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Contributed Paper

Developments in amphibian captive breeding and reintroduction programs

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Abstract: *Captive breeding and reintroduction remain high profile but controversial conservation interventions. It is important to understand how such programs develop and respond to strategic conservation initiatives. We analyzed the contribution to conservation made by amphibian captive breeding and reintroduction since the launch of the International Union for Conservation of Nature (IUCN) Amphibian Conservation Action Plan (ACAP) in 2007. We assembled data on amphibian captive breeding and reintroduction from a variety of sources including the Amphibian Ark database and the IUCN Red List. We also carried out systematic searches of Web of Science, JSTOR, and Google Scholar for relevant literature. Relative to data collected from 1966 to 2006, the number of species involved in captive breeding and reintroduction projects increased by 57% in the 7 years since release of the ACAP. However, there have been relatively few new reintroductions over this period; most programs have focused on securing captive-assurance populations (i.e., species taken into captivity as a precaution against extinctions in the wild) and conservation-related research. There has been a shift to a broader representation of frogs, salamanders, and caecilians within programs and an increasing emphasis on threatened species. There has been a relative increase of species in programs from Central and South America and the Caribbean, where amphibian biodiversity is high. About half of the programs involve zoos and aquaria with a similar proportion represented in specialist facilities run by governmental or nongovernmental agencies. Despite successful reintroduction often being regarded as the ultimate milestone for such programs, the irreversibility of many current threats to amphibians may make this an impractical goal. Instead, research on captive assurance populations may be needed to develop imaginative solutions to enable amphibians to survive alongside current, emerging, and future threats.*

Keywords: amphibian decline, captive assurance, ex situ conservation, frog, translocation, toad

Avances en la Reproducción de Anfibios en Cautiverio y en los Programas de Reintroducción

Resumen: *La reproducción en cautiverio y la reintroducción permanecen como intervenciones de conservación de alto perfil pero controversiales. Es importante entender cómo dichos programas se desarrollan y responden a las iniciativas estratégicas de conservación. Analizamos la contribución para la conservación que han hecho la reproducción en cautiverio de anfibios y su reintroducción desde la creación del Plan de Acción de Conservación de Anfibios (PACA) de la Unión Internacional para la Conservación de la Naturaleza (UICN) en 2007. Ensamblamos datos sobre la reproducción en cautiverio de anfibios y su reintroducción a partir de una variedad de fuentes, que incluyeron la base de datos Arca de Anfibios y la Lista Roja de la UICN. También realizamos búsquedas sistemáticas de bibliografía relevante en Web of Science, JSTOR y Google Scholar. En relación con los datos colectados desde 1966 y hasta 2006, el número de especies involucrado en los proyectos de reproducción en cautiverio y reintroducción incrementó en un 57% en los siete años desde el lanzamiento del PACA. Sin embargo, ha habido relativamente pocas reintroducciones nuevas en este periodo; la mayoría de los programas se han enfocado en asegurar poblaciones de garantía en cautiverio (es decir, especies puestas en cautiverio como precaución contra las extinciones en libertad) y en investigaciones relacionadas con las conservación. Ha habido un cambio hacia una mayor representación de ranas, salamandras y cecilias*

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dentro de los programas y un énfasis creciente sobre las especies amenazadas. Ha habido un incremento relativo en las especies dentro de los programas de América Central, América del Sur y el Caribe, en donde la diversidad de anfibios es alta. Aproximadamente la mitad de los programas involucra a zoológicos y acuarios con una proporción similar representada en las instalaciones especializadas a cargo de agencias gubernamentales y no gubernamentales. A pesar de que se tiene a la reintroducción exitosa como el hito para dichos programas, lo irreversible de muchas de las amenazas actuales para los anfibios puede hacer de esta una meta poco práctica. En su lugar, es probable que se requiera de investigación sobre las poblaciones de garantía en cautiverio para desarrollar soluciones imaginativas que permitan que los anfibios sobrevivan a las amenazas actuales, las emergentes y las futuras.

Palabras Clave: conservación *ex situ*, declinación de anfibios, garantía en cautiverio, rana, reubicación, sapo

Introduction

Despite ongoing debates about their effectiveness, risks, and cost, captive breeding and reintroduction remain high-profile tools in species conservation management (e.g., Fischer & Lindenmayer 2000; Jule et al. 2008; Ewen et al. 2012). The range of approaches is diverse, embracing sophisticated captive metapopulation management, captive assurance populations, short-term head starting of stock temporarily removed from the wild, and wild–wild translocations with no captive component. Although there are numerous case studies concerning the reintroduction of captive-bred animals (e.g., Soorae 2013), there remain concerns about the fitness of reintroduced animals, inbreeding depression, adaptation to captivity, and disease risks (e.g., Kraaijeveld-Smit et al. 2006; Walker et al. 2008; Christie et al. 2012). The development of new guidelines for reintroduction (IUCN/SSC 2013) has refocused attention on rigorous planning, risk assessment, and evaluation of projects.

Although mammals and birds are prominent within reintroduction case studies (e.g., Wilson & Stanley Price 1994; Fischer & Lindenmayer 2000; Ewen et al. 2012), long-lived, large-bodied species with relatively low fecundity and complex social systems may not necessarily be ideal or cost-effective candidates for ex situ conservation programs. In contrast, many fishes, amphibians, reptiles, and invertebrates possess life-history attributes that may make them more favorable candidates for such programmes (Bloxam & Tonge 1995; Jones 2002; Griffiths & Pavajeau 2008). Nevertheless, not all amphibians may be suitable for such programs (Tapley et al. 2015). Improved understanding of natural history may therefore contribute to improved success rates in amphibian and reptile translocations (Germano & Bishop 2009).

