The Case of the Vanishing Frogs

ARE THE WORLD'S AMPHIBIANS—VULNERABLE TO ECOLOGICAL CHANGES IN WATER AND ON LAND—ACTING LIKE CANARIES IN A COAL MINE, WARNING US OF ENVIRONMENTAL DANGERS BELOW THE THRESHOLD OF HUMAN PERCEPTION?

In the summer of 1982, David Wake, director of the Museum of Vertebrate Zoology at the University of California at Berkeley, set out to solve a little mystery. Several months earlier he had pointed David Green, then a postdoctoral fellow, to a site in the nearby Sierra Nevada that Wake knew to be abundant in Rana muscosa, a mottled yellow and brown frog Green was studying because of its unusually broken distribution patterns. But when Green reached the designated location, he couldn't find a single specimen.

Puzzled by Green's account, Wake decided to accompany him to the site, assuming he had simply missed it the first time. But when they arrived, Wake, too, was surprised to find that all the adults had disappeared and only a couple of tadpoles remained.

Wake and his other students soon began to notice similar disappearances at other popular frog localities in central and northern California. Wake wondered if he had stumbled upon a bigger puzzle: Was this decline in amphibian populations occurring only in California, or was it part of some larger pattern?

By coincidence, the First World Congress of Herpetology was scheduled to take place later that year in Canterbury, England. So Wake seized the opportunity to discuss his disturbing observations with other herpetologists. What he discovered, to his dismay, was that many of the attendees had witnessed the same phenomenon in scattered areas around the globe.

Wake took their reports and his own to the next meeting of the National Academy of Sciences Board of Biology, to which he belonged, and convinced its members to assemble a group of leading international amphibian experts to evaluate the evidence. The group, which convened in February 1990 in Irvine, Calif., quickly concluded that although most of the evidence for amphibian declines was anecdotal, the sheer number of widely dispersed informal reports indicated that the situation could be an environmental emergency, and that an international working group should conduct a full scientific investigation.

By the end of the year, after approaching several potential sponsors, Wake created the Declining Amphibian Populations Task Force (DAPTF) under the aegis of the Species Survival Commission of the World Conservation Union, an international organization comprising more than 500 environmental groups including the U.S. Fish and Wildlife Service and the U.S. National Park Service. Based at the Open University in Milton Keynes, England, the task force recruited more than 1,200 scientists to determine whether declining amphibian populations will simply rebound as part of some normal cycle or whether they truly are disappearing from the face of the earth.

Why We Care about the Victims

One reason so many amphibian biologists were eager to join the task force was simply because they were worried they might be losing their objects of study. But they were even more concerned for other reasons that everyone can appreciate. The first is the ethical consideration that amphibians have the right to exist. If people are responsible for amphibian disappearances, then people have a moral obligation to prevent them. Most religious traditions assign value to all living organisms. Even Judeo-Christianity, which espouses that humans are a special creation of God and are given dominion over the rest of the living organisms on earth, teaches that this relationship should be a stewardship, not a slaughter.

Second, amphibians are fascinating organisms that interact in complex ways with each and their environments. Consider the life history of the Central American strawberry poison frog Dendrobates pumilio. At the beginning of their reproductive cycle, males call for females from perches on the tropical forest floor. After mating, the female lays her eggs in the forest's leaf litter. The father then revisits the eggs and keeps them moist with bladder water. When the eggs hatch into tadpoles, the mother carries them on her back and deposits each one into a tiny pool of water,
often dew that collects at the base of bromeliad leaves. Because there is seldom enough food for even a single tadpole in these pools, the mother revisits each one every few days and lays an unfertilized egg for her offspring to eat. As the frogs mature, they synthesize poison toxins in their brightly colored skin from compounds found in the native arthropods on which they feed. If such frog species disappear, we lose valuable information about life on earth.

Third, amphibians may provide direct benefit to humans. One example is the gastric brooding frog, Rheobatrachus silus, of Queensland, Australia. After the female's eggs are fertilized, she swallows them and uses her stomach as a brood pouch, somehow switching off her digestive enzymes during the incubation period. Knowledge of such an enzyme-suppression mechanism might have proven helpful to people suffering from gastric ulcers. Unfortunately, while these and other biological aspects of R. silus were being investigated, the species disappeared from its natural environment, and all specimens in the laboratory died. For a rough idea of what we'd be losing if many such species disappeared, consider some benefits that have already been realized, including a pain killer recently derived from poison-frog toxins and a nonirritating vaginal cream made from frog skin that prevents pregnancy and protects against sexually transmitted diseases (see "All Natural AIDS Protection?" TR August/September 1996).

