Determinant Factors of Summer Roost Selection for Cave Bats (*Myotis velifer*) in Central Texas

A Thesis

Presented to the Department of Environmental Studies

Antioch University New England

In Partial Fulfillment

Of the Requirements for the Degree of

Master of Science

By Sofia Angelo

May 2009

ACKNOWLEDGEMENTS

I would like to thank my thesis advisor, Jonathan Atwood, for all the hours spent with me in the GIS lab, laboring over maps and statistics. Also, my work would not have been possible without the time and resources put in by committee member and mentor, Jim Kennedy. I truly appreciate everything you have done for me. Thank you to Dave Yates for also agreeing to be on my thesis committee and taking time out of your busy schedule. Mark Sanders, Bill Russell, Niki Lake, Charles Pekins, Kevin Ferguson and others who helped me identify caves to include in my study, thank you for your trust and support. I would also like to thank all the people that volunteered their time, hiked under the summer sun and crawled through hot, humid caves with me including: Lee Jay Graves, Devra Heyer, Mike Sisson and others from the UT Grotto!

Thank you to Texas Parks and Wildlife, the City of Austin, Fort Hood, Texas Cave Management Association and local landowners for granting me access to visit caves on your property, and the Texas Speleological Survey for allowing me to use the TSS database and their cave maps. Bat Conservation International supported me in more ways than one, allowing me to use their offices and library, giving me the experience necessary for my data collection, including making it possible to attend a bat conservation and management workshop and partially funding my research. Thank you. Funding was also provided by the National Speleological Society. Lastly, I would like to thank my family for supporting me endlessly and always believing in me.

ABSTRACT

Summer roosting populations of the cave bat (*Myotis velifer*) have abandoned a number of Texas caves, possibly indicating an overall decline of this species. Microclimate and other factors were compared between caves that have been used by *M. velifer* during the summer and caves that are not known to have been previously used by this species. Eighteen of the caves used in the study were categorized as "*velifer* caves" based on current presence, documentation of past occupation or by the presence of roost stain. Sixteen additional caves were categorized as "non-*velifer* caves," based on the absence of roost stain and any reports of the species' presence. Factors measured at each site included: cave entrance width and height, cave length, temperature, humidity and ceiling height at roost locations or potential roost locations, proximity of cave to a permanent water source, and vegetation density surrounding the entrance. Past and present cave use by *M. velifer* was significantly related to disturbance, relative humidity. Also, the height of a roost was found to be a predictor for the area of that roost.

TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS ……..	i
ABSTRACT ……..	ii
LIST OF TABLES ……	iv
LIST OF FIGURES……	v
INTRODUCTION …….	1
Cave Bat *(Myotis velifer)* Natural History and Ecology ……...	3
STUDY AREA AND METHODS ……	8
Study Sites …….....	8
Variables Collected ……...	9
Data Analysis ……	10
RESULTS ……..	12
DISCUSSION ……...	14
Recommendations……..	16
LITERATURE CITED ……..	18
TABLES ……	21
FIGURES ……..	25
APPENDIX A……..……...	30

LIST OF TABLES

Pages

A. Estimated *M. velifer* population loss from 17 Texas caves (Jim Kennedy, Bat Conservation International, unpubl. data)…….. 21

B. Central Texas caves visited during the summer of 2008..…….. 22

C. Roost stain measurements and *Myotis velifer* counts obtained in central Texas caves during summer 2008……..... 23

D. Variability in temperature and humidity variables between "*velifer* caves" (n = 44) and "non-*velifer* caves" (n = 30) caves..... 24

LIST OF FIGURES

Page

1. Names and locations of caves included in this study.…….…….. 25

2. Ecoregions in which study caves are located ……..... 26

3. Vegetation cover types in which study caves are located…….. 27

4. An example of well-defined roost stain from Gorman Cave, San Saba County, Texas …….……... 28

5. An example of a *Myotis velifer* colony with roost stain from Stowers Cave, Kerr County, Texas ……..... 29

INTRODUCTION

Bats (order Chiroptera) are found on every continent except Antarctica (Park 2000, Pennisi et al. 2004), and make up a quarter of all known mammals on earth (Park 2000). Bats exhibit many positive ecological and economic influences (Scheel et al. 1996). However, 45% of the 1,105 known species of bats are endangered, threatened or close to becoming threatened (Pennisi et al. 2004). Ecologically, bats help maintain plant diversity through pollination and seed dispersal (Hutson et al. 2001); there are about 500 plant species that are chiropterophilous, depending, at least partially, on pollination by bats. These plants are typically found in grasslands, deserts and savannahs; however, there is evidence of a large number of tropical plants being visited by bats, as well (Troll 1975). Consumption of agriculture pests and production of large amounts of guano, which can be used as fertilizer, also illustrate the positive affect that bats can have on the human economy (Schmidly 1991, Hutson et al. 2001, Mickleburgh et al. 2002).

The importance of bats is most apparent when looking at large colonies. In Texas, an estimated 100 million Mexican free-tailed bats (*Tadarida brasiliensis*) occupy maternity colonies during the summer; with each pregnant female consuming 50-70% of their body weight, these colonies can consume up to 1,000 tons of insects per night (Hutson et al. 2001). In developed regions artificial fertilizers have replaced the need for the use of guano; however, guano is still considered an important fertilizer in developing countries. In the US and Mexico, where the world's largest bat colonies are found, population declines and range reductions have been observed (Hutson et al. 2001). Suitable roosts and food availability, which may restrict

population size and diversity (Whitaker et al. 2006), is becoming limited due to increasing human populations and demand for resources (Mickleburgh et al. 2002).

Changes in forests and forest structure, where bats forage and roost in trees, have a negative effect on some bat populations. The endemic Neotropical species, *Musonycteris harrisoni*, has been found to exclusively feed in unfragmented forests of Mexico. Some other bats, such as *Glossophaga soricina* and *Leptonycteris curasoae*, however, prefer disturbed areas for travel and foraging (Stoner et al. 2002). Many bat species use tree lines, edges and forest openings as travel corridors and foraging areas and will roost in both live and dead trees (Mickleburgh et al. 2002). Direct human disturbances to caves have also been reported as causes of decline for many bat species. For example, the endangered gray bat (*Myotis grisescens*), which is dependent on cave roosts, has been hit hard by extirpation attempts by humans (Tuttle 1979). In addition to the purposeful removal of bats, they are also affected indirectly by tourists and cave enthusiasts. Caves can be an attractive place to explore, but can hurt bat populations if not managed correctly. Abandoned mines, another crucial roosting space for bats in areas with limited cave access, are being threatened by resumption of mining practices and the sealing of inactive mines due to safety concerns (Mickleburgh et al. 2002).

Suitability of roosts is also determined by microclimatic factors (Schmidly 1991). Bats have the poorest thermal regulatory abilities of mammals (Hutson et al. 2001) and have significantly higher rates of heat loss than other small mammals due to increased surface area during wing expansion. This makes temperature control a very important factor, and much of their behavioral ecology has evolved in response to the need to conserve energy (Twente 1955b). Hibernating bats, such as *Myotis*, have a higher temperature range tolerance than non-hibernating species (Stones and Wiebers 1965). During hibernation, bats seek out roosts with cooler

temperatures to slow their metabolic rate and retain fat reserves; during the summer months, however, bats require roosts with warmer temperatures to promote efficient digestion and absorption (Twente 1955b).

Availability of roost sites with proper thermal characteristics is critical to bat survival (Twente 1955b). Some factors that influence cave temperature are geographic location, water and air circulation, cave structure and volume, and conduction from cave walls. The mean annual temperature of the external environment of a cave is directly related to the mean annual temperature inside the cave (Tuttle and Stevenson 1977). Scheel et al. (1996) predicted that changes in climate and vegetation in Texas would cause range changes, but not extinction of any of the state's bat species. However, more information is needed detailing the microclimate needs of specific bat species, and the relationship between broad climate changes and roost conditions (Scheel et al. 1996).

Cave Bat *(Myotis velifer)* Natural History and Ecology

Myotis velifer, also known as the cave bat or cave myotis, is a cave-dependant, insectivorous bat with a range reaching from south-central Kansas through California, and south into Mexico and Guatemala (Twente 1955b). The species roosts in large colonies found in caves throughout its range. The earliest *M. velifer* fossils have been found in caves in Texas and Arizona, dating from the late Pleistocene (Fitch et al. 1981).

Myotis velifer is one of the largest North American species of the genus, with a maximum weight of 15 gm. Females differ from males in that they have a significantly longer forearm and maxillary tooth row, but are similar in all other measurements. *M. velifer* molt once per year

during July and August. Males molt earlier than females because females do not molt until lactating ends (Fitch et al. 1981).

Females become reproductively active in their first year; males do not breed until their second year (Hayward 1970). Mating occurs in the fall, and sperm is stored in the ova until ovulation in April. A single offspring is born to each reproductive female in June or early July. Young bats begin to fly by their third week of life, when about 90% of the young have achieved adult weight (Kunz 1973). The life span of *M. velifer* is believed to range from 6-12 years (Hayward 1970).

With only a single offspring produced per year, Twente (1955a) suggested that an annual survival rate of 66.7% is necessary to maintain a constant population size. *Myotis velifer* have a relatively high number of predators including snakes, raccoons (*Procyon lotor*), hawks, owls, ring-tailed cats *(Bassariscus astutus)*, skunks and gray foxes *(Urocyon cinereoargenteus)*; roosting and emerging in large groups may help protect individuals (Twente 1955a, Hayward 1970). Hawks and owls have been observed waiting outside roosts at sunset, and, in one instance, the remains of 14 *M. velifer* were found in the gut of a single raccoon (Hayward 1970). Roost availability and predation seem to be the major factors limiting populations of this bat species (Twente 1955a, Scheel et al. 1996).

Hibernation begins in late September to early October in caves in the eastern part of their range and in the highlands of Mexico (Fitch et al. 1981). In southern Arizona, males return from hibernation sites at the beginning of March, and large numbers of females are present by the beginning of May. In mid-May, the females disperse to maternity colonies. Males follow in June, roosting with females until the males return to their original roosts in late July or August.

Females and young then rejoin males by August (Fitch et al. 1981). Hayward (1970) found that all summer roosts were located at elevations < 1,067 m, and winter roosts were found > 1,829 m; however, the main hibernating roosts were not located. In southern Arizona summer roosts were primarily found in short abandoned mine tunnels, probably due to the abundant availability of such sites (Hayward 1970).

Like many other insectivorous bat species, *M. velifer* are opportunistic feeders, with diets that fluctuate by season (Kunz 1974). They feed twice per night with 80% of their daily food intake during the first 2 hours of emergence (Fitch et al. 1981). Foraging in Oklahoma occurs at a height of 6-60 m, predominately above stream vegetation at 6-15 m (Caire et al. 1984); Kunz (1974) reported a similar pattern in Kansas (4-12 m). Most emerging bats fly directly to a water source to drink and forage (Hayward 1970, Fitch 1981); the bats usually do not return to their day roosts in between feedings, but roost temporarily near foraging sites. *M. velifer* are estimated to fly up to 10-15 miles during foraging at an average speed of approximately 10 miles per hour (Hayward 1970). Large colonies of this species have been observed flying in separate directions, potentially to avoid intraspecific competition (Caire et al. 1984).

In some species, temperature has been shown to affect bat foraging patterns. Kunz (1974) observed that in warmer temperatures, bats forage in open areas adjacent to wooded areas and over canyons, while in cooler temperatures they forage closer to dense vegetation. Descriptions of vegetation at the landscape level has been provided within the foraging range of *M. velifer* in Oklahoma and Kansas (Kunz 1973, Caire et al. 1984), but no information has been provided about vegetation directly outside and on top of *M. velifer* caves, which may affect the cave's humidity and temperature.

During hibernation, *M. velifer,* like many other bat species, occupy cooler caves, moving to warmer caves during spring and summer. Dunnigan *et al.* (1967) suggested that *M. velifer* may prefer roosts with extreme variations in ceiling height, which would restrict air movement and prevent total flooding; in one such cave, these authors found that air temperature was higher than that of neighboring caves. In the Texas panhandle, nursing females were found in the warmest parts of the warmer caves (Fitch et al. 1981). According to Fitch et al. (1981), ambient humidity in hibernacula caves is usually over 55%; however, Hayward (1970) speculated that humidity was not a factor in roost selection during the summer months, noting that bats were found in tunnels with a humidity as low as 20% and as high as 95%.

There is some evidence that nursery roosts in caves may need to have a stable humidity and temperature. For example, at a nursery cave in Kansas the temperature remained near 20° C and 100% relative humidity during a 2 week period in July 1969 (Kunz 1973). A nursery located in a building, however, had greater fluctuations; during the same 2 week period a building roost ranged from 25-35° C, with a relative humidity varying from 40-100%. These fluctuations could be caused by the physical structure of the roost (Kunz 1973).

Quantitative analysis of the humidity requirements of *M. velifer* during the summer months is still lacking. Kunz (1973) attempted to examine the relationship between bat growth and roost microclimate, under the assumption that thermal neutrality may promote increased development in young bats; however, no significant correlation was found. Tuttle (1975) explains that this may have been due to unequal clustering of bats between the roosts.

The majority of published data on *M. velifer* is over 20 years old (Hayward 1970, Kunz 1973, Fitch et al. 1981, Caire et al. 1984). Although various comments have been published

about the possible habitat requirements of this species, quantitative analysis is greatly lacking (Dunnigan 1967, Hayward 1970, Fitch et al. 1981, Caire et al. 1984), and some factors that might be associated with site selection, such as characteristics of surrounding vegetation, have been overlooked. A very small amount of work in reference to *M. velifer* in Texas has been published (Patterson 1961, Tinkle and Patterson 1965, Manning et al. 1987).

Summer populations *M. velifer* appear to have either partially or completely abandoned some Texas caves, which may indicate an overall decline in the species (Table A, Jim Kennedy, Bat Conservation International, unpubl. data). Historically, *M. velifer* has been considered abundant in Texas (Schmidly 1991), and few studies have been conducted to monitor this species. However, O'Shea and Vaughn (1999) found that the species has abandoned some of its previously-used summer roost caves in central Arizona, suggesting that the anecdotal observations of cave abandonment in Texas may be part of a more widespread problem. The gray bat (*M. grisescens*), which is believed to have similar habitat requirements and behaviors to *M. velifer* (Tuttle 1975, Tuttle 1976, Brack 2006), was federally listed as an endangered species in 1976 (Brack 2006), probably due to the loss and human disturbance of suitable roosts (Tuttle 1975).

STUDY AREA AND METHODS

Study Sites

Thirty-four caves were included in the study and are all located in central Texas (Table B, Fig. 1), within the Edwards Plateau, Cross Timbers and Black Land Prairie ecoregions (Texas Parks and Wildlife 2004; Fig. 2). Cave locations were identified through a search of the Texas Speleological Survey (TSS) database and through personal contacts within Bat Conservation International, the City of Austin, Texas Parks and Wildlife, Fort Hood Military Base and the UT Grotto (a local caving group). Caves included in this study are located in the following counties: Bell, Bexar, Coryell, Hays, Kendall, Kerr, San Saba, Travis and Williamson. The majority of the caves are in Live Oak-Ashe Juniper vegetation communities; however, other communities represented include: Live Oak-Mesquite-Ashe Juniper, Silver Bluestem-Texas Wintergrass Grasslands and urban environments (Texas Parks and Wildlife 2004; Fig 3).

Caves were visited from 30 June – 9 September 2008; entry into caves with current populations was delayed until 17 July in order to avoid disturbing flightless young. *Myotis velifer* in Texas have been observed to be volant by late June (Davis et al. 1962, Kunz 1973), which differs from observations in Kansas that suggest flight of newborn individuals does not occur until early July (Kunz 1973). Each cave was only visited once due to logistic challenges.

Eighteen of the caves used in the study were categorized as "*velifer* caves" based on current presence, past documentation of presence and/or by the presence of roost stain. Roost stain is a darkened, pitted area left on cave ceilings by bat colonies that roost in the same location year after year (Tuttle 1979; Fig. 4, Fig. 5). In central Texas, *Tadarida brasiliensis* is the only other species that roost in large enough groups to produce roost stain that could be confused with

that of *M. velifer*. While *M. velifer* have been observed sharing caves with this species (Schmidly 1991), the caves included in this study did not meet *T. brasiliensis* minimum roost requirements of 10x5m entrances and large dome ceilings of 18.2m^2. (Davis et al. 1962). The 16 remaining caves were categorized as "non-*velifer* caves"; these sites were determined based on the absence of roost stain and any reports of the species' presence. For purposes of this paper, only caves where *M. velifer* was actually observed are considered "current use" caves. That is, presence of roost staining or prior documentation of the species' presence by other observers was not considered to be sufficient evidence of current occupancy.

Variables Collected

Variables were measured both outside and inside each cave to assess the roost requirements of the species. Height and width of the cave entrances were estimated based on measurements taken with a Leica Disto D3 laser distance meter or a Lufkin 30 m measuring tape. Approximate vegetation density surrounding the entrances was subjectively classified as open, moderate or dense, based on the presence and size of possible flyways. The area of the entrance and density of surrounding vegetation may affect the bats ability to access the cave.

Variables measured inside *velifer* caves included ceiling temperature, relative humidity, area covered by roosting bats or roost stain, and ceiling height at roost locations (Appendix A). Presence or absence of bats during the cave visit was also recorded. Using the size of the roost or roost stain, population numbers can be estimated. Caves with larger populations may be considered more suitable than caves with smaller populations (relative to cave size). Temperature, humidity and height of roost were identified as potential predictors for the size of a roost because temperature and humidity may affect either how densely the bats roost or the

number of bats that use a roost, and height may impact protection from predation, making the roost more suitable. Similar variables were measured inside non-*velifer* caves: ceiling temperature, relative humidity, and ceiling height (recorded at locations where temperature and humidity data were collected, Appendix A). In these caves, data collection locations were based on areas of the cave that had potential to be roost locations. These sites were usually in a larger room (in relation to the size of the cave) with relatively flat ceilings that provided space for roosting. Data was collected at various locations throughout the length of the cave when possible; however, some caves were not surveyed fully due to bad air (low levels of oxygen), water in lower passages, and/or time limitations.

Ceiling temperature was obtained using a Raytek Raynger ST Pro laser thermometer and relative humidity was recorded using a Skymaster model SM-28 pocket weather station. Roost areas and ceiling heights were measured using a Leica Disto D3 laser distance meter or a Lufkin 30 m measuring tape. For all caves, cave length (obtained using TSS database and cave maps; Appendix A), evidence of human disturbance (trash, graffiti, etc.), and distances of the cave entrance to the nearest water source were also recorded. Open water sources are important feeding and drinking grounds for *M. velifer* (Hayward 1970, Fitch 1981); therefore, one would assume there must be a limit to the distance that this species will travel to such sites.

Data Analysis

Data was analyzed by cave, by roost, or by entrance, depending on the variable under consideration. Each has specific variables that have single values associated with that category. Cave length, water source proximity and disturbance were analyzed by cave because there was only one data line for each cave. Temperature, humidity, roost area and roost height were

analyzed by roost because each roost within a single cave were considered to represent independent data points. Similarly, multiple entrances to a single cave were treated as independent values to assess entrance size and surrounding vegetation density.

Statistical analyses were performed using JMP7 (SAS Institute 1989-2007), with an alpha of 0.05. Logistic and linear regressions, likelihood ratios chi-square analyses, and Fisher's exact tests were used to examine the relationships between the variables where appropriate.

RESULTS

Thirty-four caves, with a total of 53 entrances and 79 roosts or potential roosts, were surveyed during this study. A total of 43 roosts had stain, but no present bat populations, only six roosts had current colonies at the time of the cave visit (Table C). The remaining 30 potential roost locations had never been known to be used by *M. velifer*.

