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Bullfrogs - a Trojan horse for a deadly fungus?

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Abstract

Did you know that *amphibians* have very special skin? They use their skin to breathe and drink water. But a skin-eating *fungus, Batrachochytrium dendrobatidis (Bd)*, is killing them. Since the 1970s, over 200 species of amphibians have declined or gone extinct. Amphibians in the eastern US seem to be unaffected by *Bd*, but *Bd outbreaks* have caused mass die-offs in the western US. A frog species native to the eastern US, American bullfrogs *(Rana catesbeiana)* (Figure 1), may have helped spread *Bd*. Bullfrogs don't show signs of sickness when they are infected, which makes them *Bd vectors*. This is alarming because they are traded alive globally and could continue spreading *Bd* to amphibians around the world. Here, we analyzed the history of bullfrogs and *Bd* in the western US. We found a link between bullfrogs' arrival and *Bd* outbreaks. Then we predicted areas with high disease risk. These results can help us control the spread of *Bd* and save amphibians.

Introduction

Many amphibians, such as frogs and salamanders, live both on land and in water for some or all of their lives. Most need water specifically for reproduction and laying eggs. This makes them vulnerable to aquatic *pathogens*, such as the deadly fungus *Batrachochytrium dendrobatidis (Bd for short)* (Figure 2a). *Bd* causes the disease *chytridiomycosis*, which attacks amphibian skin. Amphibian skin is more than an outer covering; it helps absorb water and important *electrolytes*. In fact, some lungless amphibians even use their skin to breathe!

Bd can kill an amphibian in a matter of weeks (Figure 2b). Since the 1970s, the fungus has driven the decline or extinction of over 200 amphibian species worldwide. That makes chytridiomycosis the most devastating wildlife disease ever recorded.

How did *Bd* spread so far and wide? If a pathogen is so deadly that it kills all its hosts, it will soon die off without them. However, each amphibian species responds differently to the infection. Many die quickly, while others carry *Bd* for a long time without any signs of sickness. These species are called carriers and can transmit the disease to other amphibians without succumbing to the disease themselves. The American bullfrog, native to the eastern US, is one of

Figure 1: The American bullfrog *(Rana [Aquarana] catesbeiana)* is native to the eastern United States. Bullfrogs are effective carriers of *Bd*. We think that human movement of bullfrogs – such as the pet and food trade – has contributed to spreading *Bd* around the world.
(Photo credit: Carl D. Howe)

them. *Bd* has been recorded in the eastern US since the 1880's. Scientists think that bullfrogs may have spread *Bd* to the western US when settlers brought them from the East and released them in the West. Here, we tested this hypothesis. If indeed bullfrogs played a role in the spread of *Bd*, then they must have arrived before or at the same time as the fungus. Using our findings, we predicted where *Bd* might occur next to help prevent more *Bd* outbreaks.

