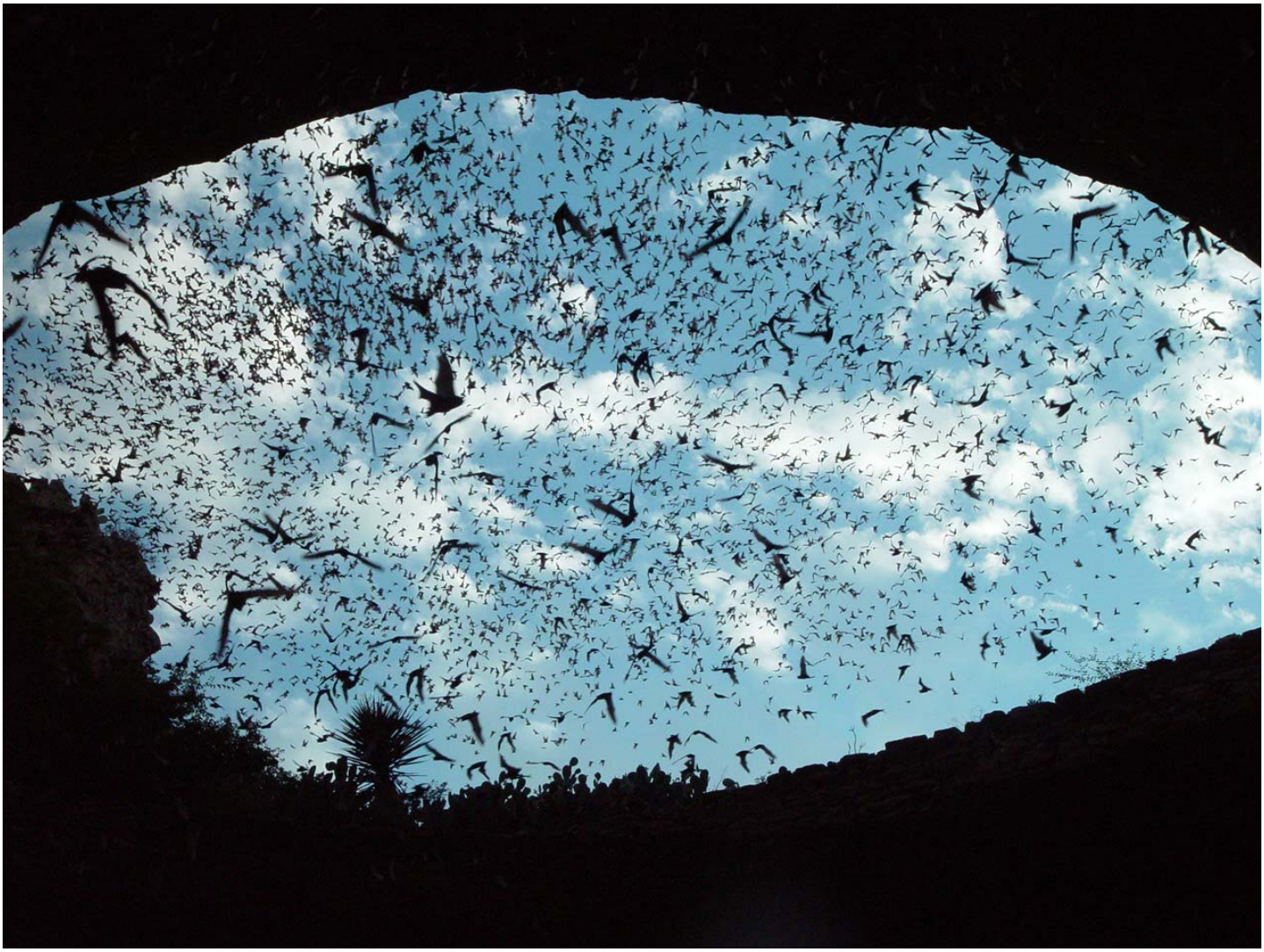
Carlsbad Caverns National Park

CANYONS & CAVES

A Newsletter from the Resources Stewardship & Science Division

Issue No. 26 **Autumn 2002**



An exceptional flight from Carlsbad Cavern on June 12, 2002 during the nightly exodus of Mexican Free-tailed bats. (Photo © Rick Wiedenmann)

