Amphibian Warning Bell of Mass Extinctions

"Amphibians are an ancient organism, which has survived past extinctions, and is telling us that something is wrong right now (on Earth). The question is whether we humans will listen before it's too late." - Vance Vredenburg, Ph.D., Biology, San Francisco State

Already steeply in decline, the critically endangered yellow-legged frogs died at Sixty Lake Basin in California in August 2006. Their killer is the Chytrid fungus (*Chytridiomycosis)* which has devastated amphibian populations from California to Panama to Brazil to Australia over the past decade. Image courtesy David Wake, Ph.D. and Vance Vredenburg, Ph.D., co-authors of August 12, 2008, report in the *Proceedings of the National Academy of Sciences.*

August 15, 2008 Berkeley, California - Frogs, toads, salamanders, newts and caecilians – all amphibians – are among the oldest creatures on Earth. Amphibians have survived the last four of five mass extinctions on this planet.

[Editor's Note: From the August 12, 2008, *Proceedings of the National Academy of Sciences,* "Are We in the Midst of the Sixth Mass Extinction? A view from the world of amphibians. Authors: David B. Wake, Director of Herpetology, Museum of Vertebrate Zoology, University of California, Berkeley, California; and Vance T. Vredenburg, Prof. of Biology, San Francisco State University, San Francisco, California. See websites below.

"Five Mass Extinctions

It is generally thought that there have been five great mass extinctions during the history of life on this planet. In each of the five events, there was a profound loss of biodiversity during a relatively short period.

1) The oldest mass extinction occurred at the **Ordovician–Silurian boundary (≈ 439 Million Years Ago)**. Approximately 25% of the families and nearly 60% of the genera of marine

organisms were lost. Contributing factors were great fluctuations in sea level, which resulted from extensive glaciations, followed by a period of great global warming. Terrestrial vertebrates had not yet evolved.

2) The next great extinction was in the **Late Devonian (≈364 Mya)**, when 22% of marine families and 57% of marine genera, including nearly all jawless fishes, disappeared. Global cooling after bolide impacts may have been responsible because warm water taxa were most strongly affected. Amphibians, the first terrestrial vertebrates, evolved in the Late Devonian, and they survived this extinction event.

3) The **Permian–Triassic extinction (≈ 251 Mya)** was by far the worst of the five mass extinctions; 95% of all species (marine as well as terrestrial) were lost, including 53% of marine families, 84% of marine genera, and 70% of land plants, insects, and vertebrates. Causes are debated, but the leading candidate is flood volcanism emanating from the Siberian Traps, which led to profound climate change. Volcanism may have been initiated by a bolide impact, which led to loss of oxygen in the sea. The atmosphere at that time was severely hypoxic, which likely acted synergistically with other factors. Most terrestrial vertebrates perished, but among the few that survived were early representatives of the three orders of amphibians that survive to this day.

4) The **End Triassic extinction (≈199–214 Mya)** was associated with the opening of the Atlantic Ocean by sea floor spreading related to massive lava floods that caused significant global warming. Marine organisms were most strongly affected (22% of marine families and 53% of marine genera were lost), but terrestrial organisms also experienced much extinction. Again, representatives of the three living orders of amphibians survived.

5) The most recent mass extinction was at the **Cretaceous–Tertiary boundary (≈65 Mya)**; 16% of families, 47% of genera of marine organisms, and 18% of vertebrate families were lost. Most notable was the disappearance of nonavian dinosaurs. Causes continue to be debated. Leading candidates include diverse climatic changes (e.g., temperature increases in deep seas) resulting from volcanic floods in India (Deccan Traps) and consequences of a giant asteroid impact in the Gulf of Mexico. Not only did all three orders of amphibians again escape extinction, but many, if not all, families and even a number of extant amphibian genera survived.

6) **A Sixth Extinction?**

The possibility that a sixth mass extinction spasm is upon us has received much attention. Substantial evidence suggests that an extinction event is underway."]

Since the 1990s, amphibians have been dying out around the world in increasing numbers. In fact, 2008 was declared the Year of the Frog by the Amphibian Ark organization dedicated to saving amphibians.

One of the culprits behind the alarming amphibian die-off is called the chytrid (KYE-trid) fungus. Surprisingly, it was not identified by scientists until 1998, only ten years ago. By 2008, after ten years of intense study, no one yet understands how the chytrid fungus is killing frogs, toads, salamanders and other amphibians. Another mystery is how does the fungus spread so fast? Scientists have documented year-by-year waves of amphibian die-offs moving over vast geographic distances. Once the chytrid fungus is in a new region, most of the amphibians are killed in only a year's time.

