

The Puzzle of Declining Amphibian Populations

The number of frogs, toads and salamanders is dropping in many areas of the world. The causes range from destruction of their local habitats to global depletion of the ozone layer

by Andrew R. Blaustein and David B. Wake

Perhaps our fascination with frogs and other amphibians starts in childhood, with the discovery of tadpoles and the observation of their metamorphosis. But for many adults today, interest stems more from observation of another type of change: amphibian populations in many parts of the world seem to be dwindling, and some groups are disappearing from their native habitats completely. The loss—first recognized as a global phenomenon in 1990—deserves attention not only because it is disturbing in its own right but also because frogs and their kin (mainly toads and salamanders) may serve as indicators of the overall condition of the environment.

Amphibians are valuable as gauges of the planet's health for a few reasons. First, they are in intimate contact with

many components of their natural surroundings. For example, as larvae, frogs live in water, but as adults most find themselves at least partially on land. Their moist, delicate skins are thin enough to allow respiration, and their unshelled eggs are directly exposed to soil, water and sunlight. As larvae, they are herbivores and as adults, carnivores. Because amphibians sample many parts of the environment, their health reflects the combined effects of many separate influences in their ecosystem. Second, these animals are good monitors of local conditions because they are homebodies, remaining in fairly confined regions for their entire lives. What happens to frogs and their brethren is happening where humans live and might affect our species as well.

Finally, amphibians are so varied that any single characteristic, unique to the class, can be dismissed as the cause of the dwindling numbers; hence, we suspect that environmental factors are indeed the main cause for their decline. Amphibians are diverse in color, form, behavior and natural history. They vary in physical size, reproductive capacity and population density. And they are found in many ecosystems and habitats, including deserts, grasslands and forests, from sea level to high mountaintops. Although these creatures are most abundant in the tropics, they are also common in temperate zones and can even be found at higher latitudes, such as in Alaska and northern Canada.

Which environmental factors might

account for the rapid decline of animals that have managed, over hundreds of millions of years, to survive events that led to the mass extinction of many species, including the dinosaurs? The explanations that have been proposed are almost as diverse as the amphibian species in jeopardy, ranging from destruction of habitat to natural fluctuations in population size.

One or more of the suggestions do seem to explain the shrinkage of many populations. But in other cases, the reasons for the declines are not obvious. In those instances, the damage may be caused by subtle, interacting aspects of regional or even global conditions. In particular, recent work, completed last spring, has led to the surprising discovery that stratospheric ozone depletion may well be harming amphibian species in some parts of the world.

We began to suspect that the ozone problem might play a role as a result of studies that one of us (Blaustein) and

ULTRAVIOLET RADIATION breaking through the dwindling ozone shield in the stratosphere is a newly discovered danger to amphibians who lay their eggs in the open. The radiation, which can damage DNA (*inset*), has recently been shown to account for severe losses of fertilized eggs in at least two such species in the Cascade Mountains of Oregon, including the Cascades frog (*Rana cascadae*) depicted here. The egg losses, in turn, may have led to declines in overall population sizes.

