Ghosts in Our Midst: Coming to Terms with Amphibian Extinctions

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Ghosts in Our Midst: Coming to Terms with Amphibian Extinctions

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A global mass extinction of amphibians is well under way, driven both by habitat loss and by environmental changes. As amphibian communities in Central America are being decimated by chytrid disease, scientists are working to fashion an emergency response. They are also sending out an urgent warning about what the loss of these environmentally sensitive species may portend.

Disappearing creatures, they resemble us in more ways than not. Frogs and salamanders are, after all, fellow vertebrates with arms and legs, hands and feet, fingers and toes. What we see, when we see a frog, is usually a face: paired eyes and nostrils set above a broad jaw and a wide, flat-lipped mouth. Behind its face resides a brain, similar to ours, though the cerebrum is small. We are evolutionary brethren, the harlequin frog, the axolotl, and us. Much of our elemental architecture is the same, bred deep in the germ layers of a body plan more ancient than flowers. Identical chemicals send the same signals inside their bodies and ours, and much of what we know about our own embryonic development we have learned by studying theirs.

The first vertebrates to set foot on earth, amphibians are now becoming ghostly in our midst. Already at least a third, and perhaps half, are at high risk of extinction. Such widespread endangerment makes it virtually certain that many hundreds, if not thousands, of frogs, toads, salamanders, newts, and caecilians will become extinct in the wild in this century. It doesn't easily sink in that this is the prognosis for an entire vertebrate class, like birds or mammals. But that, precisely, is the scale of the problem. In just a few decades since the first glimmerings of a biodiversity crisis, concern over endangered species has progressed upward through the taxonomic hierarchy—genus, family, order—to this.

Once common in Costa Rica and Panama, the lemur leaf frog, Phyllomedusa lemur, *now clings to life in the wild. A successful captive breeding program for this species has been established at the Atlanta Botanical Garden. Photograph: Ron Holt, courtesy of the Atlanta Botanical Garden.*

Why are these losses occurring, and what do they portend? Relatively few people—a small community of researchers and conservationists—have seriously grappled with these questions. Much has been written about amphibian declines, and many people are aware of the issue—to a point. But amphibians are creatures most of us encounter only rarely, and we tend to believe a great distance separates their lives and ours. The troubles of frogs, while sad and perhaps alarming, are their own. We are not so delicate; our skin is not so thin.

This unnamed species of Eleutherodactylus *is known only from dead individuals collected during a chytrid disease die-off in El Cope, Panama. The species may now be extinct. Photograph: Forrest Brem.*

But amphibian biologists are scared, and not only on behalf of the animals whose plight they have been documenting. Many see the crisis as our first real face-to-face brush with our own ecological mortality. The sense of alarm has been growing since the first Global Amphibian Assessment (GAA) was completed in 2004. The GAA revealed a striking fact: Around the world and in large numbers, amphibians are declining both where their habitat is being destroyed and in remote areas that appear to our eyes pristine. This is particularly true in parts of the Americas and Australia, where infectious fungal disease has decimated populations, species, entire amphibian faunas. Even in protected areas, for many frogs and salamanders, the inhabitable world is shrinking to nothing.

These are indeed fearful discoveries, and they have prompted the amphibian research community to collectively declare a state of emergency. Calls have gone out for an unprecedented global response, but so far little new funding has emerged for mobilizing research and conservation much beyond the failing status quo. Captive breeding is emerging as a stopgap measure to ward off extinctions, but even proponents of this approach agree it's no solution if amphibians can't also be protected in the wild. New networks and secretariats with ambitious agendas have been established, but largely through the volunteer efforts of scientists and conservation professionals with other jobs and other obligations. At some point, said one leading researcher, "we're going to have to stop relying on people doing this work in their spare time."

