..

7. What has been the main focus of your research or conservation practice over the last 5 years?

……………………………………………………………………………………………………….……...

..……………………………………………………………………………………….……………………

Conservation programme: A planned and coordinated initiative designed to improve the status of a species, habitat and/or ecosystem through targeted conservation interventions.
Conservation intervention: Any activity that is carried out with the aim of facilitating and/or promoting the conservation of a species / habitat / ecosystem.

8. How many *amphibian* conservation programmes are you currently involved in?

Please provide actual number ……………………….

9. Please provide basic details of any amphibian conservation programmes are you currently involved in:

……

……

10. Please list up to 5 amphibian conservation programmes that **you believe** to be ***successful*** – where possible, please write the name of the species and programme concerned (if you know of none, please write 'none')

1.)……...

2.)……...

3.)……...

4.)……...

5.)……………………………………………………………………………………….………………...

11. Please list up to 5 amphibian conservation programmes that **you believe** to be ***unsuccessful*** – where possible, please write the name of the species and programme concerned (if you know of none, please write 'none')

1.)……………………………………………………………………………………………………...

2.)……………………………………………………………………………………………………...

3.)……………………………………………………………………………………………………...

4.)……………………………………………………………………………………………………...

5.)……………………………………………………………………………………………………...

12. How do you perceive "success" in a conservation programme? Please write briefly about what success means to you in the context of a conservation programme.

……...

……...

……...

……...

Conservation research: The study of a species / habitat / ecosystem for conservation science purposes with the intention of publication in the peer-reviewed literature.
Conservation evidence: Scientific research that seeks to evaluate the degree to which a conservation intervention is effective at reducing threats to a species / habitat / ecosystem, or promotes the ability of a target species / habitat / ecosystem to resist or respond to those threats.

13. In your opinion, which areas of conservation research are most important for the successful *practice of conservation*? Please select your **TOP 5** choices.

	Conservation research categories	**Most important for the successful *practice of conservation*:** Please select your TOP 5 choices
	Baseline data (assessing species presence and distribution)	
	Study of species biology / ecology	
	Long-term species monitoring	
	Population Viability Analysis	
	Population genetics	
	Species systematics	
	Captive breeding	
	Threat processes	
	Developing management strategies	
	Analyses of the overall performance of conservation programmes	
	Conservation evidence	
	Prioritising species or conservation areas	
Other: ***Please specify***	*(i.)*	
	(ii.)	
	(iii.)	

14. Please read the following statements and score each statement on a scale of **'Highly important'** to **'Not important'** in terms of which best describe success in conservation, in your opinion. Tick any irrelevant statements as 'Not Applicable (**N/A**)'. Please then *select* your **TOP 3** statements (final column) according to which best describe success in conservation overall, in your opinion.

	Statement	**N/A**	**SCALE** Highly important → Not important **a**	**b**	**c**	**d**	**e**	*Please* select *your* ***TOP 3*** *choices*
1.	*Increasing the likelihood of persistence of native ecosystems, habitats, species and/or populations in the wild without adverse effects on human well-being*		a	b	c	d	e	
2.	*Long-term persistence of reintroduced population(s) of conservation target species*		a	b	c	d	e	
3.	*Wild population of conservation target species is stable or increasing, as indicated by appropriate monitoring and evaluation*		a	b	c	d	e	
4.	*The status of the conservation target species has been downgraded on the IUCN Red List of Threatened Species (e.g. from CR to EN)*		a	b	c	d	e	
5.	*The status of the conservation target species has been downgraded by national level government relevant to the range area*		a	b	c	d	e	
6.	*Defined conservation project goals have been achieved through measurable indicators*		a	b	c	d	e	
7.	*Conservation target species is declining at a slower rate than before conservation interventions were initiated*		a	b	c	d	e	
8.	*The reduction of the intensity of conservation actions over time as the outcomes of these actions have been effective, and become less significant to the overall survival of the species*		a	b	c	d	e	

15. Please read the following statements and score each statement on a scale of **'Highly important'** to **'Not important'** in terms of which actions are most significant in bringing about success in a conservation programme, in your opinion. Tick any irrelevant statements as 'Not Applicable (**N/A**)'. Please then *select* your **TOP 3** statements (final column) according to which are most significant overall in bringing about success in a conservation programme, in your opinion.

	Statement	**N/A**	**SCALE** Highly important → Not important **a**	**b**	**c**	**d**	**e**	*Please* select *your* ***TOP 3*** *choices*
1.	*Reducing known threats to improve the response of conservation target species to conservation interventions*		a	b	c	d	e	
2.	*Promoting sustainable resource use and minimising damaging practices by relevant stakeholders*		a	b	c	d	e	
3.	*Implementing relevant policies and/or promoting legislation relevant to conservation aims*		a	b	c	d	e	
4.	*Increasing the quality and/or quantity of conservation action(s) through appropriate capacity building (training of project staff)*		a	b	c	d	e	
5.	*Increasing support for the conservation of a species among appropriate target audience(s) through a communication, education and public awareness strategy*		a	b	c	d	e	
6.	*Applying appropriate research results to conservation practice*		a	b	c	d	e	

16. Please read the following statements and score each statement on a scale of **'Highly important'** to **'Not important'** in terms of which would best facilitate success in a conservation programme, in your opinion. Tick any irrelevant statements as 'Not Applicable (**N/A**)'.

	Statement	**N/A**	**SCALE** Highly important → Not important				
			a	**b**	**c**	**d**	**e**
1.	*Leaders understand the project in the context of their role as a conservation leader*		a	b	c	d	e
2.	*Leaders provide people with clear direction and priorities that are relevant to conservation*		a	b	c	d	e
3.	*Leaders encourage discussion of difficulties and technical problems*		a	b	c	d	e
4.	*Leaders encourage the flow of ideas/opinions, both up and down the hierarchy*		a	b	c	d	e
5.	*Plans are adapted if approaches are ineffective or circumstances / project priorities change*		a	b	c	d	e
6.	*Goals are set on the basis of conservation needs and not on arbitrary aspirations*		a	b	c	d	e
7.	*Goals are established from knowledge or reasonable assumptions*		a	b	c	d	e
8.	*Plans and priorities are communicated clearly to people working on the project*		a	b	c	d	e
9.	*Plans are used to guide the work undertaken by colleagues and partner organisations*		a	b	c	d	e

17. Please read the following statements and score each statement on a scale of **'Highly important'** to **'Not important'** in terms of which would best facilitate success in a conservation programme, in your opinion. Tick any irrelevant statements as 'Not Applicable (**N/A**)'.

	Statement	**N/A**	**SCALE** Highly important → Not important				
			a	**b**	**c**	**d**	**e**
1.	*People are selected, trained & given roles that suit their skills, capability & team contribution*		a	b	c	d	e
2.	*People are given authority to make decisions and implement action according to their ability and close proximity to the work*		a	b	c	d	e
3.	*Funding is accessed to meet priorities, rather than funding itself determining what work should be done*		a	b	c	d	e
4.	*Conservation results are actively investigated and measured to establish effectiveness*		a	b	c	d	e
5.	*Conservation results are analysed to inform future decision-making and action*		a	b	c	d	e
6.	*Funding & resources are allocated to meet the needs of conservation work 'on the ground'*		a	b	c	d	e
7.	*Funding and project resources are allocated in a timely manner*		a	b	c	d	e
8.	*Conservation work and decision-making is informed by scientific knowledge and where possible scientific, social or economic data*		a	b	c	d	e

18. Please *select* your **TOP 5** statements according to which are most important overall to the success of a conservation programme, in your opinion.

	Statement	*Please select **TOP 5** choices*
1.	*Leaders understand the project in the context of their role as a conservation leader*	
2.	*Leaders provide people with clear direction and priorities that are relevant to conservation*	
3.	*People are selected, trained & given roles that suit their skills, capability & team contribution*	
4.	*Leaders encourage discussion of difficulties and technical problems*	
5.	*People are given authority to make decisions and implement action according to their ability and close proximity to the work*	
6.	*Leaders encourage the flow of ideas/opinions, both up and down the hierarchy*	
7.	*Funds are accessed to meet priorities, rather than funding itself setting the agenda*	
8.	*Plans are adapted if approaches are ineffective or circumstances / project priorities change*	
9.	*Goals are set on the basis of conservation needs and not on arbitrary aspirations*	
10.	*Goals are established from knowledge or reasonable assumptions*	
11.	*Conservation results are actively investigated and measured to establish effectiveness*	
12.	*Conservation results are analysed to inform future decision-making and action*	
13.	*Funding & resources are allocated to meet the needs of conservation work 'on the ground'*	
14.	*Funding and project resources are allocated in a timely manner*	
15.	*Conservation work and decision-making is informed by scientific knowledge and scientific, social or economic data (where possible)*	
16.	*Plans and priorities are communicated clearly to people working on the project*	
17.	*Plans are used to guide the work undertaken by colleagues and partner organisations*	

Thank you for taking the time to participate in this questionnaire!

I am currently selecting a sample of amphibian conservation programmes to evaluate. If you are willing to be contacted about this in the future, please provide your contact details:

....

APPENDIX II. Explanatory variables and open-ended question codes (Ch. 2)

(i) Explanatory variables use in all models

Table 1. Information collected from respondents forming the basis of five potential explanatory variables

Explanatory variables	Type	Definition
Institution	Categorical Levels: Academic; Non-academic	***Employer and/or institutional base of respondent*** Academic institutions: any organisation with the principle objective of research and contributing to peer-reviewed literature, e.g. universities, research institutes, research-led museums. Non-academic institutions: any organisation with non-academic principle remits associated with amphibian-related matters, such as conservation practice, policy, husbandry, non-research based awareness-raising activities e.g. NGOs; government agencies, zoos and aquaria.
Country	Categorical Levels: MEDC; LEDC	***Location of respondent's employer and/or institution*** Countries are listed as a More Economically Developed Country (MEDC) or a Less Economically Developed Country (LEDC) by the International Monetary Fund (i.e. Advanced and Developing Economy countries (IMF 2014)).
Practitioner	Categorical Levels: Conservation Practitioner - Yes; No	***Respondents asked to specify whether they described themselves as a 'conservation practitioner'*** "Conservation practitioner" describes anyone with active practical involvement (i.e. aside from research) in conservation programme(s) - defined in this questionnaire as: "*a planned and coordinated initiative designed to improve the status of a species, habitat and/or ecosystem through targeted conservation interventions*". A practitioner may or may not also be a conservation scientist/researcher.
Experience	Continuous (in years)	**The number of years the respondent has worked in amphibian research and/or conservation practice.**
Programmes	Continuous (number of programmes)	**The number of operational conservation projects currently undertaken by the respondent as a participant/partner.**

(ii) Point categories and counts for open-ended question: "*How do you perceive success in a conservation programme?*"

Table A. Species & Habitat: point categories and counts

Response Variable	Sub category	Point types	How do you perceive 'success' in conservation? Example quotes	Total number of points across all respondents
Species & Habitat	**In situ conservation actions**	Wild population improvement (numbers, persistence)	*"Success would be turning negative population trends into positive or stable population trends"* *"Persistence of the population, together with links to the wider countryside, successful recruitment and continued expansion of their range"*	200
		Habitat improvement (condition, size, connectivity, protection)	*"The habitat is protected and intact enough to allow the species to exist on an ongoing basis"*	72
		Threat mitigation	*"A resilient target species, community or ecological function by the reduction of key threats"*	30
		Wild population re-establishment	*"Successful re-establishment of a threatened species in the wild, including wild reproduction into the second generation"*	18
		Wild population condition (e.g. genetic diversity, health)	*"Succeeding in obtaining a system that maintains population dynamics, demographic numbers and genetic diversity"*	9
		Species status improvement	*"Long term survival of the target species illustrated through potential downlisting of the species on the IUCN Red List"*	6
	Ex situ conservation actions	Captive breeding and genome banking for conservation purposes	*"For species where the threats cannot be mitigated in time to save the species, a successful conservation program involves bringing a large enough number of founders into captivity within the range country, to establish an ex situ assurance population in biosecure facilities while the threats are mitigated, and then releasing captive-bred animals back into the wild"* *"Safe-guarding biodiversity - not just recovery in situ but also ex situ population and genome resource banking for the future"*	14

Table B. Programme Management: point categories and counts

Response Variable	Sub category	Point types	How do you perceive 'success' in conservation? Example quotes	Total number of points across all respondents
Programme Management	**General programme structure, timeframe and management**	General programme structure and management	*“The programme is well thought-out, addresses all necessary components and is being undertaken in an adaptive manner”* *“Successful development of the programme, including personnel, funding and activities”* *"Using an adaptive management and learning programme framework – increasing knowledge and changing programme to accommodate change”*	39
		Programme has reached a point where interventions can be reduced or are no longer required	*“Top level success would be where there are sustainable populations in the wild with the minimum amount of actions or no further actions needed at all by conservation practitioners”*	14
		Programme timeframe (i.e. long-term programme action)	*“Success in a conservation programme is a long term goal and it cannot be determined over a short period”*	13
		There are different types/degrees/stages of success that must be managed	*“Success is a very broad term when dealing with the conservation of amphibians. There are so many different factors and influences. Success is often gauged in steps rather than final outcomes”*	13
		Policy and legislation	*“The mindset of the government is such that the programme will continue”*	8
	Achievement of stated programme goals	Programme outcome achievements: goals and objectives	*“As a trained project manager I think success is achieving the stated goals. But I must admit that the goals are often not 1 on 1 with real conservation”* *" To me the success of a project relates to the aim and objectives for that particular project, which should be specific, objective, and within a certain timeframe. I think many projects fail to have clear objectives, and therefore it is difficult to establish whether or not they have been a success"*	25

Table C. Education & Engagement and Research & Evaluation: point categories and counts

Response Variable	Sub category	Point types	How do you perceive 'success' in conservation? Example quotes	Total number of points across all respondents
Education & Engagement	**Public education & awareness activities**	Public education and awareness activities	*"Engage in educating people to be aware of the reasons for decline of native amphibian populations and ways they can make a positive difference in protecting the native species in their localities"* *"All 'successful' programs need to have outreach components in order for them to be truly successful in the long run"*	44
	Local community/ stakeholder support & involvement	Fostering local community/stakeholder involvement	*"Programmes that save wild places (not just wild animals) seem to have the greatest impact when there is local community involvement and support"*	21
		Benefiting local stakeholders and/or gaining their support	*"Every program will be successful if the focus is on people, especially in developing and poor nations. The general public will not show interest in the project until it is directly linked with the sustenance of the people"*	12
		Capacity Building	*"Capacity that is built within the region through involvement of local agencies"*	1
Research & Evaluation	**Species/habitat scientific research**	Species/habitat scientific research	*"Filling knowledge or data gaps that contribute indirectly to conservation"* *"A solid understanding of the species biology and disease risk is vital"* *"Basic research that informs any aspect of amphibian conservation or biodiversity or natural history should be considered as a success"*	25
	Evaluation of programme outcomes through appropriate monitoring	Evaluation of programme outcomes through appropriate monitoring	*"A program that is executed efficiently and that involves multiple agencies to implement conservation results as well as monitoring or evaluating successes"* *"Success comes with a lot of population monitoring and going out of your own way to save that species"*	15

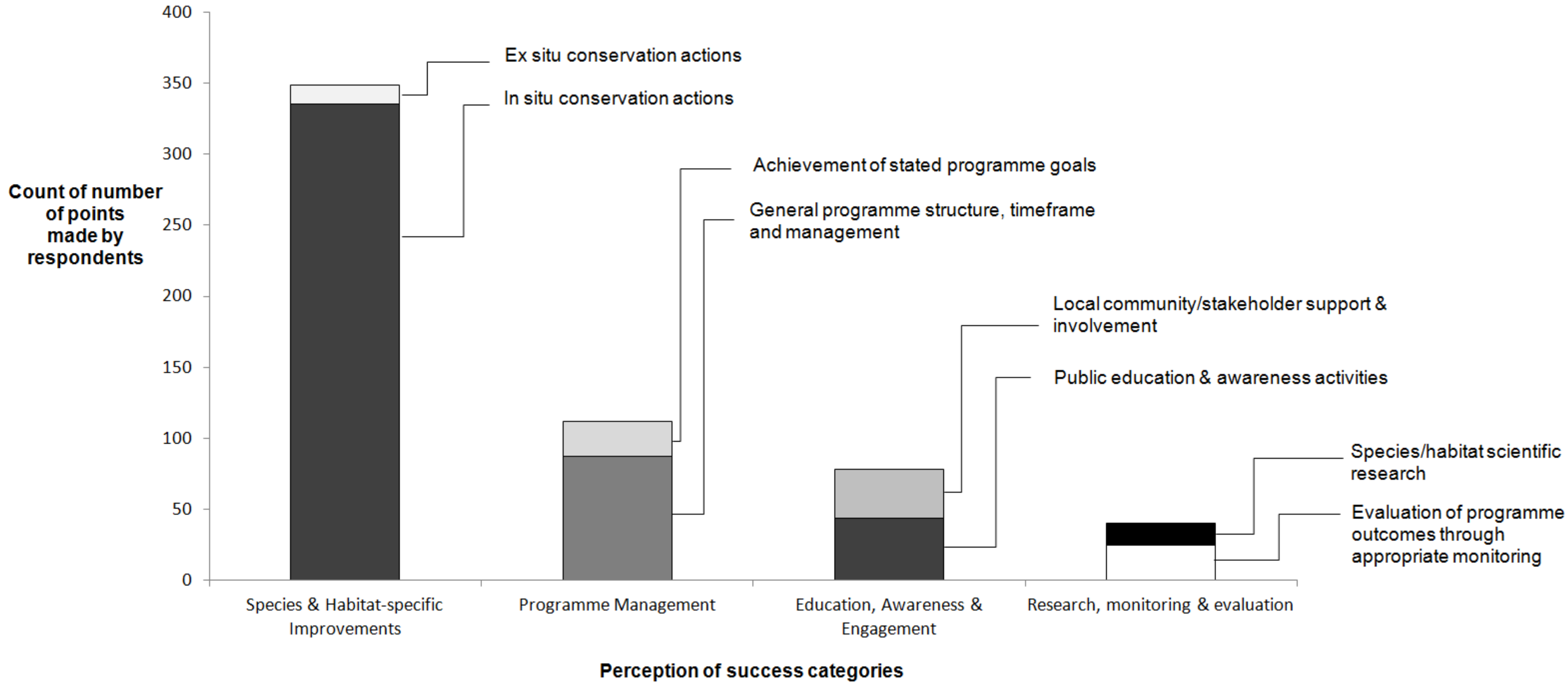


Fig. 1 Stacked column chart of categories (and sub-categories) displaying the number of points made in response to the question "*How do you perceive 'success' in a conservation programme? Please write briefly about what success means to you in the context of a conservation programme*" (n = 242 respondents/579 discrete response points).