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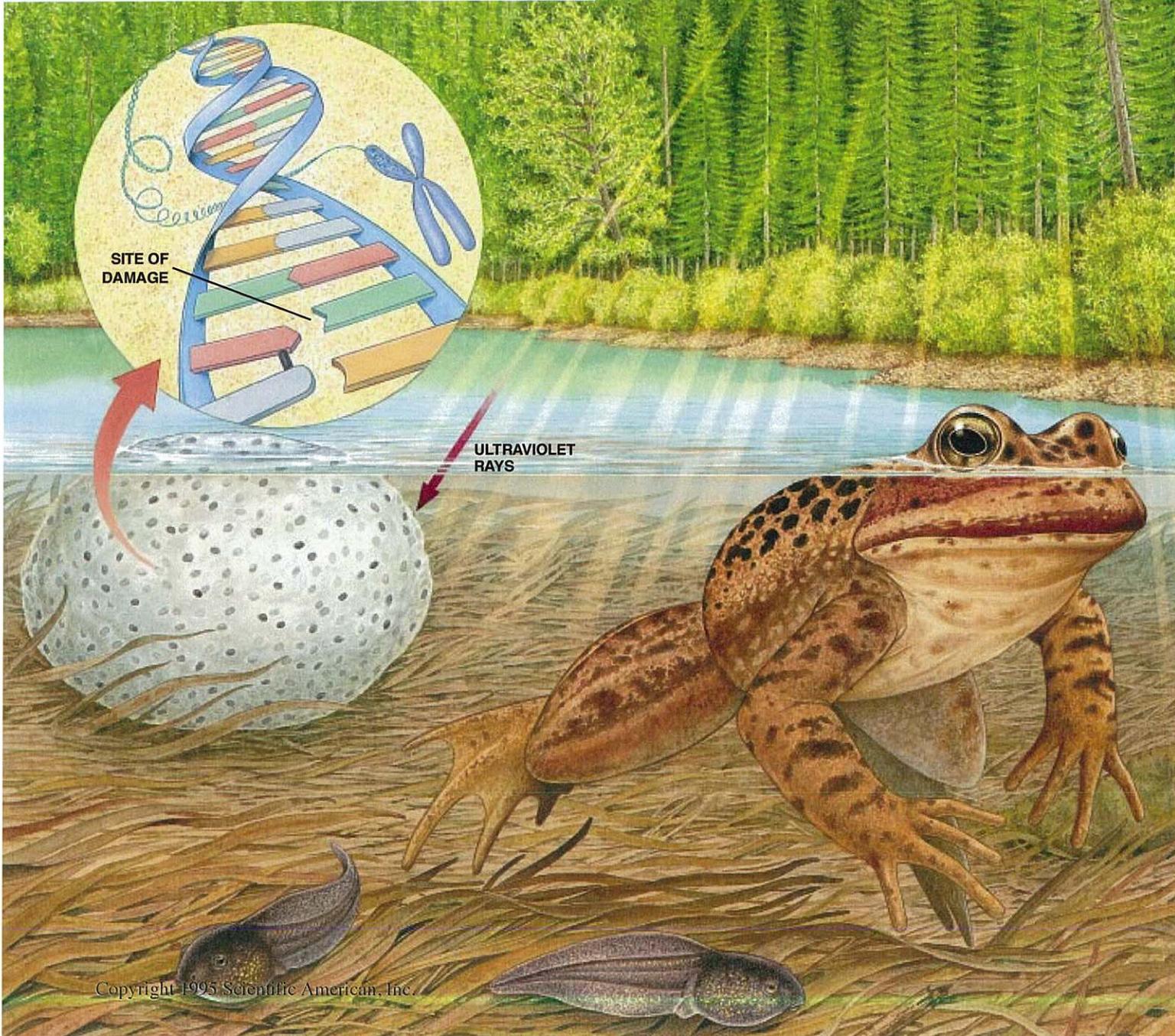
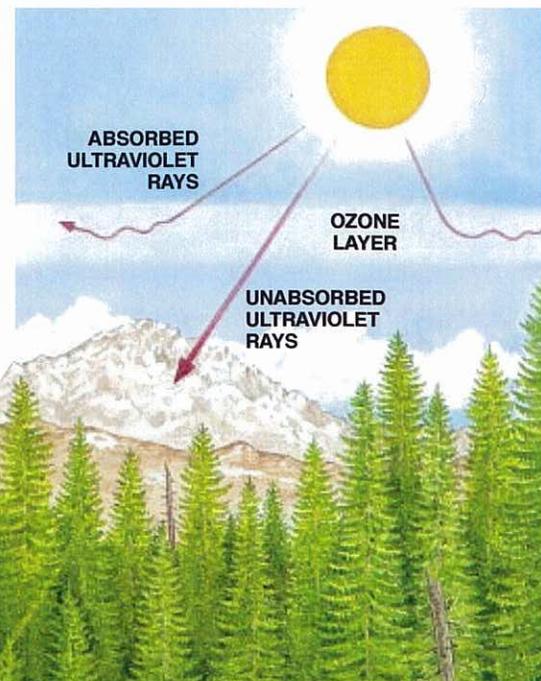
his students began in Oregon in 1979. The most recent experiments, often conducted at relatively high elevations (above 4,000 feet) in remote, undisturbed parts of the Cascade Mountains, examined various aspects of life for several species of amphibians monitored from the egg, or embryonic, stage through the tadpole phase and into adulthood. Although the group intended to carry out a straightforward survey of amphibian behavior and ecology, it discovered some unexpected results.