Concerns about the global scale of amphibian declines were initially voiced at the First World Congress of Herpetology in 1989 and precipitated a range of initiatives to address them (Stuart et al. 2004; Bishop et al. 2012; Stuart 2012). The IUCN Species Survival Commission Declining Amphibian Populations Task Force (DAPTF) was created in 2001 and was followed by the Global Amphibian Assessment, which assessed all known species based on the IUCN Red List Criteria (Stuart et al. 2004). The latest reassessment in 2008 showed that 42% of amphibian species were in decline and 32% were threatened with extinction (IUCN 2013). Overall, this suggests that amphibians are more at risk than mammals and birds, and current amphibian extinctions may be happening at over 200 times the expected background rate of amphibian loss (McCallum 2007). With the initial assessment complete in 2004, the Amphibian Conservation Action Plan (ACAP) provided a blueprint for action (Gascon et al. 2007). Two out of 11 themes within the ACAP focus on captive breeding and reintroduction. Indeed, the plan states that "the only hope in the short-term for populations and species at immediate risk of extinction is immediate rescue for the establishment and management of captive survival-assurance colonies" (Mendelson et al. 2007).

The emergence of infectious disease that can result in rapid extinctions in the wild (e.g., Stuart et al. 2004; Mendelson et al. 2006; Conde et al. 2011) has led to a resurgence of the zoos-as-arks concept, whereby species at risk of disease are rescued and placed in captive assurance populations until such time that the threats in the wild can be mitigated. Amphibian Ark (AArk) was formed in 2006 with the task of implementing the ex situ components of the ACAP. So far, AArk has evaluated the conservation needs of 46% of the world's amphibian species through 26 workshops in various countries (Amphibian Ark 2014).

Despite the considerable effort that has been devoted to strategic planning for amphibian conservation, there remains a mismatch between the scale of the problem and the response (Gascon et al. 2012). In a review of programs in place prior to the ACAP, Griffiths and Pavajeau (2008) identified 110 species in captive breeding and reintroduction programs, but most of these programs were in industrialized countries with relatively low amphibian diversity. At that time, 13 out of 21 species that had been reintroduced to the wild had established self-sustaining populations. However, the threats faced by amphibians are complex and often synergistic, which means that mitigating threats in the wild remains a major challenge for such programs (Scheele et al. 2014).

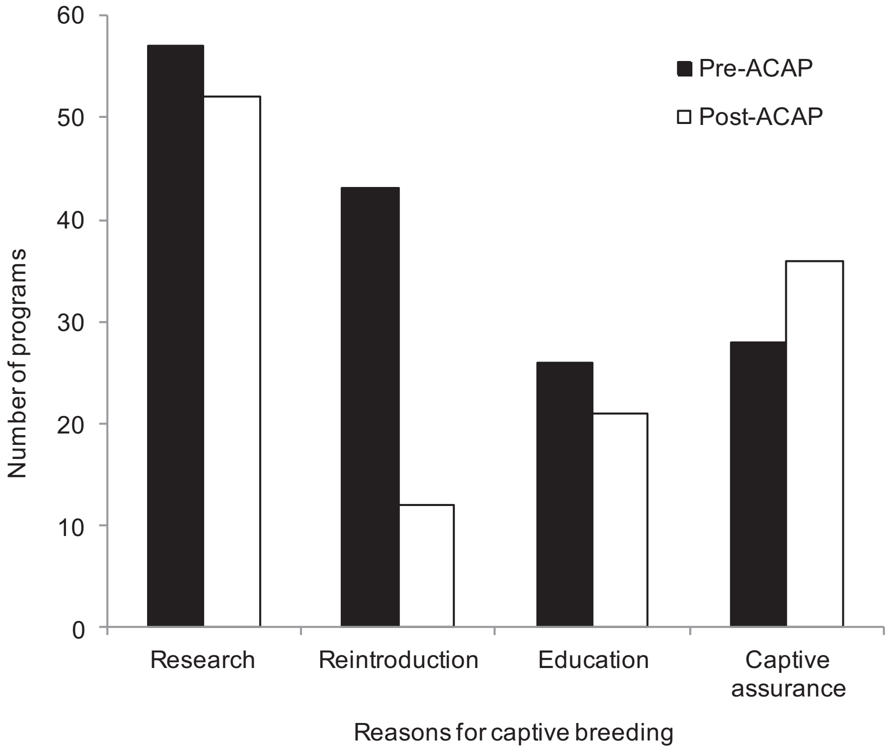

Figure 1. Reasons for captive breeding programs pre- and post-Amphibian Conservation Action Plan (ACAP). Two programs for which the project purpose was unknown are excluded.

Equally, the species most in need of ex situ intervention may be tropical species with poorly understood requirements (Tapley et al. 2015).

We updated the earlier analyses by Griffiths and Pavajeau (2008) to identify how captive breeding and reintroduction programs have progressed since the ACAP in 2007. In particular, we examined how programs have changed in terms of numbers and geographical distribution of species and the focus on threatened species. This review ties in with the recent relaunch of the ACAP, which provides updated strategies for captive breeding and reintroduction (Wren et al. 2015).

Methods

Sources of Data

Following the methodology of Griffiths and Pavajeau (2008), we assembled data on captive breeding and reintroduction from a variety of sources. The main sources were the Amphibian Ark database (Amphibian Ark 2013) and the IUCN Red List (IUCN 2013), within which the Global Amphibian Assessment (GAA) data reside. In addition, we searched the following online databases for information on captive breeding and reintroduction programs: AmphibiaWeb (http://amphibiaweb.org/), World Zoo and Aquarium Conservation Database (WZACD) (http://www.conservation-db.net/), Edge Amphibians (http://www.edgeofexistence.org/amphibians/), Amphibian Specialist Group (http://www.amphibians.org/publications/), United States Fish and Wildlife Service (http://ecos.fws.gov), and individual zoo or institution websites.

