

Impact case study (REF3)

Institution: University College London		
Unit of Assessment: 5 - Biological Sciences		
Title of case study: Combatting global infectious disease threats to amphibian biodiversity		
Period when the underpinning research was undertaken: 2000 - 2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Trenton Garner Andrew Cunningham	Professor Professor	31 March 2004 - present 5 December, 1988 - present
Period when the claimed impact occurred: Between 2013 and 2020		
Is this case study continued from a case study submitted in 2014? Yes		
1. Summary of Impact		
<p>Amphibians are being lost at a global scale and at a rate far greater than any other vertebrate order. Institute of Zoology (IoZ) scientists were the first to show that two infectious diseases, chytridiomycosis and ranavirosis, are responsible for the global amphibian declines, and have been working ever since to respond to this crisis. They have further shown how globalization is contributing to the spread of the pathogens that cause these diseases and transformed their research into real-world applications that have changed policy, saved amphibians and fulfilled the UK's international responsibilities to respond to the crisis. As a result of this work, IoZ researchers have trained scientists, built research capacity in multiple countries, developed diagnostic tools, and successfully campaigned for the diseases to be listed as notifiable diseases by the OIE (World Organization for Animal Health). Furthermore, their scientific outputs have underpinned the decision by the EU, USA, Canada and Caribbean states to enact trade restrictions to control disease and develop action plans to conserve the threatened species. Scientists at the IoZ are also some of the very few who are trialling strategies for mitigation in the field and the only ones who have reported significant successes.</p>		
2. Underpinning research		
<p>The global amphibian decline remains the worst example of biodiversity loss in vertebrates and is almost entirely attributable to human activities. For nearly 30 years, the Institute of Zoology (IoZ) has been at the forefront of work on infectious disease threats to amphibian biodiversity. Previously, amphibian conservation was wholly focussed on widely accepted threats, for example habitat loss, pollution and invasive species. However, work by IoZ scientists placed amphibian infectious disease firmly on the conservation map. Key research insights from IoZ scientists over the past two decades comprise: identifying the pathogens responsible for global amphibian declines; characterizing when these pathogens pose the greatest risk; and developing the strategies, informing policies and training the international cadre devoted to mitigating these diseases.</p>		
Identifying the pathogens responsible:		
<p>IoZ scientists are at the forefront of pathological investigations of the causes of wildlife mortality. This has played a pivotal role in establishing their credentials in wildlife epidemiology. Specifically, the work of IoZ researchers shows how two groups of pathogens (batrachochytrid fungi and ranaviruses) are consistently and globally associated with recurring amphibian mass mortality events that result in catastrophic population declines. In the case of infections with the <i>Batrachochytrium dendrobatidis</i> fungal species there have</p>		

even been population extirpations and entire species have become extinct [R1, R2, R3, R4, R5].

Characterising when and where the pathogens pose the greatest risk:

IoZ researchers have identified which amphibian species are at greatest risk of extinction, which life history stages are most likely to manifest severe disease, and have characterised the habitats and environments where this is most likely to happen [R1, R2, R3, R4, R5]. They have illustrated key roles for habitat alteration and climate warming in exacerbating the effects of disease [R4, R5], and determined that not all pathogen isolates are equal, identifying the pathogen genotypes that are behind mass mortality events. Using this genetic information, Garner and Cunningham have also identified routes of invasion and the processes by which batrachochytrids and ranaviruses spread at national, regional and even global scales [R1, R2, R3]. They have shown the overwhelming role of trade and other human activities that are behind an ever-growing distribution of lethal batrachochytrids and ranaviruses [R3].

Trials to eliminate infection and disease:

The IoZ team have used their research to run two of the first field trials to reduce infection and disease in wild amphibian populations. Their work on Mallorca has led to the elimination of infections in one of two drainages where infections occurred, and ongoing efforts should lead to complete clearance from the island in the next years [R6]. On Montserrat, field trials led to short-term benefits that may provide the opportunity for frogs to tolerate infections long enough to reproduce and therefore bolster their severely reduced numbers.