There was no evidence that cave length and proximity to water were significant predictors of *M. velifer* use of caves (logistic regression, chi-square = 0.521, p = 0.469; chi-square = 0.485, p = 0.486 respectively). However, bat presence during time of the study was influenced by human disturbance; caves that showed evidence of recent human activity were less likely to be occupied than caves where human activity was not evident (Fisher's exact test, 2-tail, p = 0.031).

Ceiling temperatures ranged from 17.2 to 28.6 ˚C, and relative humidity ranged from 53% to 92% in caves where there was current or past evidence of use by *M. velifer*. In caves not known to have been inhabited by the species, ceiling temperatures ranged from 19.4 – 28.6 ˚C and relative humidity ranged from 51% to 95% (Table D). In caves used by *M. velifer*, no relationship between ceiling temperature or humidity and areal extent of roost areas was found (linear regression; F = 2.935, P = 0.094 and F = 0.058, P = 0.811, respectively). However, there was a relationship between cave ceiling height and area of the roost (linear regression; F = 9.409, P = 0.004). Humidity was a significant predictor of both whether or not caves have been used in the past by *M. velifer* (logistic regression, chi-square = 17.875, p < 0.001) and whether not or not the caves were being used at the time of the study (logistic regression, chi-square = 5.15, p = 0.023). Ceiling temperature did not significantly predict past or present use of caves by *M.*

velifer (logistic regression; chi-square = 0.030, p = 0.865; chi-square =0.68, p = 0.411, respectively).

There was no evidence that size of cave entrances significantly predicted past use of caves by bats (logistic regression; chi-square = 2.10, p = 0.147). Similarly, there was no evidence that vegetation density surrounding the entrance predicted present cave use by this species (likelihood ratio chi-square = 1.80, p = 0.407).

DISCUSSION

Some of the populations that were present at the time of the study were the largest recorded during the summer for *Myotis velifer*. Of the 6 caves that were currently occupied by *M. velifer*, numbers ranged from 5,000 – 40,000 bats. Estimates this large and larger have been previously recorded for hibernacula of this species (Tinkle and Patterson 1965, Dunnigan and Fitch 1967), but the largest estimated summer colony that has been previously published is 15,000 – 20,000 (Twente 1955b, Dunnigan and Fitch 1967). Undoubtedly, there may be unpublished populations of this size throughout this species' range.

There was no evidence that longer caves have more suitable roost space or more likely to be occupied by bats. Similar results were obtained by Tinkle and Patterson (1965), who failed to find a correlation between cave size and bat numbers. Longer caves do not necessarily have more suitable roost space than smaller caves because they are often narrow with low ceilings. For example, Airmans Cave in Travis County is over 3,000 meters long, but has very little roost space for bats (and has never been used by this species), while Government Canyon Bat Cave, which opens up into one large room and is 104 meters long, is currently being used by approximately 40,000 bats (Appendix A).

Proximity to external water sources also did not predict use of a cave by *M. velifer*. However, this variable may have importance that was not detected in this study; for the majority of the caves, water sources were determined using topographic maps and aerial photography after the field season, and it is possible that permanent water sources being used by the bats went undetected. Also, at caves for which there was documented past use, the time in which the cave

was last occupied is often unknown; therefore, water sources that were present at that time are also unknown.

Human disturbance significantly affected present use of caves by *M. velifer*. As observed during this study, this species is very sensitive to human disturbance, flying from the roosts immediately upon human presence. This behavior did not seem to differ in relation to ceiling height, although no data was collected to support this theory. Mann et al. (2002) examined the effect of cave tours on breeding *M. velifer*, and found that disturbance tolerance did not decrease over time. A future study would be useful to identifying levels of disturbance that lead to cave abandonment.

Temperature and humidity did not significantly affect the size of past and present roosts. This result may be different in drier climates where optimal temperature and humidity are harder to come by. Ceiling height, however, did have a significant relationship to roost size. Although this result may give us an indication that this species tends to have larger roosts in higher places, it could also indicate that there is a relationship between ceiling surface area and ceiling height, which is a relationship that was unable to be tested based on the data that was collected.

Microclimate is believed to be a vital component of roost selection of cave dwelling bats (Raesly and Gates 1987, Brunet and Medellin 2001, Sedgeley 2001). Humidity was significantly lower in caves that had past bat use, but because humidity fluctuates over time, this relationship was not a strong indicator of humidity preference. A better indication was found by comparing humidity and caves that were currently occupied, which also showed a significant relationship. This relationship seems to contradict a paper that suggest *Myotis velifer* prefer high humidity in nursery colonies (Kunz 1973). However, it is supported by Dunnigan and Fitch (1967) who

found that hibernating *M. velifer* preferred cooler temperature and higher humidity, while summer colonies seemed to prefer warmer temperature and lower humidity. In Kansas, Kunz (1973) found that relative humidity was near 100% in the maternity roost cave that he examined; however, he found that humidity was much lower in a nursery found in a building. He explains this variation by suggesting that the soaking of wood joints with urine raised the humidity during occupation. In another study, Studier et al. (1970) recorded the daytime humidity for a *M. velifer* roost ranging from 53% - 96% RH, with the mean being 64% RH. This is lower than the mean of 76% RH found for the *velifer* caves in this study. Temperature did not show a significant relationship to cave use. This is most likely a result of all the caves fitting into the required temperature range for this species (Twente 1955b, Hayward 1970) and not differing significantly between *velifer* and non-*velifer* caves.

Cave entrance size does not generally change over time without human influence; therefore, I only compared these characteristic to past use. According to this study, entrance size did not significantly affect the habitat suitability. Density of vegetation, however, is less permanent; thus, I tested the relationship based on current use and found no correlation. Both of these results may be explained by the belief that this species is a strong flyer (Fitch et al. 1981), and therefore, able to avoid obstacles associated with small fly-ways. A variable that was not included in this study was verticality of entrances and vegetation fly-ways. It would be interesting to see if structures of these factors play a role in suitability.

Recommendations

This study was intended to be the first step towards the identification of cave roost requirements of *Myotis velifer*. While the results give some clues to the preferences of this

species, a study that concentrates solely on current colonies is recommended. To accurately reflect the temperature and humidity requirements of this species, dataloggers should be installed in the caves where bats are currently roosting and evening emergence counts should be conducted to monitor the population fluctuations over the summer. Disturbance to caves with known colonies should be limited, as disturbance is shown to affect the presence of *M. velifer*, until further studies identifying the tolerance of this species have been conducted. Some variables such as cave structure and vegetation type surrounding and on top of caves were not included in this study due to time and resource restrictions. These may be factors that influence cave suitability and should be considered in future studies. Both of these variables may affect temperature and humidity within the caves and may also be limiting factors due to maneuverability.

LITERATURE CITED

Brack, V. Jr. and R. K. LaVal. 2006. Diet of the gray myotis (*Myotis grisescens*): variability and consistency, opportunism and selectivity. Journal of Mammalogy 87 (1): 7-18.

Brunet, A. K. and R. A. Medellin. 2001. The species-area relationship in bat assemblages of tropical caves. Journal of Mammalogy 82 (4) : 1114-1122.

Caire, W., J. F. Smith, S. McGuire and M. A. Royce. 1984. Early foraging behavior of insectivorous bats in Western Oklahoma. Journal of Mammalogy 65 (2): 319-324.

Davis, R. B., C. F. Harried and H. L. Short. 1962. Mexican free-tailed bats in Texas. Ecological Monographs 32 (4): 311-346.

Dunnigan, P. B. and J. H. Fitch. 1967. Seasonal movements and population fluctuations of the cave bat (*Myotis velifer*) in South-Central Kansas. Transactions of the Kansas Academy of Science 70 (2): 210-218.

Fitch, J. H., K. A. Shump, Jr., and A. U. Shump. 1981. *Myotis velifer*. Mammalian Species 149: 1-5.

Hayward, B. J. 1970. The natural history of the cave bat, *Myotis velifer* 1 (1):1-73.

Hutson, A. M., S. P. Mickleburg and P. A. Racey (comp.). 2001. Microchiropteran bats: global status survey and conservation action plan. Pages 2-3,36. IUCN/SSC Chiroptera Specialist Group. IUCN, Gland Switzerland and Cambridge UK.

JMP, Version 7. SAS Institute Inc., Cary, NC, 1989-2007.

Kunz, T. H. 1973. Population studies of the cave bat (*Myotis velifer*): reproduction, growth and development. Occasional Papers of the Museum of Natural History 15: 1-43.

Kunz, T. H. 1974. Feeding ecology of a temperate insectivorous bat (*Myotis velifer*). Ecology 55 (4): 693-711.

Manning, R. W., J. K. Jones Jr., R. R. Hollander, and C. Jones. 1987. Notes on distribution and natural history of some bats on the Edwards Plateau and in adjacent areas of Texas. The Texas Journal of Science 39 (3): 279-285.

Mickleburgh, S. P., A. M. Hutson and P. A. Racey. 2002. A review of the global conservation status of bats. Oryx 36 (1): 18-34.

O'Shea, T. J. and T. A. Vaughan. 1999. Population changes in bats from Central Arizona: 1972 and 1997. The Southwestern Naturalist 44 (4): 495-500.

Park, K. 2000. Book review, bat biology and conservation. Journal of Applied Ecology 37 (5): 894.

Pennisi, L. A., S. M. Holland and T. V. Stein. 2004. Achieving bat conservation through tourism. Journal of Ecotourism 3 (3): 195-207.

Raesly R. L. and J. E. Gates. 1987. Winter habitat selection by north temperate cave bats. American Midland Naturalist 118 (1): 15-31.

Scheel, D., T. L. S. Vincent and G. N. Cameron. 1996. Global warming and the species richness of bats in Texas. Conservation Biology 10 (2): 452-464.

Schmidly, D.J. 1991. The bats of Texas. Texas A&M University Press, College Station.

Sedgeley, J. A. 2001. Quality of cavity microclimate as a factor influencing selection of maternity roost by a tree-dwelling bat, *Chalinolobus tuberculatus*, in New Zealand. The Journal of Applied Ecology 38 (2): 425-438.

Stoner, K. E., M. Quesada, V. Rosas-Guerrero and J. A. Lobo. 2002. Effect of forest fragmentation on the Colima long-nosed bat (*Musonycteris harrisoni*) foraging in tropical dry forest of Jalisco, Mexico. Biotropica 34 (3): 462-467.

Stones, R. C. and J. E. Wiebers. 1965. A review of temperature regulation in bats (Chiroptera). American Midland Naturalist 74 (1): 155-167.

Studier, E. H., J. W. Proctor and D.J. Howell. 1970. Diurnal body weight loss and tolerance of weight loss in five species of *Myotis*. Journal of Mammalogy 51 (2): 302-309.

Texas Parks and Wildlife. 2004. "Ecological Regions." [Map]. 1:250,000. Texas Parks and Wildlife GIS Lab. [Computer files]. Austin, Texas: Using: ArcView GIS [GIS Software].

Tinkle, D. W. and I. G. Patterson. 1965. A study of hibernating populations of Myotis velifer of Northwestern Texas. Journal of Mammalogy 46 (4): 612-633.

Troll, R. 1975. Chiropterophily. Bios 46 (3): 150-152.

Tuttle, M. D. 1975. Population ecology of the gray bat (*Myotis grisescens*): factors influencing early growth and development. Occasional Papers of the Museum of Natural History 36: 1-24.

Tuttle, M. D. 1976. Population ecology of the gray bat (*Myotis grisescens*): factors influencing growth and survival of newly volant young. Ecology 57: 587-595.

Tuttle, M. D. and D. E. Stevenson. 1977. Variation in the cave environment and its biological implications. National Cave Management Symposium Proceedings: 108-122.

Tuttle, M. D. 1979. Status, causes of decline and management of endangered gray bats. Journal of Wildlife Management 43(1): 1-17.

Twente, J. W. 1955a. Aspects of a population study of cavern-dwelling bats. Journal of Mammalogy 36 (3): 379-390.

Twente, J. W. 1955b. Some aspects of habitat selection and other behavior of cavern-dwelling bats. Ecology 36 (4): 706-732.

Whitaker, J.O., D. W. Sparks and V. Brack. 2006. Use of artificial roost structure by at the Indianapolis International Airport. Environmental Management 38 (1): 28-36.

TABLES

TABLE A. Estimated *M. velifer* population loss from 17 Texas caves (Jim Kennedy, Bat Conservation International, unpubl. data).

	County	Historic Estimate	Present Estimate	% Loss
Barker Bat Cave*	Travis	17000	0	100
Beck Ranch Cave*	Williamson	30000	200	99.33
Brehmmer Cave	Comal	51500	6300	87.77
Cicurina Cave*	San Saba	1900	0	100
County Line Bat Cave*	Hays	25000	0	100
Critchfield Bat Cave*	Williamson	7200	7200	0
Fawcetts Cave	Val Verde	3100	2700	12.9
Flemming Bat Cave	Kimble	14000	1000	92.86
Goat Cave*	Travis	14800	0	100
Gorman Cave*	San Saba	71400	25000	64.99
Government Canyon Bat Cave*	Bexar	71500	40000	44.06
Harrells Cave	San Saba	20000	6000	70
Longhorn Caverns	Burnet	41000	0	100
McCarty Cave*	Hays	21900	0	100
Spring Creek Cave*	Kendall	40000	5000	87.5
Stowers Cave*	Kerr	34500	10000	71
Taylor Bat Cave*	Hays	35900	7000	80.5
TOTAL		500700	110400	77.95%

***** Caves visited during the summer of 2008 as a part of this study.

TABLE B. Central Texas caves visited during the summer of 2008.

Cave Name	County	Date Visited	*"Velifer* Caves" / "Non-*velifer* Caves"	Total number of Entrances
Airmans Cave	Travis	13-Aug	Non-*velifer*	1
Barker Bat Cave	Travis	18-Jul	*Velifer*	2
Barker Ranch Cave No. 1	Travis	18-Jul	*Velifer*	1
Barker Ranch Cave No. 2	Travis	18-Jul	*Velifer*	1
Beck Ranch Cave	Williamson	31-Jul	*Velifer*	1
Blacktail Cave	Bexar	17-Jul	Non-*velifer*	1
Bone Pile Cave	Bexar	4-Sep	Non-*velifer*	1
Cave X	Travis	4-Sep	Non-*velifer*	1
Cicurina Cave	San Saba	10-Jul	*Velifer*	4
County Line Bat Cave	Hays	18-Jul	*Velifer*	3
Critchfield Bat Cave	Williamson	1-Aug	*Velifer*	2
Dynamite Cave	San Saba	24-Aug	Non-*velifer*	2
Get Down Cave	Travis	17-Aug	Non-*velifer*	1
Goat Cave	Travis	18-Jul	*Velifer*	1
Gorman Cave	San Saba	11-Jul	*Velifer*	2
Government Canyon Bat Cave	Bexar	17-Jul	*Velifer*	2
Hays Ranch Bat Cave	Hays	18-Jul	*Velifer*	1
Hidden Pool Cave	Coryell	26-Aug	Non-*velifer*	1
Jeanette's Cave	Hays	27-Aug	*Velifer*	1
Lemons Ranch Cave	San Saba	24-Aug	Non-*velifer*	1
Lithic Ridge Cave	Bexar	17-Jul	*Velifer*	1
Lost Chasm Cave	Bell	26-Aug	Non-*velifer*	1
McCarty Cave	Hays	30-Jul	*Velifer*	4
McDonald Cave	Travis	29-Aug	Non-*velifer*	1
Robber Baron Cave	Bexar	22-Jul	Non-*velifer*	2
Saltpeter Cave	Coryell	30-Jun	*Velifer*	1
Sevenmile Mountain Cave	Coryell	26-Aug	Non-*velifer*	1
Spring Creek Cave	Kendall	5-Aug	*Velifer*	2
Stowers Cave	Kerr	10-Aug	*Velifer*	2
Sunspot Cave	Travis	9-Aug	Non-*velifer*	1
Surprise Sink Cave	Bexar	4-Sep	Non-*velifer*	1
Taylor Bat Cave	Hays	2-Jul	*Velifer*	1
Testudo Tube Cave	Williamson	30-Aug	Non-*velifer*	1
Turtle Shell Cave	San Saba	24-Aug	Non-*velifer*	3

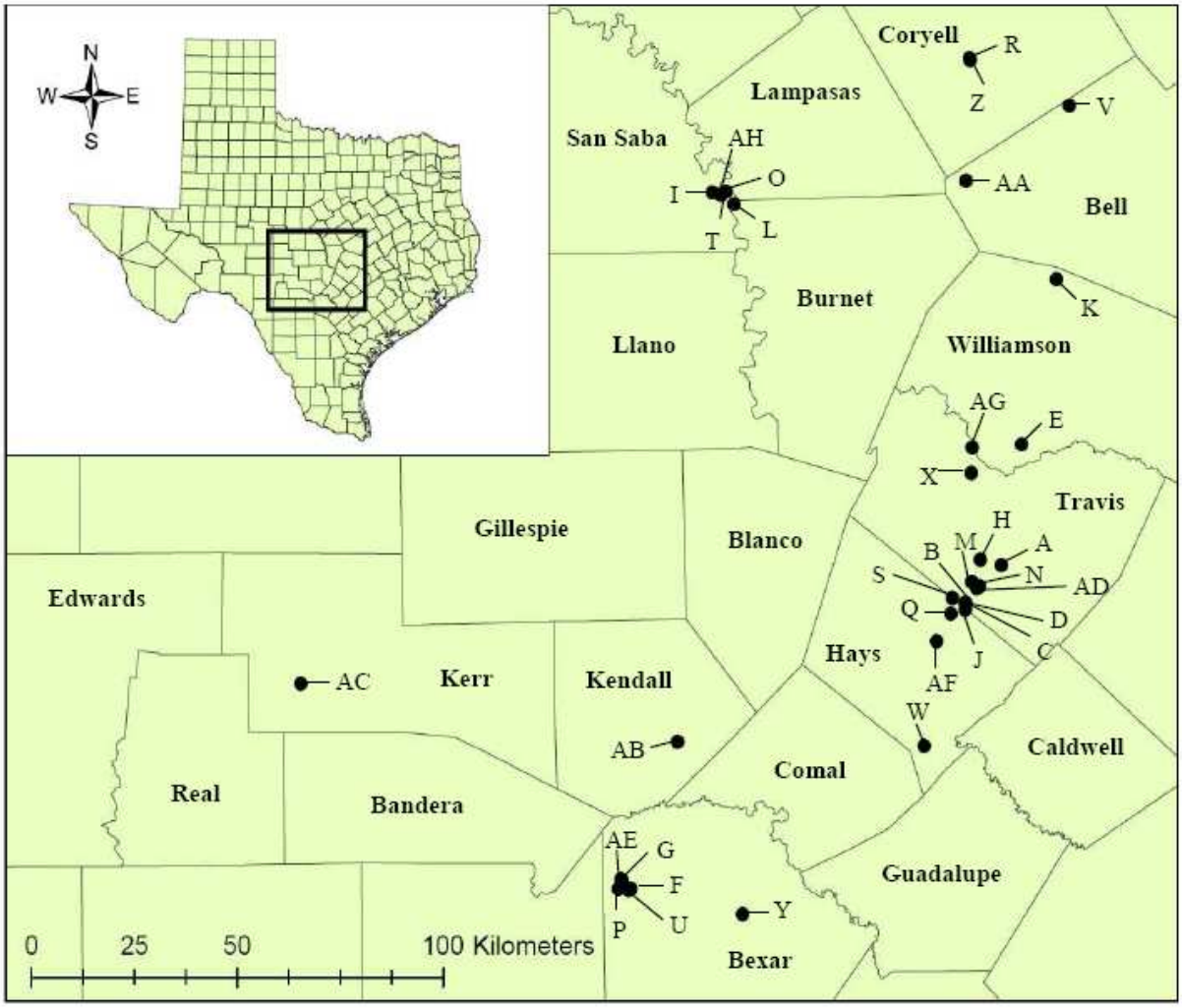
TABLE C. Roost stain measurements and *Myotis velifer* counts obtained in central Texas caves during summer 2008.