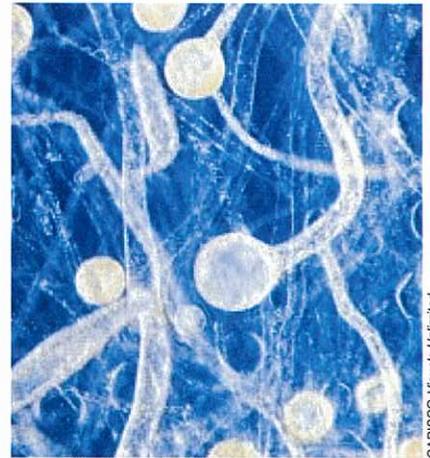
The Role of Ultraviolet Rays

As part of the research, the team documented massive die-offs of fertilized eggs in two species in particular: the Cascades frog (*Rana cascadae*) and

the western toad (*Bufo boreas*). Additionally, over the course of 10 years, the group noticed that the numbers of adults of these species were dropping. The investigators guessed that the shrinking numbers of adult frogs and toads could result from the fact that so few fertilized eggs survived, and thus they began to explore the reasons for the damage to the eggs.

The researchers quickly ruled out the possibility that the chemistry of the water where the animals were laying their eggs was at fault. They brought eggs into the laboratory and reared the resulting embryos in a sample of the same lake water in which other eggs left be-





KEVIN HORGAN

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CAUSES OF AMPHIBIAN DECLINES are varied. The most significant threat to populations remains habitat destruction, such as the burning of Brazilian rain forests (far left). Other proposed causes include diseases, such as infection by the *Saprolegnia* fungus (left),

hind had perished. The embryonic frogs and toads developed and hatched normally in the laboratory. Furthermore, chemical analyses of the lakes and ponds where eggs died revealed no obvious pollution or excess acidity.

By the late 1980s another possible cause of egg destruction had presented itself. Scientists in several disciplines documented a decrease in the stratospheric ozone shield that blocks most ultraviolet rays from reaching the ground. These observations led Blaustein and his co-workers to wonder whether increased exposure to ultraviolet radiation could explain the reproductive problems they had seen. They also thought it might explain why many of the amphibian species known to be in decline were mountain dwellers that lay their eggs in open, often shallow, water. Such eggs undergo prolonged exposure to sunlight and thus to any ultraviolet radiation that passes through the ozone shield.

The researchers speculated that excessive exposure to ultraviolet radiation could be contributing to the problems of the Cascades frog and western toad because they were aware of evidence showing that ultraviolet rays can damage plant and animal life. In particular, ultraviolet-B radiation (with a wavelength ranging from 280 to 320 nanometers), in the middle of the ultraviolet spectrum, is especially harmful to living organisms. In humans, for example, it can suppress the immune system, cause cataracts and contribute to skin cancer. What is more, as early as the mid-1970s, Robert C. Worrest of Oregon State University had shown that ultraviolet-B rays

could cause amphibian embryos to develop abnormally in the laboratory.

Few experiments, however, had considered the consequences of ultraviolet radiation on amphibians or other animals in nature. Blaustein and his colleagues therefore set out to determine whether increasing levels of ultraviolet-B radiation could play a role in the decline of amphibian populations in the wild. The team for this enterprise included ecologist Susan C. Walls and molecular geneticists John B. Hays and Peter D. Hoffman, as well as graduate students D. Grant Hokit and Joseph M. Kiesecker, all then at Oregon State University.

The crew based its procedure on an understanding of how ultraviolet radiation affects DNA. When DNA absorbs energy from such rays, the bonds that hold the molecule together break, and new structures are formed. The changes in DNA can disrupt the functioning of cells and may even kill them. But many organisms have the capacity to repair DNA damage caused by ultraviolet radiation. As part of this process, some of those organisms—including certain species of algae, plants, fish, marsupials and amphibians—activate an enzyme known as photolyase, which removes the harmful structures.

By measuring the amount of photolyase produced in the eggs of various amphibians, the workers found that levels varied among species. Most important, they determined that species with falling populations were generally those with eggs that produced low levels of photolyase—and therefore had little protection from ultraviolet radiation.

