ECOLOGY

Cave Biologists Unearth Buried Treasure

Researchers are bringing up a steady stream of odd cave creatures, which are shedding new light on the rules of life in the underworld

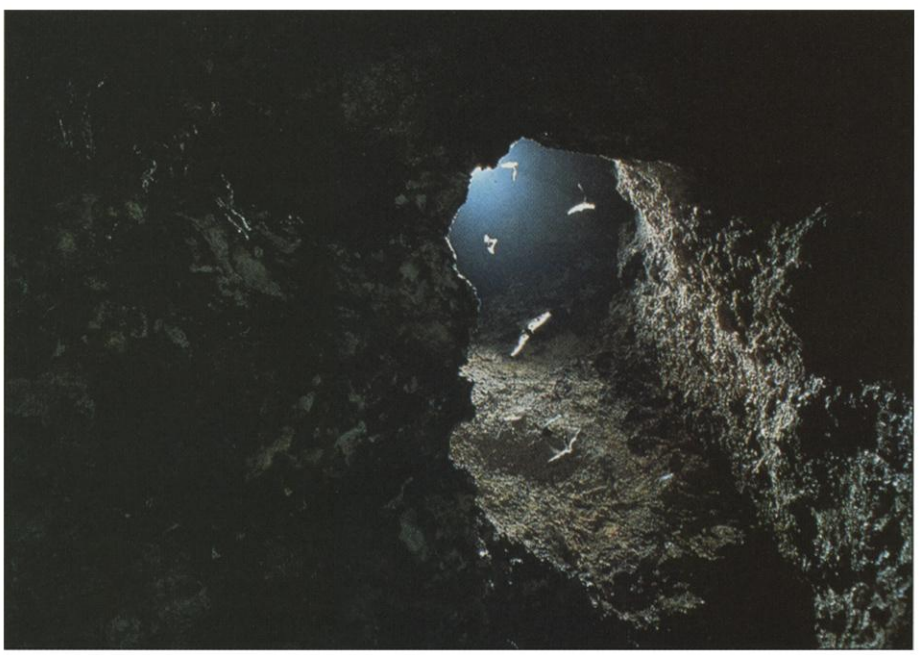
Caves have always haunted the imagination. The ancient Greeks shuddered at tales of Cerberus, the three-headed monster guarding the entrance to hell, and countless myths and Hollywood fantasies include a spine-tingling staple: unknown creatures lurking in the next claustrophobic corridor, hungry and waiting for visitors. Now it turns out that bizarre, voracious denizens of the underworld are not wholly imaginary. Biologists slithering into ever deeper, tighter recesses are coming face to eyeless face with a fast-growing list of cave-dwelling spiders, centipedes, leeches, mites, scorpions, beetles, fish, snails, worms, and salamanders, along with thick beds of bacteria and fungi that sometimes make a living off the very rocks.

Yet for biologists such discoveries involve more treasure than trepidation. Dominated by small insects, crustaceans, fish, and amphibians, cave fauna offer a glimpse into the usually inaccessible subterranean realm, where tiny air pockets and glistening crevices can be rich with life. And as more and more cave life comes to light, biologists are rethinking old generalizations about underground ecology and evolution, according to reports at a recent symposium on biospeleology (that is, cave biology), held in cave-combed Intervales State Park in southern Brazil.*

Cave dwellers, or troglodytes, may be winning newfound respect, but reports at the meeting also highlighted the fact that they are among the most delicate, endangered of creatures. Naturally hemmed in, some species may consist of just a handful of individuals from a single cave; in the United States, home to 1000 of the 6000 known species, 95% are now threatened by mining, pesticides, and sewage, not to mention invasions of bacteria, mites, and even dandruff borne by tourists and researchers, says biospeleologist John Holsinger of Old Dominion University in Norfolk, Virginia.

