Community Ecology of Three Caves in Williamson County, Texas: A Three-Year Summary

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Summary

A summary is provided of cave monitoring studies started in 1991 at LakeLine Cave. Later, Testudo Tube and Thor Cave were added to the study, which is to provide baseline ecological data on the endangered species *Rhadine persephone*, the Tooth Cave ground beetle, and *Texella reyesi*, the Bone Cave harvestman.

The study involved the extensive use of psychrometers, thermometers, data loggers, cave mapping, zone inventories, data forms, counts of cave cricket and daddy longlegs emergences, surface bait stations, computer analysis, monthly reports, and other activities. The physical environment of the caves, each of which is different, is described in detail. The microclimate of each cave is characterized spatially and temporally in graphs for a three-year period, one year of which involved intensive data-gathering. Maps are provided of each cave, showing the zones that were marked for periodic faunal inventories.

The cave communities are described with faunal lists and observations on the habitat requirements and behavior of the more important species. The results of zone inventories on principle species are given. *Texella reyesi* was observed in LakeLine Cave on 55% of the first 11 trips to LakeLine Cave, but only 8% of the last 12 trips and has not been seen there since December 1992. It is tentatively concluded that *T. reyesi* may have declined in LakeLine Cave due to climatic drying and fire ants. In LakeLine *Rhadine persephone* is common while the closely related species *R. subterranea* is rare; the opposite is true in Testudo Tube, which has more of a deep cave habitat. Thor Cave has the most abundant population of *Texella reyesi* known, which is concentrated in Zone 5, which has the optimal combination of food, cover (large rocks), and moisture. The feeding behavior of these species is discussed insofar as it is known.

The results of extensive counts of cricket and daddy longlegs emergences are given in a series of graphs. The length of delay of the emergences after sunset is related to outside temperature. Crickets nymphs and adults can travel at least 50 m from the entrance while foraging, but most stay within 10 or 15 m. Fire ant competition with cave crickets is intense.

Recommendations are given to 1) control fire ants with hot water treatments, 2) continue monitoring as planned in the LakeLine Mall Habitat Conservation Plan, especially as regards the disappearance of *Texella reyesi* in LakeLine Cave, 3) select a preserve manager to ensure that ecology studies, fire ant control, surveillance, and security measures are carried out according to the HCP, 4) discontinue further data collection with data loggers until the erratic signal problem is resolved, and 5) if possible, support the additional cost of quarterly or semi-annual cricket emergence counts, which can easily be done by one person.

Introduction

This report provides information on three Central Texas cave communities near Austin and two endangered species: *Rhadine persephone*, the Tooth Cave ground beetle, and *Texella reyesi*, the Bone Cave harvestman. I endeavor to provide an annual report on studies performed in 1993 as well as to provide a summary of results obtained from May, 1991, to May, 1994. A preliminary paper on this study was given at the National Speleological Society Convention in June, 1994 (Elliott, 1994a). All figures and data forms are found in consecutive order at the end of this report.

The discovery of two endangered species in LakeLine Cave in 1990 (Reddell, 1991), prior to the intended development of the LakeLine Mall site, led the Simon Development Co., Inc. (Simon) to seek a Sec. 10(a) permit from the U.S. Fish & Wildlife Service (FWS) to develop the property. Simon produced the LakeLine Mall Habitat Conservation Plan. During 1991 Simon agreed to support monitoring studies at LakeLine Cave. As part of the final negotiated agreement with FWS, Simon set aside a 2.3-acre preserve around LakeLine Cave and purchased two other karst preserves around the caves Testudo Tube, near Cedar Park, and Thor Cave, near Georgetown. Simon developed a 10-year budget to support studies in all three caves and manage the preserves. Deeds to the three preserves were given to the Texas Parks & Wildlife Association.

James R. Reddell, a cave biologist employed by the Texas Memorial Museum, had done the preliminary studies in LakeLine Cave for Horizon Environmental Services, under contract to Simon. In March, 1991, I was asked by Reddell to design and carry out long-term, baseline ecology studies at LakeLine and other possible sites as yet undetermined. I made monitoring trips to LakeLine in May, June, August, September, October, November, and December of 1991. I visited Testudo Tube for the first time in September, 1991, with Lee Sherrod and Brian Keely of Horizon Environmental Services, in order to assess its suitability for long-term studies. Because of a lack of proper instrumentation needed to measure humidity in caves, as well as a need to better design a long-term, comparative study, work was discontinued from December, 1991, until April, 1992. At that time I contracted directly to Simon to study the three caves that are the subject of this report. Thor Cave had been discovered in May, 1991, during a study for the City of Georgetown (Elliott and Reddell, 1991), so I was already familiar with the cave, having mapped it. Thor had a rich fauna and seemed very suitable for long-term studies. The three caves were structurally different and had somewhat different communities. LakeLine was on a fire-ant-infested tract that ultimately would be reduced to a natural area of only 2.3 acres while the surrounding area would be developed. Testudo Tube and Thor Cave were on relatively large tracts, about 50 and 100 acres respectively, and seemed to be well-protected from human impacts, although the Thor Cave area was infested with fire ants while Testudo Tube was not. These and other differences would be useful for the purposes of the study, which were to gather basic data on the habitat requirements of the endangered species and their communities but also to measure human impacts such as development and fire ants. However, fire ants were to be controlled by low-impact methods, such as hot water treatments (Elliott, 1993j).

Preparations for building data loggers began in April, 1992 and cave visits resumed in June, 1992. During these studies I was assisted by Doug Allen and Peter Sprouse. James Reddell and Robert Crowder assisted on visits in December, 1992. My revised study design was in response to a negotiated study period of 10 years. There would be one year of monthly, intensive, in-cave studies and a simultaneous monthly study of the behavior of cave crickets and daddy longlegs, important components of the cave communities. The next four years would involve quarterly monitoring visits to the three caves. The final five years would require annual visits to LakeLine Cave only, and the preserve around the cave would be reduced to the "footprint" of the cave, approximately 30 by 70 ft.

The first year of the new study was June, 1992 - May, 1993, for the most part. Unused time that was saved during the winter, when cave crickets and daddy longlegs did not emerge, was used to map Testudo Tube, investigate some sinkholes near LakeLine Cave and Testudo Tube, and to gather additional cricket emergence data at all three caves. I provided a written report of each trip to LakeLine in 1991 (Elliott, 1991a-f), and of each round of trips to the three caves in 1992-1994 (Elliott, 1992a-g, 1993a-i, 1994b). These reports were filed with Simon, FWS, and Texas Parks & Wildlife Department.

This report focuses on the intensive study period of 1992-1993, but also summarizes observations on endangered cave species from May, 1991 to May, 1994.

Materials and Methods

Psychrometers and Thermometers

During the 1991 study in LakeLine Cave I used a Hanna HI 8564 electronic psychrometer on loan from Horizon Environmental Services. Although useful to a certain extent, after extensive calibration and review of the technical data on the instrument I found that it was not suitable for cave ecology work. The psychrometer was inadequate because it was only rated for environments of 10-95% relative humidity (RH) and only had an accuracy of ±2% of the scale reading. Since most cave humidities of concern to the endangered species and other troglobites were close to 100% RH, I felt it necessary to obtain an instrument that was accurate, precise, and rated up to 100% RH. Most psychrometers based on a thin-film, hygrometric, integrated circuit cannot accurately read RH above 95%.

I obtained an Atkins digital psychrometer, Model #90023-F, through Davis Instrumentation. This seems to be the best instrument currently available on the market for cave ecology work. The psychrometer is a pistol-shaped instrument based on a dry bulb/wet bulb design. It has two matched thermocouples, one covered with a cotton wick inside a stainless steel nozzle about 13 cm long. A Ni-Cd battery operates a fan that pulls air through the nozzle and over the wet bulb and dry bulb thermocouples. This design allows one to sample air from under rocks or in small holes, unlike most psychrometers. By testing I found that the two thermocouples, when dry, read within 0.05 F° of each other. I obtained the Fahrenheit model because it provides 1.8 times the precision of the Celsius model (each reads to 0.1°). One can read the dry and wet bulb temperatures with the instrument and get a measure of the humidity by obtaining the "wet bulb depression", which is the difference between the two readings. At 100% RH the wet bulb depression is 0.0 F°, and at 99% RH it is about 0.15 F°. One can also look up the RH in a table or calculate the RH using various complex formulae (Wexler, 1976). With such an instrument, it would be possible to calculate RH to about 1%, which I thought necessary to adequately characterize the humidity preferences of some species. The Atkins psychrometer is expensive ($600-$800); it would be possible to build an instrument that is nearly as good for about $100 in parts, using a voltmeter and matched LM34 IC temperature sensors in a dry/wet bulb design, but the labor and time to build and calibrate the instrument would be extensive.

In addition we usually carried an REI pocket spirit thermometer. We installed REI mercury minimum-maximum thermometers near the entrance of each cave and at the second (mid) temperature probe connected to the data logger (see below). These thermometers, which can be read to 0.5 F°, provided backup and an independent check on the Atkins psychrometer and the data loggers, which malfunctioned from time to time.

Data Loggers

Based on the experiences of colleagues at Arizona Conservation Services, Inc., who have done a baseline ecology study in Kartchner Caverns, Arizona, I obtained parts to build three digital data loggers for recording temperature and humidity in the caves (fig. 1). The data is downloaded periodically to a notebook computer in the field and the data logger, or microcontroller, is returned to the cave immediately. Hourly data are useful in assessing the microclimatic changes that can occur in a cave over a short time. I used a Blue Earth Micro-440 microcontroller, which is a small computer about the size of an audio cassette box. This was connected to a large 12-V gel cell battery which would provide enough energy (36 amp-hours) to power the system for weeks or months. The power is stepped down to 5 V through a small voltage regulator in a hand-built circuit. The circuit also contains capacitors, which serve to damp out power fluctuations.

Five volts also are sent to six integrated-circuit sensors positioned at the ends of three long, shielded data cables at the entrance, the mid-cave, and near the end of the study area in each cave. These provide information on temperature and humidity fluctuations in three distinct ecological zones in each cave. Five of the sensors are National Semiconductor LM34A integrated circuits, which are packaged in small metal cans. These are soldered onto the power and data lines, the leads covered with heat shrink tubing, and each sensor sealed with epoxy. Each pair of sensors consists of a dry and a wet bulb sensor, except at the entrance, where a Hycal Engineering IH-3602 humidity sensor is used instead of a wet bulb. The humidity sensor can be used in an environment where a wet bulb might dry out unless there was a larger water reservoir. The wet bulbs were set up with cotton wicks conducting distilled water from small plastic can of about 20 ml capacity.

The six data lines return to the data logger via two 12-bit analog-digital convertors (ADCs), which then convey the digital output through a serial port to the Micro-440, which logs the data into about 16 kilobytes of memory. A program written in Blue Earth Basic keeps the system powered low until the on-board clock indicates the hour, at which time power to the serial port is turned on and the data lines are read. At first the data loggers could only go for about 15 or 20 days before the battery ran down. Later I obtained new low-power chips for the ADCs, which then allowed the systems to run for 40 or 50 days. The recorded data was safe in the data logger's memory because it has a small lithium battery to refresh the memory until it is cleared by the operator. I have drawn plans and tested a miniature external timer circuit that could allow the system to conserve even more power and run for months without a battery change. So far this external circuit has not been implemented because of problems with sensor reliability.

The electronics packages, including the battery, power circuit, data logger, and ADCs, were housed in sturdy plastic tool boxes in the caves. An open container of Drierite desiccant (calcium sulfate) was placed in each box to absorb excess moisture and keep the electronics from corroding. The desiccant was exchanged on each visit and recycled by heating it in an oven. Each box was locked tight with only a small, caulked hole for the three data cables to exit. In Testudo Tube and Thor Cave, where there are no security gates on the entrances, we anchored the boxes to the floor or wall with rock bolts to discourage vandals. The data logger systems were installed in the caves in June and July, 1992.

The 12-bit ADCs allow the binary sensor data to be stored with a resolution of 4,096 steps ($2^{12} = 4{,}096$). For the temperature sensors, which have an output of 0 to 5 V at 10 mV per F°, there is a theoretical resolution of 1.2 mV or 0.12 F° per step. In the case of the humidity sensors, a theoretical resolution of 0.02 %RH can be achieved. In actuality, I had quite a bit of trouble with some of the sensors giving erratic data. I transfer the data into Excel, a computer spreadsheet program, where I can convert it to F° or %RH, graph it, and adjust it according to calibrations made against the Atkins psychrometer or other thermometers. An enormous amount of data was collected but only some of it has been analyzed to date. Data conversions, calibrations, and graphing take much more time than was expected. Some data from erratic sensors will have to be discarded. However, there probably is more than enough good data to characterize the changes that occur on the hourly, daily, and weekly scale. Monthly observations and measurements with the Atkins psychrometer allowed a detailed picture of monthly and annual events and some short-term events, such as low-velocity air movements and temperature changes brought by cold fronts and nightly cool-downs.

I also obtained monthly weather data for 1991-1994 from the National Weather Service office in Austin. Although the data set pertains only to the Austin airport, which often receives less rain than areas along the Balcones Escarpment, the data should be representative of temperatures and rainfall trends over a number of years.

Cave Mapping

Existing maps of LakeLine Cave and Thor Cave were available for this study. It was necessary to map Testudo Tube to obtain an accurate representation of the cave in relation to the property lines and to indicate the ecological study zones that we set up in each cave.

Standard cave surveying methods were used: a two-man survey team equipped with Suunto hand-held compass and clinometer and a 30-m fiberglass tape. Data were taken in a water-proof field book for the stream passage portion of the cave. Data were processed with SMAPS 5.2, a cave-survey processing program, and plotted on a laser printer. Surface traverses were surveyed to Upstream Sink and several other karst features and the south, west, and north fence lines were surveyed since no property survey seems to be available. The final map of the cave was hand drafted based on the computer plot and the field notes and sketches. A draft of the surface survey overlaid with the cave plot was also produced.

Zone Inventories and Record-Keeping

Initially we took copious notes in compact field books on fauna observed in the cave. The assistant and I each had a numbered field book, in which we kept observations and the exact time according to wristwatches. LakeLine observations already were being tabulated according to the physical divisions or rooms in the cave—entrance (Zone 1), Ledge Room (Zone 2), Lower Level (Zone 3), and Upper Level (Zone 4). In September, 1992, we marked Testudo and Thor into 6 and 7 zones respectively. Later, we added Zone 0 (entrance crawlway) to Testudo Tube. The zones were not intended to be of equal area, but rather to represent physical divisions within the cave representing the entrance zone, twilight zone, and permanent dark zone and additional zones differing in substrate type. Each zone was to be no more than about 5 m long and the width of the passage, and could be inventoried for most familiar species within a reasonably short time (15 to 30 minutes). Data were summarized by zone in each monthly report. I took the zone approach instead of attempting randomized quadrat or transect studies because the species of concern are so rare as to elude randomized sampling schemes. I believed that for a baseline study we should not be overly concerned with statistical niceties but with being observant and recording all that we could. Such data do not yield highly statistically reliable population estimates, but are consistent in that the same zones are inventoried repeatedly over a long time. Population estimates of rare species, such as *Texella reyesi* or *Rhadine persephone* are difficult when the traditional mark-recapture methods depend on marking a fairly large sample to begin with.

In June, 1993, I designed and implemented two data forms for recording microclimatic and faunal observations, and I incorporated these spreadsheet forms into my reports. These provided more consistency and reduced the amount of time we had to spend writing observations, thus giving us more effective observation time. The "Cave Fauna Inventory Record" form (attached just after fig. 1) has 33 rows with 32 of the usual species or genera that we observed in all three caves (not all species are found in any one cave). The columns represent the zones, with another column for remarks. The "Cave Microclimate Data" form (attached) provides rows for the three data logger probe positions, which we always checked with the Atkins psychrometer or other thermometer, and other rows for *ad libidum* observations. The columns are for recording the type of reading, such as dry bulb or wet bulb.

Cave Cricket and Daddy Longlegs Emergence Counts

From June, 1992 until May, 1993, we kept vigils at the entrance of each cave monthly. After initial free-ranging observations of crickets, we settled on a pattern of counting the crickets in 15-minute increments from about sunset until they stopped emerging, usually an hour or two later. We used office-type mechanical thumb counters for these counts and developed rules of thumb for counting crickets. Eventually we adopted the use of three counters, one for counting emerging adult crickets, one for nymphs, and one for counting "returns" of both sizes. "Returns" were crickets who hopped back into the entrance after coming out past the edge of the entrance. Many crickets hopped in and out and with these data we were able to estimate the net number that emerged. Usually no more than 10% "returned". After we began bait runs (see below), we adopted the strategy of one person counting at the entrance while the other ran bait lines. At Testudo Tube, where there is a sizable daddy longlegs population in the summer, it often took two of us to count both daddy longlegs and cricket "hops." These data were easily summarized in spreadsheets and graphs.

During cold weather the cricket "hops" were slight or nonexistent. We abandoned such watches and used the saved time on other projects that needed to doing.

Surface Bait Stations

Initial attempts to track cave crickets after they emerged from the cave were frustrated by the tall vegetation. We painted some crickets with fluorescent tempera paint on a few occasions and attempted to follow them with black lights (camp lanterns equipped with UV lamps). It was possible to follow one cricket for long periods, but one usually lost it in tall grass. One usually had to be within 1 m of the cricket to see it in tall grass. We were not successful in relocating painted crickets with this method. We had hoped to determine how far and in what densities the crickets would travel from the entrance.

Since the crickets are easily attracted by cheese or other foods, we laid out bait stations in the four compass directions from each entrance, at distances of 5, 10, 15, 30, and approximately 50 m. The stations were marked with numbered wire surveyor flags. On a typical bait run, we would place small squares (specifically, 1/6 of a square of pre-sliced American cheese) on the ground at the flag, then come back within 10 or 15 minutes and pick them all up while recording the number of cricket adults, cricket nymphs, gryllid crickets, fire ants, or other insects, that were on , under, or immediately adjacent to the bait. It was necessary to pick the bait up quickly because of the large number of fire ants that could be attracted to it. Even 10 minutes was enough for some baits to be completely swarmed on some nights. Nevertheless, this method allowed us to obtain distance, density, and time data on both crickets and fire ants. We also made detailed observations of intense interactions and competition between crickets of different sizes and between crickets and fire ants. These data were tabulated in spreadsheets and graphed. Twenty-three bait runs were done at LakeLine from June, 1992-May, 1993. At Testudo Tube we obtained 12 bait runs. At Thor Cave we obtained only 5 bait runs because the entire preserve is so overrun with fire ants that we could not collect useful data except on cold nights when crickets were out but fire ants were not.

Other Observations on Fauna

In addition to the above studies, I built a Berlese apparatus, which hold four large plastic funnels for sampling leaf litter. Each funnel is equipped with ¼-inch (6 mm) hardware cloth to support the sample and a 40 W light bulb to provide heat to drive soil invertebrates downward to where they drop into a sample jar with preservative. To date there has been little time to process such samples because of the demands of tending to data loggers and other work.

