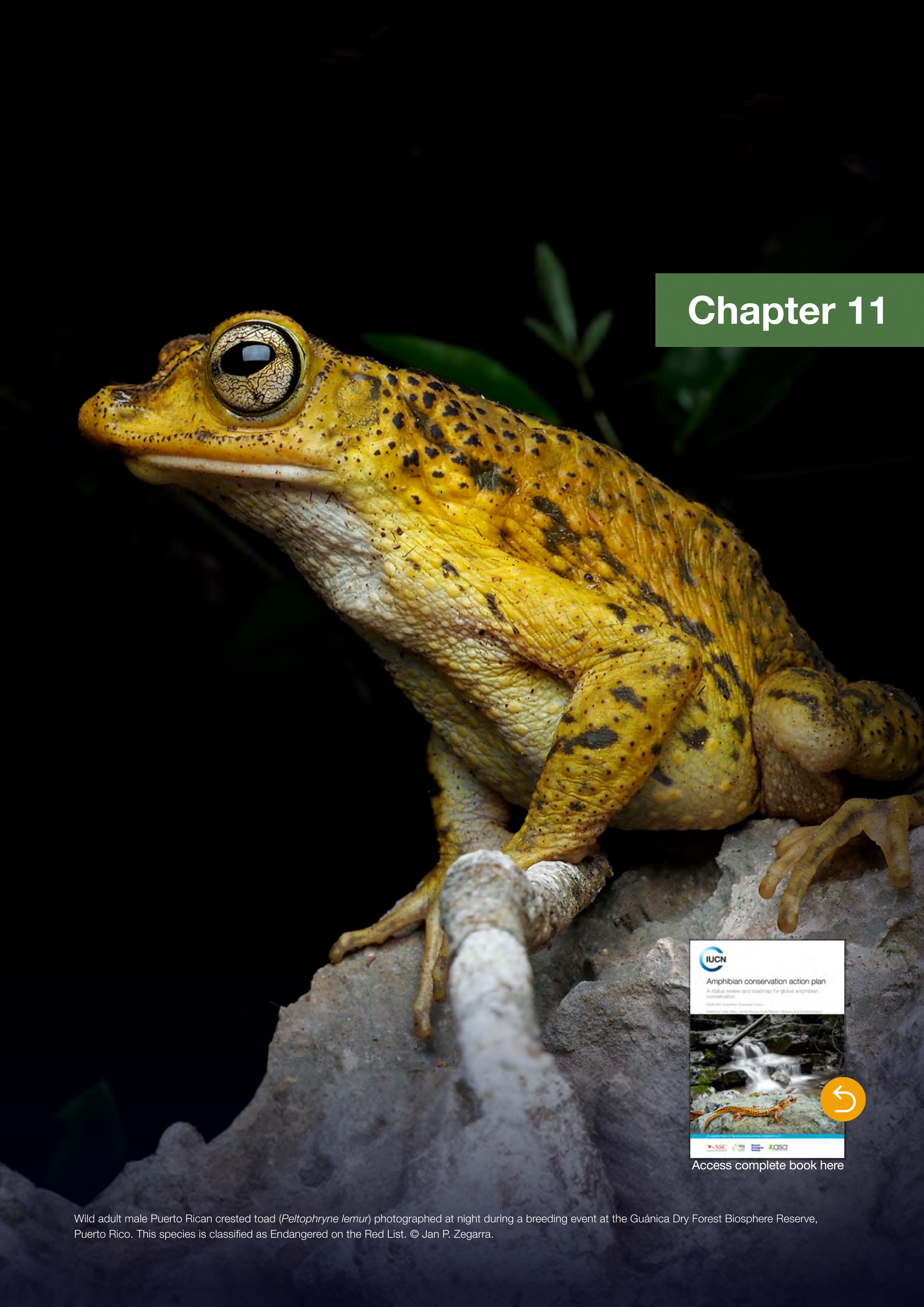
Species management

Chapter 11



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Wild adult male Puerto Rican crested toad (*Peltophryne lemur*) photographed at night during a breeding event at the Guánica Dry Forest Biosphere Reserve, Puerto Rico. This species is classified as Endangered on the Red List. © Jan P. Zegarra.

Chapter 11

Conservation breeding

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Abstract

In the face of overwhelming and sometimes acute threats to many amphibians, such as disease or habitat destruction, the only hope in the short-term for populations and species at imminent risk of extinction is immediate rescue for the establishment and management of captive survival-assurance colonies (CSCs). Such programmes are not the final solution for conservation of any species, but in some circumstances may be the only chance to preserve the potential for eventual recovery of a species or population to threat-ameliorated habitat. A captive-assurance strategy should always be implemented as part of an integrated conservation plan that includes research on amphibian biology, advances in husbandry and veterinary care, pathology, training and capacity-building in range countries, mitigation of threats in the wild, and ongoing habitat and species protection and, where appropriate, disease risk analysis and translocation. The existence of captive colonies also facilitates many of the goals of other ACAP branches, including research on amphibians and their diseases as well as the development and validation of methods that may be later used in the field. Captive programmes do not replace important programmes related to, *inter alia,* habitat preservation, control of harvesting, climate change, and ecotoxicology, but instead provide options and resources to enable survival of some species while these research programmes proceed, and to directly or indirectly support such programmes.

