INSIGHTS

PERSPECTIVES

ECOLOGY

Change is key to frog survival

Changes in host traits help amphibian populations to survive chytrid infection

By **James P. Collins**

Outbreaks of infectious wildlife diseases often reduce host population size, but rarely cause extinction. An exception is the ongoing global decline of amphibians (*1*). A pathogenic chytrid fungus, *Batrachochytrium dendrobatidis* (Bd), may affect amphibian species little to not at all, predictably reduce population size, or have a role in extinction (*2*). On page 1517 of this issue, Voyles *et al.* (*3*) report that at three sites in Panamá, amphibian population sizes declined substantially, and most species went missing after the chytrid fungus emerged in their habitats. However, other frog species survived as Bd became endemic (see the figure). Only 9 frog species to date (~12% of species before the fungus arrived) returned to population levels approaching those estimated before Bd emerged (*4*). Voyles *et al.* show that the frog species that recovered did so as a result of changes in their traits and not due to a decrease in Bd's pathogenicity.

The stage for this research was set in 2004, when Bd's arrival triggered an outbreak of the infectious disease chytridiomycosis that coincided with frog declines and extinctions at El Copé, Panamá (see the photos) (*5*). More outbreaks followed at El Valle in 2006 and Campana in 2007. The wave-like declines echoed patterns seen in South America (*6*) and from Mexico to Costa Rica (*7*). After the frog population sizes reached low points between 2006 and 2010, ongoing observations revealed increases in the populations of some species (*3*, *8*), a pattern that has also been reported in Australia (*9*). What caused the populations of some species to recover at the three study sites?

Voyles *et al.* predicted that hosts would recover because of a decrease in Bd pathogenicity, an increase in host resistance, or

A white-spotted Cochran frog (*Sachatamia albomaculata*) in Parque Nacional Omar Torrijos, El Copé, Panamá.

PHOTO: SCOTT CONNELLY

both. Bd isolates cryopreserved in 2004 as the fungus emerged in the region provided a historical baseline. In their experiments, the authors paired these samples with Bd isolates collected in 2012 to 2013, after some frog populations had increased in size. This pairing allowed the team to ask whether the pathogenicity of Bd collected recently had changed compared to Bd collected nearly a decade before. Traits assessed included changes in Bd reproductive rate, size of infective zoospores, immune evasion, outcome of infection in live hosts, and genomic structure. By all these measures, Bd was as pathogenic in 2012 to 2013 as it was nearly a decade before. Bd isolates cryopreserved in 2004 and those collected in 2012 to 2013 clustered within the Global Pandemic Lineage (Bd-GPL) (*10*). There was no strong phylogenetic divergence between isolates over 10 years—long enough for pathogenicity to decrease in vitro (*11*).

Voyles *et al.* next used two approaches to determine whether the frogs changed. The first approach was based on previous research, which analyzed whole-skin secretions to show that innate immune defenses vary substantially among rainforest stream species (*12*). Voyles *et al.* compared the effectiveness of whole-skin secretions at inhibiting the amphibian chytrid, using samples collected from frogs at locations where Bd was endemic and at sites where Bd was absent. The capacity of skin secretions to inhibit Bd varied substantially among species and was much greater in frogs from sites where the amphibian chytrid was endemic. A change in antimicrobial secretions appears to confer improved defense against the fungus, causing a shift from an outbreak phase to an endemic phase, in which hosts and pathogen coexist.

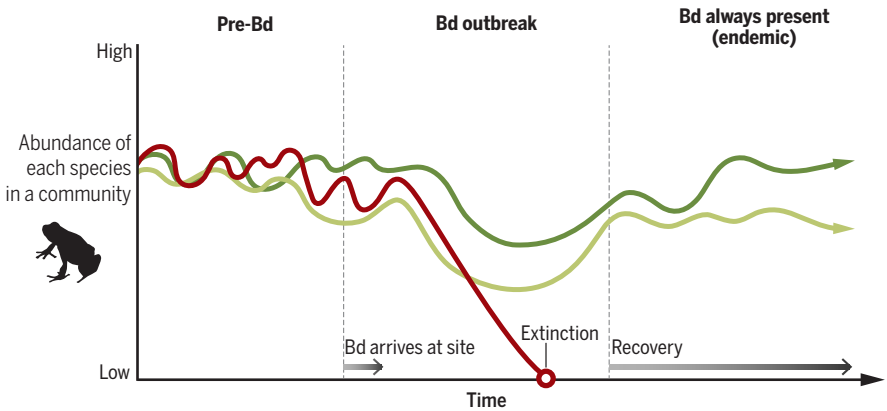
Second, the authors studied clown frogs (*Atelopus varius*), a species susceptible to Bd. Some clown frogs had been collected near El Copé before Bd emerged and bred in an off-site facility. The team tested the inhibitory effectiveness against Bd of skin secretions from these frogs, which had never been exposed to the pathogen. They then compared it with *A. varius* collected from sites where Bd is now endemic. The inhibitory effectiveness against Bd was greater in the latter frogs than in captive-bred individuals. Frogs never exposed to Bd thus had a reduced capacity to defend against it.