3. References to the research

[R1] O'Hanlon, S.J., Rieux, A., Farrer, R.A., Rosa, G.M., Waldman, B., Bataille, A., Kosch, T.A., Murray, K., Brankovics, B., Fumagalli, M., Martin, M.D., Wales, N., Alvarado-Rybak, M., Berger, L., Böll, S., Brookes, L., Clare, F., Courtois, E.A., Cunningham, A.A., Doherty-Bone, T., Ghosh, P., Gower, D.J., Hintz, W.E., Höglund, J., Jenkinson, T.S., Lin, C-F., Laurila, A., Loyau, A., Martel, A., Meurling, S., Miaud, C., Minting, P., Pasmans, F., Schmeller, D., Schmidt, B.R., Shelton J., Skerratt L.F., Smith F., Soto-Azat C., Spagnoletti M., Tessa, G., Toledo, L.F., Valenzuela-Sánchez, A., Verster, R., Vörös, J., Wierzbicki, C., Wombwell, E., Zamudio, K.R., Aanensen, D.M., James, T.Y., Gilbert, M.T.P., Weldon, C., Bosch, J., Balloux, F., Garner, T.W.J., Fisher, M.C. (2018). 'A 20th Century Out-of-Asia Origin of a panzootic threat to global amphibian biodiversity'. *Science*, **360**, 621-627. DOI: <http://doi.org/10.1126/science.aar1965> (165 citations)

[R2] Price, S.J., Garner, T.W.J., Nichols, R.A., Balloux, F., Ayres, C., Mora-Cabello de Alba, A., Bosch, J. (2014). 'Collapse of amphibian communities due to an introduced Ranavirus'. *Current Biology*, **24**, 2586-2591. DOI: <https://doi.org/10.1016/j.cub.2014.09.028> (107 citations)

[R3] Martel, A., Blooi, M., Adriaensen, C., Van Rooij, P., Beukema, W., Fisher, M.C., Farrer, R.A., Schmidt, B.R., Tobler, U., Goka, K., Lips, K.R., Muletz, C., Zamudio, K., Bosch, J., Lötters, S., Wombwell, E., Garner, T.W.J., Cunningham, A.A., Spitzen-van der Sluijs, A., Salvidio, S., Ducatelle, R., Nishikawa, K., Nguyen, T.T., Kolby, J., Van Bocxlaer, I., Bossuyt, F., Pasmans, F. (2014). 'Recent introduction of a chytrid fungus endangers Western Palearctic salamanders'. *Science*, **346**, 630-631. DOI: <http://doi.org/10.1126/science.1258268> (248 citations)

[R4] Bosch, J., Fernández-Beaskoetxea, S., Garner, T.W.J., Carrascal, L.M. (2018). 'Long-term monitoring of an amphibian community after a climate change- and infectious disease-driven species extirpation'. *Global Change Biology*, **24**, 2262-2232. DOI: <http://doi.org/10.1111/gcb.14092> (19 citations)

[R5] Price, S.J., Leung, W.T.M., Owen, C.J., Puschendorf, R., Sergeant, C., Cunningham, A.A., Balloux, F., Garner, T.W.J., Nichols, R.A. (2019). 'Effects of historic and projected climate change on the range and impacts of an emerging wildlife disease'. *Global Change Biology*, **25**, 2648–2660. DOI: <https://doi.org/10.1111/gcb.14651> (13 citations)

[R6] Bosch, J., Sanchez-Tomé, E., Fernández-Lora, A., Oliver, J.A., Fisher, M.C., Garner, T.W.J. (2015). 'Successful elimination of a lethal wildlife infectious disease in nature'. *Biology Letters*, **11**, 20150874. DOI: <https://doi.org/10.1098/rsbl.2015.0874> (68 citations)

4. Details of the impact

Training and capacity-building in amphibian disease detection and treatment:

Since 2013, IoZ researchers and technical staff have trained over 40 amphibian disease researchers from across Europe, Africa, Latin America, the Caribbean, North America and Asia in methods for detecting infections and for isolating fungal and ranaviral isolates [E1]. They have also trained researchers in experimental procedures used for examining disease dynamics in amphibians [E2]. Trainees have applied what they learned to develop their careers at the PhD, post-doctoral and faculty levels. Former trainee Dr Xavier Harrison says "*the research arising from my fellowship at the IoZ was critical in allowing me to secure a permanent academic position at the University of Exeter*". Another, Dr. David Daversa says "*training was critical to my success as a PhD student and Postdoc*" and Dr Vojtech Baláž says "*thanks to the gained skills and knowledge, I have got involved in multiple pathogen related research projects*". Several have established their own national pathogen surveillance programmes, including Professor Jacob Hoglund, who says: "*Without this assistance the first country-wide survey of [Batrachochytrium dendrobatidis] in Sweden....could not have been undertaken*". Trainees have established their own experimental facilities, diagnostic and detection facilities and NGOs, and in several cases acquired funding for their own research programmes in collaboration with IoZ scientists and as independent researchers [E2]. Dr Claudio Soto says he has been "*awarded seven amphibian conservation project grants for work in Chile....for USD540,000, including two consecutive Chilean Science and Technology Fund (the most prestigious scientific funding in Chile)*".

