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Chapter 34

CONSERVATION OF THE NORTH AMERICAN CAVE AND KARST BIOTA

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INTRODUCTION

In this chapter I briefly review the biogeography of the North American cave and karst biota, then the many threats to the biota and the remedies that have been devised. I cite cases mainly from the United States of America, with a few examples from Canada, Mexico, Belize, and Panama (Fig. 34.1, overleaf).

NORTH AMERICAN CAVE BIOGEOGRAPHY

The study of cave biota in the United States began late in the 19th Century, and has been especially productive since the 1950s (Barr, 1968). The first biological study of a Mexican cave was in 1866, and important studies were made in 1932 in Yucatán. Published works on the Mexican cave fauna accelerated since the 1950s (Reddell, 1981).

For too long many biospeleologists believed that troglobites were rare in the tropics. However, it has become apparent that many troglobites exist in Mexico, Hawaii, and other tropical areas where the high biodiversity, complex geology, rugged terrain, and multiple isolating mechanisms provide many opportunities for speciation.

Peck (1997) tabulated the troglobitic fauna of the 48 contiguous states of the United States. There are at least 1307 troglobitic species in the United States, including 401 aquatic species (31%) and 906 terrestrial species (69%). Peck thought that more species were to be discovered, but doubted that there were 6000 troglobitic species, as predicted by Culver and Holsinger (1992). In southeastern Alaska, two troglobitic amphipods of the genus *Stygobromus* are known from island caves; one of these species (*S. quatsinensis*) also occurs in caves on Vancouver Island (British Columbia, Canada) (Aley et al., 1993). Castleguard Cave in Alberta, contains Canada's only other troglobite, *Stygobromus canadensis* (Holsinger et al., 1997).

Reddell (1981) reported about 317 troglobites from caves in Mexico, Guatemala, and Belize, and nearly 1952 species in all. Troglobites were about 16% of the total number of species, and about 25% of the troglobites were aquatic. Hundreds of new species awaited study and description at that time. The number of named troglobitic species today probably would be about 500, but no recent tabulation has been published (Elliott, 1994b).

Based on these studies and typical trends, I estimate that continental North America currently contains about 1800 named troglobitic species, of which 25 to 30% are aquatic. In addition, caves provide shelter for bats and numerous other vertebrates. Humans benefit from the feeding activities of bats, in controlling night-flying insects, pollinating plants, and re-seeding forests.

Karst environments, such as deep, moist sinkholes and limestone glades, sometimes have relictual plant species, such as the Hart's tongue fern *Phyllitis scolopendrium* var. *americanum*, a Pleistocene relict found in Ontario, Michigan, New York state, and cave entrances in Tennessee and Alabama (Evans, 1982). A high degree of endemism occurs in plant species in the limestone glades of the southeastern United States (Baskauf, 1997). The only known United-States locality for the tropical hay-scented fern, *Dennstaedtia globulifera*, is in Fern Cave, Texas (Elliott, 1994f). These patchy environments are just as vulnerable as the caves.

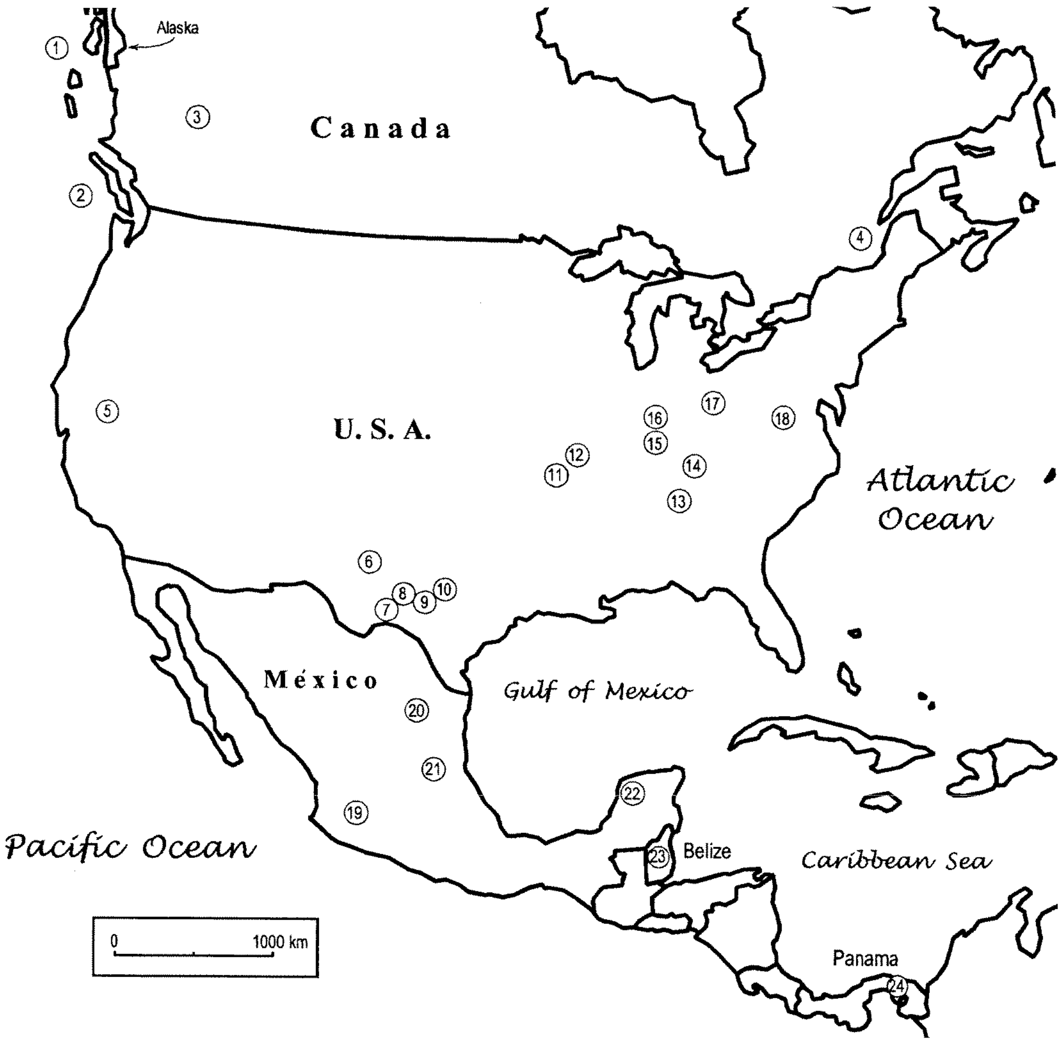

Fig. 34.1. Map of North America with selected locations discussed in text. (1) Southeast Alaska; (2) Vancouver Island; (3) Castleguard Cave, Alberta; (4) Fourth Chute Cave, Quebec; (5) McLean's Cave and Transplant Mine, California; (6) Carlsbad Cavern, New Mexico; (7) Marshall Bat Cave, Texas; (8) Valdina Farms Sinkhole, Texas; (9) San Antonio and San Marcos, Texas; (10) Austin, Texas; (11) Blanchard Springs Cavern, Arkansas; (12) Meramec Spring, Missouri; (13) Shelta Cave, Alabama; (14) caves at Cookeville, Tennessee; (15) Mammoth and Hidden River caves, Kentucky; (16) Blue River Karst, Indiana; (17) Cave Hill Cave, Ohio; (18) Virginia and West Virginia karst; (19) Mezcala, Jalisco; (20) Toxic Sink and Pozo del Cañon El Buey, Coahuila; (21) Sótano de Médico, San Luís Potosí; (22) Mérida, Yucatán; (23) Actun Chapat, Belize; (24) Chilibrillo Cave, Panama.

EXTINCT AND ENDANGERED SPECIES

Four or five North American troglobitic species are thought to be extinct, but it is likely that others became extinct before they could be discovered or described (Table 34.1). It is certain that local populations of invertebrates, fishes, salamanders and bats have been extirpated. Probably fewer than half of the United-States troglobites have been described, and in Mexico the proportion is even lower. Since some species are endemic to a single cave or a small cluster of caves, and many caves have been disturbed, filled, quarried, mined, or polluted, it is possible that some species have disappeared without it being known.

The Valdina Farms Sinkhole salamander, *Eurycea troglodytes*, may be extinct. The salamander's only known cave in Texas was used as a recharge well by the Edwards Underground Water District, which excavated a flood channel from a nearby creek to the entrance. In 1987 a large flood pulse cleaned out the

Table 34.1
Possibly extinct cave-dwelling species of North America

Species	Last year seen	Threats	Range[1]
Crustacea			
Bactrurus n.sp., amphipod	1963	sealed spring, pesticides	Indiana
Stygobromus lucifugus (=*subtilis*?) Dubious Cave amphipod	1882	?	Illinois
Insecta			
Pseudanophthalmus krameri, Kramer's cave beetle	1973?	?	Ohio
Amphibia			
Eurycea robusta, Blanco blind salamander	1951	?	Texas
Eurycea troglodytes, Valdina Farms Sinkhole salamander	1985?	recharge dam	Texas

[1] All species in this table were each known from a single cave only.

cave. Also lost were a colony of four million free-tailed bats, *Tadarida brasiliensis mexicana*, and a rare colony of the leaf-chinned bat *Mormoops megalophylla*. A follow-up study failed to find the salamander (Veni, 1987; Elliott, 1993a, 1994d).

Jordan Hall Spring, in the sub-basement of the biology department at Indiana University, was altered by construction and then poisoned by a termite treatment. The spring used to contain a unique isopod, *Caecidotea jordani* and two amphipods, *Crangonyx* n. sp. and *Bactrurus* n. sp., the latter being unique to that spring (Lewis, 1996a; John Holsinger, personal communication).

Hobbs (1997) reported that the carabid beetle *Pseudanophthalmus krameri* appears to be extinct or extremely rare. The beetle was known only from Cave Hill Cave, Ohio, which is in a mixed, mesophytic, second-growth forest with nearby fields, in a formerly glaciated area. The cave supports 23 terrestrial and aquatic species, and there were no obvious perturbations, although pesticide spraying could have occurred. Repeated visits and intense sampling yielded no individuals of *P. krameri*.