Edited by Dale L. Pate
Proofreading: Paula Bauer

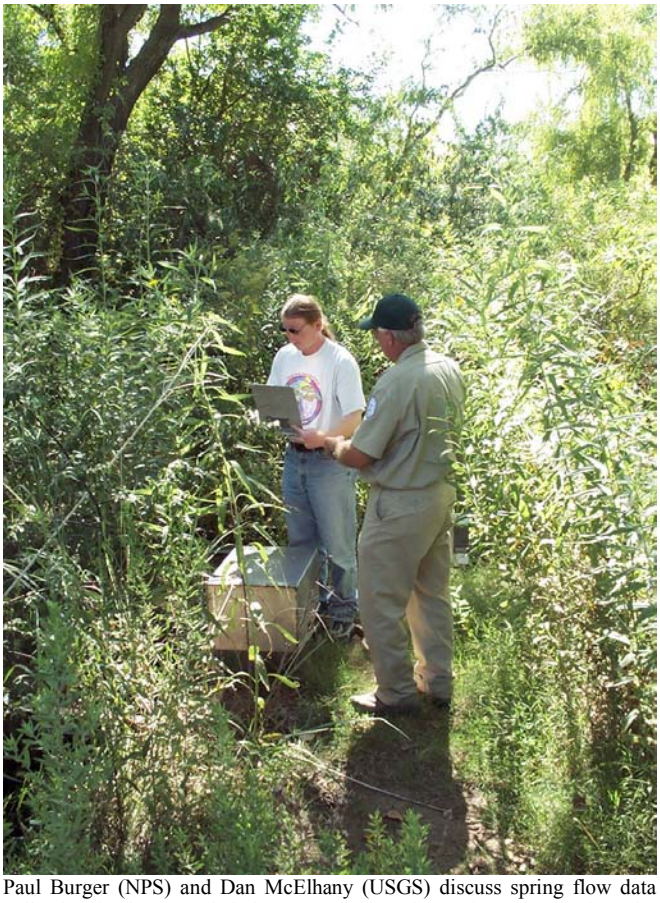
TABLE OF CONTENTS

RESOURCE NEWS

ADIOS & THANKS TO MICK HOLM – While only Superintendent at the park for slightly less than two years, Mick Holm has made major contributions to the long-term protection of Carlsbad Cavern. Mick recently became Superintendent at Glacier National Park in Montana. We wish him well in his new position.

TWO NEW CAVES – Two new caves have been surveyed in the park's backcountry bringing the total number of caves to 102.

USGS AT RATTLESNAKE SPRINGS – Dan McElhany from the Carlsbad Office, Water Resources Division of the U.S. Geological Survey met with RS&S Division personnel in August at Rattlesnake Springs. The visit was to review our data collection procedures for measuring amount of spring flow from Rattlesnake Springs and to make suggestions on how to improve accuracy of data collection.



Paul Burger (NPS) and Dan McElhany (USGS) discuss spring flow data collection in the natural drainage at Rattlesnake Springs. (NPS Photo by Dale Pate)

UPDATE ON SLAUGHTER CANYON CAVE EXCAVATION – Sorting through material excavated in April 2002 by Gary Morgan from the New Mexico Museum of Natural History has yielded thousands of bones from *Tadarida constantinei* (an extinct bat only known from Slaughter Canyon Cave) and bones from ten other vertebrates. They are as follows: Reptiles—(*Gopherus agassizi*, the Desert Tortoise and a unidentified lizard and snake); Birds—the claw of a large raptor (not identified as of yet); and Mammals—bat (a *Myotis* species), rabbit (a cottontail rabbit from the genus *Sylvilagus*), rodents (a pocket mouse from the genus *Perognatus* and a larger rodent perhaps from the genus *Neotoma*), carnivores (*Arctodus simus*, the Giant Short-faced Bear) and an ungulate (*Capromeryx minor*, a miniature pronghorn). Sorting the excavated material is not yet complete and may turn up even more vertebrates.

PALMERS VISIT – Art and Peggy Palmer were in the park in July to continue their study of the late-stage history of Guadalupe Caves with special reference to Lechuguilla Cave. Their studies this year focused on weathering processes and byproducts, the nature and correlation of cave pool deposits, including crusts and rafts, and the origin of solutional rills in limestone surfaces. Working with the Palmers were Richard Zopf, a professional surveyor from Ohio; Steve Worthington, a hydrogeologist from Ontario, Canada; Szabolcs Leel-Össy, a mineralogist from Budapest, Hungary; and our own Paul Burger, a hydrologist for the park. The Palmers research took them to Lechuguilla Cave, Carlsbad Cavern, and Spider Cave.

LECHUGUILLA CAVE – Recent survey trips into Lechuguilla Cave have added 1.3 miles of new survey bringing the length of the cave to 108.3 miles (174.3 kilometers).

DIVISION CLEANS UP – On July 31, 2002, twelve employees of the Resources Stewardship & Science Division and one Law Enforcement ranger (thanks AJ) picked up trash, chunks of concrete, wood, and other pieces of debris around the Mission 66 apartments. Some of this debris was left over from 40 years of people living in the buildings while some was the result of the recent removal of the cinder block walls. Thanks to Maintenance for removing these materials for us. Great work everyone!

