ICE CAVE MONITORING AT LAVA BEDS NATIONAL MONUMENT

Katrina Smith
Lava Beds National Monument
PO Box 1240
Tulelake, CA, 96134, USA, katrina_j_smith@nps.gov

Abstract
Lava Beds National Monument contains lava caves with a variety of significant ice resources. Caves with seasonal melting of some ice resources provide an important source of water for wildlife within the monument and have had many historic uses over the past several decades. In other caves, perennial melting of previously stable ice floors is increasing, with some caves experiencing total ice loss where deposits were greater than 2 meters (6 feet) thick. Simple ice level monitoring has occurred in sixteen of the thirty-five known ice caves since 1990, supplemented with varying amounts photo monitoring. Though this monitoring reveals changes in the level of many ice floors, it does not detect changes in ice volume or differential changes across an ice floor (Thomas, 2010). To increase the quality of ice monitoring, Lava Beds staff are field testing and refining a combination of surface area and ice level measurements to estimate the change in volume of ice floors inside the five most significant ice caves within the monument. This new protocol is being established in accordance with the National Park Service Klamath Inventory and Monitoring Network's Integrated Cave Entrance Community and Cave Ecosystem Long-term Monitoring Protocol (Krejca et al., 2011). The goal of this long-term monitoring protocol is to document changes in cave environments using several different parameters, including ice.

Keywords
Lava cave, ice floor, ice melt, ice monitoring, management, National Park Service

Introduction
Lava Beds National Monument is located in northeastern California, approximately 250 km (155 mi) northeast of Redding, California and 75 km (47 mi) southeast of Klamath Falls, Oregon. Lava Beds lies at the convergence of the Sierra-Klamath, Cascade, and Great Basin geographic provinces and ranges in elevation from 1236 to 1685 m (4055 to 5528 ft). The climate of Lava Beds is considered high elevation semi-arid desert with warm dry summers and cool winters. For the period from 1991 to 2012, average annual high temperatures were 16°C (61°F) and average annual low temperatures were 2°C (36°F). Lava Beds received an average of 37 cm (14.5 in) of precipitation annually during this period, the majority of which was derived from snowmelt. The infiltration of this annual precipitation through the bedrock provides the source of water for ice floors and formations within lava caves in the monument; the water table lays hundreds of meters below the surface while the lowest known levels of ice caves are less than a hundred meters deep.

Lava Beds National Monument contains the largest concentration of lava caves in the contiguous United States; more than 700 caves have been identified (KellerLynn, 2014). Some are multilevel and contain significant seasonal or perennial ice deposits (Knox, 1959); currently, thirty-five caves are known to have varying accumulations of ice. Many of these caves served as a historic water source for Native Americans and early settlers, a rare resource in this high desert terrain. The ice inside these caves was also used for recreational purposes. In the early 1900s, a resort at Merrill Cave beckoned visitors to ice skate on the expansive ice floor inside the cave. Some of the ice caves and associated trenches and sinks were even used to operate liquor stills during Prohibition. Today, ice resources inside caves are protected within the monument, and are enjoyed by visitors all year round. Annual melting of some ice floors provides an important source of water for wildlife within the monument.

Melting of Cave Ice

Lava Beds caves contain both seasonal and perennial ice resources. Both types of ice deposits exhibit varying degrees of seasonal changes, with the highest levels of accumulation occurring in March-May and lowest levels occurring in November (Kern and Persoiu, 2013).

Caves that are highly connected to the surface via multiple entrances or shallow vertical development experience seasonal ice growth and melt (Fryer, 2007). Some, such as Indian Well Cave, contain ice formations that form each winter but melt completely in summer, while others contain various sizes of ice floors and formations that are frozen in winter but melt partially or completely in summer. The ice floor in Big Painted Cave annually experiences nearly full melting, with up to 61 centimeters (24 inches) of water present on top of the little to no ice that remains below. This seasonal melting is also often seen in a backcountry cave that contains a pool of water approximately 45 cm deep (18 in.); this pool freezes in the winter but melts by late spring and serves as a significant water source for birds, skunks, pika, woodrats, foxes, bears, cougars, and other thirsty wildlife (Fig. 1).