Introduction

Amphibians face an overwhelming array of threats, and many species are facing imminent extinction. The fate of many species may be entirely dependent on the establishment and management of captive survival-assurance colonies (CSCs). The establishment of CSCs may offer the only chance to preserve the potential for eventual recovery of a species or population to threat-ameliorated habitat. When used, a captive-assurance strategy should always be implemented as part of an integrated and inclusive conservation strategy and such programmes should ideally be developed in the range country/countries of the target species. Whilst there are successful CSCs currently operating, the number of programmes is woefully small relative to the number of species that require CSCs. The establishment of CSCs can be supported and/or implemented by an array of stakeholders including government agencies, non-governmental organisations (e.g., Amphibian Ark Box 11.1), zoos, aquariums and even individuals.

The requirement and capacity for ex situ conservation varies regionally and is linked to spatial variation in amphibian species diversity, socioeconomic status of range states and the degree of threats posed to amphibian species in different parts of the world. The degree to which these variables are understood also varies considerably, and only ongoing field surveys, research and assessments will identify the actual numbers of species that will require a captive component to their overall conservation plan, and therefore determine the relative capacity of a region. It should also be noted that, despite continuing advances in our understanding of the captive requirements of amphibians, captive husbandry capability is not sufficient to allow some species to thrive and breed ex situ. This is usually due to insufficient species-specific data, infrastructure and/or expertise.

Recognised challenges

A number of challenges can be faced by amphibian CSCs, including a lack of funding, resources and expertise; inability to reverse some threats; insufficient understanding of species' life history and environmental parameters; limited capacity to establish the number of conservation programmes required; and sometimes very low founder numbers. Table 11.1 includes a summary of recognised challenges that can be faced by ex situ amphibian conservation programmes.

Box 11.1: The Amphibian Ark

The Amphibian Ark (AArk) was formed in 2007 to coordinate and support the ex situ component of the Amphibian Conservation Action Plan (ACAP), with the vision of ensuring the survival and diversity of amphibian species focusing on those that cannot currently be safe-guarded in their natural environments. AArk focuses its efforts on range-country programmes for those species which are otherwise likely to become extinct before the threats they face can be mitigated. In order for the Conservation Breeding Working Group (CBWG) priorities within the ACAP to be implemented, the global network of captive breeding programmes, which include CSCs, capacity-building programmes using analogue species, and applied ex situ research populations, must be explicitly linked to conservation and research programmes, both ex situ and in situ. To this end, AArk recommends that activities are implemented in five phases:

1) Assessment and prioritisation of species' conservation needs (Conservation Needs Assessment).

2) Establishment of captive operations in the range countries.

3) Research and long-term maintenance of captive operations.

4) Providing animals for research and translocation programmes.

5) Post-translocation monitoring and assessment (*see* Chapter 14).

Table 11.1: Recognised challenges faced by amphibian captive survival-assurance colonies

Insufficient funding/resources	Relative to other taxa, amphibians remain grossly underfunded (*see* Chapter 2). Funding for CSCs comes from a diversity of sources but is often piecemeal, localised and short-term. CSCs require long term investment and take time to establish, this often results in project fatigue. Difficulties in sourcing specialist equipment in some range states has the potential to undermine programmes once they have been established.
Insufficient technical expertise and a lack of species champions	Amphibian captive husbandry expertise is sometimes lacking in the countries which support the greatest amphibian biodiversity and disproportionately threatened amphibian assemblages. Attempts have been made to address this balance, however, the lack of technical expertise remains a problem. It can be difficult to train the appropriate people, there is high staff turnover and once training has occurred there are no mechanisms in place to ensure that the knowledge gained through training is put into practice and disseminated to others. This last issue is due, at least in part, to a lack of species champions to develop and formally manage programmes for target species. Some captive husbandry practitioners also have difficulty accessing scientific literature on amphibian husbandry. The expertise underpinning many programmes is based on short training experience and some programmes may lack the longer term experience required to adapt to the problems in husbandry.
Identifying suitable candidate species that require CSCs	Not all amphibians are suitable candidates for CSCs. The threats for some species are not currently reversible or may not ever be reversible. Deciding which species should be established as a CSC can be problematic and must take into account the geo-political context and likelihood that the programme will succeed.
Failing to act and acting too late	CSCs are often seen as a measure of last resort and the establishment of a CSC is often postponed until numbers in the wild are dangerously low. This can greatly reduce the chances of establishing a viable CSC due to the issues inherent with small population sizes and the time potentially required to develop species-specific husbandry techniques. There is a choice to be made between prioritising small populations or larger, rapidly declining populations; in the one case extinction may be imminent, but programmes may fail, while in the other case there may still be time for in situ only intervention.
Lack of field data on species biology and reliance on non–evidence based husbandry practices	Data on life history and environmental parameters are lacking for many species and life stages (*see* Chapter 2). This paucity of information has the potential to undermine CSCs for species which are established where little to nothing is known about the species biology, ecology and habitat / microhabitat requirements. There is a prevalence of anecdote-based husbandry over evidence-based approaches. There is a need to engage with field biologists, the scientific literature, and the application of a methodical approach to changing husbandry. Engagement with industry/technical expertise may facilitate the design of better CSC facilities to provide appropriate conditions.
New threats and limited capacity	The captive breeding community must be able to respond to new threats as they emerge, in particular emerging infectious disease. There is already limited captive breeding capacity and more species in need of CSCs than there are programmes established. As new threats emerge and more species become threatened there is a risk that the captive breeding community will be unable to respond. Working with field biologists to conduct health surveillance of wild populations is crucial.
Ex situ management can produce maladapted amphibians	Some amphibians fail to thrive and breed in captivity under the conditions currently provided to them. The husbandry requirements of amphibians are more complex than previously thought and for many species that require CSCs, the husbandry requirements are unknown. There is a danger of not producing any captive bred offspring or producing