APPENDIX III. Modelling results for spatial- and species-level analyses (Ch. 4)

A. Spatial-level analyses

(i) Modelling results for total number of evidence studies in each country. Model fit ranked by Delta AIC.

(Intercept)	scale (AmphRich)	scale (GPI)	scale (log(Area))	scale (PropEnglish Speakers)	scale (GDP per capita)	scale (PropASG)	df	logLik	AICc	Delta AIC	Weight
-0.20120172	NA	NA	1.006	0.708	1.201	NA	5	-117.985	246.804	0	0.3622566
-0.19812110	NA	NA	1.011	0.690	1.137	0.177	6	-117.622	248.427	1.623	0.1609471
-0.20440330	NA	-0.224	1.085	0.710	1.037	NA	6	-117.677	248.536	1.732	0.1523760
-0.20270778	0.034	NA	0.986	0.712	1.208	NA	6	-117.973	249.129	2.325	0.1132873
-0.20280277	NA	-0.231	1.098	0.693	0.966	0.187	7	-117.301	250.202	3.397	0.0662629
-0.20898918	0.076	-0.247	1.048	0.720	1.036	NA	7	-117.619	250.838	4.034	0.0482112
-0.19736831	-0.014	NA	1.019	0.688	1.133	0.180	7	-117.620	250.840	4.036	0.0481580
-0.20466529	0.027	-0.238	1.084	0.697	0.969	0.180	8	-117.294	252.675	5.871	0.0192399
-0.04070703	NA	-0.742	1.292	0.904	NA	0.377	6	-120.837	254.856	8.052	0.0064647
-0.00409270	NA	-0.794	1.270	0.958	NA	NA	5	-122.042	254.917	8.113	0.0062704
-0.07531878	NA	NA	1.063	NA	1.683	NA	4	-123.805	256.157	9.353	0.0033731
-0.08774253	NA	NA	1.036	NA	1.564	0.291	5	-123.047	256.928	10.124	0.0022943
-0.00990398	0.097	-0.822	1.217	0.969	NA	NA	6	-121.959	257.102	10.297	0.0021036
-0.04052773	-0.005	-0.740	1.295	0.903	NA	0.378	7	-120.836	257.273	10.469	0.0019311
-0.08194515	NA	-0.252	1.155	NA	1.519	NA	5	-123.494	257.822	11.018	0.0014672
-0.07542366	-0.125	NA	1.138	NA	1.651	NA	5	-123.687	258.207	11.403	0.0012105
-0.09335217	NA	-0.250	1.135	NA	1.396	0.307	6	-122.744	258.671	11.867	0.0009597
-0.08903272	-0.195	NA	1.155	NA	1.502	0.329	6	-122.766	258.714	11.910	0.0009393
-0.08111936	-0.099	-0.237	1.212	NA	1.504	NA	6	-123.419	260.022	13.218	0.0004885
0.19406014	NA	NA	0.925	1.092	NA	0.449	5	-124.856	260.545	13.741	0.0003760
-0.09300941	-0.172	-0.225	1.236	NA	1.357	0.343	7	-122.527	260.654	13.850	0.0003561
0.04996623	0.537	NA	NA	0.821	1.137	NA	5	-125.170	261.174	14.369	0.0002746

0.24825253	NA	NA	0.889	1.158	NA	NA	4	-126.565	261.678	14.874	0.0002134
0.17802877	-0.199	NA	1.056	1.051	NA	0.488	6	-124.527	262.238	15.433	0.0001613
0.05274933	0.522	NA	NA	0.803	1.107	0.085	6	-125.114	263.410	16.606	0.0000898
0.04999015	0.536	0.002	NA	0.821	1.138	NA	6	-125.170	263.523	16.719	0.0000848
0.24216070	-0.095	NA	0.949	1.141	NA	NA	5	-126.488	263.810	17.005	0.0000735
0.22867857	NA	NA	NA	0.882	0.972	NA	4	-128.449	265.446	18.642	0.0000324
0.05306745	0.516	0.020	NA	0.803	1.119	0.088	7	-125.112	265.823	19.019	0.0000269
0.17582006	NA	0.335	NA	0.856	1.216	NA	5	-127.766	266.364	19.560	0.0000205
0.21841031	NA	NA	NA	0.826	0.917	0.220	5	-128.124	267.081	20.276	0.0000143
0.16023093	NA	0.361	NA	0.789	1.177	0.234	6	-127.313	267.810	21.005	0.0000099
0.26858671	NA	-1.153	1.520	NA	NA	0.774	5	-129.440	269.714	22.910	0.0000038
0.24757489	0.566	NA	NA	NA	1.707	NA	4	-130.879	270.305	23.501	0.0000029
0.35227644	0.603	-0.527	NA	1.171	NA	NA	5	-129.802	270.438	23.634	0.0000027
0.23065628	-0.325	-1.096	1.750	NA	NA	0.800	6	-128.860	270.903	24.099	0.0000021
0.23388137	0.506	NA	NA	NA	1.542	0.360	5	-130.125	271.084	24.279	0.0000019
0.48218733	0.369	NA	NA	1.307	NA	NA	4	-131.497	271.542	24.738	0.0000015
0.34175292	0.562	-0.460	NA	1.116	NA	0.264	6	-129.451	272.085	25.280	0.0000012
0.44177895	0.346	NA	NA	1.211	NA	0.371	5	-130.673	272.179	25.375	0.0000011
0.55535747	NA	NA	NA	1.341	NA	NA	3	-132.931	272.186	25.382	0.0000011
0.50096033	NA	NA	NA	1.213	NA	0.416	4	-131.963	272.473	25.669	0.0000010
0.24547764	0.543	0.077	NA	NA	1.752	NA	5	-130.853	272.539	25.735	0.0000009
0.40169993	NA	-1.309	1.643	NA	NA	NA	4	-132.021	272.589	25.785	0.0000009
0.22800678	0.456	0.139	NA	NA	1.622	0.361	6	-130.042	273.268	26.464	0.0000006
0.38306201	NA	NA	NA	NA	1.420	0.531	4	-132.441	273.430	26.626	0.0000006
0.29234358	NA	0.432	NA	NA	1.697	0.466	5	-131.411	273.656	26.852	0.0000005
0.42799089	NA	NA	NA	NA	1.657	NA	3	-133.786	273.896	27.091	0.0000005
0.53834544	NA	-0.162	NA	1.313	NA	NA	4	-132.723	273.994	27.190	0.0000005
0.37957384	-0.207	-1.275	1.785	NA	NA	NA	5	-131.778	274.390	27.586	0.0000004
0.35376070	NA	0.390	NA	NA	1.880	NA	4	-132.988	274.525	27.720	0.0000003
0.49330420	NA	-0.092	NA	1.199	NA	0.402	5	-131.895	274.623	27.819	0.0000003
0.63693410	-0.602	NA	1.367	NA	NA	0.832	5	-134.701	280.236	33.432	<0.0000001
0.74805649	NA	NA	0.921	NA	NA	0.814	4	-136.211	280.970	34.166	<0.0000001
0.94908208	NA	NA	1.078	NA	NA	NA	3	-139.076	284.476	37.672	<0.0000001
0.86412367	-0.493	NA	1.421	NA	NA	NA	4	-138.090	284.727	37.923	<0.0000001

0.84979429	0.667	-0.742	NA	NA	NA	1.287	5	-138.138	287.110	40.306	<0.0000001
1.12914437	NA	NA	NA	NA	NA	1.546	3	-141.406	289.137	42.333	<0.0000001
1.06399529	NA	-0.361	NA	NA	NA	1.697	4	-140.651	289.850	43.046	<0.0000001
1.07656468	0.324	NA	NA	NA	NA	1.294	4	-140.730	290.007	43.203	<0.0000001
1.12039328	0.938	-0.934	NA	NA	NA	NA	4	-141.504	291.556	44.752	<0.0000001
1.40598647	0.600	NA	NA	NA	NA	NA	3	-144.602	295.528	48.723	<0.0000001
1.63475572	NA	NA	NA	NA	NA	NA	2	-146.978	298.116	51.312	<0.0000001
1.60875634	NA	-0.284	NA	NA	NA	NA	3	-146.720	299.765	52.961	<0.0000001

(ii) Modelling results for number of evidence studies per area (square kilometre) in each country. Model fit ranked by Delta AIC.

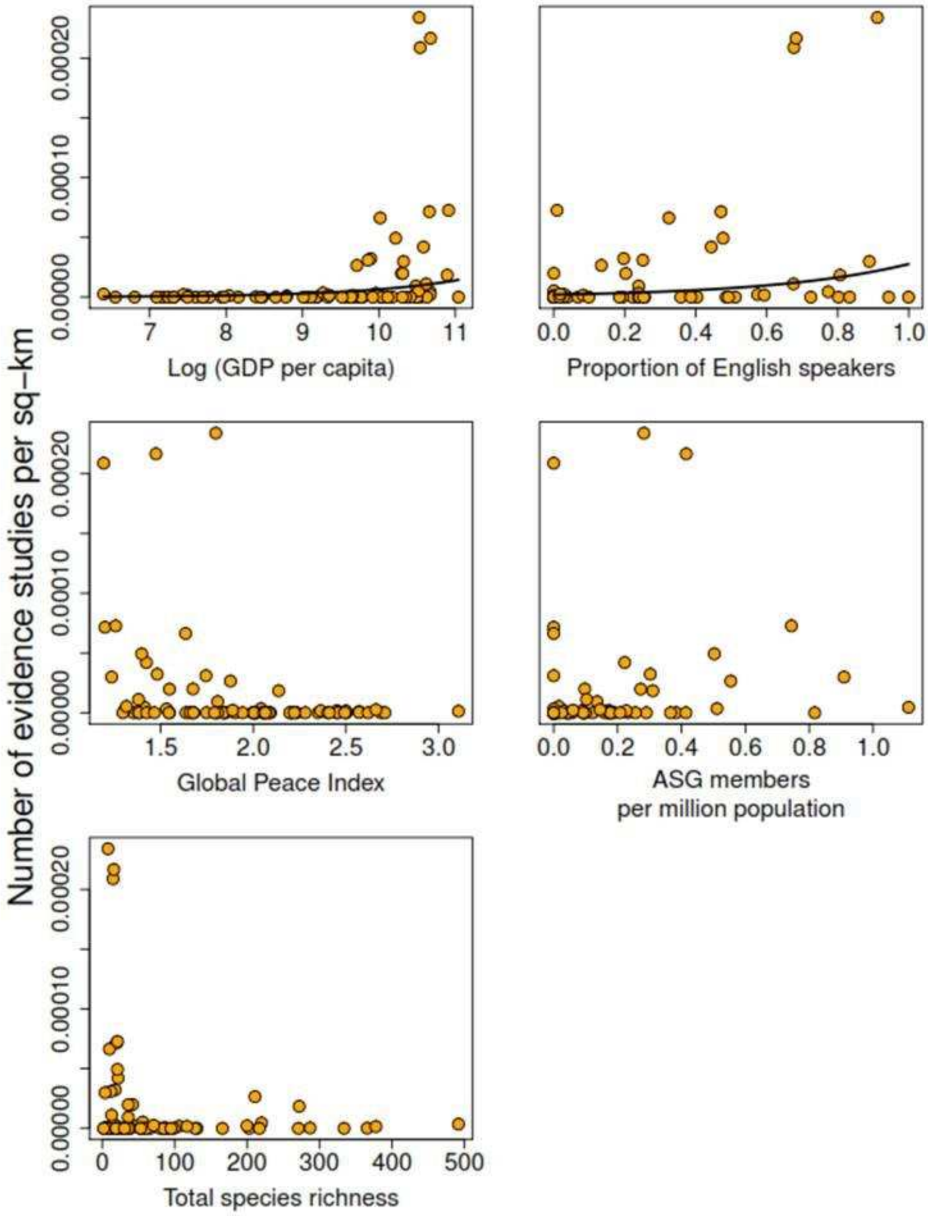
(Intercept)	scale (Amphibian Richness)	scale (GPI)	scale (PropEnglish Speakers)	scale (GDP per capita)	scale (PropASG)	offset (log(Area))	df	logLik	AICc	Delta AIC	Weight
-12.5007230	NA	-0.607	0.754	0.931	NA	+	5	-120.907	252.648	0	0.2266587
-12.5002457	NA	-0.609	0.757	0.810	0.295	+	6	-120.237	253.657	1.009	0.1368911
-12.4671595	NA	NA	0.780	1.415	NA	+	4	-122.584	253.717	1.069	0.1328346
-12.4809816	-0.132	-0.548	0.724	0.931	NA	+	6	-120.766	254.715	2.067	0.0806230
-12.4675077	NA	NA	0.797	1.302	0.276	+	5	-121.977	254.788	2.140	0.0777510
-12.4518865	-0.252	NA	0.723	1.328	NA	+	5	-122.129	255.092	2.444	0.0667945
-12.3415480	NA	-0.993	0.909	NA	0.433	+	5	-122.293	255.420	2.771	0.0566988
-12.4662605	-0.194	-0.520	0.710	0.801	0.335	+	7	-119.925	255.449	2.801	0.0558590
-12.4385612	-0.319	NA	0.718	1.170	0.343	+	6	-121.205	255.592	2.944	0.0520042
-12.2997780	NA	-1.081	0.942	NA	NA	+	4	-123.705	255.958	3.310	0.0433229
-12.3123407	-0.168	-0.903	0.873	NA	0.469	+	6	-122.052	257.287	4.639	0.0222869
-12.2873945	-0.074	-1.043	0.929	NA	NA	+	5	-123.659	258.150	5.502	0.0144736
-12.3303061	NA	-0.580	NA	1.443	NA	+	4	-125.666	259.880	7.232	0.0060950
-12.2889035	NA	NA	NA	1.870	NA	+	3	-127.039	260.402	7.753	0.0046961
-12.2810809	-0.400	NA	NA	1.689	NA	+	4	-125.995	260.537	7.889	0.0043879
-12.2956209	-0.491	NA	NA	1.515	0.399	+	5	-124.947	260.727	8.079	0.0039914
-12.3070339	-0.299	-0.481	NA	1.382	NA	+	5	-124.989	260.812	8.164	0.0038251