Other ice caves are not as well connected to the surface; many have only one entrance and exhibit multi-level development with passages more than 30 m (100 ft) deep. These caves act as cold air traps, stabilizing temperatures in the deep zone and allowing ice formations to develop and subsist year-round (Fryer, 2007). Unfortunately, these perennial ice deposits are experiencing significant melting events and subsequent ice loss. Currently, seven of the sixteen monitored ice caves have completely lost all ice resources, and five others are experiencing varying levels of declining ice deposits. Only four of the sixteen are stable or growing, and nineteen more have no record of monitoring.

Merrill Ice Cave experienced a total ice floor loss in the span of just nine years after a fist-sized hole appeared in the ice floor surface. Beneath this hole was a large void in the ice from which a strong draft blew, suggesting that a warm (relative to ice) air current had been at work beneath the ice for some time (Fuhrman, 2007). Speculation suggests a shift of rocks in a lower, inaccessible passage was the source of this airflow (Fuhrman, 2007). This ice floor abnormality was first noticed during monitoring activities by Lava Beds interpreters and the Cave Research Foundation (CRF) in 1997 (Fuhrman, 2007). Frequent photo monitoring ensued and documented the rapid enlargement of the hole and subsequent degradation of the ice floor. By November 2000, only two-thirds of the ice floor remained, and by 2006, the main ice floor had completely disappeared (Fig. 2).

Figure 1. *Three young grey foxes (Urocyon cinereoargenteus) drink from the melted ice pool in a backcountry cave, while their mother waits nearby on the right (NPS photo).*

The level of the ice floor in Caldwell Ice Cave has shown a noticeable decline over the past 20 years, but has more recently shown a rapid trend of degradation similar to that of Merrill Ice Cave. During routine monitoring activities led by Lava Beds staff in March 2011, a 0.3 m x 0.6 m (1 ft x 2 ft) hole was discovered in the northwest end of ice floor where it met the cave wall (Fig. 3). This hole extended through the entire thickness of the floor, revealing the bottom of the cave passage 2.5 m (8 ft) below. Though no strong airflow is felt through this void, the hole has tripled in size in just three years, now measuring approximately 1 m x 2 m (3 ft x 6 ft). It seems likely that the ice floor will continue to melt away from the wall, exposing the cave passage below.

A different melting phenomenon has been observed in Crystal Ice Cave, which contains the most extensive ice resources of all ice caves within the monument. Warming temperatures in the upper levels of the cave led to acute melting of large ice floors in the upper levels of the cave, such as the Fantasy Room (Fig. 4), and subsequent refreezing of ice in lower levels of the cave, such as the Red Ice Room.