Disposable plastic plates, 25 cm in diameter, were dated with indelible ink and set out in various places in each cave to capture cricket feces and other materials that might accumulate. The plan was to keep these plates in place up to a year before weighing the net contents on an electronic balance. We found that small amounts of clay and rock flaked off the ceilings of the cave in a few months. Cricket feces and other materials were noted for months, however, most of the plates were eventually overturned by marauding raccoons or *Peromyscus* mice, or else accumulated so much drip water as to make characterizing or weighing the contents a dubious exercise. Some plates were displaced by periodic flooding in Testudo Tube, which served to inform us of these events whenever green leaves and other detritus deposited by floods were not obvious. Plate sampling eventually was discontinued because of these problems.

Crickets and daddy longlegs were occasionally captured and weighed *en masse* in plastic bags to obtain average weights. We used an Acculab Pocket Pro 250 electronic balance, which has a resolution of 0.1 g and a capacity of 250 g.

Observations were often made at the beginning of the stream passage in Testudo Tube, where aquatic fauna such as *Eurycea* salamanders, *Stygobromus* amphipods, and *Sphalloplana* flatworms were visible. The water and air temperatures usually were taken and notes made on the stream level and fauna.

Physical Environment

LakeLine Cave

The cave (see map, fig. 2) is entered by a 3-m by 1.5-m sink, which drops 2.5 m to a crawlway. The entrance (Zone 1) has been gated. A 1-m diameter crawlway goes about 1.5 m to the Ledge Room (Zone 2), a 5-m-long, 1.5-m-wide, walking fissure-like passage with many ledges. The floor of this room extends under a ledge to become the Lower Level (Zone 3) at the rear of the cave, but the constriction under the ledge is impassable to humans although it is readily used as a travel route by crickets. Humans must crawl through a 50-cm-high, 60-cm-wide crawlway leading about 3 m to where it opens into a 2-m pit intersecting the Lower Level. At this point one enters the Formation Room (Upper Level, Zone 4), which overlies the Lower Level. Another, impassable, sloping hole connects the two levels 3 m to the north. Here the Upper Level has a constriction 20 cm high and 60 cm wide, which leads another 3 m to the visible end of the cave. The entire cave is formed along a joint, which percolates rainwater into the cave along the centerline. Both upper and lower levels are enlarged bedding planes about 6 m wide and the ceiling is higher at the joint. The clay soil is often visibly drier toward the edges of the bedding planes. The cave is only 21 m (69 ft.) long and 3 m (10 ft.) deep.

LakeLine Cave has a thin roof, probably only 1 to 1.5 m thick. The cave is barely long enough to have a truly dark zone at the back, and the microclimate is strongly influenced by the seasons. Temperature measurements consistently have shown that warm air is trapped in Zone 4 for long periods. Sometimes this is apparent to us from the "bad air" in Zone 4, which is high in carbon dioxide and somewhat low in oxygen. The air in Zone 4 is trapped at the back by cool air, which flows along the floor from the entrance and into Zone 3. Probably the thin overburden allows convective heat to penetrate into Zone 4, thus heating the air there even more. There is a lag time of about 3 months between outside and Zone 4 highs and lows.

"Steam" has been observed rising from the entrance on cool nights and cold air sometimes has been felt flowing along the floor of the Ledge Room and Lower Level even during the day.

In 1992-1993 the temperature range in Zone 4 (Upper Level) was 62.7°-78.1° (mean 70.7°, range 15.4°) as measured with the Atkins psychrometer and 62°-78° (16°) as measured with the min-max thermometer. Zone 3 (Lower Level) ranged from 61.3°-77.4° (16.1°), while Zone 2 (Ledge Room) ranged from 60.4°-74.8° (14.4°) near the floor. The latter range would have been much greater had we measured temperatures in the ceiling domes. These are very broad temperature ranges for a cave containing troglobites, and it is simply the result of the cave being small. The average wet bulb depression in Zone 4 was 0.3° (range 0-0.6°), which corresponds to about 98.5% RH (range 97-100%). In Zone 3 the average wet bulb depression was 0.34°(range 0.2-0.5° or 99-98%), and in Zone 2 the average wet bulb depression was 0.43° (range 0.2-1.0° or 99-95%).

The ranges of temperatures measured with the psychrometer and mix-max thermometers in LakeLine Cave in 1992-1993 are represented in fig. 3. The ranges are arrayed in order of distance from the entrance. It is apparent that the microclimate becomes more equable farther from the entrance. Comparing fig. 3 with fig. 11 for Testudo Tube shows that Testudo Tube has a much narrower temperature range at the mid and end stations. Testudo Tube is much longer than LakeLine Cave and its walls and atmosphere have much more thermal mass.

Fig. 4 compares monthly Atkins dry bulb temperatures against National Weather Service (NWS) monthly minima and maxima for 1992-1993. The entrance temperatures track the outside temperatures very well, and it can be seen that the mid and end temperature changes are much flatter. One can also see that the lag time is about one month for the maximum and about two or three months for the minimum at the cave end station. For deeper locations in LakeLine Cave the increasing lag time in tracking outside temperature changes is shown in fig. 5, which is a three-dimensional version of fig. 3.

The entire microclimate of LakeLine Cave over one year, as measured by psychrometer, can be depicted as a topographic surface (fig. 6). The different bands on this surface correspond to 10 F° temperature intervals on the Z axis. Time is on the X axis and stations farther into the cave are on the Y axis. The surface is most warped at the entrance, where temperatures can dip into the upper 40s during the winter. The curve is much flatter just 4 m inside the entrance at the mid station. At the end station in Zone 4, about 16 m from the entrance, the surface is flatter but the winter depression is delayed in time. A similar surface is seen for Testudo Tube's microclimate (fig. 13, viewed from a different angle), except that it is much flatter for the cave's interior.

The relation of humidity in LakeLine cave to monthly rainfall and to cold fronts (as measured by outside temperature minima) is hinted at in fig. 7. This is a busy graph, but several comparisons can be made. Wet bulb depression (WBD) is graphed at the entrance, mid, upper, and lower locations (Zone 1, 2, 4, and 3). As humidity decreases, WBD increases. The monthly rainfall curve is low in the first half, but higher in the second half. Monthly temperature lows, usually corresponding to strong cold fronts that move in rapidly, "bottom out" between November and March. It hardly seems likely that the higher WBD (lower humidity) in the cave entrance would correspond to the higher winter rainfall. The decrease in humidity is more likely the result of intensely cold, dry air flowing into the sinkhole and lowering the humidity. This phenomenon is familiar to cavers who sometimes visit a cave on a cold winter day to find the normally wet formations dried out.

In the last graph for Lakeline's microclimate (fig. 8), I have shown one data logger run from December 4, 1992 to January 4, 1993. The entrance curve takes many large dips and the entrance RH has several dips corresponding to these temperature drops, but not always. Meanwhile, the mid and end RHs are high and relatively flat curves (if one ignores the noise caused by some of the sensors). Some of the sensors gave erratic signals from time to time, so not all of the data in the graph is reliable—for instance the end dry curve, which has several swings of 2-3° during a time when the min-max thermometer indicated no difference in minimum and maximum.

Testudo Tube

Testudo Tube is a long, sinuous stream crawl with some moist to dry upper levels. The ecology study area runs from the cave entrance to the beginning of the stream passage (see map, fig. 9). This area is divided into 7 zones (0-6). The cave has been described by Elliott (1994).

The entrance is a 0.5-m-diameter, 2.5-m-deep sinkhole that was dug open in 1988. At the bottom of the entrance a squeeze leads into a crawl for 4 m to the top of "Velcro Dome," a 3-m climbable drop with prickly walls. On this 5-m-deep second level, a crawl leads to the left for 10 m to "Cricket Dome", the top of which reaches nearly to the surface. To the right of the junction is a meandering hands-and-knees crawl that leads for 45 m to a drop into the third level, which is a stream crawl at 8 to 9 m below the surface.

Turtle shells, identified as *Terrapene* sp. and not *Testudo*, are found on the floor and cemented into the wall 30 m from the entrance to the stream. The stream crawl, which varies little from 70° F, meanders for 300 m, ending at a squeeze over a natural bridge and near-sump. Passages are generally 2 to 3 m wide and 1.5 to 5 m high. The first half of the crawl is scoured clean, but slimy mud soon follows. An upper level, dubbed "Proctological Crawl", is little relief from the low air spaces of the stream crawl. In two places one changes levels by crawling past a "screw thread", which is a helical flange of bedrock.

The cave takes considerable runoff several times a year as evidenced by minor flood debris. There is little doubt that the cave is a major tributary to the Buttercup Creek Karst, which includes important stream caves such as Ilex, Buttercup Creek, and Marigold caves (Russell, 1993). Much of the area was proposed as an endangered species preserve but to-date only two areas around Testudo Tube and Marigold Cave are set aside as preserves. The extent of Testudo Tube Preserve is shown in fig. 10.

Besides cold air movements, the occasional floods probably induce temperature changes in the cave. Summer flooding may bring warm water far into the cave while winter flooding may bring cold water. The range of temperature changes is shown in fig. 11. As mentioned before, Testudo Tube has a smaller range of temperature than LakeLine because it is a longer cave. For example, at the end station (Zone 5 near the hole dropping into the stream) the annual temperature range was 66.4°-70.5° (mean 68.2°, range 4.1°), and the wet bulb depression ranged from 0.2-0.9° (99-95%RH, mean 0.45° or about 98%). The overall picture for Testudo Tube (figs. 12 and 13) is a much flatter aspect. This is seen also in the data logger curves (fig. 14) for July 14-31, 1992, although some variation was attenuated in data processing). Despite the fact that Testudo Tube occasionally receives runoff, it also undergoes drying episodes to the extent that cracks form in clay areas.

Thor Cave

The entrance to Temples of Thor Cave is in an area of fractured limestone at the base of a large cedar elm (map, fig. 15). It was opened on 10 May 1991 by Lee Jay Graves and Mike Warton during a study for the City of Georgetown conducted by James R. Reddell and William R. Elliott (Reddell and Elliott, 1991). The location had been pointed out to Elliott by the rancher as a possible cave. There was no obvious depression, although a fracture system was seen to strike southwest from a large cedar elm. The entrance was in the state of forming but was not yet humanly passable until some large rocks were removed. The elm tree has an unusual root system growing up out of the soil-filled part of the entrance, and one can reach completely under the base of the tree. One of the roots, as shown on the cave map, lies on top of the ground and has developed into a limb with branches. The tree's form may indicate the gradual slumping of soil into the entrance, which has undermined the root system. Imported red fire ants have become deeply entrenched in the root ball of this tree.

The cave is about 69 m (228 ft.) long from end to end, 18.6 m (61 ft.) deep, and strikes approximately north from the entrance. The total survey traverse was 194 m (637 ft.) A sloping crawlway from the small entrance room (Zone 1) leads through a constriction into a soil- and breakdown-floored area (Zone 2). *Texella reyesi* was found on the first visit at the north end of this area (Zone 3), now called the Texella Room. A climb-down over ledges leads into the Big Room, a chamber up to 15 m wide, 45 m long, and 2 m high. The south end of the Big Room is covered with thin soil and numerous rocks, which provide cover for *Texella* and other species. The southwestern-most part is Zone 5, which contains many rocks and ledges full of holes. A broad, flat area (Zones 6 and 7) is covered with thin clay and few loose rocks, but has some breakdown and holey ledges on the east side where *Rhadine noctivaga* beetles are sometimes seen. The northern two-thirds of the Big Room comprises massive breakdown covered by flowstone (Zone 8). The ceiling here is heavily encased with calcite, which prevents rapid percolation of water but also traps moisture for long periods. In contrast, the ceiling joint from the entrance area to about Zone 5 conducts rain water rapidly; this was evident on December 23, 1991, when I visited the cave during a fire ant control study. There had been 10 inches of rains over the previous four days and the ceiling joint was gushing water like a garden hose.

Climb-downs along the walls of the Big Room lead into heavily decorated areas up to 5 m below the main level of the cave. The room itself is heavily decorated with stalactites and one wide column surrounded by flowstone occurs near the end of the room. A climb-down at the north end of the room leads into a heavily decorated dome room. A climb-down along the west side of the passage leads into a clay-floored passage, Lee Jay's Crawl, which extends about 15 m before ending abruptly. Air temperature was

68°F and relative humidity 97% in May 1991. The cave was surveyed by William Elliott, Lee Jay Graves, and Mike Warton on 13 and 20 May 1991.

Observations on air movements have shown that during cool weather the denser air flows down into the entrance and along the floor in a thin layer. This can happen at night anytime of the year, but it is more apparent during the fall and winter. Such airflow displaces warm air from the cave interior toward the entrance along the ceiling, but ceiling irregularities tend to dam this flow. On the night of November 19, 1992, we observed “steam” rising from the entrance starting at 6:20 PM, about 1 hr. after sunset. Steam rose several times with intervening periods during which warm air exhaled from the entrance. The outside temperature dropped from about 60° at 6:20 PM to 57° at 8:26 PM and there was drizzle.

On December 19, 1992, we noticed a slight draft inside the cave coming from the entrance. Reddell exited at 5:20 PM to observe crickets at the entrance while I remained inside to observe if crickets moved toward the entrance. Sunset was at about 5:30 PM. I stayed in Zone 4 with my lamp off most of the time, then checked the crickets to see if they moved, but none did. At 6:00 I moved to Zone 3, where I saw no cricket movements in the south half. At 6:10 I felt cool air flowing along the floor from the entrance and “steam” in the entrance room. Reddell observed “steam” rising from the entrance, but no crickets emerging. I used the Atkins psychrometer to observe dry/wet bulb temperatures at the constriction between Zones 1 and 2, where cold air was flowing along the floor from outside. At 6:29 PM at a ceiling pocket ½ m above the floor it was 67.6/67.4; at the floor it was about 59.8-60.0/59.8-60.0, a 7.8 F° difference. I moved to the mid-probe in Zone 5 at 6:29 PM and took temperatures at the ceiling (69.1/68.7), halfway (½ m) down (68.0/67.8), and at the floor (67.1/66.8). A slight draft was felt at halfway between floor and ceiling. At 6:34 PM I moved to the middle of Zone 3 and measured 68.3/67.9 at the ceiling (1.2 m up) and 65.8/65.6 at the floor. So, obviously cold or even cool air penetrates far into the cave under the right conditions, but is rapidly warmed as it flows downhill to the Big Room. When I exited at 6:40 PM the weather was clear and the temperature was 41.3° dry/41.0° wet outside.

Thor Cave's microclimate is characterized in figs. 16-18. Fig. 16 is a 3D line graph comparing NWS daily average temperatures (for the days visited) with the dry bulb temperatures in the cave. The entrance curve follows the average outside temperature curve very closely, while the mid and end points are very flat and lag behind the outside minimum. Fig. 17 is very similar to fig. 12 for Testudo Tube. Fig. 18 shows data logger curves for February 11 to March 12, 1993. Entrance humidity frequently dipped sharply from about 76% to 72%. The erratic signals from several sensors make comparisons difficult, but the temperature range at the mid point was about 63.5-67°, about the same as indicated by the data logger system. While the entrance averaged 66.5° (range 34.2°), the mid point averaged 67.3° (range 6.2°) and the end point averaged 68.1° (range 3.7°). The WBD at the mid point (Zone 5) averaged 0.31° (range 0-0.7°), corresponding to an average RH of 98.5%. The lowest RH, about 96%, at the mid point was on November 29, 1992, following two days of freezing weather, the first frost of the fall.

Cave Communities

LakeLine Cave

LakeLine Cave contains a diverse fauna of at least 28 species, including at least 9 troglobites, making the cave one of the more significant in the area (Reddell, 1991). During this study I have added about four species to the list, none troglobites. A complete analysis of species count data has not been done yet but would be useful to discover seasonal trends, especially among crickets and troglobitic millipedes. Here is the revised fauna list, with notes on the ecology of some species:

Snails: Gastropoda undetermined (probably *Helicodiscus eigenmanni*), troglophile.

Spiders: *Cicurina* (*Cicurella*) sp., troglobite

Erigoninae genus and species, ?accidental

Eidmannella sp., troglophile or troglobite. This species is usually abundant during wet periods and spins numerous tiny, delicate webs in rocks.

Pseudoscorpions: *Hesperochernes unicolor* (Banks), ?troglophile

Microcreagris reddelli Muchmore, troglobite. This species is rarely seen and has been collected only twice in LakeLine.

Mites: Acarina undetermined

Harvestmen: *Texella reyesi* Ubick and Briggs, troglobite. This species has not been seen in LakeLine since December, 1992 (see discussion below).

Centipedes: Scutigeromorpha undetermined, troglophile. House centipedes are sometimes seen in Zone 2 in ceiling domes.

Millipedes: *Cambala speobia speobia* (Chamberlin), troglobite. This species is usually abundant.

Speodesmus bicornourus Causey, troglobite. This probably is a good “marker species” for high humidity and suitable conditions for finding other troglobites. Its temperature and humidity preferences and tolerances are more limited than those of *Cambala speobia* (Bull and Mitchell, 1972).

Myrmecodesmus formicarius Silvestri, troglophile. This species is associated with ants, especially red imported fire ants. Its presence in the cave indicates that fire ants are locally abundant.

Springtails: *Pseudosinella violenta* (Folsom), troglophile. This common species of cave springtail is abundant on soil and clay surfaces, but especially on cricket and mammal feces, where it may undergo rapid population blooms. This species presumably is the stock prey item for several small predators, probably including *Texella reyesi*, the endangered harvestman.

Insects: Undetermined larvae

Cave crickets: *Ceuthophilus* (*Ceuthophilus*) new species, trogloxene. Although unnamed, this species is common in Travis and Williamson County caves, where it forms large populations on ceilings. This species emerges from the cave in large numbers at night to feed in the surrounding area.

Ceuthophilus (*Geotettix*) *cunicularis* Hubbell, trogloxene. This small, red, shiny, short-horned species lives primarily on the floor and ledges among rocks. It has much smaller populations than *Ceuthophilus* n. sp. or *C. secretus*, the dominant ceiling-dwellers in most Central Texas caves. It probably scavenges dead insects and other detritus on the cave floor, but we observed some outside at night.

Roaches: Blattaria undetermined.

Beetles: ?*Tachys* sp.

Pselaphid beetles: ?*Batrisodes* sp., troglophile. I collected two specimens of an eyed species in Zone 3 on August 20, 1994. This small mold beetle is an eyed relative of the endangered *Batrisodes texanus*, the Coffin cave mold beetle in northern Williamson County.

Ground beetles: *Rhadine persephone* Barr, troglobite. This species is more abundant than its congener, *R. subterranea*, in LakeLine Cave, whereas the reverse is true in Testudo Tube.

Rhadine ?*subterranea* (Van Dyke), troglobite.

Rove beetles: Aleocharinae genus and species, troglophile

Eustilicus condei (Jarrige), troglophile

Orus (*Leucorus*) *rubens* Casey, *troglophile*

Fire ants: *Solenopsis* (*Solenopsis*) *invicta* Buren, trogloxene. This is the red imported fire ant from Brazil, which has been seen and collected throughout the cave. Elliott (1993) carried out a fire ant control study at the LakeLine Cave Preserve in 1991, but the species is still abundant on the site.