Amphibians, meanwhile, continue to disappear. Biologists are calling them the canary in the global coal mine, and though the phrase has been worn to death, it's worth considering anew. Recall that the canary's purpose is served by two things: a physiology it shares with the miner, and a lower threshold of susceptibility to the poison. The canary dies; the miner is warned. This is what the herpetologists are trying to tell us. Creatures with which we biologically have much in common are dying because the environment can no longer support them. Many are succumbing to a previously unknown disease that strikes multiple species indiscriminately and can erase entire populations. Imagine a comparably lethal disease affecting mammals. Even if the loss of half of the class Amphibia is something we think we can live with, shouldn't we be a little more concerned for ourselves?

Assessing the threat

To be sure, all major segments of biodiversity are threatened. Do amphibians really warrant special consideration? The GAA set out to answer that question by pooling all the available information on the state of the world's amphibian populations. Its finding in 2004 that one-third of the roughly 6000 known amphibian species are at high risk of extinction, by IUCN Red List criteria, came as a shock to many biologists. By comparison, 12 percent of birds and 23 percent of mammals are comparably at risk. In the Americas the situation is worse: Nearly 40 percent of amphibians are threatened. Among salamanders, which compose about a tenth of known amphibian species, endangerment approaches 50 percent. Perhaps most ominous of all is the GAA finding that at least 43 percent of all amphibian species are declining, while less than 1 percent are increasing.

The disproportionate threat facing amphibians is even greater than these numbers suggest. The GAA categorized nearly a quarter of known amphibian species as "data deficient," meaning their status could not be assessed. Among species that were assessed, over 40 percent are endangered, and if the true status of the data-deficient species were known, the percentage would be higher. "Quite a high number [of data-deficient species] are from areas where there is very little habitat remaining," says IUCN biologist Neil Cox. "It seems more and more likely that a large proportion of those species are endangered." The GAA estimate also falls short for another reason: Experts believe that up to half of the world's amphibian species have yet to be discovered. Of the several thousand unnamed species thought to exist, it's a good bet that most have characteristics—such as restricted range and small population size—that make them vulnerable. Given the likely status of several thousand data-deficient and unnamed species, a more realistic estimate

is that at least half of all amphibians are now threatened with extinction.

Disappearances are hard to document, and conservationists are wary of prematurely declaring a species extinct; so far, the GAA records only a few hundred "official" amphibian extinctions. New species discoveries, in fact, are outpacing the losses: Somewhat bizarrely, even as amphibians decline, their known diversity is increasing. At the same time, the potential for new discoveries grows less as species never recognized by science quietly disappear. Sometimes they are caught in the act of vanishing. Recent extensive surveys in Sri Lanka failed to turn up 19 species represented in museum collections from the region. While studying the 19th-century collections, biologists turned up two previously unknown species, which were named and declared extinct simultaneously. The case was not unique. "Three or four times I have described new species from museum specimens, knowing for a fact the species is already extinct," says Zoo Atlanta amphibian biologist Joe Mendelson. "Without a doubt, many species have been lost in Mexico and northern Central America that were never even known."

In parts of Panama, Southern Illinois University herpetologist Karen Lips has witnessed the disappearances firsthand. Her ongoing field studies have documented losses of up to 70 percent of the amphibian species and 90 percent of the individuals to chytrid fungal disease. As amphibians disappear in such numbers, so do the ecological roles and services they perform. "Basically, everything we've looked at is impacted by loss of amphibians," Lips says. "Once the frogs and tadpoles die off, the stream community changes. Algae grow, nitrogen levels change, and all that affects the stream food web. We've had some frog-eating snakes go extinct, and other snakes have increased. There are cascading effects up and down."

In addition, says zoologist George Rabb, former director of Brookfield Zoo, "we're losing the evolutionary patents that these creatures developed over a couple hundred million years." Amphibian skin secretions are a source of powerful drugs. A compound derived from one species of South American poison dart frog, for example, blocks pain 200 times more effectively than morphine. Last year researchers at Vanderbilt University reported strong inhibition of the HIV virus by skin peptides of frogs in the Americas and Australia. Each amphibian extinction entails the possible loss of a substance that may be of extraordinary benefit to humans, Rabb notes. "How can we ignore that, if we care about ourselves?"