-12.3458768	NA	-0.610	NA	1.294	0.344	+	5	-124.990	260.813	8.165	0.0038221
-12.3143143	-0.378	-0.477	NA	1.197	0.430	+	6	-123.897	260.977	8.329	0.0035221
-12.3046429	NA	NA	NA	1.774	0.274	+	4	-126.538	261.625	8.976	0.0025478
-12.0291224	-0.515	NA	1.103	NA	0.642	+	5	-127.211	265.255	12.607	0.0004147
-11.9811170	NA	NA	1.315	NA	0.596	+	4	-129.218	266.984	14.336	0.0001748
-11.9717534	NA	-1.317	NA	NA	0.742	+	4	-129.812	268.172	15.524	0.0000965
-11.9568900	-0.353	-1.119	NA	NA	0.798	+	5	-128.876	268.585	15.937	0.0000785
-11.9420397	-0.455	NA	1.141	NA	NA	+	4	-130.278	269.104	16.456	0.0000605
-11.8919687	NA	NA	1.300	NA	NA	+	3	-131.637	269.598	16.950	0.0000473
-11.8135810	NA	-1.409	NA	NA	NA	+	3	-132.154	270.632	17.984	0.0000282
-11.8007776	-0.220	-1.288	NA	NA	NA	+	4	-131.782	272.112	19.464	0.0000135
-11.5494997	-0.864	NA	NA	NA	0.804	+	4	-135.474	279.496	26.848	0.0000003
-11.3193333	-0.721	NA	NA	NA	NA	+	3	-138.705	283.734	31.086	<0.0000001
-11.2736653	NA	NA	NA	NA	0.618	+	3	-139.842	286.009	33.361	<0.0000001
-11.1085743	NA	NA	NA	NA	NA	+	2	-141.583	287.326	34.678	<0.0000001

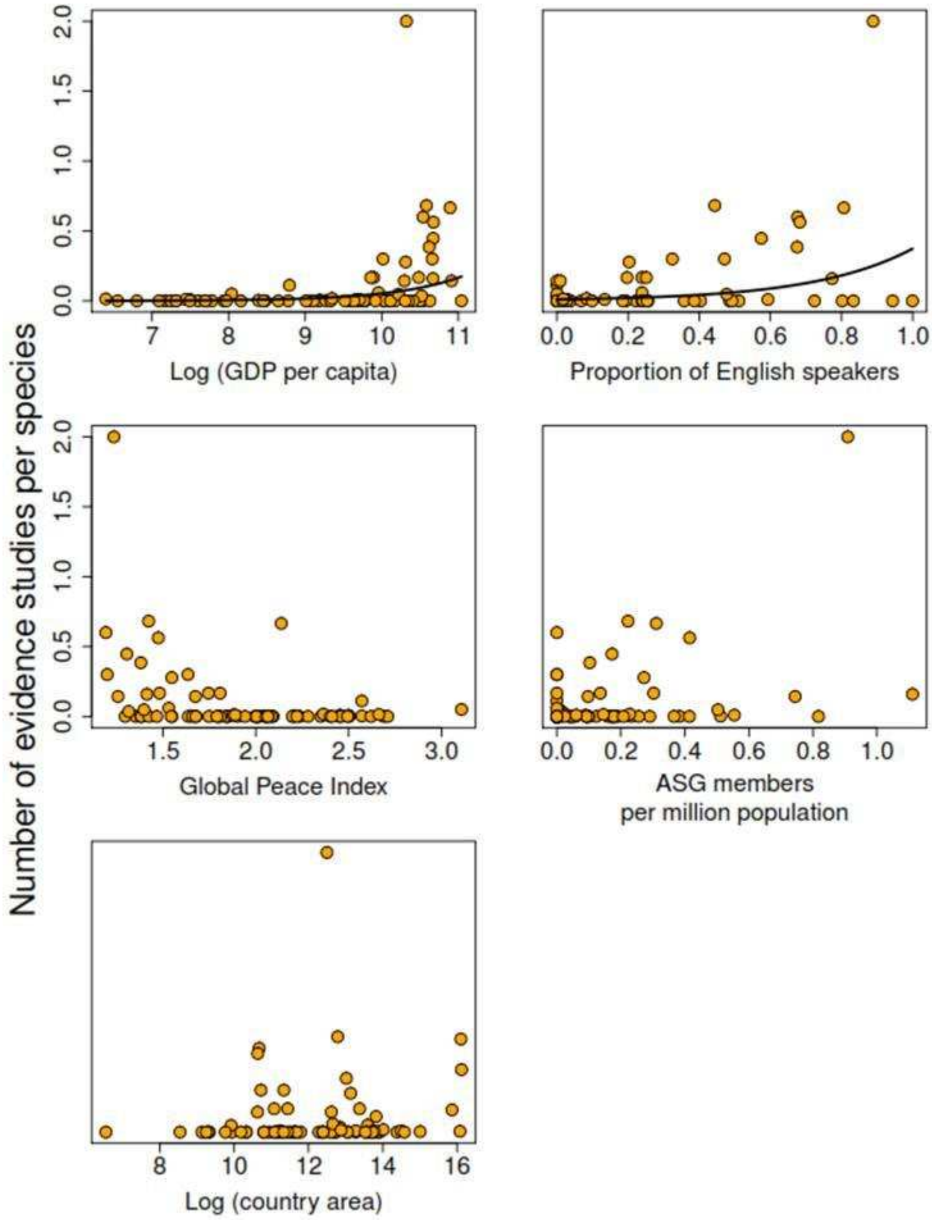
(iii) Modelling results for number of evidence studies per species in each country. Model fit ranked by Delta AIC.

(Intercept)	scale(GPI)	scale (log (Area))	scale (Prop English Speakers)	scale (GDPper capita)	scale (PropASG)	offset (log (Amphibian Richness))	df	logLik	AICc	Delta AIC	Weight
-3.7750885	NA	0.520	1.075	1.513	NA	+	5	-124.718	260.270	0	0.2936956
-3.6610479	NA	NA	1.080	1.385	NA	+	4	-125.997	260.542	0.273	0.2562784
-3.8335688	-0.291	0.596	1.076	1.337	NA	+	6	-124.430	262.043	1.773	0.1210414
-3.7757814	NA	0.523	1.063	1.493	0.060	+	6	-124.688	262.559	2.289	0.0935194
-3.6697024	-0.075	NA	1.078	1.337	NA	+	5	-125.974	262.781	2.511	0.0836791
-3.6609205	NA	NA	1.068	1.372	0.047	+	5	-125.980	262.793	2.524	0.0831576
-3.8326491	-0.283	0.596	1.070	1.330	0.034	+	7	-124.421	264.441	4.172	0.0364803
-3.6685167	-0.065	NA	1.069	1.332	0.038	+	6	-125.963	265.108	4.839	0.0261336
-3.5777157	-1.027	0.745	1.361	NA	NA	+	5	-129.489	269.811	9.541	0.0024892
-3.3567130	-0.699	NA	1.398	NA	NA	+	4	-131.467	271.481	11.211	0.0010800

-3.5910316	-0.980	0.759	1.337	NA	0.184	+	6	-129.299	271.781	11.511	0.0009296
-3.3629899	-0.655	NA	1.366	NA	0.173	+	5	-131.318	273.468	13.199	0.0003998
-3.0863554	NA	NA	1.562	NA	NA	+	3	-134.133	274.590	14.321	0.0002281
-3.1262551	NA	NA	1.496	NA	0.337	+	4	-133.505	275.558	15.288	0.0001406
-3.3180473	NA	0.754	NA	2.282	NA	+	4	-133.566	275.680	15.411	0.0001323
-3.2382973	NA	NA	NA	1.916	0.488	+	4	-133.789	276.127	15.857	0.0001058
-3.3480829	NA	0.633	NA	2.083	0.393	+	5	-132.678	276.189	15.920	0.0001026
-3.1179050	NA	0.279	1.564	NA	NA	+	4	-133.831	276.210	15.940	0.0001015
-3.1768762	NA	NA	NA	2.122	NA	+	3	-135.050	276.424	16.155	0.0000912
-3.1653990	NA	0.342	1.506	NA	0.370	+	5	-133.054	276.941	16.671	0.0000704
-3.3312983	-0.143	0.791	NA	2.194	NA	+	5	-133.503	277.838	17.569	0.0000450
-3.2324024	0.158	NA	NA	2.014	0.494	+	5	-133.707	278.248	17.978	0.0000366
-3.3504980	-0.026	0.642	NA	2.069	0.391	+	6	-132.676	278.535	18.265	0.0000317
-3.1754265	0.027	NA	NA	2.139	NA	+	4	-135.048	278.643	18.373	0.0000301
-2.6341794	-1.241	0.839	NA	NA	1.092	+	5	-141.629	294.091	33.821	<0.0000001
-2.4797812	-0.910	NA	NA	NA	1.391	+	4	-142.894	294.335	34.065	<0.0000001
-2.4298288	-1.555	1.205	NA	NA	NA	+	4	-143.729	296.006	35.736	<0.0000001
-2.0977904	NA	NA	NA	NA	1.246	+	3	-146.125	298.574	38.304	<0.0000001
-2.1095744	-1.102	NA	NA	NA	NA	+	3	-146.213	298.750	38.480	<0.0000001
-2.1063268	NA	0.152	NA	NA	1.181	+	4	-146.069	300.686	40.416	<0.0000001
-1.7039911	NA	NA	NA	NA	NA	+	2	-149.772	303.705	43.435	<0.0000001
-1.7571580	NA	0.491	NA	NA	NA	+	3	-149.333	304.991	44.721	<0.0000001



(iv) Scatter plots showing the relationship between the number of evidence studies per square kilometre and: GDP per capita; the proportion of English speakers; GPI; ASG members per million people; and total species richness per country. Regression lines were based on the model-averaged coefficients and shown only for explanatory variables with 85% confidence intervals not overlapping zero.



(v) Scatter plots showing the relationship between the number of evidence studies per species and: GDP per capita; the proportion of English speakers; GPI; ASG members per million people; and country area. Regression lines were based on the model-averaged coefficients and shown only for explanatory variables with 85% confidence intervals not overlapping zero.

B. Species-level analyses

(i) Modelling results for presence/absence of evidence studies (all amphibian species). Model fit ranked by Delta AIC.

(Intercept)	ED	IUCN Risk Status	Habit	Spawn Site	Reproductive Mode	df	logLik	AICc	Delta AIC	Weight
-3.69914554	0.023	+	NA	+	+	12	-698.051	1420.178	0	0.6193655252
-3.71796466	0.025	+	NA	NA	+	8	-703.186	1422.407	2.229	0.2031898247
-3.68614705	0.023	+	NA	+	NA	10	-702.118	1424.289	4.112	0.0792728249
-3.70339949	0.024	+	+	+	+	15	-697.518	1425.153	4.975	0.0514816266
-3.21942120	NA	+	NA	+	+	11	-702.747	1427.558	7.380	0.0154643904
-3.72142333	0.025	+	+	NA	+	11	-702.934	1427.932	7.754	0.0128268418
-3.68276117	0.024	+	+	+	NA	13	-701.596	1429.281	9.103	0.0065362387
-3.92541802	0.026	+	NA	NA	NA	6	-708.928	1429.876	9.699	0.0048522098
-3.19420440	NA	+	NA	NA	+	7	-708.359	1430.745	10.567	0.0031425394
-3.19215741	NA	+	NA	+	NA	9	-706.919	1431.882	11.704	0.0017802649
-3.22311382	NA	+	+	+	+	14	-702.470	1433.042	12.864	0.0009965444
-3.81757301	0.023	NA	NA	+	+	9	-708.611	1435.266	15.088	0.0003278373
-3.95554025	0.026	+	+	NA	NA	9	-708.689	1435.422	15.244	0.0003032378
-3.19937071	NA	+	+	NA	+	10	-708.279	1436.611	16.434	0.0001672769
-3.17956431	NA	+	+	+	NA	12	-706.663	1437.402	17.224	0.0001126686
-3.85754679	0.025	NA	NA	NA	+	5	-714.374	1438.763	18.585	0.0000570601
-3.81585012	0.023	NA	NA	+	NA	7	-712.688	1439.403	19.225	0.0000414209
-3.39569603	NA	+	NA	NA	NA	5	-714.793	1439.601	19.423	0.0000375287
-3.80375565	0.024	NA	+	+	+	12	-708.136	1440.348	20.170	0.0000258278
-3.35096851	NA	NA	NA	+	+	8	-713.504	1443.043	22.865	0.0000067120
-3.84566271	0.025	NA	+	NA	+	8	-714.137	1444.309	24.131	0.0000035640
-3.79078948	0.024	NA	+	+	NA	10	-712.225	1444.503	24.326	0.0000032338
-3.42385624	NA	+	+	NA	NA	8	-714.660	1445.355	25.177	0.0000021126
-3.33314432	NA	NA	NA	+	NA	6	-717.654	1447.328	27.151	0.0000007876
-3.34641214	NA	NA	NA	NA	+	4	-719.701	1447.412	27.234	0.0000007554
-4.11313208	0.026	NA	NA	NA	NA	3	-720.921	1447.848	27.670	0.0000006074
-3.33704813	NA	NA	+	+	+	11	-713.285	1448.634	28.456	0.0000004100

-3.29917930	NA	NA	+	+	NA	9	-717.441	1452.926	32.748	0.0000000480
-3.33792953	NA	NA	+	NA	+	7	-719.636	1453.299	33.121	0.0000000398
-4.12593328	0.027	NA	+	NA	NA	6	-720.721	1453.462	33.285	0.0000000367
-3.58777383	NA	NA	NA	NA	NA	2	-727.048	1458.099	37.921	0.0000000036
-3.59856813	NA	NA	+	NA	NA	5	-726.932	1463.879	43.701	0.0000000002

(ii) Modelling results for number of evidence studies (species with evidence). Model fit ranked by Delta AIC.

(Intercept)	ED	IUCN Risk Status	Habit	Spawn Site	Reproductive Mode	df	logLik	AICc	Delta AIC	Weight
0.81438174	NA	NA	NA	NA	NA	3	-432.706	871.535	0	0.3743291930
0.91077366	NA	+	NA	NA	NA	6	-430.422	873.282	1.746	0.1563229511
0.85187093	-0.001	NA	NA	NA	NA	4	-432.660	873.526	1.991	0.1383215827
0.85706318	NA	NA	NA	NA	+	5	-432.258	874.827	3.292	0.0721850999
0.94298646	-0.001	+	NA	NA	NA	7	-430.386	875.358	3.823	0.0553391353
0.94794158	NA	NA	+	NA	NA	6	-431.835	876.108	4.572	0.0380508745
0.94037570	NA	+	NA	NA	+	8	-430.027	876.812	5.277	0.0267551425
0.92332077	NA	NA	NA	+	NA	7	-431.123	876.832	5.297	0.0264823997
0.88772398	-0.001	NA	NA	NA	+	6	-432.224	876.886	5.350	0.0257883817
0.95252172	0.000	NA	+	NA	NA	7	-431.834	878.254	6.719	0.0130069047
1.02401843	NA	+	+	NA	NA	9	-429.744	878.440	6.905	0.0118518455
0.98182510	-0.002	NA	NA	+	NA	8	-430.991	878.740	7.205	0.0102034582
0.96618683	-0.001	+	NA	NA	+	9	-430.001	878.954	7.419	0.0091658406
1.00987699	NA	NA	+	NA	+	8	-431.284	879.326	7.791	0.0076120057
0.98392896	NA	+	NA	+	NA	10	-429.089	879.348	7.813	0.0075275354
1.14689792	NA	NA	+	+	NA	10	-429.450	880.070	8.535	0.0052465341
1.02795467	0.000	+	+	NA	NA	10	-429.744	880.658	9.123	0.0039101185
0.92195820	NA	NA	NA	+	+	9	-430.994	880.940	9.405	0.0033956106
1.03758960	-0.002	+	NA	+	NA	11	-428.975	881.362	9.827	0.0027505248
1.00653830	0.000	NA	+	NA	+	9	-431.283	881.518	9.983	0.0025433538
1.06555632	NA	+	+	NA	+	11	-429.312	882.036	10.501	0.0019636239
1.16484370	-0.001	NA	+	+	NA	11	-429.434	882.280	10.745	0.0017380985
0.98333989	-0.002	NA	NA	+	+	10	-430.850	882.870	11.335	0.0012937794

1.18379975	NA	+	+	+	NA	13	-427.698	883.364	11.828	0.0010109498
0.98510889	NA	+	NA	+	+	12	-428.887	883.451	11.916	0.0009675041
1.06347440	0.000	+	+	NA	+	12	-429.312	884.301	12.766	0.0006325250
1.14322811	NA	NA	+	+	+	12	-429.376	884.429	12.894	0.0005933116
1.04109431	-0.002	+	NA	+	+	13	-428.763	885.494	13.958	0.0003485026
1.20246475	-0.001	+	+	+	NA	14	-427.681	885.645	14.110	0.0003231527
1.16477158	-0.001	NA	+	+	+	13	-429.353	886.674	15.138	0.0001931845
1.17990959	NA	+	+	+	+	15	-427.573	887.769	16.234	0.0001117153
1.20318097	-0.001	+	+	+	+	16	-427.546	890.081	18.546	0.0000351605

APPENDIX IV. Guidance provided in expert assessment (Ch. 5)

(i) Project Information Sheet

Project: Informing amphibian conservation with scientific evidence
Participating institutions: Conservation Science Group, Department of Zoology, University of Cambridge; Durrell Institute of Conservation and Ecology, University of Kent; Institute of Zoology, Zoological Society of London
Funding body: Arcadia and NERC CASE (with ZSL)

Background to the project:
The University of Cambridge Conservation Science Group aims to promote the use of scientific evidence in conservation and land management decisions. Supported by Synchronicity Earth and Arcadia, we have collated a database of studies that test the effectiveness of different interventions for the conservation of amphibians. Over 400 of these studies have been summarised, relating to 129 different conservation actions.