And that's just the known species, for the science of biospeleology is still in the early discovery phase. In the 1830s biologists started exploring caves in limestone, which underlies 15% of Earth's surface, but not until the 1970s, with advances in caving and research techniques, did they find creatures in other rocks and in climes that seemed unpromising. Now scores of species come to light annually, with no end in sight. Specialists estimate that 90% of known caves have never been biologically surveyed—and 90% of caves remain undiscovered altogether, because most lack visible surface openings. "That's the thrill: To pioneer, all you have to do is crawl in and look," says William Elliott, a biospeleologist for the Department of Conservation in Missouri, where a growing cadre of amateur spelunkers report dozens of new caves each year. Elliott's own recent finds include a dozen new species of mites, millipedes, and amphipods; an all-black salamander; and a blind crayfish.

Even with these revelations, what we see in caves may be only a taste of what actually lives in the underworld. Frank Howarth, an entomologist at the Bishop Museum in Honolulu, Hawaii, says that the lives of many troglodytes are undiscoverable, because they dwell in "microcaverns" and "mesocaverns": endless tiny crevices, fissures, and tubes that may or may not open into what we think of as a cave—that is, anything big enough for people to fit in. "With the possible exception of the deep ocean, no other habitat is so foreign to human experience," he says.



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Flying food source. In many caves, bats deliver the chief source of nutrition: guano.

Underworld lifestyles

Caves provide generally predictable weather, but troglodytes face a scarcity of creature comforts—space, light, food—and a panoply of dangers, including rough vertical terrain, endless mazes, lethal gases, radioactive rocks, and catastrophic floods. Beyond the classic missing eyes and lack of pigment, many have adapted with eerily long legs and sensory organs, the ability to deal with 100% humidity, and incredibly low metabolic rates. Long-term studies of the small *Orconectes australis* crayfish in Shelta Cave, Alabama, for example, suggest that it reproduces at age 35 and lives past 100.

Confinement amid rock layers prevents most animals from dispersing far, which keeps most species local and numbers vanishingly small. Richard Borowsky, a New York University geneticist who addressed the recent conference, says that 12 cave-fish species he has analyzed have a fifth or less of the genetic variation of surface relatives, suggesting that some gene pools may consist of as few as 100 individuals. But some aquatic cave species—called stygobites, for the mythical underground Styx, river of the dead—can travel freely in groundwater. For example, blind catfish and salamanders shooting up through artesian wells alerted researchers to the richness of southern Texas's Edwards Aquifer, a 10,000-square-kilometer complex of watery limestone caverns with some four dozen known species.

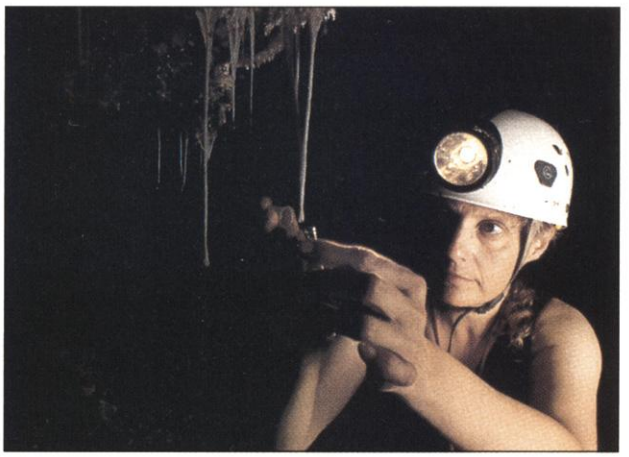
* The 15th International Symposium on Biospeleology, 8–15 July.

Food is the other limiting factor. Because there is no photosynthesis in deep caverns, the main source is often meager dribbles from the surface: nutrients dissolved in seep water, or bugs or leaves swept down sinkholes. Although no known mammals dwell exclusively underground, in many caves the most significant source of nutrition is bats. Some caverns contain millions that forage topside but roost or nest below, depositing guano that fuels perhaps 40% of cave species, according to cave biologist David Culver of American University in Washington, D.C. In caves lacking bats, the occasional "accidental"—a raccoon that wanders in too far to escape, a log washed in during a storm—provides an orgiastic banquet that may resound through the food chain for centuries.