The fourth and primary reason that the task force was established is that amphibians are important indicators of general environmental health. Because most amphibians have a biphasic life cycle—they spend their early stages in water and their adult life on land—and have extremely thin, permeable skin, any changes in either aquatic or terrestrial environments may significantly affect these creatures. Thus, amphibians may provide early warnings of deteriorating environments that appear unaltered to human perception.

Gathering Evidence

A concerted effort by the enlisted scientists has provided us with far greater documentation of amphibian decline than we had in 1990 when the task force was formed. One suspicion that researchers confirmed is that most amphibian declines and disappearances are directly related to habitat modification. Furthermore, when the habitat change is dramatic, so are the effects. For example, in the United Kingdom, where many—in some areas 80 percent—of breeding ponds have been filled in over the past 50 years, all six native amphibian species have suffered dramatic population declines. Elsewhere, along a well-studied area on Volcan Tajumulco, the highest mountain in Guatemala, only 1 of 8 species of salamanders was able to survive after cattle ranchers converted the upper cloud forest zone into grazing pastures. Herpetologists also discovered that seemingly modest changes in habitats can also have profound effects. For instance, to the casual observer, it would appear that the arroyo toad (Bufo microscaphus californicus), whose habitat now exists entirely within uninhabited parks in California, is well protected. But the major streams that fed the best breeding sites have been dammed, and what remains of the stream bed plains is now being overrun by all-terrain sport vehicles. Because the larvae cannot live in the silty conditions that result from these modifications, toad populations have decreased alarmingly.

Perhaps the most disturbing finding, however, is that amphibian declines are occurring in diverse locations in relatively undisturbed habitats. Consider the following cases:

In Australia, herpetologists have known since the late 1970s that populations of R. silus, the gastric brooding frog, were declining in pristine sites. After learning at the First World Congress of Herpetology that the decline might be symptomatic of a worldwide problem, the Australians launched a campaign to inventory all known amphibian localities throughout their rainforests, and to initiate long-term monitoring programs in some key areas. The researchers had since counted 14 frog species from remote habitats whose once-abundant populations had either completely vanished or had been reduced to only a few frogs.

In California, biologists Charles Drost and Gary Fellers, both of whom are now with the U.S. Geological Survey, devised a clever approach to evaluate the status of amphibian populations in Yosemite National Park. Using extensive field notes of biologists Joseph Grinnell and Tracy Storer—who recorded detailed descriptions of the area's amphibian breeding sites between 1915 and 1919—Drost and Fellers were able to reassess the amphibian populations at the same sites. The fact that the researchers were able to relocate every site proved that no obvious change had occurred in the habitat during the intervening 75 years. Sadly, they also found that most of the amphibians were gone: whereas Grinnell and Storer counted 7 different amphibian species at 70 locations, Drost and Fellers could now find only 4 at 26 sites.
The elfin forests on the ridge crest at Monteverde, Costa Rica, have witnessed perhaps the most notorious disappearance of an amphibian population from an undisturbed habitat—that of Bufo periglenes, the golden toad. Among the world's most colorful amphibians, the brilliant golden males differ dramatically from the equally flamboyant black, red, and yellow females. Largely because of their spectacular beauty, golden toads—known to science only since the 1960s (although the Quakers who colonized the Monteverde area were aware of their existence before then)—served as the focus of concerted efforts to conserve the local habitat. In fact, a golden toad is depicted on the same sign with a panda to mark the entrance to a 328-hectare preserve established in 1972 by the Tropical Science Center of Costa Rica and the World Wildlife Fund for Nature. Later endeavors by other conservation groups tripled the size of the preserve to 10,500 hectares and finally more than doubled it again by adjoining it to the 16,000-hectare Children's International Rainforest.

Despite these conservation efforts, the golden-toad population crashed in 1988. During April and May of 1987, "more than 1,500 toads gathered to mate in temporary pools at Brillante, the principal known breeding site," report biologists Martha Crump and Alan Pounds, in the March 1994 issue of Conservation Biology. "But in 1988 and again in 1989, only a single toad appeared at Brillante, and a few others gathered 4 to 5 kilometers [to the southeast]. During 1990 to 1992," the researchers note, "despite our intense surveys, no golden toads were found." Nor have any been seen since.