Flies: Diptera undetermined.

Frogs: *Syrrhophus marnocki* Cope, cliff frog. This species is usually seen and heard in ledges around the entrance. It probably preys on cave crickets.

Rodents: *Peromyscus ?maniculatus*, white-footed deer mouse. This species has been observed many times feeding on cave crickets in the entrance sink during their emergence at night. Judging from the activity of these mice, they may eat thousands of cave crickets per year.

Testudo Tube

A complete fauna list for Testudo Tube was not included in Elliott and Reddell (1989) or Reddell (1991), because it had not been thoroughly investigated at that time. Reddell (1991), however, did provide some tentative identifications, most of which still need confirmation by a taxonomist. At least 19 species inhabit the cave, of which 3 are aquatic troglobites and 5 or 6 are terrestrial troglobites. The cave lacks *Texella* harvestmen, as do all caves studied to date in the Buttercup Creek karst near Cedar Park. Russell's (1993) mention of *Texella* occurring in this area is in error. Testudo Tube has a diverse fauna, a partial list of which follows:

Flatworms: *Sphalloplana* sp., troglobite. This large, white flatworm is abundant in the stream passage, but is not always seen on periodic visits.

Snails: Gastropoda undetermined (probably *Helicodiscus eigenmanni*), troglophile.

Amphipods: *Stygobromus russelli* Holsinger, troglobite. This species is abundant in the stream passage and probably is the main prey for cave salamanders.

Spiders: *Cicurina* (*Cicurella*) *elliotti* Ubick and Briggs, troglobite. This species occurs in caves of southern Williamson and northern Travis counties.

Eidmannella sp., troglophile or troglobite.

Centipedes: Geophilomorpha undetermined.

Millipedes: *Cambala speobia speobia* (Chamberlin), troglobite.

Speodesmus bicornourus Causey, troglobite.

Springtails: *Pseudosinella violenta* (Folsom), troglophile.

Cave crickets: *Ceuthophilus* (*Ceuthophilus*) new species, trogloxene.

Ceuthophilus (*Ceuthophilus*) *secretus*, trogloxene.

Ceuthophilus (*Geotettix*) *cunicularis* Hubbell, trogloxene.

Beetles: ?*Tachys* sp.

Ground beetles: *Rhadine persephone* Barr, troglobite. This species is less abundant than its congener, *R. subterranea*, in Testudo Tube, whereas the reverse is true in LakeLine Cave.

Rhadine ?*subterranea* (Van Dyke), troglobite. This may be a closely related, but undescribed species or subspecies.

Rove beetles: Undetermined material.

Ants: *Labidus coecus*, trogloxene. This subterranean army ant sometimes is abundant in Testudo Tube. It appears to prefer “boneyard” crevices in the walls of Zones 1 to 4, where it has processed reddish clay soils into granular drifts. Flooding flushes the ants out of the crevices and into the main passage, where they struggle to build soil mounds along the edges of the water. They then retreat into the crevices. The ants appear to be more active at night. On August 28, 1993, as Peter Sprouse and I returned at 8:30 PM from a long mapping trip in the stream passage, we found thousands of these large red ants swarming from the walls into the main passage from Zone 3 to Zone 1. This species does not sting, but is related to other species of army ants in South America. Members of this genus are predators of other arthropods, but may also feed on nuts and other vegetable matter (Hölldobler and Wilson, 1990). This species has not been observed preying on anything in Testudo Tube, but has been seen on the surface at night.

Flies: Culicidae undetermined. Hundreds of mosquitoes inhabited the study zones in the summer of 1992, but were practically absent the following summer. The 1992 population may have been the result of the 9 inches of rain that fell in May (see fig. 21), which may have hatched a large mosquito population that later sought shelter in the cave. Or there may have been a fortuitous colonization of the stream passage by mosquito larvae washed into the cave.

Salamanders: *Eurycea* sp. A probable new species of small-eyed, neotenic occurs in the stream passage. Its genetics and taxonomy are being studied by Paul Chippindale at the University of Texas at Austin.

Rodents: *Peromyscus ?maniculatus*, white-footed deer mouse. This species has been observed many times feeding on cave crickets in the entrance sink during their emergence at night. Two young mice were seen feeding together on one occasion. This species probably is far more common in Central Texas cave entrances than the published records indicate.

Thor Cave

Temples of Thor Cave contains at least 24 species, 5 of which are troglobites, including *Texella reyesi*, the endangered harvestman. This probably is the richest *Texella* cave in the entire Austin area, probably because of the optimal occurrence of food, cover, and moisture that can be found, particularly in Zone 5. A fauna list follows:

Snails: Gastropoda undetermined.

Scorpions: *Vaejovis reddelli,* Gertsch and Soleglad, troglophile).

Spiders: *Cicurina* (*Cicurella*) new species, troglobite.

Salticidae genus and species (jumping spider), accidental.

Mites: Acarina undetermined

Acarina undetermined (parasite of *Speodesmus bicornourus*).

Harvestmen: *Texella reyesi* Ubick and Briggs, troglobite.

Centipedes: Lithobiomorpha undetermined

Millipedes: *Cambala speobia speobia* (Chamberlin), troglobite.

Speodesmus bicornourus Causey, troglobite.

Springtails: Collembola undetermined

Slender entotrophs: Campodeidae genus and species

Insects: Insecta undetermined (larvae)

Cave crickets: *Ceuthophilus* (*Ceuthophilus*) new species, trogloxene.

Ceuthophilus (*Ceuthophilus) secretus* Scudder, trogloxene.

Ceuthophilus (*Geotettix) cunicularis* Hubbell, trogloxene.

Ground beetles: *Rhadine noctivaga* (Van Dyke), troglobite.

Rove beetles: Staphylinidae genus and species

Fire ants: *Solenopsis* (*Solenopsis*) *invicta* Buren , trogloxene.

Crane flies: Tipulidae genus and species (trogloxene)

Rodents: *Peromyscus ?maniculatus*, white-footed deer mouse. This species has been observed feeding on cave crickets at the entrance at night.

Bats: *Pipistrellus subflavus*, eastern pipistrelle. This small bat likes to hibernate in the entrance room singly or in clusters of 2 or 3 during cold weather. Lone bats have also been found in Zones 4 and 8 on occasion.

Myotis velifer, cave myotis. Single individuals of this species may have been seen in Zone 8 from time to time, but may be confused with eastern pipistrelles unless measurement are taken.

Carnivores: *Procyon lotor*, raccoon. Thor Cave is a center of racoon activity, and their scats provide a rich nutrient source for springtails and other invertebrates. I have never seen so much evidence for use of a cave by raccoons Two dead raccoons have been observed in the cave and notes were made on the ecological succession that attended the corpses. One dead coon was observed on the west side of the Big Room near the Coral Room. It slowly deteriorated through bacterial and fungal growth (see notes on *Texella* feeding on fungi). The second coon died in Zone 7 and was soon taken over by a large invasion of fire ants, who attempted to bury the corpse in the thin layer of soil by tunneling under it. This was followed by a succession of bacteria, fungi, and flies. The ants and maggots eventually devoured most of the flesh and within a few months little remained but bones and fur.

Observations on Endangered Species

Texella reyesi, Rhadine persephone and Related Species

Careful zone inventories in the three caves have resulted in enough accumulated data to prepare a series of graphs showing the spatial and temporal distributions of the species of concern. I have included data on *Rhadine subterranea* in LakeLine Cave and Testudo Tube because of the competitive interaction that this species apparently is having with the endangered *R. persephone*. A few sightings of *R. noctivaga* in Thor Cave are included, but it seems to have little interaction with other fauna except for cave crickets. The inclusion of *Rhadine* data in graphs with *Texella* data does not imply any particular known ecological relationship between the two at this time—it is a matter of convenience only.

In LakeLine Cave *R. persephone* commonly occurs in Zones 2, 3, and 4 but *R. subterranea* is uncommon (fig. 19). *Texella reyesi* has been observed only 8 times (in Zones 3 and 4) in 23 trips to LakeLine Cave, including the most recent trip on August 20, 1994. In fact, we have not observed *T. reyesi* in LakeLine Cave since December 14, 1992 (fig. 20). *T. reyesi* was observed In contrast *R. persephone* has been observed on about 70% of all trips to LakeLine. We have observed a *R. persephone* carrying a small cricket nymph in its mandibles in LakeLine Cave. Both *Rhadine* species are more active in the winter months, as fig. 20 indicates.

I have no ready explanation for this apparent decline in the occurrence of *Texella reyesi* in LakeLine Cave. Several hypotheses come to mind, but none can be disproven without many more visits to the cave. One possibility is that fire ants have preyed upon *T. reyesi* and reduced its numbers. Fire ants have been present on the site since it the cave was first studied biologically in 1990, despite several attempts to control them. No fire ant control has been carried out on the site since my last fire ant study there in 1991. We have not observed fire ants preying on the harvestman but have seen them preying on many other species in various caves and have watched them carrying bits of flesh and arthropod body parts in LakeLine and Thor caves. It would be a rare event to be there at the right time to see a fire ant prey upon a harvestman because harvestman sightings are rare to begin with. This brings to mind the second hypothesis, which is that the apparent decline in *T. reyesi* is due to chance alone. This is highly unlikely because based on the first 11 visits, we should have seen another *T. reyesi* at least 6 times since December, 1992, but we have not. A third hypothesis is that annual rainfall, which determines plant and animal productivity and cave humidity, has declined since 1992. Austin's rainfall in inches was 52 in 1991, 46 in 1992, 26.5 in 1993, and so far slightly behind normal in 1994. “Normal” for Austin is 31.88 inches per year, but a typical year has many fluctuations. Fig. 21 shows the pattern for a normal year, 1992, and 1993. Two dry years in a row also could force more fire ants underground to forage for moisture and food.

Fig. 22 shows the spatial distribution of *Rhadine* beetles in Testudo Tube, which lacks fire ants and *Texella*. In this cave *R. subterranea* is more common than *R. persephone*, which occurs slightly more often closer to the entrance. There also are two species of ceiling crickets here, although not as abundant as in LakeLine. We have observed *R. subterranea* even at the beginning of the stream passage on the walls (Zone 6), but not *R. persephone*. The two beetle species do overlap, and one may occasionally see the two species within a short distance of each other, but we have not seen them interact. Both patrol the walls and especially are prone to hunt and dig in soft bedrock, called “pulverulite,” where cave crickets may lay their eggs. However, wherever *R. subterranea* is common, *R. persephone* is uncommon. *R. subterranea* is a more slender and more cave-adapted species than *R. persephone*. Their coexistence in the same cave may depend on slightly different feeding habits and habitat preferences. As in LakeLine both species appear to be more active in the fall and winter (fig. 23). This presumably is when cave crickets are most actively laying eggs, although we have not been able to observe the crickets doing this.

Fig. 24 depicts the distribution of *Texella reyesi* and *Rhadine noctivaga* in Thor Cave. Again there are two species of ceiling crickets. *R. noctivaga* has been seen only in a few areas along the east side of Zones 6 and 7 and on the ceiling of Zone 5. As in all Central Texas *Rhadine*, they rapidly patrol silty areas or ceiling, presumably in search of cricket eggs or possibly nymphs. *T. reyesi* is found very preferentially in Zone 5, which has an optimal combination of food, cover (large rocks), and humidity. Up to 7 *Texella reyesi* have been observed on one visit to the cave, but sometimes none can be found, usually owing to dry and cold conditions.

We have observed *T. reyesi* feeding only once during the many hundreds of man-hours spent in LakeLine and Thor caves. On March 12, 1993 Peter Sprouse and I observed an adult *T. reyesi* feeding on white fungus on top of a raccoon carcass near the Coral Room, on the west side of the Big Room. I quote from my monthly report (Elliott, 1993d):

> I went down to the west side of the Big Room at 5:50 to observe the rotten raccoon we had found in February. It had further decomposed but still had plenty of white fungus and some green and yellow ones too. Then I saw an adult *Texella reyesi* feeding on a small, white ball of fungus on top of the carcass! This is the first reported observation of *Texella* feeding. It put the fungus ball down once, but then came back to it. It kept working the fungus ball with its pedipalps, but I could not see well enough to tell if the chelicerae were moving. Then its two front legs got stuck in the gooey fungus ball. It took the creature several minutes to get free, by gripping surrounding protrusions and pulling itself until the legs came free. It then walked off onto the soil and spent about 2 minutes sitting and slowly “scanning” from side to side with the front four legs upraised. This gave me the impression that it was smelling the air with sensors on its legs. Then it sat still. These observations lasted from 5:50 to 6:15.

This type of feeding surprised me because I had assumed that *Texella* probably was a predator, since it has relatively large raptorial pedipalps. However, some cave-adapted species may opportunistically feed on other rich food sources.

Fig. 25 shows the temporal distribution of *Texella reyesi* and *Rhadine noctivaga* in Thor Cave. *Texella reyesi* was more visible to us in January and February of 1993, but has been seen on almost every visit to the cave.

Observations on Cave Crickets, Daddy Longlegs, and Fire Ants

In this section I will sometimes refer to the evening emergence of crickets and daddy longlegs (DLLs) as a “hop”. We used this shorter and more descriptive term in the field, although in reference to DLLs the term might better be a “bob.”

Rhaphidophorid cave (or “camel”) crickets of the genus *Ceuthophilus* occur in many species across North America. Some are more cave-adapted than others, nevertheless all species that have been studied leave their cave or shelter at night to feed. In the tropics some cave-adapted gryllid crickets remain in the cave all the time. In Kentucky and surrounding areas the rhaphidophorid genus *Hadenoecus* inhabits deep cave areas and has an ecological relationship with *Neaphenops* beetles, who hunt cricket eggs like some *Rhadine* beetles.

Cave crickets are scavenger-predators, or “detritivores,” who prefer high-energy foods such as dead insects, carrion, or some fruits. They do not feed on foliage, but will readily come to baits of cheese, oatmeal, peanut butter, various pet foods, molasses, wheat germ, apples, bananas, and pears (personal observations and S. Hubble, 1993). S. Hubble wrote that they ignored lettuce, alfalfa, and bean sprouts offered to them in a terrarium. Cave crickets are not pests of agricultural crops. They sometimes enter houses but are not pests in the usual sense. In our observations of these crickets we once observed one eating a small, white bracket fungus under a rock and I saw one with a tiny, green fruit in its palps. They like crushed gryllid ("field") crickets and ripe Texas persimmons dropped on the ground, but we have not seen them attracted to ripe prickly pears offered on the ground. In this study they quickly came to slices of American cheese, but so did fire ants.

Competition between crickets and fire ants for cheese is quick and intense. The ecological succession, or battle, for the bait is usually over in a few minutes if many fire ants are nearby. Crickets usually find the cheese first and will circle it to feed. Large adults often come in and kick out the other adults and larger nymphs with their hind legs, but the smaller nymphs usually hold on and are not affected by this. After a few fire ants get on the cheese the crickets usually leave, especially if the ants attack the crickets. We have seen crickets pick up and carry off dead fire ants.

T.H. Hubbell (1936) noted that *Ceuthophilus secretus* apparently begins to mature in May, based on specimens collected on different dates. Nymphs become available in May and July. In this study we found at least some nymphs year-round in the caves and we counted both nymphs and adults during the hops. Hops occurred year-round except in the coldest weather (40° F or below). There were two or three species participating in the hops but we could not usually distinguish them at a distance, especially the nymphs. The in-cave cricket inventories showed a definite shift toward ceiling-species nymphs in the summer and fall, but these data have not been analyzed as yet. The floor-dwelling species, *C. cunicularis* probably was several months out of phase in its reproduction and maturation compared to the ceiling species. It is possible that the two ceiling species were also out of phase, but we were not able to distinguish the adults of *C. secretus* and *C.* n. sp. well enough to include them in the counts. We noticed that the nymphs seemed relatively oblivious to cold air and to our headlamps when we observed a hop. Adults would often skitter back into the entrance when we shone our lights directly on them. At first we used red filters on our lamps, but this made it difficult to count so we adopted a strategy of keeping the light beam directed above the edge of the entrance. Nymphs were nearly always the first to emerge from the entrance, often within 10 or 15 minutes after sunset. Adults would tarry much longer before coming out, especially on cold nights. On some cold nights only nymphs emerged.

The common daddy longlegs harvestman, *Leiobunum townsendi*, did not inhabit LakeLine Cave. A few were occasionally seen in the entrance of Thor Cave but were not abundant enough to bother counting. Testudo Tube contained a large population of this species and a smaller population of three cricket species. Daddy longlegs are not spiders, but harmless members of the arachnid order Opilionida, as are *Texella*. Their anatomy and behavior is very different from a spider and they lack poison glands, but they do give off an odor from scent glands. The secretion is considered by some to be a species-specific repugnatory secretion (S. Hubbell, 1993). Most DLLs are very gregarious and pack themselves into moist retreats and cave entrances. They are very sensitive to desiccation and undergo a dramatic die-off each fall. At Testudo Tube they inhabited the upper ledges and crevices of the entrance sink, whereas the crickets were farther inside the cave during the day. At sunset the DLLS often were poised to come out or were already resting on the ground around the edge of the entrance. They would exit the cave first, followed by the cricket 10 or 15 minutes later.

DLLs are detritivores that feed on carrion or other smelly, high-energy foods. Some species reportedly eat aphids. In the summer of 1994 I collected and shipped live specimens of *Leiobunum townsendi* to a wildlife cinematographer in California who is making a film on garden life for the National Geographic Society. He has reported that this species does eat aphids in captivity. During this study we rarely saw DLLs attempting to eat anything—most of them hung in the Ashe junipers all night and did nothing. On one occasion we saw several of them "tasting" or biting the backs of snails crawling out of Testudo Tube, but these attempts were very brief. DLLs are attracted to cheese and other smelly foods left on the ground.

LakeLine Cave

The cricket hops at LakeLine Cave occurred year-round except in December, 1992. Fig. 26 shows the numbers of nymphs and adults that emerged each month from August, 1992 to June, 1993. Another count was made in August, 1993 to provide a comparison to the previous year. (Ideally, a little more data would have been desirable, but the budgeted work hours ran out.) The graph shows that nymphs outnumbered adults during most emergences until the summer of 1993, when adults were more abundant. Summer probably was at the peak of maturation for the season's new crop of young. The data represent the gross numbers of emerging nymphs and adults. Typically only about 10% or fewer of the crickets hop back into the entrance immediately, so these counts are reasonably representative.

Testudo Tube

Fig. 27 shows the hops at Testudo Tube from August, 1992 to June, 1993, plus a September, 1993 count. The DLLs had populations up to nearly 1,000 in August, 1992, then rapidly declined through October due to the usual annual die-off. The DLLs overwinter as eggs, then begin emerging again in May. The cricket crop in September, 1993 appeared much larger than the previous September, and the proportion of adults to nymphs was much higher. One can only speculate as to why there was such a change—1992 was a wet year and that may have resulted in a larger crop of young to mature in 1993, but 1991 was an even wetter year. Probably many factors can influence the success of crickets from one year to the next. A few factors that come to mind are the number of mice preying on the crickets, the amount of freezing weather, the amount of food available, and disease.