Cave Name	County	Total Area (m^2) of Roost Stain	Estimated Number of Bats Present	Number of Occupied Roosts
Barker Bat Cave	Travis	31.45	0	0
Barker Ranch Cave No. 1	Travis	10.35	0	0
Barker Ranch Cave No. 2	Travis	0.05	0	0
Beck Ranch Cave	Williamson	40.59	0	0
Cicurina Cave	San Saba	2.83	0	0
County Line Bat Cave	Hays	24.16	0	0
Critchfield bat Cave	Williamson	72.00	7,200	1
Goat Cave	Travis	13.84	0	0
Gorman Cave	San Saba	91.53	0	0
Government Canyon Bat Cave	Bexar	87.65	40,000	3
Hays Ranch Bat Cave	Hays	12.00	8,600	1
Jeanette's Cave	Hays	20.10	0	0
Lithic Ridge Cave	Bexar	3.90	6,450	1
McCarty Cave	Hays	67.71	0	0
Saltpeter Cave	Coryell	11.00	0	0
Spring Creek Cave	Kendall	259.47	5,000	1
Stowers Cave	Kerr	33.27	10,000	2
Taylor Bat Cave	Hays	51.59	0	0

TABLE D. Variability in temperature and humidity variables between "*velifer* caves" (n = 44) and "non-*velifer* caves" (n = 30) caves.

	"*velifer* caves"			"non-*velifer* caves"			Chi-square	Probability
	Mean	SD	Range	Mean	SD	Range		
Temperature (˚C)	21.6	2.4	17.2 – 28.6	21.7	2.1	19.4 – 28.6	0.003	0.961
Humidity (%)	76	11	53 - 92	85	8	51 - 95	13.805	< 0.001

FIGURES



A. Airmans Cave
B. Barker Bat Cave
C. Barker Ranch Cave No. 1
D. Barker Ranch Cave No. 2
E. Beck Ranch Cave
F. Blacktail Cave
G. Bone Pile Cave
H. Cave X
I. Cicurina Cave
J. County Line Bat Cave
K. Critchfield Bat Cave
L. Dynamite Cave
M. Get Down Cave
N. Goat Cave
O. Gorman Cave
P. Government Canyon Bat Cave
Q. Hays Ranch Bat Cave
R. Hidden Pool Cave
S. Jeanette's Cave
T. Lemons Ranch Cave
U. Lithic Ridge Cave
V. Lost Chasm Cave
W. McCarty Cave
X. McDonalds Cave
Y. Robber Baron Cave
Z. Saltpeter Cave
AA. Sevenmile Mountain Cave
AB. Spring Creek Cave
AC. Stowers Cave
AD. Sunspot Cave
AE. Surprise Sink Cave
AF. Taylor Bat Cave
AG. Testudo Tube
AH. Turtle Shell Cave

Figure 1. Names and locations of caves included in this study

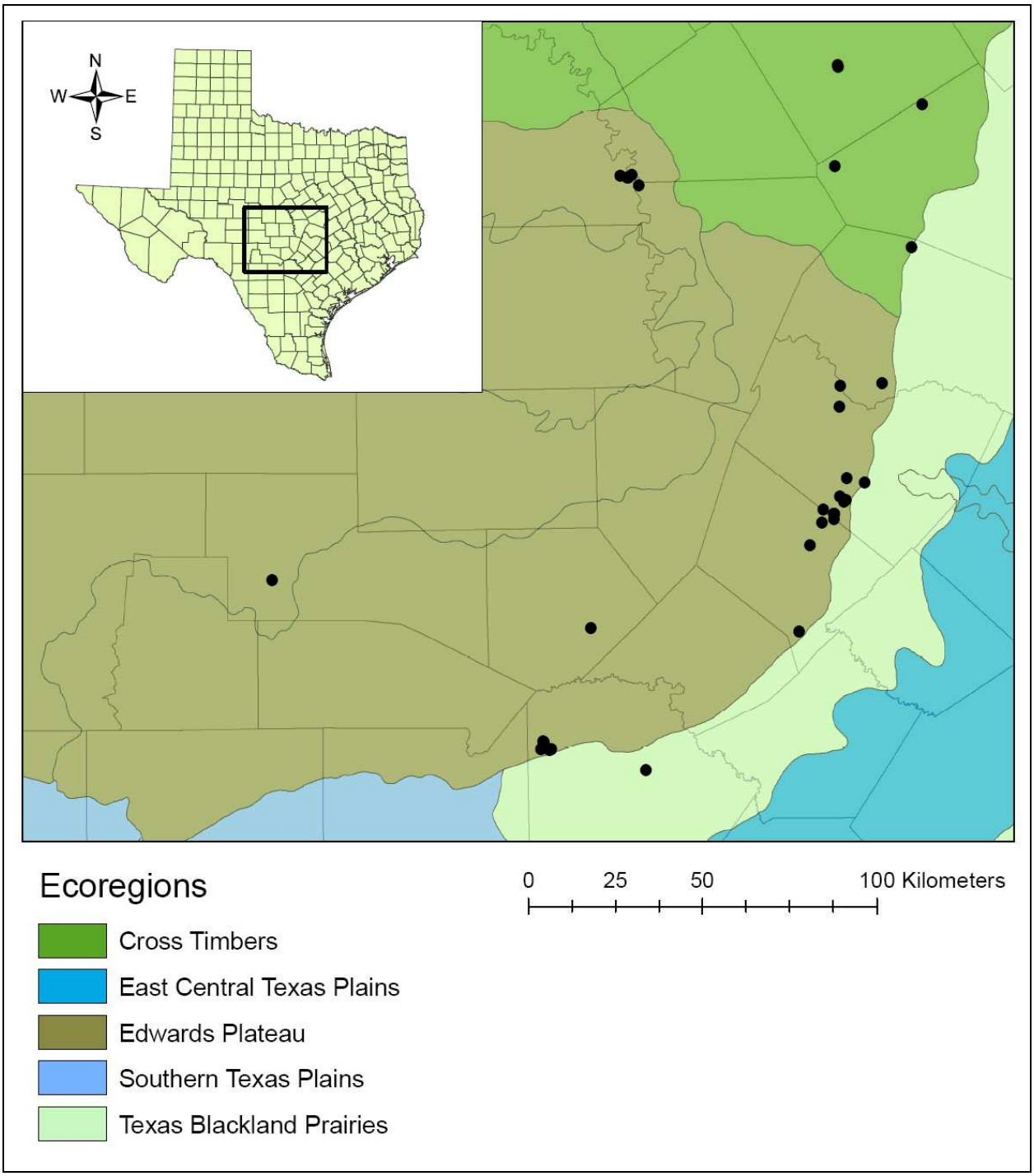


Figure 2. Ecoregions in which study caves are located

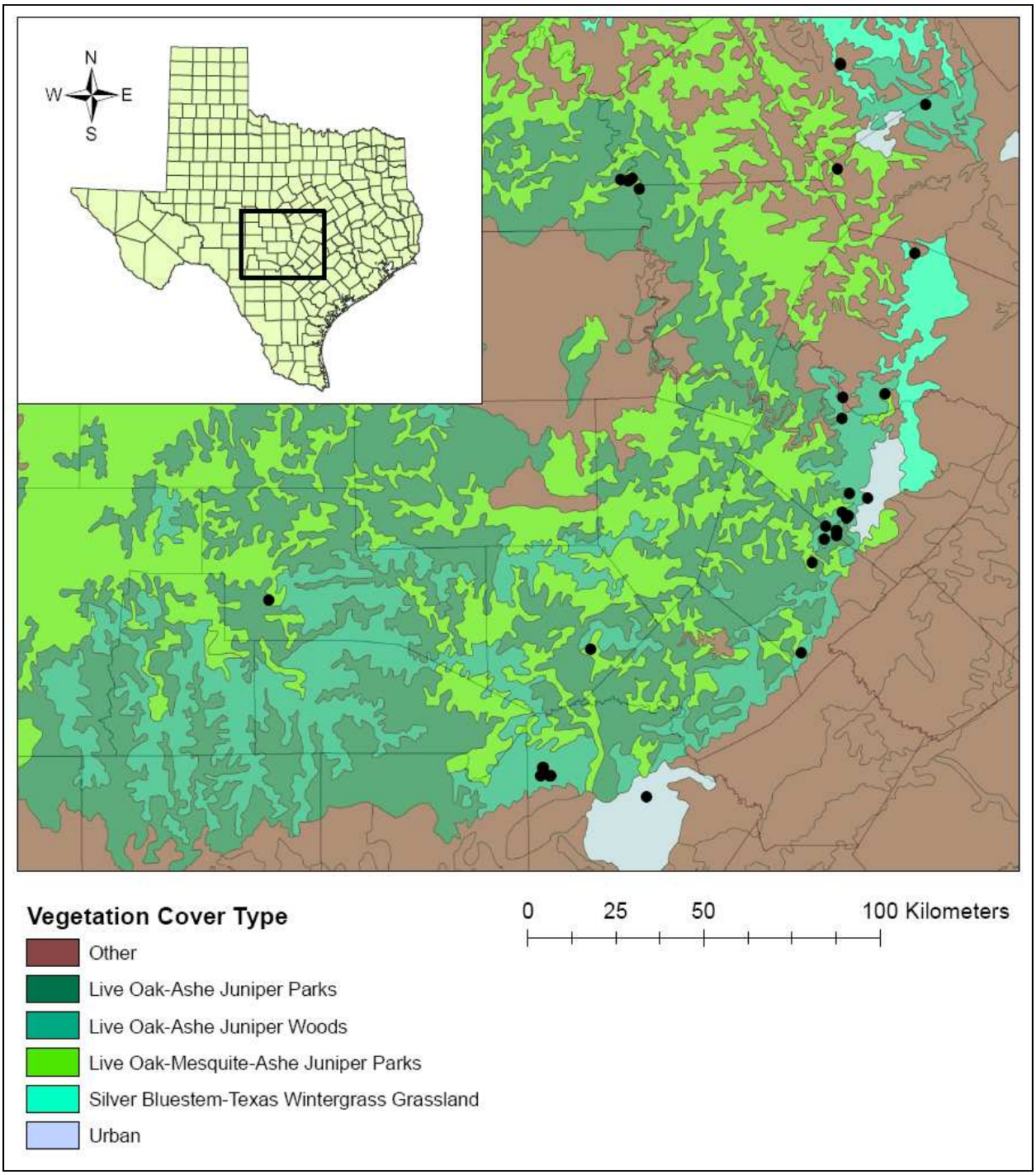


Figure 3. Vegetation cover types in which study caves are located



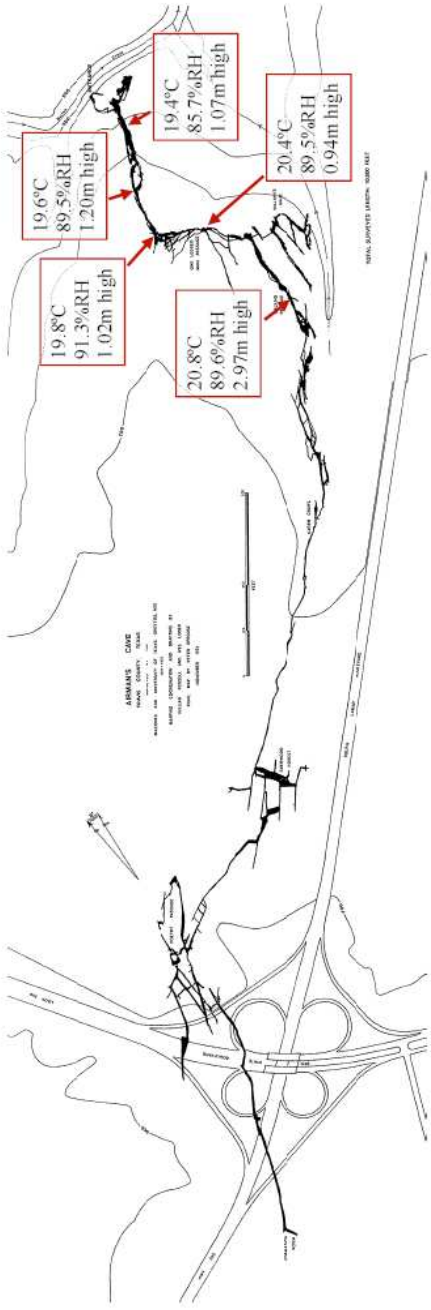
Figure 4. An example of well-defined roost stain from Gorman Cave, San Saba County, Texas (see Appendix). The approximate size of the roost is 15m^2. *Photo by Sofia Angelo*



Figure 5. An example of a *Myotis velifer* colony with roost stain from Stowers Cave, Kerr County, Texas (see Appendix). *Photo by Jim Kennedy*

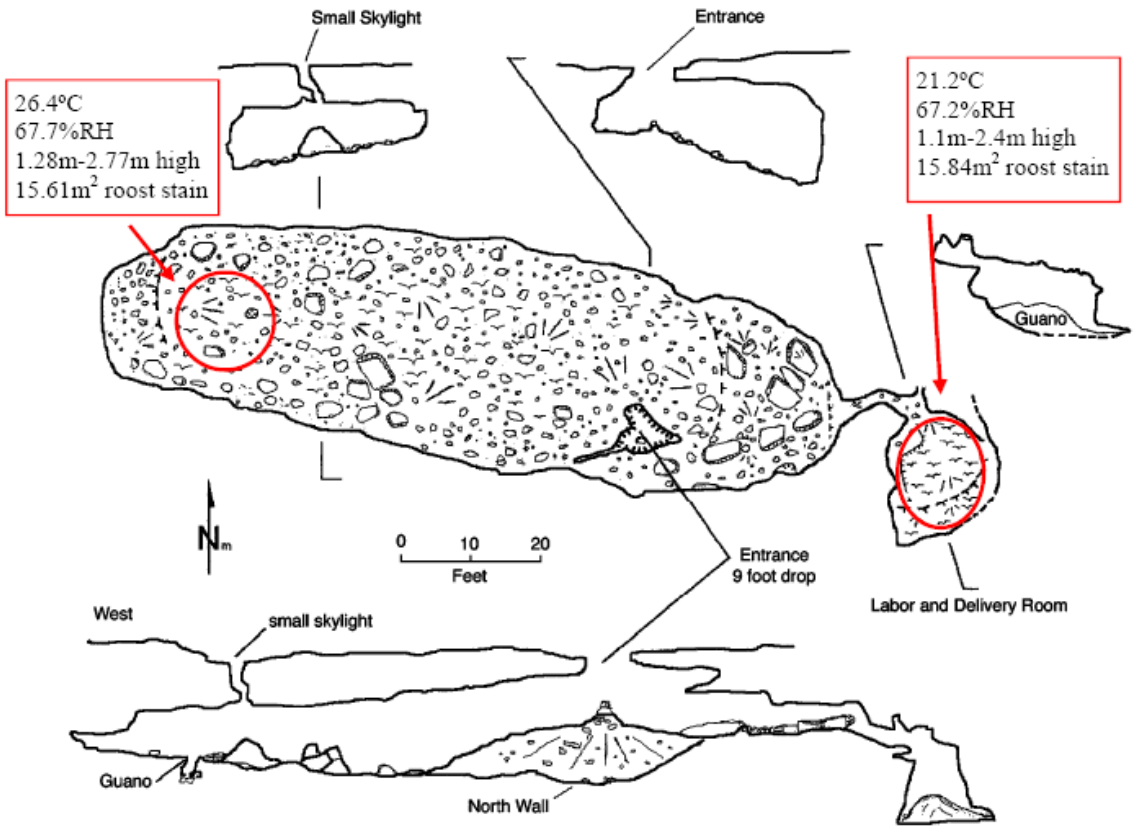
APPENDIX A

Airmans Cave, Travis County – No Bats/Roost Stain



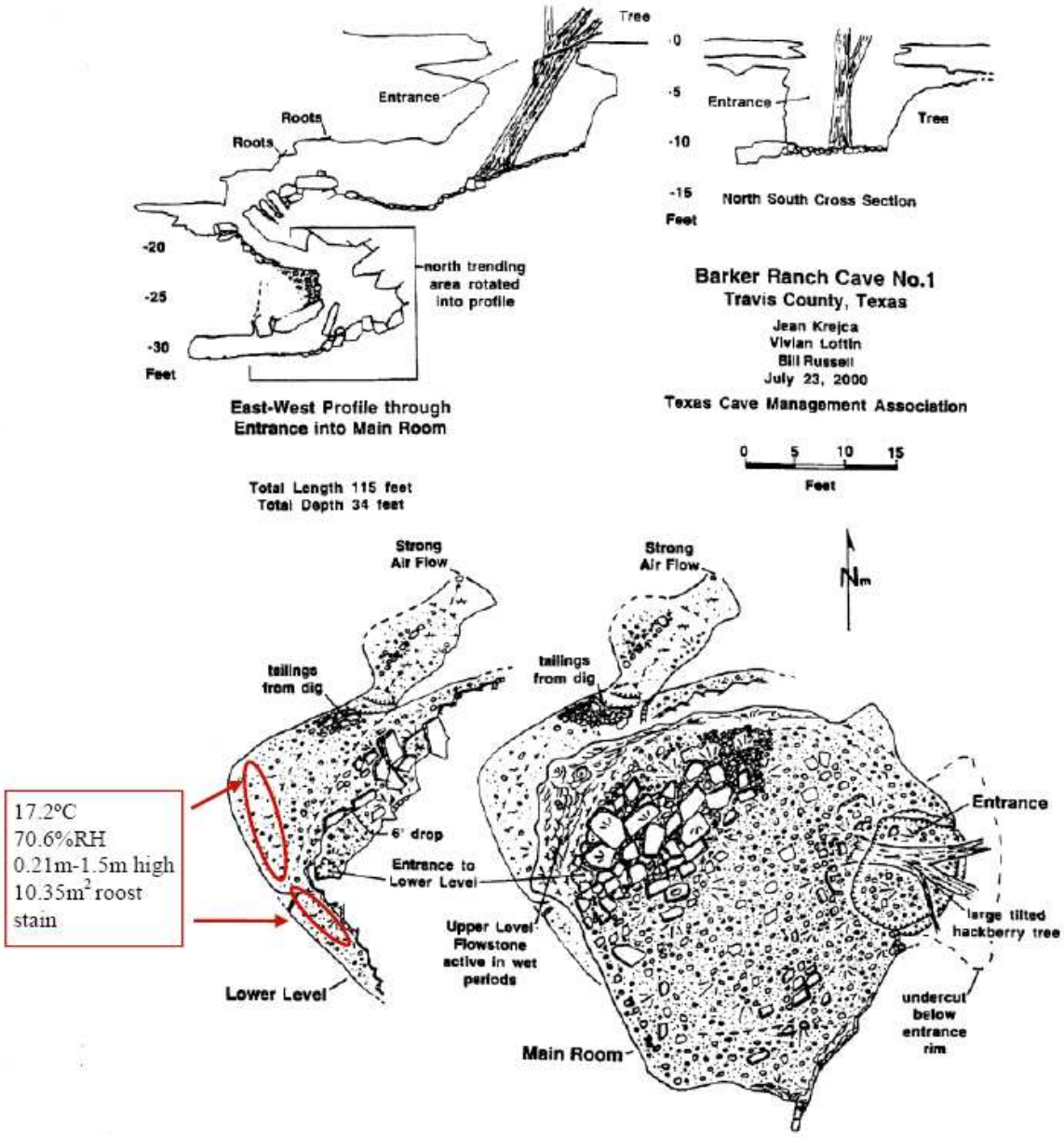
Note: The entire cave was not surveyed do to time constraints.