	maladapted amphibians in CSCs which may not be suitable for reintroduction, especially if captive conditions differ greatly from field conditions.
Risk of novel pathogens in ex situ facilities	CSC facilities should be located within the indigenous range of a species to minimise the risk of individuals in such programmes becoming exposed to novel pathogens, or bringing pathogens into existing captive populations. Doing so may also simplify the provision of some environmental and climatic variables that may be important for successful husbandry. Capacity may be lacking in some regions, and as a result, facilities may need to be located outside of the range state and / or distributional range of the target species and there is a risk that such populations of amphibians will become exposed to novel pathogens. This is especially an issue if hosting organisations maintain cosmopolitan animal collections. Many pathogens of concern cannot currently be effectively screened for, and this has the potential to undermine programmes and risk sympatric species at release sites at risk.
National, regional or local conservation authorities are/ become unsupportive	Conservation priorities depend on the scale of operation. A regionally threatened species may not be a national or global priority, and vice versa. This can result in different priorities within organisations operating at different scales. Equally, the level of support provided will depend on the political motivations of the authorities concerned. State support is likely to improve with appropriate engagement with in-country parties.
Lack of sufficient numbers or genetic diversity for founding populations	Currently, some studbooks are not well implemented in existing CSCs. Furthermore, genetic analysis is expensive, and the resources and expertise are not available to determine the genetic viability of many populations (both in the field and in captivity) that would benefit from it.
Lack of post release monitoring	Many amphibians are challenging to monitor as they may have cryptic lifestyles, have highly seasonal behaviours and natural population fluctuations. Inadequate post-release monitoring does not allow captive breeding practitioners to assess the success of their programmes. Poor survival and/or breeding of captive bred animals following their release to the wild needs to be identified as quickly as possible so that husbandry changes aimed at improving success can be identified and implemented.
Conflict of interests	Whilst conservation research has an important role in developing new husbandry techniques, disease mitigation and for developing reintroduction strategies, there is a risk that producing animals for research becomes the priority to the detriment of the captive population. The practical benefits of using captive bred offspring for research rather than release need to be critically assessed on a case-by-case basis.
Government and political constraints	If CSCs are implemented outside of range countries, the acquisition of permits to export wild-caught founder animals (and to subsequently import animals for eventual reintroduction) can be time-consuming and problematic. In-country collection permits can also be difficult to obtain in some countries, with long delays leading to further population declines in the wild.
Lack of stakeholder buy-in or involvement	Not all threatened amphibians are charismatic, which can make it difficult to attract resources, community, and government buy-in to conservation actions, especially for long-term commitment. Within the ex situ community, these are also often ignored in favour of more charismatic species, not only other amphibians, but charismatic, larger species. There is an increasing trend in zoos and aquariums for merging departments together, which can lead to a loss of species-specific expertise.

Lack of academic engagement	While the body of knowledge of emerging diseases has grown immensely in the last two decades, with some of this knowledge being derived from captive animals, we are still not at a stage where we can re-establish wild populations. Additionally, due to the nature of the threats to many amphibians, it has been difficult to apply some of that generated knowledge to 'real life' management decisions. Conservation initiatives are often not attractive to academics due their long-term commitment combined with the potential of failure. This makes it hard for researchers to generate outputs and meet academic metrics of impact. Moreover, it may also explain why so few translocation feasibility trials have been conducted on captive populations, or why alternative actions and scenarios have not been more thoroughly explored. Moreover, the research/academic community is probably best positioned to help address current uncertainties that may be holding back the next steps of these programmes.