The species with the most photolyase,

the Pacific treefrog (*Hyla regilla*), was not suffering from a decrease in population. Pacific treefrog eggs have about three times as much photolyase as do Cascades frog eggs and six times as much as western toad eggs. Hence, it seems that because the embryonic Cascades frogs and western toads produce low levels of photolyase, they do not make enough of the enzyme to counteract exposure to unusually high amounts of ultraviolet radiation. This lack of protection in turn may lead to the high mortality observed for the eggs and explain why these two species are candidates for threatened status in some states.

Once the group noticed a correlation between lack of protection from ultraviolet radiation and declining population, the next challenge was to find supporting evidence that the rays were actually at fault. The team collected freshly laid eggs of Cascades frogs, western toads, Pacific treefrogs and northwestern salamanders (*Ambystoma gracile*). The salamanders, like the other three groups, lay their fertilized eggs in open, shallow water. Additionally, these salamanders produce extremely low levels of photolyase.

Exposed Eggs Fail to Hatch

The researchers placed the eggs in the bottom of screened enclosures. Atop one third of the containers they placed a cover of clear plastic (Mylar) that shielded the eggs from ultraviolet-B radiation. A second set remained open, fully exposing the eggs. On the remaining third of the boxes, they placed a clear cover of plastic acetate



and human consumption of frogs (right). Such consumption was a particular problem in the U.S. in the early part of this century, before protective measures began taking effect. Pollution (far right) of waterways and of the air also threatens amphibians.



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that allowed transmission of radiation. This treatment served as a control to ensure that the outcome observed in shaded boxes was not caused by the covers.

The workers placed a total of 48 boxes randomly around lakes and ponds at several different sites where each species normally lays its eggs. The experiments on frog and toad eggs were conducted in the spring of 1993 at relatively high altitudes (greater than 4,000 feet) in the Cascade Range of Oregon. The team studied the eggs of the northwestern salamanders in the foothills of the Oregon Coast Range (600-foot elevation) during 1994. The research continued until all the eggs either hatched or perished, a process that took from one to two weeks because of varying weather conditions.

If it were true that an inability to combat the harm caused by excessive exposure to ultraviolet radiation was destroying the eggs of many amphibian species, the producers of the lower amounts of photolyase would be expected to fare worse, and the producers of higher levels, better. The results of the field experiments were dramatic. More than 90 percent of the northwestern salamander eggs exposed to ultraviolet-B radiation died (compared with 45 percent of eggs protected from the rays). More than 40 percent of the exposed western toad and Cascades frog eggs died (compared with 10 to 20 percent of the shielded eggs). In contrast, almost all the eggs of Pacific treefrogs in all three experimental treatments hatched successfully.

Clearly, amphibian eggs in wild populations were dying from exposure to

ultraviolet-B radiation. And this damage to the eggs was very possibly contributing to the decline in adult populations that had been observed earlier. Investigators do not know whether northwestern salamanders are disappearing, but if these experiments are any indication, chances are good that those creatures, too, are in jeopardy.

By what mechanism does ultraviolet radiation lead to the destruction of amphibian eggs and embryos? Other research by Blaustein and his colleagues may have uncovered a partial explanation. It turns out that since the late 1980s, increasing numbers of amphibians in Oregon have been sickened by the fungus *Saprolegnia*, which is found naturally in lakes and ponds. The fungus is also known to infect hatchery-reared fishes, especially salmon and trout. Perhaps fish that have been released into lakes and are infected with *Saprolegnia* contaminate amphibian eggs in those waters. Because ultraviolet rays can impair immune function in many animals, it seems reasonable to guess that some amount of egg damage in amphibians is caused by an ultraviolet-induced breakdown in the ability of amphibian embryos to resist infection by the fungus.

Aside from harming fertilized eggs, ultraviolet radiation may contribute to declines in amphibian populations by reducing the supply of aquatic insects on which frogs and their relatives feed. High levels of such radiation have been known to kill insect larvae as well as aquatic algae.

The work in Oregon has provided one potentially important clue to the mys-

tery of amphibian disappearance. But many questions still remain. How many eggs can fail to hatch before a population itself begins to decline? Does ultraviolet radiation harm growing tadpoles that congregate in shallow water? And are adults that bask in sunlight affected directly by ultraviolet radiation? The two of us are now beginning to focus on these issues.