Barker Bat Cave, Travis County – Roost Stain Present

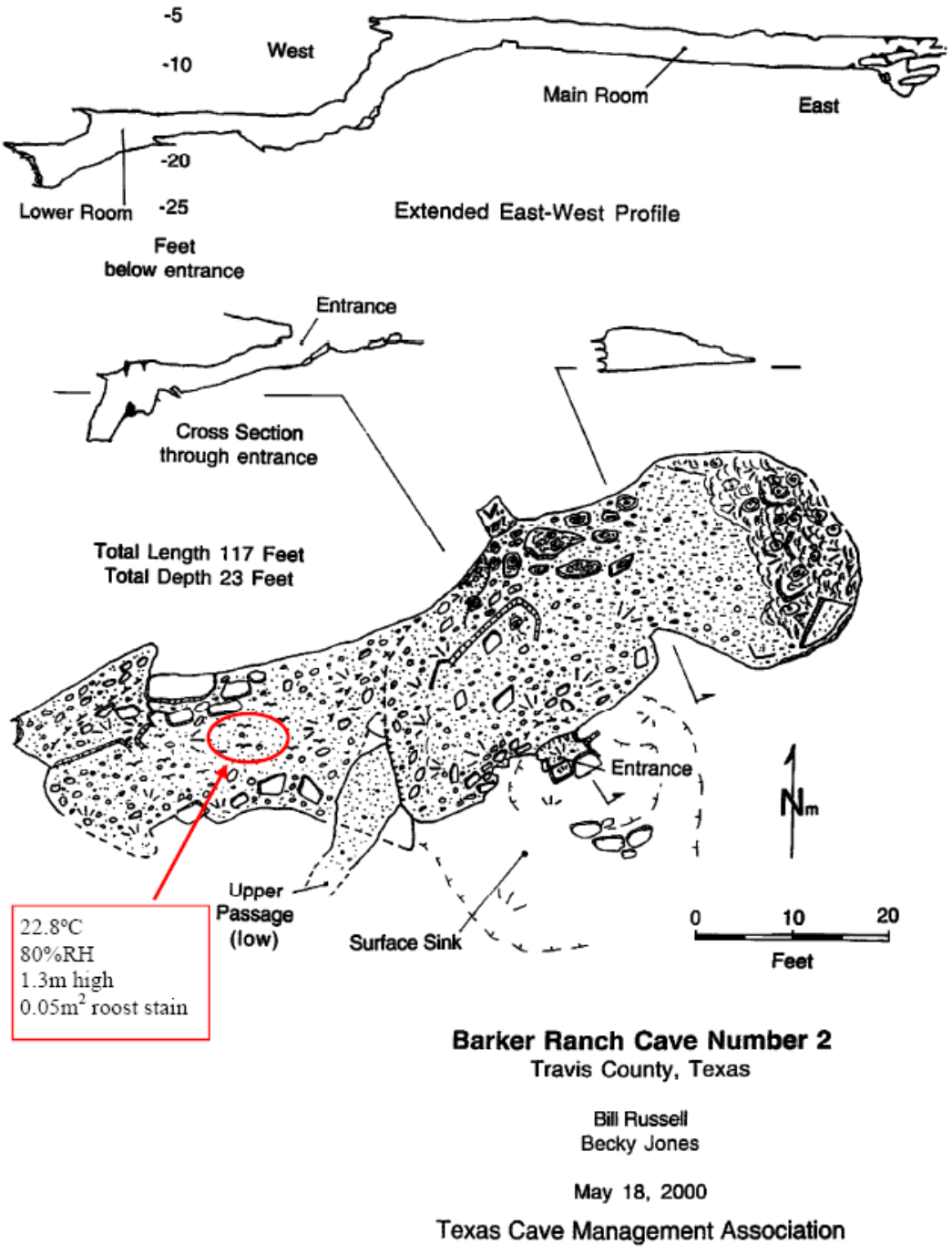


Barker Bat Cave
Travis County, Texas
(Main Room Survey)
James Green, John McDowell, Bill Russell
April 8, 1984
(Labor and Delivery Room Survey)
Bill Russell, Julie Jenkins
January 09, 2004
Texas Cave Management Association

Barker Ranch Cave No. 1, Travis County – Roost Stain Present

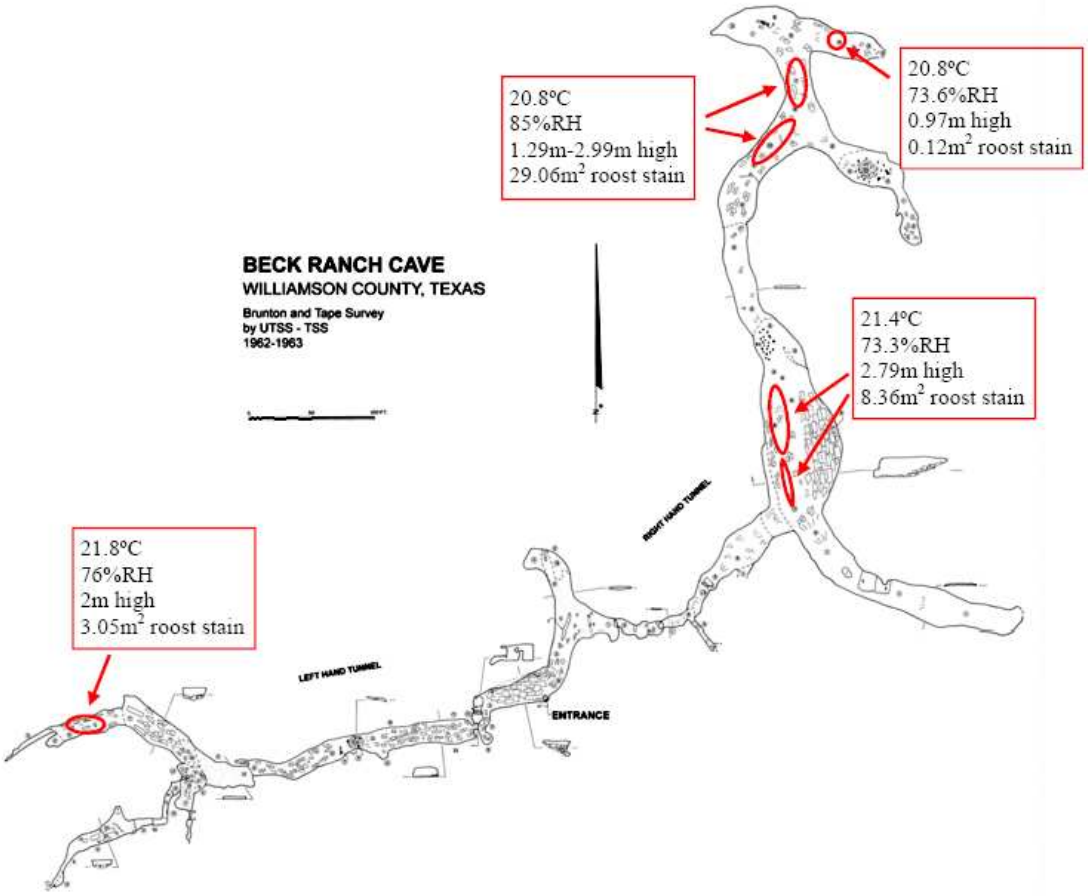


Barker Ranch Cave No. 2, Travis County – Roost Stain Present

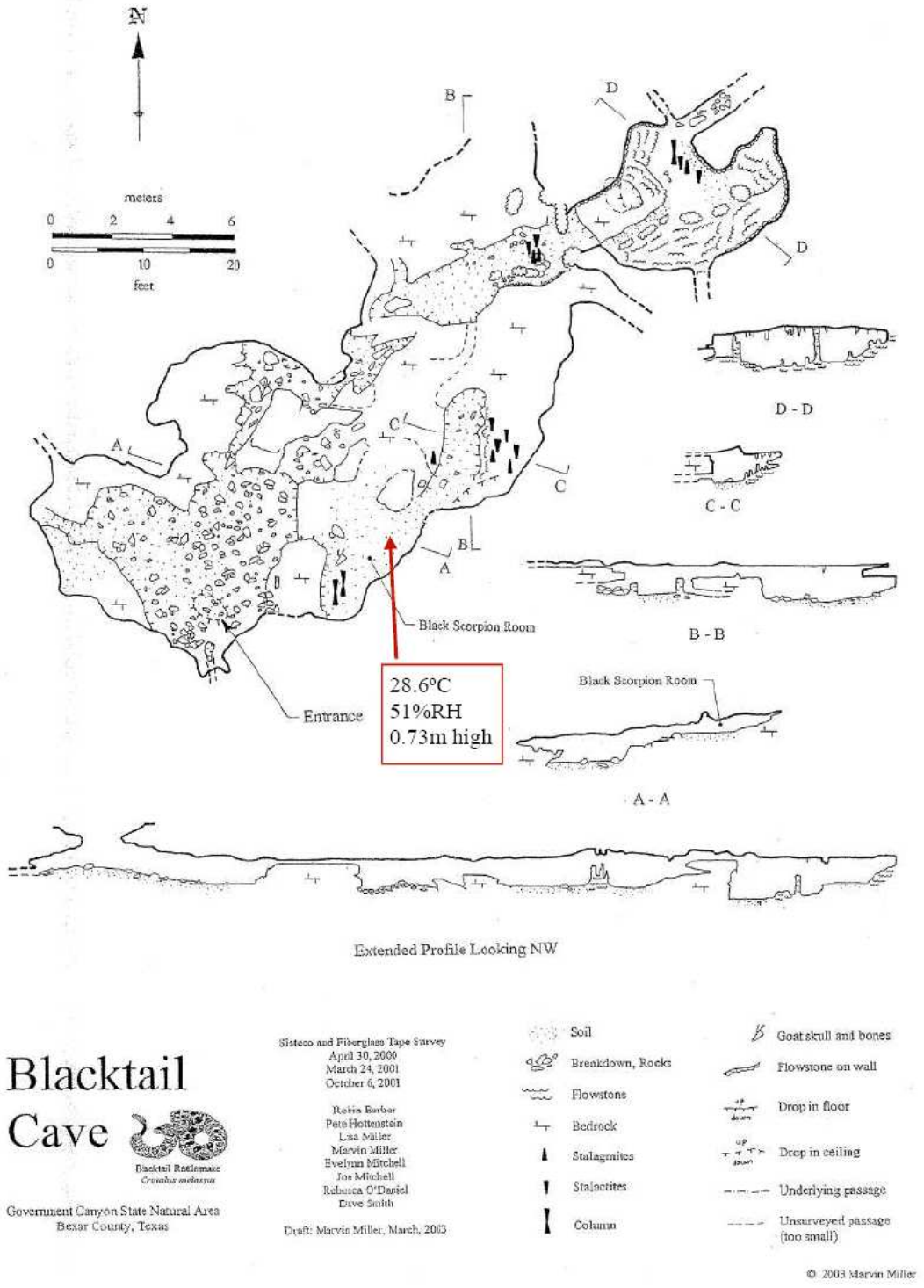


Note: Map was unavailable at the time of visit, roost stain location is based on notes and memory.

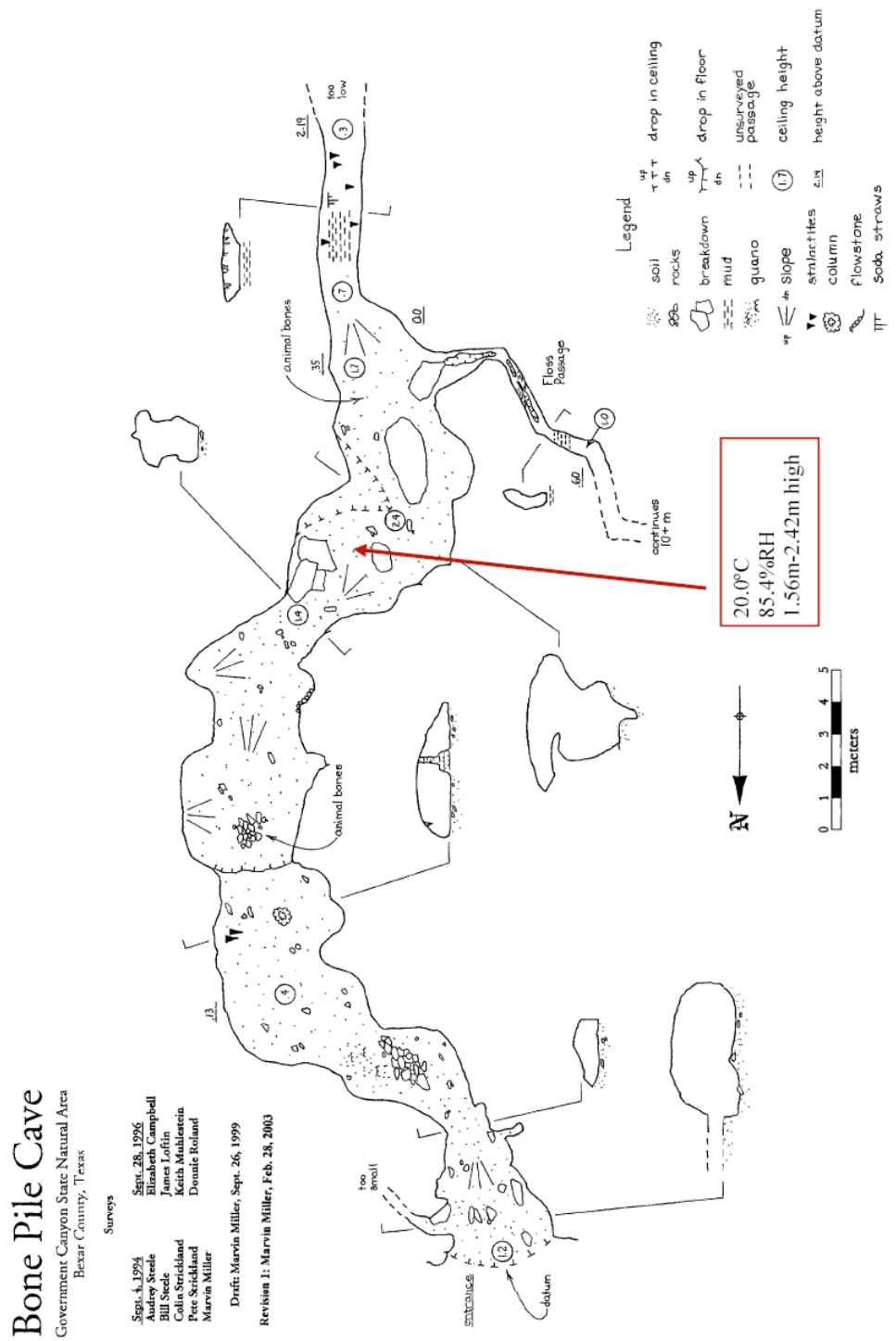
Beck Ranch Cave, Williamson County – Roost Stain Present



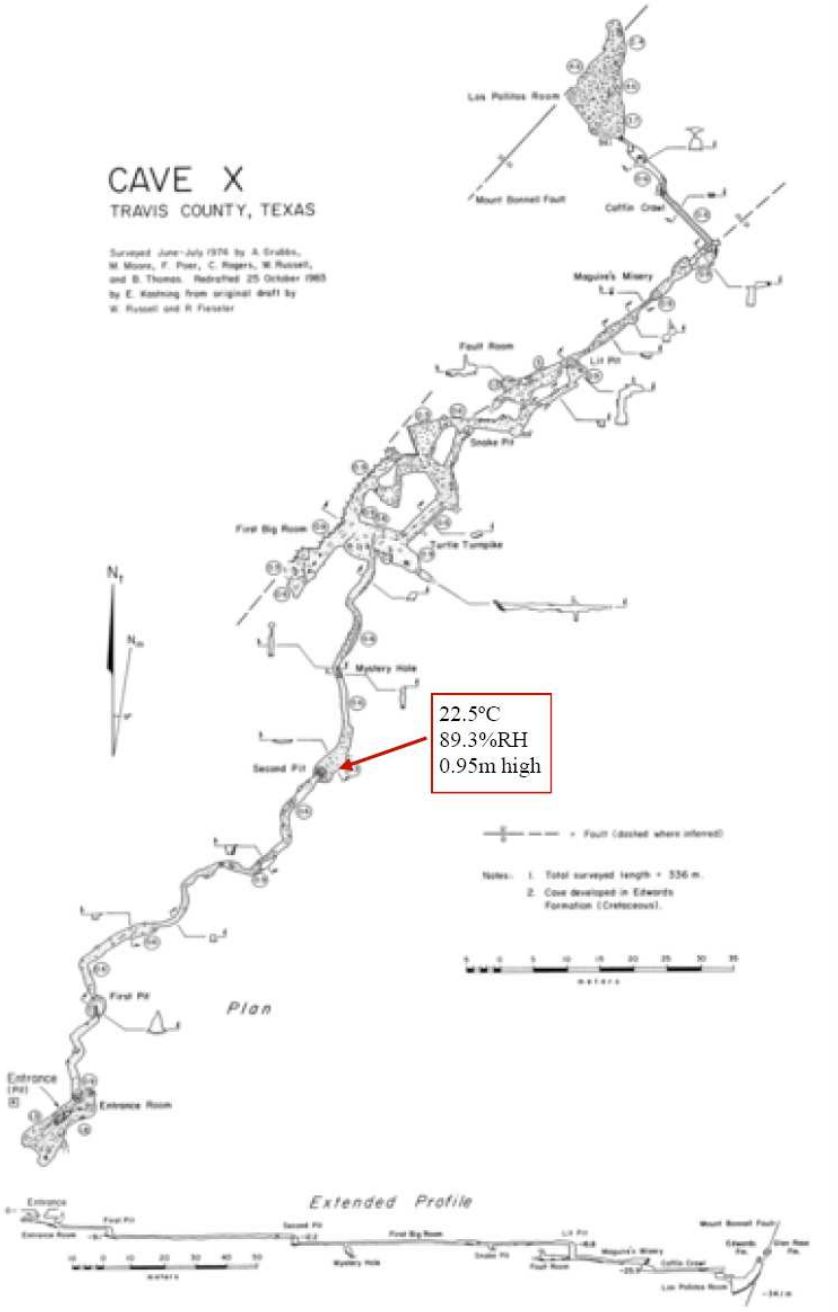
Blacktail Cave, Bexar County – No Bats/Roost Stain