Aim of this project:
We will use an expert assessment process to evaluate evidence concerning the effectiveness of different interventions for the conservation of amphibians. This will assess the likely effects – both positive and negative – of each intervention and the certainty of the scientific evidence about these effects. The ultimate goal is to provide summarised scientific evidence to help improve the impact of amphibian conservation initiatives using evidence-based decision-making.

Who can take part?
We are looking to put together a multi-disciplinary expert panel of amphibian conservation scientists and practitioners to carry out the expert assessment. Members of the group should be able to evaluate different amphibian conservation interventions in terms of their likely effectiveness, based on evidence from summarised scientific literature, and also evaluate the quality of the evidence that is currently available.

What is involved?
Members of the expert panel will be asked to review the evidence presented in the Amphibian Synopsis of Conservation Evidence (**http://conservationevidence.com/synopsis/download/13**). We will send you an online survey where you will be asked to enter scores to reflect the effectiveness and quality of evidence available for each intervention. Of the 129 conservation actions agreed by the Amphibian Synopsis Advisory Board, 98 currently have evidence available to review and will be included in this assessment. We are using the Delphi process, which involves rounds of anonymous scoring. The rounds can be summarised as follows:

Round 1: In the first survey, you will be asked to:
1. Read summarised evidence for the effects of 98 different amphibian conservation interventions.
2. Complete a scoring survey to assess: i) the likely effectiveness of each intervention, ii) the potential negative side-effects of each intervention, if any, and iii) the strength of the evidence on the effectiveness of each intervention.

Round 2: You will be sent a summary of the expert group's scores and comments from Round 1. This will enable you to review your scores against those of the rest of the panel and make any changes based on this additional information.

Round 3: You will be sent a final summary of scores and will be asked to review a provisional categorisation of the interventions made based on the group's scores for effectiveness, strength of evidence and potential negative side-effects. If there is disagreement about the categorisation of some of the interventions, these will be reassessed again in a brief final scoring round.

What are the outputs and benefits of participating?
The ultimate aim of this work is to develop a tool to aid decision-making in amphibian conservation, and also highlight where scientific evidence is currently lacking to support the practice of certain conservation interventions. This will be an essential resource that will guide science and practice to help improve the effectiveness of conservation action. By taking part, you will lend your expertise to informing the future of amphibian conservation, and contribute to improving effective conservation action in the long-term. You will also have the opportunity to review scientific evidence about a range of widely-used amphibian conservation interventions.

Overall time commitment:
We estimate that your involvement in the project – including the initial survey (Round 1) and subsequent rounds of reviewing the expert group's scores and a categorisation of the interventions – will require 2-3 days of work which you can complete at your convenience over specified time periods for each round.

The period for completion of Round 1 is anticipated to be mid-June 2014, with subsequent rounds to be completed by early July 2014.

What happens if I want to withdraw?
You have the right to withdraw from this process at any time without prejudice and without providing a reason. You can tell us verbally or in writing if you no longer want to be involved. If you choose to withdraw, we will ask whether you are still happy for us to use the information you have given so far, anonymously, in our analysis.

Thank you very much for your kind consideration.

Helen Meredith
Durrell Institute of Conservation and Ecology, University of Kent
Institute of Zoology, Zoological Society of London

Dr Rebecca K. Smith
University of Cambridge

Professor William Sutherland
University of Cambridge

If you have specific queries, please contact Helen Meredith at:
Email: **helen.meredith@zsl.org**

(ii) Round 1

Informing Amphibian Conservation with Scientific Evidence:
Interventions to benefit amphibians

Instructions and Guidelines for Round 1
This survey is the first stage of the consultation process for our exercise on evaluating evidence for interventions designed to benefit amphibians in the context of their conservation, which ultimately refers to increasing healthy amphibian populations within their natural/*in situ* habitat. For more details of the study process, please see the Project Information Sheet.

Please read these guidance notes carefully before beginning the survey. They contain important information to help you answer the questions. You may find it useful to have a copy open to refer to as you work through the survey.

The deadline for completion is: **Thursday 5th June 2014.**

The general method:
The survey is an assessment of 98 interventions for amphibian conservation. Scientific studies on the effects of each of these interventions has been summarised in the Amphibian Synopsis of Conservation Evidence (Smith & Sutherland 2014). In the survey, you are asked to read the summarised evidence for each intervention and make an assessment of:

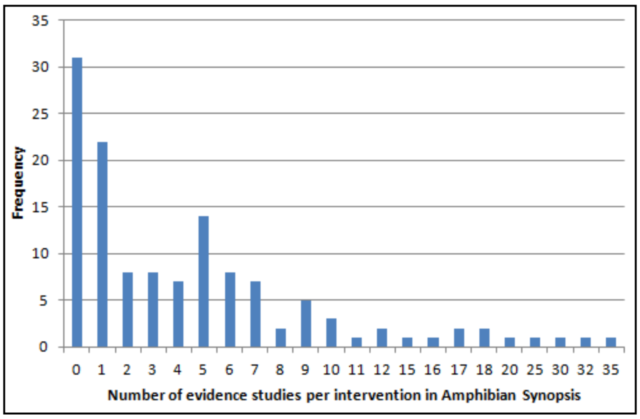
i) The effectiveness of the intervention in benefitting amphibians in the context of their conservation;
ii) The certainty about the effectiveness of the intervention, based on the evidence summarised in the synopsis;
iii) The potential negative side-effects of the intervention.

You are encouraged to add supporting comments.

Instructions:

Getting started:
1. Save or print a copy of the Amphibian Synopsis of Conservation Evidence from the email you have received. Keep this open to complete the survey.
2. Read these guidelines carefully. Keep a copy to refer to as you work through the survey.
3. Follow the unique survey link in the email you received. This will open the online survey.

Completing the survey:
- Aim to assess all of the interventions but particularly prioritise the ones you are most knowledgeable about.
- We suggest you take each intervention in turn. Read the evidence in the synopsis for one intervention and answer questions on it before moving onto the next one. This will require approximately 10 minutes per intervention, although it will vary depending how much evidence is available (ranging from one to 35 studies, with the majority having fewer than 10 studies each –see figure). The first few may be slow but you will speed up as you become familiar with the process.



Remember, you can exit and return to the survey several times at your convenience.

- This is an assessment of *evidence* extracted by a formal literature review process. **It is critical that your answers are based on information in the synopsis**. Your expertise is invaluable for understanding and interpreting the evidence, but please *do not* base your assessments on your own personal knowledge or opinions about an intervention, or on anecdotal evidence.
- However, if you know of additional quantitative studies testing the effects of an intervention, you should take these into account when scoring, and please add the full reference information for additional relevant studies in the comments box.

- When reading the synopsis, the grey 'background' box gives a description of each intervention and the bullet points provide an overview of the evidence. Below this, each supporting evidence study is summarised in no more than 150 words. Please aim to read all of the evidence for the intervention before answering questions on it.

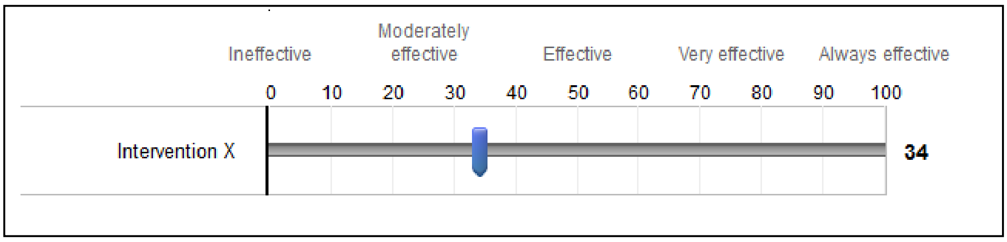
Guide to the questions:

QUESTION 1:
Based on the evidence presented in the synopsis, how ***effective*** *is this intervention in benefitting amphibians?*

What do we mean by 'effective'?
The 'effectiveness' of an intervention in benefitting the conservation of amphibians could be evaluated in a variety of different ways. It is important to note that studies in the synopsis measure different outcomes and parameters of effectiveness depending on the intervention. However, we would like you to score according to what we know about whether the ultimate objective of the intervention is being achieved, i.e. whether the intervention leads to an increase in healthy amphibian populations in their natural/*in situ* habitat. Knowledge about whether the intervention serves its proximate purpose, such as whether an amphibian species breeds in captivity or whether amphibians make use of a provided resource, should not provide full certainty with regard to the achievement of the ultimate goal of *in situ* population recovery. We want you to take all of the relevant factors into account and consider overall: *how good is this intervention at benefiting amphibians in the wider context of their* in situ *conservation?*

Your assessment should be based on the information available in the evidence synopsis. You may take additional quantitative studies into account if they are missing from the synopsis, but please make a note of these in the comments section.

The 'effectiveness' scale is from 0 (ineffective) to 100 (always effective). Move the pointer along the scale to the rating you think is most appropriate. To enter a score of 0, you must click on the scale, otherwise it will be recorded as no response.

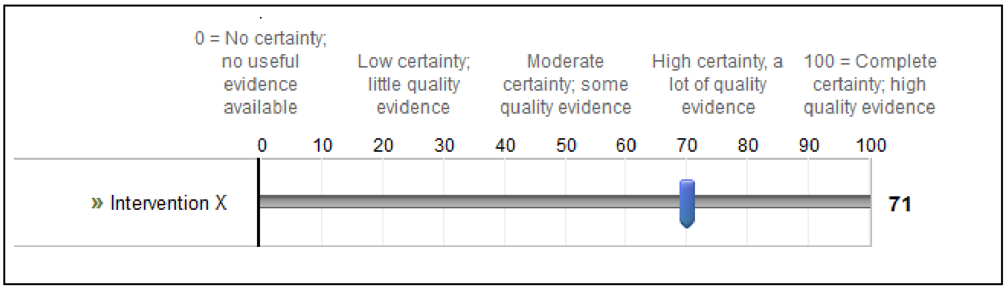


If you have comments, please add them in Question 4 (see below).

QUESTION 2:
What is the ***certainty of evidence for the effectiveness*** *of this intervention in benefitting amphibians as covered in the synopsis?*

What do we mean by 'certainty of evidence' for effectiveness?
The 'certainty of evidence' is quite different from the measure of effectiveness. It is a rating of how *confident* we can be about the effectiveness based on the evidence in the synopsis. For this question, assess how good the evidence is for the intervention that it covers. In other words, you are asked to assess the *quality* of evidence. You should think about the number of studies, coverage and wider applicability of the studies, the similarity of results across different studies, and the robustness of the experimental designs (e.g. randomised, replicated, controlled experiments with a large sample size will tend to give more dependable results than, for example, a single before-and-after comparison).

The ‘certainty’ scale is from 0 (no certainty; no useful evidence) to 100 (complete certainty; high quality evidence). Move the pointer along the scale to the score you think is most appropriate. To enter a score of 0, you must click on the scale otherwise it will be recorded as no response.



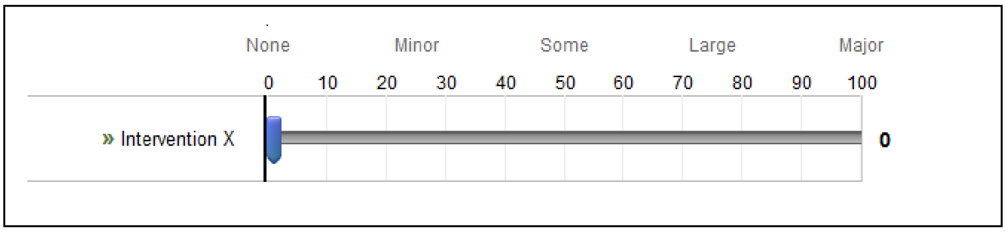
If you have comments, please add them in Question 4 (see below).

QUESTION 3:
Based on the evidence in the synopsis, are there any ***potential negative side-effects*** *of implementing this intervention?*

What are ‘potential negative side-effects’?
It is important to consider some of the potential trade-offs associated with the interventions. For example, if there is evidence in the synopsis to suggest that an intervention may enhance conditions for one amphibian species but have negative implications for another species, it is important to consider these consequences.

Using the information in the synopsis, consider the potential side-effects of each intervention. Based on the evidence, assess how significant these potential side-effects might be. It may be helpful to think about how much of a factor they would be in deciding whether to implement this intervention. Please avoid basing your answers on personal opinion or anecdotal evidence. We understand that this may be difficult, and slightly unrealistic in a conservation management scenario, but it is essential for the purpose of this exercise to get an evidence-based assessment of the interventions. If you know of any additional studies that are not included in the synopsis, please consider them in your answer, but you must provide references in the comments section so that they can be made available to the rest of the group.

The ‘side-effects’ scale is from 0 (none) to 100 (major). Move the pointer along the scale to the score you think is most appropriate. If you judge that an intervention does not have any side-effects, entering a score of zero is fine. To enter a score of 0, you must click on the scale otherwise it will be recorded as no response.



If you have comments, please add them in Question 4 (see below).

QUESTION 4:
Please provide ***comments*** *about this intervention and/or a justified reason for your rating of its effectiveness, side-effects and certainty. Remember, comments should be informative to the rest of the group and based on causal arguments and evidence, rather than opinion.*

You will be asked for comments about each intervention. These form an important component of the process as they will be shared with other group members to inform further discussion and re-scoring. This is your opportunity to tell others in the group about a relevant piece of information that is not included in the synopsis, or to provide a reason for why you scored the way you did. You are particularly encouraged to comment on the interventions you know most about. Comments should be:

- Concise and clearly stated so that other group members can understand them;
- Well-reasoned and based on causal argument, rather than personal opinion;
- Providing information or other studies not captured in the synopsis.

All comments will be kept anonymous. Comments that do not contribute valuable insight to the discussion will not be included in the summaries shared with other group members.

Example of a well-reasoned and useful comment:

> The evidence shows that the intervention was beneficial to enhancing population recovery of amphibians in almost all cases. The evidence is of high quality as most studies used randomised, replicated, controlled trials and there are a good number of studies, which show consistent results. The evidence covers a wide range of different species and locations. However, the evidence also shows there are some trade-offs as the intervention is likely to affect certain species negatively. This is also shown by a study that is not in the synopsis currently, reference:
>
> Green (2013), DOI: 10.1016/j.biocon.2013.01.014.

Example of a poorly justified and subjective comment:

> I have visited some projects where I have seen this intervention working well. However, I also know that the intervention can be detrimental to the population recovery of certain species if implemented incorrectly. Overall it is a preferable alternative to doing nothing. It is also one of the easiest interventions to implement.

(iii) Round 2

Informing amphibian conservation with scientific evidence
Guidelines for Round 2

Below are some guidelines you should follow when re-assessing your scores.

Throughout the round 2 process, remember that **this is an assessment of the evidence in the synopsis**. It is therefore critical that your answers are based on information in the synopsis. Your expertise is invaluable for understanding and interpreting the evidence, and for helping you make informed judgements about the interventions, but please try to avoid basing your assessments on your own personal opinion about an intervention. For the purposes of re-scoring, please base your scores on the evidence currently available in the synopsis in order to standardise the information that the entire panel is using to make their scores.

All additional sources of evidence recommended by the panel during the round 1 survey will be incorporated, where appropriate, into an updated synopsis. Meanwhile, the evidence that has been summarised in the current synopsis should form the basis for all of your scoring. It is important to note that where evidence appears to be more limited than anticipated, this may be (at least partially) explained by the nature of evidence that the synopsis targets. **The synopsis aims to include all quantitative scientific evidence testing the effects of**

interventions to conserve amphibians. Literature on specific threats is not summarised for this purpose unless it also tests an intervention designed to mitigate the threat, and intervention studies that focus on other taxa may be included in other relevant synopses. For a comprehensive explanation, please see pages 10-16 of the Amphibian Synopsis: *Amphibian Conservation: Global evidence for the effects of interventions* (Smith & Sutherland 2014).

Round 2: Re-scoring

Please review your scores by Thursday 10th July 2014.

Please consider how your assessments compare to the rest of the group. Look through the synthesised comments to see reasons why other panel members may have scored differently. You can also see the scores and comments you made in round 1 in the accompanying re-scoring spreadsheet, where you can change any of your scores and add additional comments as necessary. **You should pay particular attention to the interventions that you are most knowledgeable about, and those where your scores differ significantly from the rest of the panel's assessment.**

We are using the Delphi process to evaluate amphibian conservation interventions based on available evidence. This approach gives expert panel members the opportunity to influence each other's scores through subsequent rounds of comments and re-scoring. If you are happy with your scores, you do not need to change them. However, comments that bring to light important details from the evidence, or interpret the evidence differently yet convincingly, may make you want to change some scores. Viewing the spread of scores from the expert panel in box plots presented in the round 2 summary document may also make you want to recalibrate your scoring. Please consider adding comments to the re-scoring spreadsheet where necessary to explain why you changed (or retained) a score.