Thor Cave

Thor Cave had the largest apparent cricket population, probably because it is a larger cave with many areas for crickets to roost. Nymphs outnumbered adults at all times during the hops, whereas adults and nymphs sometimes swapped in this regard at the other two caves. The August, 1993, crop was larger than the August, 1992, crop. It is encouraging that such a large population may be maintaining its abundance, but we have no data before 1992 or before red imported fire ants invaded that area, presumably in about 1989 or 1990 (Elliott, 1992h, 1993j). It may yet be possible that fire ants will have an effect on the cricket populations there. No fire ant control has been done around the entrance since 1991 (Elliott, 1993j).

Timing of Cricket Hops

The timing of the cricket and daddy longlegs hops is graphed for the caves in figs. 29-31. The emergence usually begins within 15 or 20 minutes after sunset, but tends to delay longer in the winter because of colder temperatures. The length of the entire hop starts increasing in November, due to cold weather, but drops to zero in December or January, or whenever the outside temperature drops to about 40-45° F , as illustrated for LakeLine in fig. 32. The minimum hop lengths (other than zero) are about 2 or 2.5 hours while the maximum hop lengths are about 4 or 5 hours during cool weather. The crickets, being poikilothermic, simply slow down in the cold weather. Cave crickets have one advantage over fire ants in that they can forage on many cold nights long after fire ants have given up—this was observed many times during our overnight vigils. Fig. 33 shows the relation of hop delay to outside temperature at Testudo Tube. This graph would have looked just like fig. 32 for LakeLine except that the April, 1993, hop was delayed for an extra 30 or 35 minutes even though it was 69° F outside. The reason for that delay probably is that Peter Sprouse and I were in the cave mapping rather late. We exited about 7:30 PM and sunset was at 7:56. Our tardy exit probably frightened the crickets into crevices and caused a delay in the onset of the hop. The crickets usually begin moving toward the entrance an hour or so before sunset.

Surface Bait Stations

Results of bait stations at the three caves are shown in figs. 34-37. At LakeLine we were able to run 23 replicates from August, 1992 to May, 1993. Fig. 34 shows that the great majority of cricket nymphs forage within 10 m of the entrance although some can go as far as 50 m from the entrance. Adults easily travel to 30 m and some as far as 50 m. One a few occasions we saw crickets beyond the preserve enclosure, and on one night we set a 60 m station outside the enclosure and found a large female cricket at the bait. The largest adults probably are capable of traveling far beyond 60 m from the entrance, but I have no data to establish just how far they go. From the looks of the graph probably 95% of the foraging population would remain within 50 m of the entrance. In fig. 35 I had to use a logarithmic scale on the Y axis to show the number of fire ants found at bait stations in contrast to the number of crickets. This graph includes data taken on cold nights when fire ants were not out, so it does not show the worst case. The fire ants on the bait were 1 to 1.5 orders of magnitude greater than the crickets. This does not mean that the crickets are completely prevented from foraging, but the competition for mutually desired foods must be intense, just as when we dropped cheese on the ground and observed competition between the species over a few minutes.

At Testudo Tube, where there were fewer fire ants, the number of fire ants can be shown on a regular arithmetic scale. There happened to be more fire ants near the entrance than far away, so the number of crickets on the bait was depressed near the entrance. Again, some crickets traveled as far as 50 m from the entrance, and probably farther. We accumulated data over 12 replicates at this site.

At Thor Cave the number of fire ants was so huge that we could only achieve 5 replicates—it would have been futile to try on most warm nights when fire ants were foraging. Even so, the dominance of the ants on the bait swamped our attempts to find crickets beyond 10 m of the entrance. No adult crickets were seen on the baits. Instead, we spent more time trying to observe the natural feeding behavior of the crickets. This was when we discovered that they like Texas persimmons (fortunately, a persimmon was growing right at the entrance).

Discussion

It is my opinion that the apparent disappearence of *Texella reyesi* from LakeLine Cave since December, 1992, is the result of climatic drying and fire ant predation on the species. The cave also is somewhat suboptimal habitat for *Texella reyesi*, so it is possible that the species may reappear there later. Continued monitoring, as planned, is needed.

It is obvious from the data collected that fire ants compete intensively with cave crickets during foraging. This probably will lead to the eventual decline of the cave communities unless the fire ants are controlled with low-impact methods. Porter and Savignano (1990) have demonstrated that native soil communities in Central Texas are decimated by red imported fire ants. Cave communities are largely derived from soil communities and so are very similar.

No cave invertebrate community study like this has ever been done in Texas. Baseline ecological data collected during this study will prove valuable in assessing the long-term changes that may occur in these three cave communities, but it also provides basic biological data on a poorly known type of community in Texas. Even three years of data is not enough to smooth out short-term trends. Biological communities are dynamic, and no two years are exactly alike. With the zone inventories and cricket counts that have been done, it will be possible to compare data many years hence with data from the 1990s to assess whether any unwanted changes have occurred. The assessment of more subtle changes, however, may not be possible with the level of detail that we are now using. Further cricket emergence data on a quarterly or semiannual basis would be easy to collect and would provide information on whether or not a major component of the cave community remains healthy. The cost of a factory repair and calibration of the Atkins psychrometer would also be well spent (it is currently malfunctioning).

A few comments on logistics and a little self-criticism are in order. The level of effort that went into designing, building, maintaining the data loggers was not worth the results, which are problematical. Much of the data logger information may have to be discarded because of erratic signals from some of the sensors. Ideally the data loggers should have been tested for a month or two before putting them in the caves. Some of the sensors malfunctioned probably because they were sealed with hot glue early on instead of a more hydrophobic material, such as epoxy. Much more work will have to be done to analyze the large amount of data from the data loggers. On the positive side, however, we collected enough good data from the excellent Atkins psychrometer and the minimum-maximum thermometers to give us a good characterization of the microclimate in each of the three caves.

Management of these three preserves has not followed the schedule that was conceived in the LakeLine Mall Habitat Conservation Plan. There has been no fire ant control paid for and little surveillance of the preserves, even though funds were set aside for those purposes. The responsibility for the preserves was supposed to have been transferred to the Texas Parks & Wildlife Department, but to my knowledge no person in that agency has clearly been assigned the duty of making sure that the HCP is carried out. There is no officially designated manager for the preserves, though I have served that role on an informal basis. I have not been able to make these things happen because I have no authority to do so.

Recommendations

1. Fire ant control using low-impact methods, such as hot water treatments, needs to be implemented at the three preserves in order to preserve the cave communities from eventual decline.
2. Further monitoring in the caves should be continued as planned, especially with regard to the apparent disappearance of *Texella reyesi* in LakeLine Cave.
3. Either the Fish & Wildlife Service or the Texas Parks & Wildlife Department should select a manager for the three cave preserves and give that manager the authority to make sure that ecology studies, fire ant control, surveillance, and security measures are carried out according to the HCP. I am quite willing to serve as the manager in conjunction with an official of either agency who has the authority to manage the money that has been set aside by the Simon Co. for these activities. The Simon Co. should not be required to continue to manage funds for the preserves—they have done their part. Principles for biological management of karst preserves may be found in Elliott (1993i, 1993j, 1994c).
4. Further collection of data logger data has been discontinued and should not be revived until the erratic signal problem can be solved. No funds are budgeted for further analysis of the data that was collected.
5. If possible, quarterly or semiannual cricket emergence counts should be done at each of the three caves to provide comparison data for the future. Since the Simon Co. has provided the funds for the one-year cricket study, as agreed, perhaps funding for this could come from an agency source. Estimated cost for myself to do a semiannual count is about $2,500, including travel. No assistant is required for this work, which does not involve entering the caves.

Acknowledgments

My thanks go to Mr. Joe Stallsmith for his kindness and patience in supporting this study on behalf of the Simon Development Co., Inc. I am grateful to my colleagues in the field, Peter Sprouse, Doug Allen, James Reddell, and Robert Crowder, for their hard work and many helpful ideas. Working with them is always a pleasure. I would also like to thank Rune Burnett of the Texas Parks & Wildlife Department for helping us at Thor Cave on August 31, 1993.

Literature Cited

Bull, E., and R.W. Mitchell. 1972. Temperature and relative humidity responses of two Texas cave-adapted millipedes, *Cambala speobia* (Cambalida: Cambalidae) and *Speodesmus bicornourus* (Polydesmida: Vanhoeffeniidae). *International Journal of Speleology,* 4:365-393.

Elliott, W.R., and J.R. Reddell. 1989. The status and range of five endangered arthropods from caves in the Austin, Texas, region. Austin Regional Habitat Conservation Plan. 100 pp.

Elliott, W.R. 1990. Endangered species, endangered caves. NSS News, Sept., 48(9):225-231.

———. 1991a. Preliminary ecological monitoring at LakeLine Cave, 9 May 1991. Report to Melvin Simon and Assocs. and Horizon Environmental Services, Inc. 4 pp.

———. 1991b. Ecological monitoring at LakeLine Cave, 21 June 1991. Report to Melvin Simon and Assocs. and Horizon Environmental Services, Inc. 5 pp.

———. 1991c. Ecological monitoring at LakeLine Cave, 6 August 1991. Report to Melvin Simon and Assocs. and Horizon Environmental Services, Inc. 7 pp.

———. 1991d. Ecological monitoring at LakeLine Cave and Testudo Tube, 24 September 1991. Report to Melvin Simon and Assocs. and Horizon Environmental Services, Inc. 6 pp.

———. 1991e. Ecological monitoring at LakeLine Cave, 30 October & 29 November 1991. Report to Melvin Simon and Assocs. and Horizon Environmental Services, Inc. 7 pp.

———. 1991f. Ecological monitoring at LakeLine Cave, 31 December 1991. Report to Melvin Simon and Assocs. and Horizon Environmental Services, Inc. 2 pp.

———. 1992a. Ecological studies of three caves in Williamson County, Texas: June, 1992. Report to Melvin Simon & Assocs., Indianapolis. 2 pp.

———. 1992b. Ecological studies of three caves in Williamson County, Texas: June, 1992. Report to Melvin Simon & Assocs., Indianapolis. 2 pp.

———. 1992c. Ecological studies of three caves in Williamson County, Texas: July, 1992. Report to Melvin Simon & Assocs., Indianapolis. 3 pp.

———. 1992d. Ecological studies of three caves in Williamson County, Texas: August, 1992. Report to Melvin Simon & Assocs., Indianapolis. 5 pp.

———. 1992e. Ecological studies of three caves in Williamson County, Texas: September, 1992. Report to Melvin Simon & Assocs., Indianapolis. 3 pp.

———. 1992f. Ecological studies of three caves in Williamson County, Texas: October, 1992. Report to Melvin Simon & Assocs., Indianapolis. 4 pp.

———. 1992g. Ecological studies of three caves in Williamson County, Texas: November, 1992. Report to Melvin Simon & Assocs., Indianapolis. 4 pp.

———. 1992h. Fire ants invade Texas caves. *American Caves*, Winter 1992: 13.

———. 1993a. Ecological studies of three caves in Williamson County, Texas: December, 1992. Report to Melvin Simon & Assocs., Indianapolis. 5 pp.

———. 1993b. Ecological studies of three caves in Williamson County, Texas: January, 1993. Report to Melvin Simon & Assocs., Indianapolis. 4 pp.

———. 1993c. Ecological studies of three caves in Williamson County, Texas: February, 1993. Report to Melvin Simon & Assocs., Indianapolis. 11 pp.

———. 1993d. Ecological studies of three caves in Williamson County, Texas: March, 1993. Report to Melvin Simon & Assocs., Indianapolis. 4 pp.

———. 1993e. Ecological studies of three caves in Williamson County, Texas: April, 1993. Report to Melvin Simon & Assocs., Indianapolis. 3 pp.

———. 1993f. Ecological studies of three caves in Williamson County, Texas: May-July, 1993. Report to Melvin Simon & Assocs., Indianapolis. 7 pp.

———. 1993g. Ecological studies of three caves in Williamson County, Texas: August, 1993. Report to Melvin Simon & Assocs., Indianapolis. 7 pp.

———. 1993h. Ecological studies of three caves in Williamson County, Texas: November-December, 1993. Report to Melvin Simon & Assocs., Indianapolis. 7 pp.

———. 1993i. Cave fauna conservation in Texas. pp. 323-337 in Foster, D. [ed.], Proc. Natl. Cave Mgmt. Symp., 1992, Bowling Green, Kentucky. Amer. Cave Consv. Assoc., Horse Cave, Kentucky.

———. 1993j. Fire ants and endangered cave invertebrates: a control and ecological study. Report to Texas Parks & Wildlife Dept. 33 pp.

———. 1994a. Community ecology of three Central Texas caves. 1994 NSS Convention Program Abstracts, p. 54.

———. 1994b. Ecological studies of three caves in Williamson County, Texas: May, 1994. Report to Melvin Simon & Assocs., Indianapolis. 7 pp.

———. 1994c. Conservation of Texas caves and karst. pp. 85-98 *in* Elliott, W.R., and G. Veni (eds.), *The Caves and Karst of Texas*. 1994 National Speleological Society Convention Guidebook. 342 pp. + vii + 12 map pp.

Hölldobler, B., and E.O. Wilson, 1990. *The Ants.* Belknap Press of Harvard Univ. Press, Cambridge, Mass. 732 pp.

Hubbell, S. 1993. *Broadsides from the Other Orders: A Book of Bugs.* Random House, New York. 276 pp.

Hubbell, T.H. 1936. A monographic revision of the genus *Ceuthophilus* (Orthoptera, Gryllacrididae, Rhaphidophorinae). Univ. of Florida Publ., 2(1):551 + XXXVIII pl.

Porter, S. and D.A. Savignano. 1990. Invasion of polygyne fire ants decimates native ants and disrupts arthropod community. Ecology, 71:2095-2106.

Reddell, J.R. 1991. Further study of the status and range of endangered arthropods from caves in the Austin, Texas, region. A report on a study for the U. S. Fish & Wildlife Service. iv + 178 pp.

——— and W.R. Elliott. 1991. Distribution of endangered karst invertebrates in the Georgetown area, Williamson County, Texas. Report to the City of Georgetown. 64 pp.

———. 1994. The cave fauna of Texas. pp. 31-50 *in* Elliott, W.R., and G. Veni (eds.), *The Caves and Karst of Texas*. 1994 National Speleological Society Convention Guidebook. 342 pp. + vii + 12 map pp.

Russell, W. H. 1993. The Buttercup Creek Karst, Travis and Williamson counties, Texas. Geology, biology, and land development. Univ. Speleol. Soc., Univ. Texas, Austin. 76 pp.

Ubick, D., and T.S. Briggs. 1992. The harvestman family Phalangodidae. 3. Revision of *Texella* Goodnight and Goodnight. Texas Mem. Mus., Speleol. Monogr.,3:155-240.

Wexler, A. 1976. Vapor pressure formulation for water in range 0 to 100°C. A revision. *Journal of Research of the National Bureau of Standards. A. Physics and Chemistry.* 80A:775-785.

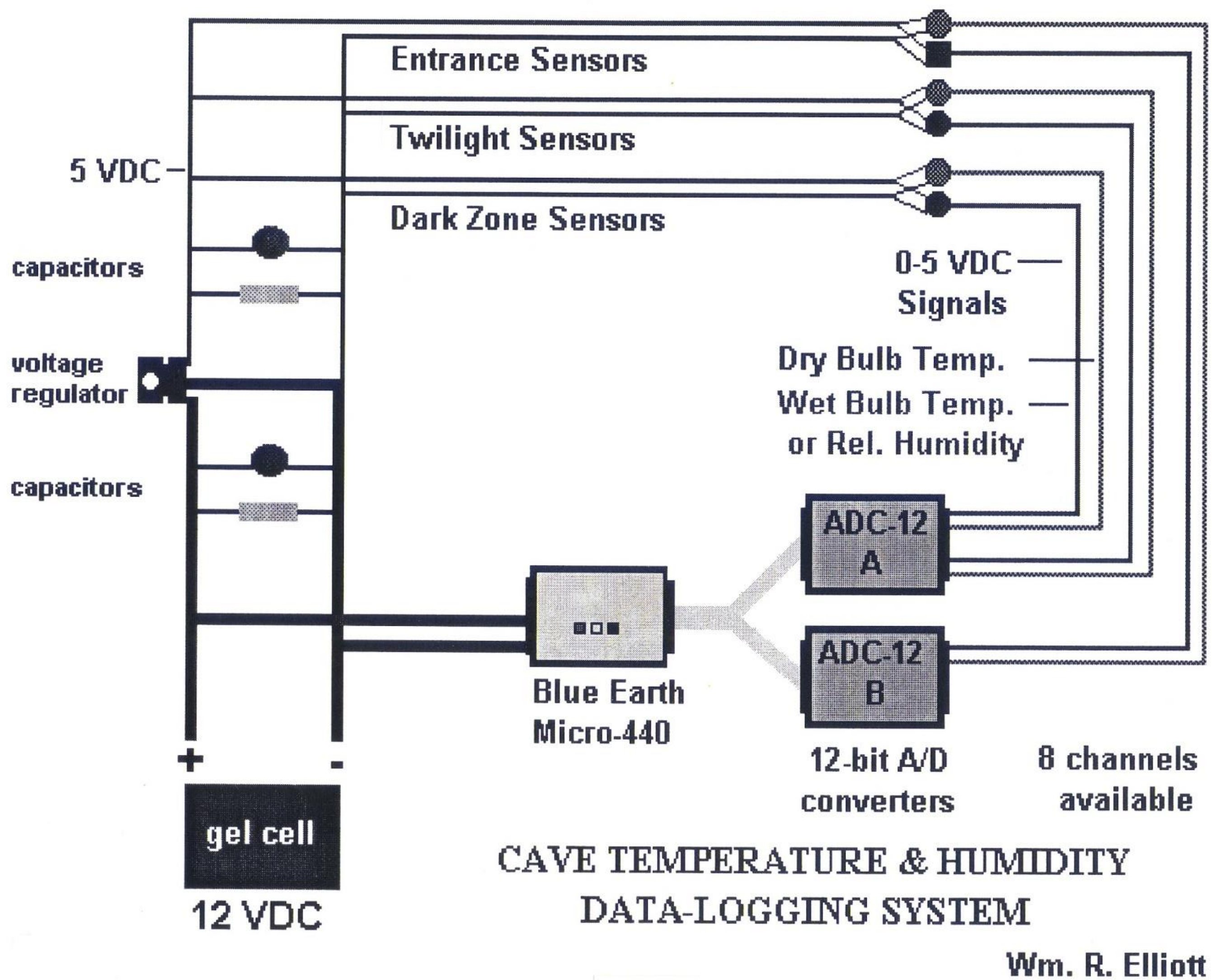

Entrance Sensors
Twilight Sensors
Dark Zone Sensors
5 VDC
capacitors
voltage regulator
capacitors
+
-
gel cell
12 VDC
0-5 VDC Signals
Dry Bulb Temp.
Wet Bulb Temp. or Rel. Humidity
ADC-12 A
ADC-12 B
Blue Earth Micro-440
12-bit A/D converters
8 channels available
CAVE TEMPERATURE & HUMIDITY DATA-LOGGING SYSTEM
Wm. R. Elliott

Fig. 1

CAVE FAUNA INVENTORY

Baseline Ecology Study of LakeLine, Testudo, Thor caves

CAVE: **DATE:** **TIME:** **OBSERVER:**

REMARKS (moisture conditions, signs of flooding, anything unusual):

ZONES

	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Other**
Start/stop time, each									
New coon scats/other									
Crickets, ceiling, adults									
Crickets, ceiling,									
Crickets, ceiling,									
Crickets, floor, adults									
Crickets, floor,									
Crickets, floor, nymphs									
Leiobunum townsendii									
Texella reyesi									
Rhadine persephone									
Rhadine subterranea									
Rhadine noctivaga									
Tachys									
Staphylinidae									
Collembola									
Campodeid diplurans									
Texoreddellia									
Bristletails									
Solenopsis invicta									
Myrmecodesmus									
Cambala									
Speodesmus									
Centipedes									
Cicurina varians									
Cicurina, small white									
Eidmannella									
Small spiders (specify)									
Mites									
Snails									
Sphalloplana									
Stygobromus									
Eurycea									
Other (specify)									

spform.doc 9-93

CAVE MICROCLIMATE DATA
Baseline Ecology Study of LakeLine, Testudo, Thor Caves

CAVE: **DATE:** **TIME:** **OBSERVER:**
REMARKS: Unless otherwise stated, all are °F. Note if reading is in water, soil, etc.