Culver says troglodytes live up to their fantasy image in one respect: An unusual proportion are predators, armed to subdue struggling prey with nasty pincers or stingers. But they will eat anything, alive or dead. "They can't afford to be picky," says Culver, who reviewed U.S. cave fauna in the journal *Conservation Biology* last year.

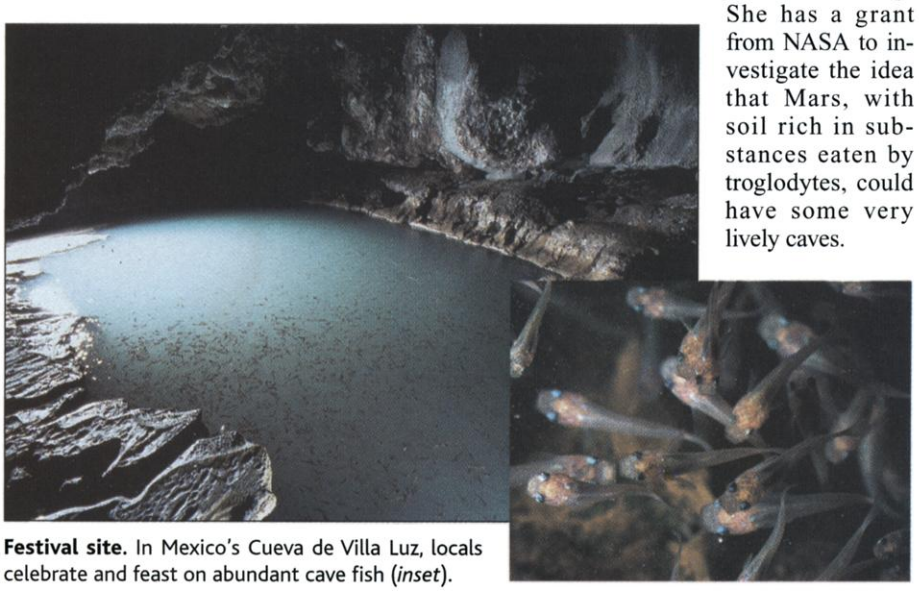
Cave dwellers rely on stranger sources of nutrition, too. Some newly found troglodytic microorganisms appear to live on methane fumes belching from the deeps, manganese and iron dissolved in water, and, in some cases, the rocks themselves, phenomena detailed in an upcoming special cave issue of *Geomicrobiology Journal*. Because the food sources in such geologically fueled systems are basically endless, the caves explode with life. The first such discovery was Movile Cave, a blind cavern in Romania accidentally breached in 1986. There, geologically fueled bacteria and fungi feed a higher fauna of 31 endemics, from worm-sucking leeches to water scorpions.

The latest is Cueva de Villa Luz (Cave of the Lighted House) in southern Mexico, revered by the local Soque people, who have long held yearly religious rituals there to catch and feast upon swarms of tiny bright pink fish. A 1998 expedition led by geologist Louise Hose of Chapman University in Orange, California, showed that the extraordinarily numerous fish—a new species—thrive because hydrogen sulfide in the air and water produces so much prey. Deep inside the cave are highly acidic "snottites," mucusy, stalactite-like drips made of massed sulfur-eating bacteria. The walls host thick fluorescent bacterial and fungal tapestries, springy as raw oysters and crawling with bright red insect larvae. "Spider webs and eggs totally cover some of those slimes, and [there are] more spiders than you ever want to think about," says microbiologist Penelope Boston of the University of New Mexico, Albuquerque. Bats, buzzing midges, and crane flies fill the sulfurous air—poisonous for humans, who suffer rashes, eye infections, and headaches.



Underworld explorer. Penelope Boston samples "snottites": slimy strings of bacteria.

Hose says such ecosystems, once thought oddities, may be widespread. Work on the Edwards Aquifer by the Texas Memorial Museum now suggests that the food chain there may get a boost from sulfur- and methane-eating bacteria in the lower reaches. Other investigators are looking into smaller sulfur-fed systems in backcountry Wyoming and Kentucky. Hose has been asked by the government of Oman to explore a cave with another odd fish population, and Boston has gone the next step: She has a grant from NASA to investigate the idea that Mars, with soil rich in substances eaten by troglodytes, could have some very lively caves.