In Puerto Rico, researchers have discovered that two species, including Eleutherodactylus jasperi—one of the world's few viviparous frog species (which like mammals produce live young instead of eggs)—have apparently become extinct though their habitat still appears suitable.

In Ecuador and Venezuela, eight species have been reported absent from the cloud forests of the Andes mountains. One genus in particular, the Atelopus, was once incredibly abundant (researchers could collect hundreds in an hour). But in 1990, Enrique LaMarca, a biologist at the University of the Andes in Venezuela—having spent more than 300 hours during 34 separate field trips searching for the frogs—reported finding only one specimen of A. mucabajensis and two A. soriani. Another species in the genus, A. oxyrhynchus, which LaMarca reported observing walking by the dozens on the forest floor, has not been seen since 1978.

In the Atlantic Forests of southeast Brazil, specifically at a well-studied site in Boraceia, Sao Paulo, seven common amphibian species disappeared in 1979. The site has since been revisited numerous times by several herpetologists including Jaime Bertolucci, a doctoral student at the University of Sao Paulo, who conducted an intensive year-long study of the ecology of tadpoles. But none of the species that disappeared in 1979 have ever been found.

Similarly well-documented studies have found amphibian disappearances or declines from relatively undisturbed habitats elsewhere in these and other regions, including the U.S. Rocky Mountains and the Cascade Mountain Range in Washington, Oregon, and California.

Possible Suspects

Though more work must be done to plug the gaps in our knowledge of amphibian declines, these studies allow us to draw an important conclusion: amphibian populations, in far-flung locations, are indeed disappearing even in seemingly virgin environments. The challenge, therefore, is no longer merely to preserve habitat, though that is still a vital task. We must also discover and address the less obvious reasons for the demise of these creatures as well as determine what fate they might portend for other species, including ourselves.

Prominent among the suspects thought responsible for declining amphibian populations, at least in specific locales, include agricultural chemicals and pesticides. In many parts of the world, certain amphibian species have thrived in agricultural areas, taking advantage of artificial water bodies used for irrigation and watering livestock. But the chemicals found in farmland breeding sites interfere with normal amphibian development. Michael Tyler, a biologist at the University of Adelaide in Australia and a board member of the Declining Amphibian Populations Task Force, explains that the problem with some herbicides is not the active ingredient itself, for example glyphosate, but rather a detergent additive that acts as a dispersant or wetting agent. The detergent breaks down the surface tension at the leaf surface to enable spray droplets to completely cover the leaf. However, the agent also interferes with respiration in frogs through the skin and even more so with respiration of tadpoles through gills. Michael Lannoo, a biologist at Ball State University, also points out that some pesticides such as methoprene (used for mosquito
control) break down into a compound resembling retonic acid, which has been shown in the laboratory to produce severe amphibian limb deformities that would render individuals incapable of escaping predators.

Other pollutants under investigation are being blamed for more regional amphibian declines. Among the leading culprits for these losses may be acid rain. In fact, researchers have found that almost all amphibian eggs or larvae tested so far cannot survive in water with a pH of less than 4.5. Yet acid rains, commonly in the 3.5 range, can lower the pH of ponds and streams from a normal average of about 7.0 to lethal levels. In fact, acid rain has been identified as a cause of amphibian declines in lakes and ponds in Canada, Scandinavia, and Eastern Europe.

Chief among the candidates likely to be responsible for amphibian declines on an even wider, perhaps global, basis is ozone depletion. Recent studies in Oregon have shown that rising levels of ultraviolet-B (UV-B) radiation resulting from the depletion of the earth’s ozone layer have undermined the hatching success of eggs in some native amphibian species. The researchers suggest that other amphibians most likely to be affected by increased UV-B radiation—such as those living at cooler, higher elevations and extreme latitudes, where the ozone layer is thinnest but where amphibians must bask in the sunlight to regulate body temperature.

Environmental estrogens may also be responsible for global declines. Researchers believe that these pollutants, which result from the chemical breakdown of pesticides such as DDT, are likely to severely affect the reproductive biology of amphibians, as they have been shown to do in other aquatic organisms, such as fish and alligators. In fact, in laboratory studies, Tyrone Hayes, an endocrinologist at the University of California, Berkeley, found that such environmental estrogens masculinized female Japanese tree frogs, Buergeria buergeri, and feminized male pine woods tree frogs, Hyla femoralis, causing both populations to become sterile. These estrogens, whose molecules do not break down easily in the environment, stockpile in silt on the bottoms of ponds and lakes, where they are ingested by bottom-feeding amphibian larvae. Some of these agents are effective in very small concentrations and are easily wind-borne, making them a global threat regardless of their point of origin.