Some troglobites are extremely rare, so that it is difficult to prove or disprove whether they are extinct. For example, intensive surveys of the Blue River Bioreserve, Indiana, turned up a cave pseudoscorpion, *Kleptochthonius packardi*, which had not been seen for over 100 years (Lewis et al., 1997). The endangered blind Kentucky cave shrimp *Palaemonias ganteri* was thought to be extinct because it was not seen between 1967 and 1979, although it was seen again subsequently (Lisowski, 1982, 1983). There had been a reduction in sightings of cave fish, crayfish, and shrimps just after brine contamination from oilfields in 1961. In Mammoth Cave (near Bowling Green, Kentucky), the shrimp inhabits quiet, silt-bottomed pools with seasonal sediment deposition. This was altered by river dams, which caused back-flooding, back-ponding, siltation, temperature changes, and increased pollution input to streams in the Mammoth Cave system (Fig. 34.2). The normal levels of back-ponding were documented by Hovey in 1897 and 1909.

The rarity of the blindfish *Amblyopsis spelaea* in Mammoth Cave and its absence from adjacent areas to the north led to speculation that it was either introduced or decimated during the long period when blindfish were sold as curios. Poulson (1968) examined historical and scientific records, and found that most early records from Mammoth Cave were for *A. spelaea*, not *Typhlichthys subterraneus*, which also inhabits the cave. *Amblyopsis spelaea* was the dominant species in the Echo and Roaring River areas of Mammoth Cave around 1890, and it is still common in Roaring River. The present rarity of *A. spelaea* is probably related to silting and flooding associated with deforestation, forest fires, and the construction of Lock and Dam #6 on the nearby Green River (Poulson, 1968).

Table 34.2 details the twenty troglobitic species in the United States and one in Mexico that are on the lists of endangered or threatened species for the United States or for individual states. The Texas blind salamander, *Typhlomolge rathbuni*, was the first endangered species listed by the United States under the Endangered Species Conservation Act, a forerunner to the current Endangered Species Act. The salamander

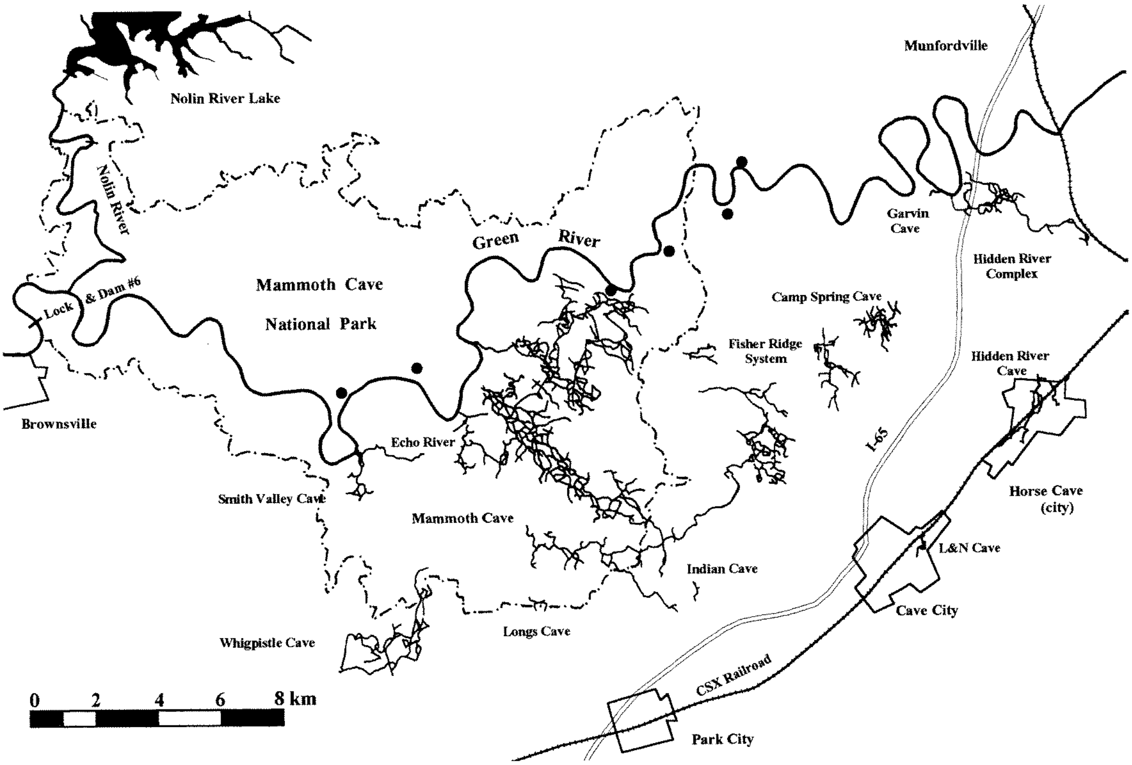

Fig. 34.2. The region around Mammoth Cave, Kentucky, depicting places mentioned in the text. The Green River flows to the west (left), and is impounded by Lock & Dam #6, which causes backflooding into some caves. Cave City and Horse Cave (city) are hydrologically connected to the Green River via Hidden River Cave and its downstream Complex.

was first seen in 1895 when an artesian well was drilled close to the San Marcos River. It is considered one of the most cave-adapted vertebrates in the world. Today it is also known in the nearby Ezell's Cave, which is protected by The Nature Conservancy, and two or three other localities in the vicinity. These localities are threatened by excessive pumping from the Edwards Aquifer, which serves as the sole drinking water source to more than 1.5 million people in central Texas (Longley, 1991).

The first seven Texas species in Table 34.2 all occur in two counties around Austin, and were listed in 1988 as endangered by urbanization, road-building, quarrying, and imported red fire ants (*Solenopsis invicta*). Subsequent studies have expanded the known range of some of the species, but all are still significantly threatened. Williamson County in Texas is currently the second fastest growing county in the United States. Since 1850, Austin (Travis County) has doubled in population about every 20 years (Reddell and Elliott, 1994).

Table 34.3 lists the six bats in the continental United States that are currently on the United States endangered species list. All are dependent on caves for part of their life cycle, and disturbance has been the major factor in their decline. Indiana bats, *Myotis sodalis,* have lost significant numbers, largely through disturbance of their hibernacula and improper gating, but also through loss of their typical summer habitat (under the bark of riparian trees).

My work in ten caves in Belize in 1992 and 1993 convinced me that insectivorous and frugivorous bats are often dependent on caves for roost sites in the tropics. In a cave called Actun Chapat, I found the frugivore *Artibeus jamaicensis* and the insectivores *Glossophaga* sp. and *Mormoops megalophylla* (unpublished data). In two other caves I found *Carollia* sp., a frugivore. "Ecotours" are increasing their visits to some of these caves. Disturbance of these cave roosts could lead to a decline in the reseeding of cut-over forest areas by bats.

McCracken (1989) questioned the utility of the IUCN *Red Data Book*, which in 1988 listed 4% of the world's bat species as endangered or threatened; he thought that this list gave an inaccurate and minimal

Table 34.2
Endangered and threatened cave and karst species of North America[1]

Species	Status[2]	Year listed	Range
Arachnida			
Neoleptoneta myopica, Tooth Cave spider	E	1988	Texas
Tartarocreagris texana, Tooth Cave pseudoscorpion	E	1988	Texas
Texella reddelli, Bee Creek Cave harvestman	E	1988	Texas
Texella reyesi, Bone Cave harvestman	E	1988	Texas
Crustacea			
Antrolana lira, Madison Cave isopod	T	1982	Virginia
Cambarus aculabrum, cave crayfish	E	1993	Arkansas
Cambarus zophonastes, cave crayfish	E	1987	Arkansas
Gammarus acherondytes, Illinois cave amphipod	E	1998	Illinois
Lirceus usdagalun, Lee County cave isopod	E	1992	Virginia
Palaemonetes cummingi, Squirrel Chimney Cave = Florida cave shrimp	T	1990	Florida
Palaemonias alabamae, Alabama cave shrimp	E	1988	Alabama
Palaemonias ganteri, Kentucky cave shrimp	E	1983	Kentucky
Insecta			
Batrisodes texanus, Coffin Cave mold beetle	E	1988	Texas
Rhadine persephone, Tooth Cave ground beetle	E	1988	Texas
Texamaurops reddelli, Kretschmarr Cave mold beetle	E	1988	Texas
Pisces			
Amblyopsis rosae, Ozark cavefish	T	1984	Arkansas, Missouri, Oklahoma
Prietella phreatophila, Mexican blindcat (catfish)	E	1970	Mexico (Coahuila)
Speoplatyrhinus poulsoni, Alabama cavefish	E	1977	Alabama
Amphibia			
Gyrinophilus palleucus, Tennessee cave salamander	ST (Tenn.)		Tennessee, Alabama, Georgia
Typhlomolge rathbuni, Texas blind salamander	E	1967	Texas
Typhlomolge robusta, Blanco blind salamander	SE	P 1995	Texas

[1] From the U.S.Fish and Wildlife Service, http://www.fws.gov/~r9endspp/endspp.html, and state web sites.
[2] E, endangered; T, threatened; P, subjects of citizen petitions; SE, State endangered list; ST, State threatened list.

assessment of our current extinction crisis. This was because the list largely reflects the ignorance of the status of bats in most parts of the world. Besides the six endangered United States bats, another 13 species in the United States rely substantially on caves; but this does not mean that the other 34 United States bat species are doing well.

Table 34.4 lists twelve species that are being seriously considered for listing by the United States Fish and Wildlife Service (USFWS). Some were the subject of citizen petitions, and some were promoted by the Service because of imminent land development, as in the case of *Cicurina wartoni* (Ruth Stanford, USFWS, personal communication). In 1996 the Service discontinued the C2 list, a sort of "pre-candidate list".

The United States Fish and Wildlife Service has received many petitions for additional listings of cave species, but has not acted on most of the petitions because of a lack of data, lack of funding and staff, or political pressure. Table 34.5 summarizes the 11 species which are the subject of petitions still being considered; for at least 64 others that were the subject of petitions, they were ruled "not substantial", "not warranted", "warranted but precluded", or "withdrawn" (Susan Lawrence, USFWS, personal communication). Frequently there was a lack of information in the

Table 34.3
Endangered North American bats and their use of cave roosts[1]

Species	Food preferences	Cave roost requirements	Range
Leptonycteris sanborni, Lesser (Sanborn's) long-nosed bat	agave nectar, pollen, insects	Year-round	southern Arizona, Mexico
Leptonycteris nivalis, Mexican long-nosed bat	agave nectar, pollen	Year-round	West Texas, Mexico
Myotis grisescens, Gray bat	insects	Year-round	Oklahoma, Kansas to Kentucky, then south to Florida
Myotis sodalis, Indiana bat	insects	Winter hibernacula	Vermont to Oklahoma, Michigan to Florida
Corynorhinus townsendii ingens, Ozark big-eared bat	moths	Year-round	Oklahoma, Arkansas (now absent from Missouri)
Corynorhinus townsendii virginianus, Virginia big-eared bat	moths	Year-round	Kentucky, Virginia, West Virginia

[1] Sources: Barbour and Davis (1969); McCracken (1989); U.S. Fish and Wildlife Service web site, http://www.fws.gov/~r9endspp/endspp.html.