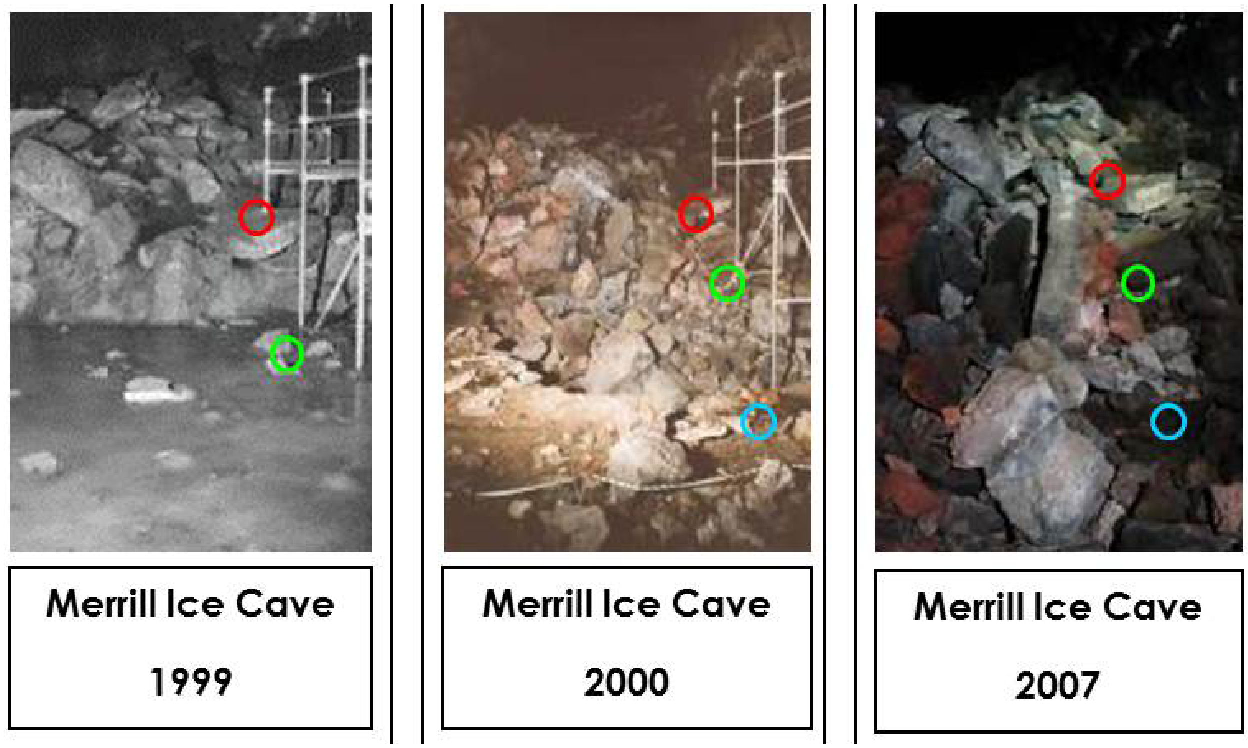

Figure 2. *Photo monitoring shows the precipitous loss of the ice floor in Merrill Cave. The catwalk was removed prior to 2007 due to destabilization (NPS photos).*

Figure 3. *A new hole appeared at the back of the ice floor in Caldwell Ice Cave in 2011 and has tripled in size in just three years (NPS photos).*