We also searched Web of Science, JSTOR, and Google Scholar for relevant literature using the following search terms: *introduction*, *translocation*, *repatriation*, *reintroduction*, or *captive breeding* in combinations with the terms *amphibian*, *frog*, *salamander*, *newt*, *toad*, or *caecilian*. We searched Froglog and the Amphibian Ark Newsletter using the search terms *captive breeding*, *reintroduction*, and *translocation*. We located and searched conference proceedings via the World Congress of Herpetology (WCH) and the Societas Europaea Herpetologica (SEH) websites and via congresses and conferences attended in person (such as the Herpetofauna Workers Meetings in the United Kingdom and the 7th World Congress of Herpetology in Canada).

We cross-checked the results of the various searches and if necessary contacted the relevant personnel involved by email for additional or missing information. All searches were completed by 31 December 2013, and we used a cut-off date of 31 January 2014 for receipt of supplementary information we requested through direct enquiry.

Data Analyses

We excluded programs where captive breeding or translocation was carried out for commercial or medical purposes or to resolve human–wildlife conflict that did not have conservation as an explicit goal (Germano et al. 2015). We also excluded programs that were not supported by a documented recovery plan or lacked evidence of support from a conservation body.

In the Griffiths and Pavajeau (2008) study, all records of amphibian captive breeding were utilized from 1966 up to and including programs started in 2006. We cross-referenced all the programs obtained from the new searches with those documented by Griffiths and Pavajeau (2008) to ensure no duplicate data were used. We identified 26 pre-ACAP species programs that were not included in the original Griffiths and Pavajeau (2008) study and added these to the original data. It is likely that these additional species programs were not widely publicized or in peer-reviewed journals and would have therefore been missed in the initial data search by Griffiths and Pavajeau (2008). We classified all new programs that were identified from the searches and started since 2007 as post-ACAP.

Following Griffiths and Pavajeau (2008), we classified programs into 3 groups: captive breeding, captive breeding and reintroduction, and relocations. Captive breeding (CB) species were kept solely for captive breeding and were not associated with immediate plans for reintroduction or release. These species were in programs conducting research into species biology to inform in situ conservation, captive assurance colonies, and zoo exhibits for education. Captive breeding and reintroduction (CB&R) species were captive bred for the purposes of reintroduction. The reintroductions may already have taken place or were planned for the future. Relocation species (R) were species in wild-to-wild translocation programs that may have included head-starting with a captive component. Reasons for captive breeding, threats, IUCN Red List status, and the geographic region of the species and captive program were recorded for each species. The categorized list of species is in Supporting Information.

Following Griffiths and Pavajeau (2008), we classified those species released into the wild based on the reintroduction success: high (evidence of self-sustaining populations breeding over several generations); partial (evidence of successful breeding); low (evidence of released animals surviving); unsuccessful (no evidence of survival in the wild); early stage (insufficient time elapsed to determine whether the program at least fits the low-success category, or the reintroduction was ongoing); or unknown (unable to trace any data on the project).

Results

Program Types

We identified 213 species—approximately 3% of all amphibian species—as having been involved in captive breeding and reintroduction programs related to conservation up to the end of 2013. Including the 26 species programs started before the ACAP but not included in the previous analysis by Griffiths and Pavajeau (2008) raises the pre-ACAP total to 136. Seventy-seven species programs were initiated since the 2007 publication of the ACAP (Supporting Information). Compared with earlier data from 1966–2006, this represents an increase of 57% over the past 7 years. Prior to the ACAP, the distribution of species among the 3 programme types was CB 54%, CB&R 31%, and R 15%. Post-ACAP the percentage of CB programs increased relative to those programs involving releases: CB 83%, CB&R 16%, and R 1%. With relatively fewer programs progressing through to reintroduction in later years, the change in the distribution of species among program types was significant ($\chi^2 = 18.4$, df $= 2$, $p = <0.001$). With a decrease in reintroductions and a relative increase in captive assurance programs post-ACAP, reasons for captive breeding also changed over time ($\chi^2 = 15.5$, df $= 3$, $p = <0.001$) (Fig. 1). However, research remained the most frequent reason for captive breeding, and a relatively low number of programs were devoted to conservation education.

Since the ACAP, 35 (45.5%) species programs were contained in zoos, 35 (45.5%) in specialist captive breeding facilities run by the government or nongovernmental organizations, and 6 (8%) in both types of organizations. For 1 (1%) program, the type of organization could not be determined. Forty-nine (64%) of the species programs had links to in situ conservation initiatives such as, research, public awareness, and public education.

Frogs, Salamanders, and Caecilians

Although anurans outnumbered other amphibians in captive breeding programs (pre-ACAP, $n = 108$; post-ACAP, $n = 67$), prior to the ACAP salamanders comprised about 21% of species in the programs—a disproportionately large number considering that salamanders comprise only 9% of all amphibian species (AmphibiaWeb 2015). The representation of salamanders in programs post-ACAP fell to 10%, which is now in line with their representation within the class Amphibia (pre-ACAP, $n = 28$; post-ACAP, $n = 8$). We found 2 species of caecilians in captive breeding programs, whereas prior to the ACAP there were none. Consequently, the representation of Anura, Caudata, and Gymnophiona in captive programs reflected their representation within the class Amphibia as a whole with no bias toward any one order ($\chi^2 = 0.16$, df $= 2$, $p > 0.05$). The elimination of this bias means the changes in representation of the 3 amphibian orders pre-and post-ACAP were significant ($\chi^2 = 6.90$, df $= 2$, $p < 0.05$).