Table 34.4
Candidates for the United States list of endangered species[1]

Species	Status and priority[2]	Threats	Range (and number of sites)
Mollusca			
Antrobia culveri, Tumbling Creek cave snail	C, 7	potential pollution	Missouri (1)
Arachnida			
Adelocosa anops, Kauai cave wolf spider or pe'e pe'e maka 'ole	C, 1	land development	Hawaii
Cicurina bandida, Spider	SC?	land development	Texas (1)
Cicurina cueva, Spider	SC?	land development	Texas (1)
Cicurina wartoni, Warton's cave spider	C, 2	land development	Texas (1)
Neoleptoneta microps, spider	SC?	land development	Texas (1)
Crustacea			
Spelaeorchestia koloana, Kauai cave amphipod	C, 1	land development	Hawaii
Stygobromus pecki, Peck's cave amphipod	PE[3]	overuse of aquifer	Texas (1)
Caecidotea filicispeluncae, isopod	SC	tree cutting, microclimatic changes	Ohio (1)
Caecidotea rotunda, isopod	SC	human visitation	Ohio (1), Indiana (4)
Insecta			
Pseudanophthalmus holsingeri, Holsinger's cave beetle	C, 2	gasoline, sewage, siltation	Virginia (1)
Pseudanophthalmus ohioensis, beetle	SC	small population, flooding, visitation	Ohio (1)

[1] U.S. Fish and Wildlife Service web site, http://www.fws.gov/~r9endspp/endspp.html.

[2] PE, formally proposed for the list of endangered species. C, species that probably will be listed as endangered (priority increases from 12 to 1). SC, species of concern (lowest status).

[3] Year of petition 1990.

Table 34.5
Cave species for which petitions by United States citizens for listing as "endangered" are currently being considered

Species	Year of petition	Range
Arachnida		
Cicurina (Cicurella) baronia, Robber Baron Cave spider	1992	Texas [1]
Cicurina (Cicurella) madla, Madla's Cave spider	1992	Texas [1]
Cicurina (Cicurella) venii, Cave spider	1992	Texas [1]
Cicurina (Cicurella) vespera, Vesper Cave spider	1992	Texas [1]
Neoleptoneta microps, Government Canyon Cave spider	1992	Texas [1]
Texella cokendolpheri, Robber Baron Cave harvestman	1992	Texas [1]
Crustacea		
Stygobromus clantoni, Clanton's Cave amphipod	1989	Kansas
Insecta		
Rhadine exilis, ground beetle	1992	Texas [1]
Rhadine infernalis infernalis, ground beetle	1992	Texas [1]
Rhadine infernalis ewersi, ground beetle	1992	Texas [1]
Batrisodes (Excavodes) venyivi, Helotes mold beetle	1992	Texas [1]

[1] All Texas species in this table are from Bexar County, the San Antonio area.

Table 34.6
Species wholly dependent on karst aquifers, which have been listed as "endangered" or "threatened", or have been proposed for listing [1]

Species	Status [2]	Year of listing or petition	Range
Insecta			
Heterelmis comalensis, Comal Springs riffle beetle	PE	1990	Texas
Stygoparnus comalensis, Comal Springs dryopid beetle	PE	1990	Texas
Pisces			
Cyprinodon diabolis, Devil's Hole pupfish	E	1967	Nevada
Cyprinodon elegans, Comanche Springs pupfish	E	1967	Texas
Cyprinodon bovinus, Leon Springs pupfish	E	1980	Texas
Etheostoma fonticola, fountain darter	E	1970	Texas
Amphibia			
Eurycea nana, San Marcos salamander	T	1978	Texas
Eurycea sosorum, Barton Springs salamander	E	1997	Texas
Liliopsida			
Zizania texana, Texas wild rice	E	1978	Texas

[1] U.S. Fish and Wildlife Service web site, http://www.fws.gov/~r9endspp/endspp.html.
[2] E, listed as "Endangered"; T, listed as "Threatened"; P, subject of citizens' petition.

petitions about population trends or threats. However, few of the species are under study because of little or no funding from any source.

Table 34.6 summarizes endangered "karst-dependent" species; these are not particularly cave-adapted, but are wholly dependent on the flow of karst springs. The San Marcos and Comal rivers in central Texas are fed by large springs from the Edwards Aquifer. The rivers support multiple endemic species, and contribute to the Guadalupe River, which feeds the San Antonio Bay estuary on the Gulf of Mexico coast, where there are important fisheries.

The process by which endangered species are listed in the United States is haphazard (Elliott, 1990, 1992a). Not only must there be adequate scientific knowledge to list a species, often there must be a political push in the form of a petition from conservationists and scientists. Consequently, unpopular or obscure species, even if they be declining, often are not listed because they are not championed by anyone. Although the cave species that are currently listed have multiple threats against them, other species may be in more danger than those already listed. Species on the list often serve, however imperfectly, as proxies that protect other species which should also be listed. Elliott (1991) analyzed the biogeography of more than 100 rare cave species in the Balcones Fault Zone of Texas. Travis County contains more than 30 troglobitic species endemic to that county, but only six of them were listed. His analysis selected a list of caves for the Balcones Canyonlands Conservation Plan that would protect all the endangered species as well as most of the other rare endemics, all of which are vulnerable. That plan now includes about 65 caves, half of which contain endangered species. However, lack of funding has imperiled even those caves (Elliott, 1997c).

The value of cave species to the public often is considered low; but cave species have potential scientific, practical, and educational value. To many, the size or intelligence of a creature is equated with its importance. Cave species may have good potential value to humans as "indicator species" in karst areas. That is, the decline of sensitive species because of pests or pollution may serve as a natural alarm for regulators and public health agencies. This is especially true of groundwater species, which may be affected by pollutants, pathogens, or nutrient stress over long distances. These contaminants can also affect people.

THREATS TO CAVE AND KARST COMMUNITIES

Declines in cave bat populations were noted as early as 1952 (Mohr, 1972). Studies of troglobites lagged behind because of the small number of biospeleologists. Poulson and Kane (1977) outlined several kinds of disturbance in cave ecosystems. They gave examples from Mammoth Cave, and with a flow chart they illustrated the results and interrelations of these disturbances. For a scientific management program, they outlined the elements of a biological inventory coupled with environmental measurements, taxonomic identifications, and evaluation of results. Many of the threats discussed below are so interrelated that researchers have difficulty determining which threats cause the greatest problems.

Hydrological threats

Water projects have caused many problems for cave biota. The Mammoth Cave system in Kentucky has the longest and best documented ecological history of any cave in North America. The Styx and Echo river areas in Mammoth Cave had an apparent decline of troglobites from the late 1800s to the 1910s or 1920s. In 1906, an impoundment (Lock and Dam #6) was installed on the Green River below Mammoth Cave. Green River naturally back-floods into the cave, but the levels are higher now than before this construction (Lisowski and Poulson, 1981; Lewis, 1982). About 1937, back-flooding into Bat Cave killed 300 000 individuals of *Myotis sodalis* (Mohr, 1972). From the late 1950s to the 1970s, the cavefish and cave crayfish seen were all large, but in low numbers. In the 1970s the Nolin River, a tributary to Green River, was dammed below Mammoth Cave, and Green River was dammed upstream. Since then the maximum height of floods has decreased and the time to return to base-level flow after floods has increased. The Kentucky blind shrimp (*Palaemonias ganteri*) declined, and is now found farther upstream in the cave. Poulson (1996) concluded that toxins and organic enrichment, though present, were not the cause of the declines in the biota, which was probably due to siltation. Loss of nutrients also may have occurred (see below). The present rarity of *Amblyopsis spelaea* is probably related to silting and flooding associated with deforestation, forest fires, and the construction of Lock and Dam #6 (Poulson, 1968).

Lewis and Lewis (1980) studied *Caecidotea stygia* and another unnamed species of *Caecidotea* in Mammoth Cave. Base-level streams typically provide greater microhabitat diversity and perennial water supplies, but environmental disturbances have reduced habitat diversity and introduced physical and chemical conditions which cause animal communities to deteriorate. Isopods do not usually occur in Echo or Styx rivers, except where large breakdown slabs remain above the silt or where boards from old tourist trails have been discarded into the stream, creating artificial microhabitats harboring isopods. The once abundant crayfish *Orconectes pellucidus*, reported by Hay about 1902 in the River Styx, is no longer common, since the food source (*Caecidotea*) has disappeared.

A water-quality monitoring program in Mammoth Cave National Park from 1990 to 1993 provided baseline data on spatial and temporal changes, but no biological data were gathered. Two rivers and eight springs were sampled synoptically in natural woodlands, agricultural lands, and areas influenced by urban use and oil and gas exploration. The 36 parameters recorded at monthly intervals included discharge, turbidity, chloride, fecal coliform, organisms and triazine herbicides. The first 19 months of data demonstrated a strong correlation between land use in the drainage basin and water quality. In June 1990, Echo River Spring back-flooded from the Green River and received a large amount of flow from heavily used agricultural land, whereas its normal input is of low-turbidity water from parkland (Meiman, 1993).

In the late 1970s the New Melones Reservoir was built on the Stanislaus River in California. About 30 caves were inundated, including McLean's Cave, one of only two known localities for the troglobitic harvestman *Banksula melones*. The McLean's Cave community was transplanted to a nearby mine, but in a follow-up study *B. melones* was found in 18 caves and is now considered safe (Elliott, 1978, 1981). [See further discussion of this case under Ecological Transplantation below, p. 684].

The loss of recharge to and excessive pumping from a karst aquifer results in a gradual decline of water quantity and quality. The Devil's Hole pupfish (*Cyprinidon diabolis*) in Nevada is endangered by excessive pumping from the regional aquifer, which has reduced the fish to a tiny population at the bottom of a sinkhole (Elliott, 1981). Other karst pupfishes are also endangered (Table 34.6).