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Festival site. In Mexico's Cueva de Villa Luz, locals celebrate and feast on abundant cave fish (*inset*).

Seeking stability

Whether troglodytes exist below Mars's harsh surface or not, earthly troglodytes seem to have originally descended from surface dwellers, often fleeing climate and landscape changes. Once below, they may speciate further over the millennia as they adapt to underground niches.

For example, the eastern United States holds 240 troglodytic *Pseudanophthalmus* beetle species. Their diversity suggests that their ancestors may have been common and widespread on the surface in leaf litter, shady ravines, and sinkholes during moist, cool conditions caused by intermittent glaciers farther north over the past 2 million years, says Holsinger of Old Dominion. He surmises that when the ice pulled back, the beetles did not like the resulting warmth and dryness, retreated ever deeper, and then split into local varieties as their populations separated. Biologists have spotted cave creatures in various stages of this speciation process. For example, a single millipede species, *Cambala speobia*, may be in the first stages of evolutionary adaptation to life underground. It was recently discovered in many Texas limestone caves and in cavelike spaces in loose boulder piles, all too far apart to be connected underground. Because Texas was much cooler and wetter just 1000 years ago, and the underground millipedes are still all alike, with no evidence of divergence from each other, they may have gone underground within recorded history, says Missouri's Elliott. "It's continuous: Animals are probably in the process of becoming troglodytes all the time," he says.

Until the last 20 years or so, the notion of troglodytes as refugees from surface climate change neatly explained their distribution: They were most commonly found in so-called temperate zones, where climate periodically turns hostile, but they were thought to be scarce or absent in the tropics, where climate offers little reason to escape

underground. But a string of studies has played havoc with that theory.

In 1971, Howarth of the Bishop Museum began braving the depths of Hawaiian lava tubes. There, in a narrow passage, he met an eyeless 8-centimeter arachnid: the Kauai cave wolf spider, one of the largest troglodytes yet discovered. Predecessors missed them because they cluster in the deepest recesses, accessible only through scary U-shaped drains that exclude outside air. "It's not that I'm braver," says Howarth. "They just didn't have modern electric lights or respirators." In the years since, he and others have found 75 assorted Hawaiian lava-tube creatures.

Many of these evidently descended not to escape anything but to get at underground goodies, says Howarth. The volcanic islands are constantly renewed by fresh lava flows that solidify with endless air spaces inside, which range from several stories high to capillary-sized and are largely interconnected. The new surface may host just a few scrubby trees, but 10 meters or more down, the trees develop luxuriant root systems hanging off cave ceilings, and along with fungi, these roots provide abundant food. Cave creatures colonize fast; 9 months after one eruption, Howarth found troglodytes in a brand-new tube, its walls still almost too hot to touch. Taking his lead, tropical biospeleology is now booming, with varied new communities being documented from Brazil to Malaysia and Thailand.

Indeed, cave animals are now turning up in most of the environments where they were once thought absent, including formerly glaciated sites (the ice was thought to crush or freeze them) and ancient, arid rocks (once thought to lack sufficient limestone and water). For example, 3 years ago William Humphreys, a senior curator at the Western Australian Museum in Perth, began investigating the ancient rocks below the interior deserts of northwestern Australia and found water-filled caverns of calcrete, a form of limestone. In checking just a tenth of those aquifers, Humphreys has already found dozens of amphipod and diving-beetle species, all apparently endemic. "This must be the merest glimpse so far," says Humphreys, who addressed the Brazil meeting. He has never entered the caverns; the only access is water pumped up through ranchers' wells and mineral-exploration boreholes.

Armed and ready. Many cave dwellers, like this spider, are predators.