Advances in species prioritisation and holistic programme planning

Given the inadequate global capacity to establish and maintain CSCs for all threatened species, and the necessary long-term nature of most CSCs, species prioritisation is a critical tool in a strategic approach to amphibian conservation, and a number of advances have been made in this area since the first ACAP (e.g. Gumbs et al., 2018; Isaac et al., 2012; Johnson et al., 2018). Additionally, the need for integration of ex- and in situ interventions (i.e. following the IUCN Conservation Planning Specialist Group's One Plan Approach), which was not always the case for captive breeding programmes historically, was highlighted initially by the IUCN/SSC (2002), then subsequently by the first ACAP (Gascon et al., 2007) and continues to be the case. In 2006, a taxon selection and prioritisation working group developed a decision tree to help select and prioritise which species are most in need of ex situ assistance. In 2009, the AArk began expanding and refining this tool into the Conservation Needs Assessment (CNA process (www.ConservationNeeds.org), as a method to promote needs-based species prioritisation, and holistic programme planning with defined exit strategies. A CNA assigns recommended actions to a species from a range of eleven conservation roles, from no current needs, through in situ conservation or research only, to full ex situ rescue or ark operations (Johnson et al., 2018), with national species priorities determined by scores allocated to responses within each CNA. Prioritisation of species is still constrained partly by incomplete knowledge of the total diversity of amphibians, and the current conservation status of the majority of described amphibian species (Tapley et al., 2018), and CNAs should be updated as additional or updated data are available, to ensure accurate priorities and recommendations for action. In order to inform conservation prioritisation the conservation needs of all threatened amphibians must be evaluated, and then re-evaluated every ten years, or when new data are available, to ensure the assessments remain current and valuable. CSCs should be established based on priorities at the time and reviewed as priorities change. Since 2018, a number of joint amphibian IUCN Red List of Threatened Species™ (Red List) and Conservation Needs Assessment workshops have taken place. This joint approach considerably reduces the financial and human resources required compared to conducting the two assessments separately and facilitates the necessary close link between the processes. It is envisioned that joint IUCN Red List and CNA assessments will continue into the future. However, completing assessments for all threatened amphibians and updating them on a cyclic basis to inform conservation action is costly. Moreover, the prioritisation process is only of value if it is followed by the establishment of captive programmes, as well as the other CNA recommendations, for those species that are identified as requiring them as part of integrated (or holistic) conservation recovery programmes. Therefore, the ex situ response must be strategically linked to the CNA process.

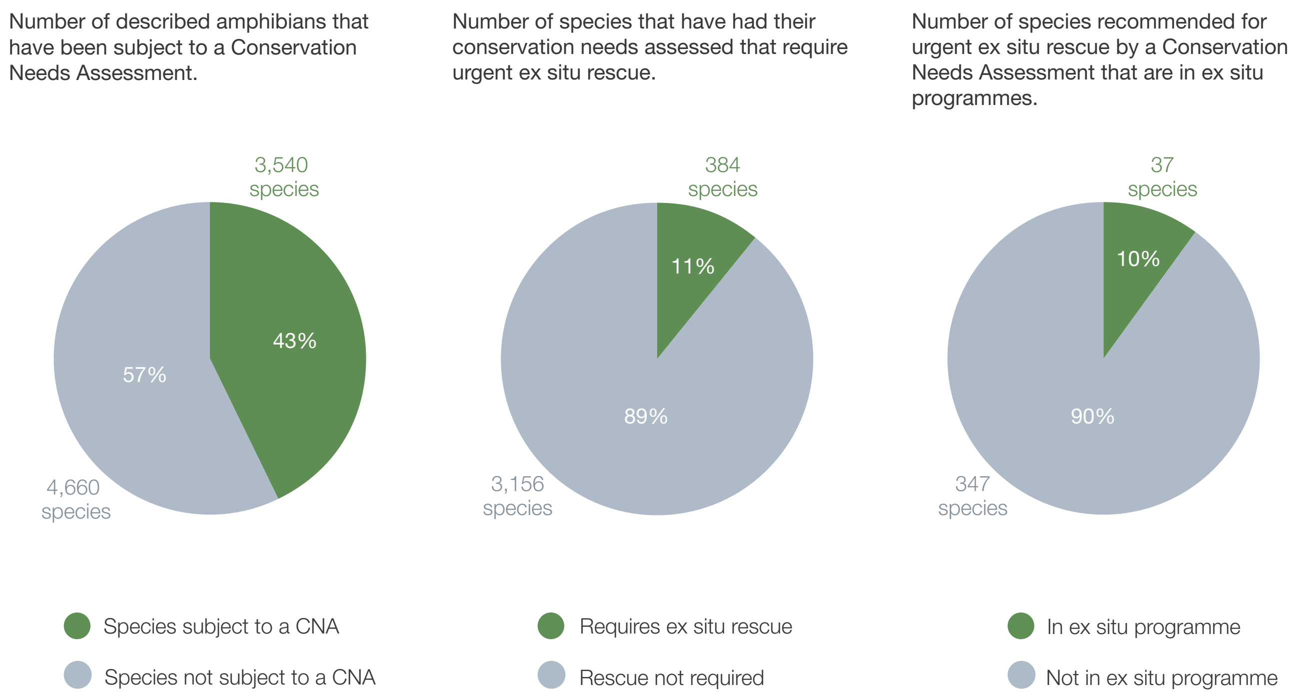

Figure 11.1: The number of amphibians that have had their conservation needs assessed, the proportion of assessed species that require urgent ex situ rescue and the proportion of the species requiring urgent ex situ rescue that are currently established as an CSC. Source: Data from AArk's programme progress database, October 2021.

The conservation breeding community has responded positively to CNAs (Figure 11.1), as these assessments have been a pivotal consideration in the collection planning processes adopted by some regional zoo and aquarium associations (e.g. Barber & Poole, 2014; Garcia et al., 2020). However, many individual zoos appear to be unaware of the CNA tool (Dos Santos et al., 2021). Mechanisms need to be developed to ensure that CNA recommendations are more-widely adopted at the national level when conservation strategies are developed for amphibians.

