REVIEW ARTICLE
The Herpetological Bulletin 139, 2017: 1-6

Zoological Society of London: contributions towards advancing the field of herpetology through conservation, research, captive management and education

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INTRODUCTION

Founded in 1826, the Zoological Society of London (ZSL) is a world-renowned centre of excellence for conservation science and applied conservation. ZSL's mission is to promote and achieve the worldwide conservation of animals and their habitats and this is realised by carrying out field conservation and research in over 50 countries, conducting original scientific research, and through education and awareness at its two zoos, London Zoo and Whipsnade Zoo, inspiring people to take conservation action. ZSL has always had a strong herpetological focus and the emphasis on reptiles and amphibians is perhaps now stronger than ever before with many different aspects of herpetology being advanced through close collaboration between the different departments within ZSL.

LIVING COLLECTIONS

ZSL's reptile and amphibian house was opened in 1927. The current collection is composed of 70 reptile and 29 amphibian species. The collection focuses on displaying a diverse array of reptiles and amphibians to an audience of 1.3 million visitors per year, educating and inspiring our visitors, and supports applied research on aspects of species biology. ZSL's herpetology team has a strong focus on developing evidence-based husbandry practices and advancing the field of herpetoculture, focusing especially on the management of venomous reptiles (Gill, 2014), training (Bryant et al., 2015), enrichment (Bryant & Kother, 2014; Januszczak et al., 2016), water quality (Michaels et al., 2015a), and UVB provision (Baines et al., 2015; Tapley et al., 2015a).

Zoos are in a unique position to undertake research that may underpin conservation efforts (e.g. Michaels et al., 2016a). Key areas of research include the development of husbandry techniques, which are frequently subtle, complex and highly specific, and elucidation of species biology, which is often difficult, if not impossible, to observe in the field. ZSL's herpetology team recently bred the Critically Endangered Lake Oku clawed frog (*Xenopus longipes*) by replicating in captivity environmental data collected from the field (Michaels et al., 2015), and used this success to document the reproductive biology and larvae of the species (Tapley et al., 2015b). ZSL has a large collection of caecilians, a group of amphibians about which little is known. Through partnership with the Natural History Museum, London, UK, husbandry protocols have been developed (Tapley et al., 2014a) and significant advances in disease diagnosis and subsequent treatment have been made (Gower et al., 2013; Rendle et al., 2015). These findings have direct relevance to the conservation of caecilians in the wild.

ZSL's herpetology team is directly involved in ZSL's wider conservation and research projects, most notably the long-term conservation programmes for mountain chicken frog (*Leptodactylus fallax*) (coordinated by Durrell Wildlife Conservation Trust, see Adams et al., 2014; Tapley et al., 2014b), Mallorcan midwife toad (*Alytes muletensis*, Fig. 1) and Chinese giant salamander (*Andrias davidianus*, Fig. 2) (Tapley et al., 2015c). The team is currently assisting in the development of initiatives focusing on gharial (*Gavialis gangeticus*) in Nepal (Fig. 3), amphibians (in partnership with the Australian Museum and Hoang Lien National Park (Tapley et al., 2017), freshwater turtles in Vietnam (in partnership with The Asian Turtle Program), and amphibians in the Western Ghats of India (Harpalini et al., 2015). Capacity building is another vital component of our work, which is achieved through the mentoring of EDGE Fellows (EDGE of Existence, 2016) and other conservationists, the hosting of interns and students from a variety of institutions and countries, and the delivery of training courses addressing topics as varied as venomous reptile management and amphibian conservation (Tapley et al., 2015d). Thus, the team invest in the future of

Figure 1. The Mallorcan midwife toad (*A. muletensis*) has been the focus of field interventions to mitigate the impacts of chytridiomycosis

Figure 2. A Chinese giant salamander (*A. davidianus*) that was caught and later released as part of our range wide ecological surveys in China

herpetological conservation around the world while delivering direct conservation outputs in the present.