Survival down under

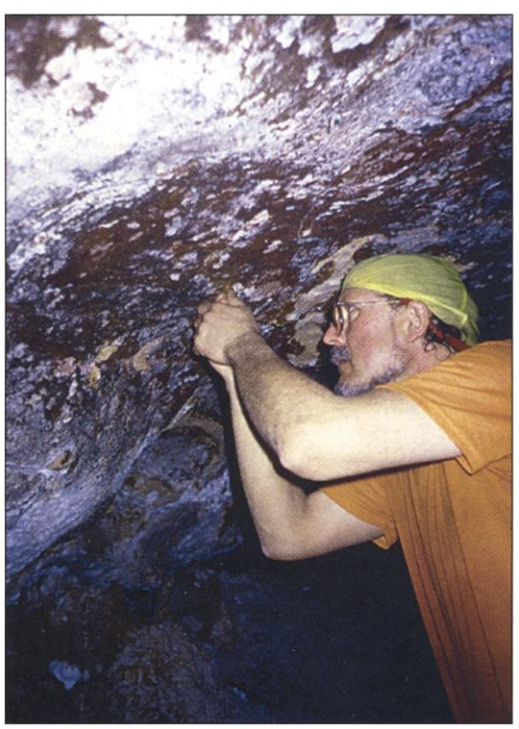
Those boreholes may raise the biggest question of all: whether many of these creatures can survive growing intrusions by humans. When groundwater levels drop, aquatic habitats disappear, and many troglodytes appear exquisitely vulnerable to water pollution. One Australian company is proposing gigantic "water mines" that would empty aquifers into pipelines (*Science*, 2 June 2000, p. 1581), and Australia's mineral companies want more traditional open-pit nickel, gold, and iron mines. The story is similar the world over. So much water has already been pumped from Texas's Edwards Aquifer that nearly all the subterranean aquatic species are threatened, as are nine nonaquatic ones, which were put on the U.S. endangered species list last year. The Kauai cave wolf spider was declared endangered last year because of sewage from new houses, golf-course insecticides, and competition from an adaptable new invader: the American cockroach. In Alaska, loggers are stripping land around unexplored caverns, causing silt to rush in. At least 10 U.S. species are already gone, estimates Missouri's Elliott in the recent book *Subterranean Ecosystems*.

Although surface activities are the main threat, tourism—and research—may be the final assault for some caves. Every hour, a human visitor sheds 60,000 skin fragments; millions of dust, hair, and clothing-lint particles; 24 liters of carbon dioxide; 170 watts of heat; and alien bacteria and fungi—to say nothing of the effect of a hiking boot on a half-centimeter insect. "This messes with the system pretty fast, with cascading results," says Rod Horrocks, a manager at Wind Cave National Park in South Dakota. Horrocks says lights switched on for tourists have allowed photosynthetic algae—and newly emboldened rats—to take root, and lint in unvented spaces "makes some formations look like the back of your clothes dryer." Even in the vast depths of New Mexico's Lechuguilla Cave, where only researchers enter, biologists' urine introduces nutrients, causing foreign bacteria and fungi to proliferate, according to a report by Diana Northup, a microbiologist at the University of New Mexico, Albuquerque, in the *Journal of Cave and Karst Studies* last year. As a result, Lechuguilla researchers now wear clean clothes, transport wastes out, and eat over drop cloths.

Some "show caves," such as Arizona's Kartchner Caverns, are trying to minimize the damage with trailside curbs to contain lint, airlocks and misters to keep humidity constant, and lights that come on only when people show up. But "this stuff doesn't always work," says Gary Berdeaux, who runs Diamond Caverns in Park City, Kentucky, the country's oldest continuously operated show cave. "Unfortunately, show caves are sacrificial lambs."

At Diamond Caverns, at least a few cave creatures have managed to coexist with visitors. No one knows what lived there before August 1859, when the cave opened for business, but a few blind beetles and crayfish still hang on, occasionally scuttling ahead of guides' flashlights. "We like to see them," says Berdeaux. "It means there's something left." **–KEVIN KRAJICK**

Kevin Krajick is the author of *Barren Lands: An Epic Search for Diamonds in the North American Arctic.*



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Sample with care. Researchers work carefully so as not to upset the ecological balance in Lechuguilla Cave.