The Threat of Habitat Destruction

As worrisome as the increase in ultraviolet radiation seems to be, it is not the only potentially significant cause of shrinkage of amphibian populations. In the Monteverde cloud forest of Costa Rica and in the Australian rain forests, for example, amphibians typically live under a dense foliage canopy and hide their eggs. Yet many of their numbers are also in decline.

One of us (Wake) has been investigating causes of dwindling amphibian populations since the 1970s, when the first hints of a problem began to emerge. The issue is indeed compelling, for although evidence of falling numbers is strong in various parts of the world, in other areas amphibians appear to be doing well. This puzzling situation has prompted us and others to examine closely the possible reasons for the declines we have seen.

No single explanation fits every case, but all seem to be important to one degree or another. Destruction and modification of habitat are probably the most serious causes of falling amphibian populations. Like other animals, amphibians are threatened when forests are de-

Sharp-Snouted Torrent Frog (*Taudactylus acutirostris*), found in Australia
Cause of decline unknown



KLAUS UHLENHUST Animals Animals

Common Toad (*Bufo bufo*), found in Europe
Cause of decline unknown



KIM TAYLOR Bruce Coleman Inc.

Tiger Salamander (*Ambystoma tigrinum*), found in North America
Pollution, possibly acid precipitation



Z. LESZCZYNSKI Animals Animals



JAMES HANKEN Bruce Coleman Inc.

Mountain Yellow-Legged Frog (*Rana muscosa*), found in California
Introduction of fish to habitat



MICHAEL FOGDEN Bruce Coleman Inc.

Harlequin Frog (*Atelopus varius*), found in Costa Rica
Cause of decline unknown

AMPHIBIAN SPECIES shown here are among the many with dwindling populations—or are already extinct—for reasons that are now being investigated in

stroyed and wetlands are filled in or paved. Indeed, such activities probably account for the decrease in a majority of species threatened today.

In one striking example of this phenomenon, a recent survey in western North Carolina showed that clear-cutting of national forests leads to the deaths of enormous numbers of salamanders every year. Although most of the species involved have relatively large geographic ranges and are not in danger of extinction, the findings have distressing implications for amphibians living in tropical America, Africa and Asia. There many amphibians are more vulnerable because they have very limited geographic ranges.

Pollution Plays a Part

Pollutants, too, may have altered amphibian populations in some parts of the world, although data on the effects of pollution on these creatures are sparse. Some evidence suggests that acid rain and snow, fungicides, herbicides, insecticides and industrial chemicals may all act by impairing the reproduction and development of amphibians. Certain synthetic compounds can mimic the activity of naturally occurring hormones. Examination of birds, fish and reptiles indicates that these substances can have drastic consequences, such as a reduction in sperm count

and the alteration of male genitalia.

Diseases—possibly related to environmental pollution—seem to jeopardize some amphibians as well. Recall, for instance, that eggs of the Cascades frog and western toad are vulnerable to the fungus *Saprolegnia* and that susceptibility to the fungal infection is probably increased by exposure to excessive ultraviolet radiation. Further, the late Arthur N. Bragg, when he was at the University of Oklahoma, showed that *Saprolegnia* can destroy whole populations of tadpoles, although this discovery has been largely overlooked as a cause of amphibian deaths.

So far only a few studies have linked a disease to the extinction of an entire population of amphibians. Investigators have found, however, that the bacterium *Aeromonas hydrophila* may have triggered the disappearance of several populations of western toads in Colorado. The bacterium is highly contagious and has been implicated as well in the death of adult frogs, toads and salamanders in several other states.

Some scientists attribute the apparent shrinkage of amphibian populations to natural fluctuations in population size. Yet certain long-term investigations show a more or less steady decline in the number of amphibians over the past 20 to 30 years—an indication that in some populations other forces are at work.

Additional causes may explain isolated cases of dropping numbers of amphibians. Some populations may be decreasing because they are collected for human consumption. In France, for instance, the demand for frog legs is tremendous: the French eat 3,000 to 4,000 metric tons of them a year. Some 20,000 frogs must be sacrificed in order to supply a single metric ton of legs. And before the turn of the century, red-legged frogs (*R. aurora*) were probably overharvested as a food source in Oregon and California.