In the August 12, 2008, *Proceedings of the National Academy of Sciences*, a zoologist and biologist presented data about the question: Is Earth now in a 6th mass extinction that could see thousands of species on land, in water and air die off forever, as happened 65 million years ago when it is hypothesized that an asteroid slammed into the Gulf of Mexico and wiped out the dinosaurs along with 70% of all earth life in the fifth mass extinction event? Scientists are concerned that a growing data base of die-offs means the answer is yes and that the increasing decline of amphibians is the alarm bell.

This time, human civilization is equivalent to the destructive asteroid. Our human territories continue to expand, which shrinks the natural wild habitats. Human industries are warming the planet, forcing animals and plants to move with temperature changes into new territories. Changing ecosystems provoke insects, bacteria, viruses, algae and fungi to also change their tactics in living off other earth creatures. Further, our massive commercial food industries are filling soils and plants with a wide range of pesticides that scientists know can be especially hard on amphibians that breathe through their skin.

One of the NAS Proceedings authors is Prof. Vance Vredenburg, Asst. Professor of Biology at San Francisco State University. He says that because amphibians are such ancient earth animals that survived previous mass extinctions, we humans should all be alarmed that "something is wrong in our world. We humans might be doing OK right now, but the amphibians are doing poorly." The question is - will humans pay serious attention to the amphibian warning before it's too late for all life?

Prof. Vredenburg's co-author is David Wake, Curator of Herpetology in the Museum of Vertebrate Zoology at the University of California-Berkeley. This week I talked with him about data from the 2004 first global assessment of all species in the world. That study concluded there are about 6,000 species of amphibians. Of those, one-third were on the brink of extinction and another 40% are threatened with extinction. And for reasons unknown, the chytrid fungus is the leading killer of amphibians.

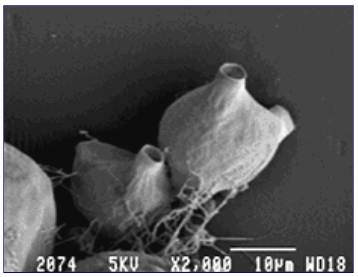
Interview:

David Wake, Ph.D., Curator of Herpetology, Museum of Vertebrate Zoology, University of California-Berkeley: "By 2005 to 2006, the results were in and the chytrid fungus has had a profound impact on populations of amphibians, particularly in Central America and the mountains of California and in the tropical mountains of Australia.

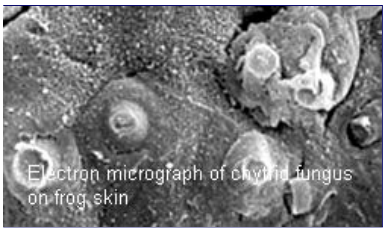
HOW DOES THE CHYTRID FUNGUS KILL?

Left: *Chytrid* fungus infection shows in the pink underbelly of green tree frog.
Right: Great barred frog has a severe *Chytrid* fungus infection that is causing its skin to peel off.
Images by Australia National Parks and Wildlife Service.

We don't know exactly. That's the question I always ask in scientific meetings. What is the immediate cause of death? There are hypotheses. The chytrid fungus is a rather simple organism – genetically complex – but simple in structure that invades the superficial surface of the skin of amphibians. The chytrid fungus lives on keratin. When we feel our skin, that's what we are feeling. [Keratins are the main constituent of structures that grow from the skin.] Keratin is the outermost surface. So, the chytrid fungus eats this keratin stuff that was not considered nutritious for organisms, but the chytrid fungus favors keratin.



Above: *Chytrid* fungus cells about to release more spores.
Below: Electron micrograph of chytrid fungus on frog skin.
Photomicrographs by Lee Berger, Australia's Commonwealth Scientific and Industrial Research Organization (CSIRO).



When an amphibian gets a massive infection of the chytrid fungus, it probably interferes with the amphibian's respiration because even those creatures with excellent lungs actually have most of the gaseous exchange across their moist skins. So, they suffocate in their own skin. I can't prove that, but it's a general consensus of researchers.

BECAUSE AMPHIBIANS BREATHE THROUGH THEIR SKIN.

They do. They get 90%, or in some cases 100%, of their respiration through their skin. There are many frogs and salamanders that are even lungless. So, the lungs are not necessary at all for amphibian respiration. Amphibians depend upon their highly vascularized, moist skins for respiration.