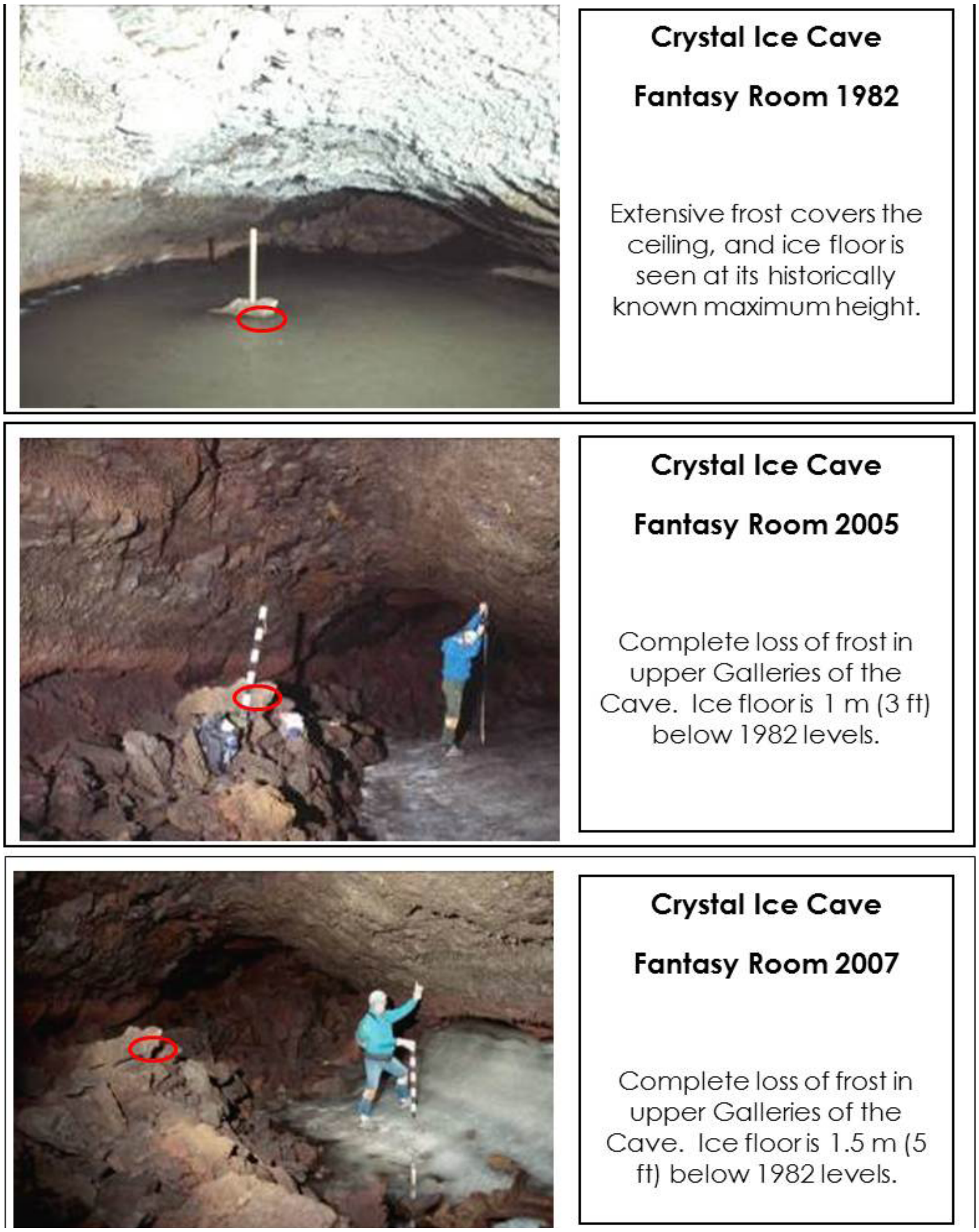

Figure 4. *Photo monitoring shows the loss of the ice floor in the Fantasy Room in the upper level Crystal Ice Cave (NPS photos).*

These trends clearly show the fragility of ice cave resources; because of this and the high resource significance of cave ice, Lava Beds management staff is committed to protecting and monitoring these sites as best as possible for the long-term future.

Historic Monitoring of Cave Ice

The earliest ice monitoring data within the monument goes back to 1982 in Crystal Ice Cave. Ice floor levels in fifteen additional caves have been monitored annually since 1990. The majority of this monitoring has been completed by volunteers of the CRF, predominately Bill Devereaux, Ed Bobrow, and Mike Sims, in association with Lava Beds National Monument. The simple and time-tested method used involves measuring the distance from a fixed point on the cave wall or ceiling above the ice floor, marked by a screw permanently inserted into the rock, to the surface of the ice floor. When water is present on top of the ice, the depth of the water is also recorded. For simplicity and minimal resource impact to the cave wall or ceiling, each ice floor has only one or two monitoring sites. Cave temperature is recorded at designated sites within each cave during the monitoring visit.

On a smaller scale, some photo monitoring of ice deposits has occurred in a few ice caves. As with the quantitative data, the earliest and most extensive photo monitoring data goes back to 1982 in Crystal Ice Cave, and photo monitoring of the ice floor in Skull Ice Cave started in 1989. More recently, photo monitoring began in Caldwell Ice Cave when a hole appeared at the end of the ice floor in spring 2011. Other photo monitoring sites will be established and implemented as staff and volunteer time allows. As with the quantitative data, volunteers from the CRF completed the majority of the photo monitoring fieldwork, and Lava Beds is incredibly grateful for their assistance in monitoring this important resource.

Methods

Over the past several years, staff from Lava Beds have been assisting with the development of the Klamath Inventory and Monitoring Network's Integrated Cave Entrance Community and Cave Ecosystem Long-term Monitoring Protocol (Krejca et al., 2011). This protocol measures seven parameters: cave meteorology, ice and water levels, human visitation, entrance vegetation, bat populations, scat and organic material deposition, and cave invertebrates. Implementation will occur at both Lava Beds and Oregon Caves National Monuments. Thirty-one caves within Lava Beds were selected for inclusion in this protocol; five of these have significant ice resources.

The application of an extensive long-term monitoring protocol in caves is unprecedented within the National Park Service, and therefore has taken several years to develop and refine. In particular, the ice monitoring protocol is one of the last parameters to be refined, and field testing of methods is ongoing at the time of this publication.

In order to qualitatively assess the changes in ice floor volume within the five caves selected for monitoring, two different measuring strategies are being employed.

The first monitoring method establishes the level of the ice floor and is an extension of the ice level monitoring established in 1990 by the CRF. While their method has been able to show changes in ice levels over time, it leaves us unable to detect changes in ice volume or in differential changes across an ice floor (Thomas, 2010). The new method proposed by the long-term monitoring protocol uses transect methods similar to those commonly used in vegetation sampling. Permanent transects will be established across each ice floor, marked at each end with a screw in the cave wall. For data collection, a measuring tape will be pulled taught from one wall to the other, and the distance from the tape to the surface of the ice floor will be measured using a plumb bob and measuring tape or laser distometer. Depth of water, if any, will also be recorded. Each ice floor will have at least 20 transect points; the final number of points will be established by field technicians to strike a balance between ensuring adequate spatial coverage of the ice floor and minimizing of the number of transects and therefore permanent impact on the cave walls.

