

REF2021 Impact Case Study: Combatting global infectious disease threats to amphibian biodiversity

The global amphibian decline remains the most devastating example of biodiversity loss in vertebrates and is almost entirely attributable to human activities. Researchers at ZSL's Institute of Zoology (IOZ) were the first to show that two infectious diseases, chytridiomycosis and ranavirosis, are responsible for the global amphibian declines, and we have been working ever since to respond to this crisis. Our research has shown how globalization is contributing to the spread of the pathogens that cause these diseases, which has 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. In addition, IOZ researchers have 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).

Underpinning research

For nearly 30 years, ZSL has been at the forefront of work on infectious disease threats to amphibian biodiversity. Previously, amphibian conservation was wholly focussed on widely accepted threats, such as habitat loss, pollution and invasive species. However, our research placed amphibian infectious disease firmly on the conservation map. Our research has shown 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 *Batrachochytrium dendrobatidis*, there have been population extirpations and entire species have become extinct.

When and where pathogens pose the greatest risk

As well as identifying which amphibian species are at greatest risk of extinction, and which life history stages are most likely to manifest severe disease, our research has illustrated the roles of habitat alteration and climate warming in exacerbating the effects of disease. We have identified the pathogen genotypes behind mass mortality events, allowing us to better understand routes of invasion and the processes by which batrachochytrids and ranaviruses spread at national, regional and global scales. This research showed the overwhelming role of trade and other human activities that are behind an ever-growing distribution of lethal batrachochytrids and ranaviruses.

Trials to eliminate infection and disease

IOZ researchers ran two of the first field trials to reduce infection and disease in wild amphibian populations. Our work on Mallorca has led to the elimination of infections in one of two areas where infections occurred, and ongoing efforts should lead to complete clearance from the island in the next years. 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.

Conservation impacts

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, isolating fungal and ranaviral isolates and in experimental procedures used for examining disease dynamics. Our trainees have progressed this research at PhD, post-doctoral and faculty levels, and several have established national pathogen surveillance programmes, diagnostic and detection facilities, and NGOs.

In 2019 we held a workshop on rapid decision making when disease outbreaks are identified. Contributors from across North America and Europe provided inputs that were used to manage the site the workshop was based on; 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 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.

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. 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. We achieve this through the Garden Wildlife Health project, in which members of the public, ecological consultants and herpetologists submit observations of amphibian morbidity or mortality online. 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 GBWDSP reports.

Raising awareness of best practice to safeguard wild amphibian health

The Garden Wildlife Health project, which incorporated the IOZ-founded Frog Mortality Project, was launched in 2013. Since this time citizen scientists have submitted approximately 2,000 amphibian disease incidents, and ZSL's veterinarians have carried out over 600 amphibian post-mortem examinations. This is the longest-running citizen science amphibian health project globally. We have created ten amphibian disease factsheets targeted at the public and fieldworkers that 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'. In collaboration with 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 Great Britain, and the biosecurity measures that can be taken by herpetologists with captive collections to mitigate this threat.

Controlling spread of amphibian infections through amphibian trade

IOZ's Professor Andrew 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. This work led to amphibian chytridiomycosis and ranaviruses 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. 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. This evidence was used to enact international restrictions on the importation of caudate amphibians into the USA (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.

Impacts on the environment and Conservation Action Plans

IOZ researchers have identified 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. 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. On Montserrat, treatment of adult frogs provided short-term benefits and further research is now guiding the design of habitat refuges to prevent severe manifestations of disease. 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. 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 in Chile, and setting priorities of the Infectious Diseases Thematic Working Group of the IUCN's Amphibian Conservation Action Plan.



Majorcan midwife toad (*Alytes muletensis*). Photo: P. Jervis