Chytrid Fungus "Jumps Boundaries and Causes Havoc"

PROF. VREDENBURG, YOUR COLLEAGUE ON THIS RESEARCH, WAS QUOTED IN *SCIENCE DAILY* AS SAYING, 'IT'S IMPORTANT FOR PEOPLE TO UNDERSTAND WHAT'S INFECTING AND KILLING THESE FROGS. THIS DISEASE IS A REMARKABLE EXAMPLE OF A PATHOGEN JUMPING BOUNDARIES AND CAUSING HAVOC. COULD YOU EXPLAIN THAT?

Yes, because we don't really know how this pathogen moves around. First, we don't know where it came from. It just emerged. It's a phylogenetically very isolated taxon. It has no close relative, so we can't look at any close relatives and ask: how do they live? What do they live on? The chytrid fungus is very isolated. But it has been traced back to the 1940s in the clawed frog of Africa. The leading hypothesis about its spread is that people started spreading the clawed frog around.

> [Editor's Note: *Wikipedia* - Phylogenetics means relative to birth and is the study of evolutionary relatedness among various groups of organisms. Taxonomy, the classification of organisms according to similarity, has been richly informed by phylogenetics, but remains methodologically and logically distinct. A taxon (plural taxa), or taxonomic unit, is a name designating an organism or a group of organisms.]

Clawed Frog - Origin of Chytrid Fungus?

African clawed frog (*Xenopus laevis*), also known as platanna.
Image © by John Elkington.

[Editor's Note: The genus *Xenopus* is aquatic and the only frog with clawed toes. The African clawed frog has a flat body with a relatively small head. Its skin is smooth, with dorsal surfaces usually colored in mottled hues of olive-brown or gray with darker marks and ventral surfaces a creamy white color. This frog has no tongue, no teeth, no eyelids, and no external eardrums. Its forelimbs have four unwebbed fingers and its hind limbs have five long, webbed toes with dark claws on the three outer toes.

The genus is found throughout much of Europe, North America, South America and Africa. When African clawed frogs are imported into non-native countries, they have the capacity to wreck entire ecosystems by eating native wildlife such as fish and turtles that have no natural defense against these creatures.

In 2007, these frogs invaded a pond in San Francisco, where much debate exists on how to terminate these creatures and keep them from spreading. It is unknown if these frogs entered the San Francisco ecosystem through intentional release or escape into the wild.

Because these frogs are immune to the fungi *Batrachochytrium dendrobatidis* (a chytridomycota) and *B. dendrobatidis* has been traced back to the habitat of *Xenopus laevis* in Africa, many scholars believe it is the source of the worldwide amphibian die-off caused by the chytrid fungus.]

David Wake, Ph.D.: "I remember this well when clawed frogs were the main organisms used for human pregnancy tests. What happened was that you would take urine from a possibly pregnant woman. You would inject the urine into a clawed frog and if the frog laid eggs, the woman was pregnant. That was the way it was done! So, these frogs, which are aquatic, lived in aquariums in doctor's offices all around the world and the frogs were moved around. Then, these frogs were heavily used as model organisms. They became THE amphibian for the model organism. That meant the clawed frog was heavily used in laboratories. People released them into streams and ponds when they were done with them. That should not have happened, but now there are established populations of clawed frogs in southern California, for example. So we know this was happening.

But now what we would like to know is that once the chytrid fungus was in the clawed frogs, somehow the fungus jumped the boundaries. They jumped from one species into another. Now, the chytrid fungus seems to be able to move quite long distances and we would really like to know how they do that.

Now, why is the chytrid fungus having this profound impact on amphibians? Some people think it's linked to global climate change. Other people question that. But, it's undeniable that there is this high correlation between the arrival of the chytrid fungus in the

population and the collapse of that amphibian population within a year.

WITHIN A YEAR?

Within a year.

WHAT WOULD THERE BE ABOUT THE AVERAGE GLOBAL TEMPERATURE OF THE EARTH INCREASING THAT WOULD SUDDENLY MAKE A CHYTRID FUNGUS BE ABLE TO KILL SO MANY AMPHIBIANS?

The chytrid fungus operates in mountain environments. There are people who have presented the argument that the cloud line is rising. What that means is in these mountain areas, you have clouds at night. That means it is warmer at night than it used to be in the past and it's cooler by day. This narrower range of temperatures, it is hypothesized, favors the growth of the chytrid fungus.