LOCATION	Time	Psychro. Dry Bulb	Psychro. Wet Bulb	R.H.	Min. Min-max	Max. Min-max	Reset Min-max	Alc. Therm.	Remarks
Outside (shade)									
Entrance Probe									
Mid Probe									
End Probe									
Lower Level									

William R. Elliott, tempform.doc, 5-94

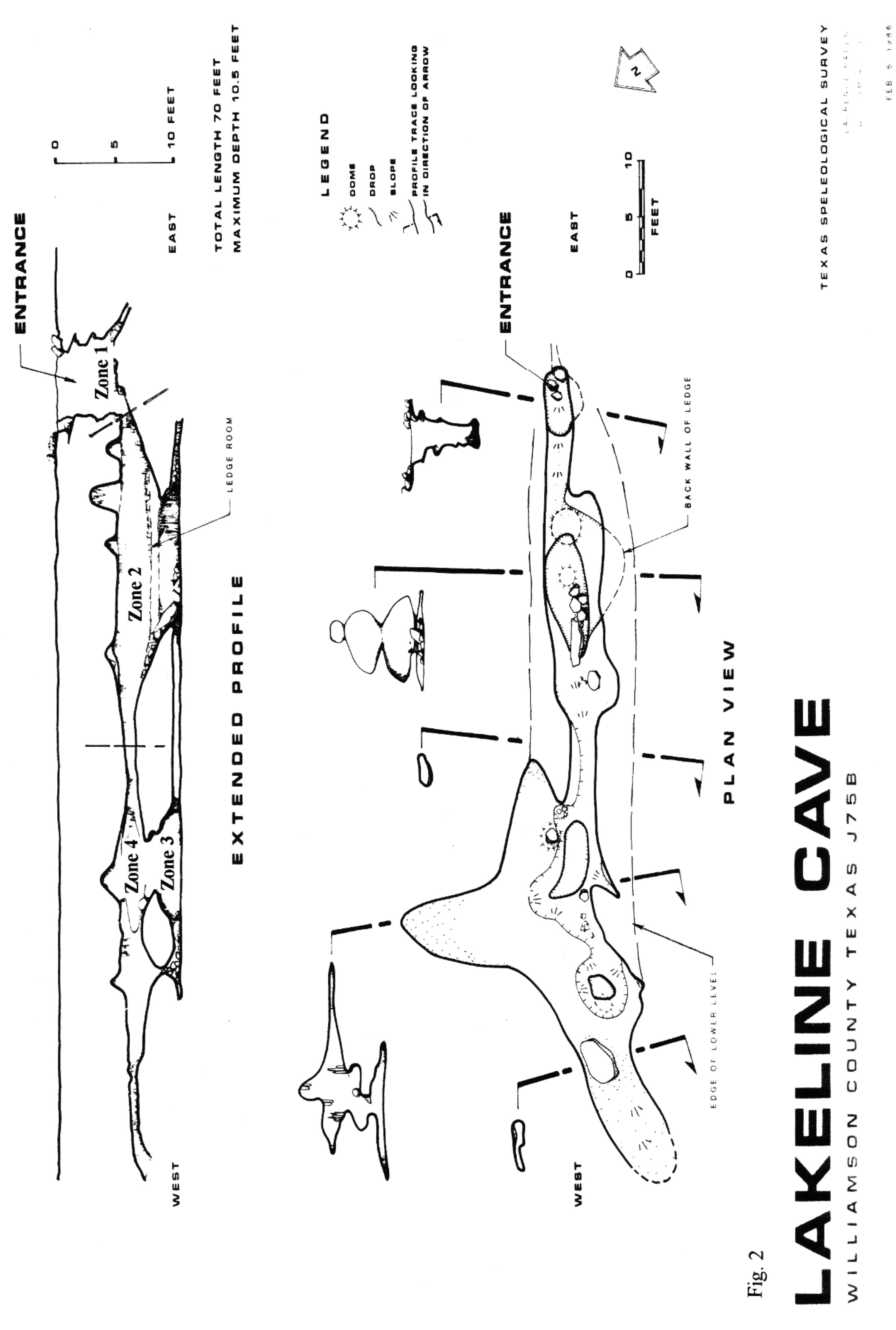

ENTRANCE
EAST
WEST
0
5
10 FEET
TOTAL LENGTH 70 FEET
MAXIMUM DEPTH 10.5 FEET
Zone 1
Zone 2
Zone 3
Zone 4
LEDGE ROOM
EXTENDED PROFILE
LEGEND
DOME
DROP
SLOPE
PROFILE TRACE LOOKING IN DIRECTION OF ARROW
N
ENTRANCE
EAST
WEST
0 5 10
FEET
BACK WALL OF LEDGE
EDGE OF LOWER LEVEL
PLAN VIEW
LAKELINE CAVE
WILLIAMSON COUNTY TEXAS J75B
TEXAS SPELEOLOGICAL SURVEY

Fig. 2

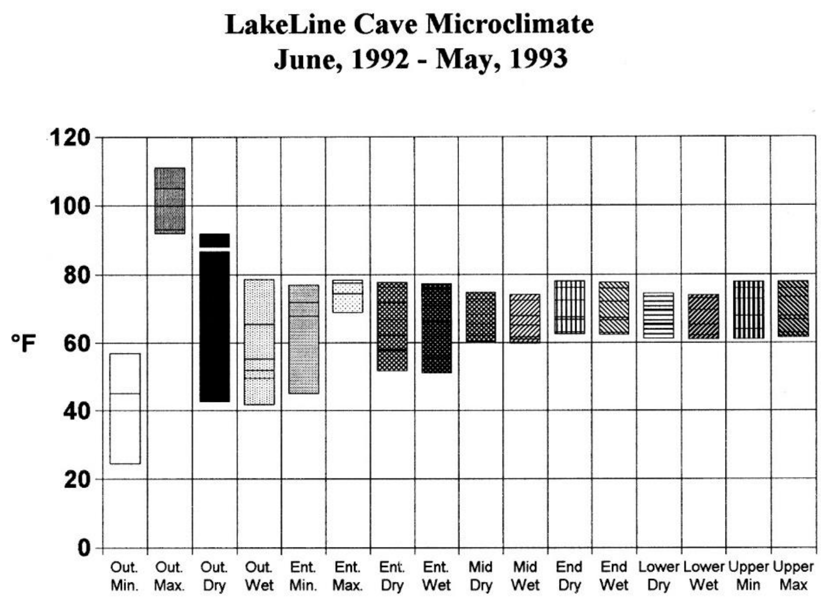

LakeLine Cave Microclimate
June, 1992 - May, 1993
120
100
80
°F 60
40
20
0
Out. Min.
Out. Max.
Out. Dry
Out. Wet
Ent. Min.
Ent. Max.
Ent. Dry
Ent. Wet
Mid Dry
Mid Wet
End Dry
End Wet
Lower Dry
Lower Wet
Upper Min
Upper Max

Fig. 3

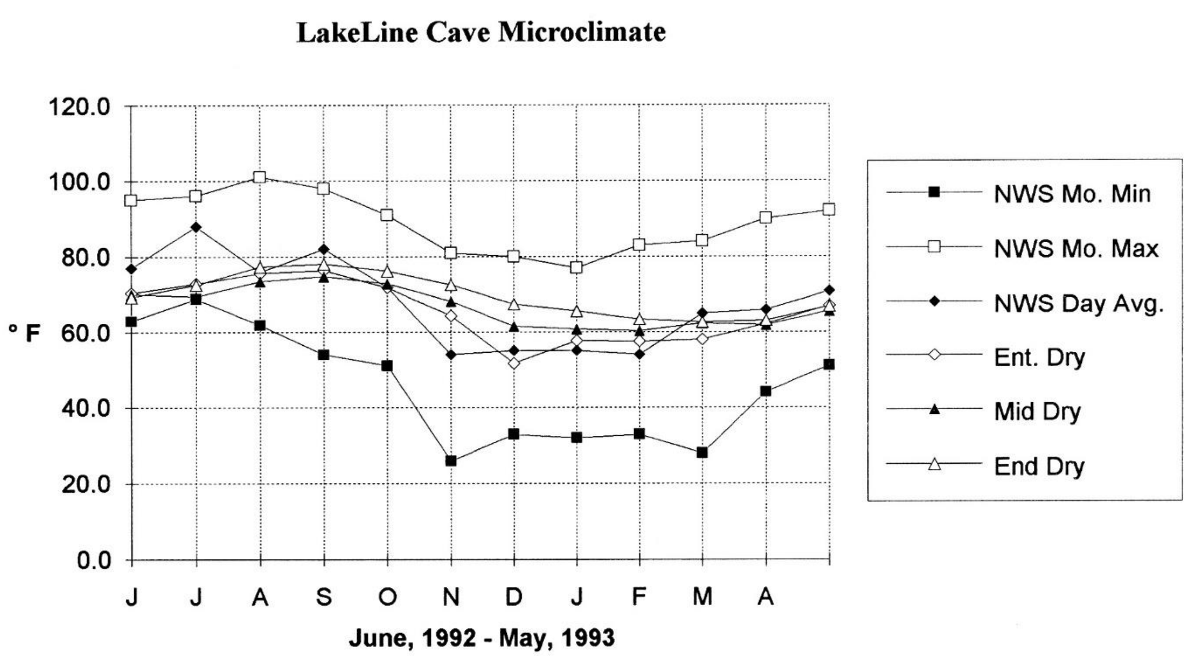

LakeLine Cave Microclimate
120.0
100.0
80.0
° F 60.0
40.0
20.0
0.0
J
J
A
S
O
N
D
J
F
M
A
June, 1992 - May, 1993
NWS Mo. Min
NWS Mo. Max
NWS Day Avg.
Ent. Dry
Mid Dry
End Dry

Fig. 4

LakeLine Cave Microclimate
June, 1992 - May, 1993

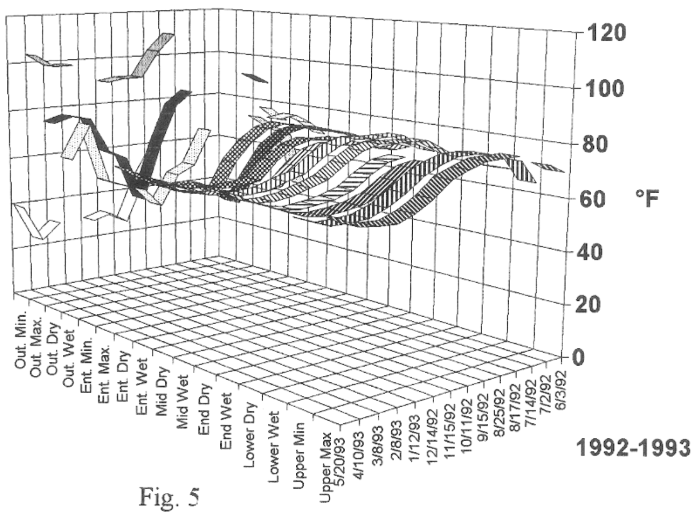
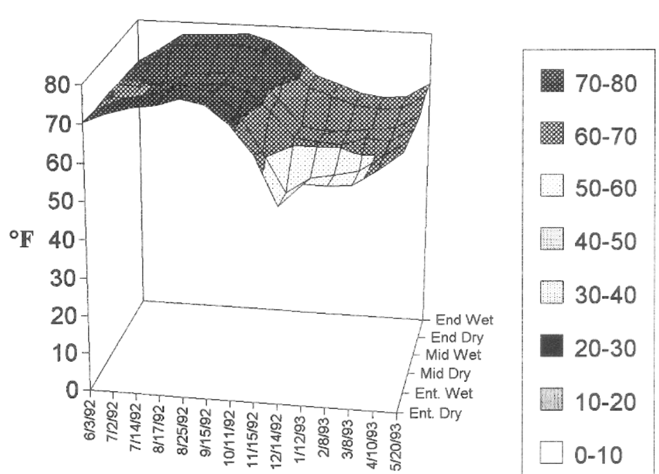


Fig. 5

LakeLine Cave Microclimate
(depicted as topographic surface)



June, 1992 - May 1993

Fig. 6

LakeLine Cave, Rainfall & Cold Fronts (Minimum Temperature) vs. Wet Bulb Depression (WBD)

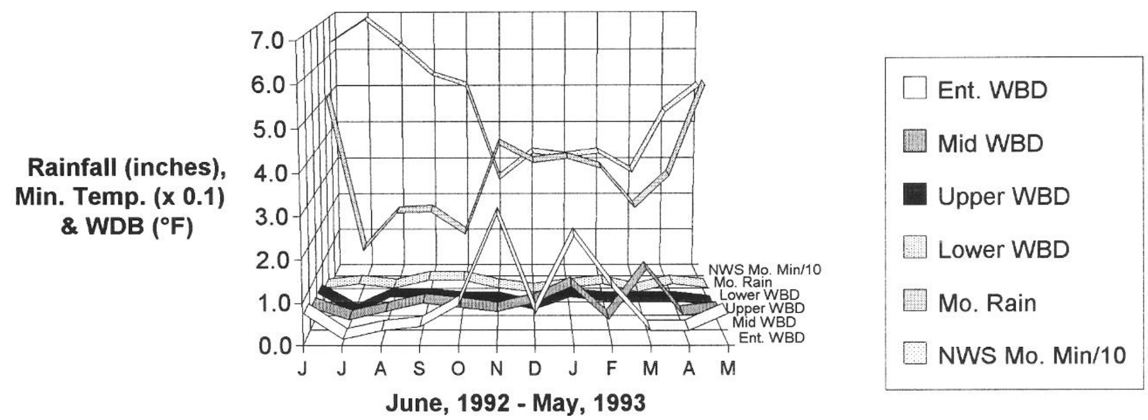


Fig. 7

LakeLine Cave Microclimate

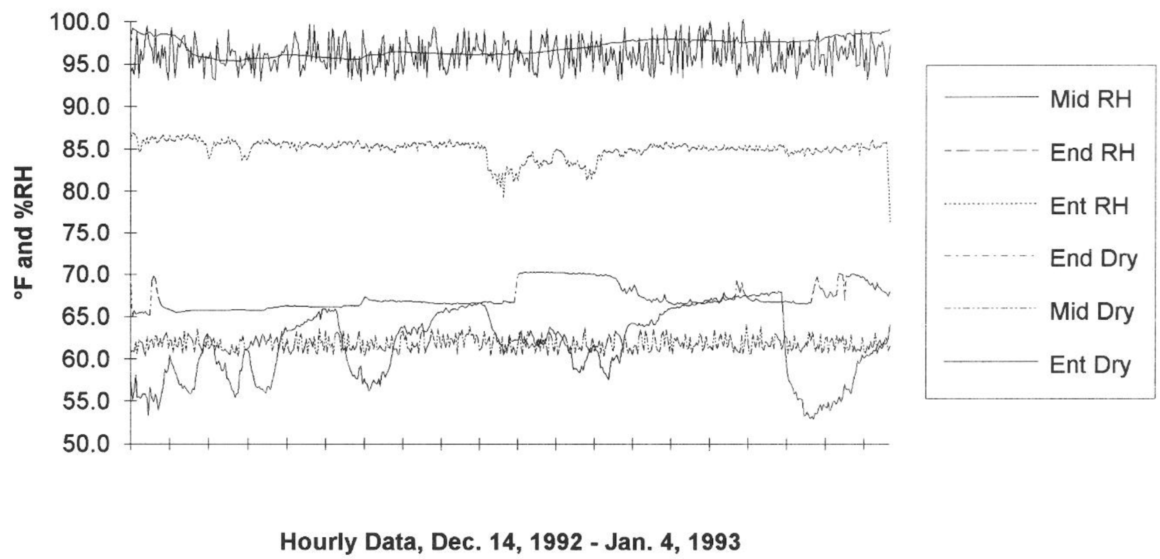
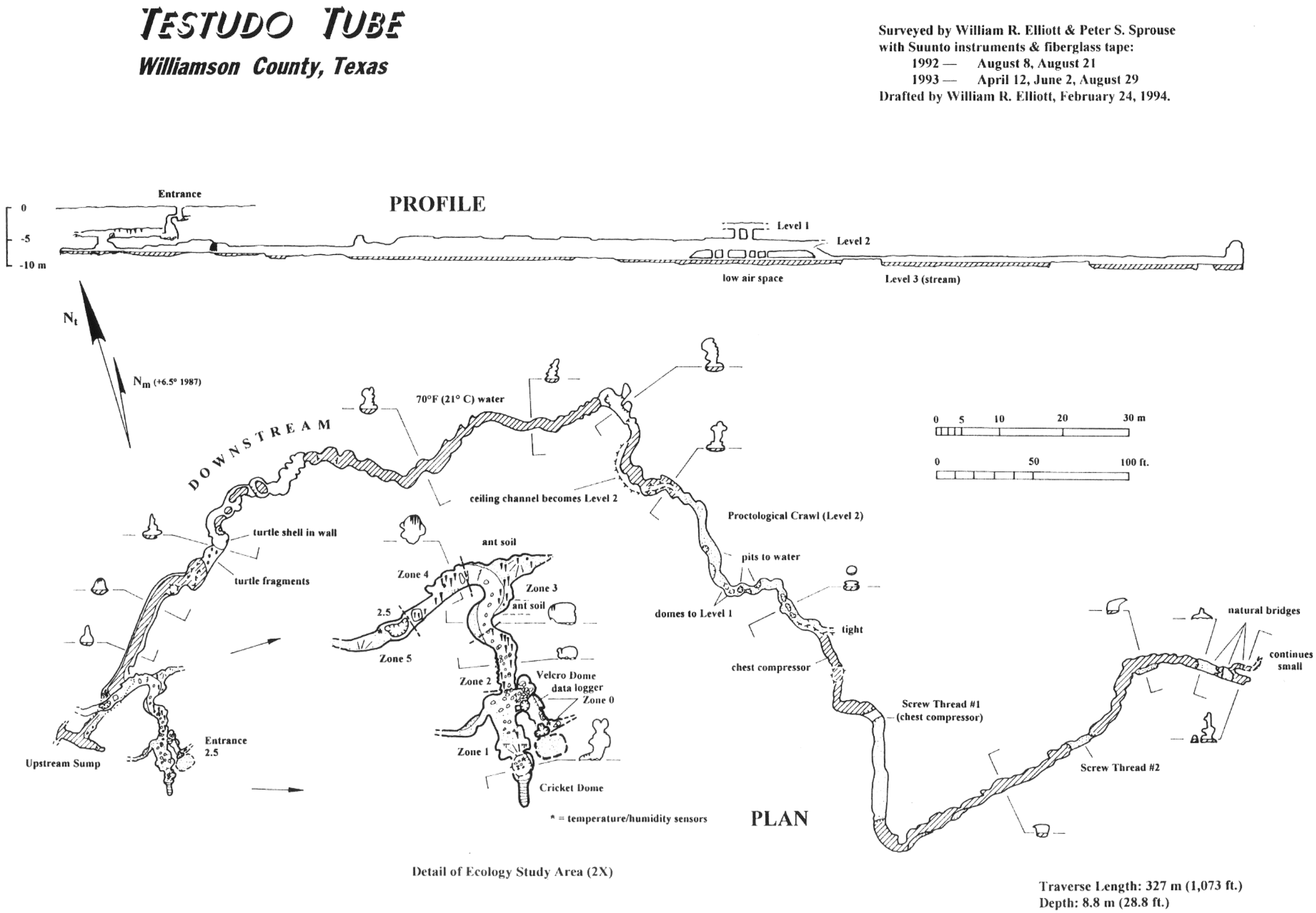