Paradigm shift and the development of regional capacity

The 2007 ACAP recognised the importance of establishing CSCs within species range countries and using facilities dedicated to sympatric species with shared management histories (Gascon et al., 2007), and this recommendation is maintained by the CBWG and AArk (Zippel et al., 2011). If this is not the case, exposure to alien pathogens is much more likely (Pessier & Mendelson III, 2017; Zippel et al., 2011), which may create additional threats for the focal species and/or syntopic taxa following translocation of captive individuals (Cunningham, Daszak & Rodríguez, 2003). Such pathogens have been detected in cosmopolitan amphibian collections (Cunningham et al., 2015; Miller et al., 2008; Walker et al., 2008), or may be unknown or unreliably detected and difficult to eradicate (e.g. Blooi et al., 2015; Rijks et al., 2018), and so pose a substantial and real threat (e.g. Walker et al., 2008). In addition to infectious disease, hosting CSCs outside of range countries potentially has cultural, political, legal, and social implications for the long-term success of conservation programmes (Tapley et al., 2015). An in-range approach requires capacity building, however, as regions most in need of CSCs are often those where few resources currently exist (Edmonds et al., 2012; Gagliardo et al., 2008). A number of high-profile CSCs have therefore been established outside of range countries because it was not possible to build capacity in time to rescue populations from acute declines, e.g. mountain chicken frogs (*Leptodactylus fallax*) and Kihansi spray toads (*Nectophrynoides asperginis*). Although these programmes are key to species survival

Box 11.2: Puerto Rican crested toad (*Peltophryne lemur)*

As the Puerto Rican crested toad (*Peltophryne lemur*) reintroduction programme nears its fourth decade, the ebb and flow of failures and achievements is recognised as part of the programme's functionality. Throughout this process, people working on this programme have discovered that trust between partners is paramount and failures are not about proving someone wrong or assigning blame. Rather, failures are learning opportunities to build upon, adapt, and move forward as a group.

One of the biggest hurdles for this programme was transitioning leadership from a few invested individuals overseeing a small reintroduction effort, to an island-wide programme instilling stewardship for a Critically Endangered species — connecting volunteers, universities, zoos, local and federal agencies, and nongovernmental organisations. The development of a Memorandum of Understanding (MOU) between primary agency partners responsible for the species protection and recovery, establishment of a Puerto Rican Crested Toad Working Group for all stakeholders, and increased communication and capacity building was a slow process, but resulted in improved functionality and will prove paramount for this programme's long-term stability.

Wild crested toad populations were originally divided into two distinct northern (N) and southern (S) populations. Genetic analysis of the two populations revealed that mitochondrial haplotypes within the lineages were moderately divergent, but they were determined to be no more divergent than other populations of amphibians (Beauclerc, Johnson & White, 2010). By 1992 the N wild population was believed to be extirpated but N toads were still maintained as a distinct breeding group in the captive population. The N zoo population was established in 1980 from four inbred siblings and by 2008 was exhibiting signs of inbreeding depression. In 2011 it was decided to perform a genetic rescue of the N population by breeding them with wild caught S toads to establish a captive NxS population. Releases of NxS toads began at northern reintroduction sites in 2012 while S population releases continued at the southern sites. For the next several years, the Puerto Rican crested toad were managed as two populations (NxS and S), but limited space and resources created the need to manage the population as one species. However, not all partners agreed to a final merger despite the NxS toads' ability to thrive in wet forest habitat in comparison to the wild toads' dry scrub habitat in the south. There were concerns that there could be some deleterious alleles that might negatively impact survivorship for any toads ultimately released in the dry scrub forest habitat in the south. After soliciting opinions from geneticists and biologists outside of the programme and thoughtful debate, it was agreed in 2017 to combine the captive populations and manage the Puerto Rican crested toad as one population. Resources were simply too limited to continue effective management of two captive populations and maximisation of genetic diversity and the potential for increasing overall fitness for the population outweighed concerns of low probability of negative outbreeding effects. Additionally, all reintroduction sites are isolated by geographic and anthropogenic barriers, which helped alleviate concerns of causing any risk to the remaining wild population.

Lastly, there were many challenges related to the creation and maintenance of reintroduction sites and monitoring in general. There is still limited knowledge of the toads' natural history and population sizes, and despite proven survivorship and recruitment at all but one reintroduction site, funding and staff shortages continue to hinder this programme. However, the establishment of reintroduction and field management standard operating procedures to assist partners at pond sites and increase monitoring efforts was a useful tool and most importantly, progress continues to be made and new insights gained along the way have allowed the team working to recover this species to reevaluate and adapt management strategies for the remaining wild population to be protected and new populations to be established.

and supported by AArk, they are acknowledged to be suboptimal in this respect. Both programmes work closely with in-range governments and communities, however, to partially address this issue.

In the years immediately following the publication of the ACAP in 2007, the number of amphibian captive programmes increased (Harding, Griffiths & Pavajeau, 2016), and several well-equipped facilities dedicated to amphibian conservation breeding were established in regions where capacity was previously lacking (Bourke, 2010; Edmonds et al., 2012; Harding et al., 2016; Hernández Díaz, 2013; Tapley et al., 2014; Ziegler, 2015). According to Harding et al. (2016), by 2014, approximately half of captive breeding programmes were undertaken by government or non-government agencies rather than zoos or aquariums. It is therefore important to avoid conflation of ex situ conservation as a concept with zoo and aquarium populations of animals.