The ZSL veterinary department, consisting of five veterinary clinicians, six veterinary nurses, a veterinary pathologist and assistant, microbiologist, animal welfare officer, administrator and animal keeper, works closely with the ZSL herpetology team to promote excellence in the health and welfare of amphibians and reptiles. In addition to providing health care for the reptiles and amphibians at our zoos, the veterinary team is a key component of ZSL's *in situ* conservation programmes. Preventive medicine forms an important part of the veterinary department's role in ZSL's captive breeding and reintroduction programmes through development of quarantine and health screening procedures and protocols. In conjunction with the herpetology team, the veterinary department also helps to further knowledge of best husbandry practices for captive amphibians and reptiles; recent outputs include understanding UV-B radiation requirements for the Critically Endangered mountain chicken frog (Tapley et al., 2015a) and substrate preference in the caecilian *Geotrypetes seraphini* (Tapley et al., 2014a). Advancing the detection and management of disease forms an important area of research, and recent examples include the first reported diagnosis of intestinal adenocarcinoma in the mountain chicken frog (Jaffe et al., 2015), the first case of lethal chytridiomycosis in caecilian amphibians (Gower et al., 2013), the first report of *Batrachochytrium dendrobatidis* (Bd) infection in a wild neotropical caecilian (Rendle et al., 2015), and the effective use of itraconazole for treatment of Bd infection in captive caecilians (Rendle et al., 2015). In association with ZSL's Institute of Zoology, the veterinary team has assisted with development of disease risk analysis tools for herpetofauna translocations. Several collaborative research projects between the ZSL veterinary department and herpetology team are either planned or currently underway, spanning a range of herpetological taxa and health aspects, from anaesthesia and nutrition to pathology and reproduction.

AMPHIBIAN AND REPTILE DISEASE

Infectious diseases are now accepted as a serious and global threat to the conservation of amphibians, but this was not always the case. Researchers at ZSL played pivotal roles in proving infectious agents were responsible for amphibian mass mortality and population declines, including the first identification of ranavirus infection as a cause of wild amphibian mortality in Europe (Cunningham et al., 1996), and led the international multidisciplinary team that first identified the chytrid fungus, (Bd), as a cause of amphibian population declines (Berger et al., 1998; Cunningham et al., 1998). This work has stood the test of time: these two pathogen groups (chytridiomycete fungi of the genus *Batrachochytrium* and ranaviruses) are consistently identified as the pathogens causing amphibian mass mortalities and declines. Input from ZSL, amongst others, led to these being listed by the World Organisation for Animal Health (OIE), becoming the first, and to date only, notifiable amphibian pathogens (Schloegel et al., 2010).

ZSL has taken a role at the forefront of global research to understand the spread and impact of amphibian disease, focussing mainly on chytridiomycosis and ranaviral disease. This work has ranged from identifying at-risk species (e.g. Bielby et al., 2008), understanding the emergence and spread of these diseases (e.g. Fisher et al., 2009; Price et al., 2016), their impact on populations and species (e.g. Soto-Azat et al., 2013; Price et al., 2014; Hudson et al., 2016a), and their infection dynamics (e.g. Hudson, 2016). Together, results from these studies help identify how to be reactive and proactive to minimise disease impacts on amphibians, but also inform methods to minimise impacts of other diseases of wildlife more generally.

ZSL's Institute of Zoology has undertaken national scanning surveillance of amphibian disease since the early 1990s in partnership with Froglife, UK and other conservation organisations. A citizen science approach is employed, appealing to members of the public to report sightings of sick or dead amphibians: this has transitioned from telephone reporting to the Frog Mortality Project

Figure 3. This gharial (*G. gangeticus*) was captured on the Chambal River for radio telemetry tag attachment

Figure 4. The pool frog (*P. lessonae*) at one of the reintroduction sites in the England; disease risk analysis has been an important component of this project.

in the 1990s to online reporting as part of the Garden Wildlife Health project which began in 2013. The latter also includes wild reptile disease investigation, a neglected topic, for the first time in Great Britain (i.e. England, Scotland and Wales). The established network facilitates horizon scanning and provides an early warning system for novel threats, such as the potential risk of incursion of *Batrachochytrium salamandrivorans* into wild amphibians, and reports findings directly to government and the OIE.

To increase the application and conservation impact of our research, ZSL staff have developed and promoted biosecurity guidelines for fieldworkers (http://www.arguk.org/info-advice/advice-notes) and keepers (http://www.gardenwildlifehealth.org/files/2013/06/Amphibian-disease-alert_June-2015.pdf) and developed a library of amphibian disease factsheets for members of the public. In order to characterise distributions of the emerging pathogen Bd, track its spread and identify amphibian species at risk, ZSL staff have collaborated with others to develop a global mapping project for this pathogen (Olson et al., 2013). By combining collaborative field studies with fundamental scientific studies on pathogen genomic architecture and experimental studies on pathogen infectivity and virulence, we have described how the invasion process and disease dynamics are regulated by evolutionary as well as ecological processes. The expeditious use of experimental studies is extremely important for conservation research, being used to identify the causes of newly recognised amphibian diseases, inform on their likely impact, and develop mitigation strategies. At ZSL, we use these findings to develop and improve disease interventions in both captive and wild settings. Recently, we have trialled field interventions to mitigate the impacts of chytridiomycosis on highly threatened amphibian species (Bosch et al., 2015; Garner et al., 2016; Hudson et al., 2016b). These interventions have provided short-term and multi-year respite from threatening disease dynamics (Hudson et al., 2016b).