Bone Pile Cave, Bexar County – No Bats/Roost Stain

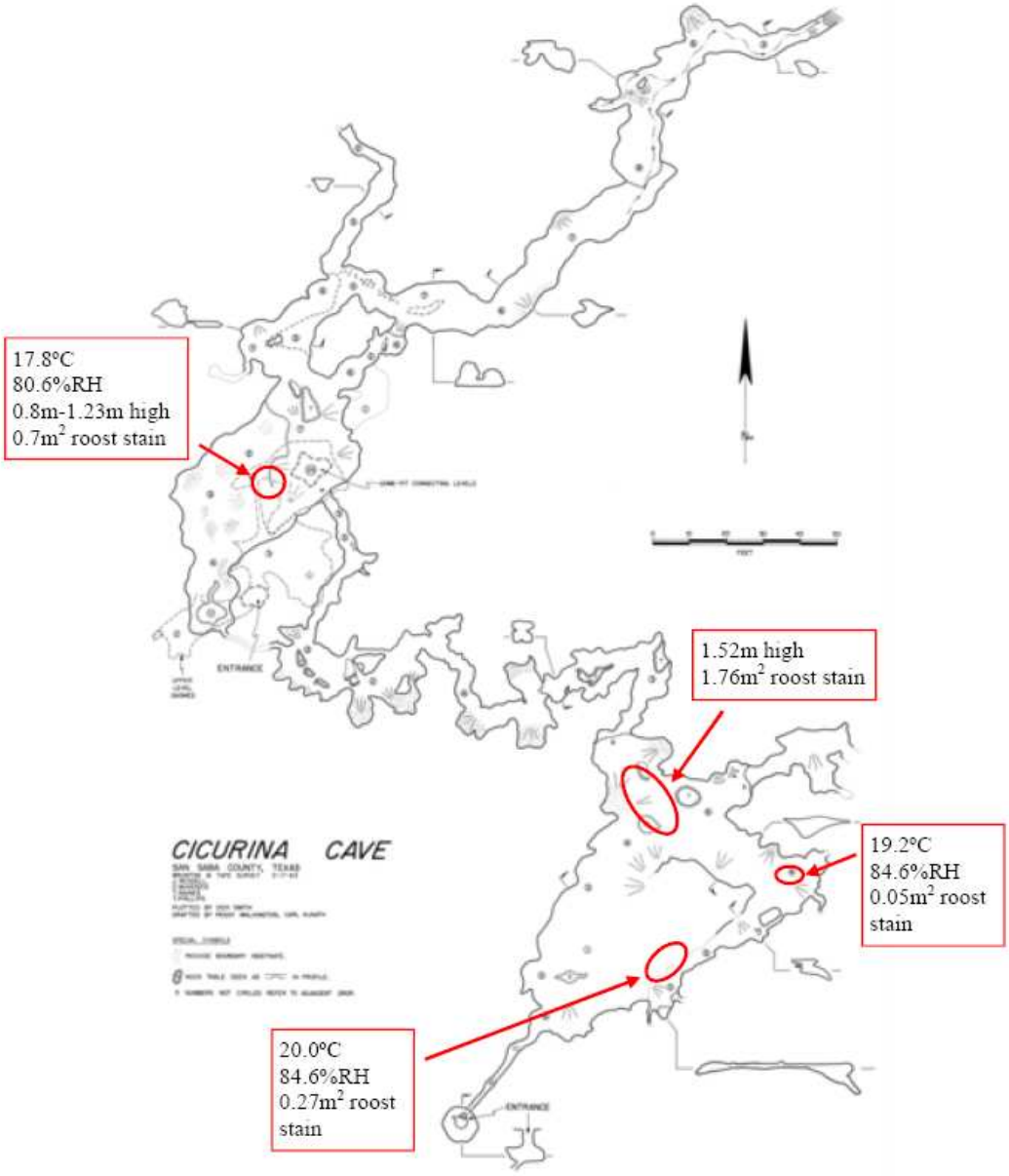


Cave X, Travis County – No Bats/Roost Stain

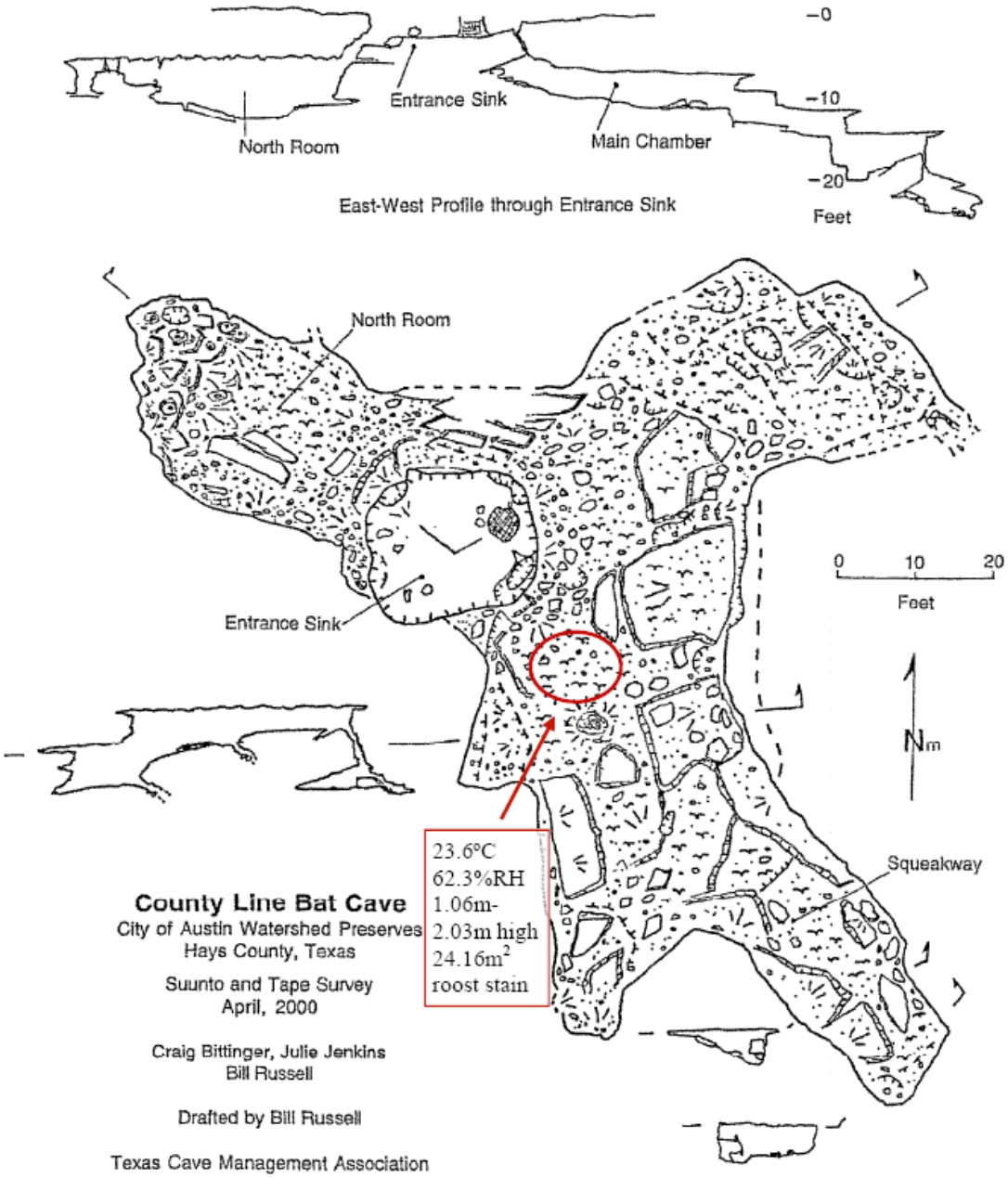


Note: The entire cave was not surveyed due to water in lower passages.

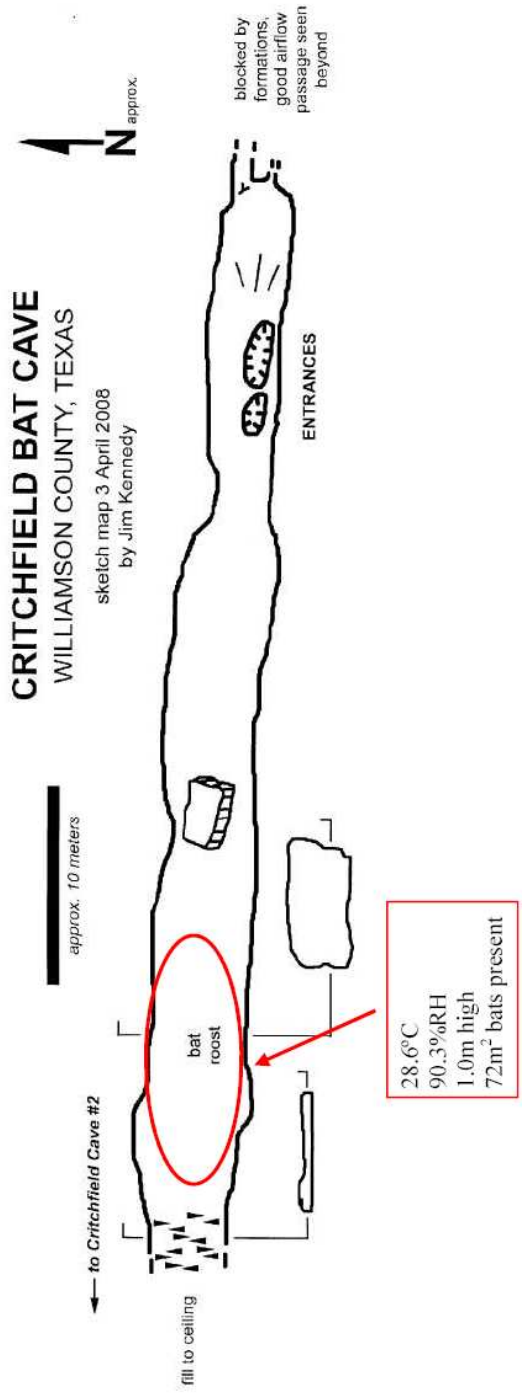
Cicurina Cave, San Saba County – Roost Stain Present



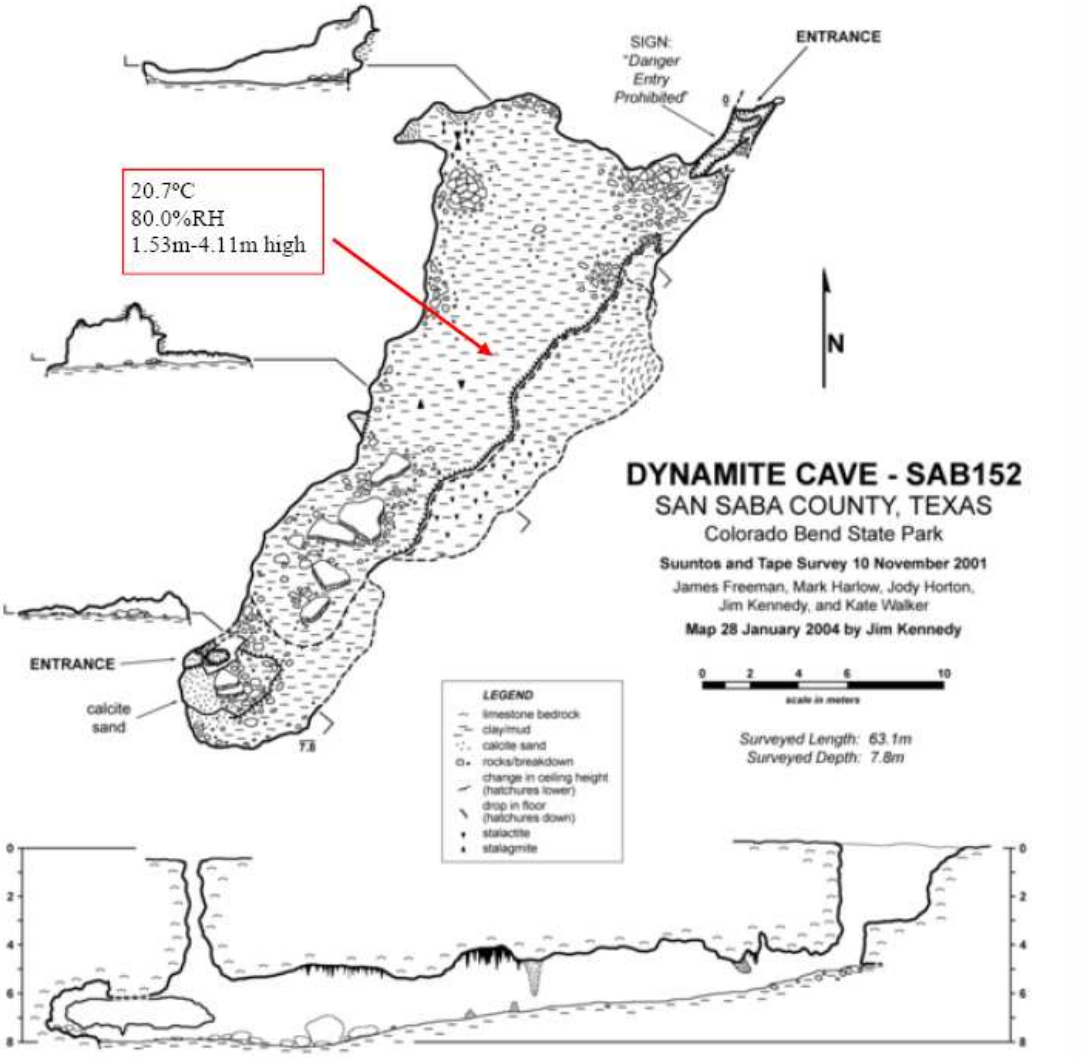
County Line Bat Cave, Hays County – Roost Stain Present



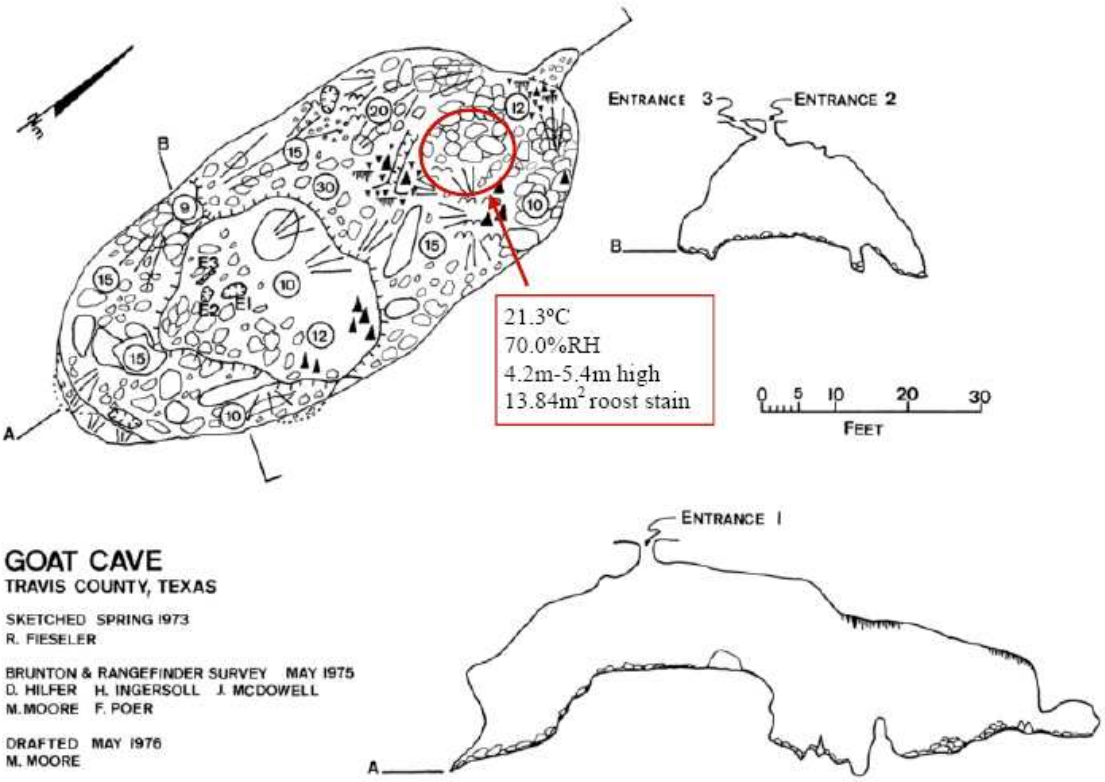
Critchfield Bat Cave, Williamson County – Bats Present



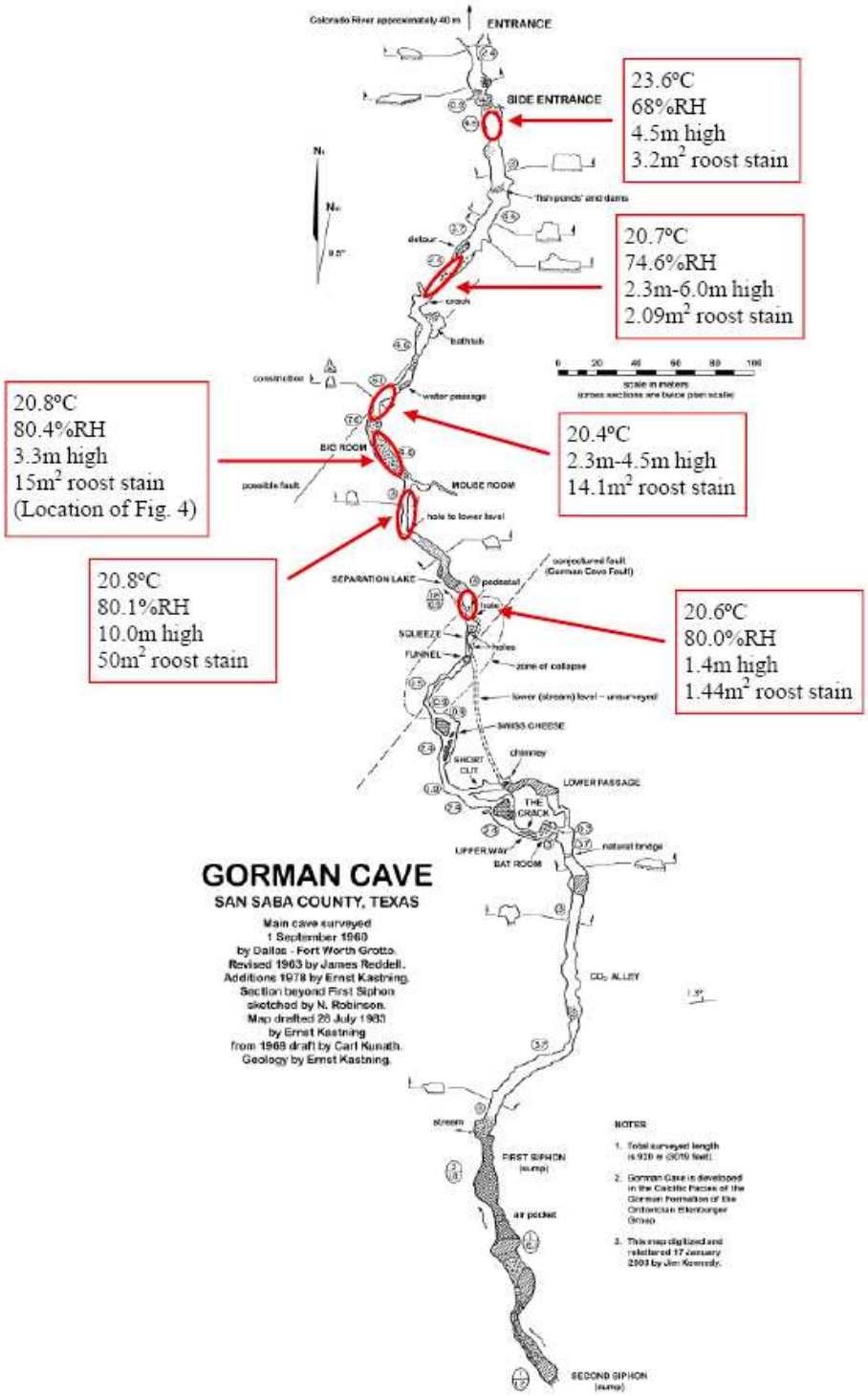
Dynamite Cave, San Saba County – No Bats/Roost Stain