Captive husbandry: advances and current limitations

There have been notable advances in a number of relevant areas since the publication of the 2007 ACAP (Table 11.2)

Species-specific husbandry and management protocols have also been developed for a host of species via a range of channels including peer-reviewed articles and technical reports (Jameson et al., 2019; Poole & Grow, 2012; Tapley et al., 2016). Furthermore, techniques have been developed and validated that aid in situ actions such as population monitoring and disease mitigation (Hudson et al., 2016; Jayson et al., 2018; Scheele et al., 2014; Tapley et al., 2020) and the establishment of facilities in range states (e.g. Nicolson et al., 2017).

While these advances have contributed to the ex situ community's ability to successfully maintain and breed an increasing number of species (e.g Ettling et al., 2013; McFadden et al., 2018; Michaels et al., 2015; Preininger et al., 2012), it is still unable to meet the needs of many species due to husbandry limitations that ultimately derive from inadequate understanding of species biology and pathology, insufficient resources and regional expertise (Flach et al., 2020; Pessier et al., 2014) and because the required technology is not currently available. These knowledge gaps are more profound for some amphibian groups, such as Gymnophiona (Murphy & Gratwicke, 2017; Flach et al., 2020).

Adaptation to captivity

Over time, any captive population of amphibians will adapt genetically, phenotypically and behaviourally to captive environments, which inevitably differ from wild conditions in myriad ways. Potential adaptations to captivity include:

- Vocalisations/phonotaxis (Passos, Garcia & Young, 2021, 2017)
- Antipredator behaviour (Crane & Mathis, 2011)
- Induced morphological antipredator responses (Kraaijeveld-Smit et al., 2006)
- Microbial communities (Antwis et al., 2014; Becker et al., 2014; Michaels & Preziosi, 2020; Passos, Garcia & Young, 2018)
- Colouration (Dugas et al., 2013; Ogilvy et al., 2012)
- Size/morphology (Bennett & Murray, 2015)
- Nutritional state (Silla et al., 2016)
- Fecundity and offspring viability (Dugas et al., 2013)

Maximising genetic diversity is crucially important, particularly in instances where animals bred in captivity serve as a source population for reintroduction and translocation (Grueber et al., 2015; Jameson et al., 2019). However, outbreeding depression should also be an important consideration when managing breeding programmes (Allentoft & O'Brien, 2010). Understanding species-specific histories, early viability selection and local

Table 11.2: Selected references regarding advances in amphibian husbandry since the publication of the first ACAP

Area of husbandry	Associated references
Enclosure use and design	Cikanek et al., 2014; Mannings et al., 2023
Nutrition	Antwis, Preziosi & Fidgett, 2014; Antwis et al., 2014; Byrne & Silla, 2017; Dierenfeld & King 2008; Dugas, Yeager & Richards-Zawacki, 2013; Edwards et al., 2017; Jayson et al., 2018; Keogh et al., 2018; McInerney, Silla & Byrne, 2019; Michaels et al., 2021; Newton-Youens, Michaels & Preziosi, 2022; Ogilvy & Preziosi, 2012; Ogilvy, Preziosi & Fidgett, 2012; Rodríguez & Pessier, 2014; Silla, McInerney & Byrne, 2016; Stückler et al., 2022; Venesky et al., 2012
Provision of appropriate lighting	Antwis & Browne, 2009; Baines et al., 2016; Michaels, Antwis & Preziosi, 2015; Shaw et al., 2012; Tapley et al., 2014; Verschooren et al., 2011; Whatley et al., 2020
Provision of enrichment	Michaels, Downie & Campbell-Palmer, 2014
Behavioural syndromes	*See review* in Kelleher, Silla & Byrne, 2018
Artificial manipulation of seasonally dependent adaptations (brumation, aestivation, torpor)	Calatayud et al., 2015; Calatayud et al., 2020
Water quality and larval rearing techniques	Behr & Rödder, 2018; Ciani et al., 2018; Fenolio et al., 2014; Gawor et al., 2012; Gower et al., 2012; Higgins et al., 2021; Lassiter et al., 2020; Michaels, Antwis & Preziosi, 2014; Michaels & Preziosi, 2015; Michaels et al., 2015; Pasmans et al., 2012
Health assessment	Davis & Maerz, 2011; Jayson et al., 2018; Narayan & Hero, 2011; Narayan, Hero & Cockrem, 2012
Substrates	Tapley et al., 2014; Whatley, Tapley & Michaels, 2020
Disease treatment protocols and pathogen management	Blooi et al., 2015; Blooi, et al., 2015; Brannelly, Richards-Zawacki & Pessier, 2012; Garner et al., 2009; Martel et al., 2011; Michaels et al., 2018; Rendle et al., 2015; Ujszegi et al., 2021
Microbiome	Becker et al., 2014; Fieschi-Méric et al., 2023; Micahels, & Preziosi, 2020; Michaels, 2022
Welfare	Boultwood, O'Brien & Rose, 2021; Brod, Brookes & Garner, 2019; Carter, et al., 2021; Dias et al., 2022; Graves, Dias & Michaels, 2023; Holmes et al., 2016; Holmes et al., 2018; Ramos & Ortiz-Díez, 2021; Slight, Nichols & Arbuckle, 2015
Pre-translocation training	Crane & Mathis, 2011
Assisted reproductive techniques and biobanking	*See* Chapter 12

environmental adaptation is necessary as not all species will respond to inbreeding and artificial selection uniformly (Grueber et al., 2015). Suboptimal captive husbandry may also result in individuals with lower phenotypic fitness that are less likely to establish in wild habitats following translocation.