CAN YOU PROJECT INTO THE FUTURE ABOUT WHAT THIS DIE-OFF MEANS FOR THE FUTURE POPULATION OF AMPHIBIANS?

Yes, I can in fact, because this has been done by Karen Lips at the Univ. of Southern Illinois. [See websites below.] She has been working from Costa Rico into Panama. In 1990, I was in the field with her when she was choosing her study site. By 1994, the frogs were beginning to disappear from her study site. She could not figure out why. Karen Lips and Australian scientists almost simultaneously discovered that the chytrid fungus was hitting both Australian frogs and Costa Rican frogs. Really weird!

A Panamanian Golden Frog killed by chytrid fungus in central Panama.
Source: Saveafrog.org.

So, Karen shifted her attention to an area further south. A year later in 1995, that area was hit by chytrid fungus and devastated. Then Karen Lips made a prediction. She hypothesized that there was a wave-affect of this chytrid fungus and it was moving south. She started taking extreme precautions herself by disinfecting her boots before she went into her study site. She laid out study areas further to the south and the east and she predicted the pathogen would arrive there and have a devastating effect. And she was right, absolutely right.

Chytrid Fungus Devastated Amphibians in Panama's El Cope National Park

El Cope National Park, Panama.

Finally, she predicted that the pathogen would reach El Cope National Park in Panama. It did and wiped out the population of amphibians there. At that point, the Amphibian Ark was established. [See websites below.] Amphibian Ark is an organization associated with the American Zoological Park, sponsored by them, and headed by some highly competent

herpetologists who know amphibians extremely well. They went through the extraordinary activity of removing living frogs from the field at the next place down from the devastated Panama site. The scientists moved those still-uninfected amphibians into captive breeding, taking them out of their natural environment and moving them into captive breeding to protect them. This is really an extreme measure because you have to assume you're going to be successful – and thankfully, I think they are being successful in getting the amphibians to thrive in captivity.

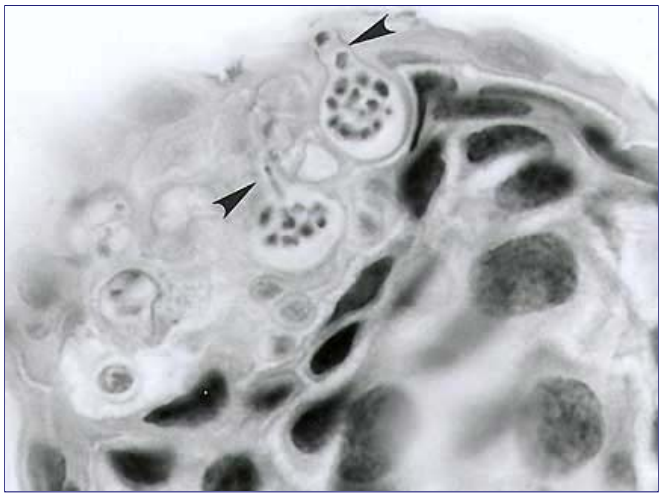
But you have to hope that something is going to change in the environment so that it will be safe for them to be returned to their natural home at some point. Possibly, if the environment is free of frogs, there will be nothing for the chytrid fungus to live on and it will die out. That's the hope, as I understand it.

How Does the Chytrid Fungus Spread So Rapidly?

HOW DO YOU THINK THE CHYTRID FUNGUS SPREADS SO RAPIDLY?

That's THE question. We do not know how it's making it. Chytrid seems to go too fast to be explained by adjacency from one frog to the next to the next. Some people think maybe birds are transmitting the chytrid fungus on their legs. But, as far as I know, it's never been shown that the fungus has infected a bird.

The chytrid fungus zoospores are really quite fragile. They dry out easily and they die easily. So, transmission is really the big question in my mind. This was directed at herpetologists themselves – maybe they were transmitting it in mud on their boots. So, this is why all herpetologists going into the field now disinfect their boots.



Chytridiomycosis. Ventral skin of upper hind limb of *Atelopus varius* from western Panama. Two sporangia (spore-containing bodies of Batrachochytrium sp.) containing numerous zoospores are visible within cells of the stratum corneum. Each flask-shaped sporangium has a single characteristic discharge tube (arrows) at the skin surface. Exiting zoospores are visible in the discharge tubes of both sporangia. Source: Daszak P, Berger L, Cunningham A, Hyatt A, Green D, Speare R. *Emerging Infectious Diseases and Amphibian Population Declines.* 1999 Nov-Dec.