The Balcones Fault Zone portion of the Edwards Aquifer (Texas) supports more than 40 aquatic species. This unique community is in danger of severe impact from excessive pumping of groundwater, which will cause spring failures and dewatering of some of the system, and also cause encroachment of highly saline water into areas that now have high-quality water. The annual withdrawal by pumping of about 666 080 000 m^3 now approaches the annual average recharge of 774 627 000 m^3 (Longley, 1991). Four endangered animal species (the beetles *Heterelmis comalensis* and *Stygoparnus comalensis*, the fountain darter *Etheostoma fonticola*, and the salamander *Eurycea sosorum*), as well as the endangered Texas wild rice *Zizania texana*, and one threatened species (*Eurycea nana*), are dependent on this aquifer (see Tables 34.2 and 34.6).

Land development

The development of karst areas without regard to sensitive natural features has destroyed or filled numerous caves. In the area of Austin (Texas), caves are often searched out before the construction of roads and buildings because of endangered species protected by the United States Fish and Wildlife Service (USFWS). The excavation of sealed cave entrances during karst studies may lead to drying of the entrance zone. However, this may be offset by increased nutrient input from organic detritus, colonizing cave crickets, bats, and other species; but pests, such as fire ants, may also invade the caves more easily (see below, p. 678). Studies have shown that occasional feces deposited by visiting raccoons (*Procyon lotor*), who routinely use caves, enhances the population sizes of terrestrial cave communities; therefore the opening of sealed caves may be beneficial to cave communities if inputs and disturbance are not excessive (Elliott, 1994c; Elliott and Reddell, 1989; Reddell, 1991; Reddell and Elliott, 1991).

The mining of caves for saltpeter, bat guano, or other minerals can have a drastic effect on bat colonies and other fauna. Mexican free-tailed bats, *Tadarida brasiliensis mexicana*, have been disturbed by some guano mining in Texas, whereas other miners may have aided the colonies by mining-out rooms that might eventually have filled with guano. The better operations mine only in the winter when the bats are gone (Elliott, 1994d).

Quarrying and road building has completely destroyed many caves, but has also revealed some significant caves that were put to good use. Inner Space Cavern, near Georgetown, Texas, was discovered in 1963 during construction of Interstate Highway 35. It proved to be an important biological and paleontological cave, and was so attractive that it was developed as a show cave in 1966. The cave also contains two endangered species, but it is threatened by road spills, quarrying (and its possible effects on troglobite populations and groundwater), utilities, and encroaching residential developments (Elliott, 1994g).

The opening of large second entrances can severely alter the meteorology of a cave, causing bats to vacate it. Marshall Bat Cave in Texas lost its colony of free-tail bats after 1945, when a large shaft 40 m deep was dug into the rear of the cave to hoist out guano, causing too much ventilation and cooling of the cave (Elliott, 1994d). Free-tails require warmth and large caverns for maternity roosts (Herreid, 1963, 1967). Mammoth Cave in Kentucky probably harbored bats prehistorically, before the entrance was modified to block incursions of cold winter air. The National Park Service is currently trying to reinstate the natural temperature profile of the cave (Rick Olson, personal communication).

Sealing caves can be very harmful to cave fauna – even an imperfect gate can harm bats and other fauna (see below). Although there is little direct information on the effects of actually sealing a cave, I have observed that areas of caves that are naturally sealed by calcite, or truly entranceless caves that have been bored into, are rather depauperate. Poulson (1997) has noted the dry areas of Mammoth Cave caused by the sandstone cap-rock, which hinders percolation and food input. In the shallow caves of central Texas, those areas with soil creeping in from plugged sinkholes, or near tree roots, or with feces from crickets, bats or raccoons, have more abundant and diverse communities (Elliott and Reddell, 1989; Reddell and Elliott, 1991; Reddell, 1991). Some cave communities are highly dependent on cave crickets, which leave at night to scavenge on the surface; for example, different species of troglobitic beetles that prey on cricket eggs are found from Indiana to Alabama and Texas. Therefore, if entrances are sealed the input from cave crickets ceases unless access through small holes is still possible.

Caves that are sealed under pavement or buildings usually receive less infiltrating water, and may become barren. For example, Mayor Elliott Cave, which was entranceless, was discovered under a street and a house in Georgetown, Texas, in May, 1997. Investigation of the cave showed that the speleothem areas under the house slab foundation were dry, and there was no fauna. Passageways under a street received infiltration from irrigation of lawns and leaking street gutters. A moist soil slope from a sink or crevice in the yard contained a delicate, endangered, troglobitic harvestman, *Texella reyesi* (Elliott, 1997b).

Nutrient stress

Nutrient loss

Cases in which nutrient loss has resulted in noticeable effects in a cave have rarely been documented; one that is often cited is Shelta Cave, in Huntsville, Alabama. Shelta had the most diverse cave community known in the southeastern United States, but land development encroached on the cave in the 1960s, and the townspeople were concerned about youths entering the cave. The cave harbored a large colony of *Myotis grisescens*, the endangered gray bat. The National Speleological Society purchased the cave in 1967 to save it, and they moved their headquarters to a building nearby. The cave was gated in 1968 with a strong, cross-barred gate taken from an old jail. In hindsight, this gate was inappropriate for bats, and they abandoned the cave within two years. However, the urbanization of the area might also have doomed the colony. In 1981 a modern, horizontal-bar, "Tuttle style" door was put on the gate, but no bats returned to the cave (Hobbs and Bagley, 1989). *Myotis grisescens* usually does not tolerate even well-designed gates, especially for its maternity colonies (Robert Currie, personal communication).

Studies by Cooper (1969, 1975) elucidated the rich aquatic community in Shelta Cave, which included three species of extremely long-lived crayfish with low reproductive rates, a shrimp, cavefish, and numerous other troglobites. The aquatic system was dependent on food from bat guano, and it declined after the bats disappeared in 1970. The counts in Cooper's 1968–1969 census studies, when compared to data collected from 1985 to 1989 by Hobbs and Bagley (1989), showed that, after the bats left, crayfish decreased from a usual range of 49–250 (usually >100) to 0–10, cavefish decreased from "many" to 3–15, and the Alabama cave shrimp dropped from 1–25 to none (Hobbs, 1996). Hobbs and Bagley analyzed cave water samples and found small amounts of heptachlor epoxide ($0.5\,\mu g\,\ell^{-1}$ in 1987, $0.04\,\mu g\,\ell^{-1}$ in 1988). The insecticide probably was leaching into the groundwater from house foundations in the area treated against termites. The shrimp was known from two caves, and was listed as endangered in 1988 (Table 34.2), but has since been found in a river cave in the area (H.H. Hobbs, III, personal communication). It is still not certain whether the cave gate, which caused a nutrient loss by causing the bats to leave, was the primary cause of the community's decline, or if toxins and disturbance were also to blame. All of these factors probably played a role in the decline.

Poulson (1996) suggested that loss of fine particulate organic matter, caused by river damming, could have influenced the decline of aquatic fauna in Mammoth Cave.

Sometimes terrestrial invertebrate cave communities can survive well in urban areas. Elliott and Reddell in 1989 found that Bandit Cave, under a wooded lot in a residential area of Austin, Texas, still contained all of the species found there in the 1960s. The owner protects the cave, and raccoons still visit it, leaving feces. However, there are no real census data to evaluate the situation properly. It may be difficult to maintain aquatic communities and colonies of some bat species in urban areas.

Nutrient enrichment

Enrichment appears to be a much more common problem in caves than nutrient loss. Pasquarell and Boyer (1993) reported on weekly water samples taken in the fall of 1990 from four springs in Greenbrier County, West Virginia. Besides low levels of the herbicide atrazine being detected in all springs, mean nitrate levels were 13.6 and 10.8 $\mathrm{mg}\,\ell^{-1}$ from two basins. Mean bacterial levels for the two basins were 101 and 139 fecal coliform colonies per 100 ml and 266 and 276 fecal *Streptococcus* colonies per 100 ml. Samples from nine cave stream sites had nitrates ranging from 13.4 to 63.7 $\mathrm{mg}\,\ell^{-1}$. Fecal coliforms ranged from 110 to 28 588 colonies per 100 ml. One cave, which had the highest levels of nitrate and fecal coliforms, receives flow from a sinkhole which is immediately adjacent to a feedlot on the surface. Species diversity in this last cave was substantially reduced as compared with the figures for other, less contaminated caves. Aley (1997) mentioned the odor of animal wastes from a hog-raising operation permeating the air of one of the largest caves in Missouri.

A study of three caves in Cookeville, Tennessee, suggested a relationship between degraded water quality and reduced biotic diversity. Capshaw and Ament caves, which receive sewage-contaminated runoff, were dominated by oligochaetes and dipterans, and had larger coefficients of variation for most water-quality parameters than City Spring Cave (Pride et al., 1988).

Karstic groundwater is the major water source in the Yucatán Peninsula, and had a major influence on the Maya culture. In Mérida some waste water is disposed of by deep-well injection, but its fate has not been traced. Pig farms and cattle ranches are another potential source of pollution, and use of fertilizers and pesticides threatens the local water supply in some areas. Solid waste is often dumped at the edges of towns or discarded into dry caves. Cenote Dzitya, near Mérida, was contaminated by a nearby pig farm, according to water chemistry and algal data. Preliminary data from 75 water bodies showed that undisturbed inland water bodies contained relatively low concentrations of nutrients (0.6–16.0 μmol $NO_3^- + NO_2^-$, 0.1–6.0 μmol NH_4^+, 0.2–1.8 μmol P, and 2.3–74 μmol Si), whereas culturally impacted ecosystems and coastal lagoons had evidence of enrichment (19–162 μmol $NO_3^- + NO_2^-$, 6–62 μmol NH_4^+, 2.5–13.8 μmol P, and 93–544 μmol Si). A pig farm (Agropecuaria Yucatán) was constructed above Cueva de El Pochote, which contained a unique cave fauna, including the fishes *Ogilbia pearsei*, *Ophisternon infernale*, the isopod *Creaseriella anops*, and the shrimps *Creaseria morleyi* and *Typhlatya pearsei* (Horst Wilkens, personal communication). Cenotes provide important habitat for stygobionts and other species, such as the threatened Morelet's crocodile, and provide drinking water for endangered mammals such as the jaguar (Brenner et al., 1995). No studies of pollution effects on cave species of this region have been published to date.

In July 1993 I observed many annelid worms in a stream in Whispering Canyon Cave, in the Tongass National Forest, southeastern Alaska, which may have reflected elevated nutrient loads from nearby logged areas (Aley et al., 1993). Problems caused by logging have been reported in similar cave areas on Vancouver Island (British Columbia, Canada). Many caves were choked with slash and sediments, and small buffer zones of uncut timber around caves were blown down by windstorms because they were inadequate in size and design (Blackwell and Associates, Ltd., 1995; Stokes, 1996; Paul Griffiths, personal communication).