Adaptation to artificial captive environments could be reduced if every aspect of the natural environments could be replicated in captivity, although this is currently logistically and/or technologically impossible (Tapley et al., 2015) or ethically challenging in terms of animal welfare in the case of predators, pathogens, parasites, and other stressors. Minimising the number of generations that a species is kept in captivity by reducing the length of time a species is held in captivity, increasing generation length, or using cryopreservation and other assisted reproductive technologies are other methods that can be used to minimise adaptation to artificial captive environments (Frankham, 2008; Williams & Hoffman, 2009; Chapter 12). Periodically importing individuals from nature (Frankham & Loebel, 1992) and equalising families at each generation (Frankham et al., 2000) are other strategies that can substantially reduce adaptation to captivity. Another strategy is to manage a population as several small reproductively isolated units where different components of diversity are lost randomly by drift, then crossing these units to rescue genetic diversity and produce animals for translocations (Margan et al., 1998); outbreeding depression should be considered as a potential risk when managing populations in this way.

Lessons learnt from reintroductions and translocations

Several high-profile amphibian species have been subject to captive breeding programmes that also include reintroduction efforts. Some of the reintroductions have been more successful than others, but for all of them, learning from any failings, as well as modifying processes, is vital to improving the

Box 11.3: White-bellied frog (*Geocrinia alba*)

Critically Endangered white-bellied frogs (*Geocrinia alba*) have a highly restricted and fragmented distribution in south-west Western Australia, with more than 50% of known populations disappearing over recent decades. Perth Zoo has been head-starting white-bellied frogs since 2008 to contribute to in situ recovery efforts. This is an effective strategy as more than 95% of fertile eggs/larvae brought into the Zoo survive to release, whereas survival to metamorphosis in the wild is only approximately 20% (McFadden et al., 2018). By late 2020, over 1,000 juvenile white-bellied frogs had been released to the wild to establish new populations and supplement existing small ones (K. Bradfield, personal observation). To minimise any adverse impacts of egg clutch collection on source populations, a proportion of each clutch is released at the site where it was collected (McFadden et al., 2018).

The results of post-release monitoring indicate that translocations of this species can be successful; a population established with head-started frogs is now one of the largest self-sustaining wild populations with others in a stable or increasing trend. However, one translocation attempt appears to have failed, and the distribution of frogs at one of the supplementation sites has changed (K. Williams, pers. comm.). Understanding the primary drivers of translocation success vs failure is therefore critical to on-going recovery efforts. Hoffmann et al. (2021) found that dry season soil moisture, which is likely to be decreasing in the area where *G. alba* occurs due to regional changes in climate and hydrology, predicts the outcomes of the translocations undertaken to date with a high degree of accuracy, and also explains the persistence/extinction of naturally occurring populations. This clearly highlights the importance of understanding the fine-scale habitat associations of threatened amphibians when selecting release sites, particularly for species with limited dispersal ability.

success of future attempts. Reintroductions and other translocations are covered in more detail in Chapter 14 of this publication; however, examples of lessons learned from a few programmes can be *seen in* Boxes 11.2-11.5.

Future directions

People working with ex situ amphibian populations have made major advances in core areas since the launch of the first ACAP. However, further development is required to meet the global need for these programmes. Whilst substantial advances have been made in the development of regional amphibian husbandry capacity, there are still gaps, particularly in West, Central and East Africa, and southern and Southeast Asia, which should be addressed by investment in these regions going forward. Furthermore, there must be continued effort to identify the conservation needs of individual species through the CNA process and to ensure that these CNAs remain up to date.

Our knowledge of the husbandry requirements of many amphibians has been enhanced by a substantial

Box 11.4: El Rincon stream frog (*Pleurodema somuncurense*)

The El Rincon stream frog, (*Pleurodema somuncurense*), is an endemic species comprised of a few isolated subpopulations, restricted to the hot springs of the headwaters of the Valcheta Stream in northern Patagonia, Argentina (Velasco, 2018). During the last four decades, this frog's range dramatically declined, and some subpopulations have become extinct (Velasco, 2018).

In 2012 an ambitious recovery plan for this species and its habitat began, following guidelines outlined in the *Amphibian Conservation Action Plan* (Gascon et al., 2007), the *El Rincon Stream Frog Conservation Action Plan* (Kacoliris et al., 2018), and the *Conservation Action Plan for Amphibians of Argentina* (Vaira, Akmentins & Lavilla, 2018). As part of this plan, in 2015 a CSC was established for this species with the aim of producing individuals for reintroduction. Between 2017 and 2021, five translocations of a total of 200 young frogs and 3,000 tadpoles, all bred in captivity, were undertaken to restored wild habitats where subpopulations of this species had gone extinct. Post release monitoring demonstrated the establishment of the reintroduced individuals (Martínez Aguirre et al., 2019). This news encouraged the team working on this species to proceed to the second step of the reintroduction plan, which concluded in 2021 with translocations of a total of 2,500 tadpoles hatched and raised in captivity to three new restored habitats. Monitoring carried out a few months later showed that the tadpoles completed metamorphosis in the wild. If successful, these reintroductions will add a total of four new subpopulations of this Critically Endangered species, enhancing metapopulation dynamics and increasing long-term viability. Further research will determine which strategy is best in terms of effort and biological success (i.e. translocation of tadpoles vs translocation of froglets).