The Disease Risk Analysis and Health Surveillance (DRAHS) team at ZSL's Institute of Zoology has been investigating methods to assess and minimise the risk of disease in interventions, such as reintroductions, undertaken for conservation purposes. Working with Natural England on its Species Recovery Programme since 1989, we conduct disease risk analysis and post-release health surveillance on a number of conservation priority native species across a broad taxonomic range. Species we have worked with include pool frogs (*Pelophylax lessonae*, Fig. 4) (Sainsbury et al., 2016), sand lizards (*Lacerta agilis*), smooth snakes (*Coronella austriaca*) and northern viper (*Vipera berus*).

Conducting a disease risk analysis (DRA) prior to wild animal translocation is now advised by the IUCN (IUCN / SSC, 2013). A DRA involves describing the translocation pathway and any ecological or geographic barriers crossed during translocation, followed by conducting a comprehensive literature review and liaising with experts to build an understanding of the parasites in the source and destination populations (Sainsbury & Vaughan-Higgins, 2012). A good DRA should also build an understanding of which parasites or non-infectious hazards, such as toxins, may pose a threat to the translocated animals at the release site. In some cases, if little is known about a species' parasites, then a field survey may be undertaken to carry out diagnostic testing for parasites. One of the key objectives is to minimise the risk of the translocated animals releasing pathogens into the ecosystem at the release site. Once a hazard list has been created, a disease risk assessment is conducted by examining the probability of the hazard being released, the likelihood that the population of concern may become exposed to it, and the potential magnitude of these consequences on wider biodiversity.

Importantly, the DRAHS team conducts post-release health surveillance to determine what effects, if any, translocation has had on the health of both translocated animals and naturally-occurring populations at the release site. Surveillance includes health examinations at the destination site as well as post-mortem examination of any animals found dead, and is undertaken over the long-term, in combination with longitudinal population monitoring, to assess the effectiveness of the translocation and to improve future translocation techniques.

EDGE

Launched in 2007, ZSL's EDGE of Existence programme highlights the world's most Evolutionarily Distinct and Globally Endangered species, many of which are receiving little or no conservation attention. The 'top 100' priority EDGE amphibian list was launched in 2008 (Isaac et al., 2012). As well as raising the profile of these extraordinary species, EDGE supports early-career conservationists, called EDGE Fellows, around the globe to develop and implement conservation projects focusing on EDGE species in their native country. To date, the EDGE of Existence programme has supported 68 fellows from 36 countries working on 63 species of EDGE mammals, amphibians, birds and corals; EDGE has supported 19 fellows from 10 countries working on 18 amphibian species. Long-term monitoring programmes have been established for species previously overlooked by conservationists, including the sooglossid frogs of Seychelles, the olm (*Proteus anguinus*) of Croatia, and ambystomatid salamanders of Mexico. Research supported by ZSL has provided insights into the role of chytridiomycosis in the decline of Darwin's frogs (*Rhinoderma*), and the apparent extinction of the Northern Darwin's frog (*R. rufum*) (Soto-Azat et al., 2013b). Current projects include three fellows working on three Mexican ambystomatid salamanders (*Ambystoma granulosum*, *A. lermaense*, and *A. taylori*). The *Ambystoma* project has screened populations for Bd, discovered new populations of *A. lermaense* (Fig. 4), recorded fatal parasitic infection (Michaels et al., 2016b), and established community conservation initiatives to reduce pollution in critical habitats. EDGE also highlights the conservation of the Critically Endangered Chinese giant salamander (Fig. 2), an EDGE priority species, through the support of four EDGE Fellows working on this species. Activities have included assessing the distribution of the remaining wild populations through field surveys (Tapley et al., 2015c) and local ecological knowledge (Pan et al., 2015), investigating the effects of the salamander farming industry (Cunningham et al., 2015), assessing the genetic composition of wild and captive salamanders and developing a community, education and public awareness (CEPA) programme. Plans are also underway to finalise and launch the first EDGE reptile list, with new projects on the West African slender-snouted crocodile (*Mecistops cataphractus*) and Round Island keel-scaled boa (*Casarea dussumieri*).