Ironically, efforts to boost amphibian populations in the western U.S. probably created more problems for the native amphibians there and provided an illustration of yet another possible cause of population declines: the introduction of nonnative species to an area.

To make up for decreases in the number of red-legged frogs, inhabitants of Oregon and California introduced the bullfrog (*R. catesbeiana*). This animal, with its voracious appetite, competed with or preyed on native amphibians in its new habitat. Noting that the introduced bullfrogs have become quite abundant in some places where the original frog species have declined, many biologists have recently suggested that bullfrogs are a major cause of falling numbers. And at least two ongoing studies have directly linked the introduction of bullfrogs to the dwindling of native frog species.

Similarly, introduction of fish into an ecosystem may hurt amphibians, especially in regions with few species of fish, low numbers of individual fish or no fish at all. In the southern Sierra Nevada Mountains of California, the introduction of salmon and trout into streams has been implicated in the demise of mountain yellow-legged frogs (*R. muscosa*). These fish species directly harm

Treefrog (*Nyctimystes dayi*),
found in Australia
Cause of decline unknown



STEPHEN J. RICHARDS

Natterjack Toad (*Bufo calamita*),
found in Great Britain
Pollution, particularly acid rain



HANS REINHARD Bruce Coleman Inc.

Golden Toad (*Bufo periglenes*),
found in Costa Rica (possibly extinct)
Cause of decline unknown



MICHAEL FOGDEN Bruce Coleman Inc.

detail. In many cases, the declines remain puzzling. For each species, the causes of trouble implicated are given next to each picture.

amphibians by eating eggs, tadpoles and even adults, but they also have a broader and potentially more profound result.

Many separate amphibian populations are linked to one another by streams patrolled by few or no fish. These links are important because frogs and their relatives are extremely vulnerable to changes in their local habitat, and they rely on the appearance of occasional migrants to help them rebuild diminished communities. The addition of new fish species into an area can block migration between communities and thus prevent the reconstitution of endangered populations.

Dangerous Consequences

The disappearance of amphibians represents more than just a loss of esthetically and behaviorally appealing creatures. These animals are crucial components of many ecological communities, and they can directly benefit humans. In some ecosystems, amphibians are the most abundant vertebrates, and so their absence can seriously disrupt the functioning of the rest of the ecological community. Adult amphibians are hunters of various animals, including mosquitoes, flies, fish, birds and even small mammals. Also, amphibian larvae serve as a food supply for aquatic insects, fish, mammals and birds. Destruction of frogs, toads and salamanders thus has repercussions elsewhere in the food chain.

From the perspective of humans, amphibians represent a storehouse of pharmaceutical products waiting to be tapped fully. Hundreds of chemical secretions have been isolated from amphibian skin, and scientists are just beginning to learn how valuable these substances may be. Some of these compounds are already used as painkillers



BOB AND CLARA CALHOUN Bruce Coleman Inc.

Western Toad (*Bufo boreas*),
found in western North America
Disease related to ultraviolet radiation

and in treatment of victims of traumas ranging from burns to heart attacks. Others are being investigated for their antibacterial and antiviral properties. As amphibians disappear, potential cures for a number of maladies go with them.

The evidence that depletion of the ozone shield in the stratosphere can harm the developing embryos of amphibians highlights the complexity of the forces leading to the elimination of species. Nevertheless, habitat degradation and destruction clearly remain the most powerful causes of amphibian disappearance around the world. If habitat modification occurs slowly enough—as it did for 3,000 years in western Europe—amphibians can adjust and even



W. DUELLMANN U. Kansas Natural Hist. Museum

Gastric Brooding Frog (*Rheobatrachus silus*),
found in Australia (possibly extinct)
Cause of decline unknown

adapt to human-induced alterations. But many of the changes we have discussed, such as rises in ultraviolet levels and in the amounts of pollutants in the environment, have occurred so rapidly that species with long generation times often cannot adapt quickly enough.

There are a lot more species of amphibians than scientists studying them. Of those that are known, many have been seen only once, at the time of their discovery. The number of species described continues to increase at a rate of 1 to 2 percent a year. If, as we believe, many of these species are at risk, a wonderfully diverse group of creatures is vanishing from the planet at a time when study of them has just begun.

FURTHER READING

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