The current status of the Central American salamander Oedipina collaris *is unknown, but nearly half of all salamanders are considered threatened. Salamander diversity is highest not in the tropics but in the eastern United States, including the Appalachian Mountains. The impact of chytrid fungus in this region remains largely unknown. Photograph: Karen Lips.*

Complexity and chytrid disease

The cause of amphibian declines has been a contentious issue since mysterious die-offs were first noted in Costa Rica in the 1980s. Initially there was a search for single-factor explanations: Were declines caused by thinning of the ozone layer? Or pesticide contamination? Since then, a broad consensus has emerged that understanding amphibian declines is something more akin to understanding what causes cancer. In this "biocomplexity" paradigm, there are no single, simple explanations but rather chains of causality and synergy among multiple factors. "It's more complex than just habitat loss here, water pollution there, disease in a third place," says biologist Claude Gascon, who cochairs the IUCN's Amphibian Specialist Group. "These threats are acting cumulatively."

The most pervasive single danger facing amphibians is loss of habitat, which can directly bring about the extinction of narrowly distributed species. But habitat loss cannot account for the widespread "enigmatic" declines observed since the 1980s. The discovery of the chytrid fungus in 1998 established that infectious disease is a major factor driving the declines, at least in the Americas and Australia. But the stage for the emergence and spread of chytridiomycosis may have been set by other factors. At a minimum, it is likely that international trade in amphibians—including the widespread use of African clawed frogs for pregnancy tests in the 1940s—has contributed to the disease becoming globally established.

Alan Pounds, an ecologist working in Costa Rica since 1981, has assembled evidence that climate change may help to unleash chytrid's lethal potential. Last year in *Nature* he reported a strong correlation between the timing of disease-related die-offs and periods of broad-scale warming. A linkage between chytridiomycosis and global warming is something of a paradox, since the fungus generally thrives best in cool, moist conditions—which is why it has struck primarily in upland habitats. Pounds's hypothesis is that increased cloud cover associated with periods of warming has effectively cooled amphibians' microscale environment by reducing the amount of direct sunlight. But he stresses that even if his proposed mechanism is disproved, the observed linkage to climate change still stands. "Frogs tend to decline when it gets warm," Pounds says.

Lips, on the other hand, says that while temperature variation probably does affect the severity of the infection, the epidemic wave is spreading every year regardless of climate. "I think climate is important in the chytrid story, but we are still determining exactly how," Lips says. "I don't think it is necessary to invoke climate change to explain the spread of the fungus among my cloud forest sites in Central America." Whatever may underlie its origin, Lips says, chytrid fungus is now acting as a novel pathogen affecting populations with no prior exposure or resistance.

The marsupial frog, Gastrotheca cornuta *(top left), once ranged from Costa Rica to Ecuador, but now is restricted to a small portion of Panama and possibly Colombia. The Panamanian golden frog,* Atelopus zeteki *(top right), has declined more than 80 percent over the past decade and is considered critically endangered by the IUCN. Small populations remain in the wild and in a number of captive breeding facilities.* Hemiphractus fasciatus *(bottom left) is known from only a few localities in Panama, Colombia, and Ecuador. The red-eyed tree frog,* Agalychnis callidryas *(bottom right), remains a common resident in low-elevation forests of southern Mexico and Central America. Photographs: Ron Holt, courtesy of the Atlanta Botanical Garden (*Gastrotheca cornuta, Agalychnis callidryas*), Roberto Brenes (*Atelopus zeteki*), and Forrest Brem (*Hemiphractus fasciatus*).*

Regardless of what environmental synergies may underlie its emergence and spread, chytrid disease presents the clearest and most tangible evidence of an agent capable of bringing about multiple amphibian extinctions. Unfortunately, little is known about the disease outside the few areas where it has been extensively studied. In most locations where enigmatic amphibian declines have occurred, the involvement and present status of chytrid fungus remain unknown. This is a colossal blind spot for scientists studying amphibian declines. There are simply too few field studies, and far too few laboratories worldwide can perform the molecular PCR (polymerase chain reaction) test, which is the best way of tracking the disease. Currently, says Mendelson, most herpetologists working in Latin America have no way to get their field samples analyzed. Use of private labs in the United States may be prohibitively expensive, and shipping of samples may be illegal because of conservation-minded export restrictions that apply to all biological materials.