Geographical Regions

We identified a significant change in the geographical spread of amphibian species involved in captive breeding and reintroduction programs ($\chi^2 = 35.3$, df

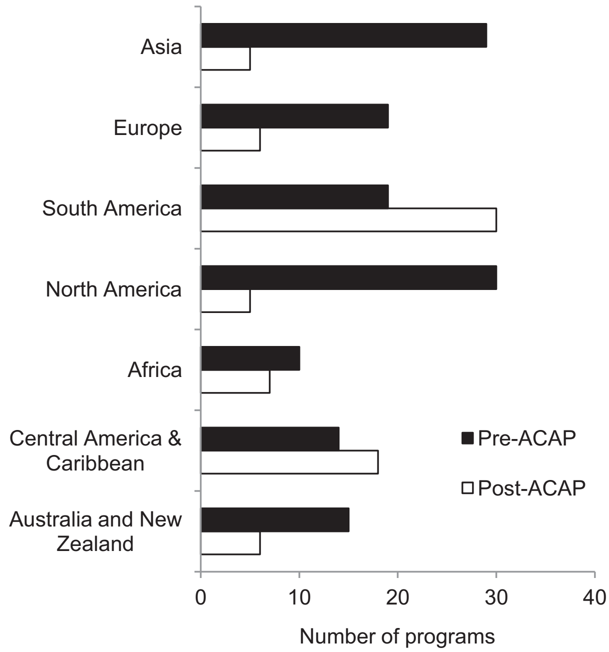

Figure 2. Geographical distribution of species involved in captive breeding and reintroduction programmes pre- and post-Amphibian Conservation Action Plan (ACAP). The data are for species that have conservation programs based in their native country even if they have ex situ components with partners in other countries.

= 6, p = <0.001; Fig. 2). The most noticeable change was an increase in species from South America, which comprised almost 40% of all the programs identified since the ACAP. Pre-ACAP 14% of programs were from South America. Similarly, the Caribbean and Central America showed increases; each comprised 11% of the total post-ACAP species relative to 2% and 8% pre-ACAP. In contrast, species programs shifted away from northern temperate countries. For example, North American species, which pre-ACAP accounted for 22% of programs, accounted for 5% of the programs post-ACAP. Despite the large increase in programs in South America, their focus did not change significantly. Pre-ACAP all programs were CB only, and post-ACAP 90% of species fell into this category. The majority of ex situ programs were in-country; 13 of the 77 species had their main captive breeding program outside the range country.

Threats

The major threat to amphibians in captive breeding programs continued to be habitat loss affecting wild populations (Fig. 3). The relative importance of trade, climate change, human use, and invasive species appeared to be lower for species in post-ACAP programs than for those in pre-ACAP programs ($\chi^2 = 24.7$, df = 5, $p < 0.001$) (Fig. 3). Consequently, after habitat loss, disease became the main threat to wild populations of species in captive breeding programs.

The relative number of critically endangered species in captive breeding and reintroduction programs rose from 18% pre-ACAP to 38% post-ACAP. Likewise, least-concern species declined from 36% to 16% ($\chi^2 = 33.2$, df = 5, $p < 0.01$) (Fig. 4). Consequently, the emphasis on threatened species within captive breeding and conservation programs increased. Post-ACAP, 56 threatened species were part of captive breeding and reintroduction programs, representing about 2.9% of all threatened amphibian species.

Progress with Reintroductions

Since the ACAP was published, 5 species listed as CB&R and earmarked for future release have been released: axolotl (*Ambystoma mexicanum*), Kihansi Spray Toad (*Nectophrynoides asperginis*), including experimental releases for Ozark hellbender (*Cryptobranchus alleganiensis bishopi*), Mountain Chicken Frog (*Leptodactylus fallax*), and Spotted tree frog (*Litoria spenceri*).

Reintroductions of 9 species that were previously classified as unsuccessful, unknown, or early stage showed some degree of success (Supporting Information). Eight species not considered by Griffiths and Pavajeau (2008) or documented post-ACAP were in the low- or partial-success categories. Of the 21 species previously in the low-, partial- or high-success categories (Griffiths & Pavajeau 2008), 16 stayed at the same level of success, and the fire-bellied toad (*Bombina bombina*) progressed from the partial- to high-success category. However, 2 species previously classified in the high-success category—Maud Island frog (*Leiopelma pakeka*) and Hamilton's frog (*L. hamiltoni*)—were downlisted to the partial-success category as a result of uncertainty over whether sustainable populations have been established (Bishop et al. 2013). Likewise, 2 species previously in the partial-success category—the Ramsey Canyon leopard frog (*Lithobates subaquavocalis*) and the spadefoot toad (*Pelobates fuscus*)—moved to the unknown category because we were unable to trace any further information relating to the status of the reintroductions (Supporting Information).