Part of the debris picked up from around the Mission 66 buildings (NPS Photo by Dale Pate)

BAT CONSERVATION INTERNATIONAL GRANTS – BCI will award approximately 15 student grants ranging from $500 to $2,500 in 2003. Grants will go to research that best helps document the roosting and feeding habitat requirements of bats, their ecological or economic roles, or their conservation needs. Students enrolled in any college or university worldwide are eligible to apply. Projects must have bat conservation relevance. The application deadline for 2003 scholarships is 16 December 2002. All application information and forms are available on the following web page at: http://www.batcon.org/schol/schol.html, by writing to: Bat Conservation International, Student Scholarship Program, P.O. Box 162603, Austin, TX 78716-2603, or by emailing apuntch @batcon.org.

BAT GUANO AND COSMETICS
AN APPARENTLY APOCRYPHAL TALE

by Rick Toomey

Several rangers and volunteers have asked me about the use of bat guano in makeup (specifically things like, "*Is it still used for makeup*?"). As far as I can find, bat guano has never been used for producing makeup. There is a chemical called GUANINE that is sometimes used in makeup. It is chemical that is used to create pearly luster (pearl essence). It is the chemical that produces the shine on the skin of fish and amphibians.

Around 1650 a French rosary maker concentrated the sticky material on fish scales and used it to coat beads to give them a pearly look. He called the stuff "pearl essence." The substance later turned out to be guanine. Guanine was discovered in bird guano in 1846. By 1910 guanine was found to be a component of DNA (and RNA). Guanine is found in all plant and animal tissues

From my search in books on cosmetics ingredients, cosmetics history, bats, and the guano industry, I have found no information that indicates that guano has ever been used to commercially produce guanine. I also contacted several cosmetics companies and none indicated that they use guanine derived from bat guano. Guanine is produced commercially from scraping the scales of fish such as herrings and alewives. Because guanine is expensive, other substances that create pearl essence are now more commonly used.

Based on the research I have done, I would say that the idea that guano is used in makeup is apocryphal (of questionable authorship or authenticity).

Rick Toomey is the Cave Resources Manager for the Arizona State Parks system and is stationed at Kartchner Caverns State Park. Thanks to Rick for sending this to us.

WEST NILE VIRUS AND BIRDS

by Myra Barnes

After detailed news coverage and educational campaigns, most people are now familiar with the method of transmission and risk of West Nile virus. The virus can only be transmitted to humans and other mammals by the bite of a mosquito that has fed on an infected bird. Since the level of virus is too low in mammals to transmit the infection from one mammal to another, birds are believed to be the only reservoir. (An exception appears to be the transfer of large amounts of blood in a transfusion or an organ transplant in humans.) Birds in the corvid family, such as ravens, crows, jays, and magpies, appear to be the most vulnerable and have been identified as indicator species. Horses are also especially vulnerable to West Nile virus and the presence of the disease is often diagnosed in horses and other single-hoofed animals before a human case is detected. Since counties and states want to identify the presence of West Nile virus, they usually test primarily horses and corvids to document the presence of the virus. Horses are large and easy to track by owners and veterinarians, and a vaccine has been developed for horses. Unfortunately, there is little information about how West Nile virus will affect birds, the animals with the highest recorded virus levels.

A blue jay (Photo borrowed from the National Wildlife Federation webpage)

The emergence of West Nile virus in 1999 in New York was quickly associated with dead crows that succumbed to the infection. Public health concerns have dominated epidemiological investigations and the news coverage, as they should. However, as research on transmission, treatment, risk, and prevention has increased, more biologists are questioning the impact of West Nile virus on bird populations and ecosystem processes.

An American crow (Photo borrowed from the National Wildlife Federation webpage)

West Nile virus has been documented in more than 115 bird species in the U.S. so far. Infected birds range from hummingbirds to eagles and include exotic species such as flamingoes and penguins. Since many states, including New Mexico, only test corvids, the presence of the virus in other species comes from zoos, wildlife rehabilitation centers, breeding centers for endangered species, and species of special concern that are submitted to the overworked USGS lab in Wisconsin. Most states and their wildlife departments do not have the money to test all bird species. It can also be difficult to find dead birds for testing. Dead birds in Carlsbad Caverns National Park quickly become food for predators and scavengers. In towns, cats may consume dead birds.