Goat Cave, Travis County – Roost Stain Present

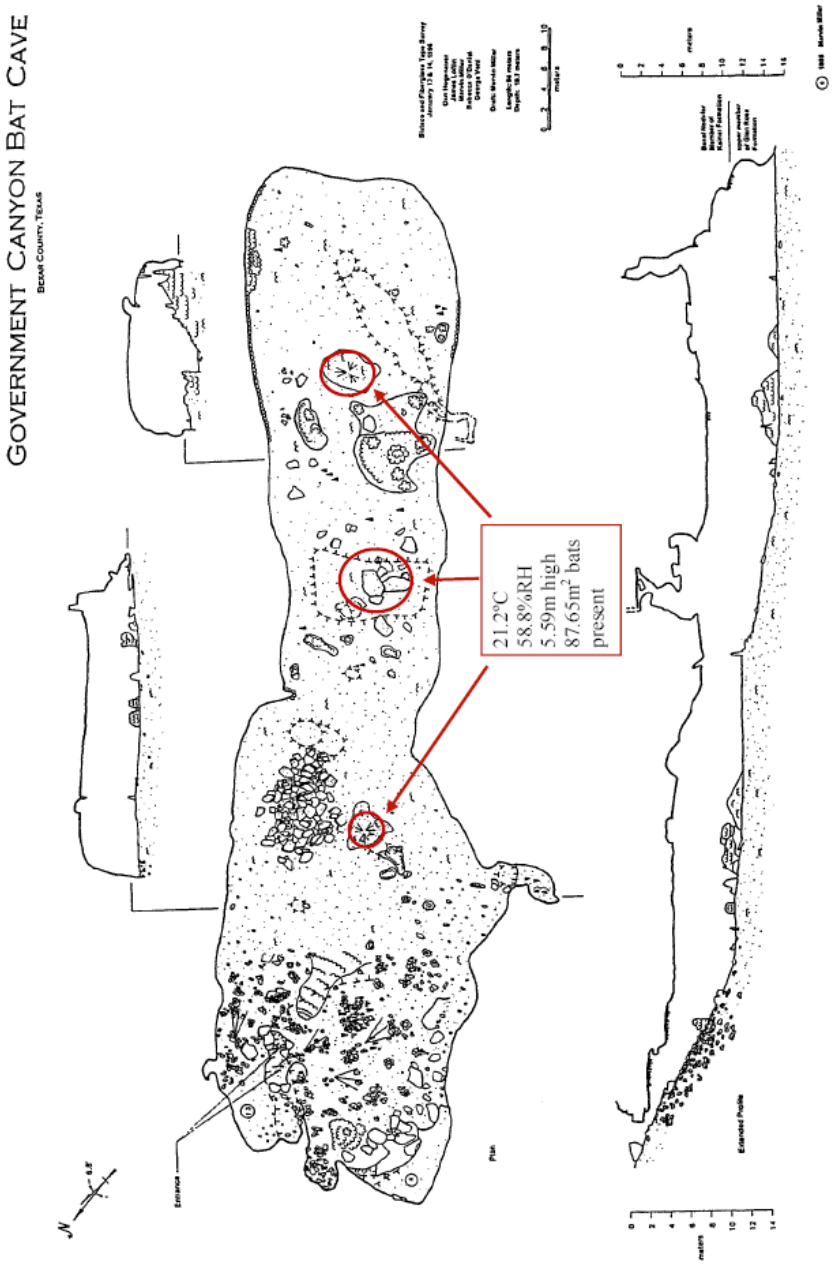


Gorman Cave, San Saba County – Roost Stain Present

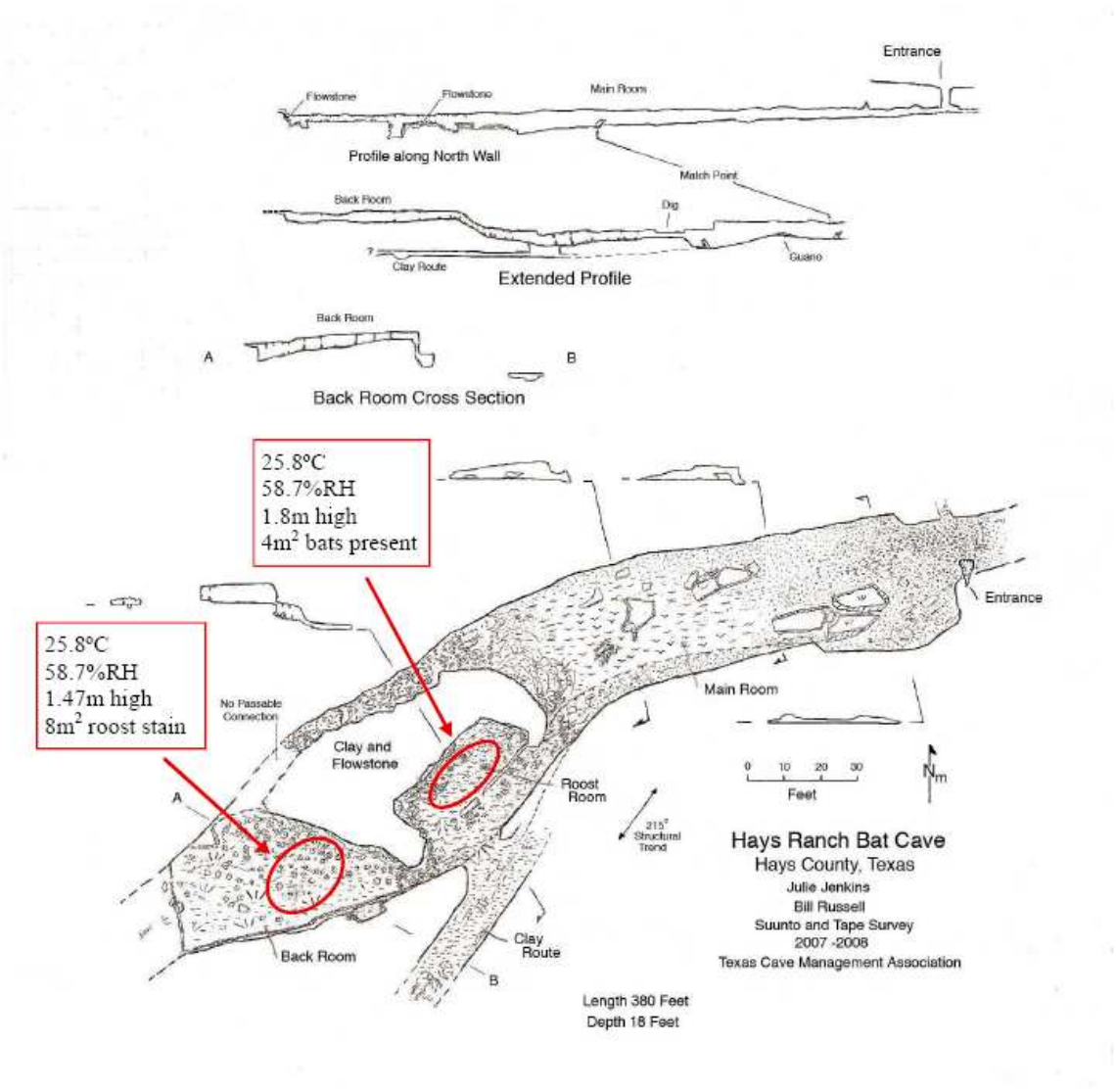


Note: The entire cave was not surveyed due to bad air.

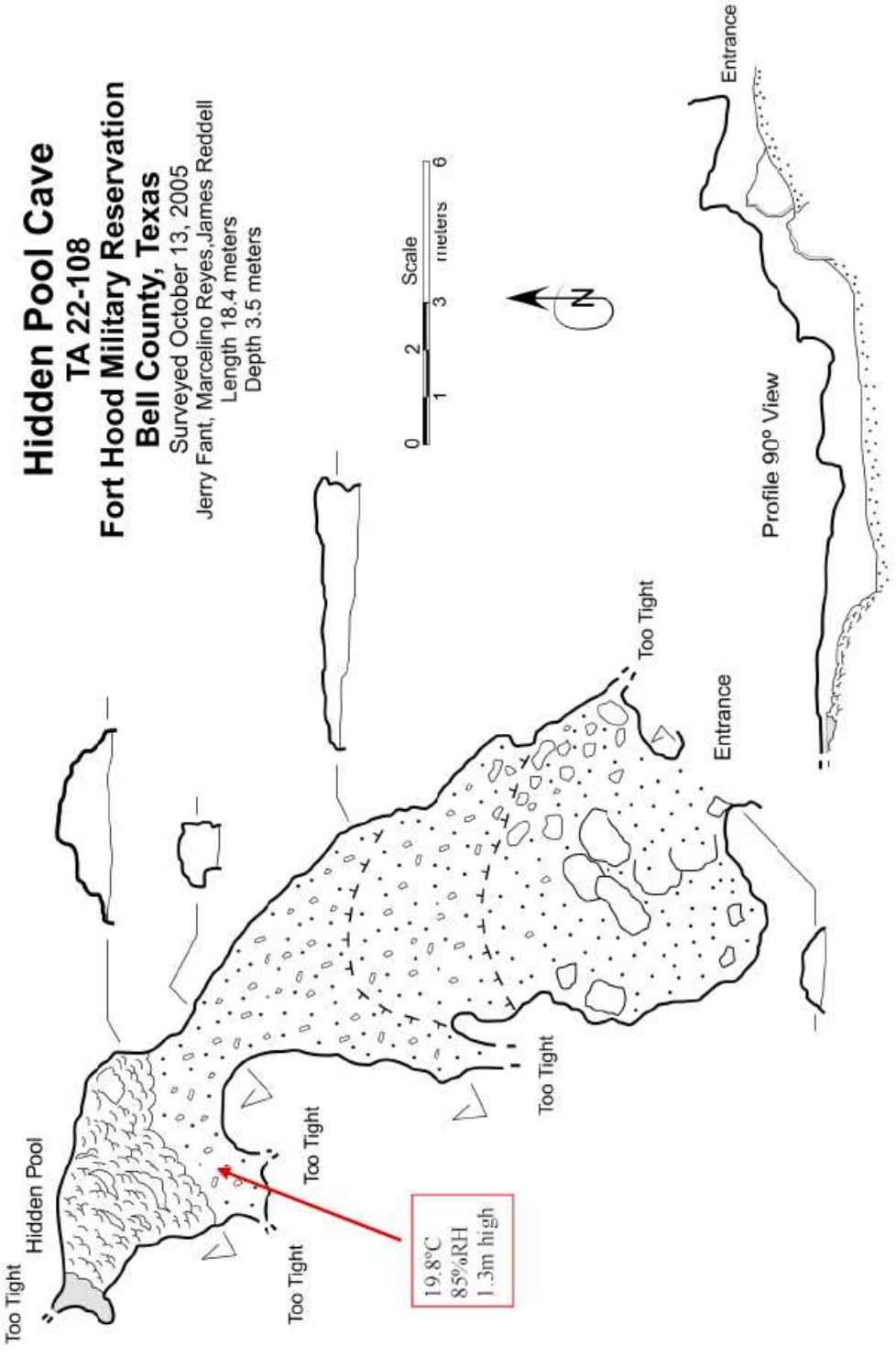
Government Canyon Bat Cave, Bexar County – Bats Present



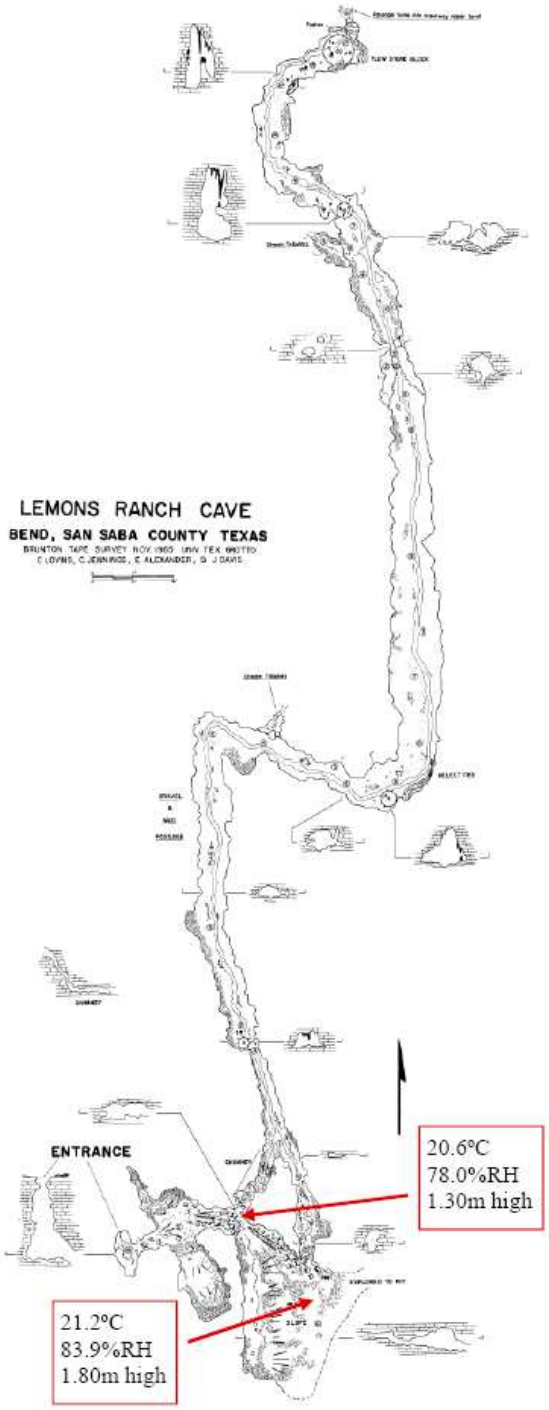
Hays Ranch Bat Cave, Hays County – Bats Present



Hidden Pool Cave, Coryell County – No Bats/Roost Stain

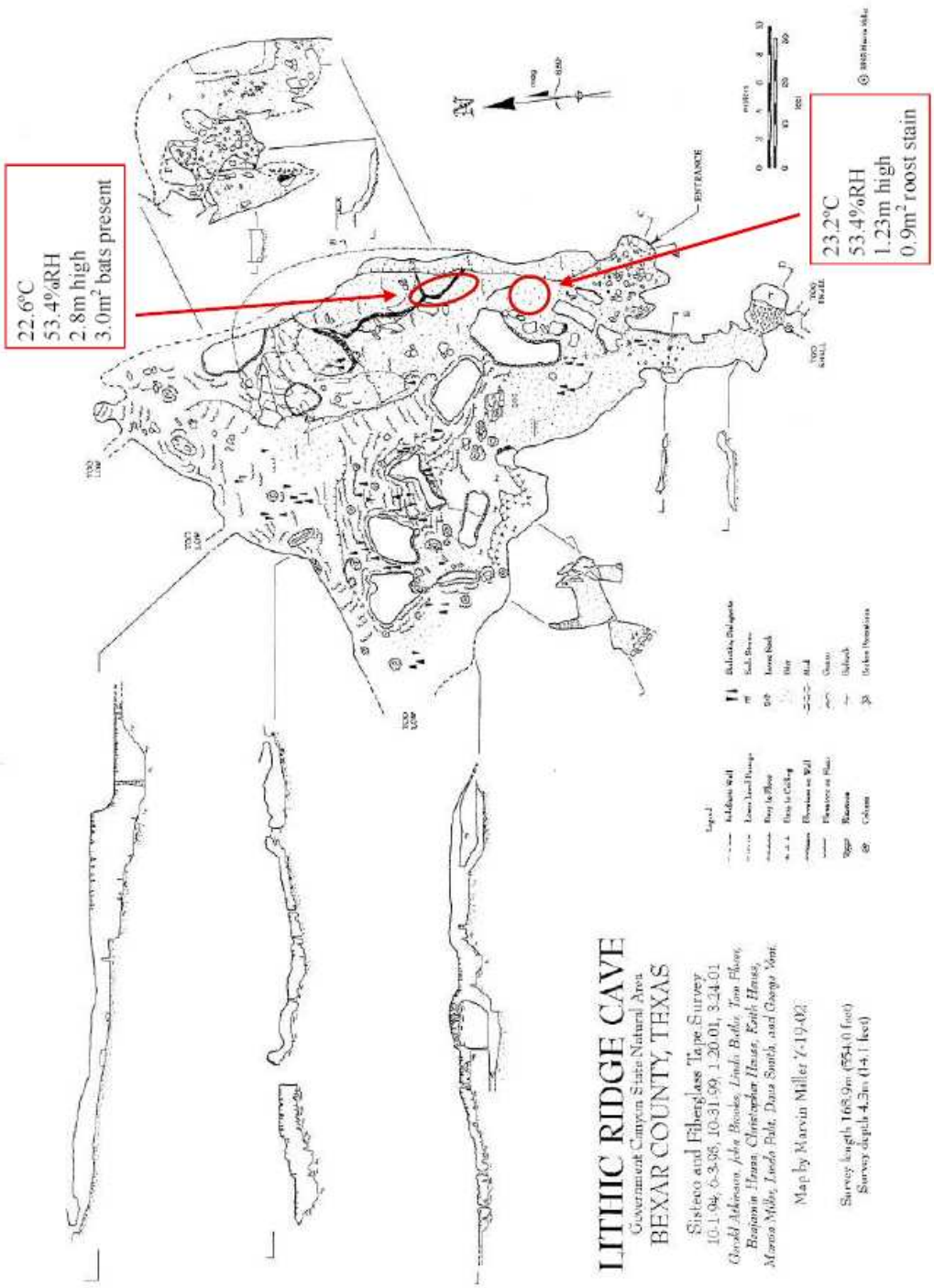


Lemons Ranch Cave, San Saba County – No Bats/Roost Stain

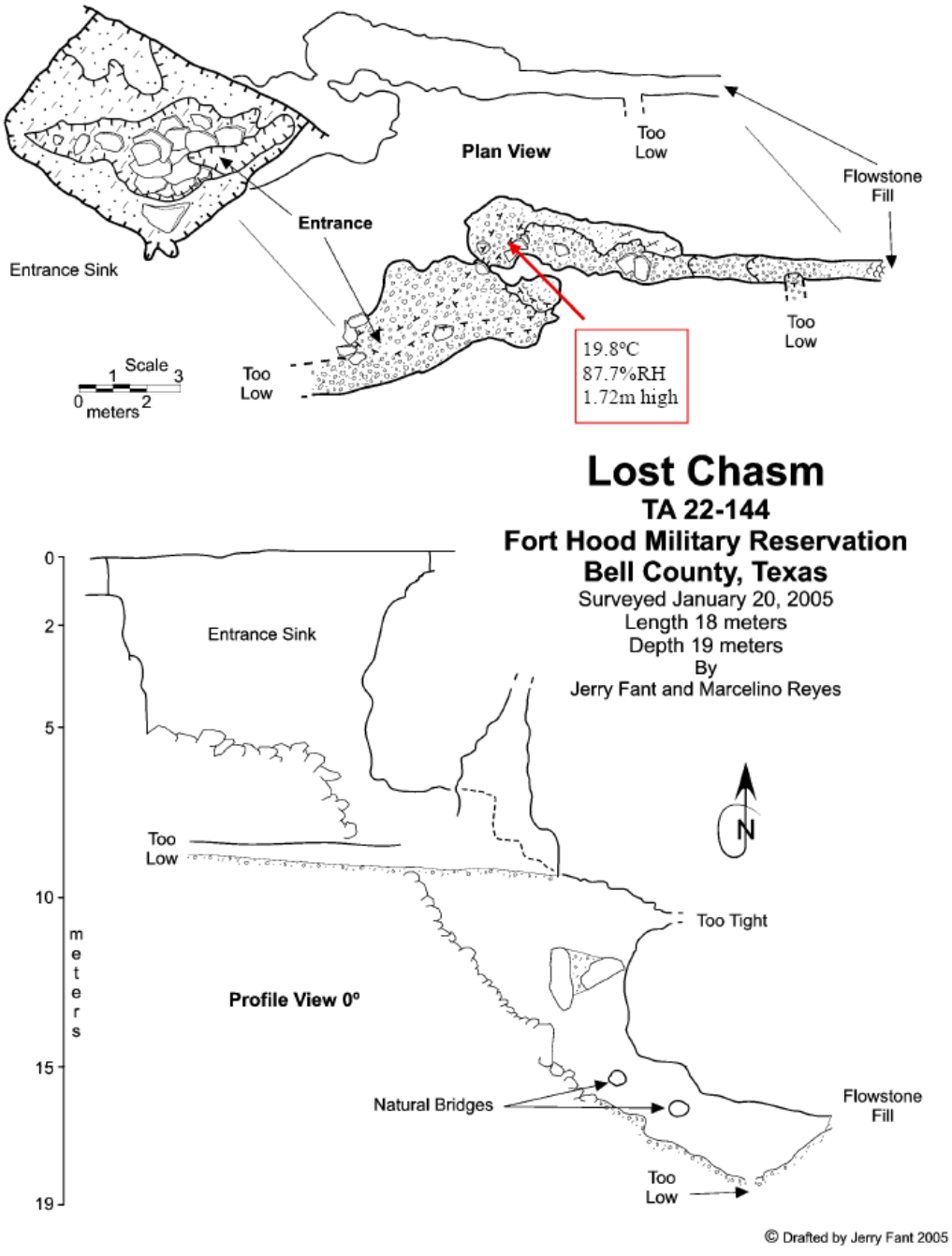


Note: The entire cave was not surveyed due to bad air.