BUT YOU SAID THAT THE CHYTRID FUNGUS HAS BEEN DEVASTATING AMPHIBIAN POPULATIONS IN REGIONS AS REMOTE AND SEPARATE AS BRAZIL AND THE CALIFORNIA MOUNTAINS.

Yes. The only explanation that has come up that makes any global sense is the transportation of the African clawed frogs around the world. That is purely an hypothesis. There is no strong evidence for that, but that's all we've got. I don't know how this fungus is getting around.

WHY IS IT THAT THE WAY THE CHYTRID FUNGUS IS KILLING AMPHIBIANS IS STILL NOT UNDERSTOOD?

Very good question. There are a lot of people working on that. It's a difficult question. I can tell you that the number of amphibian experimentalists has increased dramatically in the past couple of decades, but we still do not know the answers to those questions. Fungi are really hard things to study. Fungi are tough and difficult to get rid of. Have you ever looked at a magazine and seen all the ads for nail (form of keratin) fungus remedies? There are hundreds of fungi that attack different organisms and we are *not* able to handle most of them.

Why do we have so much trouble with fungi? Because they are complex organisms and we haven't learned our lessons about fungi yet. There are a lot of things we have to learn.

How Serious Is the Amphibian Extinction Threat?

PROJECTING FORWARD IN 2008 AND BEYOND WITH WHAT YOU KNOW RIGHT NOW, HOW BAD DO YOU THINK THE DECLINE OF AMPHIBIANS COULD BE?

It's terrible! Even if only 40% of amphibian species are at risk of extinction, that's terrible. And it might be much higher than that. But remember, we discovered the chytrid in 1998. That doesn't mean it's not been around for awhile. It might have been responsible for a lot of the earlier declines that we only detected much later.

IN YOUR RESEARCH, WHAT WILL BE THE NEXT STEP?

One of the things I'm really excited about is finding the chytrid fungus infecting strictly terrestrial amphibians that never go near the water. I think if we can crack that, we have some interesting leads because this chytrid fungus is an aquatic fungus. What is an aquatic fungus doing infecting a strictly terrestrial animal that never goes near the water at all?

Right in Berkeley. It's happening right here. So, that's a real opportunity and we've got people working on that. We have to know a lot more about this chytrid fungus. We have to know what kills. Why are amphibians killed by it? We've got ideas, but we haven't got proof. We've got to know how it spreads. We've got to know how it can live on strictly terrestrial organisms. I think if we could crack open some of the biology of the chytrid fungus, we'd make a lot more headway.

WHAT WOULD THIS PLANET BE LIKE WITHOUT AMPHIBIANS?

Well, that's a good question. A lot more insects! But I think we probably won't be here to see it. I suspect that enough amphibians will get through this extinction crisis and they will outlast us. I don't give *Homo sapiens* a very high probability of surviving terribly long on this planet. We are creatures on the same planet and the amphibians are not being affected by just one, but many factors. It's like death from a thousand cuts. We have a lot to learn from them.

IF THE AMPHIBIANS ARE DYING OUT, LIKE THE CANARIES IN THE COAL MINE, WE COULD BE NEXT?

It's interesting that you say canaries in the coal mine. Some people don't like that analogy for amphibians. I can tell you why. What did the miner do when the canary died?

HE HAD TO GET OUT OF THE MINE.

Yes. Where are you going?

I SEE. IT'S A REAL REALITY CHECK ON THE FACT THAT WE ARE ALL ON ONE PLANET.

That's exactly it. We're all in the same coal mine.

AND IF THE AMPHIBIANS ARE DYING, THEN WHAT IS NEXT FOR US HUMANS?

Good question."

More Information:

For further information about amphibian die-offs, please see reports below in **Earthfiles Archive**:

• 06/21/2008 — Updated June 25, 2008: Increasingly Acidic Pacific Coast Waters Threaten Marine Life
• 02/29/2008 — Mysterious Bat Deaths in New York, Vermont and Massachusetts
• 02/05/2008 — Federal Court Rejects Bush Navy Sonar Exemption
• 01/18/2008 — Amphibians Dying Out At Alarming Rate
• 08/08/2007 — 2007's Warm, Erratic Global Weather
• 07/11/2007 — Mystery of Night Shining Clouds - Another Global Warming Change?
• 06/28/2007 — Hackenberg Apiary, Pennsylvania - 75-80% Honey Bee Loss in 2007. What Happens If Colony Collapse Disorder Returns?
• 06/21/2007 — Large Lake in Southern Chile Has Disappeared
• 06/01/2007 — Is Earth Close to Dangerous Tipping Point in Global Warming?
• 05/29/2007 — Deadly VHS Fish Virus Has Spread to Lake Michigan
• 03/17/2007 — Honey Bee Disappearances Continue: Could Pesticides Play A Role?