Discussion

Since the publication of the ACAP in 2007, 77 species have been incorporated into amphibian captive breeding and reintroduction programs for conservation. Relative to the number of programs carried out over the previous 4 decades, this represents a 57% increase in programs in less than a decade. With over 30 of the 77 programs comprising rescues to establish captive assurance

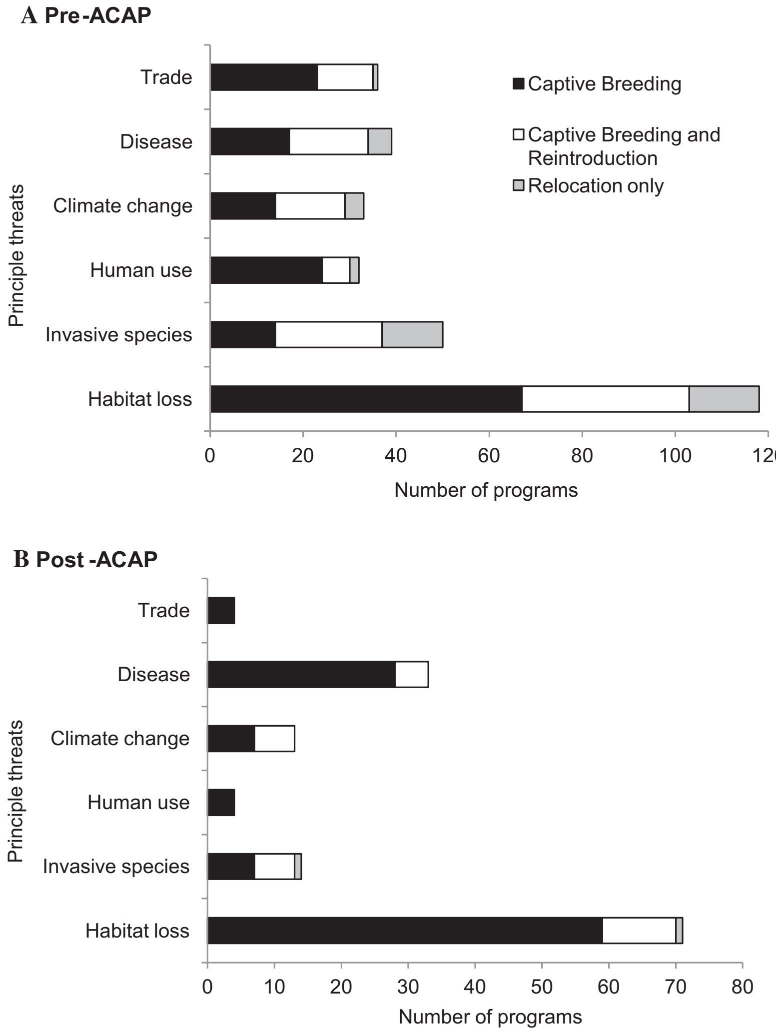

Figure 3. Principle threats to amphibian species in captive breeding (no reintroduction planned), captive breeding and reintroduction, and reintroduction only programs (A) pre-Amphibian Conservation Action Plan (ACAP) and (B) post-ACAP.

populations and a 20% increase in critically endangered species, our results suggest that the ex situ response to the ACAP has been substantive. However, has the response been effective?

Reasons for Captive Breeding

Although the reintroduction of animals is frequently promoted as the primary reason for captive breeding (Wilson & Stanley Price 1994; Balmford et al. 1996), the relative number of species programs using reintroduction has actually fallen from 41% to 16% post-ACAP. This may be partly attributed to the apparent rise in captive assurance programs, which comprise 31% of captive breeding programs post-ACAP (Amphibian Ark 2013). Such programs are usually carried out when populations of a species would otherwise be presumed to be lost as a result of threats that cannot currently be mitigated. With ongoing threats—such as infectious disease and climate change—present in the wild, this raises the question of whether such species can ever be successfully reintroduced. Equally, a shortage of suitable reintroduction sites is a common issue for threatened species, and the potential for habitat creation or enhancement either within or outside a species' range is often limited. In such cases, reintroductions may rely on imaginative solutions that combine reducing exposure to threats with increasing resistance to threats, rather than wholesale threat neutralization (Scheele et al. 2014). Such solutions may include, for example, the development of disease-resistant frogs or the use of antifungal peptides produced by skin bacteria to mitigate the impact of disease (Harris et al. 2006; Cashins et al. 2013; Gewin 2008). The increasing emphasis on opportunities for research by zoos both in situ and ex situ (Browne et al. 2011) is reflected by the fact that conservation research—rather than reintroduction or public education—remains the main reason for the establishment of captive breeding programs.

IUCN Red List Status

A comparison of pre- and post-ACAP data showed a significant increase in threatened species within conservation breeding programs, including a 20% increase in critically

