RECENT RESEARCH AND MONITORING EFFORTS AT ONONDAGA CAVE STATE PARK

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Abstract

Over the past four years research and monitoring of cave resources has increased at Onondaga Cave State Park (OCSP). Projects were initiated through partnerships with local state universities and federal agencies, and by Park staff. Biological research was done recently in two significant cave systems. Studies on potential interbreeding of salamander species have begun in a previously commercialized portion of Onondaga Cave. This project, led by Maria Potter, OCSP, will attempt to identify potential hybrid salamanders through DNA fingerprinting using Amplified Fragment Length Polymorphism. By partnering with Dr David C. Ashley, Missouri Western State University, *Fontigens aldrichi* snail counts resumed in the stream in Cathedral Cave. In 2003 a project was started to determine the recharge areas of Onondaga Cave and Cathedral Cave. The delineation of the recharge areas of the cave stream was accomplished through dye-tracing techniques, with 18 total dye injections to date. This cooperative project, led by Ben Miller, OCSP and Bob Lerch, USDA/ARS, has thus far outlined a recharge area of 19.8 km^2 for Onondaga Cave and 2.4 km^2 for Cathedral Cave. Flow monitoring recently began to better study the hydrologic behavior of both cave streams. Microclimate data have been collected in various portions of Onondaga Cave using Hobo® dataloggers. By continuing to partner with educational institutions and other public agencies, additional research and monitoring opportunities will lead to better understanding of these cave systems.

Key words: show cave management, cave ecology, genetics, salamanders, cavesnails, hydrology, dye tracing, water quality, contaminants, sediments, handrails, cultural resources, speleothems, microclimate, Onondaga Cave, Cathedral Cave, Missouri

Introduction

Onondaga Cave State Park is located in Crawford County, Missouri along the Meramec River. This area is within the Upper Ozarks Region of the Salem Plateau. The Park consists of approximately 526 ha (1,300 ac.) split between the Main Park Unit and the Vilander Bluff Natural Area. Located on the Park are two significant cave systems, Onondaga Cave and Cathedral Cave, and more than 25 other small caves. Onondaga Cave, with 2.7 km of passage, is known for its large quantity and high quality of speleothems as well as being extremely biodiverse. Cathedral Cave, with 4.7 km of passage, is a large stream cave with areas of intense speleothem development. Both Onondaga Cave and Cathedral Cave are shown on commercial cave tours led by Park staff, however only Onondaga Cave has electric lighting in use today.

Over the past four or five years research and monitoring were done to better understand the processes ongoing in the cave systems. These efforts were initiated by Park staff and outside researchers, in most cases requiring a partnership between agencies and educational institutions. The projects focused on three major areas: biological investigations and inventories, geological and hydrological studies and the impact of a handrail-replacement project in Onondaga Cave. Many of these projects are continually ongoing and this paper is to highlight the major areas of each project undertaken thus far.

Recent Research Initiated

A variety of different research projects were initiated in Onondaga Cave and Cathedral Cave since 2002. The major projects included a study of salamander genetics in Onondaga Cave, population counts of the aquatic cavesnail *Fontigens aldricihi* in Cathedral Cave, recharge delineation for both Onondaga Cave and Cathedral Cave, and size analysis of cave sediment particles in Cathedral Cave.

Salamander genetics study in Onondaga Cave. In September 2005 Park superintendent Maria Potter began examining the potential interbreeding of salamander species within a previously commercialized section of Onondaga Cave. Six species of salamanders are known to currently reside in the Missouri Caverns portion of Onondaga Cave. Of these six species, four species are *Eurycea* and two are *Plethodon*. It is believed that three of the *Eurycea* salamanders may be interbreeding. These three are *Eurycea longicauda* (Longtail Salamander), the subspecies *E. longicauda melanopleura* (Dark-sided Salamander) and *E. lucifuga* (Cave Salamander). The reason for this speculation is the observation of unusual salamanders, which seem to share morphological attributes between one another but not characteristic for their own species. The fourth *Eurycea* species, *E. spelaea* (Grotto Salamander), is a cave-adapted species which is much rarer and typically found deeper into the cave system near water sources. It is also strongly believed that the absence of human interaction from this portion of the cave system may have played a role as well as the fact the majority of salamanders are located near an old artificial entrance.

Developing methods for sampling and testing has been a multi-phased process. The number of individuals per species may be different based on time, season, and outside temperature. Therefore multiple trips into this portion of the cave are conducted in order to see what species are present. Any Cave, Longtailed, or Dark-sided Salamanders are collected, photographed, and measured for head width, head length, body length, femur length, weight and number of costal grooves. A 3–5mm segment of the tip of the individual salamander's tail is then clipped and placed in a small sealed tube to await DNA analysis. The salamander is then released back into the cave environment. Duplication of salamander documentation is avoided through the photographing of the individual and the morphological measurements. Once the samples have been collected they are taken to the lab and analyzed using DNA fingerprinting or Amplified Fragment Length Polymorphism (AFLP) analysis, which measures genotypic differences. The results from this process are then scored to determine the individual species and at this point any hybrid salamanders can be identified. As of the writing of this paper, AFLP analysis has been completed and the samples are being scored.