Please see your personalised round 2 summary document for more information.

Advice on how to score in particular situations:

- This expert assessment is an evidence-based approach designed to encourage publication and dissemination of conservation evidence through high-quality quantitative studies. Hence, in all situations, adhering to evidence-based assessments is of paramount importance. If you know of any additional studies that do not currently feature in the synopsis, please make a note of these in the comments section of your re-scoring spreadsheet. They will be taken into account when updating the synopsis. However, as before, **please base your scores on the evidence that is currently in the synopsis**.

- When scoring for **effectiveness**, please remember that **your assessment should be based on the information in the synopsis**. The evidence is usually from a mix of locations and approaches, pertaining to a range of species. Your scoring will therefore encompass the performance of the intervention across different locations, approaches and species. Once you have digested the evidence about an intervention, please consider for the species covered in the synopsis, does this seem like an effective way to increase healthy amphibian populations within their natural/*in situ* habitat?

- You can link your **effectiveness** score to your score for **certainty**. If the intervention seems to be effective in some contexts but not others – i.e. there is inconsistency in the findings between studies, perhaps influenced by location /approach/species – this means there is less certainty about the overall effectiveness of the intervention, and the certainty score should be lower.

- If there is only one study, and it shows the intervention was effective, this should score high for effectiveness, but low for certainty of evidence (due to the small number of studies).

- If there are a number of well-designed studies, but they record variable effectiveness of the intervention, you might give a middling effectiveness score and a high certainty score (i.e. we are very certain that the effects vary).

- If you know of **side-effects** associated with a particular intervention, but the summarised evidence currently makes absolutely no mention of this information, you should score side-effects as 0. The side-effects score only relates to side-effects that are mentioned in the synopsis. If there is uncertainty or a lack of evidence/information about side-effects in the synopsis, add a comment to reflect this. If there is a well-acknowledged, major potential side-effect that is not mentioned in the synopsis, do not include it in your score, but add a detailed comment describing it.

- Whether or not an intervention is effective may vary; what works in one situation may not work in another and it depends on how well a particular intervention has been deployed. If there is evidence in the summarised studies that the effectiveness of an intervention varies between contexts, you should indicate this in your certainty score. Variability in how well an intervention performs reduces the certainty about its overall effectiveness. You should base this scoring only on the studies in the synopsis, rather than on your own knowledge or opinion of an intervention.

- Similarly, if the intervention has not been implemented in an optimal way in the studies in the synopsis, then this reflects an aspect of the **quality** of the evidence. Again, this should be reflected in your score for 'certainty of evidence'.

Reminder: Guide to the Questions

The purpose of this expert assessment consultation process is to evaluate evidence for interventions designed to benefit amphibians in the context of their conservation, which ultimately refers to **increasing healthy amphibian populations within their natural/*in situ* habitat.**

QUESTION 1:
*Based on the evidence presented in the synopsis, how **effective** is this intervention in benefitting amphibians?*

What do we mean by 'effective'?
The 'effectiveness' of an intervention in benefitting the conservation of amphibians could be evaluated in a variety of different ways. It is important to note that studies in the synopsis measure different outcomes and parameters of effectiveness depending on the intervention. However, we would like you to score according to what we know about whether the ultimate objective of the intervention is being achieved, i.e. whether the intervention leads to an increase in healthy amphibian populations in their natural/*in situ* habitat. Knowledge about whether the intervention serves its proximate purpose, such as whether an amphibian species breeds in captivity or whether amphibians make use of a provided resource, should not provide full certainty with regard to the achievement of the ultimate goal of *in situ* population recovery. We want you to take all of the relevant factors

into account and consider overall: *how good is this intervention at benefiting amphibians in the wider context of their* in situ *conservation?*

Your assessment should be based on the information available in the evidence synopsis. You may take additional quantitative studies into account if they are missing from the synopsis, but please make a note of these in the comments section.

The 'effectiveness' scale is from 0 (ineffective) to 100 (always effective). More specifically:

0	**=**	Ineffective
~25	**=**	Moderately effective
~50	**=**	Effective
~75	**=**	Very effective
100	**=**	Always effective

If you have comments associated with a particular score, whether you have decided to change it or not, these can be added to the comments section of the re-scoring spreadsheet.

QUESTION 2:
What is the ***certainty of evidence for the effectiveness*** *of this intervention in benefitting amphibians as covered in the synopsis?*

What do we mean by 'certainty of evidence' for effectiveness?
The 'certainty of evidence' is quite different from the measure of effectiveness. It is a rating of how *confident* we can be about the effectiveness based on the evidence in the synopsis. For this question, assess how good the evidence is for the intervention that it covers. In other words, you are asked to assess the *quality* of evidence. You should think about the number of studies, coverage and wider applicability of the studies, the similarity of results across different studies, and the robustness of the experimental designs (e.g. randomised, replicated, controlled experiments with a large sample size will tend to give more dependable results than, for example, a single before-and-after comparison).

The 'certainty' scale is from 0 (no certainty; no useful evidence) to 100 (complete certainty; high quality evidence). More specifically:

0	**=**	No certainty; no useful evidence available
~25	**=**	Low certainty; little quality evidence
~50	**=**	Moderate certainty; some quality evidence
~75	**=**	High certainty, a lot of quality evidence
100	**=**	Complete certainty; high quality evidence

If you have comments associated with a particular score, whether you have decided to change it or not, these can be added to the comments section of the re-scoring spreadsheet.

QUESTION 3:
Based on the evidence in the synopsis, are there any ***potential negative side-effects*** *of implementing this intervention?*

What are 'potential negative side-effects'?
It is important to consider some of the potential trade-offs associated with the interventions. For example, if there is evidence in the synopsis to suggest that an intervention may enhance conditions for one amphibian species but have negative implications for another species, it is important to consider these consequences.

Using the information in the synopsis, consider the potential side-effects of each intervention. Based on the evidence, assess how significant these potential side-effects might be. It may be helpful to think about how much of a factor they would be in deciding whether to implement this intervention. Please avoid basing your answers on personal opinion or anecdotal evidence. We understand that this may be difficult, and slightly unrealistic in a conservation management scenario, but it is essential for the purpose of this exercise to get an evidence-based assessment of the interventions. If you know of any additional studies that are not included in the synopsis, please consider them in your answer, but you must provide references in the comments section so that they can be made available to the rest of the group.

The 'side-effects' scale is from 0 (none) to 100 (major). More specifically:

0	**=**	None
~25	**=**	Minor
~50	**=**	Some
~75	**=**	Large
100	**=**	Major

If you have comments associated with a particular score, whether you have decided to change it or not, these can be added to the comments section of the re-scoring spreadsheet.

QUESTION 4:
*Please provide **comments** about this intervention and/or a justified reason for your rating of its effectiveness, side-effects and certainty. Remember, comments should be informative to the rest of the group and based on causal arguments and evidence, rather than opinion.*

You will be asked for comments about each intervention. These form an important component of the process as they will be shared with other group members to inform further discussion and re-scoring. This is your opportunity to tell others in the group about a relevant piece of information that is not included in the synopsis, or to provide a reason for why you scored the way you did. You are particularly encouraged to comment on the interventions you know most about. Comments should be:

- Concise and clearly stated so that other group members can understand them;
- Well-reasoned and based on causal argument, rather than personal opinion;
- Providing information or other studies not captured in the synopsis.

All comments will be kept anonymous. Comments that do not contribute valuable insight to the discussion will not be included in the summaries shared with other group members.

Example of a well-reasoned and useful comment:

> The evidence shows that the intervention was beneficial to enhancing population recovery of amphibians in almost all cases. The evidence is of high quality as most studies used randomised, replicated, controlled trials and there are a good number of studies, which show consistent results. The evidence covers a wide range of different species and locations. However, the evidence also shows there are some trade-offs as the intervention is likely to affect certain species negatively. This is also shown by a study that is not in the synopsis currently, reference:
>
> Green (2013), DOI: 10.1016/j.biocon.2013.01.014.

Example of a poorly justified and subjective comment:

I have visited some projects where I have seen this intervention working well. However, I also know that the intervention can be detrimental to the population recovery of certain species if implemented incorrectly. Overall it is a preferable alternative to doing nothing. It is also one of the easiest interventions to implement.

If you have any queries, please do not hesitate to get in touch: helen.meredith@zsl.org

(vi) Round 3

Informing amphibian conservation with scientific evidence
Guidelines for Round 3

Please see the accompanying Excel spreadsheet to view preliminary categorisations of effectiveness for the interventions scored in rounds 1 and 2. We have used median scores from the panel (minimising the effect of extreme outliers) to put interventions into categories based on fixed score boundaries:

Category	Effectiveness	Certainty	Side-effects
Beneficial	>60	>60	<20
Likely to be beneficial - criteria 1	>60	40 - 60	<20
Likely to be beneficial - criteria 2	40 - 60	≥40	<20
Trade-offs between benefits and harms	≥40	≥40	≥20
Unlikely to be beneficial	<40	40-60	<20
Likely to be ineffective or harmful - criteria 1	<40	>60	
Likely to be ineffective or harmful - criteria 2	<40	≥40	≥20
Unknown effectiveness		<40	

The task in round 3 is to look at the category received by each intervention. Based on the median scores received, if you believe that an intervention is not in an appropriate effectiveness category, please state this by adding “YES” to the adjacent “Strongly disagree?” column. Please also explain your reasoning in the “Supporting comments?” column, *making note of the category you believe may be more appropriate*. Your suggestions should be based on the evidence in the Amphibian Synopsis rather than personal opinion.

Brief definitions of the categories:

Category	Description	General criteria
Beneficial	Effectiveness has been demonstrated by clear evidence. Expectation of harms is small compared with the benefits	High median effectiveness score Low mean side-effects score High mean certainty score
Likely to be beneficial	Effectiveness is less well established than for those listed under 'beneficial' **OR** There is clear evidence of medium effectiveness	High mean effectiveness score Low side-effects score Lower mean certainty score **OR** Medium mean effectiveness score Low side-effects score High mean certainty score
Trade-off between benefit and harms	Interventions for which practitioners must weigh up the beneficial and harmful effects according to individual circumstances and priorities	Medium effectiveness and medium side-effects scores **OR** High effectiveness and high side-effects High certainty scores
Unlikely to be beneficial	Lack of effectiveness is less well established than for those listed under 'likely to be ineffective or harmful'	Low effectiveness scores Medium certainty score and/or some variation between experts
Likely to be ineffective or harmful	Ineffectiveness or harmfulness has been demonstrated by clear evidence	Low effectiveness scores High side-effects scores High certainty scores
Unknown effectiveness	Currently insufficient data or data of inadequate quality	Low certainty scores

Please send your Excel spreadsheet back to helen.meredith@zsl.org by Friday 15th August 2014.

Any intervention categories receiving objections from several respondents, and/or for very well justified reasons, may be re-considered in a final round of re-scoring.

Additional considerations on the scoring process
Given that the categorisations are based on scores for effectiveness, certainty and side-effects, it is crucial to calibrate these scores correctly according to the appropriate score boundaries. If you think an intervention has ended up in an inappropriate category, it is important to consider why this may have happened based on how the scores it received compare to the category boundaries. The Conservation Evidence team have made some initial suggestions in the accompanying spreadsheet as guidance on what you should consider for certain interventions.

Side-effects scoring relates to impacts of an intervention that reduce or actively harm amphibian populations in a direct manner. Some negative consequences are more indirect, and these should usually be considered within the effectiveness score. For example, in intervention 3.1. Pay farmers to cover the costs of conservation measures, some farmers may take the funds but not carry out the required conservation activities. In this case, the negative consequence is reducing the effectiveness of the intervention, and therefore should be reflected in a lower score for effectiveness. A score in the side-effects category should *only* reflect direct harm to amphibians caused by the action of the intervention. As another example, in intervention 5.1. Install culverts or tunnels as road crossings, certain tunnel structures can kill amphibians. This is therefore a direct side-effect of the intervention and should be recorded in the side-effects score. However, where tunnels are not utilised, this lowers the effectiveness of the intervention and should be reflected in a lower effectiveness score.

We are evaluating each intervention in terms of how it benefits amphibians in the context of their conservation, which ultimately refers to **increasing healthy amphibian populations within their natural/*in situ* habitat**. If the evidence presented does not address the effectiveness of the intervention in achieving this end goal (e.g. if no population level data are presented), scores for certainty and effectiveness should be lowered accordingly.

Final note on the Delphi process
Throughout the round 3 process, please remember that **this is an assessment of the evidence in the synopsis**. It is therefore critical that your answers are based on information in the synopsis. Your expertise is invaluable for understanding and interpreting the evidence, and for helping you make informed judgements about the interventions, but please try to avoid basing your assessments on your own personal opinions about the interventions. Please base your assessment of the categories on the evidence currently available in the synopsis and the scores that the interventions received from the panel based on this evidence.

All additional sources of evidence recommended by the panel during round 1 and round 2 will be incorporated, where appropriate, into an updated synopsis. Meanwhile, the evidence that has been summarised in the current synopsis should form the basis for your assessment. It is important to note that where evidence appears to be more limited than anticipated, this may be (at least partially) explained by the nature of evidence that the synopsis targets. **The synopsis aims to include all quantitative scientific evidence testing the effects of interventions to conserve amphibians.** Literature on specific threats is not summarised for this purpose unless it also tests an intervention designed to mitigate the threat, and intervention studies that focus on other taxa may be included in other relevant synopses. For a comprehensive explanation, please see pages 10-16 of the Amphibian Synopsis: *Amphibian Conservation: Global evidence for the effects of interventions* (Smith & Sutherland 2014).

Please see **www.ConservationEvidence.com** for all available synopses for other taxa.

APPENDIX V. Results of Expert Assessment (Ch. 5)

Publication: Smith, R.K., Meredith, H., and Sutherland, W.J. 2015. Amphibian Conservation in Sutherland, W.J., Dicks, L.V., Ockendon, N., and Smith, R.K. What Works in Conservation. Cambridge, UK: Open Book Publishers, 2015.

AMPHIBIAN CONSERVATION

Key messages from: Smith, R.K. & Sutherland, W.J. (2014) Amphibian Conservation: Global evidence for the effects of interventions. Pelagic Publishing, Exeter.

Assessment coordinator: Helen Meredith, Durrell Institute of Conservation & Ecology, University of Kent, and Institute of Zoology, Zoological Society of London.

Expert assessors:

Ariadne Angulo, IUCN SSC Amphibian Red List Authority Coordinator, Canada
Robert Brodman, Saint Joseph's College, Indiana, USA
Jeff Dawson, Durrell Wildlife Conservation Trust, UK
Rob Gandola, Univeristy of Southampton, UK
Jaime García Moreno, Amphibian Survival Alliance, the Netherlands
Trent Garner, Institute of Zoology, Zoological Society of London, UK
Richard Griffiths, Durrell Institute of Conservation and Ecology, UK
Sergei Kuzmin, Russian Academy of Sciences
Michael Lanoo, Indiana University, USA
Michael Lau, WWF-Hong Kong
James Lewis, Amphibian Survival Alliance/Global Wildlife Conservation, USA
An Martel, Ghent University, Belgium
LeGrand Nono Gonwouo, Cameroon Biodiversity Conservation Society
Deanna Olson, US Forest Service
Timo Paasikunnas, Curator of Conservation at Helsinki Zoo, Finland
Frank Pasmans, Ghent University, Belgium
Silviu Petrovan, Froglife, UK
Carlos Martínez Rivera, Philadelphia Zoo, USA
Gonçalo Rosa, Institute of Zoology, Zoological Society of London, UK
David Sewell, Durrell Institute of Conservation and Ecology, UK
Rebecca Smith, Department of Zoology, Cambridge University, UK
Ben Tapley, Zoological Society of London, UK
Jeanne Tarrant, Endangered Wildlife Trust, South Africa
Karthikeyan Vasudevan, Wildlife Institute of India
Victor Wasonga, National Museums of Kenya
Ché Weldon, North-West University, South Africa
Sally Wren, Amphibian Specialist Group Programme Officer, New Zealand

Effectiveness measure is the median % score for effectiveness.
Certainty measure is the median % certainty of evidence for effectiveness, determined by the quantity and quality of the evidence in the synopsis.
Harm measure is the median % score for negative side-effects to the group of species of concern.