In April 2019 IoZ scientists held a workshop on rapid decision making when disease outbreaks are identified. Contributors from across North America and Europe participated in the simulated emergency meeting and provided inputs that were i) used to manage the site the workshop was based on; ii) used in the management advice for the province in the Netherlands responsible for the management, as well as in the national action plan for *B. salamandrivorans*, written for the Dutch Ministry of Agriculture, Nature and Food Quality; and; iii) co-developed and shared with the United States Department of Interior inter-agency advisory task force on *B. salamandrivorans* "*for uptake in subsequent management recommendations*" [E3].

Meeting UK responsibilities for amphibian disease surveillance and reporting:

Chytridiomycete fungi and ranaviruses are the only OIE-listed pathogens that affect amphibians, and as an OIE member the UK is mandated to report cases of infection with either pathogen. The IoZ has been a partner of the government's GB Wildlife Disease Surveillance Partnership (GBWDSP) since its inception in 2011 and is contracted to carry out national disease surveillance of amphibians. IoZ scientists accomplish this through the IoZ's Garden Wildlife Health project, in which members of the public, ecological consultants and herpetologists are encouraged to submit observations of amphibian morbidity or mortality online. Where possible, the IoZ researchers obtain specimens for post-mortem examination to establish cause of death. Samples are collected as a routine to screen for chytridiomycete fungi and ranaviruses and results are included in the UK's annual submission to the OIE. Novel findings on amphibian disease are communicated to the government's Veterinary Risk Group and reported in quarterly open access GBWDSP reports [E4].

Raising awareness of best practice to safeguard wild amphibian health:

Incorporating the IoZ-founded Frog Mortality Project, the Garden Wildlife Health (GWH) project was launched in 2013: since this time citizen scientists have submitted approximately 2,000 amphibian disease incidents, and IoZ veterinarians have carried out approximately 600 amphibian post-mortem examinations. Running for 30 years, this is the longest-running citizen science amphibian health project globally. IoZ has converted surveillance findings and peer-reviewed studies to a library of 10 amphibian disease factsheets targeted at the public and fieldworkers, available via the GWH website. These provide science-based guidance for habitat management for amphibian disease prevention and control. This includes 2017's Amphibian and Reptile Groups of the UK (ARG UK; 72 regional groups across the UK) and IoZ's 'Amphibian disease precautions: a guide for UK fieldworkers who are working with amphibians' [E4]. In addition, in collaboration with a network of ten zoological organisations, NGOs, industry and government, IoZ researchers created the Amphibian Disease Alert to highlight the risk of *B. salamandrivorans* incursion to the wild in GB, and the biosecurity measures that can be taken by herpetologists with captive collections to mitigate this threat [E4]. Over the last 12 months, the GWH website received >58,000 user sessions by >48,000 users, who viewed >93,000 pages.

Controlling flow of amphibian infections through amphibian trade:

Cunningham's membership on the OIE's Ad Hoc Group for Amphibian Diseases was a direct outcome of the science he produced investigating the infectious disease causes of amphibian declines [E5]. This work led to amphibian chytridiomycosis and ranavirosis and their causative agents being included in the Aquatic Animal Health Code and directly contributed to the addition of *B. salamandrivorans* to the code in 2018 [E5]. Collaborative work by IoZ researchers involved screening more than 5,000 amphibians across four continents and combined experimental assessment of pathogenicity with phylogenetic methods to estimate the threat that the infection poses to amphibian diversity. This work also provided the scientific evidence that *B. salamandrivorans* is a recently emerged amphibian pathogen that arrived in Europe via the transport of Asian amphibians in the pet trade [R3], [E5]. This evidence was used to enact international restrictions on the importation of caudate amphibians into the U.S.A. (U.S. Fish and Wildlife Service listing 201 salamander species as potentially injurious wildlife species through carrying *B. salamandrivorans*) and Canada (adding all salamanders to Schedule II of the Wild Animal and Plant Trade Regulation) and into and between EU member states (European Commission implementation OJ L 062 5.3.2018, page 18) [E5], [E6].