Inconclusive Evidence

We must conduct more research to determine which, if any, of these factors are responsible for declining amphibian populations in relatively pristine habitats. One approach would be to compare undisturbed sites where amphibian populations are healthy to similar habitats where the populations are in serious decline. One such grouping exists in the Andes mountains in Ecuador, Colombia, and Venezuela. While amphibians continue to thrive in high-elevation habitats in Colombia, they have disappeared from virtually identical habitats in Ecuador and Venezuela. Might something as straightforward as introducing predators such as trout into the waters of Ecuador and Venezuela, but not Colombia, be responsible? Or might atmospheric transport of agricultural chemicals applied in lowland regions of Ecuador and Venezuela be causing problems? An elegant set of comparative studies and experiments could be designed to address such questions at these and other promising groups of undisturbed sites in lowland and cloud forest habitats of Africa, South America, southeast Asia, and Madagascar.

Another approach would include studies aimed at rejecting regional or global factors as causes of amphibian declines. Most research has tried to verify the link between reduced frog populations and factors such as high UV-B concentrations. But some studies suggest that UV-B as a single factor, is not responsible for all amphibian declines, since several species, such as the golden toad of Costa Rica, are never exposed to the sun’s ultraviolet rays. In fact, golden toads lived underground all year long, except for a few days at the end of the dry season when they emerged to breed. But even then they were protected under the canopy of Monteverde's elfin forest, which (even though short by tropical lowland standards) effectively filters out the ultraviolet radiation. Moreover, because females chose to lay their eggs in well-shaded pools, the now-extinct golden toads were never exposed to UV-B even as eggs or larvae.

Such an analysis doesn't mean that rising UV-B levels are not killing off amphibians elsewhere. In fact, studies of amphibians exposed to such radiation are under way in the mountains of Chile and Argentina. It does, however, suggest that no single factor may be responsible for all declines. Perhaps more significant, the analysis also raises the possibility that more than one factor may be at play at each location. For example, if an amphibian population is subject to sublethal stresses from habitat fragmentation and acid rain, might it be more likely to succumb to an additional stress from some regional or global factor such as climate change or estrogen mimics?
Some research shows that such scenarios are possible. A study of the western toad Bufo boreas, common to the Elk and West Elk Mountains of Colorado, serves as one example. Cynthia Carey, a biologist at the University of Colorado, who began studying these toads in 1974, discovered that they had contracted "red leg" disease, a normally nonfatal illness caused by Aeromonas hydrophila, a naturally occurring bacterium. Over the next eight years, Carey found that the toads, once common in the mountains, had almost completely disappeared. Her conclusion was that some environmental factor, or the synergistic effects of several factors, may have caused the toads to secrete elevated levels of hormones that compromised their immune system and led to their infection and eventual death.

Studies such as these demonstrate that the underlying causes of amphibian declines may be far more complex than anyone originally imagined. Thus, studies that examine possible synergistic effects and help us tease out the relative contribution of each must be among our research priorities.

**Interim Recommendations**

Though much research lies ahead, we can take some practical steps immediately to halt the decline of amphibian populations. Perhaps the most obvious is to preserve remaining amphibian habitats. One novel approach would be to consider the health of amphibians in environmental impact assessments. In fact, this practice proved highly successful at a highway-construction site in British Columbia recently. Typically, whenever highways are built in the forested Canadian province, workers create roadside ditches and scour them of all vegetation. But in this case, thanks to a herpetologist included on the environmental-impact study team, the road builders added parts of fallen trees to the ditches, enabling native amphibians to use them as breeding sites.

Another simple but valuable step would be to consider amphibians in environmental assessment programs as bioindicators of overall ecosystem health. Because the eggs of many amphibians lack a protective covering and are laid at or near the surface of a body of water, they are very sensitive to both air- and water-borne pollutants. Also, because the climatic factors typically determine the onset, duration, and intensity of amphibian mating activity, careful monitoring of breeding populations can provide an extremely sensitive assay of climate change.

Finally, the latest findings regarding causes of amphibian declines need to be communicated both to international policymakers, who are in a position to set research priorities and fund additional studies, and to the public at large, which can influence their decisions. Americans are now much more aware of issues concerning amphibians than they were even a decade ago, thanks in large part to a number of excellent television documentaries that have focused on dwindling amphibian populations. But scientists and the media must continue to spread the word to convince people around the world that these precious creatures are worth their concern.