Some disturbing trends have been noted among raptors such as eagles, hawks, owls, and falcons. Raptors in educational centers and zoos are dying at an alarming rate. Wildlife rehabilitators report a significant increase in sick raptors brought in for care. It is difficult to know if raptors are affected more than songbirds or if their large size just makes them easier to locate. While some raptor mortality from West Nile virus has been confirmed by a series of tests, many facilities cannot afford to test all birds. Therefore, other causes of death cannot be ruled out. Pesticide poisoning can cause similar neurological symptoms, as can other diseases. While the affect of West Nile virus on birds is significant, there is concern that other causes of death may be overlooked that would otherwise be addressed if a verified diagnosis were available for each bird. In New Mexico and other parts of the country, the ongoing drought may reduce reproductive success and increase mortality in wild bird populations.

A peregrine falcon (Photo borrowed from the National Wildlife Federation webpage)

Bird mortality from predators and other natural causes are part of the ecological process. Birds are an important food source for numerous carnivores such as snakes or foxes. Peregrine falcons take smaller birds from the air and bald eagles can grab sitting ducks from the water. Each night, ringtails consume dead or injured cave swallows and bats on the floor of Carlsbad Cavern. While some birds fit into the food web as important prey items, others are important consumers. Many birds eat insects, including mosquitoes that carry West Nile virus. The healthiest and most resilient ecosystems are those that retain all of their components, prey and consumers.

The loss or reduction of any bird species can have an impact on other species. However, long-lived bird species with low reproductive rates are at higher risk. Ospreys, bald eagles, and peregrine falcons are a few of the species that are just recovering from severe population declines from DDT and other pesticides in past decades. While humans and most other mammals, except horses, appear to have a very low risk of serious illness from West Nile virus, birds are especially vulnerable. From daily foraging flights to long distance migration, flying birds can easily move from place to place. However, it is not known how far a bird can fly once infected before dying of West Nile virus. As with any new, emerging disease, there is still much we don't know about West Nile virus. While West Nile virus is closely monitored in people, it may be a long time before we know the impact on birds and ecosystem processes in Carlsbad Caverns National Park and other natural areas.

"TUNNEL VISION" AND THE 1925 BUDGET AT CARLSBAD CAVE NATIONAL MONUMENT

by Bob Hoff

From the beginning of cave visitation in June 1924 right up to the present, getting visitors in and out of the caverns safely and comfortably has been a National Park Service priority. Just how to do that has been an ongoing experiment over the years.

Three months after General Land Office Mineral Examiner Robert Holley's five-week expedition here in 1923, El Paso attorney Richard Burges, in mid-August, entered the caverns with Vernon L. Sullivan of El Paso, and George Neel of the New Mexico State Engineer's Office. Jim White and his assistant Henry Samples guided the three. On August 26, 1923, Burges published a feature article entitled "Rare Beauties to be Found in Wonderful Carlsbad Caverns," in the *El Paso Times.* In the article, Burges said,

> *The writer suggests that the traverse of the cave made by the United States Geological Survey should be run out upon the surface on the hill, and with the information thus obtained, a tunnel should be dug from some point in the hillside to the scenic portions of the cavern. The present approach, for a mile and a half before the King's Palace is reached, is arduous, at places perilous. If the cave is to be visited by the thousands of tourists who should see it, access must be provided for the vast numbers who would wish to visit it in safety and without too arduous exertion.*

Burges' enthusiasm for the cavern turned into a letter writing campaign, involving the United States Geological Survey, the National Geographic Society, the Carlsbad Chamber of Commerce, two New Mexico U.S. Congressman and two New Mexico U.S. Senators and the National Park Service.

He wrote to the USGS and urged them to send a representative to investigate the cavern; he wrote to the NGS and urged them to pay attention to the cavern; he wrote to the President of the Carlsbad Chamber of Commerce President W.F. Mcllvain and said,

> *It is my confident belief that if these caves can be made accessible, as I believe they can, by a short tunnel into the scenic portions of the cave from the side of the hill…they will bring thousands of tourists to your city. There is…a constant stream of visitors to the Mammoth Cave in Kentucky and the Luray Caverns in Virginia and I doubt whether either or those two famous caves contain anything more beautiful or wonderful than the sights I saw in the Carlsbad Cave.*

Assigned to investigate leaking irrigation reservoirs north of Carlsbad, United States Geological Survey geologist Willis T. Lee visited the caverns on September 19, 1923 and spent two week at the caverns. Like Holley, he was amazed. And like Holley, he recommended national monument status.

In the January 1924 issue of *The National Geographic* Lee published an article on the caverns, bringing it to national attention. The caverns astonished Dr. Lee.