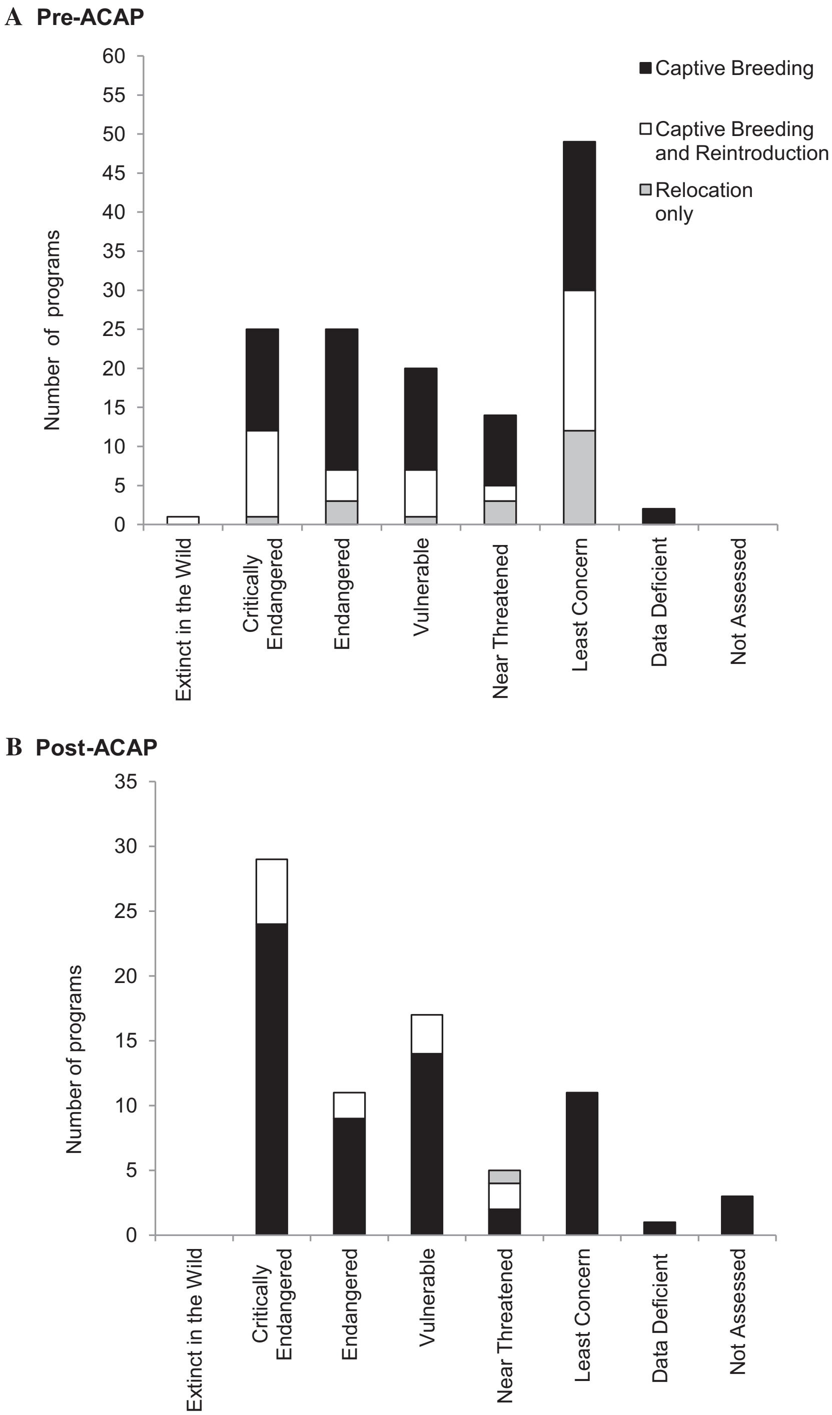

Figure 4. Distribution of amphibian species program across the International Union for Conservation of Nature Red List categories (A) pre-Amphibian Conservation Action Plan (ACAP) and (B) post-ACAP.

endangered species. There are 2 likely reasons for such an increase: IUCN Red List Index values for amphibians declined by 3.4% from 1980 to 2004 (Hoffmann et al. 2010) and the ACAP outlines the need for programs for species at immediate risk of extinction to form assurance colonies. Likewise, an analysis of amphibian data held within the International Species Information System (ISIS) showed that the proportion of threatened amphibian species held by zoos increased since 2004 (Dawson et al. 2015). Nevertheless, amphibians remain considerably underrepresented relative to the number of threatened mammals and birds in zoos (Conde et al. 2011; Dawson et al. 2015). Moreover, nearly half of amphibian species programs did not involve zoos and were led instead by government or nongovernment organizations.

A further issue concerns the use of the IUCN Red List as a basis for prioritization. Although many of the species in captive breeding and reintroduction programs are still classified as least concern on a global basis, they may be local, regional, or national conservation priorities.

With zoos and conservation agencies increasingly focusing on local conservation issues under the think-globally-act-locally mantra, measuring contributions against global criteria may underestimate their true impact.

Many of the current threats to amphibians are complex and not easily mitigated (Griffiths & Kuzmin 2011), and in many recent cases are not even fully known or understood (Mendelson et al. 2006). Climate change is a difficult threat to quantify and was stated as a principle threat for just 14 programs. Much of the threat data were obtained through the IUCN Red List, which for a number of cases stated climate change as only a possible cause of decline (IUCN 2013); climate change was not therefore included as the main threat for many species. Because the implications for amphibian declines are poorly understood, the threat that climate change poses may be underestimated. This underestimation is likely to continue until it is determined how changes to species life cycle events, health, and habitats will be affected by climate change (Bellard et al. 2012). Although amphibians have survived previous extinction events that have involved climatic upheaval, they remain sensitive to environmental temperature changes (Wake & Vredenburg 2008). The current scenario of rapid climate change is therefore expected to become a greater threat to many species.

Geographic Regions Global and Taxonomic Patterns

After the ACAP was published, the number of species programs declined in developed, industrialized countries and increased in the tropics, where amphibian diversity and declines are highest. This was particularly evident for Central and South America and the Caribbean, where many programs have been driven by efforts to create assurance populations in regions where disease or other factors are having a dramatic impact. The AArk projects have enabled the training of local biologists via workshops and the creation of facilities for projects in countries such as Bolivia, Ecuador, and Panama (Zippel et al. 2011). Although the move toward more in-country work is encouraging, there remain challenges in terms of ensuring ongoing funding, biosecurity, appropriate facilities, and—in some cases—political stability (Gewin 2008; Gippoliti 2012). Equally, poorly studied tropical frogs may be harder to establish in captivity than the well-studied species in developed countries that have so far been the subject of many of the successful reintroductions. Refocusing attention on little-studied species in high biodiversity areas such as the Neotropics may therefore pose challenges for achieving success in the future (Tapley et al. 2015). Consequently, well-resourced zoos, conservation agencies, and NGOs remain important vehicles for creating and maintaining awareness, assisting in captive breeding, and sharing the important skills and knowledge required for such programs (IUCN 2002; Gascon et al. 2007; Gippoliti 2012).