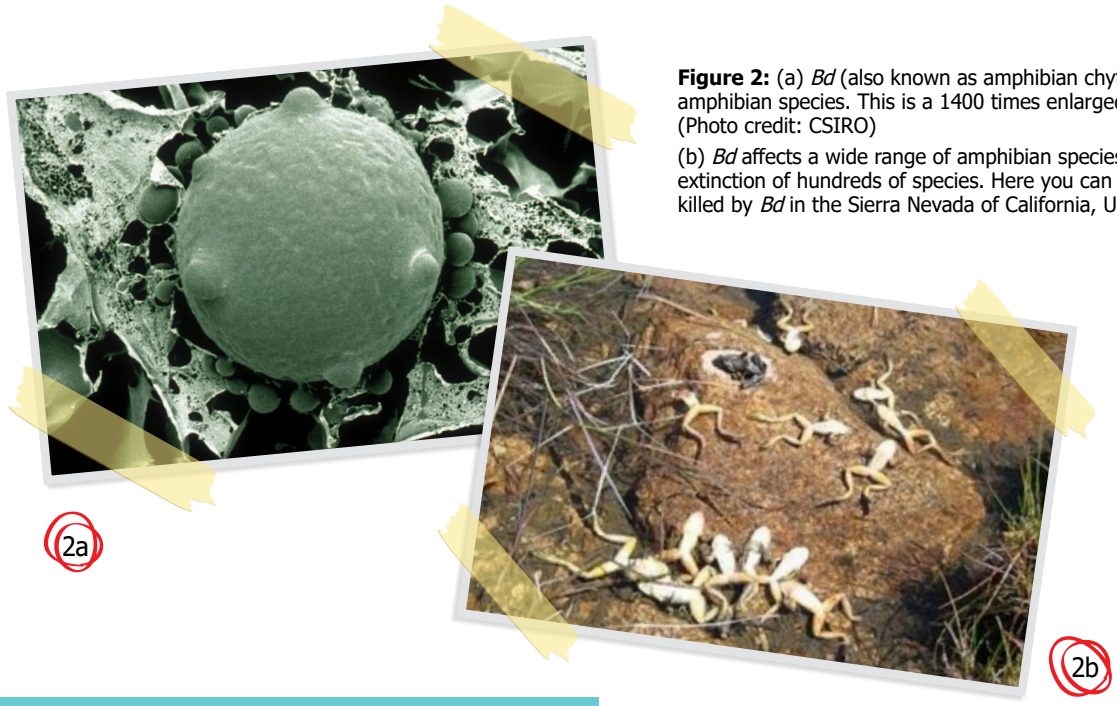

Figure 2: (a) *Bd* (also known as amphibian chytrid) can infect a wide range of amphibian species. This is a 1400 times enlarged picture of the aquatic fungus. (Photo credit: CSIRO)

(b) *Bd* affects a wide range of amphibian species and has caused the decline and extinction of hundreds of species. Here you can see Mountain yellow-legged frogs killed by *Bd* in the Sierra Nevada of California, USA. (Photo credit: Vance Vredenburg)

Methods

Invasion history: We studied *watersheds* west of the Rocky Mountains – outside of the native range of bullfrogs.

First, we looked if watersheds

- currently have both the fungus and the bullfrog,
- currently have only *Bd*,
- currently have only bullfrogs.

Using natural history museum records, we compared the timing of each species' earliest occurrence in the watersheds that have both *Bd* and bullfrogs.

We categorized watersheds depending on when bullfrogs or the fungus arrived:

1. *Bd* arrived in the same year or after bullfrogs
2. *Bd* arrived before bullfrogs

***Bd* suitability model:** All pathogens (including *Bd*) need suitable *habitat* and *host* species to spread.

- Habitat suitability (how well *Bd* can survive and spread in an area) depends on the environmental conditions and human influences of the area, such as: temperature, precipitation, land cover, land use, and human population density.
- Host species: We analyzed amphibian species richness (the number of different frog and salamander species that live in the same area) in mainland North America using data from two online resources (AmphibiaWeb and the IUCN Red List).

We created a model that combined these *abiotic* and *biotic* factors and calculated a "*Bd* suitability score" for each watershed. We then looked at areas of overlap, where both bullfrogs live and where habitats are highly suitable for *Bd*. These areas have the greatest risk of disease outbreaks.

Results

- We investigated 6141 watersheds in the western US and found that 202 have only *Bd*, 301 have only bullfrogs, and 100 have both.
- Historic data revealed that bullfrogs appeared either before or at the same time as *Bd* in most (83 out of 100) of the watersheds shared by both species.

- We identified mountain ranges along the West Coast of the US, the highlands of Central Mexico, the Coastal Plains of the Southeast US, and the Ozark Mountains as high *Bd* suitability areas (Figure 3).
- Of the 301 watersheds where only bullfrogs were found, 173 of them overlap with high *Bd* suitability areas. These areas have the highest risk of disease outbreaks.

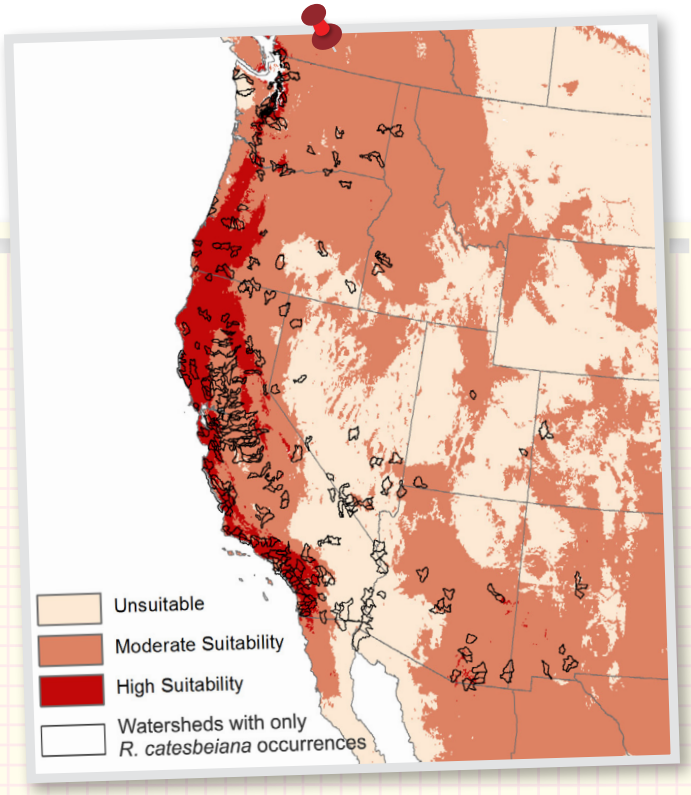

Figure 3: Areas predicted to have high habitat suitability for *Bd* are dark read. Watersheds in the Western US that have American bullfrogs but no record of *Bd* are outlined in black.

Which areas would have the highest risk of *Bd* outbreaks?