Burges and Lee weren't the only ones with "tunnel vision." On January 21, 1924 in a letter from Frederick Coville, chairman for the NGS research committee to NGS President Gilbert Grosvenor Coville said,

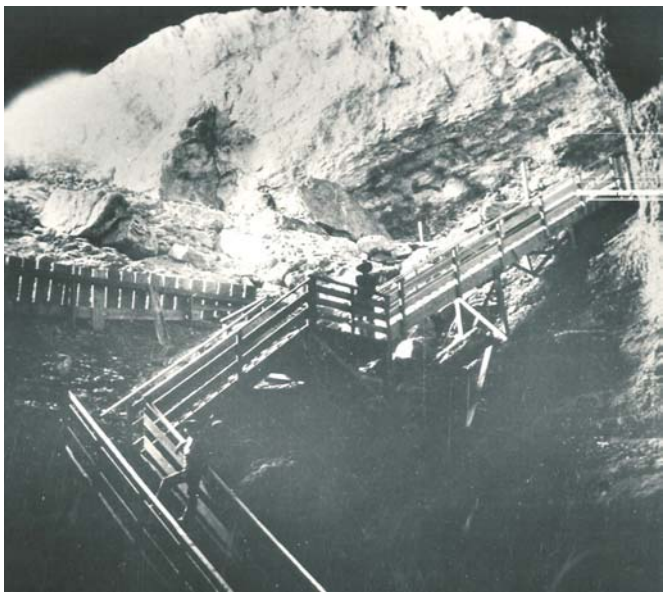
> *…The interior survey, which will be made under the Geographic Society grant early in the coming season, will show the thinnest places in the rock shell covering the cavern and will make possible the selection of the most favorable point for an artificial entrance. The present entrance is exceedingly inconvenient, involving a climb of about a thousand feet from the valley bottom and then a descent in a guano bucket through an artificial shaft… remote from the spectacular and interesting portion of the main cavern. It is highly desirable that a new and convenient artificial entrance be made at the earliest possible date.*

Willis T. Lee took a leave of absence from the USGS and led the 6-month (March – September 1924, day trips only) expedition while serving as the NPS custodian for the *Carlsbad Cave National Monument*. Lee envisioned the tunnel as 1,100' to 1,200' long, entering the Big Room and initially estimated a cost of about $5,000. As experts and engineers took a further look, the estimates for tunnel construction began to rise like the long climb back out of the cave.

In those days, the NPS was between a rock and a hard place. The guano bucket, the traditional means of cavern entry and exit, was on non-NPS land and could be closed to the NPS. Also, increasingly some people felt that a serious accident with the guano bucket was probably but a matter of time. The alternative to the tunnel was to build a wooden stairway at the natural entrance.

The budget estimate continued to spiral upwards. $10,000, $15,000… Lee stood firm on constructing the tunnel. On July 31, 1924, Lee wrote to Arno Cammerer and said, "I am enclosing copies of letters from the Governor and the representatives, also a copy of the Santa Fe paper. The New Mexico people and the Texas people are all backing the proposed tunnel even though it may cost $20,000." Lee brought to bear all the pressure he knew how to use

But budget estimates surged even higher—to $30,000. While $30,000 was available, it was needed for general development of the caverns.



The completed stairway built in the natural entrance to Carlsbad Cavern in 1925. (NPS Photo)

By March 1925, carpentry sounds echoed at the natural entrance as laborers, using wood and supplies donated by the Chamber of Commerce hammered a 200+step wooden stairway into place. The hammering noises sounded the death knell for the "tunnel vision."

After his second visit to Carlsbad, NPS Director Mather noted,

> *The general impression was that we would need all the $30,000 to build the tunnel and would have nothing left to protect the cave and handle the people. The sensible thing I think is to put our money on the building of paths, concrete bridges and stairs and a rail protection similar to Luray Caverns…*
>
> *I believe we can build a good system of paths and possibly install a powerful Delco lighting system, pay a superintendent, build a small residence and work out something in sanitation all for the amount of the appropriation; possibly we could use the money available this fiscal year in the purchase of a lighting plant*.

Though the budget nixed "tunnel vision" in 1925. Six years later rising visitation would lead to more generous appropriations and the caverns would build another artificial entrance after all—an elevator shaft.

INVERTEBRATE NEWS

by Renée West

POTTER WASPS FOUND IN CARLSBAD CAVERNS NP

Actually, they weren't discovered by active investigation. But when an unknown animal chooses to nest right outside your window, it's an opportunity to learn more about the park's wildlife. That's what happened August 20 at the Biology offices. I noticed some activity and found a perfect little mud 'pot' being built there, about a half inch diameter. It reminded me of a Native American pot or jar with a narrow mouth at the top.

We kept track over a day or so as the mother wasp finished building her nest right up to a small opening at the top, bringing small batches of mud from a nearby puddle (it was overcast, with intermittent showers, August 19-21). She carefully packed the mud in place with her mandibles. Then she probably laid an egg inside, according to scientists. Later we saw her bringing a tiny black caterpillar and putting it inside the nest. By August 22, the opening was sealed with mud and the mother wasp was gone.