Fig. 8



TESTUDO TUBE
Williamson County, Texas
Surveyed by William R. Elliott & Peter S. Sprouse
with Suunto instruments & fiberglass tape:
1992 — August 8, August 21
1993 — April 12, June 2, August 29
Drafted by William R. Elliott, February 24, 1994.
PROFILE
Entrance
0
-5
-10 m
Level 1
Level 2
low air space
Level 3 (stream)
N_t
N_m (+6.5° 1987)
DOWNSTREAM
70°F (21° C) water
ceiling channel becomes Level 2
Proctological Crawl (Level 2)
pits to water
domes to Level 1
tight
chest compressor
Screw Thread #1
(chest compressor)
Screw Thread #2
natural bridges
continues
small
turtle shell in wall
turtle fragments
Upstream Sump
Entrance
2.5
ant soil
Zone 4
Zone 3
ant soil
2.5
Zone 5
Zone 2
Velcro Dome
data logger
Zone 0
Zone 1
Cricket Dome
* = temperature/humidity sensors
PLAN
Detail of Ecology Study Area (2X)
0 5 10 20 30 m
0 50 100 ft.
Traverse Length: 327 m (1,073 ft.)
Depth: 8.8 m (28.8 ft.)
Measurements in meters

Fig. 9

[Area map of Godwin Ranch, available only to selected researchers on request.]

Testudo Tube Microclimate
June, 1992 - May, 1993

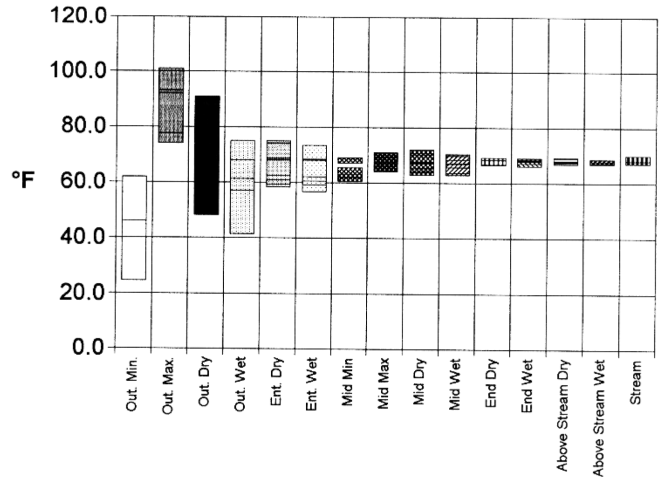


Fig. 11

Testudo Tube Microclimate

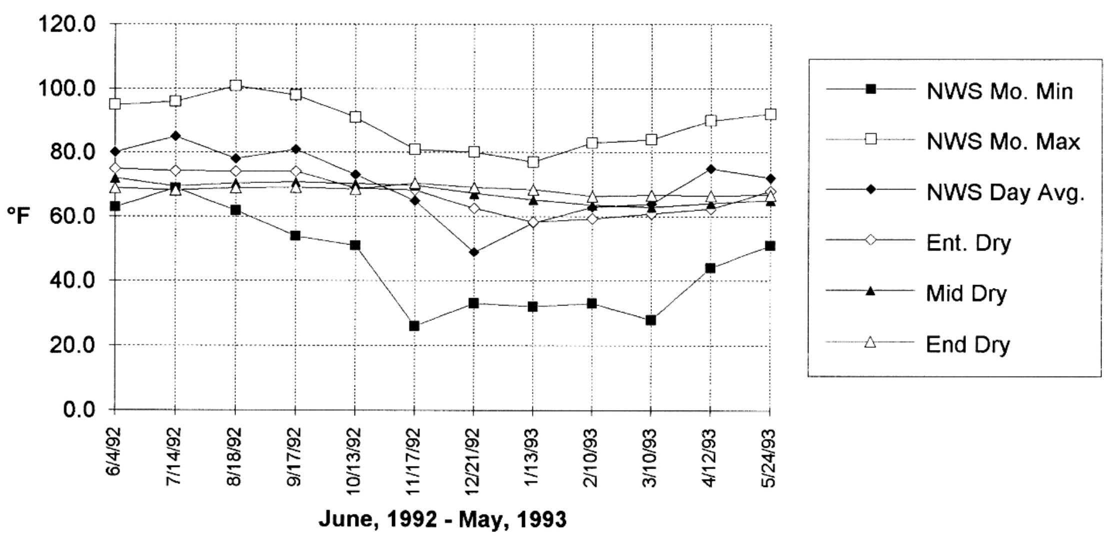
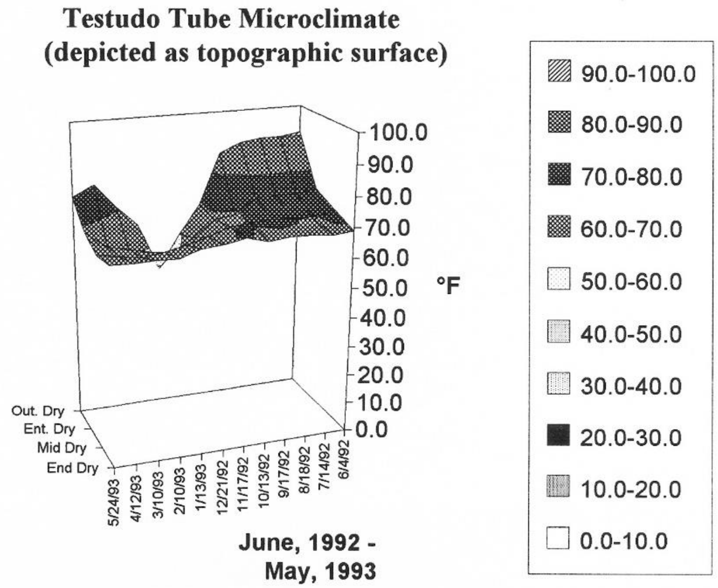
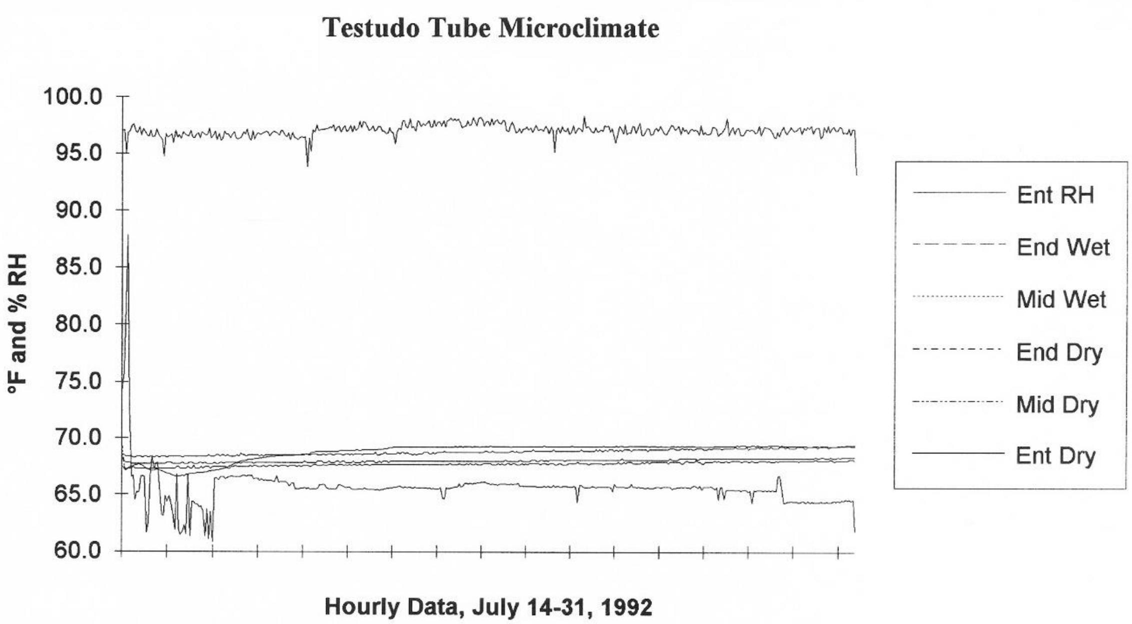


Fig. 12



Testudo Tube Microclimate
(depicted as topographic surface)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
°F
Out. Dry
Ent. Dry
Mid Dry
End Dry
5/24/93
4/12/93
3/10/93
2/10/93
1/13/93
12/21/92
11/17/92
10/13/92
9/17/92
8/18/92
7/14/92
6/4/92
June, 1992 -
May, 1993
90.0-100.0
80.0-90.0
70.0-80.0
60.0-70.0
50.0-60.0
40.0-50.0
30.0-40.0
20.0-30.0
10.0-20.0
0.0-10.0

Fig. 13



Testudo Tube Microclimate
100.0
95.0
90.0
85.0
80.0
75.0
70.0
65.0
60.0
°F and % RH
Ent RH
End Wet
Mid Wet
End Dry
Mid Dry
Ent Dry
Hourly Data, July 14-31, 1992

Fig. 14

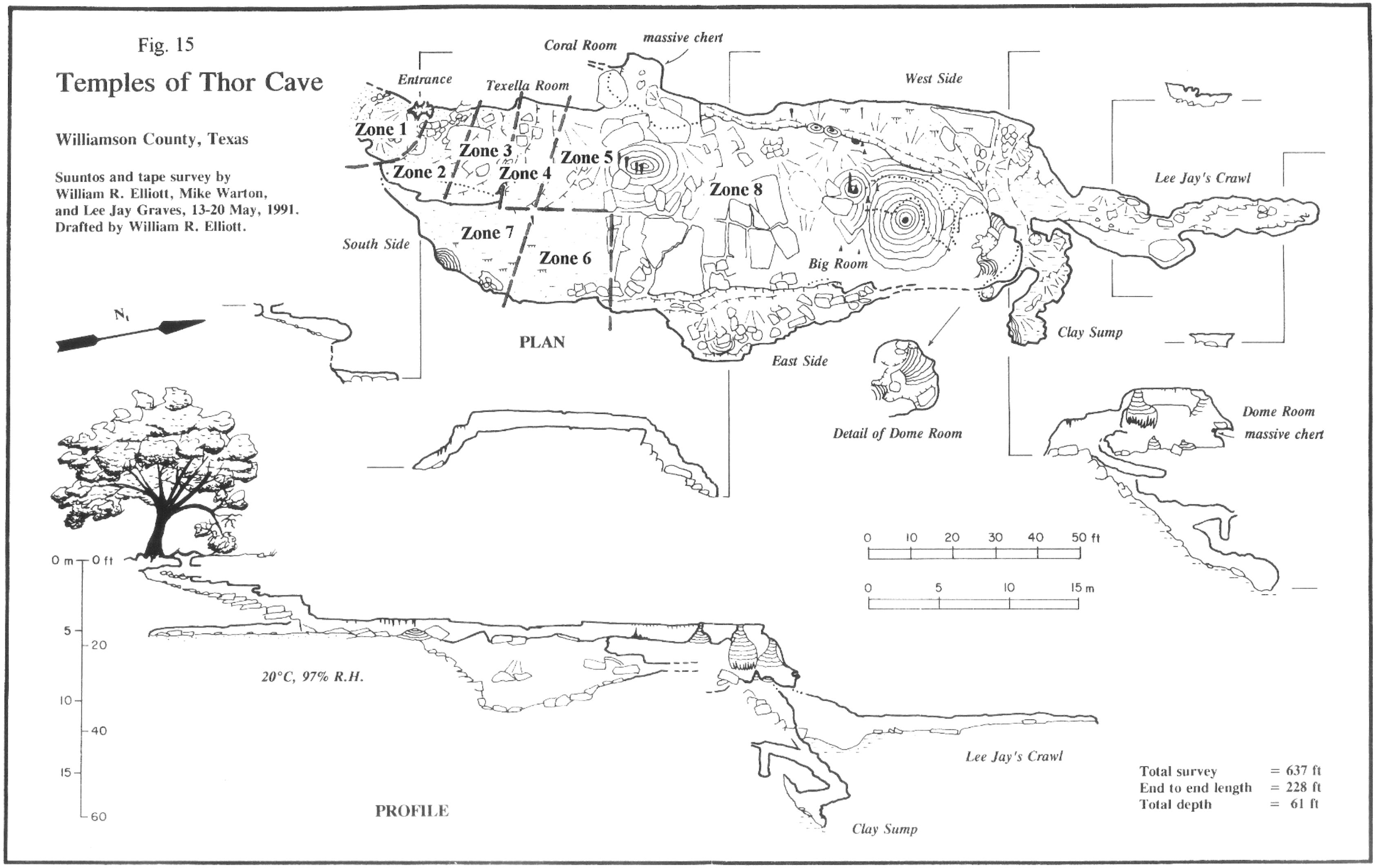


Fig. 15

Temples of Thor Cave

Thor Cave Microclimate

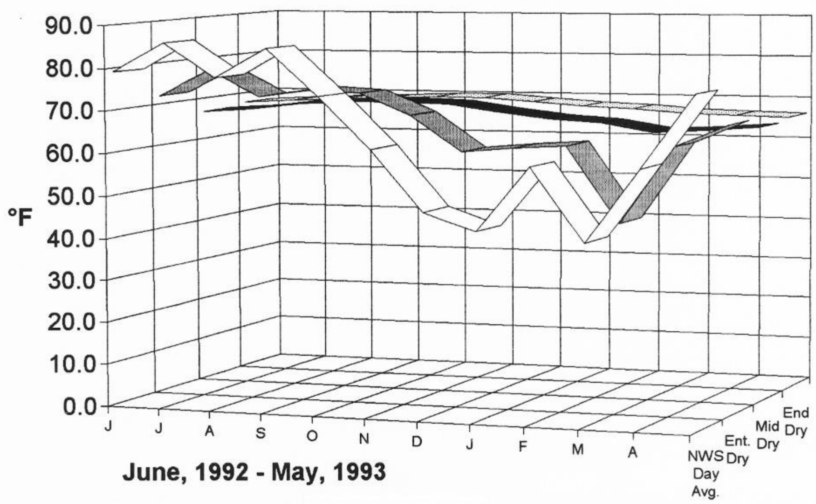


Fig. 16

Thor Cave Microclimate

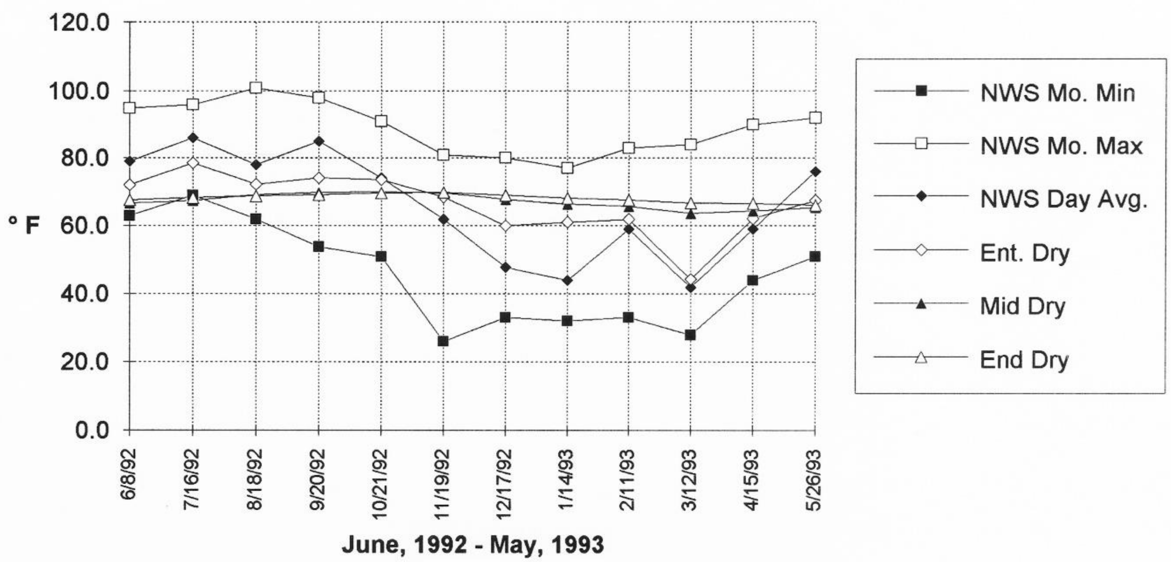


Fig. 17

Thor Cave Microclimate

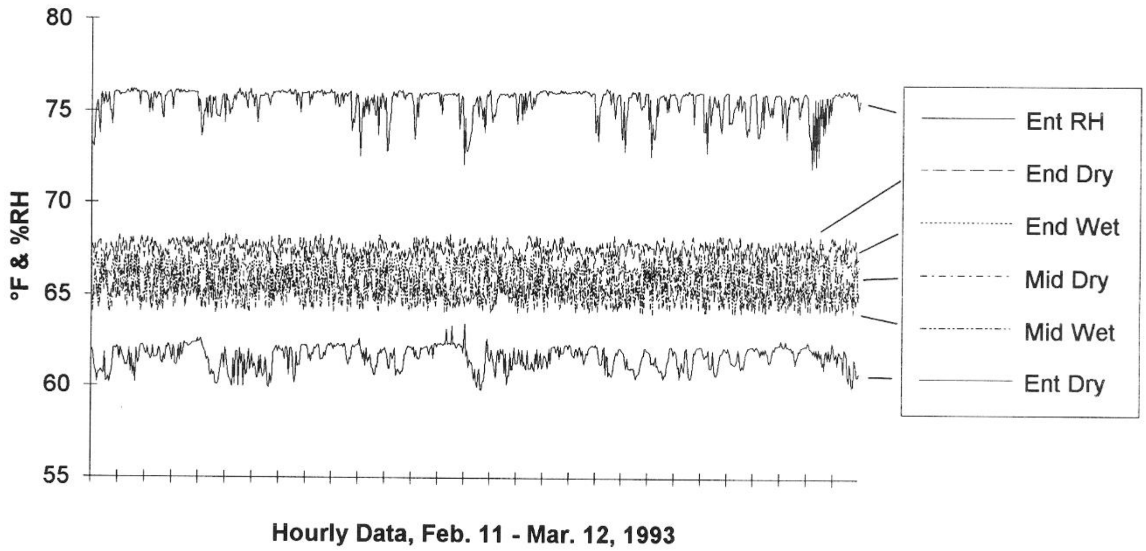


Fig. 18

Rhadine & Texella Distribution in LakeLine Cave
(May, 1991 - May, 1994)