Population counts of aquatic cavesnail, *Fontigens aldrichi*. Cathedral Cave has a large, active stream, which flows through the majority of the cave system. This stream is an essential corridor for the movement of the biota. One of the important species found in the cave stream is the aquatic cavesnail *Fontigens aldrichi*. For the past 14 years Dr David C. Ashley from Missouri Western State University (MWSU) brought students from MWSU and St. Louis University to the Park to conduct snail population surveys. The surveys take place along a 20-meter section of the main cave stream near the commercial tour path. By examining chert and dolomite cobbles in the cave stream individual cavesnails are counted and observations recorded about the location where the snail was found. These surveys observe and record different factors including color and dimensions of the stream cobble, number of snails per rock, distance from start of survey, and location within the width of the cave stream. Three transportable PVC pipe grids are used in order to better facilitate the survey and provide easy recording of the sample location. A data recorder writes down all observations into a form that is later transferred to digital format. As the snails measure only 1-2 mm in diameter there may be questionable specimens, so Dr Ashley brings a portable field station with a microscope, which is used to verify individual snails.

The *F. aldrichi* counts in Cathedral Cave indicate that there is a fairly healthy population within the main cave stream. The snails need a chert or dolomite stream substrate in order to inhabit an area, though the snails seem to prefer manganese-coated chert cobbles. Along the 20 m of cave stream, regularly-surveyed population counts have varied from 130 to four cavesnails. If recent numbers and densities of the snails were extrapolated to the other portions of the cave system with similar stream substrate the total population for the cave could easily be in the thousands of individuals.

Recharge delineation of Onondaga Cave and Cathedral Cave. A major area of research since the winter of 2003 was dye tracing to delineate the recharge areas of Onondaga Cave and Cathedral Cave. This project has been a cooperative effort between Ben Miller, Onondaga Cave State Park, and Bob Lerch, USDA, Agricultural Research Service. In 2003 none of the recharge area for either cave was known, and as a management consideration the project was initiated, and it continues today. Dye tracing was conducted using three distinct fluorescent dyes: fluorescein, eosin, and Rhodamine WT. Local springs, streams, and each of the cave streams were monitored using activated-charcoal packets. The charcoal packets were changed at regular intervals in order to determine travel time from the injection site. Analysis of the charcoal was completed by the Environmental Geology Section of the Missouri Division of Geology and Land Survey in Rolla, Missouri.

Since the start of this project 17 dye injections were done. From these 17 injections, five were successfully traced to Onondaga Cave and one was successfully traced to Cathedral Cave. This work has allowed for a recharge delineation of Onondaga Cave, which has a total area of 19.8 km^2. The one successful trace to Cathedral Cave was in a very small, second-order stream, which does not seem significant enough to fully account for the stream flow observed in the cave. Further work will be needed to delineate the recharge area of Cathedral Cave. The work from this project can now be used in the management of the caves as well as help to work with neighboring landowners located within the recharge areas of the cave systems.

Size analysis of sediment particles from Cathedral Cave. In August of 2007 work began in Cathedral Cave looking at various aspects of the geology and morphology of the cave to determine what processes may have contributed to the formation of the cave system. As part of this work clay samples were collected from five sites located along the main cave stream. This clay is a distinct feature of the cave system, nearly filling some cave passages, and is a common characteristic of caves located in the Salem Plateau of Missouri. Sample sites in Cathedral Cave were selected based on the vertical faces of the clay bank, location within the cave system, any visibly distinct layers and the approachability of the sample site. The exterior face of the clay bank was excavated to remove any superficial clay deposits. Once this thin outer layer was removed stratification of the sediments became apparent. Using a metric fiberglass tape, each layer was described in a field book and a representative sample was bagged for removal from the cave. The clay samples, once removed from the cave, were sorted using soil sieves, dried in a forced-air oven and analyzed for particle size. This lab work took place in the USDA, Agricultural Research Service soil lab located in Columbia, Missouri.

The particle-size analysis indicated much more about the speleogenesis of the cave system than might have been previously speculated. One of the major findings was that the cave system appeared to have been in an air-filled environment during the time period when the sediments were being deposited. This conclusion is based on the observation of thin layers of calcite intermixed in the sediment beds at multiple locations in the cave system. Previous theories about the processes depositing this clay had placed the deposition event during the phreatic stage in cave development. Also discovered was that the sediments appear to be from episodic events. Multiple flood events washing sediments into the cave might account for the distinct stratification of the clay banks. The clay banks were not homogenous, but in fact the individual layers within a site would have differing amounts of silt, sand, and gravel-sized particles. This difference would indicate a change in flow velocities during the period of deposition. Work on the sediments of Cathedral Cave will continue as mineralogical analysis and sediment dating are examined.