According to the scientists, potter wasps are solitary wasps, not like social wasps that build group nests. Each female builds her own nests (egg chambers) but does not defend them. As with solitary bees, only the females have stingers, and they are very docile. Female potter wasps build these pot-like chambers often on twigs or vines, lay a single egg inside each one, and paralyze small caterpillars and add them to the chamber as food for the larva after it hatches from the egg. Adults feed on nectar.

Potter wasp nest built on Biology office window, August 2002. (NPS Photo by Kristin Dorman-Johnson)

It took entomologist Dr. Eric Grissell (personal communication) to give us the name potter wasp. But we don't know which species we have here—probably several. There are hundreds of different species of potter wasps in the United States and Canada, thousands worldwide. Most North American species are in the genus *Eumenes*. They are in the same family as the commonly known social wasps: paper wasps, hornets, and yellowjackets.

Potter wasps are technically called "predatory wasps" or "predators". According to Grissell (2001), almost all solitary and social wasps are predators. Like the potter wasp putting a caterpillar in her nest, in most cases they do not eat their prey but give it to their larvae. Whatever the mother wasp places in the nest is all the food the larva will get until it starts hunting as an adult. There are many thousands of species of solitary wasps, but they are not well known like the social wasps. Each species hunts a specific type of insect. They range in size from wasps small enough to hunt aphids to those large enough to grab cicadas.

The insect order Hymenoptera (ants, bees, and wasps) "is considered one of the preeminent forces for insect poulation control," says Grissell (2001). "Because there are scarcely any negative effects of Hymenoptera in the garden, their presence should be strongly encouraged."

According to various sources, some potter wasp larvae build cocoons within their nests and spend the winter there, while some species have several generations annually. This one seems to be in the latter group: by September 25 there was a hole in the side of the pot where the young wasp had exited.

FURTHER READING:

Grissell, Eric. 2001. *Insects and Gardens, In Pursuit of a Garden Ecology*. Timber Press, Portland, OR.

http://naturalsciences.org/funstuff/notebook/inverts/potter_wasp.html

http://ag.arizona.edu/urbanipm/insects/bees/potterwasps.html

http://www.pestspecialists.com/html/solitary_wasps_.html

FROG FRUIT PROVIDES IMPORTANT FALL FOOD FOR WILDLIFE

The patches of "weeds" growing in front of the Mission 66 Resources offices is, in fact, a wonderful garden of native flowers that bloom through the fall when few other flowers are available for nectar feeders. And there are lots and lots of nectar feeders busily working away all through August and September.

Orange skipperling feeding on frog fruit at Rattlesnake Springs. (NPS Photo by Gavin Emmons)

These flowers are indeed native. Despite a strange name—frog fruit—they are very pretty and produce a lot of nectar without any extra water. They are in the vervain family, Verbenaceae, along with lantana and verbena. There are at least three native frog fruit species that occur in southern New Mexico; these patches are *Phyla lanceolata*. They also grow profusely at Rattlesnake Springs, where they feed many of those 100+ species of butterflies on the park list.

Unidentified stripped bee feeds on frog fruit. (NPS Photo by Renée West)

A walk by the frog fruit patches any sunny day in late summer or fall will reveal a multitude of native insects busily feeding among these flowers. Without knowing the names or numbers of species, we can name: thread-waisted wasps, mud-daubers, potter wasps, other solitary wasps, paper wasps, butterflies, house flies, bee flies, and a number of different solitary bees. Also working in and under these flower patches are various beetles and ants, and probably lots of others we haven't noticed yet.

RECENT RESTORATION IN CARLSBAD CAVERN

by Dale Pate

BEXAR GROTTO – Led by Joe Ranzau, five members of the San Antonio based Bexar Grotto volunteered on a recent weekend day (Saturday, Sept. 21) to continue restoration of a flowstone area and in Lower Cave. They also mopped up mud from about 150 feet of flowstone along the visitor trail soon after entering Lower Cave. Christi Bennett, Libby Holt, Evelyn Mitchell, Joe Mitchell and Joe Ranzau volunteered their time for this effort.

Mopping up mud off flowstone from along the visitor trail through Lower Cave. (NPS Photo by Tom Bemis)

CAVE RESEARCH FOUNDATION (CRF) – Over the Labor Day weekend (Aug. 31-Sept. 2) 25 CRF members donated over 300 hours to help restore and survey various areas in Carlsbad Cavern. Led by Sherry McClure, long-term restoration projects were the focus of their efforts over this weekend. CRF members worked in the Rookery area of Lower Cave, the Dome Room, the Guadalupe Room and Longfellow's Bathtub in the Big Room. A team also surveyed in Left-Hand Tunnel. Attending the weekend volunteer effort were: Brian Alger, Susan Alger, Barbe Barker, Sue Bennett, Kelli Bergthold, Sara Bergthold, Sonya Boyd, Tim Boyd, Pat Chappelle, Sean Durrum, Frank Everitt, Tonia Harper, Kelly Holladay, Kevin Justus, Ed Knetsch, Tracey Knetsch, Angie Langolf, Lois Lyles, Pam Massey, Greg McCarty, Sherry McClure, Bill Payne, Georganne Payne, Rick Wiedenmann, and Jimmie Worrell.