Enrichment is a common problem, especially in show caves, where it is caused by lunch rooms, garbage, litter, sewage, cave lint, and lighting that promotes the growth of Cyanobacteria. These disturbances change the distribution and abundance of species within the cave. Examples from several prominent caves are given below.

Mammoth Cave, Kentucky. The cave amphipod, *Crangonyx packardi*, used to be common in Shalers Brook in Mammoth Cave, which at one time was enriched by sewage effluent from the Mammoth Cave

Hotel. The sewage problem has now abated and *C. packardi* is no longer there, but *Stygobromus vitreus*, which is more cave-adapted, is present (Lewis, 1984). The artificial Crystal Lake, near the Frozen Niagara Entrance, was created from damming a short shaft drain, and was used for boat rides. Barr and Kuehne (1971) reported that *Caecidotea stygia* and *Orconectes pellucidus* were there, but Lewis (1984) found neither and noted that, "Prying boards from the bottom of the lake uncovers a black layer of anaerobically produced *sapropel* with its characteristic accompanying odor, a habitat which does not seem conducive to cavernicoles."

Pollution from the flushing of a sewage lagoon used by the Job Corps in the summer of 1967 reduced the complexity of the cave community from that seen under unpolluted conditions in 1966. It also reduced the numbers of terrestrial organisms trapped per trap–day by a factor of more than ten at two stations near the headwaters of Eyeless Fish Trail. Organic content was 240% of the 1966 level. A "high-tide-line" of Cyanobacteria, like that associated with foam and coliform pollution in Keller Shafts, was marked (Poulson, 1967). The Job Corps Center was removed several years later. Attention was focused on potential sources of contamination. The United States Environmental Protection Agency issued an Environmental Impact Statement on Mammoth Cave. New waste-load allocations were to be issued for public treatment plants in the area. The National Park Service financed a regional sewage treatment plant (Poulson, 1997).

In Mammoth Cave most contaminant transfer occurs in the first flush of rainfall events. Farmlands on karst contribute non-point-source sediments, pesticides, herbicides, animal wastes, and bacterial loads to cave streams. Urban development brings sewage, solid waste, and leakage from buried storage tanks and pipelines. Unnatural sediment deposition, entry of exotic species, and changes in deposition of particulate organic matter from upstream threaten ecosystems at the water table or base level (Poulson, 1996, 1997).

The pathogen *Salmonella choleraesuis* was recovered in water from the Hawkins River and Owl Cave in Mammoth Cave National Park, and *Salmonella* sp. was found in Owl Cave sediment. Echo River in Mammoth Cave lacked *Salmonella*. A possible source of the bacteria was septic systems that had failed (Rusterholtz and Mallory, 1990).

Poulson (1992) developed community signatures for different kinds of pollutants, contrasting acute toxins, chronic toxins, organic enrichment, and siltation. "Indices of biological integrity" included the number of species and metrics for their well-being, and the presence and relative abundance of tolerant and intolerant species. Gross enrichment is usually from point sources, and can be detected as a slippery biofilm on rocks in cave streams, with stimulation of short-lived troglobites like flatworms and isopods.

In many show caves, plant growth around electric lights is a continual problem. Algae and moss protonemata had to be steam-cleaned from ceiling formations at Frozen Niagara in Mammoth Cave (Aley, 1997).

Enrichment sometimes comes from unusual sources. Lisowski et al. (1986) found that release of oil brines or sulphur water from oil and gas exploration could have major adverse impacts on the Mammoth Cave system. They found sulfur bacteria in Sulphur River in Parker's Cave, which is strikingly different from other cave streams in the region. The water contained high levels of sodium chloride (up to 1.6% Cl^-) and sulfide. The substrate of the stream was covered with a white mat-like material several centimeters thick. Two sulfur oxidizers, *Beggiatoa alba* and "*Thiothrix tenuissima*", were in the mat along with others. Water and mat samples contained a number of Protozoa in 12 genera, including flagellates, ciliates, and amoeboid forms. Two species of annelids, a cave snail, five species of collembolans, a cave carabid, a linyphiid spider *Phanetta subterranea*, and several species of mites were found. Water droplets on a spider's web were milky white because of rod-shaped bacteria, and had a pH of 0.13. Northup et al. (1997a) characterized the bacteria as sulfide oxidizers, and found phylogenetic relationships with communities of deep-sea thermal vents and tidal mud-flats.

Hidden River Cave, Kentucky. The Hidden River (Horse) Cave system was commercialized in 1916, the tourist industry co-existing with water pumping and hydroelectric generation. Hidden River Cave had a troglobitic fauna, including the cavefish *Typhlichthys subterraneus*, the crayfish *Orconectes pellucidus* and the isopod *Caecidotea bicrenata*. However, increasing groundwater contamination from indiscriminate sewage disposal led to closing of the cave's tourist operation in 1943. Creamery wastes, and sewage from Cave City and the City of Horse Cave, were introduced into the cave stream. In 1970 waste water from a chrome-plating factory was added to the sewage-plant effluent entering the cave. The troglobitic community was extirpated as a result of degradation of the cave. The South Branch of Hidden River Cave contained large numbers of red tubificid worms (*Tubifex* sp.) at the edges of stream pools, "sewage fungus" (characterized by the bacterium *Sphaerotilus natans*), nearly anaerobic conditions, low nitrates, high nitrites, and blackened iron sulfide. In 1983 the East Branch of Hidden River had recovered much of its natural character by the time it reached Hidden River Cave from the Cave City treatment plant. The water was nearly saturated with oxygen and probably supported troglobites. In 1989, new sewage-treatment facilities were opened and the flow of effluent to the cave stopped. By about 1995 the original animal community had substantially recolonized the section of the cave which had once been heavily polluted, from relatively unpolluted, upstream tributaries (Lewis et al., 1983; Lewis, 1996a). Such an outcome could not have occurred in many other hydrologic situations. Today, visitors can take an ecological tour into the cave and observe the troglobites.

Carlsbad Cavern, New Mexico. Except for the Bat Cave section, where a large colony of free-tail bats (*Tadarida brasiliensis mexicana*) resides, Carlsbad Cavern had a sparse fauna which became disturbed after the cave was opened to the public in 1923. Bailey (1928) observed that the Lunch Room in the cave was already in the 1920s leading to an invasion of the King's Palace area, the southern Big Room, and the lower cave by *Peromyscus leucopus* mice. Although this species commonly is found in cave entrance areas, where it feeds on crickets, the mice already were permanent residents deep in the cave, as evidenced by females with embryos or nursing young. Bailey found cave crickets and tourists' lunches in the mouse stomachs.

Studies of rhaphidophorid crickets in Carlsbad Cavern have shown unnatural distributions. *Ceuthophilus carlsbadensis* naturally occurs in the Bat Cave section. *Ceuthophilus longipes* now occurs far from the entrance in total darkness in the Sand Passage. In the Left Hand Tunnel (just past the Lunch Room) *C. carlsbadensis* and *C. longipes* occurred near reliable food sources such as trash containers. In the Left Hand Tunnel, a greater number of crickets was found directly behind the gate about 100 m from the Lunch Room, and also 300 m from there at a probable oviposition site. This appears to be an artificial-entrance situation, with the lighted Lunch Room serving as an *Ersatz* outdoors, complete with food, and the crickets hiding in a darkened area behind the gate, and ovipositing farther back. Any food dropped by park visitors attracts crickets to feed upon it. Rangers have reported crickets feeding on bat carcasses in the Queen's Chamber, and on human feces left on or near visitor trails (Northup and Kuper, 1987; Northup et al., 1987, 1989). The National Park Service instituted tighter housekeeping controls on the Lunch Room operators, and now removes the contents of all trash barrels by the end of the day to combat the large number of raccoons that invaded the cave at night (National Park Service, 1996; Dale Pate, personal communication). The National Park Service's new management plan (1996) would remove the facilities from the Lunch Room.

Aley et al. (1985) conducted studies on exotic plant growth in Carlsbad Caverns. They identified 26 species of algae, together with moss protonemata and two ferns (*Cyrtomium auriculatum* and *Dryopteris filix-mas*). There may have been a total of 100 to 200 species of algae growing in the cave. The growths in the cave included about 70% Cyanobacteria, 20% green algae, and 10% moss protonemata. Diatoms were present in about 25% of all clusters, and a few yellow-green algae were present. Many of the algal genera, and three of the algal species, in Carlsbad have also been found growing in total darkness in other caves. Algal growth, once abundantly established due to artificial lighting, will not quickly disappear if it is deprived of light (Aley et al., 1985). Light intensities were measured at a number of sites. In alcoves the minimum light intensity threshold for algal growth had a mean value of 17.2 lx (1.6 ft c) with a standard deviation of 7.5 lx. In non-alcove sites (most situations) the mean threshold was 47.4 lx (SD = 20.5 lx).

Cave lint studies more or less started in Carlsbad Caverns in connection with annual "lint camp" clean-ups by volunteers. Jablonsky et al. (1995) placed "seeded lint" (which looks different under ultraviolet light from normal lint) on the trail, and found that it moved up to 100 m down the trail; much of it moved to the edge or off the trail. Slides of lint contained synthetic and natural fibers, dirt, wood, insect parts, human hair, animal fur, fungus, processed tobacco, paper, and other things. Unidentified mites were seen in some of the samples (Pat Jablonsky, personal communication).

In Carlsbad Cavern, Elliott (1997a) studied old woodpiles, which probably were remnants of structures installed in the 1920s. Most of the wood was depleted of nutrients and supported little visible fungal or bacterial growth any longer. However, some wood was sodden, consisting of up to 80% water by weight, and served as a moist substrate. Some piles contained almost no invertebrates, while others were a haven for several species. Elliott recommended removing most of some of the piles over a period of time, leaving a small residue for the fauna to utilize. He studied Signature Pool near the trail, which is a microcosm of algae, eyed flatworms (*Phagocata* sp.) and eyed copepods which probably were introduced; the small community is driven by a light bulb hanging over the pool. In another part of the cave a sewage leak infiltrated into the cave and caused some localized fungal growths and swarms of fungus gnats, which supported a local community of spiders.

In another part of Carlsbad Caverns National Park, urine and feces left by cavers in Lechuguilla Cave contaminated some areas with bacteria, despite strict rules about carrying wastes out of the cave. The National Park Service was concerned about such microbiota altering the cave environment, possible effects on any cave-adapted species, and health effects. Allowing contaminated areas to "rest" for a few months often resulted in the disappearance of the exotic species, provided that visible residues were removed (Northup et al., 1997b).