Monitoring of Cave Systems

Each of the major cave systems at Onondaga Cave State Park has had various forms of monitoring in the past. Most of this work related to photo monitoring, water quality, airflow, and commercial tour impacts. Additional monitoring at the Park has contributed to previous knowledge of the caves, and added new information for that proper cave management. This monitoring includes discharge measurements of the cave streams, water-quality testing, and examining the impact of a handrail-replacement project that incorporated metals/geochemical analysis of drip pools and microclimate data collection.

Discharge measurements of cave streams. Onondaga Cave has a large stream, which flows through the majority of the cave system and issues as a spring from the cave's natural entrance. While some sporadic measurements had been taken in the past, no concentrated effort had regularly measured the stream discharge. Cathedral Cave, which also contains a perennial cave stream, had little to no previous work relating to discharge measurements. As part of the dye-tracing research, discharge measurements were taken at Onondaga Spring, the King's Canopy in Onondaga Cave and in the Cathedral Cave stream. These measurements were taken using a wade stick and pygmy meter. At each location the stream channel was divided into several sub-channels across the width of the stream. The depth was recorded at the middle of each sub-channel. The pygmy meter was placed in the middle of the sub-channel and at a depth of 40% below the surface of the stream. Rotations of the pygmy meter were then recorded for 20-40 seconds based on relative velocity of the stream. Discharge was then computed using the measured velocity and the cross-sectional area of the stream channel.

Discharge monitoring trends have begun to appear which, we hope, will contribute to establishing a rating curve for the cave streams and spring. Onondaga Spring has an average base flow of approximately 5,000,000 L/day, though following rain events this can jump to as much as 18,000,000 L/day. Interestingly, a difference in volume was noted between the in-cave location in Onondaga Cave and the spring outlet. The cave stream at the King's Canopy in Onondaga Cave routinely averages approximately 2,000,000 L/day less than the flow recorded at the Onondaga Spring outlet. Cathedral Cave has a significantly smaller cave stream, which averages 280,000 L/day with a high flow of 2,300,000 L/day. Measurements continue to be collected, and it is hoped that in the future a pressure transducer can be installed at the spring in order to provide a higher resolution of discharge data.

Water-quality testing. Water-quality tests were done at Onondaga Cave State Park since 1994. Much of this earlier work focused on testing the Meramec River and occasionally an in-cave site, or the spring would be monitored as well. Originally Park staff tested for 13 elements and chemicals. The analysis of water samples is conducted on-site using several small Hach field test kits; laboratory work used a Hach spectro-photometer. These tests indicated that Onondaga Cave and Cathedral Cave are exceptionally high-quality water sources. The Meramec River, which flows through the Park, is designated as a Missouri Outstanding State Resource Water by the Clean Water Commission.

Recent, primary changes include streamlining of the testing process, adding additional information collected, increased frequency of testing dates, and incorporation of cave sites as permanent testing sites. Today the water-quality monitoring process has been somewhat streamlined with nine elements and chemicals being tested in the samples. This testing continues to use the same equipment as before. Turbidity, conductivity, surface weather conditions, temperature and other stream conditions have been added to the process for all testing sites. Park staff increased the testing frequency to monthly and seasonal spans. The frequency depends on the availability of staff and the conditions at the testing site. Water quality monitoring has typically not taken place directly following major rain events. Cave sites incorporated as permanent testing sites are Onondaga Cave stream at the King's Canopy, the Lily Pad Room (Figre 1) in Onondaga Cave, and the main cave stream in Cathedral Cave. Onondaga Spring has also been added as a permanent site, though cave-related this site is technically a surface site. The addition of these sites and the increase in the frequency of testing have given Park staff a much deeper understanding of the hydrologic processes in each cave.

Metals and geochemical analysis of drip pools. In November 2005 a project was started at Onondaga Cave State Park to replace the existing iron and aluminum handrails with a new stainless-steel handrail system. This decision was made based on the height and structural integrity of the older handrails. To better study the impacts of this project a number of different monitoring methods were undertaken. Drip pools, located near the tour route, were monitored before and after the handrail project for metals as well as a thorough geochemical analysis. Park staff was concerned that the cutting of the old handrails would create a large amount of metal shavings that could contam-

Figure 1 The Lily Pad Room in Onondaga Cave. Photo by Eugene Vale.

inate the drip pools and harm biota. The project was initiated by Park superintendent Maria Potter and was assisted by Park staff Ben Miller as well as Missouri University of Science and Technology (University of Missouri, Rolla) student, Jeffery Crews. Grab samples of water from the drip pools were collected along with some sediment samples taken nearby. Samples were sent to Environmental Analysis South Incorporated, a private chemical and metals analysis company located in Jackson, Missouri.