Longfellow's Bathtub in the Big Room acquired its red color in the summer of 1997 when a bridge was installed over the pool. The main trail originally traversed the pool by running on top of rock and debris fill that had been dumped into the pool dividing it into two smaller pools. The red color came from the red clays that had been used as part of the fill that were accidentally introduced into the rest of the pool during the removal of the fill. The long-term goal is to remove the red clays and restore the pool to its normal color. The photos on the following page illustrate the recent restoration done on Longfellow's Bathtub.

A recent pool level drop provided an opportunity to clean some of the red clays from out of Longfellow's Bathtub in the Big Room in Carlsbad Cavern. Before, during and after photos of the recent restoration. (CRF Photo by William Payne)

CARLSBAD AREA PALEOCLIMATE RESEARCH

by Emily Buehler

Researchers have studied animal remains, layers of speleothems to determine wet and dry periods, tree rings, evidence of former lakes, pollen, plant material preserved in packrat middens, present and relict plant communities, geological evidence, and past global and regional weather patterns to paint a picture of what the environment around Carlsbad Caverns National Park once looked like. The following is a brief summary of some of these studies.

Wilkins and Currey (1997) studied the area between the Pecos River and the Rio Grande drainages in West Texas and south central New Mexico. They found sediments and

remnants of shorelines where two late Quaternary lakes (Lake King and Lake Sacramento) existed. Radiocarbon dates using Carbon 14 (C^{14}) were obtained from Lake King sediments. Four abrupt climate changes and periods of rapid lake growth were found: 22,570 C^{14} years before present (YBP)(***See Note on next page)**; 19,090 C^{14} YBP; 17,180 C^{14} YBP; 15,940 C^{14} YBP, with a periodicity of approximately 2,000 years.

Various dating techniques have been used to study speleothems to reconstruct past climates. At Ogle Cave, Harmon and Curl (1978) studied a broken stalagmite using Th^{230}/U^{234} and found that the formation began growing about 200,000 YBP and grew continuously for 80,000 years until about 125,000 YBP. This coincides with dates for North American glaciation and suggests dry conditions before and after growth, and wetter conditions during the years of speleothem deposition.

Polyak and Asmerom (2001) performed uranium-series dating on five stalagmites from two caves in the Guadalupe Mountains to build a late Holocene climatic record. Growth bands indicated annual deposition of calcite and band thickness indicated growth rate, thicker bands suggesting increased annual precipitation. They found that from about 4,000 to 3,000 YBP there was an intermittent increase of precipitation. From about 3,000 to 1,700 YBP there was a significantly greater increase in annual precipitation with the highest during 2,800 to 2,600 YBP. Another increase occurs at 2,000 YBP. From about 1,700 to 1,300 YBP annual precipitation was reduced to slightly above present-day levels. Slight increases occurred at 835 +/- 25, 819 +/- 82, and 888 +/-144 YBP, then equal to or drier than present day conditions occurred, and finally an increase from about 440 to 290 YBP.

Eubanks (1985) examined the geochronology and stable isotope relationships of the "Georgia Giant" speleothem in Carlsbad Cavern. About 187 samples were analyzed for stable carbon and oxygen isotope ratios and 39 samples were dated by uranium disequilibrium methods. He found a direct correlation between maximum growth rates and cooler climate, and minimum growth rates and warmer climate. He also found that during cooler times the source of water was from the west (Pacific Ocean), and during the warmer times the source of water was from the southeast (Gulf of Mexico). This study indicates that 173,000-134,000 YBP was temperate (cooler and moister); 118,000-84,000 YBP oscillations occurred between semi-arid and semi-temperate; 84,000-71,000 YBP was hot and arid; and 71,000-43,000 YBP varied around moderately cool and semi-arid.

Van Devender (1980) studied fossil packrat middens to reconstruct past climates in two canyons in Eddy County, New Mexico, by the presence or absence of characteristic plants and carbon dating. A juniper-oak plant community was found to have been present 10,500 to 10,000 C^{14} YBP. About 8,000 C^{14} YBP the environment was warmer and wetter in the summer and drier in the winter. The area was a desert grassland/desert scrub for the last 4,000 years. Fires and ample summer rain would have encouraged grassland growth; overgrazing and drought would have encouraged desert scrub community growth. Lechuguilla agave is thought to have been present since 4,000 C^{14} YBP and possibly during all of the Holocene (the last 10,000 years.)