The more recent concerns of amphibian scientists relate to the lack of progress with in situ conservation coming out of the ACAP objectives (Pounds et al. 2006; Gewin 2008; Bishop et al. 2012; Stuart 2012). The AArk states that their conservation plan is only one component of the ACAP and that ultimately the safeguarding of species in situ will be the real measure of success (Zippel 2007).

The evolution of captive breeding and reintroduction over the past decades has been driven by shifting agendas and philosophies that in some respects have come full circle. Although the early conservation-oriented zoos were set up as Noah's Arks, often with reintroduction to the wild as a distant goal, the limitations of this approach started to be widely aired in the 1990s (Bowkett 2009). This culminated with Caughley (1994) robustly pointing out that without proper threat neutralization, many species reintroduction programs will fail. However, with the emergence of complex threats, such as disease and climate change—for which neutralization remains an intractable problem—the arks have sailed once again. Although decision-making processes are in place regarding which species should join the new arks and success rates of translocations are apparently improving (Germano & Bishop 2009), important questions remain unanswered. How should an endangered tropical frog with unknown husbandry requirements be weighed against a less-threatened species with a better known natural history? Should the emphasis be on doomed species or on reintroducable species that will have some chance of survival in the wild? The pros and cons may ultimately boil down to ethical arguments versus ecological arguments. The recently relaunched ACAP highlights the considerable challenges facing captive breeding and reintroduction in terms of knowledge, resources, expertise, capacity building, and the ability to respond quickly (Wren et al. 2015). There also remains a shortage of space for all the species in need, and the challenge for ex situ amphibian conservation may therefore lie in developing novel conservation strategies that allow amphibians to live with—rather than live without—current, emerging, and future threats.

Acknowledgments

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Supporting Information

The list of species classified into CB, CB&R, and R both pre- and post-ACAP (Appendix S1) and the success of species reintroductions pre- and post-ACAP

(Appendix S2) are available online. The authors are solely responsible for the content and functionality of these materials. Queries (other than absence of the material) should be directed to the corresponding author.

Literature Cited

Amphibian Ark. 2013. Amphibian Ark: Progress of ex situ conservation programmes. Available from https://aark.portal.isis.org/ExSituPrograms/default.aspx (accessed June 2013).

Amphibian Ark. 2014. Planning workshops. Available from http://www.amphibianark.org/about-us/aark-activities/planning-workshops/ (accessed April 2015).

AmphibiaWeb. 2015. Information on amphibian biology and conservation. AmphibianWeb, Berkeley, California. Available from http://amphibiaweb.org/ (accessed July 2015).

Balmford A, Mace GM, Leader-Williams N. 1996. Designing the ark: setting priorities for captive breeding. Conservation Biology **10:**719–727.

Bellard C, Bertelsmeier C, Leadley P, Thuiller W, Courchamp F. 2012. Impacts of climate change on the future of biodiversity. Ecology Letters **15:**365–377.

Bishop PJ, Angulo A, Lewis JP, Moore RD, Rabb GB, Garcia Moreno J. 2012. The Amphibian extinction crisis - what will it take to put the action into the Amphibian Conservation Action Plan? S.A.P.I.EN.S **5.2**. Available from http://sapiens.revues.org/1406. (accessed July 2015).

Bishop PJ, Daglish LA, Haigh AJM, Marshall LJ, Tocher MD, McKenzie KL 2013. Native frog (*Leiopelma* spp.) recovery plan, 2013 – 2018. Wellington, New Zealand: Department of Conservation.

Bloxam QMC, Tonge SJ. 1995. Amphibians: suitable candidates for breeding-release programmes. Biodiversity and Conservation **4:**636–644.

Bowkett AE. 2009. Recent captive-breeding proposals and the return of the ark concept to global species conservation. Conservation Biology **23:**773–776.

Browne RK, Wolfram K, García G, Bagaturov MF, Pereboom ZJJM. 2011. Zoo-based amphibian research and conservation breeding programs. Amphibian and Reptile Conservation **5:**1–14.

Cashins SD, Grogan LF, McFadden M, Hunter D, Harlow PS, Berger L, Skerratt LF. 2013. Prior infection does not improve survival against the amphibian disease chytridiomycosis. PLoS ONE **8**(2) (e56747). DOI: 10.1371/journal.pone.0056747.

Caughley G. 1994. Directions in conservation biology. Journal of Animal Ecology **63:**215-244.

Christie MR, Marine ML, French RA, Blouin MS. 2012. Genetic adaptation to captivity can occur in a single generation. Proceedings of the National Academy of Science **109:**238–242.

Conde DA, Flesness N, Colchero F, Jones OR, Scheuerlein A. 2011. An emerging role of zoos to conserve biodiversity. Science **331:**1390–1391.

Dawson J, Patel F, Grifffiths RA, Young RP. 2015. Assessing the global zoo response to the amphibian crisis through 20-year trends in captive collections. Conservation Biology. DOI:10.1111/cobi12563.

Ewen J, Armstrong DP, Parker KA, Seddon PJ. 2012. Reintroduction biology: integrating science and management. Wiley-Blackwell, Sussex, United Kingdom.

Fischer J, Lindenmayer DB. 2000. An assessment of the published results of animal relocations. Biological Conservation **96:**1–11.

Gascon C, Collins JP, Moore RD, Church DR, McKay JE, Mendelson JR III. 2007. Amphibian conservation action plan. Proceedings of the IUCN/SSC Amphibian Conservation Summit 2005. IUCN/SSC Amphibian Specialist Group, Gland, Switzerland.

Gascon C, et al. 2012. Scaling a global plan into regional strategies for amphibian conservation. Alytes **29:**15–27.