It remains to be shown how skin secretions came to be more effective after Bd invaded. If the capacity to resist epidermal fungi existed before Bd emerged, then its arrival perhaps stimulated in individuals a standing physiological capacity to respond to microscopic fungi in general, a capacity that varies among species (*12*). Alternatively, mutations in host genomes favoring a capacity to resist Bd may have occurred over the ~10 years of the study. That would be rapid, given that these frog species likely have a generation time of more than 6 months. Finally, the capacity to resist a Bd-like fungus may have been a polymorphic trait, in place in these frogs before Bd invaded. If so, selection by Bd presumably shifted allele frequencies to those favoring a defense against Bd, a novel fungal threat but one perhaps within the scope of variation in antimicrobial secretions that could be produced. Other host defense traits (such as behavior or life history characters) could be as important as skin secretions.

Why do infectious disease outbreaks in tropical frogs end? In Panamá and at other sites, host extinction, or in general death of susceptible individuals, is part of the answer. Based on the study by Voyles *et al.*, another part of the answer is that initially susceptible hosts become less susceptible through changes in their capacity to tolerate or resist Bd, fostering a transition from an emergent to endemic epidemiological phase. To understand fully why some Neotropical frog species are unaffected by Bd, others decline and recover, and yet others go extinct, scientists must learn a lot more about how frogs react to pathogens. ■

Surviving a fungal killer

In amphibian communities, population sizes and number of species vary with time. When Bd's arrival triggers a chytridiomycosis outbreak, populations fall below the lower limits of their pre-Bd population sizes. Some species go extinct, but others recover partially or fully as the amphibian chytrid becomes endemic (always present) in the community.



The population of this amphibian species initially falls after Bd's arrival. Over time, defenses against the fungus improve allowing recovery to pre-Bd levels.

The population of this species falls more sharply and recovers only partially as Bd becomes endemic because defenses against Bd are less effective.

Defenses against Bd are insufficient and the species goes extinct during the outbreak phase.

A stream in Parque Nacional Omar Torrijos, El Copé, Panamá, where Bd has caused amphibian declines.

Arizona State University, School of Life Sciences, Tempe, AZ 85287, USA. Email: jcollins@asu.edu

CREDITS: (GRAPHIC) N. CARY/*SCIENCE*; (PHOTO) JAMIE VOYLES

REFERENCES AND NOTES

1. J. P. Collins, M. L. Crump, *Extinction in Our Times. Global Amphibian Decline* (Oxford Univ. Press, 2009).
2. *Batrachochytrium salamandrivorans* is associated with declines in Europe.
3. J. Voyles *et al.*, *Science* **359**, 1517 (2018).
4. A. J. Crawford *et al.*, *Proc. Natl. Acad. Sci. U.S.A.* **107**, 13777 (2010).
5. K. R. Lips *et al.*, *Proc. Natl. Acad. Sci. U.S.A.* **103**, 3165 (2006).
6. K. R. Lips *et al.*, *PLOS Biol.* **6**, e72 (2008).
7. T. L. Cheng *et al.*, *Proc. Natl. Acad. Sci. U.S.A.* **108**, 9502 (2011).
8. N. F. Angeli *et al.*, *J. Herpet.* **49**, 388 (2015).
9. D. A. Newell *et al.*, *PLOS ONE* **8**, e58559 (2013).
10. E. B. Rosenblum *et al.*, *Proc. Natl. Acad. Sci. U.S.A.* **110**, 9385 (2013).
11. P. F. Langhammer *et al.*, *PLOS ONE* **8**, e77630 (2013).
12. D. C. Woodhams *et al.*, *J. Wildl. Dis.* **42**, 207 (2006).

10.1126/science.aat1996