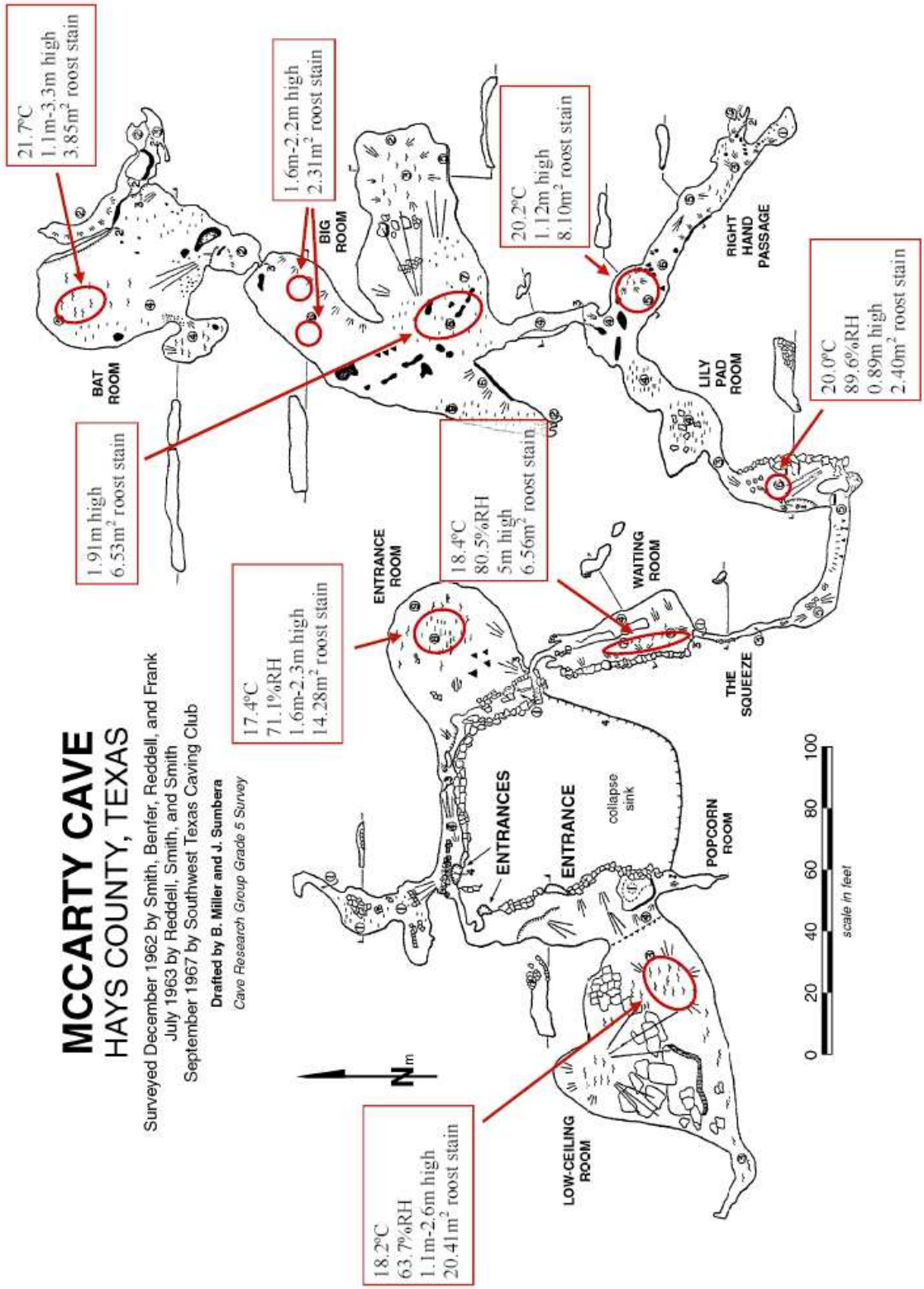
Lithic Ridge Cave, Bexar County – Bats Present



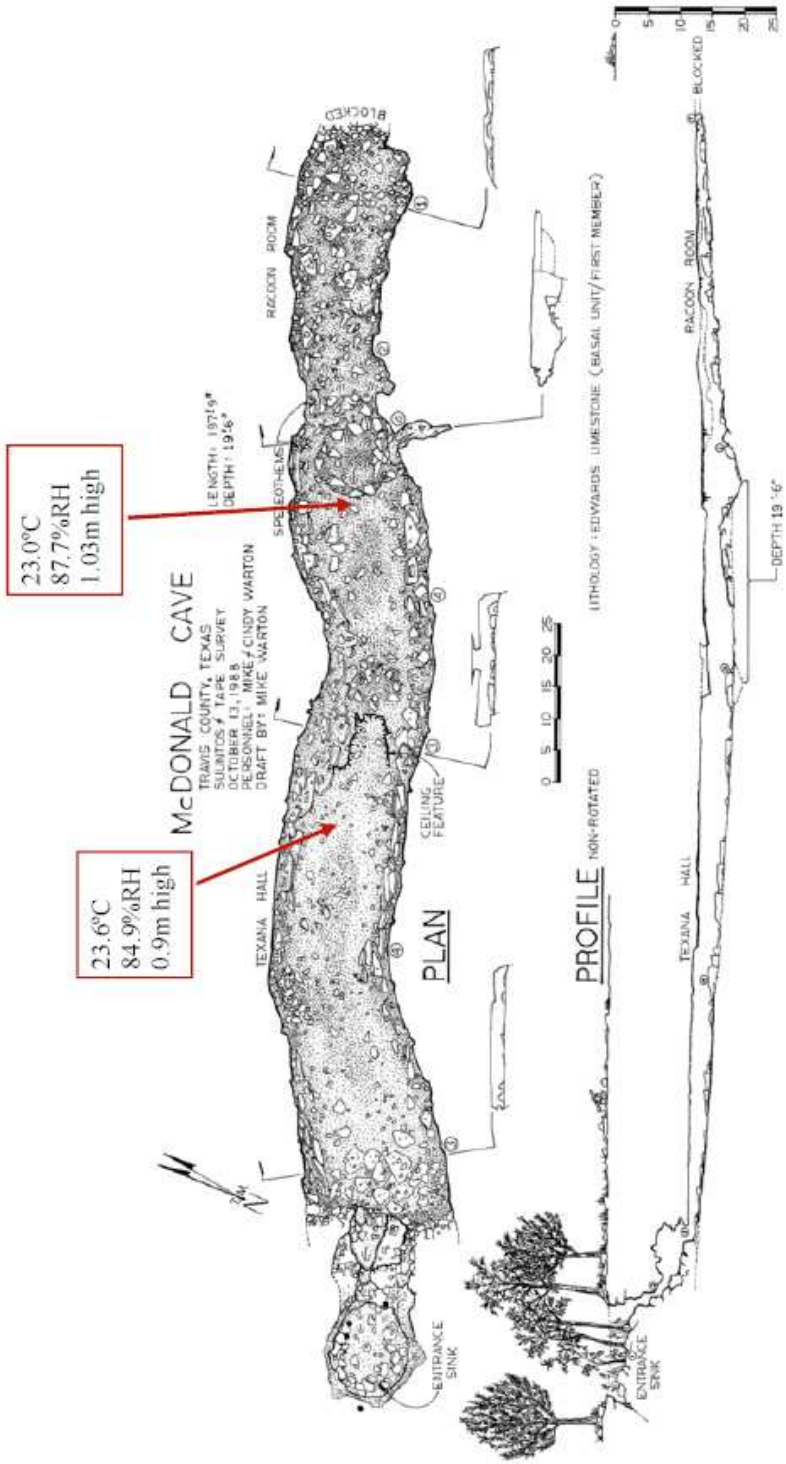
Lost Chasm Cave, Bell County – No Bats/Roost Stain



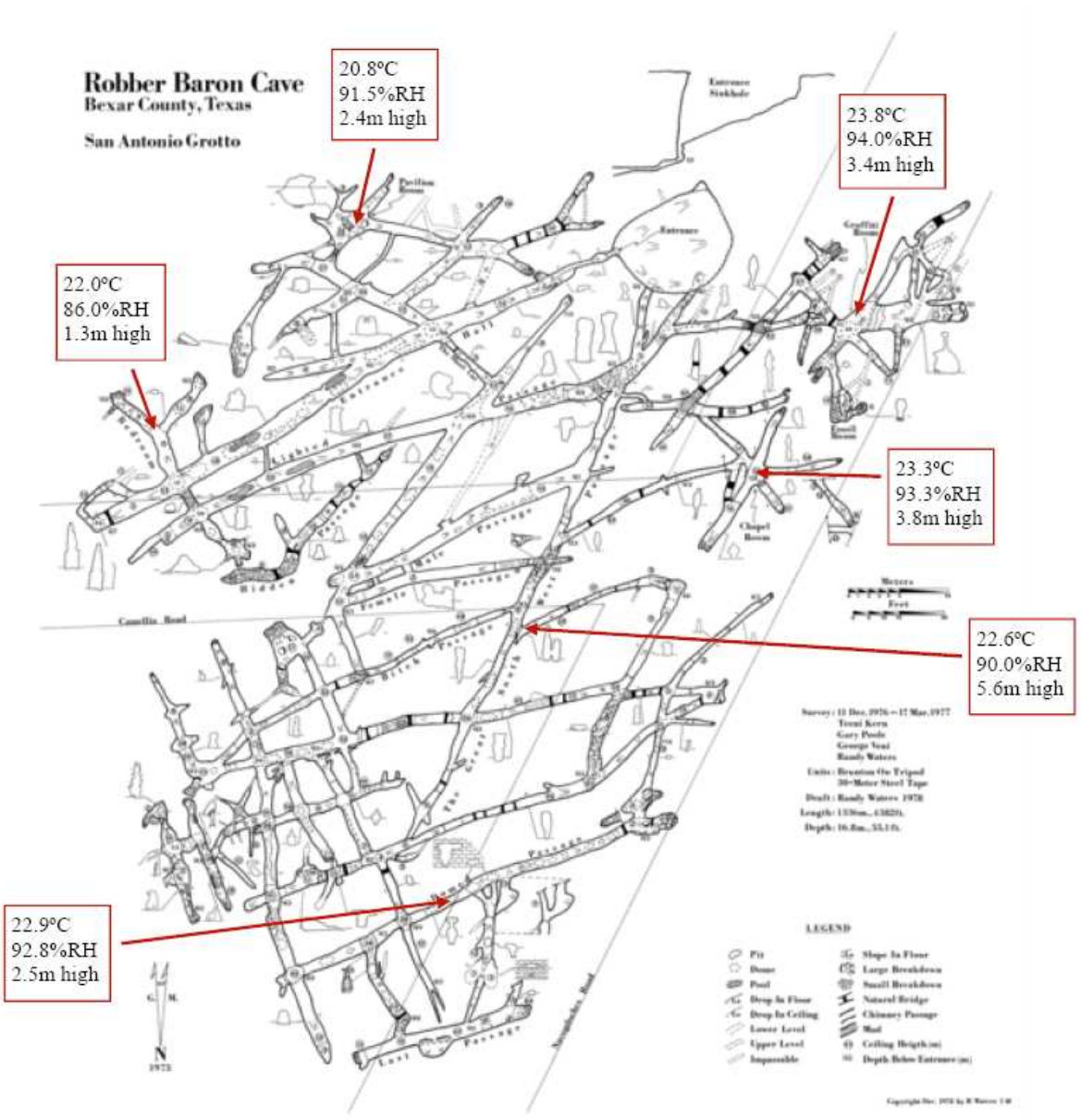
McCarty Cave, Hays County – Roost Stain Present



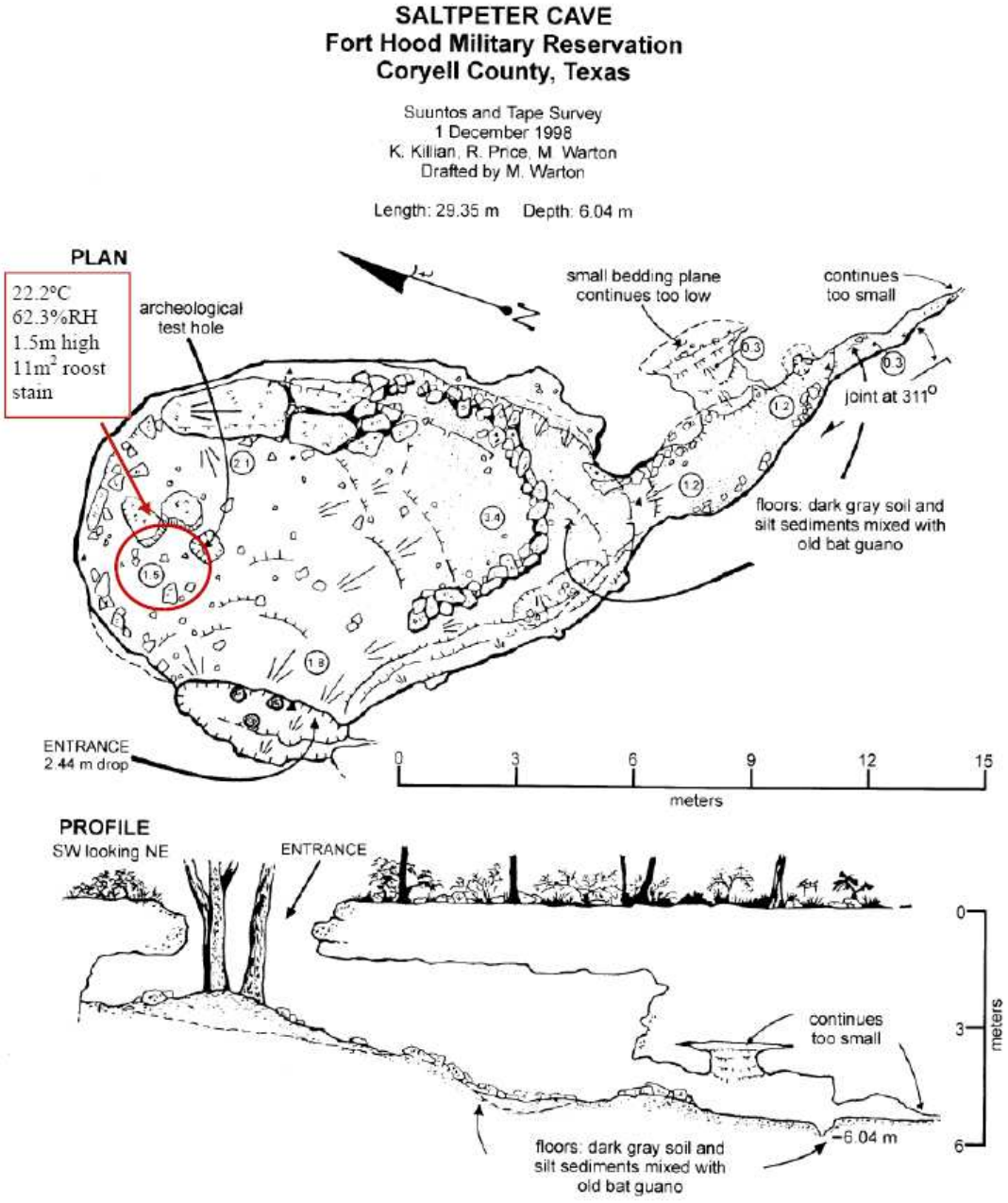
McDonald Cave, Travis County – No Bats/Roost Stain



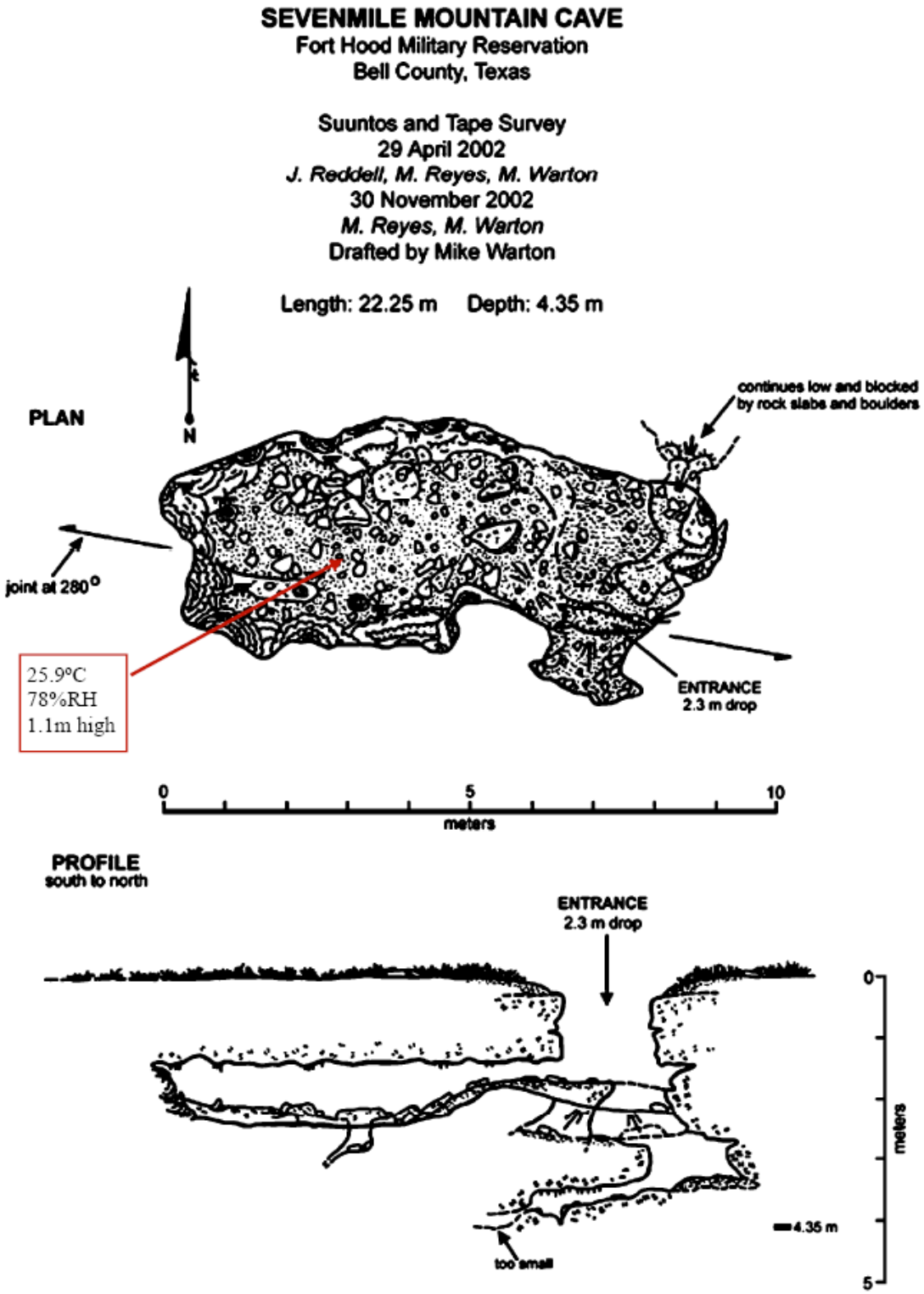
Robber Baron Cave, Bexar County – No Bats/Roost Stain