Germano JM, Bishop PJ. 2009. Suitability of amphibians and reptiles for translocation. Conservation Biology **23:**7–15.

Germano JM, Field KJ, Griffiths RA, Clulow S, Foster J, Harding G, Swaisgood RR. 2015. Mitigation-driven translocations: Are we moving wildlife in the right direction? Frontiers in Ecology and the Environment **13:**100–105.

Gewin V. 2008. Riders of a modern-day Ark. PLoS Biology **6**(1): e24. DOI:10.1371/journal.pbio.0060024.

Gippoliti S. 2012. Ex situ conservation programmes in European zoological gardens: Can we afford to lose them? Biodiversity and Conservation **21:**1359–1364.

Griffiths RA, Kuzmin SL. 2011. Captive breeding of amphibians for conservation. Pages 3687–3703 in Heatwole H, Wilkinson J, editors. Amphibian biology. Volume 10. Conservation and decline of amphibians: ecological aspects, effects of humans, and management. Surrey Beatty, Australia.

Griffiths RA, Pavajeau L. 2008. Captive breeding, reintroduction, and the conservation of amphibians. Conservation Biology **22:**852–861.

Harris RN, James TY, Lauer A, Simon MA, Patel A. 2006. The amphibian pathogen *Batrachochytrium dendrobatidis* is inhibited by the cutaneous bacteria of amphibian species. EcoHealth **3:**53–56.

Hoffmann M, et al. 2010. The impact of conservation on the status of the world's vertebrates. Science **330:**1503–1509.

IUCN. 2002. Technical guidelines on management of ex-situ populations for conservation. IUCN, Gland, Switzerland.

IUCN. 2013. IUCN red list of threatened species. IUCN, Gland, Switzerland. Available from http://www.iucnredlist.org/ (accessed April 2015).

IUCN/SSC. 2013. Guidelines for reintroductions and other conservation translocations. IUCN Species Survival Commission, Gland, Switzerland.

Jones CG. 2002. Reptiles and amphibians. Pages 355–375 in Merrow MR, Davy AJ, editors. Handbook of ecological restoration. Cambridge University Press, Cambridge.

Jule KR, Leaver LA, Lea SEG. 2008. The effects of captive experience on reintroduction survival in carnivores: a review and analysis. Biological Conservation **141:**355–363.

Kraaijeveld-Smit FJL, Griffiths RA, Moore RD, Beebee TJC. 2006. Captive breeding and the fitness of reintroduced species: a test of the responses to predators in a threatened amphibian. Journal of Applied Ecology **43:**360–365.

McCallum ML. 2007. Amphibian decline or extinction? Current declines dwarf background extinction rate. Journal of Herpetology **41:**483–491.

Mendelson JR, et al. 2006. Confronting amphibian declines and extinctions. Science **313:**11–12.

Mendelson JR, et al. 2007. Captive programs. Pages 36–37 in Gascon C, et al. editors. Amphibian Conservation Action Plan, Proceedings of the IUCN/SSC Amphibian Conservation Summit 2005. IUCN/SSC Amphibian Specialist Group, Gland, Switzerland.

Pounds JA, Carnaval AC, Puschendorf R, Haddad CFB, Masters KL. 2006. Responding to amphibian loss [Response]. Science **314:**1541–1542.

Scheele BC, Hunter DA, Grogan LF, Berger L, Kolby JE, McFadden MS, Marantelli G, Skerratt LF, Driscoll DA. 2014. Interventions for reducing extinction risk in chytridiomycosis-threatened amphibians. Conservation Biology **28:**1195–1205.

Soorae PS, editor. 2013. Global re-introduction perspectives: 2013. Further case studies from around the globe. Gland, Switzerland: IUCN/SSC Re-introduction Specialist Group and Abu Dhabi, UAE: Environment Agency-Abu Dhabi.

Stuart SN. 2012. Responding to the amphibian crisis: Too little, too late? Alytes **29:**9–12.

Stuart SN, Chanson JS, Cox NA, Young BE, Ana SL, Fischman DL, Waller RW, Rodrigues ASL. 2004. Status and trends of amphibian declines and extinctions worldwide. Science **306:**1783–1786.

Tapley B, Bradfield KS, Michaels C, Bungard M. 2015. Amphibians and conservation breeding programmes: Do all threatened amphibians belong on the ark? Biodiversity and Conservation **24:**2625–2646.

Wake DB, Vredenburg VT. 2008. Are we in the midst of the sixth mass extinction? A view from the world of amphibians. Proceedings of the National Academy of Sciences of the United States of America **105:**11466–11473.

Walker SF, et al. 2008. Invasive pathogens threaten species recovery programs. Current Biology **18:**853–854.

Wilson AC, Stanley Price MR. 1994. Reintroduction as a reason for captive breeding. Pages 243–264 in Olney PJS, Mace GM, Feistner ATC, editors. Creative Conservation: Interactive management of wild and captive animals. Chapman & Hall, London.

Wren S, Angulo A, Meredith H, Kielgast J, Dos Santos L, Bishop P. 2015. IUCN SSC Amphibian Specialist Group Amphibian Conservation Action Plan. Available from http://www.amphibians.org/publications/amphibian-conservation-action-plan/ (accessed 19 July 2015).

Zippel KC. 2007. Why do we need an amphibian ark? http://www.actionbioscience.org/biodiversity/zippel.html#articlereferences (accessed March 10, 2014).

Zippel K, Johnson K, Gagliardo R, Gibson R, McFadden M, Browne R, Martinez C, Townsend E. 2011. The amphibian ark: a global community for ex situ conservation of amphibians. Herpetological Conservation and Biology **6:**340–352.