1. Threat: Residential and commercial development

Based on the collated evidence, what is the current assessment of the effectiveness of interventions for residential and commercial development?	
Beneficial	
Likely to be beneficial	
Trade-off between benefit and harms	
Unknown effectiveness (limited evidence)	• Legal protection of species
Unlikely to be beneficial	
Likely to be ineffective or harmful	

No evidence (or assessment)	• Protect brownfield or ex-industrial sites • Restrict herbicide, fungicide and pesticide use on and around ponds on golf courses

Key messages

Protect brownfield or ex-industrial sites

We captured no evidence for the effects of protecting brownfield sites on amphibian populations.

Restrict herbicide, fungicide and pesticide use on and around ponds on golf courses

We captured no evidence for the effects of restricting herbicide, fungicide or pesticide use on or around ponds on golf courses on amphibian populations.

Legal protection of species

Three reviews, including one systematic review, in the Netherlands and UK found that legal protection of amphibians was not effective at protecting populations during development. Two reviews found that the number of great crested newt mitigation licences issued in England and Wales increased over 10 years. Assessment: unknown effectiveness - limited evidence (effectiveness 10%; certainty 35%; harms 7%).

2. Threat: Agriculture

Based on the collated evidence, what is the current assessment of the effectiveness of interventions for agriculture?	
Beneficial	
Likely to be beneficial	• Pay farmers to cover the costs of conservation measures • Engage landowners and other volunteers to manage land for amphibians • Manage ditches
Trade-off between benefit and harms	
Unknown effectiveness (limited evidence)	• Manage cutting regime • Manage grazing regime

Unlikely to be beneficial	
Likely to be ineffective or harmful	• Exclude domestic animals or wild hogs from ponds by fencing

No evidence (or assessment)	• Reduced tillage • Maintain or restore hedges • Plant new hedges

Key messages - Engage farmers and other volunteers

Pay farmers to cover the costs of conservation measures

Four of five studies, including two replicated studies, in Denmark, Sweden and Taiwan found that payments to farmers increased amphibian populations, numbers of species or breeding habitat. One found that amphibian habitat was not maintained. Assessment: likely to be beneficial (effectiveness 70%; certainty 53%; harms 10%).

Engage landowners and other volunteers to manage land for amphibians

Three studies, including one replicated and one controlled study, in Estonia, Mexico and Taiwan found that engaging landowners and other volunteers in habitat management increased amphibian populations and axolotl weight. Six studies in Estonia, the USA and UK found that up to 41,000 volunteers were engaged in habitat restoration programmes for amphibians and restored up to 1,023 ponds or 11,500 km2 of habitat. Assessment: likely to be beneficial (effectiveness 70%; certainty 55%; harms 5%).

Key messages - Terrestrial habitat management

Manage cutting regime

Studies investigating the effects of changing mowing regimes are discussed in ‘Habitat restoration and creation – Change mowing regime’. Assessment for ‘Change mowing regime’: unknown effectiveness – limited evidence (effectiveness 50%; certainty 30%; harms 0%).

Manage grazing regime

Two studies, including one replicated, controlled study, in the UK and USA found that grazed plots had lower numbers of toads than ungrazed plots and that grazing, along with burning, decreased numbers of amphibian species. Five studies, including four replicated studies, in Denmark, Estonia and the UK found that habitat management that included reintroduction of grazing maintained or increased toad populations. Assessment: unknown effectiveness – limited evidence (effectiveness 45%; certainty 39%; harms 10%).

Reduced tillage

We captured no evidence for the effects of reduced tillage on amphibian populations.

Maintain or restore hedges

We captured no evidence for the effects of maintaining or restoring hedges on amphibian populations.

Plant new hedges

We captured no evidence for the effects of planting new hedges on amphibian populations.

Manage silviculture practices in plantations

Studies investigating the effects of silviculture practices are discussed in ‘Threat: Biological resource use – Logging & wood harvesting’.

Key messages - Aquatic habitat management

Exclude domestic animals or wild hogs from ponds by fencing

Four replicated studies, including one randomized, controlled, before-and-after study, in the USA found that excluding livestock from streams or ponds did not increase overall numbers of amphibians, species, eggs or larval survival, but did increase larval and metamorph abundance. One before-and-after study in the UK found that pond restoration that included livestock exclusion increased pond use by breeding toads. Assessment: likely to be ineffective or harmful (effectiveness 31%; certainty 50%; harms 25%).

Manage ditches

One controlled, before-and-after study in the UK found that managing ditches increased toad numbers. One replicated, site comparison study in the Netherlands found that numbers of amphibians and species were higher in ditches managed under agri-environment schemes compared to those managed conventionally. Assessment: likely to be beneficial (effectiveness 71%; certainty 60%; harms 0%).

3. Threat: Energy production and mining

Based on the collated evidence, what is the current assessment of the effectiveness of interventions for energy production and mining?	
Beneficial	
Likely to be beneficial	
Trade-off between benefit and harms	
Unknown effectiveness (limited evidence)	• Artificially mist habitat to keep it damp
Unlikely to be beneficial	
Likely to be ineffective or harmful	

Key messages

Artificially mist habitat to keep it damp

One before-and-after study in Tanzania found that installing a sprinkler system to mitigate against a reduction of river flow did not maintain a population of Kihansi spray toads. Assessment: unknown effectiveness – limited evidence (effectiveness 24%; certainty 20%; harms 0%).

4. Threat: Transportation and service corridors

Based on the collated evidence, what is the current assessment of the effectiveness of interventions for transportation and service corridors?	
Beneficial	
Likely to be beneficial	• Modify gully pots and kerbs • Close roads during seasonal amphibian migration
Trade-off between benefit and harms	• Install culverts or tunnels as road crossings • Install barrier fencing along roads
Unknown effectiveness (limited evidence)	• Use signage to warn motorists
Unlikely to be beneficial	• Use humans to assist migrating amphibians across roads
Likely to be ineffective or	

harmful	

Key messages

Install culverts or tunnels as road crossings

Thirty-two studies investigated the effectiveness of installing culverts or tunnels as road crossings for amphibians. Six of seven studies, including three replicated studies, in Canada, Europe and the USA found that installing culverts or tunnels decreased amphibian road deaths. One found no effect on road deaths. Fifteen of 24 studies, including one review, in Australia, Canada, Europe and the USA found that tunnels were used by amphibians. Four found mixed effects depending on species, site or culvert type. Five found that culverts were not used or were used by less than 10% of amphibians. Six studies, including one replicated, controlled study, in Canada, Europe and the USA investigated the use of culverts with flowing water. Two found that they were used by amphibians. Three found that they were rarely or not used. Certain culvert designs were found not to be suitable for amphibians. Assessment: trade-offs between benefits and harms (effectiveness 60%; certainty 75%; harms 25%).

Install barrier fencing along roads

Seven of eight studies, including one replicated and two controlled studies, in Germany, Canada and the USA found that barrier fencing with culverts decreased amphibian road deaths, in three cases depending on fence design. One study found that few amphibians were diverted by barriers. Assessment: trade-offs between benefits and harms (effectiveness 65%; certainty 68%; harms 23%).

Modify gully pots and kerbs

One before-and-after study in the UK found that moving gully pots 10 cm away from the kerb decreased the number of great crested newts that fell in by 80%. Assessment: likely to be beneficial (effectiveness 80%; certainty 40%; harms 0%).

Use signage to warn motorists

One study in the UK found that despite warning signs and human assistance across roads, some toads were still killed on roads. Assessment: unknown effectiveness – limited evidence (effectiveness 10%; certainty 10%; harms 0%).

Close roads during seasonal amphibian migration

Two studies, including one replicated study, in Germany found that road closure sites protected large numbers of amphibians from mortality during breeding migrations. Assessment: likely to be beneficial (effectiveness 85%; certainty 50%; harms 0%).

Use humans to assist migrating amphibians across roads

Three studies, including one replicated study, in Italy and the UK found that despite assisting toads across roads during breeding migrations, toads were still killed on roads and 64–70% of populations declined. Five studies in Germany, Italy and the UK found that large numbers of amphibians were moved across roads by up to 400 patrols. Assessment: likely to be beneficial (effectiveness 35%; certainty 40%; harms 3%).

5. Threat: Biological resource use

Based on the collated evidence, what is the current assessment of the effectiveness of interventions for biological resource use?	
Beneficial	
Likely to be beneficial	• Reduce impact of amphibian trade • Use shelterwood harvesting instead of clearcutting • Retain riparian buffer strips during timber harvest
Trade-off between benefit and harms	• Leave coarse woody debris in forests
Unknown effectiveness (limited	• Use legislative regulation to protect wild populations • Use patch retention harvesting instead of clearcutting

evidence)	
Unlikely to be beneficial	• Use leave-tree harvesting instead of clearcutting • Leave standing deadwood/snags in forests
Likely to be ineffective or harmful	• Thin trees within forests • Harvest groups of trees instead of clearcutting

No evidence (or assessment)	• Use amphibians sustainably • Commercially breed amphibians for the pet trade

Key messages - Hunting & collecting terrestrial animals

Use amphibians sustainably

We captured no evidence for the effects of using amphibians sustainably.

Reduce impact of amphibian trade

One review found that reducing trade through legislation allowed frog populations to recover from over-exploitation. Assessment: likely to be beneficial (effectiveness 76%; certainty 40%; harms 0%).

Use legislative regulation to protect wild populations

One review found that legislation to reduce trade resulted in the recovery of frog populations. One study in South Africa found that the number of permits issued for scientific and educational use of amphibians increased from 1987 to 1990. Assessment: unknown effectiveness – limited evidence (effectiveness 60%; certainty 30%; harms 5%).

Commercially breed amphibians for the pet trade

We captured no evidence for the effects of commercially breeding amphibians for the pet trade on wild amphibian populations.

Key messages - Logging & wood harvesting

Thin trees within forests

Six studies, including five replicated and/or controlled studies, in the USA compared amphibians in thinned to unharvested forest. Three found that thinning had mixed effects and one found no effect on abundance. One found that amphibian abundance increased following thinning but the body condition of ensatina salamanders decreased. One found a negative overall response of amphibians. Four studies, including two replicated, controlled studies, in the USA compared amphibians in thinned to clearcut forest. Two found that thinning had mixed effects on abundance and two found higher amphibian abundance or a less negative overall response of amphibians following thinning. One meta-analysis of studies in North America found that partial harvest, which included thinning, decreased salamander populations, but resulted in smaller reductions than clearcutting. Assessment: likely to be ineffective or harmful (effectiveness 35%; certainty 60%; harms 40%).

Harvest groups of trees instead of clearcutting

Three studies, including two randomized, replicated, controlled, before-and-after studies, in the USA found that harvesting trees in small groups resulted in similar amphibian abundance to clearcutting. One meta-analysis and one randomized, replicated, controlled, before-and-after study in North America and the USA found that harvesting, which included harvesting groups of trees, resulted in smaller reductions in salamander populations than clearcutting. Assessment: likely to be ineffective or harmful (effectiveness 33%; certainty 60%; harms 23%).

Use patch retention harvesting instead of clearcutting

We found no evidence for the effect of retaining patches of trees rather than clearcutting on amphibian populations. One replicated study in Canada found that although released red-legged frogs did not move towards retained tree patches, large patches were selected more and moved out of less than small patches. Assessment: unknown effectiveness – limited evidence (effectiveness 20%; certainty 25%; harms 0%).

Use leave-tree harvesting instead of clearcutting

Two studies, including one randomized, replicated, controlled, before-and-after study, in the USA found that compared to clearcutting, leaving a low density of trees during harvest did not result in higher salamander abundance. Assessment: unlikely to be beneficial (effectiveness 10%; certainty 48%; harms 11%).

Use shelterwood harvesting instead of clearcutting

Three studies, including two randomized, replicated, controlled, before-and-after studies, in the USA found that compared to clearcutting, shelterwood harvesting resulted in higher or similar salamander abundance. One meta-analysis of studies in North America found that partial harvest, which included shelterwood harvesting, resulted in smaller reductions in salamander populations than clearcutting. Assessment: likely to be beneficial (effectiveness 40%; certainty 57%; harms 10%).

Leave standing deadwood/snags in forests

One randomized, replicated, controlled, before-and-after study in the USA found that compared to total clearcutting, leaving dead and wildlife trees did not result in higher abundances of salamanders. One randomized, replicated, controlled study in the USA found that numbers of amphibians and species were similar with removal or creation of dead trees within forest. Assessment: unlikely to be beneficial (effectiveness 5%; certainty 58%; harms 2%).

Leave coarse woody debris in forests

Two replicated, controlled studies in the USA found that abundance was similar in clearcuts with woody debris retained or removed for eight of nine amphibian species, but that the overall response of amphibians was more negative where woody debris was retained. Two replicated, controlled studies in the USA and Indonesia found that the removal of coarse woody debris from standing forest did not effect amphibian diversity or overall amphibian abundance, but did reduce species richness. One replicated, controlled study in the USA found that migrating amphibians used clearcuts where woody debris was retained more than where it was removed. One replicated, site comparison study in the USA found that within clearcut forest, survival of juvenile amphibians was significantly higher within piles of woody debris than in open areas. Assessment: trade-offs between benefits and harms (effectiveness 40%; certainty 60%; harms 26%).

Retain riparian buffer strips during timber harvest

Six replicated and/or controlled studies in Canada and the USA compared amphibian numbers following clearcutting with or without riparian buffer strips. Five found mixed effects and one found that abundance was higher with riparian buffers. Two of four replicated studies, including one randomized, controlled, before-and-after study, in Canada and the USA found that numbers of species and abundance were greater in wider buffer strips. Two found no effect of buffer width. Assessment: likely to be beneficial (effectiveness 50%; certainty 61%; harms 10%).

6. Threat: Human intrusions and disturbance

Based on the collated evidence, what is the current assessment of the effectiveness of interventions for human intrusions and disturbance?	
Beneficial	
Likely to be beneficial	
Trade-off between benefit and harms	
Unknown effectiveness (limited evidence)	
Unlikely to be beneficial	
Likely to be ineffective or	

harmful	

No evidence (or assessment)	• Use signs and access restrictions to reduce disturbance

Key messages

Use signs and access restrictions to reduce disturbance

We captured no evidence for the effects of using signs and access restrictions to reduce disturbance on amphibian populations.

7. Threat: Natural system modifications

Based on the collated evidence, what is the current assessment of the effectiveness of interventions for natural system modifications?	
Beneficial	• Regulate water levels
Likely to be beneficial	
Trade-off between benefit and harms	
Unknown effectiveness (limited evidence)	• Mechanically remove mid-storey or ground vegetation
Unlikely to be beneficial	
Likely to be ineffective or harmful	• Use prescribed fire or modifications to burning regime: Forests • Use prescribed fire or modifications to burning regime: Grassland • Use herbicides to control mid-storey or ground vegetation

Key messages

Use prescribed fire or modifications to burning regime

Eight of 15 studies, including three randomized, replicated, controlled studies, in Australia, North America and the USA found no effect of prescribed forest fires on amphibian abundance or numbers of species. Four found that fires had mixed effects on abundance. Four found that abundance, numbers of species or hatching success increased and one that abundance decreased. Two of three studies, including one replicated, before-and-after study, in the USA and Argentina found that prescribed fires in grassland decreased amphibian abundance or numbers of species. One found that spring, but not autumn or winter burns in grassland, decreased abundance. Assessment for forests: likely to be ineffective or harmful (effectiveness 30%; certainty 58%; harms 40%). Assessment for grassland: likely to be ineffective or harmful (effectiveness 10%; certainty 40%; harms 70%).

Use herbicides to control mid-storey or ground vegetation

Three studies, including two randomized, replicated, controlled studies, in the USA found that understory removal using herbicide had no effect or negative effects on amphibian abundance. One replicated, site comparison study in Canada found that following logging, abundance was similar or lower in stands with herbicide treatment and planting compared to those left to regenerate naturally. Assessment: likely to be ineffective or harmful (effectiveness 10%; certainty 50%; harms 50%).

Mechanically remove mid-storey or ground vegetation

One randomized, replicated, controlled study in the USA found that mechanical understory reduction increased numbers of amphibian species, but not amphibian abundance.

Assessment: unknown effectiveness – limited evidence (effectiveness 40%; certainty 30%; harms 0%).

Regulate water levels

Three studies, including one replicated, site comparison study, in the UK and USA found that maintaining pond water levels, in two cases with other habitat management, increased or maintained amphibian populations or increased breeding success. One replicated, controlled study in Brazil found that keeping rice fields flooded after harvest did not change amphibian abundance or numbers of species, but changed species composition. One replicated, controlled study in the USA found that draining ponds increased abundance and numbers of amphibian species. Assessment: beneficial (effectiveness 70%; certainty 65%; harms 10%).