Impacts on the environment and Conservation Action Plans:

IoZ scientists have identified several possible strategies for preventing disease in wild amphibians against both species of fungus that cause chytridiomycosis. Applications of some of these have achieved both short- and long-term reductions and even eliminations of infections, which has directly benefited on-the-ground conservation efforts in the Caribbean and Europe [R9]. More than 2,000 Mallorcan midwife tadpoles were collected from the two drainage basins affected by chytridiomycosis and treated for infections, and the same was done for 220 frogs on Montserrat. Treatment on Mallorca likely saved one region from species extirpation, and lessons learned on Mallorca are being applied more broadly in the Iberian peninsula [E7]. On Montserrat, treatment of dozens of adult frogs provided short-term benefits and further research is now guiding the design of habitat refuges to prevent severe manifestations of disease [E7]. IoZ researchers helped establish captive management and disease diagnostic facilities on Dominica that continue to inform amphibian conservation activities on the island and helped establish a new NGO responding to the additional impacts of habitat loss attributable to Hurricane Maria [E8]. In addition, research, position statements on mitigating disease and field trials have all contributed to national and global action plans for the conservation of species at risk of extinction through to setting priorities for the global conservation of amphibians. As examples, IoZ research has helped develop the conservation actions plans for the Mountain Chicken Frog on Dominica and for Darwin's frogs (two species) in Chile, and

setting priorities of the Infectious Diseases Thematic Working Group of the IUCN's Amphibian Conservation Action Plan [E9].

5. Sources to corroborate the impact

[E1] Fisher MC *et al.* (2018). 'Development and worldwide use of non-lethal, and minimal population level impact, protocols for the isolation of amphibian chytrid fungi.' *Scientific Reports*, **8**, 7772; Leung WTM *et al.* (2017). 'A quantitative-PCR based method to estimate ranavirus viral load following normalisation by reference to an ultraconserved vertebrate target'. *Journal of Virological Methods*, **249**, 147-155.

[E2] Training testimonials: Brazil, Dr. Joice Ruggeri, post-doctoral researcher; Chile, Dr Andrés Valenzuela-Sánchez; Chile2, Dr Claudio Azat Soto; Czech Republic, Dr. Vojtech Baláž, Assistant Professor; Finland, Dr. Bibiana Rojas, Research Fellow; Hungary, Dr. Judit Vörös, museum curator; Sweden, Professor Jacob Höglund; Switzerland, Dr. Benedikt Schmidt, Research Associate; UK, Dr. Xavier Harrison, Lecturer; USA, Dr. Lewis Campbell, post-doctoral researcher; USA2, Dr. David Daversa, Research Fellow

[E3] Workshop testimonial, Dr. A. Spitzen – van der Sluijs and Dr. S. Canessa, workshop facilitators

<https://www.salamanderfungus.org/task-force/decision-science-working-group/>

[E4] APHA animal disease surveillance reports

<https://www.gov.uk/government/collections/animal-disease-surveillance-reports#wildlife;>

<https://www.arguk.org/info-advice/advice-notes/324-advice-note-4-amphibian-disease-precautions-a-guide-for-uk-fieldworkers-pdf-2/file>

ARC Trust Conservation Director testimonial

[E5] OIE testimonial; Defra testimonial on Bsal in UK amphibian trade, Defra; Federal Register / Vol. 81, No. 8 / Wednesday, January 13, 2016

[E6] Commission Implementing Decision (EU) 2018/320 of 28 February 2018 on certain animal health protection measures for intra-Union trade in salamanders and the introduction into the Union of such animals in relation to the fungus *Batrachochytrium salamandrivorans* (notified under document C(2018) 1208); Environment and Climate Change Canada (ECCC)'s Import Restrictions on Salamanders Customs Notice 17-17

[E7] CSIC Mallorca mitigation testimonial

[E8] Montserrat mitigation testimonial; Dominica conservation testimonial, Director of Forestry, Wildlife and Parks; Dominica NGO testimonial, WildDominique

[E9] IUCN mountain chicken frog conservation plan and Darwin frog conservation plan

<https://www.iucn-amphibians.org/wp-content/uploads/2018/11/Mountain-Chicken-SAP-2014-working-draft-FINAL.pdf>; https://b73b2e05-1b4f-4faa-90f2-5d3a34ec037d.filesusr.com/ugd/5a50fd_2ab9b0ad362d4a758e911fa9b4633c60.pdf