• 02/23/2007 — Scientists Hope "Amphibian Arks" Can Save Frogs and Toads
• 02/23/2007 — Part 1: Earth Life Threats - Alarming Disappearance of Honey Bees
• 02/02/2007 — Updated: New U. N. Global Climate Change Report: Earth Could Warm Up 3.2 to 11.52 Degrees Fahrenheit by 2100
• 01/10/2007 — 2006: USA's Warmest Year On Record
• 12/16/2006 — Updated: Unprecedented Die-Off of 2,500 Mallard Ducks in Idaho
• 12/08/2006 — NASA Wants Permanent Moon Base by 2024
• 12/07/2006 — Earth Headed for Warmest Period in 55 Million Years?
• 09/09/2006 — Methane - Another Threat in Global Warming
• 08/19/2006 — Repair of Earth's Ozone Layer Has Slowed
• 07/18/2006 — 2006 - Hottest Year So Far in U. S. History
• 02/20/2006 — Mysterious Deaths of Whales in Mexico
• 08/26/2005 — What Is Killing Amphibians Around the World?
• 08/05/2005 — Scientists Puzzled by "Bizarre" Pacific Coast Die-offs in 2005
• 05/07/2005 — Did Milky Way Gas and Dust Turn Earth Into Icy Snowball Four Times?
• 04/20/2005 — Outer Space Impact At Serpent Mound, Ohio, 256 Million Years Ago
• 04/01/2005 — What's Killing Off Marine Life Every 62 Million Years?
• 03/20/2005 — Astronaut John Young: "The Moon Can Save Earth's Civilization."
• 02/26/2005 — Collapse of Societies: From Easter Island to Iraq - to Western World?
• 02/03/2005 — Kyoto Protocol Goes Into Effect February 16, 2005. British Scientists Warn Global Temperatures Could Climb Higher Than Earlier Estimates.
• 08/27/2004 — Global Warming Impact On Birds - More Extinctions Expected
• 09/02/2003 — Updated - Astronomers Don't Think Asteroid Will Hit Earth in 2014
• 11/14/2002 — What Happened 12,000 Years Ago That Killed So Many Animals?
• 07/20/2002 — Extinctions of Earth Life Are Accelerating Rapidly
• 04/27/2002 — Earth's Magnetic Anomalies - Could the Poles Flip?
• 01/05/2002 — Global Warming Update - Could Increasing Carbon Dioxide Gas Be Transformed Into Limestone?
• 12/22/2001 — Scientists Warn That Climate and Earth Life Can Change Rapidly
• 06/09/2001 — Environmental Updates and Colt Mutilated in Leitchfield, Kentucky
• 02/25/2001 — Environmental Updates
• 02/07/2001 — 94% Decline In Aleutian Islands Sea Otter Population
• 01/07/2001 — Dinosaur-Killing Asteroid Punched 22 Miles Through Earth's Entire Crust
• 11/12/2000 — Update On Increased UV Radiation and Amphibian Decline
• 05/27/1999 — Amphibian Decline - Parasites and Increased UV Radiation

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Websites:

"Are We in Midst of 6th Mass Extinction?"
August 12, 2008 *Proceedings of the National Academy of Sciences:*
http://www.pnas.org/content/105/suppl.1/11466.full

Amphibian Ark: http://www.amphibianark.org/

Amphibian Ark Chytrid Fungus: http://www.amphibianark.org/chytrid.htm

Save A Frog: http://saveafrog.org/fungus.html

CSIRO (Australia): http://www.csiro.au/science/Biodiversity.html

Frog Decline Reversal Project (Australia): http://www.fdrproject.org/pages/disease.htm

New South Wales, Australia, Dept. of Environment and Climate Change: http://www.environment.nsw.gov.au/plantsanimals/FrogChytridFungus.htm

Chytrid Fungus in Europe: http://www.cdc.gov/ncidod/EID/vol11no10/05-0109.htm

Karen Lips, Ph.D.: http://www.jcu.edu.au/school/phtm/PHTM/frogs/papers/lips-1999.pdf

Credits