A Midwestern Show Cave. In a bizarre case in 1993, earthworms (of two exotic European species, *Dendrobaena rubida* and *Eisiella tetraedra*) came out of the cave walls, and rocks fell out of the ceiling for an extended time. I was acting as consultant for the cave management, who thought that the earthworms were causing the problems, and that they should be exterminated. Systematic observation and sampling revealed that the earthworms were following infiltrating sewage into the cave from broken sewer lines and forgotten, leaking, septic tanks built on top of the cave. The epikarst in that area, though mantled with good soil, was highly transmissive. Dye traces proved that the cave was cross-connected to many input points on the surface, including septic systems. Bacteriological sampling showed the presence of *Escherichia coli*, *Salmonella*, and *Shigella* in many air and water samples from the cave. The earthworms reported were found crawling on wet surfaces in the cave, and were actually eating softer, marly beds of rock, which were probably laden with bacteria. There was little or no odor in the cave, but levels of airborne bacteria were high enough to cause concern about prolonged exposure. Clay banks in some areas were festooned with rich and colorful fungus gardens, which were inhabited by invading hothouse millipedes and isopods. No troglobites could be found in the cave. After these initial findings, the owners initiated intensive maintenance and repair of the septic system, and took steps to prevent infiltration of nutrients from the theme park above the cave. The earthworms were not killed, but were to be considered as "friends" who would eat up much of the contamination. After about two years of work, the management reported that, biologically, the cave was returning to normal, and that rock-fall (which probably was related to both high rates of water infiltrations and earthworm activity) had decreased to a low level (Elliott, unpublished data).

Exotic and pest species

As has been seen above, enrichment of caves with nutrients can bring sewage bacteria and fungi, red tubificid worms, earthworms, hothouse millipedes, isopods (sowbugs, woodlice), and other exotic species into the cave. In central Texas, imported red fire ants, *Solenopsis invicta*, began invading caves in 1988, not because of enrichment but because of the ongoing adaptation of this Brazilian pest to the southern United States. The multiple-queen colonies live in soil mounds, but the workers invade shallow caves in the summer, when the soil is hot and dry, and forage for moisture and food in the caves. They have been observed attacking and carrying off various troglobitic species and cave crickets. Some caves in the area of Austin (Texas) are so overrun with fire ants in the summer that it is unsafe to crawl into the caves. The ants retreat to the surface again in the autumn, but can reproduce year-round if the weather is mild. The best control method is to kill the mounds with boiling water. This is instantaneous, but labor-intensive; however, it avoids the problem of using insecticidal baits, which could be picked up by cave crickets as they forage on the surface at night (Elliott and Reddell, 1989; Elliott, 1990, 1991, 1992b, 1993a, 1993b, 1994b,d, 1997b; Reddell, 1991).

Chemical pollution

Cave life has been affected more often by water-borne pollutants than by solid waste. In this section I mostly discuss chemical pollutants, but waste from sewage, agriculture, or cavers can have toxic effects too, and they often go together.

Spent carbide from acetylene lamps was the most common poison recognized by cavers in their environment. Until the 1960s many cavers dumped or buried their spent carbide in caves, but the practice was discouraged. Peck (1969) pointed out that the calcium hydroxide in spent carbide was poisonous to cave fauna, which he demonstrated in experiments with the cave beetle *Ptomaphagus hirtus*. Fortunately, carbide dumping and use is declining. I found no reports of any kills resulting from spent carbide, but the effects would be subtle. Batteries left by careless cave visitors can leak toxic materials, including mercury.

The most dramatic kill of cave biota yet reported was in November of 1981, when some 80 000 ℓ of liquid fertilizer (ammonium nitrate and urea) spilled at a pipeline break near Dry Fork Creek, Missouri. Dry Fork is a disappearing stream, and a recharge area for Meramec Spring, the state's third largest spring. Seven days following the break, dissolved oxygen at Meramec Spring, a distance of 21 km from the break site, dropped to less than 1 mg ℓ^{-1} for nine days, resulting in a loss of over 37 000 fish at a hatchery. Concentrations of ammonia and nitrate nitrogen in the spring were elevated for over 38 days. Aquatic organisms killed included >10 000 of the Salem cave crayfish *Cambarus hubrichti*, nearly 1000 of the southern cavefish *Typhlichthys subterraneus*, which had not previously been reported from the Meramec basin, and a small number of the Ozark blind salamander *Typhlotriton spelaeus*. Numerous other cave organisms killed included amphipods, isopods, and gastropods, but no attempt was made to quantify these losses (Crunkilton, 1985). A few years later cave divers observed some of these species in side passages or pockets in the spring system (Eugene Vale and Jo Schaper, personal communication). Baseline data and real follow-up data are lacking, so the long-term effects of this spill are still unknown. This incident points up the need for baseline data and for ongoing hydrological and biological monitoring.

Perhaps even more devastating than the Meramec Spring kill was the presumed sterilization by nitric acid of caves at the Indiana Army Ammunition Plant, near Charlestown, Clark County, Indiana. The plant was constructed during World War II for the production, shipping, and storage of nitrocellulose propellant. The caves of the Jenny Lind Run drainage received nitric acid at a pH of 2.3 as a waste product of the nitrocellulose production process, at a rate estimated at about 85 000 ℓ min^{-1}. Now, 50 years later, six species of troglobite have recolonized the nitric acid caves of Jenny Lind Run. The aquatic troglobitic isopod *Caecidotea stygia* has recolonized all of the caves and springs on Jenny Lind Run. Terrestrial troglobites inhabiting the caves include the millipede *Pseudotermia nefanda,* the dipluran *Litocampa* sp., the collembolan *Pseudosinella* sp., the fly *Spelobia tenebrarum* and the spider *Phanetta subterranea* (Lewis, 1996b). The true composition of the original fauna is not known.

Bats with insectivorous diets, long life, and long migrations are sensitive to biological accumulation of pesticides. Mexican free-tailed bats, *Tadarida brasiliensis mexicana*, in Carlsbad Cavern declined from 8.7 million in 1936 to only 200 000 in 1973, at least partly due to residues of dichlorodiphenyltrichloroethane (DDT) in their diets. This insecticide had been used extensively on irrigated cotton in the Pecos River Valley nearby. Studies showed that residues of DDT and DDE (dichlorodiphenyldichloroethylene, a metabolite) in the colony did not decline much after the insecticide was banned in the United States in 1972. After 1980 the residues declined slightly, but rose again in 1987–1988, perhaps due to usage of DDT in Mexico. Gray bats, *Myotis grisescens,* from two maternity caves in Franklin County, Missouri were killed by dieldrin, a metabolite of aldrin[1], in 1976–1978.

Residues of dieldrin and heptachlor epoxide, which had been used locally on corn (*Zea mays*), were found in guano and insect prey. One colony declined from 1800 in 1978 to none in 1979–1982. Dieldrin also killed gray bats in three caves in Boone County, Missouri (Clark, 1988). Peck (1974) reported that public health authorities fumigated Chilibrillo Cave in Panama to remove the bat colonies shortly after his survey there. The effect on invertebrates was not studied. Other factors have also reduced bat populations (see below, p. 681).

Sewage and gasoline leaking from a service station into groundwater poisoned parts of the Young–Fugate Cave System, Virginia. The cave is inhabited by two troglobitic crustaceans, and is the only known locality for the cave beetle *Pseudanophthalmus holsingeri* (Table 34.4). The service station was removed. Contaminants that have fouled karst systems in Virginia include spills or leaks of petroleum products, herbicides, sheep

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[1] aldrin = (1R,4S,4aS,5S,8R,8aR)-1,2,3,4,10,10-hexachloro-1,4,4a,5,8,8a,hexahydro-1,4:5,8-demethanonaphthalene.
dieldrin = (1R,4S,4aS,5R,6R,7S,8S,8aR)-1,2,3,4,10,10-hexachloro-1,4,4a,5,6,7,8,8a-octahydro-6,7,epoxy-1,4:5,8-demethanonaphthalene.

Fig. 34.3. Used drums of chlordane and methamidophos in the entrance of Toxic Sink, Coahuila, Mexico. Photo by Peter S. Sprouse.

and cattle dip, solvents, fertilizers, sewage, milk, cream, and the leachate from improperly disposed waste materials (Hubbard, 1996; Hubbard and Balfour, 1993). In 1995, a resident crustacean was decimated in Wildcat Saltpeter Cave, Virginia, by diesel fuel from a leaking underground storage tank (David Hubbard, personal communication). Sawdust and bark caused a die-off of the crustaceans *Caecidotea recurvata*, *Crangonyx antennatus* and *Lirceus usdagalun* in Thompson Cedar Cave, Virginia (Culver et al., 1992).

Brine pollution from the Greensburg Oilfield upstream from Mammoth Cave began in 1958 and continued for several years. The chloride ion allowed Hendrickson (1961) to estimate the contribution of water from Green River to the cave through Styx River Spring and out again at Echo Spring – about 40% from Green River and 50% from local groundwater sources. There was a reduction in sightings of cavefish, crayfish, and shrimps just after the brine contamination. A massive kill of cave crayfish occurred in Hawkins River (Mammoth Cave) under Joppa Ridge in 1979, probably from a petroleum spill or leaking underground gasoline tank. An accident in 1980 involving two trucks spilled ink and cyanide; quick action by officials prevented large quantities from entering Hawkins River and killing all the aquatic life downstream to the Green River. At Mammoth Cave most contaminant transfer occurs in association with rainfall events (Poulson, 1996).

Slash and sedimentation from logging can choke cave entrances and alter aquatic communities. Logging and road-building practices in the karst areas of the Tongass National Forest, southeastern Alaska, caused some caves to receive elevated loads of sediment, sometimes including diesel fuel and other petroleum products, which could affect cave stream communities, salmon runs downstream, and drinking-water sources (Aley et al., 1993; Elliott, 1994a). Similar problems have occurred on the karst of Vancouver Island (British Columbia, Canada) (Blackwell and Associates, Ltd., 1995).

Waste is being dumped into caves in some parts of Mexico. The name of Sótano de Médico, near Tlamaya, San Luís Potosí, reflects the large amount of medical waste, including used syringes, that had been dumped into it (Minton, 1992). In July 1996 I personally saw used drums of the organochlorine pesticide chlordane[2] and the organophosphate pesticide methamidophos, both highly toxic, in Toxic Sink, Coahuila (Fig. 34.3).