Discussion

We show that bullfrogs may have played a major role in the spread of *Bd* in the western US. We think that *Bd evolved* together with bullfrogs in the eastern US, which would explain why the bullfrogs can tolerate the fungus. Frogs and salamanders in the western US may get sick or die from *Bd* because they did not evolve with the pathogen and have not had the chance to develop defenses against it, like bullfrogs have. Bullfrogs are traded globally as pets, for research, as food (have you ever tried frog legs?), and as fish bait. Bullfrogs that are released or escape into new areas could spread *Bd* and other diseases to amphibian populations all over the world that have not yet come in contact with *Bd*.

This would be devastating in many ways. Amphibians are an essential part of *ecosystems* and *food webs*. They are an important food source for predators like birds, mammals, and snakes. They also eat insects like flies, ticks, and mosquitos that carry and transmit diseases, so they protect us against insect-borne diseases like malaria and dengue fever. Also, frogs and salamanders help connect aquatic and terrestrial food webs because they live and grow both in water and on land. Amphibians are essential animals in our earth's ecosystems!

Identifying the areas that are at high risk of disease outbreaks can help us control the spread of *Bd* and prevent the fungus from entering these still unaffected ecosystems before it is too late. But we also need to monitor and study amphibian populations closely. If we have a clear understanding of their host-pathogen relations, we could discover ways to increase their defenses against this deadly pathogen.

Conclusion

Amphibians survived the dinosaur extinction, but now they are disappearing rapidly. While *Bd* is a major threat, it is not the only one. Habitat destruction, non-native species, climate change, and pollution also contribute to worldwide declines in amphibian populations. But don't lose hope. Instead, help amphibians by taking simple actions:

- Let wild amphibians stay in the wild. Don't keep them as pets.
- Never release your pet amphibian - it does not belong in the wild.
- Protect amphibians' local habitats by switching to environmentally friendly cleaning supplies, as well as organic pesticides and fertilizers.
- Keep our waterways and coastal shorelines clean and volunteer for a local clean-up day.

Glossary of Key Terms

Abiotic factors: non-living chemical and physical parts of the ecosystem.

Amphibians: cold-blooded vertebrates (animals with backbones) that typically live part of their lives in water and part on land. The three modern orders of amphibians are frogs, salamanders, and caecilians.

Biotic factors: living things in an ecosystem. Living things include plants, animals, bacteria, fungi and more.

Carrier: an organism (human, plant, or animal) who carries a microorganism that causes a disease but does not show any sign of the illness. They may serve as a source of infection for others.

Chytridiomycosis: an infectious disease in amphibians, caused by the aquatic chytrid fungus *Batrachochytrium dendrobatidis (Bd)*. With chytridiomycosis, the infected skin becomes very thick. This is deadly to amphibians because amphibians absorb water and electrolytes through their skin. Abnormal electrolyte levels can cause the heart to stop beating and the animal dies. (For more information, check out the reference below).

Ecosystem: a biological community of interacting organisms and their physical environment.

Electrolytes: salts and minerals, like sodium and potassium, that are important for our bodies to stay healthy.

Evolution (verb: to evolve): change in the genetic composition of a population or a species over generations.

Extinction: end of a species, dying out. About 65 millions year ago, a mass extinction killed off many dinosaurs.

Food web: an interlocking set of species that eat and are eaten by each other in an ecosystem.

Fungus: (plural: fungi) a diverse group of organisms that live by decomposing and absorbing the organic material in which they grow. Mushrooms, molds and mildew are examples of fungi. Fungi can live in air, in soil, on plants and in water.

Habitat: a natural environment of an animal or plant (or other living organism). It provides food and shelter.

Host: an animal or plant on or in which a parasite (another organism that cannot survive without a host) lives.

Native (species): a species that normally lives and thrives in a particular ecosystem.

Outbreak: a sudden increase in occurrences of a disease in a particular time and place.

Pathogen: a virus, bacterium or other microorganism that can cause disease in another organism. For example HIV, which causes AIDS in humans; or *Vibrio cholerae*, which causes cholera in humans.

Vector: an organism that transmits a pathogen to a host (example: mosquitoes are vectors of malaria to humans).

Watershed: an area of land where all the precipitation and runoff drain to a common body of water (such as a stream, river, lake etc.).

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Check your understanding

1 What is chytridiomycosis? What causes it?

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2 The deadly fungus *Bd* has been spreading rapidly. What makes *Bd* such a devastating pathogen?

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3 What do you think: Is it in the fungi's interest to kill all of their hosts?

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4 There are records of *Bd* in the eastern US as early as the 1880s. Why aren't there any *Bd* related extinctions recorded in the eastern US while there are some in the western US?

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5 Scientists formed a hypothesis about the spread of *Bd* in the western US. What was their hypothesis and how did they test it?

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6 Scientists predicted the areas under highest risk of disease outbreak. How did they do that?