The conservation response

The biocomplexity view of amphibian declines suggests that there are no fast and easy solutions. But, just as many human afflictions must be addressed from medical, epidemiological, and environmental health perspectives simultaneously, understanding and preventing amphibian declines may require an analogous range of approaches. This range is reflected in the Amphibian Conservation Action Plan (ACAP) released this spring, backed by a newly formed global network of researchers under the IUCN's Amphibian Specialist Group. The ACAP stems directly from the 2005 Amphibian Summit, where participants declared that it is "morally irresponsible to simply document amphibian declines and extinctions without also trying to stop them."

The ACAP outlines pressing research needs related to emerging diseases, climate change, and environmental contamination, and it calls for continuing diversity studies with a goal of naming 2500 new species in the next 10 years. Various long-term conservation actions are described, beginning with efforts to identify and protect key locations where habitat loss is a severe threat. The plan also calls for the formation of regionally based rapid response teams prepared to react immediately to disease outbreaks, and a network of facilities designed to support "survival assurance colonies" of captive amphibians. A fund for implementation has been established, with a target budget set at $400 million for the first five years.

The turn to captive breeding as a response of last resort has been driven largely by the situation in Central America. Last year Mendelson and Ron Gagliardo, of the Atlanta Botanical Garden, received extensive media coverage for their "airlift" of amphibians out of Panama. With permission from the Panamanian government, the scientists brought hundreds of threatened frogs to the United States in suitcases packed with damp moss. The attention they received helped raise awareness of the extinction crisis, among both the zoological community and the general public. Mendelson says part of the point was to demonstrate that an emergency response in advance of chytrid's arrival can save species. "The airlift operation hinged on the assumption that Karen Lips's model was correct," he says. "As it turned out, it was 100 percent correct. The fungus arrived on schedule and did exactly what it was expected to do. It decimated the amphibians in the El Valle region in 2006. Now all the streams in the area are virtually frogless."

Even as frogs from Panama were becoming established in Atlanta, the limits of species export were clear. "We wanted to show that you can go in, work quickly, and keep animals alive under triage circumstances," Mendelson says. "However, it is logistically and financially impracti-

cal—and diplomatically atrocious—to say those rescued amphibians have to be exported to the US or Europe." The alternative solution has been the construction of one of the world's first on-site survival assurance facilities in El Valle. The Houston Zoo is leading the project, working with biologists in Panama and the support of numerous other zoos in the United States and Canada.

The facility was still under construction when chytrid fungus arrived in El Valle last year, and biologists had no choice but to begin collecting frogs. As a temporary measure, several hundred animals were quarantined and cared for in two rooms in a local hotel. A lengthy series of delays caused the hotel stay to drag on for many months before the first animals were finally able to move into the new facility in February. The entire operation was extremely labor-intensive, says Houston Zoo's Bill Konstant, but a dozen high-priority species, and 40 overall, were protected. "Unfortunately, this is the only strategy that makes any sense right now," Konstant says. "Without actually removing them from their natural environment, there's no other way to retain these populations."

The conservation breeding approach is being advanced by the recently formed Amphibian Ark initiative, a joint effort of amphibian conservationists and zoos and aquariums worldwide. The goal is to develop a greatly expanded capacity for housing and retaining amphibian species that can no longer make it in the wild. How many species can actually be protected in this way, and how and when they may ultimately be reintroduced into the wild, are looming questions. Tim Halliday, who until last year headed the IUCN's Declining Amphibian Populations Task Force, says the approach has its limits. "Conservationists are attracted to captive breeding because it's exciting, provides good publicity, and people feel they're 'doing something,'" Halliday says.