Nearby, there was medical waste, including syringes, in Pozo del Cañon El Buey (Fig. 34.4). As mentioned above, fertilizers and pesticides threaten the local water supply in some areas of Yucatán.

In an experiment in a remote area of Mammoth

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[2] chlordane = 1,2,4,5,6,7,8,8-octachlor-2,3,3a,4,7,7a-hexahydro-4,7-methanoindane. methamidophos = O,S-dimethyl phosphoramidothioate.

Fig. 34.4. A bag of medical waste, including syringes, at the bottom of Pozo del Cañon El Buey, Coahuila, Mexico. Photo by Peter S. Sprouse.

Cave, Rusterholtz (1989) dosed core samples of saturated sand with 5 μg of chlordane per g of sample for 30 minutes, and observed a 25.8% decrease in respiration. Cell counts were 6.2 10^5–1.5 10^6 cells per gram; over 50% of the total cells were actively respiring before treatment. This shows that even a very low concentration of pesticide can kill or suppress microbes in cave sediments.

Welding fumes can be very toxic, especially if the metal being welded contains zinc or other toxic elements. Welding in caves should be preceded by a study of air movements to see if contaminants will be naturally blown out of the cave entrance, or else a temporary exhaust system should be used (Elliott, 1995).

Nicotine is a powerful insecticide, which was extensively used to fumigate greenhouses before synthetic pesticides became popular (Feinstein, 1952). Howarth (1983) warned against the use of tobacco in caves because of its nicotine content; but there are about 4000 other harmful chemicals in tobacco smoke, including acrolein, formaldehyde, α-benzopyrene, and carbon monoxide. Elliott (1995) improvised an exhaust system for removing welding fumes during the construction of a bat gate in Gorman Cave, Texas; however, the system was overwhelmed by the workers, who smoked cigarettes in the cave, creating a cloud of particulates. Nitric oxide and carbon monoxide were within acceptable limits as defined by the United States Occupational Safety and Health Administration for workers, but equipment was lacking for measuring other contaminants from tobacco smoke. Jablonsky et al. (1995) found processed tobacco in cave lint, but this was not quantified.

Killing, over-collecting, and disturbance of fauna

Bats in caves have often been killed as a result of human action; a few examples are provided. As mentioned above, back-flooding from the dammed Green River into Bat Cave in Mammoth Cave National Park killed 300 000 individuals of *Myotis sodalis* (Mohr, 1972). In 1960, three boys intentionally killed 10 000 individuals of this species in Carter Caves State Park, Kentucky (Mohr, 1972). In 1961 an entire colony of *Myotis velifer* was killed or driven off from Chinaberry Cave, Williamson County, Texas, by an intruder using a .22 caliber rifle with rat-shot (Elliott, 1994d). Eagle Creek Cave, Arizona, housed a colony of Mexican free-tailed bats, *Tadarida brasiliensis mexicana*, numbering 25 to 50 million in 1964, but the population shrank to 600 000 by 1970 (Mohr, 1972), possibly because vandals disturbed the bats, using shotguns; DDT may have also been involved. In 1973 a developer filled Bear Cave, Bexar County, Texas, with large boulders, sand, and gravel, out of fear of liability because a person had been stuck in the entrance and had to be rescued; at least 20 000 bats (probably *Myotis velifer*) were roosting in the cave at the time (Elliott, 1994d). In 1983 in Walkup Cave, Hardeman County, Texas, local people used shotguns against bats, sprayed them with gasoline, and set them on fire. Walkup was an important roost for *Eptesicus fuscus pallidus*, *Myotis velifer* and *Corynorhinus townsendii pallescens* (Elliott, 1994d,e). In 1987, four men were convicted of shooting and crushing to death at least 66 (but probably several hundred) endangered Indiana bats, *Myotis sodalis*, in Thornhill Cave, Kentucky (Foster and MacGregor, 1987).

In Ontario, Canada, *Myotis lucifugus* and other species have declined in most of the unprotected caves and mines. In Fourth Chute Cave in Quebec, Canada, where the largest known population of *Myotis leibii* in eastern North America hibernated, commercialization eliminated the cold-air circulation, and the bats abandoned the cave (Mohr, 1972). Some time between 1993 and 1996, a colony of *Leptonycteris* sp. was killed or driven off by local people from a cave near Mezcala, Jalisco (Mexico). The people probably were after the common vampire bat, *Desmodus rotundus*, which inhabits another cave nearby (Mario Sgro, personal communication). Many other colonies of cave bats have been destroyed in Mexico in efforts to kill vampire bats, or as a result of guano and phosphate mining.

A general decline in many species of bat has caused great concern to bat biologists and conservationists. Bats are especially sensitive to human disturbance, even as slight as travel past their hibernating or nursery roosts. Continued disturbance can cause bats to abandon a cave. Disturbance during either summer or winter is critical, since only a few caves have microclimates suitable for colonial bats (Mohr, 1972; Poulson, 1976). Disturbance and arousal of hibernating bats can cause fat reserves to be used that would last them for 10 to 30 days (Brady, 1982). College classes and tourists at some show caves commonly visited bat roosts until the 1970s.

The banding of bat wings with bird leg-bands was widely used by bat biologists from 1932 to about 1960, but the practice ceased when biologists became aware of the high mortality rate from the bands, which tore wing membranes and injured bones. Ironically, the banding studies alerted biologists, as early as 1952, to the ongoing declines of cave bats, some of which was caused by banding and collecting, but more by habitat destruction, disturbance, and insecticides (Mohr, 1972). The steady recovery of *Myotis sodalis* in Bat Cave, Mammoth Cave National Park (Kentucky), was reversed after a biologist banded all 250 in 1971; the population dropped to only 68 in 1975. Biologists adopted lipped bands, and today they use tiny markers or radio transmitters glued to the fur.

Over-collecting and handling of animals was an early concern of biospeleologists. Sullivan (1956) cautioned against excessive collecting of specimens, and the National Speleological Society adopted a conservation policy that discouraged collecting by amateurs or for any commercial use. Over-collecting was feared to have caused the decline of the cavefish *Amblyopsis spelaea* in Mammoth Cave, specimens of which were sold as curios in the 19th Century (Poulson, 1968). Over-collecting can threaten small populations with low reproductive rates, as in the case of Shelta Cave, where some crayfish do not become sexually mature until they are over 40 years old. Generally, larger troglobites, such as cave-fish, salamanders, and crayfish, may be long-lived, have small population sizes, and reproduce slowly; therefore collecting should be highly restrained. Smaller, more abundant troglobites, such as some amphipods, isopods, millipedes, and beetles, may withstand collecting better. However, some small species are exceedingly rare, which should be taken into account. Culver (1982) emphasized the need for restraint in collecting by reporting that he had caused a severe decline in the populations of several cave isopods.

Over-use by visitors may cause compaction of substrates, with disturbance or loss of microhabitats for small, cryptic species. Many troglobites are thigmotactic – that is, they like to hide under rocks. The effect of substrate trampling on such species has not been adequately studied.

Isolation

The isolation of caves and karst areas by land development, road-building, utilities and quarries has rarely been addressed in the academic scientific literature, but is a common concern of applied scientists. The concerns are at several levels: potential alteration of hydrologic inputs to the cave; loss of nutrient inputs by making intervening areas unsuitable for trogloxenes like cave crickets and raccoons; and vegetational changes.

A large quarry near Inner Space Cavern, Williamson County, Texas, probably has destroyed many caves since 1963. This quarry may be creating a barrier to subterranean fauna in the narrow band of Edwards Limestone south of Inner Space Cavern. For several reasons, and as a hedge against the extirpation of some populations, the species recovery plan for seven terrestrial troglobites in that area calls for at least three cave preserves in each recognized "karst faunal zone", based on geology and recognizable cave faunas particular to karst blocks (Veni, 1992; O'Donnell et al., 1994).

MANAGEMENT OF CAVES AND KARST PRESERVES

Baseline faunal and ecological surveys

It has become axiomatic that baseline faunal surveys, with simultaneous monitoring of ecological factors such as temperature, humidity, moisture, air movements, and nutrient inputs, are essential for understanding changes in cave faunas (Poulson and Kane, 1977; Elliott and Reddell, 1989; Perkins, 1990; Elliott, 1994c; Northup and Welbourn, 1995; Lewis, 1996a). Cave faunas change seasonally and in response to climate. Initial faunal surveys can be accomplished in several ways, including hand collecting, baiting, Berlese extraction, and pitfall trapping. Once a fauna list is compiled, census work in different seasons and years increases the range and value of the data set. Large fluctuations in some trogloxenic populations can occur on an annual time scale; for instance, cave cricket populations in some caves in central Texas dropped by half after a drought year in 1996 (Elliott, unpublished data). Historical data from the Mammoth Cave ecosystem over 100 years have been useful in understanding the current ecology of the cave. Comparative studies of different types of cave communities provide a better idea of how to manage a particular cave, such as a show cave that has been perturbed for many years.

Cave gating

Early cave gates were sometimes harmful to natural cave communities, especially bats; they were either too weak to exclude vandals, or too restrictive for bats and for air flow (Elliott, 1996b). MacGregor (1993) found that some early gates actually caused most of the decline in Indiana bats (*Myotis sodalis*) since the 1950s and 1960s. These gates often had crisscross bars or steel plates, which blocked air flow, and bats actually had to land on some of them to get through. Some gates had concrete sills or walls that projected into the passageway, restricting the flow of cold air along the floor, which changed the temperature profile of the cave. Indiana bats prefer very cold caves for hibernation, so they abandoned some caves that had become too warm. Better gates have allowed some of those populations to increase again. The standard bat gate now recommended by the American Cave Conservation Association, Bat Conservation International, the United States Fish and Wildlife Service, and the National Speleological Society is usually made of horizontal pieces of stiffened angle iron spaced at intervals of 15 cm, with vertical supports no closer than 1.2 m apart (Tuttle and Taylor, 1994; Elliott, 1996b). Some bat species do not tolerate gates at all, while some tolerate them better if the gate is built inside the cave instead of at the entrance, where there is more light and a higher risk of predators lurking (Robert Currie and Merlin Tuttle, personal communication). As mentioned above, *Myotis grisescens* vacated Shelta Cave after a gate was installed. *Tadarida brasiliensis mexicana*, the Mexican free-tailed bat, cannot tolerate gates because of its flight geometry and huge colonies.