TRACKING STATUS AND TRENDS OF REPTILES

ZSL's Indicators and Assessments Unit (IAU) is leading the development of global biodiversity indicators to track status and trends of biodiversity over time. The Sampled Red List Index (SRLI) relies on IUCN Red List assessments to track species' extinction risk over time, while the Living Planet Index (LPI), in collaboration with WWF, integrates vertebrate population time series to track population changes over time. Reptiles represent an important component of biodiversity but have previously been overlooked in conservation decision-making; the SRLI assessment included the assessment of 1,500 species of reptile, randomly drawn from the global species list, to give a first-ever representative and global picture of reptile extinction risk. One in five species of reptile was estimated to be threatened with extinction, with extinction risk highest in freshwater systems and tropical regions and amongst turtles and tortoises (Böhm et al., 2013). ZSL's IAU has been directly responsible for Red List assessments for more than 1,000 of the 1,500 SRLI reptile species, in collaboration with over 250 species experts. Work is continuing within the IAU and with collaborators outside ZSL to establish trends in extinction risk over time for this sample, and to develop modelling and machine-learning techniques to aid the assessment process for reptiles and other species groups. For example, identifying associations between extinction risk and biological traits or external environmental factors can help to improve the assessment process for species and estimate the true status of species currently assessed as Data Deficient (and hence potentially threatened with extinction) (Bland & Böhm, 2016; Böhm et al 2016a). Trials of resulting models as predictors of extinction risk are currently underway as part of the Global Reptile Assessment's Australian squamate assessments, in collaboration with IAU. Increasing the availability of reptile population time series data in the Living Planet Database will add to our knowledge on reptile status and trends and a first-look Living Planet Index for reptiles showing population trends over time is currently in preparation (Saha et al. in prep).

Climate change presents an emerging and often slow-acting threat to species, which is more difficult to capture on the IUCN Red List than faster-acting threats such as habitat loss. A trait-based climate change vulnerability assessment for the same random sample of reptile species has been carried out to complement extinction risk assessments, in collaboration with the IUCN Climate Change Unit (Böhm et al., 2016b). This provides the starting point for future work on refining the process and methods of climate change vulnerability assessment and the elucidation of reptile vulnerability to climate change.

The goal of completely mitigating or managing the greater problems that arise due to synergies between existing threats to amphibians and reptiles is still well beyond our grasp. ZSL staff and students will continue to work towards this objective along with an international network of scientists, wildlife managers, educators, veterinarians, conservationists, taxonomists and the *ex situ* community, as such a complex conservation issue requires collaborative approaches and will likely require a range of complex solutions. ZSL has a long history of being a convening institution, bringing scientists together to address important research and conservation issues, and as such it is uniquely positioned to catalyse these efforts. ZSL staff are committed to leading the effort to translate their research outputs into real-world solutions for the benefit of amphibian and reptile conservation.

ACKNOWLEDGEMENTS

We thank the following institutions, collaborators and donors, Amphibian Ark, Amphibian and Reptile Conservation Trust, Amphibial and Reptile Groups of

the UK, Amphibian Survival Alliance, ARC Centre of Excellence for Environmental Decisions (University of Melbourne), Asian Turtle Program, Australian Museum, British and Irish Association of Zoos and Aquariums, British Herpetological Society, Center for Rescue and Conservation of Organism, Chester Zoo, Conservation Research for Amphibians Unique to Cameroon, Darwin, Durrell Institute for Conservation and Ecology, Defra, Durrell Wildlife Conservation Trust, European Association of Zoos and Aquaria, Esmee Faibairn Foundation, Fanjingshan National Nature Reserve, Froglife, Global Reptile Assessment, Guiyang University, Herpetofauna Consultants International, Hoang Lien National Park, Imperial College London, IUCN Red List Unit, IUCN SSC, Kerala Forest Research Institute, Kunming Institute of Zoology, Mohammed Bin Zayed Species Conservation Fund, Monash University, Natural England, Natural History Museum, Nordens Ark, Royal Veterinary College, Rufford Foundation, Shaanxi Normal University, Species experts from around the world (Böhm et al. 2013), Conservation Research Group (St. Alberts College), Stony Brook University, Swansea University, The governments of Dominica and Montserrat, UCL, Thomas Doherty-Bone, Tom Langton, Universidad Nacional Autonoma de Mexico, Universities Federation for Animal Welfare and Wildfowl and Wetland Trust.

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Accepted: 28 February 2017