Wells (1966) found *Neotoma* (packrat) middens with Chihuahuan desert flora and woodland flora at much lower elevations during the Wisconsin pluvial (Wisconsin glacial maximum was about 18,000 to 20,000 YBP) than at present, including lechuguilla, sotol, whitethorn, creosote, ocotillo and prickly pear. Montane plant species were not found at sufficiently low elevations to have extended continuously from one set of mountains to another, and have been isolated from each other for a very long time. Woodland species such as pinyon pine, juniper, algerita, and shrubby live-oak were found to exist with the desert flora and extended as much as 800 meters below their current range in the Big Bend area. Radiocarbon dates for this period range from 11,560 to 20,000 C^{14} YBP and greater than 36,600 C^{14} YBP. Using meteorological records, he found that present-day mean annual precipitation for the lower woodland zone averages 45 cm, and the desert shrub zone averages 27 cm. Precipitation combined with temperature differences may have been great enough to allow both woodland and desert plant communities to be present, and close enough to allow a considerable overlap during the Wisconsin pluvial. Wells also noted a midden which contained no woodland species was carbon dated at 4,200 +/- 80 C^{14} YBP indicating the climate had changed and woodland species were now limited to higher elevations.

Van Devender and Wiseman (1977) suggested that between 18,000 and 13,000 YBP, the Guadalupe Mountains included spruce and dwarf juniper. This mixed forest then changed to Douglas fir, limber pine and Gambel oak. The late Pleistocene was characterized by cooler summers, warmer winters, and greater winter precipitation. By 11,000 to about 8,000 YBP the piñon pines died out and the juniper-oak woodland remained. They postulate that the change from late Wisconsin pluvial (wet) to nonpluvial (dry) conditions occurred about 8,000 YBP where winters became drier and warmer, and monsoonal rains occurred in the summer. The present weather conditions did not occur until sometime after 4,000 YBP.

Lanner and Van Devender (1981) studied present-day piñon pine communities, and piñon pine needles in packrat middens and found that during the late Pleistocene there was greater precipitation occurring mainly in the winter, with mild winter temperatures.

There are many other studies on the Chihuahuan Desert and especially on paleoenvironmental changes worldwide. The changes seen in the Chihuahuan Desert can be tied to changes worldwide. A particularly interesting Website on worldwide paleoenvironment is:

Adams J.M. & Faure H. (1997) (ed.s), QEN members. Review and Atlas of Palaeovegetation: Preliminary land ecosystem maps of the world since the Last Glacial Maximum. Oak Ridge National Laboratory, TN, USA. http://www.esd.ornl.gov/projects/qen/adams1.html

An extensive list of references can be found at:
http://www.esd.ornl.gov/projects/qen/refs.html

*** Note** – Because of a difficulty in calibrating the actual age of C^{14} dates in years before present, particularly in earlier studies, a C^{14} year represents a longer time period than that of a calendar year. Recent findings have made it easier to adjust C^{14} years from these earlier studies to more accurate calendar years.

YBP = calendar years before present
C^{14} YBP = Carbon 14 years before present

TIMELINE BASED ON INFORMATION FROM THESE REFERENCES:

200,000 to 125,000 YBP – period of ample precipitation to allow for speleothem growth (173,000 to 134,000 YBP temperate: cool and moist climate)

118,000 to 84,000 YBP – oscillations between semi-arid and semi-temperate 84,000 to 71,000 YBP hot and arid

71,000 to 43,000 YBP – moderately cool and semi-arid (increased precipitation enough to form a lake: 22,570; 19,090; 17,180; and 15,940)

18,000 to 13,000 YBP – spruce, dwarf juniper in Guadalupe Mountains, xerophitic woodland with increasingly mixed with desert flora when descending in elevation

13,000 to 11,000 YBP – Higher elevations gradually changing to Douglas fir, limber pine, and Gambel oak Cool summer, warm winter, winter precipitation.

11,000 to 8,000 YBP – woodland changes to juniper/oak, piñon pines die out

8,000 to 4,000 YBP – pluvial climate changing to nonpluvial, winter became drier and warmer, summers more wet

4,000 to 3,000 YBP – intermittent increase in annual precipitation, warm, wet summer, dry winter,

3,000 to 1,700 YBP – significant increase in annual precipitation (2,800 to 2,600 YBP greatest increase in annual precipitation) (2,000 YBP increase occurred)

1,700 to1,300 YBP – annual precipitation slightly above present day levels

1,300 YBP to present – equal to or drier than present day (888, 835, 819, 440-290 YBP) – slight increases occurred

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