8. Threat: Invasive and other problematic species

Based on the collated evidence, what is the current assessment of the effectiveness of interventions for invasive and other problematic species?	
Beneficial	• Remove or control fish by drying out ponds
Likely to be beneficial	• Remove or control mammals • Remove or control fish population by catching • Remove or control invasive bullfrogs • Remove or control invasive viperine snake • Use temperature treatment to reduce infection
Trade-off between benefit and harms	• Remove or control fish using Rotenone • Control invasive plants • Use antifungal treatment to reduce infection
Unknown effectiveness (limited evidence)	• Exclude fish with barriers • Reduce competition from native amphibians • Remove or control invasive Cuban tree frogs • Sterilize equipment when moving between amphibian sites* • Use gloves to handle amphibians* • Remove the chytrid fungus from ponds • Add salt to ponds • Immunize amphibians against infection • Treating amphibians in the wild or pre-release
Unlikely to be beneficial	• Use antifungal skin bacteria or peptides to reduce infection • Use antibacterial treatment to reduce infection
Likely to be ineffective or harmful	

No evidence (or assessment)	• Encourage aquatic plant growth as refuge against fish predation • Remove or control non-native crayfish • Remove or control invasive cane toads • Prevent heavy usage/exclude wildfowl from aquatic habitat • Use zooplankton to remove zoospores • Sterilize equipment to prevent ranaviruses*

*Limited evidence does not mean that the intervention should not be carried out; for disease-causing agents such as chytrid fungi (which can cause the disease chytridiomycosis) and Ranavirus, experts suggest applying the precautionary principle, i.e. carrying out the intervention as usual practice.

Key messages - Reduce predation by other species

Remove or control mammals

One controlled study in New Zealand found that controlling rats had no significant effect on numbers of Hochstetter's frog. Two studies, one of which was controlled, in New Zealand found that predator-proof enclosures enabled or increased survival of frog species. Assessment: likely to be beneficial (effectiveness 50%; certainty 40%; harms 0%).

Remove or control fish population by catching

Four of six studies, including two replicated, controlled studies, in Sweden, the USA and UK found that removing fish by catching them increased amphibian abundance, survival and recruitment. Two found no significant effect on newt populations or toad breeding success. Assessment: likely to be beneficial (effectiveness 50%; certainty 52%; harms 0%).

Remove or control fish using Rotenone

Three studies, including one replicated study, in Sweden, the UK and USA found that eliminating fish using rotenone increased numbers of amphibians, amphibian species and recruitment. One review in Australia, the UK and USA found that fish control that included using rotenone increased breeding success. Two replicated studies in Pakistan and the UK found that rotenone use resulted in frog deaths and negative effects on newts. Assessment: trade-offs between benefits and harms (effectiveness 65%; certainty 60%; harms 52%).

Remove or control fish by drying out ponds

One before-and-after study in the USA found that draining ponds to eliminate fish increased numbers of amphibian species. Four studies, including one review, in Estonia, the UK and USA found that pond drying to eliminate fish, along with other management activities, increased amphibian abundance, numbers of species and breeding success. Assessment: beneficial (effectiveness 80%; certainty 66%; harms 3%).

Exclude fish with barriers

One controlled study in Mexico found that excluding fish using a barrier increased weight gain of axolotls. Assessment: unknown effectiveness – limited evidence (effectiveness 30%; certainty 20%; harms 0%).

Encourage aquatic plant growth as refuge against fish predation

We captured no evidence for the effects of encouraging aquatic plant growth as refuge against fish predation on amphibian populations.

Remove or control invasive bullfrogs

Two studies, including one replicated, before-and-after study, in the USA and Mexico found that removing American bullfrogs increased the size and range of frog populations. One replicated, before-and-after study in the USA found that following bullfrog removal, frogs were found out in the open more. Assessment: likely to be beneficial (effectiveness 79%; certainty 60%; harms 0%).

Remove or control invasive viperine snake

One before-and-after study in Mallorca found that numbers of Mallorcan midwife toad larvae increased after intensive, but not less intensive, removal of viperine snakes. Assessment: likely to be beneficial (effectiveness 50%; certainty 40%; harms 0%).

Remove or control non-native crayfish

We captured no evidence for the effects of removing or controlling non-native crayfish on amphibian populations.

Key messages - Reduce competition with other species

Reduce competition from native amphibians

One replicated, site comparison study in the UK found that common toad control did not increase natterjack toad populations. Assessment: unknown effectiveness – limited evidence (effectiveness 10%; certainty 23%; harms 0%).

Remove or control invasive cane toads

We captured no evidence for the effects of removing or controlling invasive cane toads on amphibian populations.

Remove or control invasive Cuban tree frogs

One before-and-after study in the USA found that removal of invasive Cuban tree frogs increased numbers of native frogs. Assessment: unknown effectiveness – limited evidence (effectiveness 65%; certainty 30%; harms 0%).

Key messages - Reduce adverse habitat alteration by other species

Prevent heavy usage/exclude wildfowl from aquatic habitat

We captured no evidence for the effects of preventing heavy usage or excluding wildfowl from aquatic habitat on amphibian populations.

Control invasive plants

One before-and-after study in the UK found that habitat and species management that included controlling swamp stonecrop, increased a population of natterjack toads. One replicated, controlled study in the USA found that more Oregon spotted frogs laid eggs in areas where invasive reed canarygrass was mown. Assessment: likely to be beneficial (effectiveness 60%; certainty 47%; harms 0%).

Key messages - Reduce parasitism and disease – chytridiomycosis

Sterilize equipment when moving between amphibian sites

We found no evidence for the effects of sterilizing equipment when moving between amphibian sites on the spread of disease between amphibian populations or individuals. Two randomized, replicated, controlled study in Switzerland and Sweden found that Virkon S disinfectant did not affect survival, mass or behaviour of eggs, tadpoles or hatchlings. However, one of the studies found that bleach significantly reduced tadpole survival. Assessment: unknown effectiveness – limited evidence (effectiveness 10%; certainty 30%; harms 40%).

Use gloves to handle amphibians

We found no evidence for the effects of using gloves on the spread of disease between amphibian populations or individuals. A review for Canada and the USA found that there were no adverse effects of handling 22 amphibian species using disposable gloves. However, three replicated studies in Australia and Austria found that deaths of tadpoles were caused by latex, vinyl and nitrile gloves for 60–100% of species tested. Assessment: unknown effectiveness – limited evidence (effectiveness 9%; certainty 35%; harms 65%).

Remove the chytrid fungus from ponds

One before-and-after study in Mallorca found that drying out a pond and treating resident midwife toads with fungicide reduced levels of infection but did not eradicate chytridiomycosis. Assessment: unknown effectiveness – limited evidence (effectiveness 25%; certainty 25%; harms 0%).

Use zooplankton to remove zoospores

We captured no evidence for the effects of using zooplankton to remove chytrid zoospores on amphibian populations.

Add salt to ponds

One study in Australia found that following addition of salt to a pond containing the chytrid fungus, a population of green and golden bell frogs remained free of chytridiomycosis for over six months. Assessment: unknown effectiveness – limited evidence (effectiveness 41%; certainty 25%; harms 50%).

Immunize amphibians against infection

One randomized, replicated, controlled study in the USA found that vaccinating mountain yellow-legged frogs with formalin-killed chytrid fungus did not significantly reduce chytridiomycosis infection rate or mortality. Assessment: unknown effectiveness – limited evidence (effectiveness 0%; certainty 25%; harms 0%).

Use antifungal skin bacteria or peptides to reduce infection

Three of four randomized, replicated, controlled studies in the USA found that introducing antifungal bacteria to the skin of chytrid infected amphibians did not reduce infection rate or deaths. One found that it prevented infection and death. One randomized, replicated, controlled study in the USA found that adding antifungal skin bacteria to soil significantly reduced chytridiomycosis infection rate in salamanders. One randomized, replicated, controlled study in Switzerland found that treatment with antimicrobial skin peptides before or after infection with chytridiomycosis did not increase toad survival. Assessment: unlikely to be beneficial (effectiveness 29%; certainty 50%; harms 10%).

Use antifungal treatment to reduce infection

Twelve of 16 studies, including four randomized, replicated, controlled studies, in Europe, Australia, Tasmania, Japan and the USA found that antifungal treatment cured or increased survival of amphibians with chytridiomycosis. Four studies found that treatments did not cure chytridiomycosis, but did reduce infection levels or had mixed results. Six of the eight studies testing treatment with itraconazole found that it was effective at curing chytridiomycosis. One found that it reduced infection levels and one found mixed effects. Six studies found that specific fungicides caused death or other negative side effects in amphibians. Assessment: trade-offs between benefits and harms (effectiveness 71%; certainty 70%; harms 50%).

Use antibacterial treatment to reduce infection

Two studies, including one randomized, replicated, controlled study, in New Zealand and Australia found that treatment with chloramphenicol antibiotic, with other interventions in some cases, cured frogs of chytridiomycosis. One replicated, controlled study found that treatment with trimethoprim-sulfadiazine increased survival time but did not cure infected frogs. Assessment: unlikely to be beneficial (effectiveness 38%; certainty 45%; harms 10%).

Use temperature treatment to reduce infection

Four of five studies, including four replicated, controlled studies, in Australia, Switzerland and the USA found that increasing enclosure or water temperature to 30–37°C for over 16 hours cured amphibians of chytridiomycosis. One found that treatment did not cure frogs. Assessment: likely to be beneficial (effectiveness 60%; certainty 70%; harms 10%).

Treating amphibians in the wild or pre-release

One before-and-after study in Mallorca found that treating wild toads with fungicide and drying out the pond reduced infection levels but did not eradicate chytridiomycosis. Assessment: unknown effectiveness – limited evidence (effectiveness 27%; certainty 30%; harms 0%).

Key messages - Reduce parasitism and disease – ranaviruses

Sterilize equipment to prevent ranaviruses

We captured no evidence for the effects of sterilizing equipment to prevent ranavirus on the spread of disease between amphibian individuals or populations.

9. Threat: Pollution

Based on the collated evidence, what is the current assessment of the effectiveness of interventions for pollution?	
Beneficial	
Likely to be beneficial	
Trade-off between benefit and harms	• Add limestone to water bodies to reduce acidification
Unknown effectiveness (limited evidence)	• Plant riparian buffer strips • Create walls or barriers to exclude pollutants • Reduce pesticide, herbicide or fertilizer use
Unlikely to be beneficial	
Likely to be ineffective or harmful	

No evidence (or assessment)	• Prevent pollution from agricultural lands or sewage treatment facilities entering watercourses • Augment ponds with ground water to reduce acidification

Key messages - Agricultural pollution

Plant riparian buffer strips

One replicated, controlled study in the USA found that planting buffer strips along streams did not increase amphibian abundance or numbers of species. Assessment: unknown effectiveness – limited evidence (effectiveness 0%; certainty 30%; harms 0%).

Prevent pollution from agricultural lands or sewage treatment facilities entering watercourses

We captured no evidence for the effects of preventing pollution from agricultural lands or sewage treatment facilities entering watercourses on amphibian populations.

Create walls or barriers to exclude pollutants

One controlled study in Mexico found that installing filters across canals to improve water quality and exclude fish increased weight gain in axolotls. Assessment: unknown effectiveness – limited evidence (effectiveness 35%; certainty 29%; harms 0%).

Reduce pesticide, herbicide or fertilizer use

One study in Taiwan found that halting pesticide use, along with habitat management, increased a population of frogs. Assessment: unknown effectiveness – limited evidence (effectiveness 71%; certainty 26%; harms 0%).

Key messages - Industrial pollution

Add limestone to water bodies to reduce acidification

Five before-and-after studies, including one controlled, replicated study, in the Netherlands and UK found that adding limestone to ponds resulted in establishment of one of three translocated amphibian populations, a temporary increase in breeding and metamorphosis by natterjack toads and increased egg and larval survival of frogs. One replicated, site comparison study in the UK found that habitat management that included adding limestone to ponds increased natterjack toad populations. However, two before-and-after studies, including one controlled study, in the UK found that adding limestone to ponds resulted in increased numbers of abnormal eggs, high tadpole mortality and pond abandonment. Assessment: trade-offs between benefits and harms (effectiveness 47%; certainty 50%; harms 50%).

Augment ponds with ground water to reduce acidification

We captured no evidence for the effects of augmenting ponds with ground water to reduce acidification effects on amphibian populations.

10. Threat: Climate change and severe weather

Based on the collated evidence, what is the current assessment of the effectiveness of interventions for climate change and severe weather?	
Beneficial	• Deepen ponds to prevent desiccation
Likely to be beneficial	
Trade-off between benefit and harms	
Unknown effectiveness (limited evidence)	• Use irrigation systems for amphibian sites
Unlikely to be beneficial	
Likely to be ineffective or harmful	

No evidence (or assessment)	• Provide shelter habitat • Artificially shade ponds to prevent desiccation • Protect habitat along elevational gradients

Key messages

Use irrigation systems for amphibian sites

One study investigating the effect of applying water to an amphibian site is discussed in 'Threat: Energy production and mining'.

Maintain ephemeral ponds

Studies investigating the effects of regulating water levels or deepening ponds are discussed in 'Threat: Natural system modifications – Regulate water levels' and 'Habitat restoration and creation – Deepen, de-silt or re-profile ponds'.

Deepen ponds to prevent desiccation

Studies investigating the effects of deepening ponds are discussed in 'Habitat restoration and creation – Deepen, de-silt or re-profile ponds'. Assessment for 'Deepen, de-silt or re-profie ponds': beneficial (effectiveness 71%; certainty 65%; harms 0%).

Provide shelter habitat

We captured no evidence for the effects of providing shelter habitat on amphibian populations.

Artificially shade ponds to prevent desiccation

We captured no evidence for the effects of artificially shading ponds to prevent desiccation on amphibian populations.

Create microclimate and microhabitat refuges

Studies investigating the effects of creating refuges are discussed in 'Habitat restoration and creation' and 'Biological resource use – Leave coarse woody debris in forests'.

Protect habitat along elevational gradients

We captured no evidence for the effects of protecting habitat along elevational gradients on amphibian populations.

11. Habitat protection

Based on the collated evidence, what is the current assessment of the effectiveness of interventions for habitat protection?	
Beneficial	
Likely to be beneficial	
Trade-off between benefit and harms	• Retain buffer zones around core habitat
Unknown effectiveness (limited evidence)	• Protect habitats for amphibians • Retain connectivity between habitat patches
Unlikely to be beneficial	
Likely to be ineffective or harmful	

Key messages

Protect habitats for amphibians

One replicated, site comparison study in the UK found that statutory level habitat protection helped protect natterjack toad populations. One before-and-after study in the UK found that protecting a pond during development had mixed effects on populations of amphibians. Assessment: unknown effectiveness – limited evidence (effectiveness 51%; certainty 31%; harms 9%).

Retain connectivity between habitat patches
One before-and-after study in Australia found that retaining native vegetation corridors maintained populations of frogs over 20 years. Assessment: unknown effectiveness – limited evidence (effectiveness 60%; certainty 31%; harms 0%).

Retain buffer zones around core habitat
Two studies, including one replicated, controlled study, in Australia and the USA found that retaining unmown buffers around ponds increased numbers of frog species, but had mixed effects on tadpole mass and survival. One replicated, site comparison study in the USA found that retaining buffers along ridge tops within harvested forest increased salamander abundance, body condition and genetic diversity. However, one replicated study in the USA found that 30 m buffer zones around wetlands were not sufficient to protect marbled salamanders. Assessment: trade-offs between benefits and harms (effectiveness 50%; certainty 50%; harms 25%).