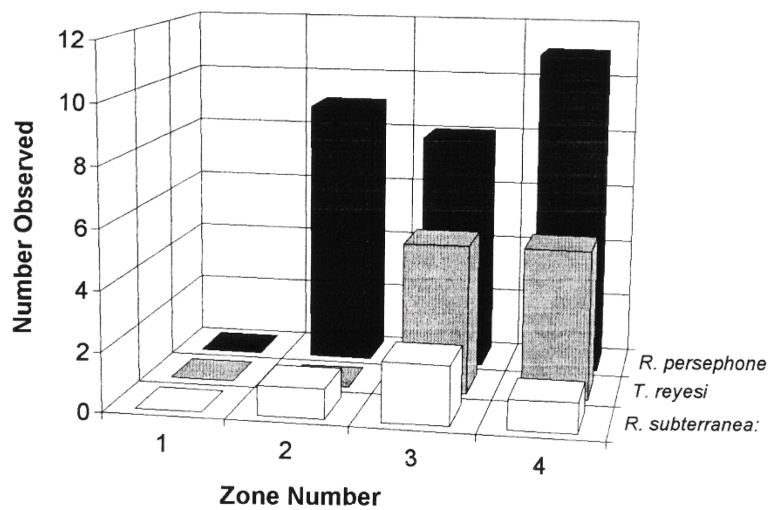


Fig. 19

Rhadine & Texella Activity in LakeLine Cave

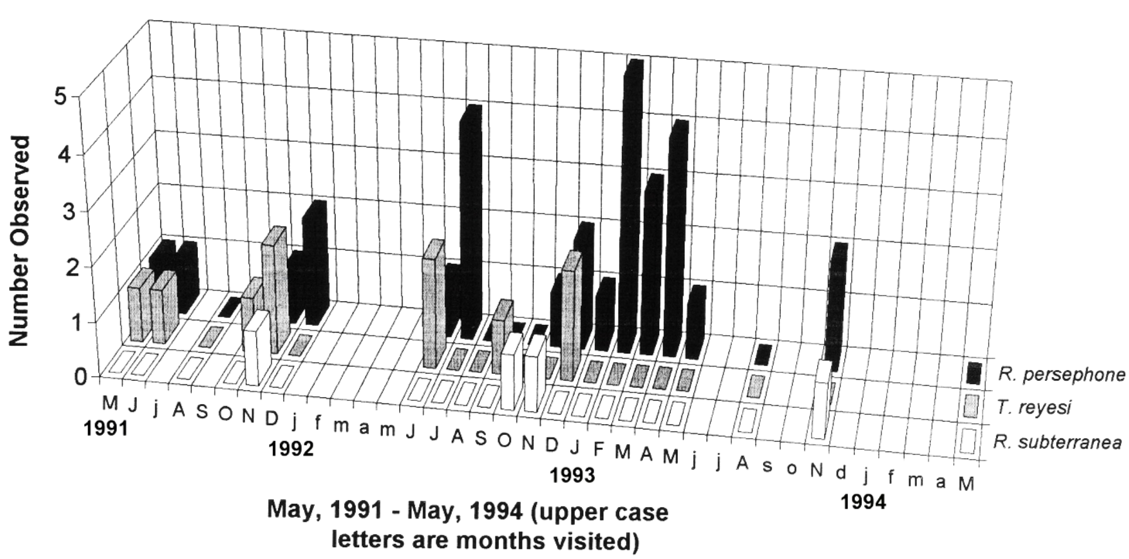


Fig. 20

Austin's Rainfall, Normal vs. 1992-1993

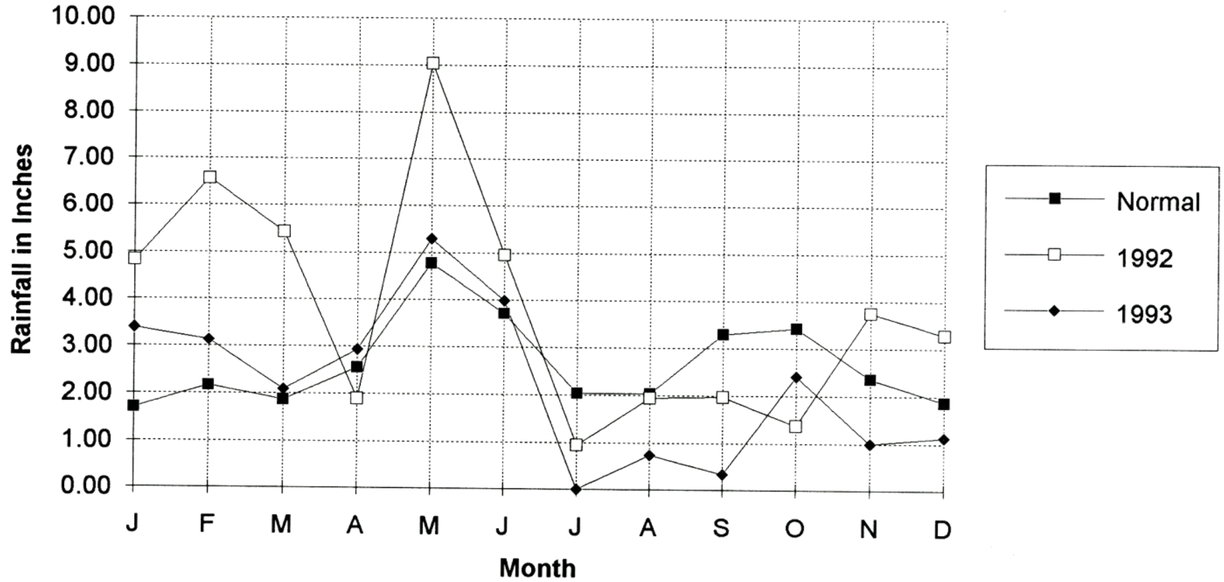


Fig. 21

Rhadine Beetle Distribution in Testudo Tube
(Sep. 1992 - May 1994)

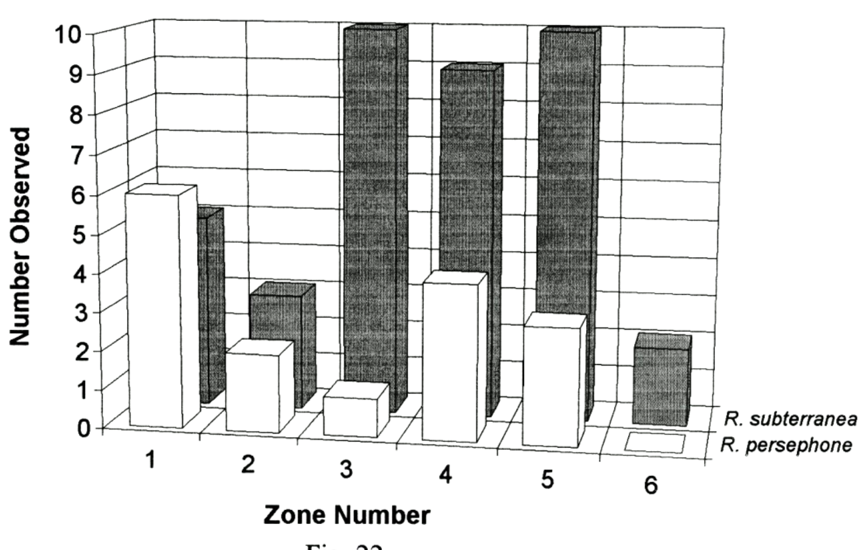


Fig. 22

Rhadine Beetle Activity in Testudo Tube

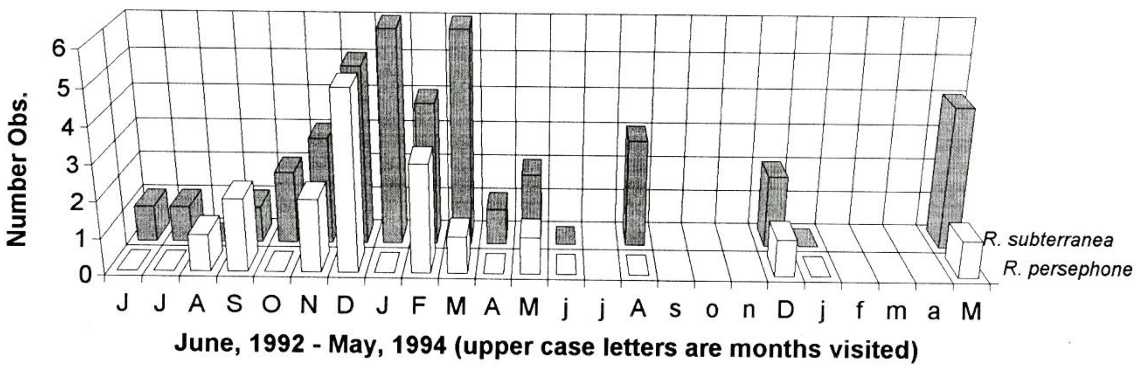


Fig. 23

Texella & Rhadine Distribution in Thor Cave (June, 1992 - May, 1994)

