New insights into how deadly amphibian disease spreads and kills

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A pile of southern mountain yellow-legged frogs in California's Sierra Nevada, where San Francisco State University Professor Vance Vredenburg and colleagues tracked the spread of the deadly amphibian disease *Chytridiomycosis* during a 13-year period. New research by Vredenburg and colleagues, published in *PNAS*, suggests that high population densities in frog communities could promote re-infection among frogs, causing the intensity of the disease to reach dangerously high levels. Reducing population density could be a way to limit infection intensity and allow some frogs to survive a *Chytridiomycosis* epidemic. Credit: Vance Vredenburg

Scientists have unraveled the dynamics of a deadly disease that is wiping out amphibian populations across the globe.

New findings, published today in the *Proceedings of the National Academy of Sciences*, suggest that infection intensity -- the severity of

the disease among individuals -- determines whether frog populations will survive or succumb to an amphibian fungal disease called *Chytridiomycosis*. The research identifies a dangerous tipping point in infection intensity, beyond which Chytrid causes mass mortalities and extinctions, and finds that continual re-infection causes the disease to reach this threshold.

Dangerous Threshold

"We found that mass frog die-offs only occur when the severity of the Chytrid infection reaches a critical threshold among the individual frogs," said Vance Vredenburg, assistant professor of biology at San Francisco State University. "Now that we know this limit, which is a specific number of fungal spores per frog, conservation efforts may be able to save susceptible frog species by preventing the disease from reaching this point."

In the first of two separate studies, Vredenburg and colleagues tracked the invasion and spread of Chytrid among frogs in California's Sierra Nevada Mountains during a 13-year period, focusing on two species of the mountain yellow-legged frog (*Rana muscosa* and *Rana sierrae*). The study found that Chytrid is particularly destructive when it invades a previously unexposed population, similar to the smallpox epidemics that devastated human populations in the 17th and 18th centuries.

"When Chytrid hits naďve host populations, it grows so quickly that the usual checks and balances, which prevent a pathogen from causing extinction, don't have a chance to kick in," Vredenburg said. "We are living in a time when the global movement of people and goods is likely spreading this disease to areas where it wasn't present before, interrupting the natural equilibrium between the pathogen and its hosts."

The authors observed no evidence of Chytrid prior to the die-offs, a

finding that stands in contrast to previous studies, which have suggested that Chytrid may be ubiquitous in the environment and that frog hosts were simply becoming more susceptible to a common microbe.

Chytrid is caused by a microscopic aquatic fungus called *Batrachochytrium dendrobatidis* (Bd) that lodges into frogs' skin. Chytrid has already wiped out more than 200 frog species and poses the greatest threat to vertebrate biodiversity of any known disease.

San Francisco State University Professor Vance Vredenburg collects a skin swab from a southern mountain yellow-legged frog in California's Sierra Nevada where he and colleagues tracked the spread of the deadly amphibian disease *Chytridiomycosis* during a 13-year period. New research by Vredenburg, published in *PNAS*, identifies a dangerous tipping point in infection intensity and suggests that mass frog deaths only tend to occur once infection intensity reaches an average of more than 10,000 fungal spores per skin swab. *Chytridiomycosis* is caused by an aquatic fungus called *Batrachochytrium dendrobatidis*. Credit: Natalie Reeder

Extinction versus survival

A companion study used mathematical models and individual-based infection data to explore why the disease drives some frog populations to

extinction, while others survive with the disease for years. This study compared frog populations in Sequoia Kings Canyon National Park, where a wave of disease has largely eliminated the mountain yellow-legged frog in the last five years, to frogs in Yosemite National Park, where Chytrid has been present for more than a decade and a smaller number of frogs have been living with the infection.

Results of this study suggest that frogs' chances of survival depend on infection intensity, not simply the presence or absence of the infection. The adult frogs in Yosemite were infected with only low level infections and individuals were found to lose and regain the infection over time.

An unusual feature of Chytrid, which makes it particularly virulent, is that it cannot replicate on a frog's body in the same way as cancer or a viral infection. A key part of the Chytrid growth lifecycle involves a swimming fungal spore that must either re-infect the same frog host after it is released outside the body or find a new host to continue growing.

Suggested Solutions

Both studies find that infection intensity, which escalates through frogs being re-infected, is central to understanding how to save amphibians from mass extinction caused by Chytrid. High population densities in naďve frog communities could promote re-infection, causing the infection to reach a dangerously high level. The importance of population density is supported by evidence from the surveys in Sequoia Kings Canyon National Park where patterns of infection spread was consistent with frog movement patterns, suggesting that frogs help re-infect each other through contact.

The authors suggest that conservation efforts should focus on limiting the severity of the fungal infection on individuals during an outbreak of

Chytrid. For example, treating individual frogs with anti-fungal compounds, or probiotics, temporarily removing tadpoles or reducing population density might lower infection intensity and allow some frogs to survive an epidemic. Such interventions could promote a stable relationship with the disease where the infection reaches an endemic steady state.

"These results are about more than just frogs," Vredenburg said. "They are about disease, how and why it spreads and how some populations can be wiped out by a disease while others survive. This is important to all of us considering that 60 percent of emerging diseases in humans come from wildlife. The models we have provided may be adapted by ecologists to better understand similar diseases that affect humans or cattle or corn, for example."

"Dynamics of an emerging disease drive large-scale amphibian population extinctions" was authored by Vance T. Vredenburg, assistant professor of biology at San Francisco State University, in collaboration with Roland A. Knapp, Tate S. Tunstall and Cheryl J. Briggs.

"Enzootic and Epizootic Dynamics of the Chytrid Fungal Pathogen of Amphibians" was authored by Cheryl J. Briggs from University of California, Santa Barbara in collaboration with Roland A. Knapp and Vance T. Vredenburg.

Both studies were published today in the Online Early Edition of the Proceedings of the National Academy of Sciences. This research was supported by the National Science Foundation.

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