12. Habitat restoration and creation

Based on the collated evidence, what is the current assessment of the effectiveness of interventions for habitat restoration and creation?	
Beneficial	• Replant vegetation • Create ponds (amphibians in general) • Create ponds: Frogs • Create ponds: Natterjack toads • Create ponds: Salamanders (including newts) • Create wetlands • Restore wetlands • Deepen, de-silt or re-profile ponds
Likely to be beneficial	• Clear vegetation • Create refuges • Create artificial hibernacula or aestivation sites • Restore habitat connectivity • Create ponds: Toads • Create ponds: Green toads • Create ponds: Great crested newts • Restore ponds
Trade-off between benefit and harms	
Unknown effectiveness (limited evidence)	• Change mowing regime • Remove tree canopy to reduce pond shading
Unlikely to be beneficial	
Likely to be ineffective or harmful	

No evidence (or assessment)	• Create habitat connectivity • Add nutrients to new ponds as larvae food source • Create refuge areas in aquatic habitats • Add woody debris to ponds • Add specific plants to aquatic habitats

Key messages - Terrestrial habitat

Replant vegetation
Four studies, including one replicated study, in Australia, Spain and the USA found that amphibians colonized replanted forest, reseeded grassland and seeded and transplanted upland habitat. Three of four studies, including two replicated studies, in Australia, Canada, Spain and the USA found that areas planted with trees or grass had similar amphibian abundance or community composition to natural sites and one found similar or lower abundance compared to naturally regenerated forest. One found that wetlands within reseeded grasslands were used less than those in natural grasslands. One before-and-after study in Australia found that numbers of frog species increased following restoration that included planting shrubs and trees. Assessment: beneficial (effectiveness 70%; certainty 63%; harms 3%).
Clear vegetation
Seven studies, including four replicated studies, in Australia, Estonia and the UK found that vegetation clearance, along with other habitat management and in some cases release of amphibians, increased or maintained amphibian populations or increased numbers of frog species. However, great crested newt populations were only maintained for six years, but not in the longer term. Assessment: likely to be beneficial (effectiveness 60%; certainty 54%; harms 10%).
Change mowing regime
One before-and-after study in Australia found that restoration that included reduced mowing increased numbers of frog species. Assessment: unknown effectiveness – limited evidence (effectiveness 50%; certainty 30%; harms 0%).
Create refuges
Two replicated, controlled studies, one of which was randomized, in the USA and Indonesia found that adding coarse woody debris to forest floors had no effect on the number of amphibian species or overall abundance, but had mixed effects on abundance of individual species. One before-and-after study in Australia found that restoration that included reintroducing coarse woody debris to the forest floor increased frog species. Three studies, including two replicated studies, in New Zealand, the UK and USA found that artificial refugia were used by amphibians and, along with other interventions, maintained newt populations. Assessment: likely to be beneficial (effectiveness 45%; certainty 55%; harms 0%).
Create artificial hibernacula or aestivation sites
Two replicated studies in the UK found that artificial hibernacula were used by two of three amphibian species and along with other terrestrial habitat management maintained populations of great crested newts. Assessment: likely to be beneficial (effectiveness 50%; certainty 44%; harms 0%).
Restore habitat connectivity
One before-and-after study in Italy found that restoring habitat connectivity by raising a road on a viaduct significantly decreased amphibian deaths. Assessment: likely to be beneficial (effectiveness 75%; certainty 40%; harms 0%).
Create habitat connectivity
We captured no evidence for the effects of creating habitat connectivity on amphibian populations.

Key messages - Aquatic habitat
Create ponds
Sixty-five studies investigated the colonization of created ponds by amphibians. Fifty-five of 56 studies, including three reviews, in Australia, Canada, China, Europe and the USA found that amphibians used, reproduced or established breeding populations in some or all created ponds. One found that captive-bred frogs did not establish populations. Sixteen of the studies found that created ponds were colonized by up to 15 naturally colonizing species, up to 10 breeding species and some captive-bred amphibians. Five of nine of the studies found that numbers of amphibian species were similar or higher in created compared to natural ponds. Four found that species composition differed and abundance, reproductive success and growth differed depending on species. One found that numbers of species were similar or lower and one found that populations in created ponds were less stable. Fourteen studies

in Europe and the USA found that pond creation, along with other interventions, maintained or increased amphibian populations, or in one case increased numbers of species. One systematic review in the UK found that habitat management, which often included pond creation, did not result in self-sustaining great crested newt populations.
Assessment for amphibians in general: beneficial
(effectiveness 80%; certainty 80%; harms 0%).
Assessment for frogs: beneficial
(effectiveness 75%; certainty 70%; harms 0%).
Assessment for toads: likely to be beneficial
(effectiveness 70%; certainty 60%; harms 0%).
Assessment for natterjack toads: beneficial
(effectiveness 75%; certainty 70%; harms 10%).
Assessment for green toads: likely to be beneficial
(effectiveness 73%; certainty 59%; harms 0%).
Assessment for salamanders (incl. newts): beneficial
(effectiveness 70%; certainty 65%; harms 0%).
Assessment for great crested newts: likely to be beneficial
(effectiveness 60%; certainty 61%; harms 0%).

Add nutrients to new ponds as larvae food source

We captured no evidence for the effects of adding nutrients such as zooplankton to new ponds on amphibian populations.

Create wetlands

Fifteen studies, including one review and seven replicated studies, in Australia, Kenya and the USA, investigated the effectiveness of creating wetlands for amphibians. Six studies found that created wetlands had similar amphibian abundance, numbers of species or communities as natural wetlands or in one case adjacent forest. Two of those studies found that created wetlands had fewer amphibians, amphibian species and different communities compared to natural wetlands. One global review and two other studies combined created and restored wetlands and found that amphibian abundance and numbers of species were similar or higher compared to natural wetlands. Five of the studies found that up to 15 amphibian species used created wetlands. One study found that captive-bred frogs did not establish in a created wetland. Assessment: beneficial (effectiveness 75%; certainty 70%; harms 0%).

Restore ponds

Fifteen studies investigated the effectiveness of pond restoration for amphibians. Three studies, including one replicated, controlled, before-and-after study in Denmark, the UK and USA found that pond restoration did not increase or had mixed effects on population numbers and hatching success. One replicated, before-and-after study in the UK found that restoration increased pond use. One replicated study in Sweden found that only 10% of restored ponds were used for breeding. Three before-and-after studies, including one replicated, controlled study, in Denmark and Italy found that restored and created ponds were colonized by up to seven species. Eight of nine studies, including one systematic review, in Denmark, Estonia, Italy and the UK found that pond restoration, along with other habitat management, maintained or increased populations, increased numbers of amphibian species, pond occupancy or ponds with breeding success. One found that numbers of species did not increase and one found that great crested newt populations did not establish. Assessment: likely to be beneficial (effectiveness 60%; certainty 63%; harms 0%).

Restore wetlands

Seventeen studies, including one review and 11 replicated studies, in Canada, Taiwan and the USA, investigated the effectiveness of wetland restoration for amphibians. Seven of ten studies found that amphibian abundance, numbers of species and species composition were similar in restored and natural wetlands. Two found that abundance or numbers of species were lower and species composition different to natural wetlands. One found mixed results. One global review found that in 89% of cases, restored and created wetlands had similar or higher amphibian abundance or numbers of species to natural wetlands. Seven of nine studies found that wetland restoration increased numbers of amphibian species, with breeding populations establishing in some cases, and maintained or increased abundance of individual species. Three found that amphibian abundance or numbers of species did not increase with restoration. Three of the studies found that restored wetlands were colonized by up to eight amphibian species. Assessment: beneficial (effectiveness 80%; certainty 73%; harms 0%).

Deepen, de-silt or re-profile ponds

Four studies, including one replicated, controlled study, in France, Denmark and the UK found that pond deepening and enlarging or re-profiling resulted in establishment or increased populations of amphibians. Four before-and-after studies in Denmark and the UK found that pond deepening, along with other interventions, maintained newt or increased toad populations. Assessment: beneficial (effectiveness 71%; certainty 65%; harms 0%).

Create refuge areas in aquatic habitats

We captured no evidence for the effects of creating refuge areas in aquatic habitats on amphibian populations.

Add woody debris to ponds

We captured no evidence for the effects of adding woody debris to ponds on amphibian populations.

Remove specific aquatic plants

Studies investigating the effects of removing specific aquatic plants are discussed in 'Threat: Invasive alien and other problematic species – Control invasive plants'.

Add specific plants to aquatic habitats

We captured no evidence for the effects of adding specific plants, such as emergent vegetation, to aquatic habitats on amphibian populations.

Remove tree canopy to reduce pond shading

One before-and-after study in the USA found that canopy removal did not increase hatching success of spotted salamanders. One before-and-after study in Denmark found that following pond restoration that included canopy removal, translocated toads established breeding populations. Assessment: unknown effectiveness – limited evidence (effectiveness 30%; certainty 25%; harms 0%).

13. Species management

Strict protocols should be followed when carrying out these interventions to minimise potential spread of disease-causing agents such as chytrid fungi and Ranavirus.

Based on the collated evidence, what is the current assessment of the effectiveness of interventions for species management?	
Beneficial	
Likely to be beneficial	• Translocate amphibians (in general) • Translocate amphibians: Wood frogs • Translocate amphibians: Toads • Translocate amphibians: Natterjack toads • Translocate amphibians: Salamanders (including newts) • Translocate amphibians: Great crested newts • Release captive-bred individuals (amphibians in general) • Release captive-bred individuals: Frogs
Trade-off between benefit and harms	• Translocate amphibians: Frogs • Breed amphibians in captivity: Frogs • Breed amphibians in captivity: Toads • Breed amphibians in captivity: Mallorcan midwife toad • Breed amphibians in captivity: Harlequin toads (Atelopus sp.) • Breed amphibians in captivity: Salamanders (including newts)

	• Use hormone treatment to induce sperm and egg release • Use artificial fertilization in captive breeding • Release captive-bred individuals: Toads • Release captive-bred individuals: Mallorcan midwife toads • Head-start amphibians for release
Unknown effectiveness (limited evidence)	• Release captive-bred individuals: Salamanders (including newts)
Unlikely to be beneficial	• Freeze sperm or eggs for future use
Likely to be ineffective or harmful	• Release captive-bred individuals: Green and golden bell frogs

Key messages - Translocate amphibians

Translocate amphibians

Fifty-four studies investigated the effectiveness of translocating amphibians. Three global reviews found that 59% of amphibian translocations that could be assessed resulted in established breeding populations or substantial recruitment to the adult population. Twenty-four of 28 studies, including three reviews, in New Zealand, Europe and the USA found that translocating amphibian eggs, tadpoles, juveniles or adults established, or in one case maintained, breeding populations at 25–100% of sites. Four found that breeding populations went extinct within five years, or did not establish. Two studies, including one replicated study, in Denmark and the UK found that translocations, with habitat management in some cases, increased existing populations. One systematic review found that mitigation that included translocations did not result in self-sustaining great crested newt populations. An additional 20 studies, including one review, in Canada, Europe, New Zealand, South Africa and the USA measured aspects of survival or breeding success of translocated amphibians and found mixed results.
Assessment for amphibians in general: likely to be beneficial
(effectiveness 60%; certainty 60%; harms 19%).
Assessment for frogs: trade-offs between benefits and harms
(effectiveness 58%; certainty 65%; harms 20%).
Assessment for toads: likely to be beneficial
(effectiveness 60%; certainty 56%; harms 10%).
Assessment for natterjack toads: likely to be beneficial
(effectiveness 60%; certainty 56%; harms 10%).
Assessment for salamanders (including newts): likely to be beneficial
(effectiveness 70%; certainty 55%; harms 0%).
Assessment for great crested newts: likely to be beneficial
(effectiveness 50%; certainty 50%; harms 10%).

Key messages - Captive breeding, rearing and releases

Breed amphibians in captivity

Sixty-two studies investigated the success of breeding amphibians in captivity. Forty-four of 60 studies, including seven reviews, from across the world found that amphibians successfully produced eggs in captivity; six studies involved captive-bred females. Twelve found mixed results depending on species, captive population or housing conditions. One found that eggs were only produced by simulating a dry and wet season and three found limited or no breeding. Thirty-three of the studies found that captive-bred amphibians were raised successfully to tadpoles, metamorphs, juveniles or adults in captivity. Five found that survival of captive-bred amphibians was low.
Assessment for frogs: trade-offs between benefits and harms
(effectiveness 60%; certainty 68%; harms 30%).

Assessment for toads: trade-offs between benefits and harms (effectiveness 65%; certainty 60%; harms 25%).
Assessment for Mallorcan midwife toad: trade-offs between benefits and harms (effectiveness 69%; certainty 55%; harms 40%).
Assessment for harlequin toads Atelopus sp.: trade-offs between benefits and harms (effectiveness 44%; certainty 50%; harms 28%).
Assessment for salamanders (incl. newts): trade-offs between benefits and harms (effectiveness 60%; certainty 50%; harms 25%).

Use hormone treatment to induce sperm and egg release

One review and nine of 10 replicated studies, including two randomized, controlled studies, in Austria, Australia, China, Latvia, Russia and the USA found that hormone treatment of male amphibians stimulated or increased sperm production, or resulted in successful breeding. One found that hormone treatment of males and females did not result in breeding. One review and nine of 14 replicated studies, including six randomized and/or controlled studies, in Australia, Canada, China, Ecuador, Latvia and the USA found that hormone treatment of female amphibians had mixed results, with 30–71% of females producing viable eggs following treatment, or with egg production depending on the combination, amount or number of doses of hormones. Three found that hormone treatment stimulated egg production or successful breeding. Two found that treatment did not stimulate or increase egg production. Assessment: trade-offs between benefits and harms (effectiveness 50%; certainty 65%; harms 30%).

Use artificial fertilization in captive breeding

Three replicated studies, including two randomized studies, in Australia and the USA found that the success of artificial fertilization depended on the type and number of doses of hormones used to stimulate egg production. One replicated study in Australia found that 55% of eggs were fertilized artificially, but soon died. Assessment: trade-offs between benefits and harms (effectiveness 40%; certainty 40%; harms 20%).

Freeze sperm or eggs for future use

Ten replicated studies, including three controlled studies, in Austria, Australia, Russia, the UK and USA found that following freezing, viability of amphibian sperm, and in one case eggs, depended on species, cryoprotectant used, storage temperature or method and freezing or thawing rate. One found that sperm could be frozen for up to 58 weeks. Assessment: unlikely to be beneficial (effectiveness 35%; certainty 50%; harms 10%).

Release captive-bred individuals

Twenty-six studies investigated the success of releasing captive-bred amphibians. Ten of 15 studies, including three reviews, in Australia, Europe, Hong Kong and the USA found that captive-bred amphibians released as larvae, juveniles, metamorphs or adults established populations at 38–100% of sites. Five found that leopard frogs, Houston toads and green and golden bell frogs did not establish breeding populations, or only established following one of four release programmes. One review and one before-and-after study in Spain found that 41–79% of release programmes of captive-bred, captive-reared and translocated frogs combined established breeding populations. An additional 10 studies, including one review, in Australia, Italy, Puerto Rico, the UK and USA measured aspects of survival or breeding success of released captive-bred amphibians and found mixed results.
Assessment for amphibians in general: likely to be beneficial (effectiveness 55%; certainty 50%; harms 10%).
Assessment for frogs: likely to be beneficial (effectiveness 60%; certainty 60%; harms 15%).
Assessment for green and golden bell frogs: likely to be ineffective or harmful (effectiveness 20%; certainty 50%; harms 20%).
Assessment for toads: trade-offs between benefits and harms (effectiveness 40%; certainty 50%; harms 20%).
Assessment for Mallorcan midwife toad: trade-offs between benefits and harms (effectiveness 68%; certainty 58%; harms 20%).
Assessment for salamanders (incl. newts): unknown effectiveness – limited evidence

(effectiveness 70%; certainty 30%; harms 0%).

Head-start amphibians for release

Twenty-two studies head-started amphibians from eggs and monitored them after release. A global review and six of 10 studies in Europe and the USA found that released head-started tadpoles, metamorphs or juveniles established breeding populations or increased existing populations. Two found mixed results with breeding populations established in 71% of studies reviewed or at 50% of sites. Two found that head-started metamorphs or adults did not establish a breeding population or prevent a population decline. An additional 10 studies in Australia, Canada, Europe and the USA measured aspects of survival or breeding success of released head-started amphibians and found mixed results. Three studies in the USA only provided results for head-starting in captivity. Two of those found that eggs could be reared to tadpoles, but only one successfully reared adults. Assessment: trade-offs between benefits and harms (effectiveness 60%; certainty 60%; harms 25%).

14. Education and awareness raising

Based on the collated evidence, what is the current assessment of the effectiveness of interventions for education and awareness raising?	
Beneficial	
Likely to be beneficial	• Raise awareness amongst the general public through campaigns and public information • Provide education programmes about amphibians • Engage volunteers to collect amphibian data (citizen science)
Trade-off between benefit and harms	
Unknown effectiveness (limited evidence)	
Unlikely to be beneficial	
Likely to be ineffective or harmful	

Key messages

Raise awareness amongst the general public through campaigns and public information

Two studies, including one replicated, before-and-after study, in Estonia and the UK found that raising public awareness, along with other interventions, increased amphibian breeding habitat and numbers of toads. One before-and-after study in Mexico found that raising awareness in tourists increased their knowledge of axolotls. However, one study in Taiwan found that holding press conferences had no effect on a frog conservation project. Assessment: likely to be beneficial (effectiveness 60%; certainty 51%; harms 0%).

Provide education programmes about amphibians

One study in Taiwan found that education programmes about wetlands and amphibians, along with other interventions, doubled a population of Taipei frogs. Four studies, including one replicated study, in Germany, Mexico, Slovenia, Zimbabwe and the USA found that education programmes increased the amphibian knowledge of students. Assessment: likely to be beneficial (effectiveness 58%; certainty 55%; harms 0%).

Engage volunteers to collect amphibian data (citizen science)

Five studies in Canada, the UK and USA found that amphibian data collection projects engaged up to 10,506 volunteers and were active in 16–17 states in the USA. Five studies in the UK and USA found that volunteers surveyed up to 7,872 sites, swabbed almost 6,000 amphibians and submitted thousands of amphibian records. Assessment: likely to be beneficial (effectiveness 66%; certainty 60%; harms 0%).