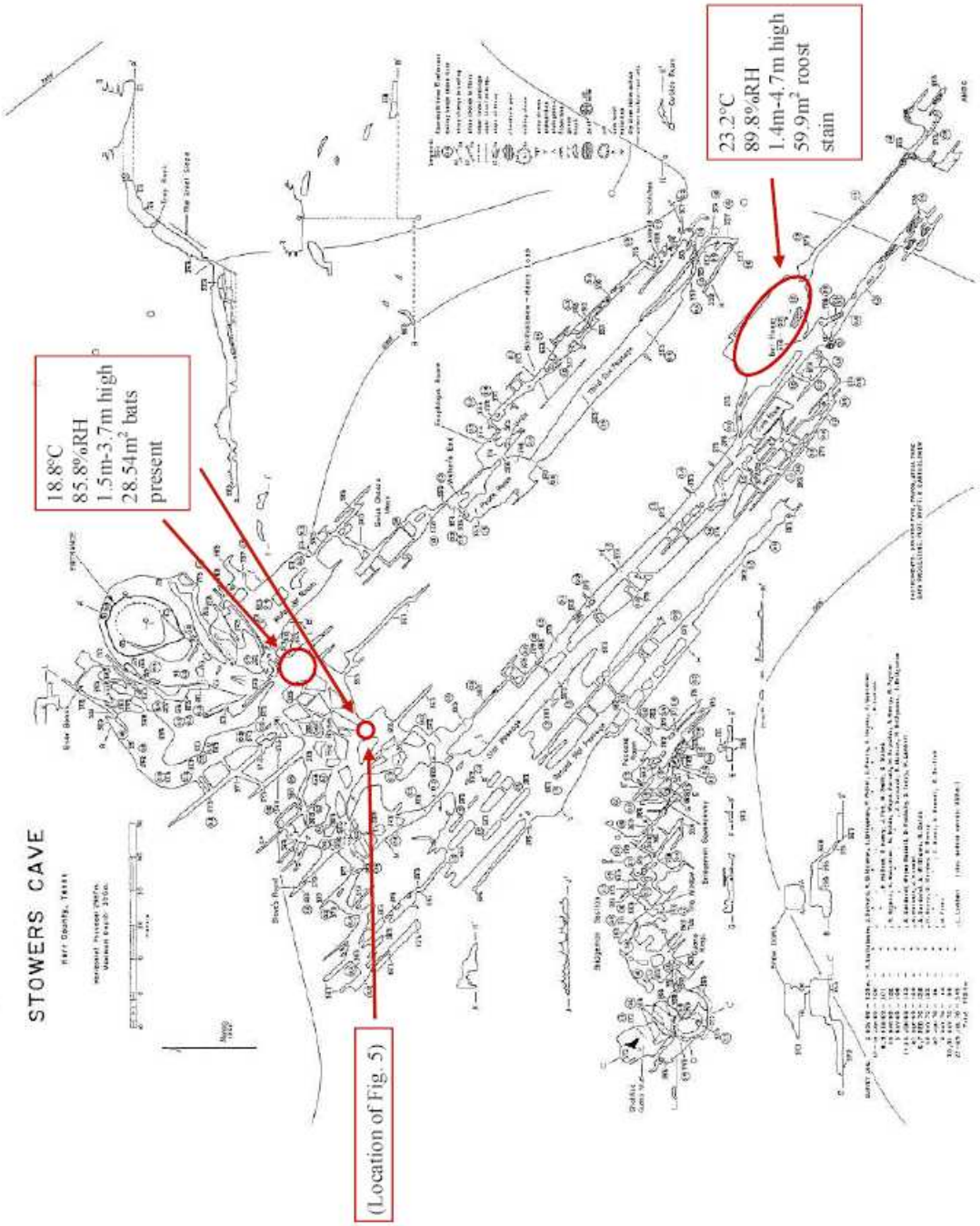
Saltpeter Cave, Coryell County – Roost Stain Present



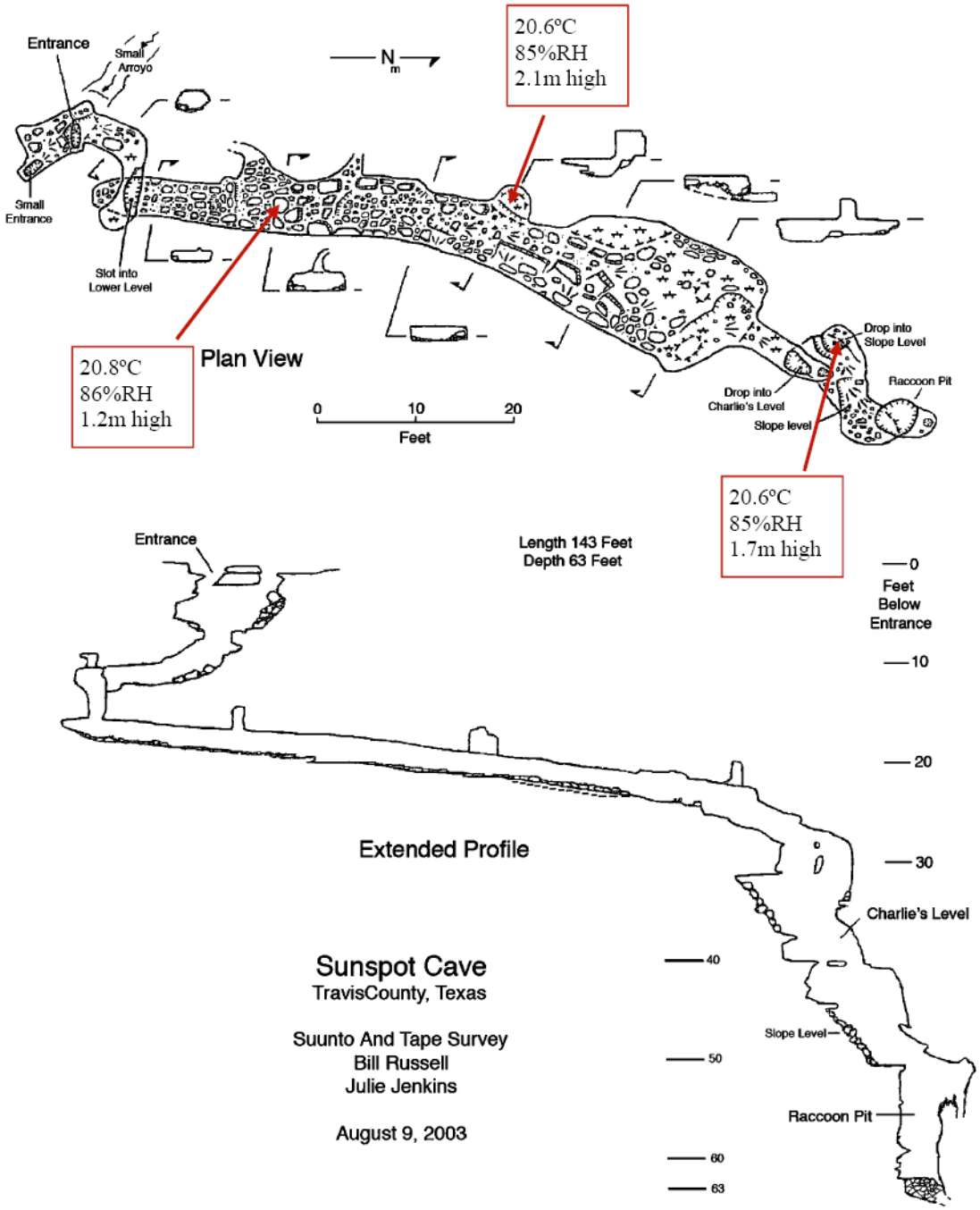
Sevenmile Mountain Cave, Bell County – No Bats/Roost Stain



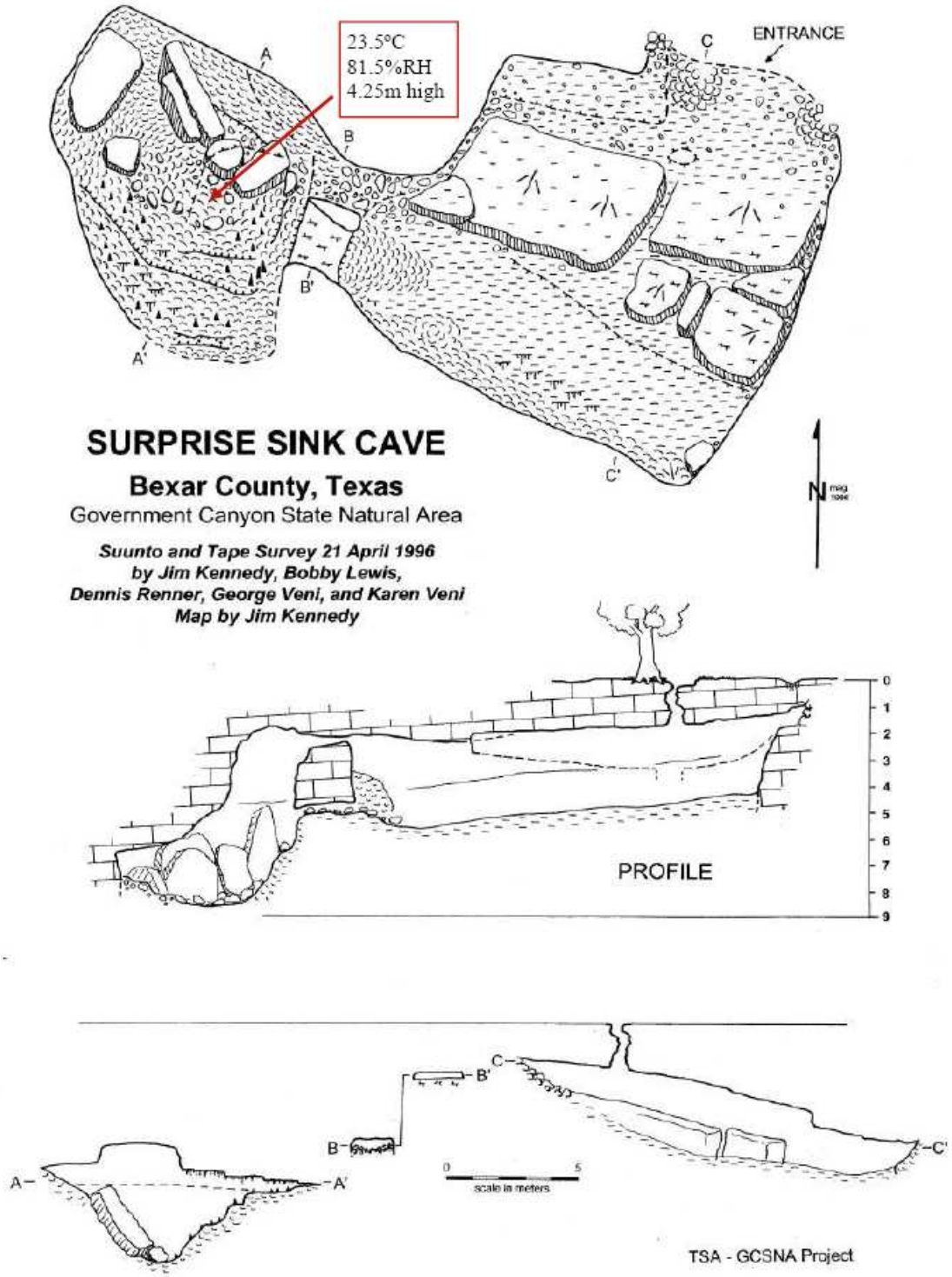
Stowers Cave, Kerr County – Bats Present



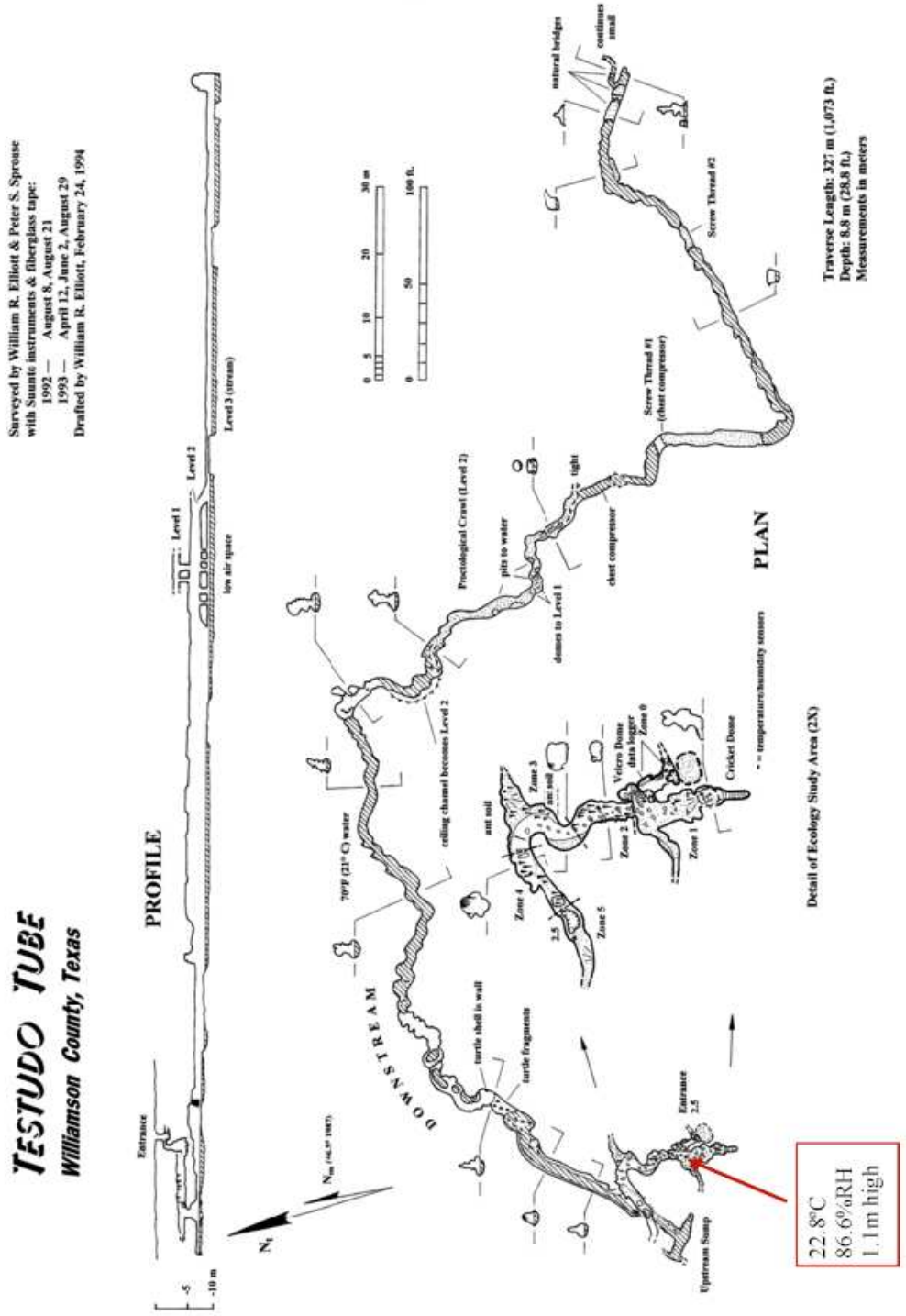
Sunspot Cave, Travis County – No Bats/Roost Stain



Surprise Sink Cave, Bexar County – No Bats/Roost Stain

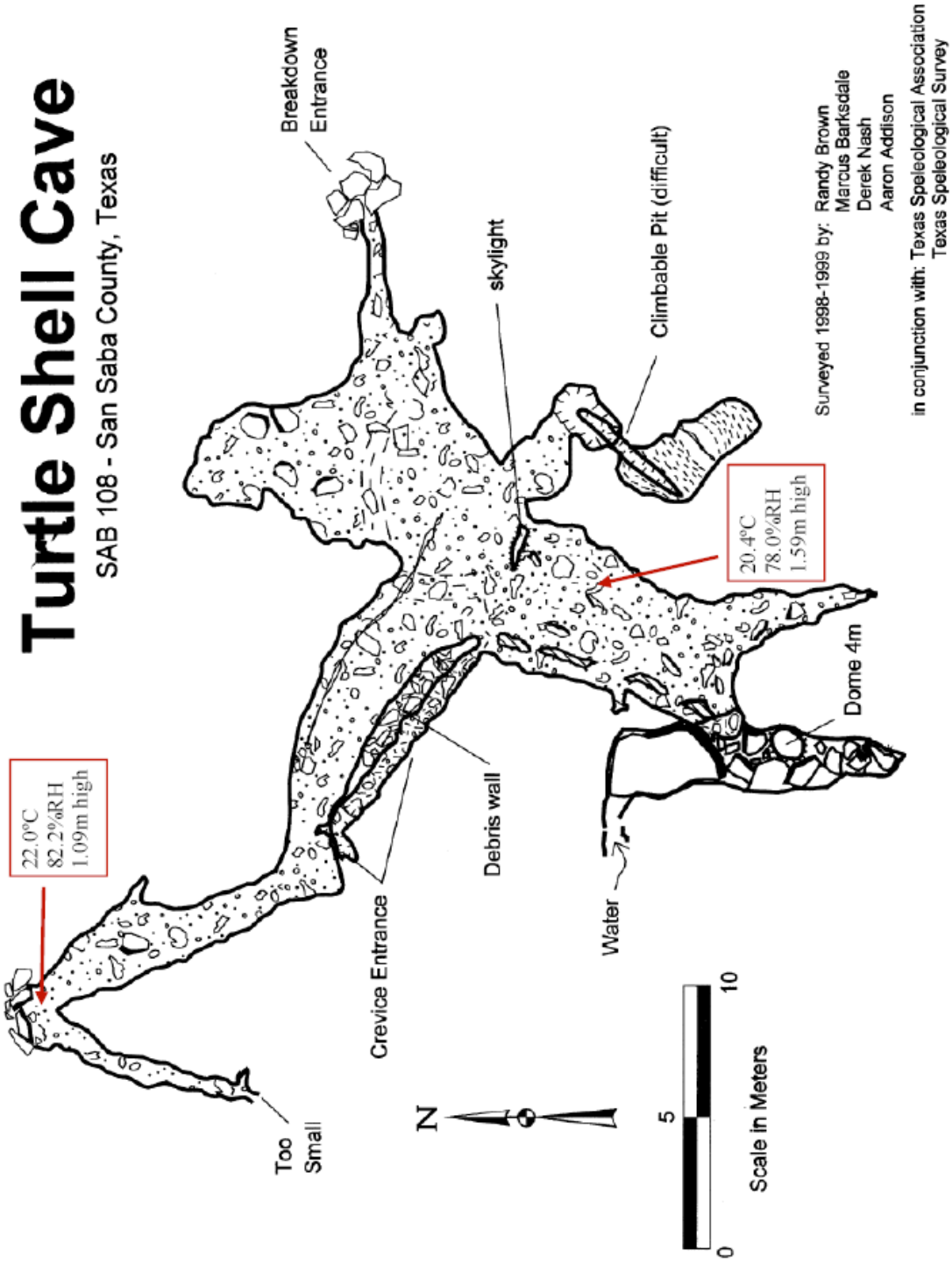


Testudo Tube Cave, Williamson County – No Bats/Roost Stain



Note: The entire cave was not surveyed due to water in lower passages.

Turtle Shell Cave, San Saba County – No Bats/Roost Stain



Cave maps unavailable

Jeanette's Cave, Hays County – Roost Stain Present

Spring Creek Cave, Kendall County – Bats Present

Taylor Bat Cave, Hays County – Roost Stain Present