Fig. 34.5. A strong cave gate on the entrance of Lakeline Cave, Texas; length about 2 m. The gate has shielded hinges and two locks for greater security. Note the animal access hole through the ledge, which provides access to raccoons and mice. Photo by William R. Elliott.

In Texas, many caves have been gated for the protection of endangered or rare troglobites. Such gates may have tight spacing of the angle iron bars, but have animal access holes at least 20 cm in diameter built into the edge to allow cave crickets, raccoons, and other fauna to pass through (Fig. 34.5). Conservationists have made so many innovations in cave-gate design and construction that the gating handbook of the National Speleological Society (NSS) (Hunt and Stitt, 1975) is being revised by the American Cave Conservation

Association, Bat Conservation International, the NSS, and the USFWS.

Helf et al. (1996) emphasized the importance of protecting and managing cave crickets at Mammoth Cave, and recommended bypasses for crickets around gates. Vale and Jones (1993) restored microclimates in Onondaga Cave, Missouri, by plugging artificial entrances which, though gated, allowed too much dry air into the cave.

Cave restoration

Cave restoration projects are beneficial in removing harmful materials, trash, and graffiti. Some precautions are needed to avoid stressing cave communities that may have colonized organic materials, particularly old woodpiles, which may be a haven for invertebrates (see p. 678 above). Elliott (1982) and Hubbard (1995) emphasized that wood should be examined by a biologist during clean-up projects, or left alone. Such woodpiles may have attracted a large population of invertebrates over decades of time, and to remove it suddenly may, in effect, remove a significant portion of the population from that area of the cave. Oftentimes such wood can be removed gradually, and a small residue kept to provide habitat for the remaining fauna (Elliott, 1997a). An important concept is to give some caves or microhabitats time to "rest".

In Blanchard Springs Cavern, Arkansas, Aley (1972) successfully killed algae, moss, and ferns growing near electric lights with a steam generator, without damaging speleothems. Aley et al. (1985) found that, in Carlsbad Cavern, lighting in moist alcove sites should be kept below 9.7 lx. In moist non-alcove sites lighting should be below 30.1 lx. Some studies were also conducted on chemical plant-control agents. The best agent for general plant control appears to be a 5.25% solution of sodium hypochlorite (bleach). Copper sulfate and calcium hypochlorite solutions have caused damage to cave features when tested in Carlsbad Cavern.

Ecological transplantation

Wildlife rescue operations have often been used for big game, but the concept has rarely been applied to cave animals. Ezell's Cave, Texas, had been sealed by the owner to keep out intruders, but the loss of the bat colony and its guano was thought to have contributed to a decline in the resident population of the salamander *Typhlomolge rathbuni*. In 1970 biologists twice attempted to re-establish the bat species *Myotis velifer* in Ezell's Cave. Bats were captured in northwestern Texas, but they did not stay in Ezell's Cave in central Texas for even a day. This species is adaptable and will readily colonize newly opened caves, but the trip and handling probably frightened them severely (Elliott, 1993a, 1994d).

In 1976, and again in 1997–1978, a threatened population of harvestmen (*Banksula melones*, a troglobitic opilionid) was transplanted from McLean's Cave, California, to a nearby mine (Elliott, 1978, 1981). This species was known from just two caves at the time, one of which was threatened by quarrying. The other site, McLean's Cave, was scheduled for complete inundation by the New Melones Reservoir. The United States Army Corps of Engineers, which was building the dam, supported the project so as to avoid this species being listed as "endangered". During the second, larger project, the cave population was intensively collected for three months, and the community of about 30 arthropod species transplanted to the Von Trump Mine, now called the "Transplant Mine". The mine was stocked like a terrarium with cave soil, rocks, and rotting wood from the surrounding area. The cave soil and fauna were brought in insulated containers to the mine and carefully placed in higher areas to avoid the minor flooding that sometimes occurs from seepage. A follow-up visit in 1979 revealed that the cave community was doing well, although the population ratios of some of the species had changed dramatically. Thomas Briggs (personal communication) returned to the mine in 1996 and found that *B. melones* was still there.

Transplanting cave fauna is an experimental technique, and it cannot seriously be considered as a good solution for endangered cave faunas. Despite the apparent success of the "New Melones Transplant", several philosophical and practical problems were pointed out by Elliott (1978, 1981). Assuming that the transplant would work, one must have a suitable "empty" habitat into which to transplant. In this case the Transplant Mine had a cave-like microclimate, was only 50 years old, and was excavated in Calaveras Limestone, which is the major speleifer in the area. However, transplanting to a natural cave would present three problems:

Problem 1: If the cave had its own natural community and if it did not already contain the endangered species to be transplanted, then a question arises as to whether the cave would be in any case suitable for that species.

Problem 2: If the cave were suitable, the transplanted species would have to compete with the existing community for resources, which might defeat the purpose of the transplantation.

Problem 3: Two cave communities would be altered or destroyed instead of one.

Ecological transplants have other potential problems, such as the need to replenish nutrients (the Transplant Mine has to be restocked with wood occasionally as it has no sinkhole-like entrance), and the need for long-term funding to monitor the transplant. Other ecologically more appropriate solutions may need to be considered. For example, ironically, a follow-up study in 1979 found that *Banksula melones* occurred in 18 caves in the area. Obviously, good faunal surveys of a karst area are needed before a questionable rescue effort should be considered.

Ecosystem management

The ultimate survival of a cave or karst community depends on the proper protection and management of the cave and the surrounding terrain. In the case of some endemic, terrestrial cave invertebrates, a one-hectare preserve may be sufficient as long as nutrient and water inputs are not altered and disturbances are minimal. However, often one must often reach beyond the immediate karst area to contributing catchments or, in the case of bats, to alternate roost habitats in planning for the survival of an ecosystem. With migratory bats, these considerations must be on a continental scale to insure success.

Many cave preserves that have been set aside only protect the entrance area, and not the entire catchment for the cave system. However, the need for ecosystem management, which considers the whole karst area, is often recognized. The trend by governments has been toward increasing aspirations for karst ecosystem management; but in practice this is very difficult financially and politically. In the Austin (Texas) area, even though seven terrestrial troglobites have been listed as endangered, the federal government has not bought any cave preserves for them, even though it has spent millions of dollars to purchase a national wildlife refuge nearby for the benefit of two endangered bird species. Sixty-five cave preserves that were planned will have to await funding through a local development fee collected by the county and city (Elliott, 1997c).

Some believe that caves cannot be managed, and that they should be left alone (except for occasional caving trips). Such a passive conservation ideal cannot work in developed areas, where drainage patterns are changed, native vegetation and faunas are gradually perturbed, nutrient and moisture inputs are altered, and pests invade. In managing cave preserves, it is important to be able to measure the results from time to time. Therefore, baseline surveys, census surveys, and written management plans are essential.

Karst groundwater issues are so important, economically and politically, that they move beyond the influence of the technical experts who best understand them (Elliott 1994d, 1996b). In Texas, the regulation of over-pumping of the Edwards Aquifer, one of the most important karst aquifers in North America, has been gradually improved only through a succession of state rulings and legislation, which were contradicted by federal court decisions. It is quite possible that the San Marcos and Comal Springs will become dry within the next decade, endangering many species and the human economy (Elliott, 1993a, 1996a).

The Karst Waters Institute, based in Charles Town, West Virginia, has begun an annual event to publicize the "Top Ten List of Endangered Karst Ecosystems". In the first edition 40 areas were nominated by biologists, and the top ten included terrestrial and aquatic cave communities in Georgia, Hawaii, Indiana, Kentucky and Texas, as well as Australia, Bermuda, the Canary Islands, France, and Vietnam (Karst Waters Institute, 1997).

GENERAL CONCLUSIONS

In general, the most dramatic declines in cave faunas have been caused by the direct disturbance and killing of bats, and massive kills of aquatic troglobites by water projects, sewage, and chemicals. Perhaps four North American cave species have become extinct as a result of human activities, and it is possible that other extinctions have occurred. Local extirpations of several species of bats, cave-fishes, and crustaceans have been documented. However, the gradual and inexorable decline of some cave communities over decades may go unnoticed because of a lack of baseline surveys and systematic monitoring. Nutrient stress is a problem that few cave biologists have studied, but the long series of records in Mammoth Cave and Carlsbad Cavern provide a few insights into this subtle process.

Although many cave-management plans have been devised across North America, and 20 species are under protection, it is apparent that many other species are just as threatened by human activities. It is more obvious than ever that the management of regional karst ecosystems and protection strategies should be encouraged, while the funding of small cave preserves to protect locally endemic species with a minimum investment is not forgotten.

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NOTE ON LITERATURE

In writing this chapter I discovered a large amount of useful literature which is difficult to obtain. I have assembled an annotated bibliography, which is too large to include here, but I shall post it on my "Biospeleology" World Wide Web site, accessible through the Internet at `http://www.utexas.edu/depts/tnhc/.www/biospeleology`

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Errata for "Conservation of the North American Cave and Karst Biota

The publisher did not include certain corrections that I sent for this chapter, and further updates have since become necessary for:

Elliott, W.R. 2000. Conservation of the North American Cave and Karst Biota. Chap. 34, pp. 665-689 *in* Wilkens, H., D.C. Culver, and W.F. Humphreys (eds.), *Subterranean Ecosystems*. Ecosystems of the World, 30. Elsevier, Amsterdam. xiv + 791 pp.

See Elsevier's web site about this book at
http://www.elsevier.com/wps/find/bookdescription.cws_home/620404/description#description

North American Cave Biogeography:

p. 665 Canada has three troglobites.

Extinct and Endangered Species:

p. 666 change to "Six North American troglobitic species are thought to be extinct…"

p. 667 add "The Rich Mountain Cave beetle, *Pseudanophthalmus krekeleri*, described by Barr in 1965, occurred in only one cave in West Virginia. The cave was destroyed by a limestone quarry in the 1980s (Tina Hall, The Nature Conservancy, pers. comm.)" and to Table 34.1.

p. 668 change to "Seven species in Table 34.2 occur in two counties around Austin, Texas…"

pp. 669-670, Tables 34.2-34.4, the U.S. Fish and Wildlife Service web site is now at
http://endangered.fws.gov/

p. 671, Table 34.5, add Missouri to the range of *Stygobromus clantoni*. Source: Missouri Department of Conservation. 2000. Missouri Species of Conservation Concern Checklist. Jefferson City, 28 pp.

An online version of this chapter may be seen at:
http://www.utexas.edu/depts/tnhc/.www/biospeleology

Readers are welcome to send me corrections or questions. I thank the editors and authors of this important book for their hard work and perseverance.

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