The reintroduction attempts carried on with the El Rincon stream frog are the first undertaken in Argentina with amphibians. Although results are even more positive than expected, there were several barriers in terms of scepticism coming mainly from colleagues from the academic realm. This scepticism, based on the fact that no previous reintroductions were carried with amphibians in Argentina, made environmental authorities more cautious about issuing permits, causing delays, and sometimes resulting in overcrowding in the ex situ facilities. This experience illustrates that future reintroduction programmes must be based on strong support from several stakeholders, engendering a more participative development of the conservation actions planned.

Box 11.5: El Valle Amphibian Conservation Center (EVACC)

Based on lessons learnt whilst undertaking this programme, it is highly recommended that, before an amphibian CSC with conservation purposes is launched, a complementary "Emergency Release Plan" (ERP) should be developed, which includes actions to be taken in the event of a serious situation within the ex situ facility (e.g. long-term lack of access during a pandemic, political instability, natural disaster or other emergency). This ERP does not replace a long-term release/reintroduction plan and should be implemented in cases involving releasing the animals back into the wild, when failing to do so could result in the imminent loss of the entire captive population. Based on the circumstances and magnitude of a given event, those releases could be evaluated as necessary and classified as soft or hard releases.

Under normal circumstances, releases or reintroductions should not be considered if life history or habitat requirements are not yet known. Basic population demographic data on the species should be gathered if these parameters are not already known, as these will be required for population viability analysis and for informing decisions about which stages of the life cycle should be used for the reintroductions. Similarly, habitat requirements need to be determined so that habitat management, restoration and creation can be carried out in a way that will maximise the chances of the reintroduction succeeding (Moore & Church, 2008).

number of research projects over the past 15 years but gaps remain, particularly regarding nutrition, diagnosis of disease and subsequent treatment, and methods for maintaining and breeding particular species in captivity, especially under biosecure conditions. These gaps can be addressed through further collaborative and co-ordinated research and partnership with, *inter alia*, nutritionists, wildlife health experts, field biologists and husbandry experts. The development of model systems based on existing knowledge from species that have been maintained successfully in captivity may be advantageous in understanding CSC requirements and implications for species that have not previously been kept in captivity, although this is not always the case.

Many amphibian conservation breeding programmes were established as a response to infectious diseases, especially fungal pathogens. Whilst there are promising advances in the mitigation of chytridiomycoses in the wild (e.g. Bosch et al., 2015; Scheele et al., 2014; Woodhams et al., 2011), these advances are not sufficient to facilitate the re-establishment of wild populations of amphibians that have been extirpated by Bd and Bsal, or other pathogens, while pathogens are still present in the environment (Mendelson III, 2018; *See* Chapter 6). Overcoming this challenge is critical to the success of many CSCs. As a result, the ex situ community must continue to fund costly breeding programmes for an indefinite period of time (Tapley et al., 2015). Exit strategies should be identified for all captive breeding programmes to ensure that limited resources are being used to the greatest effect.

The continued integration of ex situ interventions within well-defined holistic, prioritised conservation plans is critical to ensure that conservation efforts result in species recovery (e.g. Adams et al., 2014; Azat et al., 2021; Kissel et al., 2014; Lewis et al., 2019; Rosa et al., 2015; Scheele et al., 2014). Good communication and relationship-building skills, and thoughtful planning with appropriate participants who have the authority to implement actions and establish shared achievable goals are critical to achieving this. It is recommended here that holistic and inclusive planning processes, such as those utilised by the IUCN Conservation Planning Specialist Group (CPSG, 2020), are followed. Staff at captive institutions need to devote time to establishing relationships with those that work with threatened species in their region/focus area, if they do not already exist, and maintaining or strengthening existing relationships by engaging with all relevant stakeholders such as landowners, government, academia, local communities and others. Even with the above knowledge gaps addressed, there is not currently sufficient resourcing to meet the global need for CSCs. The pursuit and securing of additional funding streams and models to support long term, holistic conservation projects incorporating CSCs is needed.

It is encouraging to see the advances made over the past 15 years, and a number of successful programmes have been implemented despite the conservation breeding community falling short of the original aspiration due the constraints mentioned above. Many amphibian taxa will become extinct without ongoing or new ex situ intervention, and it is more important than ever that new CSCs are established strategically, and as part of an integrated approach to recover highly threatened amphibian species.

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The Central American worm salamander (*Oedipina elongata*) is assessed as Least Concern on the Red List. © Omar Hernández Ordóñez

An amphibian rescue pod housing Critically Endangered *Atelopus varius* at the Panama Amphibian Rescue and Conservation Project on the grounds of the Smithsonian Tropical Research Institute in Gamboa Panama. © Brian Gratwicke