The results were helpful in evaluating the impact of the handrail project on the drip pools. The tests were for ten of the more common metals: chromium, copper, iron, mercury, nickel, lead etc. The drip pools luckily did not show any major impact or increase in metals from the replacement of handrails. However, some low amounts of metals were detected in the Lily Pad Room in the form of copper, and it may be attributed to a pre-Park time when pennies were allowed to be thrown into the pools. One of the more interesting geochemical results was the high level of nitrates in a few of the drip pools. These higher levels may be from bat guano that can be seen throughout the pools in question. Septic tanks above the cave could have contributed to these elevated levels. Additional work on the drip pools is planned, including dye traces from structures above the cave to look at the interconnectivity of the surface structures to the cave environment.

Microclimate data collection. During the handrail-replacement project the airlock to Onondaga Cave was opened much more frequently than during the cave-tour season. Also during this period of time some of the lighting in the cave was on for several hours to improve work site visibility and to aid teams of workers removing old handrail material. These activities, however necessary, do have an adverse impact on the temperature and relative humidity in the cave environment. In order to better monitor the extent of this impact Hobo Pro® temperature and relative humidity dataloggers were placed at two locations within Onondaga Cave, and several Hobo temperature dataloggers were placed at four to five additional locations. The Hobo Pro monitors were provided and downloaded by Dr Ashley, MWSU, who visited the cave at least twice a year. The monitors were programmed to record a temperature and relative humidity reading once every half-hour. This resolution of data was fine enough that in many cases the start of a workday could be determined from the data output. Data loggers were placed at in-cave locations in late June 2006 during normal tour operation and were removed in mid-May, 2007 after the completion of the handrail replacement.

Once the data from the dataloggers was plotted using Boxcar Pro and Microsoft Excel, the impact on relative humidity from the handrail project became apparent. The Hobo Pro datalogger that was located in the Lily Pad Room showed a dramatic drop in relative humidity of almost 40% from the normal 99-100% level. This drop, recorded March 20, 2007, was not immediate, but it was the low point of a series of drops in relative humidity from the start of the work in early November, 2006. Upon the completion of the project the relative humidity stabilized at near 100%. Other dataloggers did not record this behavior in the cave system during the same time period. Therefore it is believed that this drop in relative humidity may have been because of the sensitive nature of the Lily Pad Room and the location of the room, which is higher in elevation than the majority of the cave system. Microclimate data is continuing to be collected today thanks to a partnering with Dr Ashley and his students from Missouri State Western University.

Future Work

An array of future projects is planned to look further at aspects of both Onondaga Cave and Cathedral Cave. Many of these upcoming projects build on research and monitoring that has already been initiated. Dye-tracing work will refine the boundaries of Onondaga Cave's recharge area, and better delineate the Cathedral Cave recharge area. Biological inventories of Cathedral Cave will be conducted to expand the list of known species in the cave system. Sediment work for Cathedral Cave may continue as mineralogical analysis could define the composition and help on potential origin of the sediments. Dating of these sediments will also be pursued which could help to understand the chain of events leading to the massive deposition of sediments seen in the cave. Cultural research is pursued as volunteers help on restoration projects in each of the cave systems. Many times this restoration work uncovers historical artifacts that can be added to the Park Cultural Resource Collections. Lighting in Onondaga Cave is also being adjusted to decrease the amount of algal growth, and to lower the amount of heat generated by the large number of bulbs. LED (light emitting diode) lighting is being added to many portions of the tour route with monitoring of temperature and algae beginning to look at the impacts of these changes. Hydrologic monitoring of stream discharge will continue to be collected using a wade stick and pygmy meter system. Eventually park staff hope to install a pressure transducer at the spillway of Onondaga Spring to gain better resolution of the discharge data. A network of temperature and relative humidity monitors is planned for Onondaga Cave and eventually Cathedral Cave. This will add to the microclimate dataloggers that Dr Ashley has helped establish in Onondaga Cave.

Summary

For the previous four or five years research and monitoring have been a major management focus at Onondaga Cave State Park. We have focused on the ongoing processes in the two major cave systems at the Park, Onondaga Cave and Cathedral Cave. This work has looked at the hydrological, geological, biological, and meteorological aspects of the caves, as well as the impacts of a handrail-replacement project. Much of the work has been a cooperative effort among Park staff, educational institutions, state agencies and federal agencies. This cooperation has allowed for a wide range of work to take place. Future projects are planned to continue the monitoring that has been established, and to pursue additional research opportunities. As this research and monitoring continue the information gathered is added to the Park records and is used in the management of the resources for each of these significant cave systems.

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