Some frog species facing likely extinction in the wild are being maintained in facilities such as these, at the Atlanta Botanical Garden. Zoos and aquariums worldwide are being urged to establish a conservation breeding program for one or more amphibian species while researchers seek solutions to the long-term threats facing them. Photograph: Ron Gagliardo/Atlanta Botanical Garden.

"But it will fail for many species because they will not thrive in captivity, for many others because there is no longer suitable habitat for them to be reintroduced into." While biologists must do all they can, Halliday says, they should not offer false hope. "We have to accept that a very large number of species will go extinct," he says, "no matter what we do."

At best, conservation breeding is a time-buying strategy, based on the hope that conditions suitable for reestablishment in nature can some day be achieved. Not all species are susceptible to chytrid fungus, and scientists are trying to figure out why. In what may prove to be an important step toward developing a response to the disease, James Madison University biologist Reid Harris has described inhibition of the fungus by bacteria isolated from the skin secretions of salamanders. Now his studies are focusing on the mountain yellow-legged frog. "Northern populations are infected and persisting with the chytrid, while southern populations decline and perhaps go extinct once it arrives," Harris says. The northern group has a significantly higher concentration of the antichytrid bacteria, perhaps enough to prevent an epidemic from taking off.

Harris has also done experiments to see if protective bacteria applied to amphibians' skin can help them ward off the disease. "So far, we have very preliminary evidence that application of an antichytrid species of skin bacteria can help salamanders clear infection at a faster rate," he says. "This offers some hope." Perhaps some day, Harris says, amphibians in survival assurance colonies can be inoculated with protective bacteria before being returned to the wild. For species that can hang on long enough, it is also possible that strong selection against individuals lacking such a defense will lead to the evolution of chytrid resistance in wild populations.

Silence in Darien

Chytridiomycosis is arguably the worst disease ever recorded among vertebrates in its ability to affect large numbers of species and drive them to extinction. On the scale by which we are used to thinking about disease in humans, its impact is scarcely conceivable. But it is just one of a growing family of diseases threatening wildlife and humans—including SARS, West Nile virus, avian influenza, and HIV/AIDS—whose emergence has been linked to human-caused environmental change. With the full effects of global warming still decades away, we can probably expect worse.

Lips, who has already seen more amphibian die-offs than anyone, is now preparing for a new survey expedition into the Darien region of Panama. "It's the last island of healthy frog populations in all of Central America, and there's a good chance there will be a lot of new species," Lips says. It's also the region that appears to be next in line for chytrid disease to

For more information, visit these sites:
www.amphibiaweb.org/declines
www.cbsg.org/amphibian.php
www.waza.org/conservation/campaigns21.php?view=campaigns&id=1

strike. "If we can get a list of what is there," she says, "we can go to the next step of trying to keep some alive." The psychic toll of working under such a mandate, Mendelson acknowledges, "is a heavy load.... Doing fieldwork, the usual presumption is you take a few samples and leave, but the animal populations you are studying remain. You assume the ecology continues. In Darien, that's not going to happen."

That's what class-level endangerment really means. Our most ingrained assumptions about the continuity of life as we know it are suddenly cast in doubt. Instinctively, perhaps, we all want to shield ourselves from such knowledge, but by doing so we render ourselves incapable of responding. The researchers who have truly come to terms with amphibian mass extinctions are unanimous on one point: The crisis is indicative of a wider and immediate danger to the biosphere and to ourselves. Amphibians are "telling us something that other groups are not about the severity of what we have done to the natural world," says Rabb. "The amphibians are singularly indicative of a global catastrophe."

"Amphibians are giving us a fire drill, and we have an opportunity to learn from it," says Mendelson. "If we don't, it will be a criminal oversight."

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