The second monitoring method establishes the area of the ice floor. A tripod will be placed in an area of the ice floor where the entire edge of the ice floor is visible, usually the approximate center of the ice floor. A Leica Disto D8 laser distometer will be attached to the tripod and used to measure the distance and inclination to the edge of the ice floor at 6 degree intervals. A total of 60 measurements will be recorded and will begin and end at one of the permanent transect screws in the cave wall. The distance, azimuth, and inclination from the tripod to this screw will be recorded, creating a fixed control point for the survey (Fig. 5). This eliminates the need for the tripod to be placed in the exact same location for each survey, a difficult task on ice floors that fluctuate through time (Thomas, 2010). Data collected will be processed in ArcGIS to obtain the area of the ice floor. Similar data processing has occurred with pilot study data (Fig. 6) using the lineplot program Compass. In this case data were collected for only 10 points, but rough characterization of the ice floor is still possible by connecting the ends of the lineplot.

Together, these two methods will allow us to monitor changes in ice volume across the expanse of each ice floor.

Figure 5. *NPS staff measure distance, azimuth, and inclination from the tripod to the permanent control point on the cave wall to begin an ice floor area survey (NPS photo).*

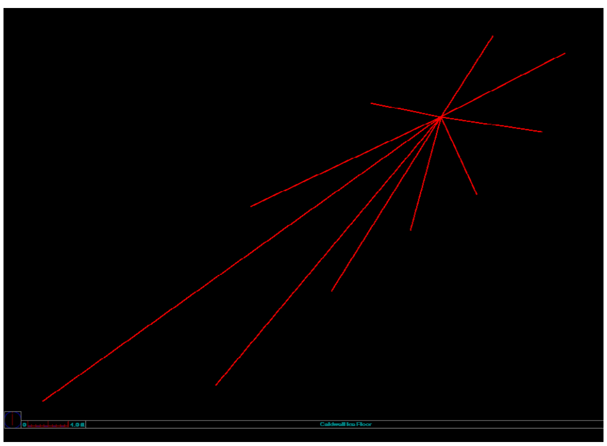

Figure 6. *Lineplot of the ice floor in Caldwell Ice Cave, taken in 2010. Tripod with survey equipment was stationed at the concentric center of the lines. A rough estimation of the ice floor area is given by connecting the ends of the lineplot.*

Conclusions/Outlook

Because field testing and implementation of monitoring methods is ongoing at the time of this publication, results are minimal and methods may change before the protocol is finalized. The goals of the protocol, however, will stay the same. Methods that are simple, repeatable, and yield high quality results about changes in ice volume over the long-term future are desired and will be implemented for many years to come.

References

Fryer S. 2007. The decline of ice resources within the caves of Lava Beds National Monument. Unpublished Report. National Park Service, Tulelake, California.

Fuhrman K. 2007. Monitoring the disappearance of a perennial ice deposit in Merrill Cave. Journal of Cave and Karst Studies 69 (2): 256-265.

Keller Lynn, K. 2014. Lava Beds National Monument: geologic resources inventory report. Natural Resource Report NPS/NRSS/GRD/NRR—2014/804. National Park Service, Fort Collins, Colorado.

Kern Z, Persoiu C. 2013. Cave ice – the imminent loss of untapped mid-latitude cryospheric palaeoenvironmental archives. Quaternary Science Reviews 67 (2013): 1-7.

Knox RG. 1959. The land of the burnt out fires Lava Beds National Monument, California, Bulletin of the National Speleological Society 21: 55-66.

Krejca JK, Myers III GR , Mohren SR, Sarr DA. 2011. Integrated cave entrance community and cave environment long-term monitoring protocol. Natural Resource Report NPS/KLM/NRR—2011/XXX. National Park Service, Fort Collins, Colorado.

Thomas SC. 2010. Monitoring Cave Entrance Communities and Cave Environments in the Klamath Network: 2010 Pilot Study Results. Natural Resource Data Series NPS/KLMN/NRDS—2010/XXX. National Park Service, Fort Collins, Colorado.