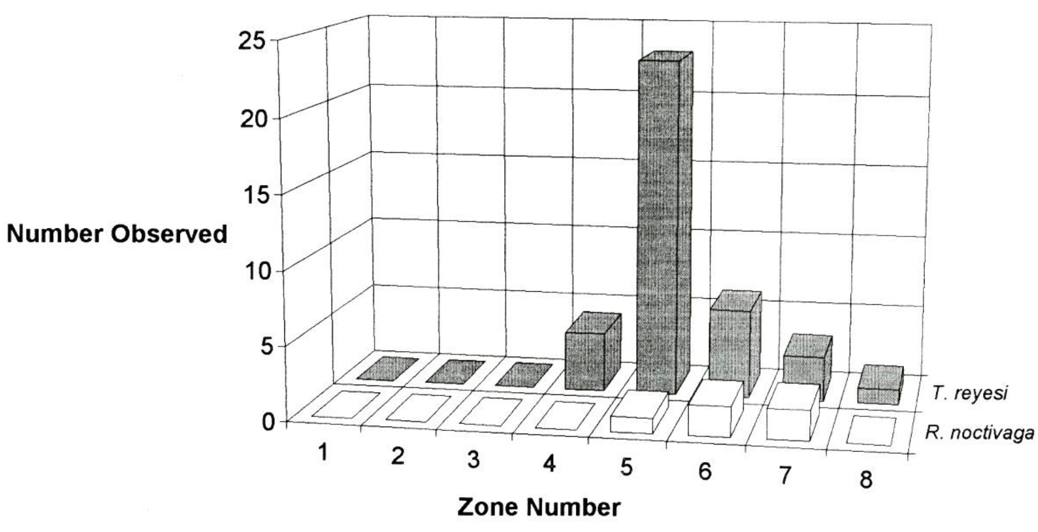


Fig. 24

Texella & Rhadine Activity in Thor Cave

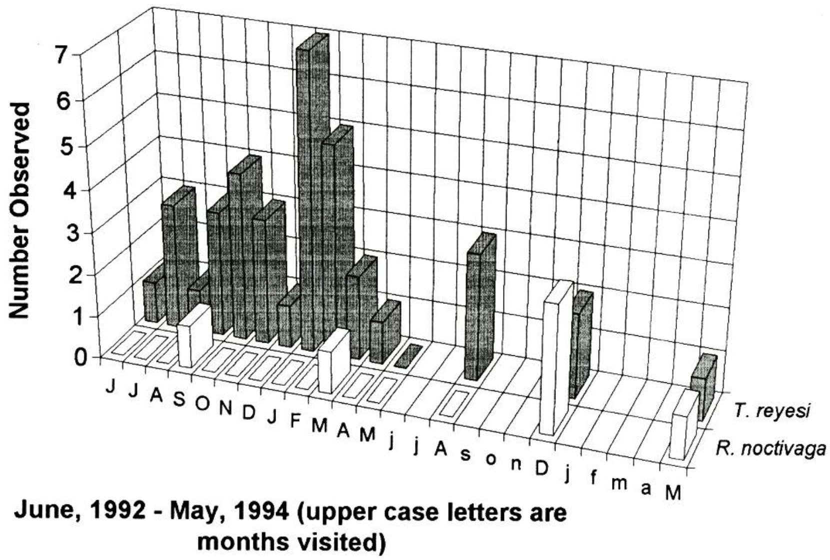


Fig. 25

LakeLine Cave: Cricket Emergences

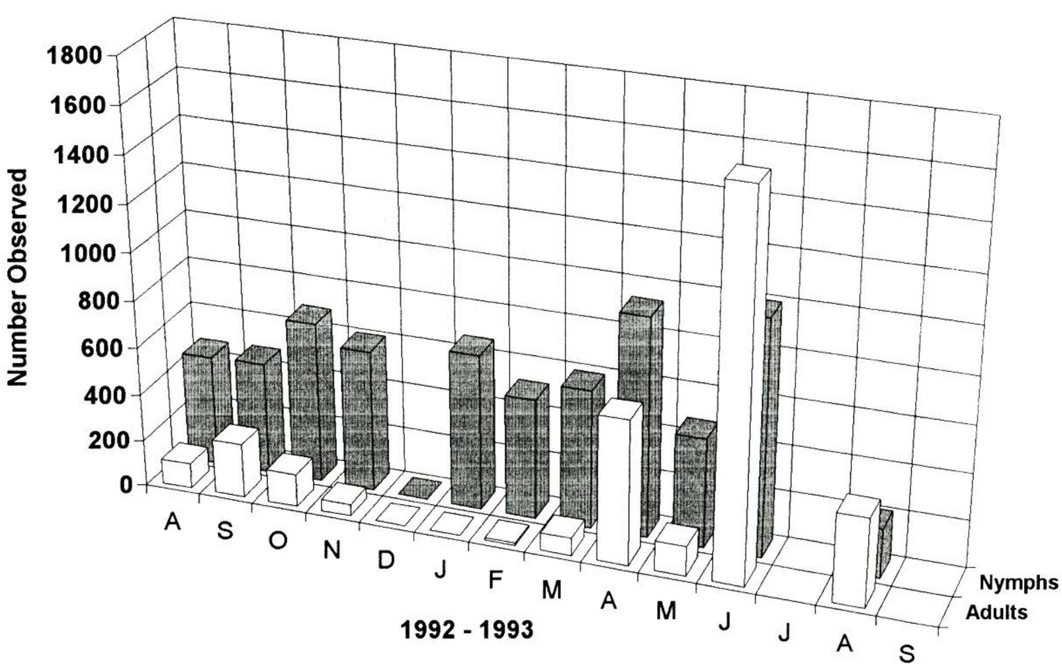


Fig. 26

Testudo Tube: Cricket & Daddy Longlegs Emergences

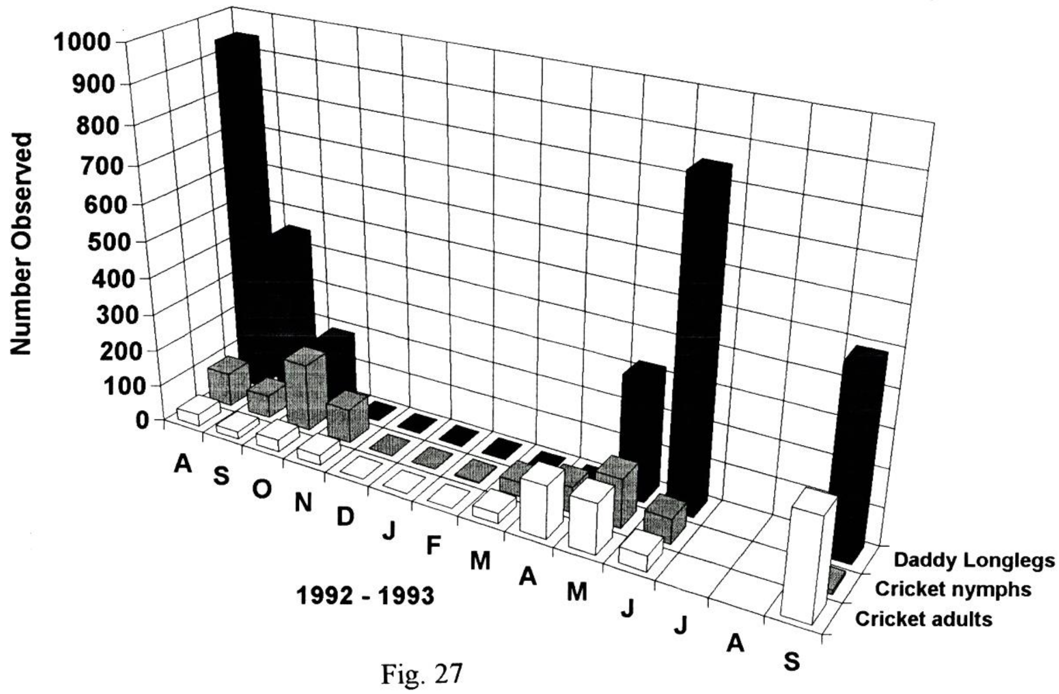


Fig. 27

Thor Cave: Cricket Emergences

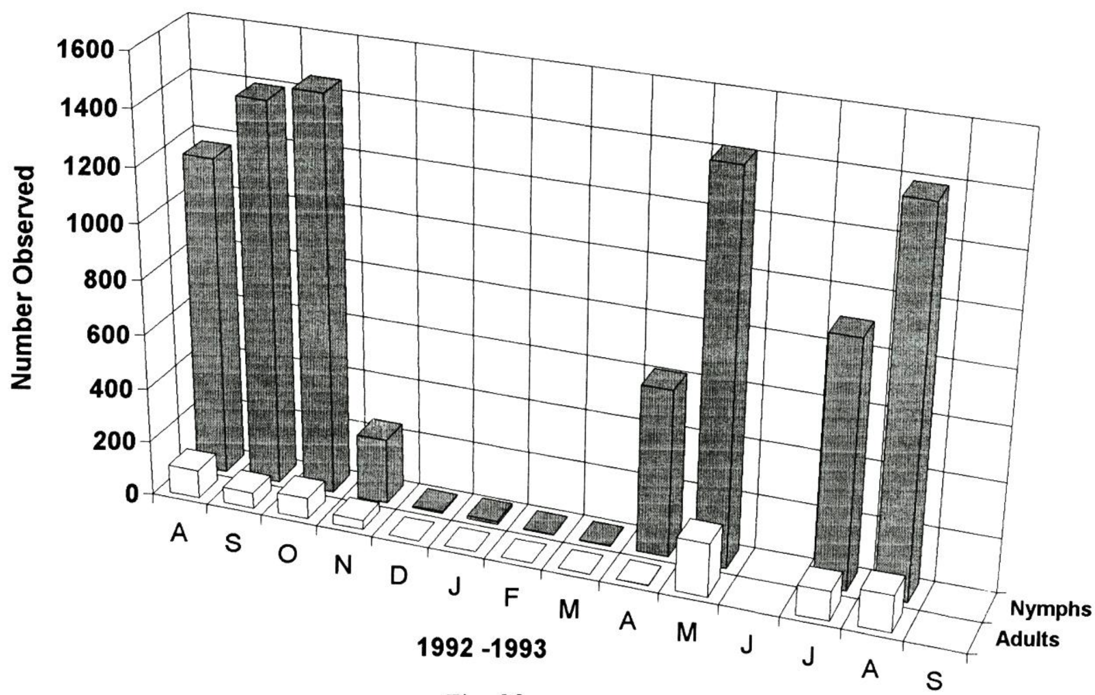


Fig. 28

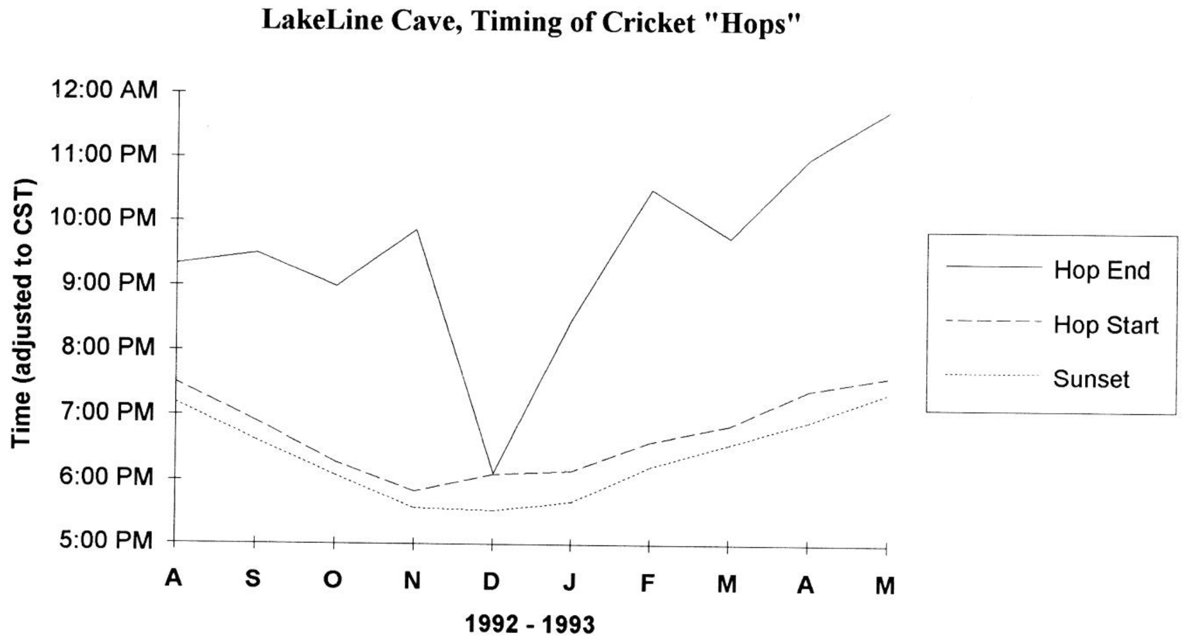

LakeLine Cave, Timing of Cricket "Hops"
12:00 AM
11:00 PM
10:00 PM
9:00 PM
8:00 PM
7:00 PM
6:00 PM
5:00 PM
Time (adjusted to CST)
A S O N D J F M A M
1992 - 1993
Hop End
Hop Start
Sunset

Fig. 29

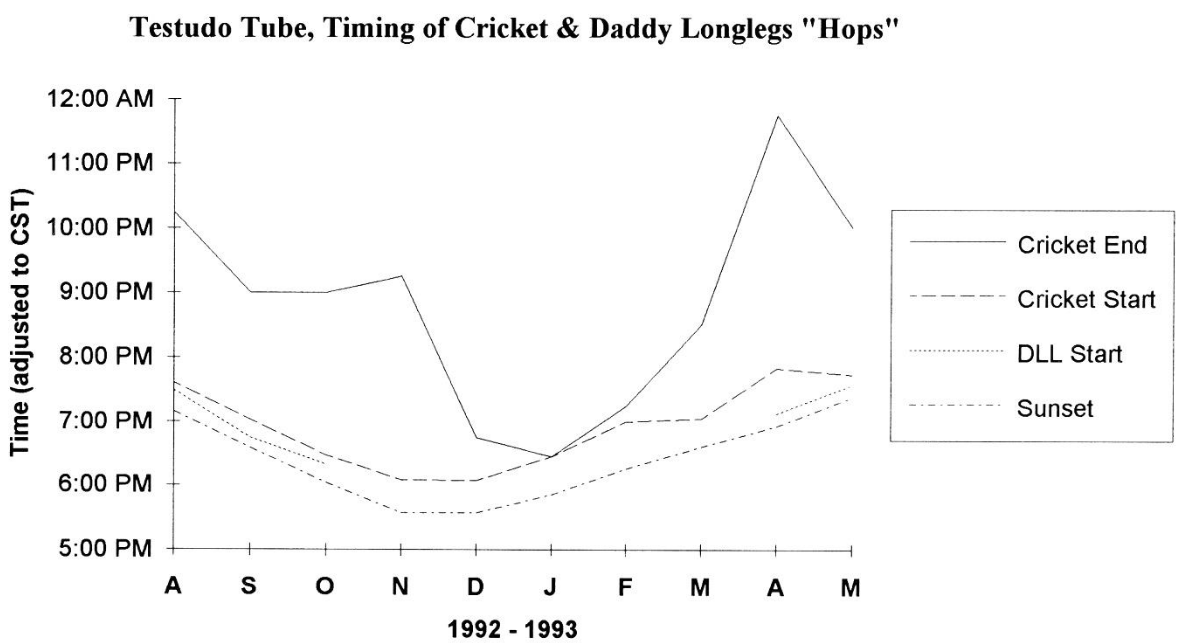

Testudo Tube, Timing of Cricket & Daddy Longlegs "Hops"
12:00 AM
11:00 PM
10:00 PM
9:00 PM
8:00 PM
7:00 PM
6:00 PM
5:00 PM
Time (adjusted to CST)
A S O N D J F M A M
1992 - 1993
Cricket End
Cricket Start
DLL Start
Sunset

Fig. 30

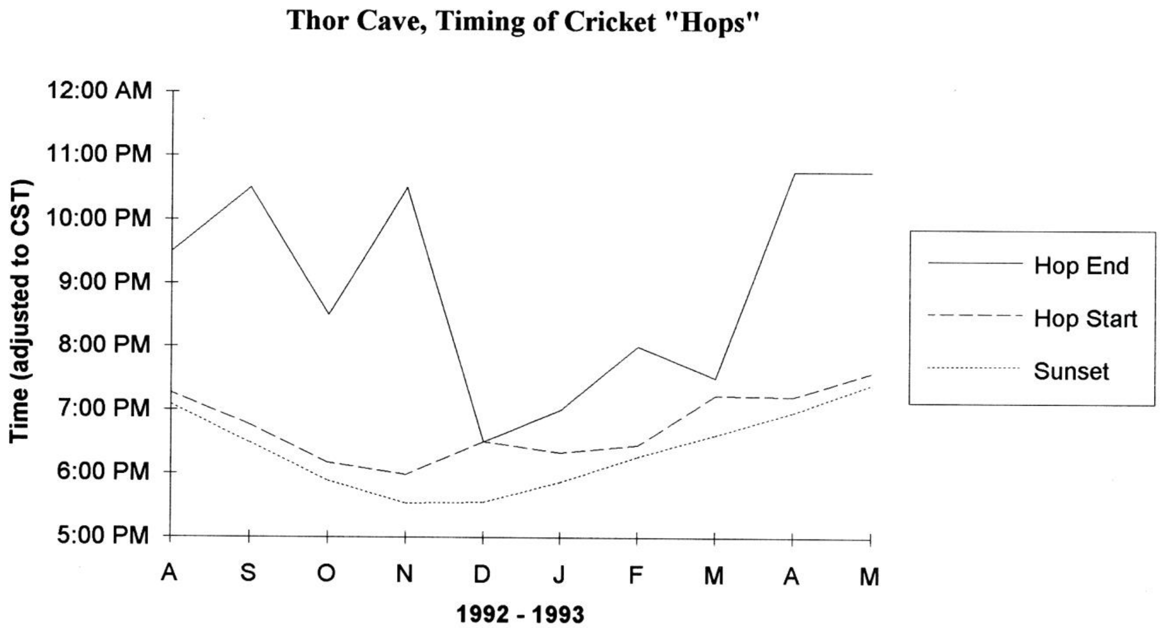

Thor Cave, Timing of Cricket "Hops"
12:00 AM
11:00 PM
10:00 PM
9:00 PM
8:00 PM
7:00 PM
6:00 PM
5:00 PM
Time (adjusted to CST)
A S O N D J F M A M
1992 - 1993
Hop End
Hop Start
Sunset

Fig. 31

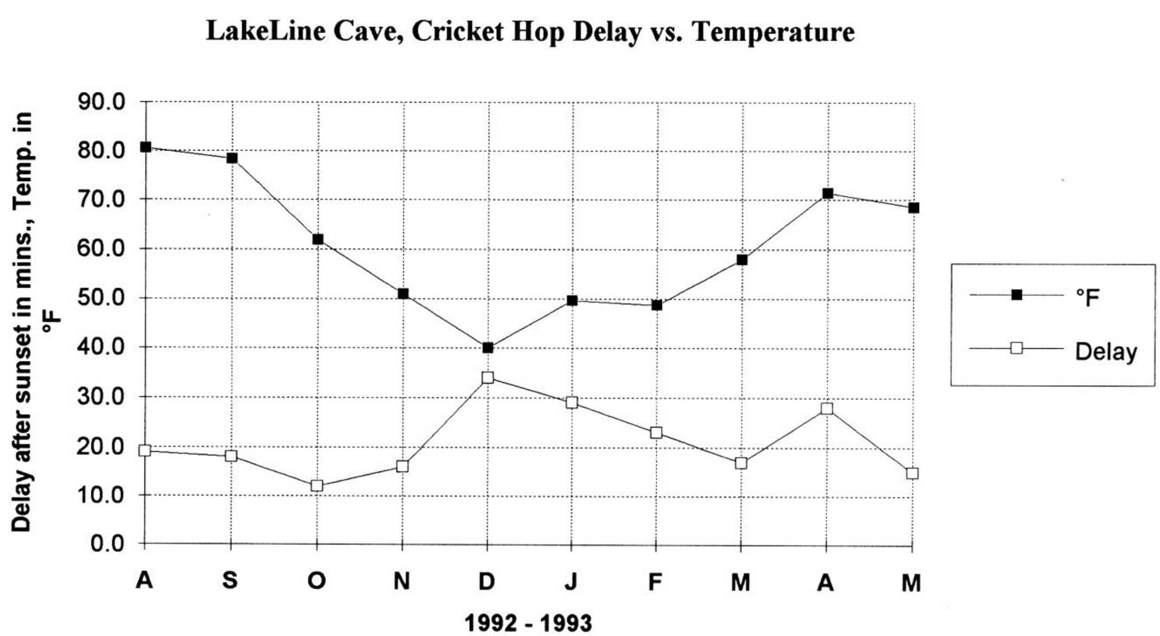

LakeLine Cave, Cricket Hop Delay vs. Temperature
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
Delay after sunset in mins., Temp. in °F
A S O N D J F M A M
1992 - 1993
°F
Delay

Fig. 32

Testudo Tube, Cricket "Hop" Delay vs. Temperature

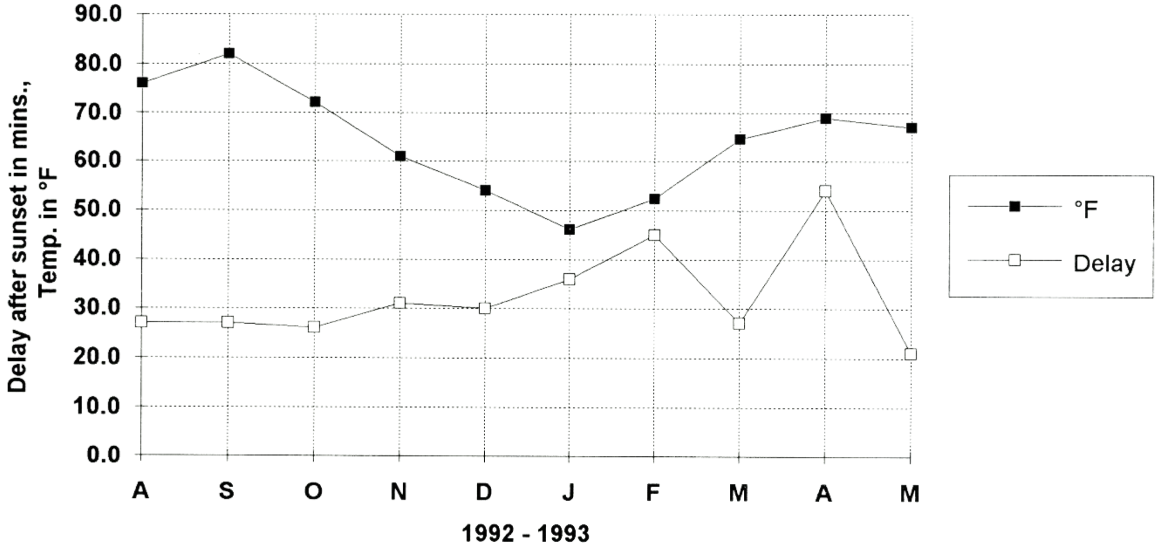


Fig. 33

LakeLine Cave, Crickets at Surface Bait Stations (23 replicates, Aug., 1992 - May, 1993)

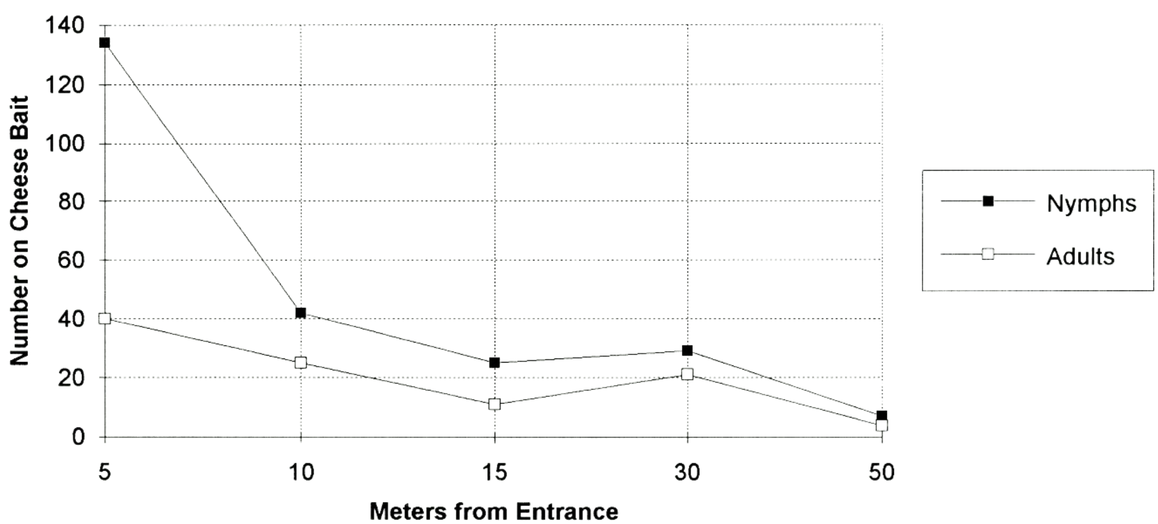


Fig. 34

LakeLine Cave, Surface Bait Stations
(23 replicates, Aug., 1992 - May, 1993)

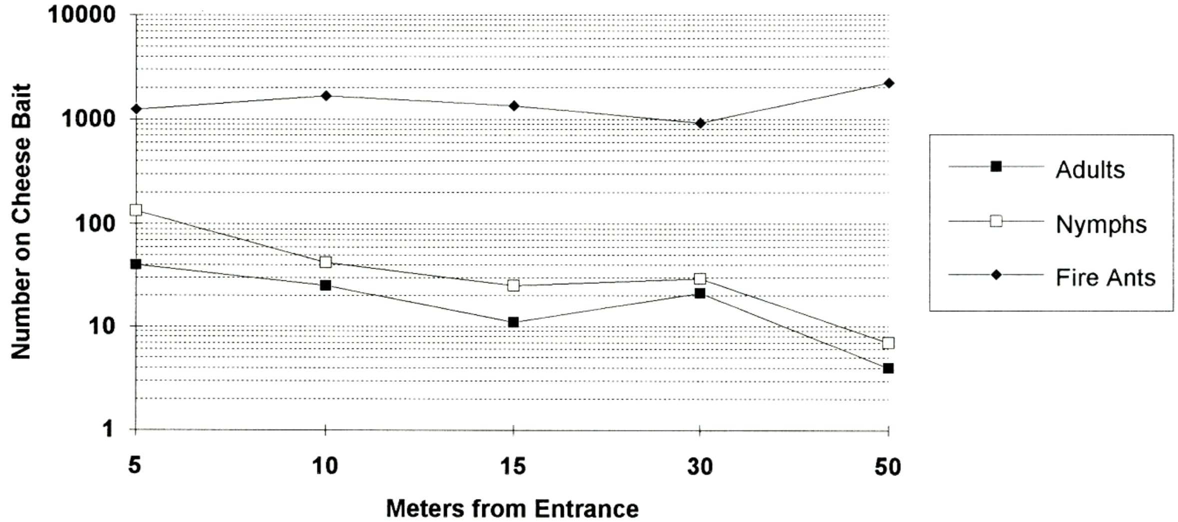


Fig. 35

Testudo Tube, Crickets & Fire Ants at Bait Stations
(12 replicates, Aug., 1992 - May, 1993)

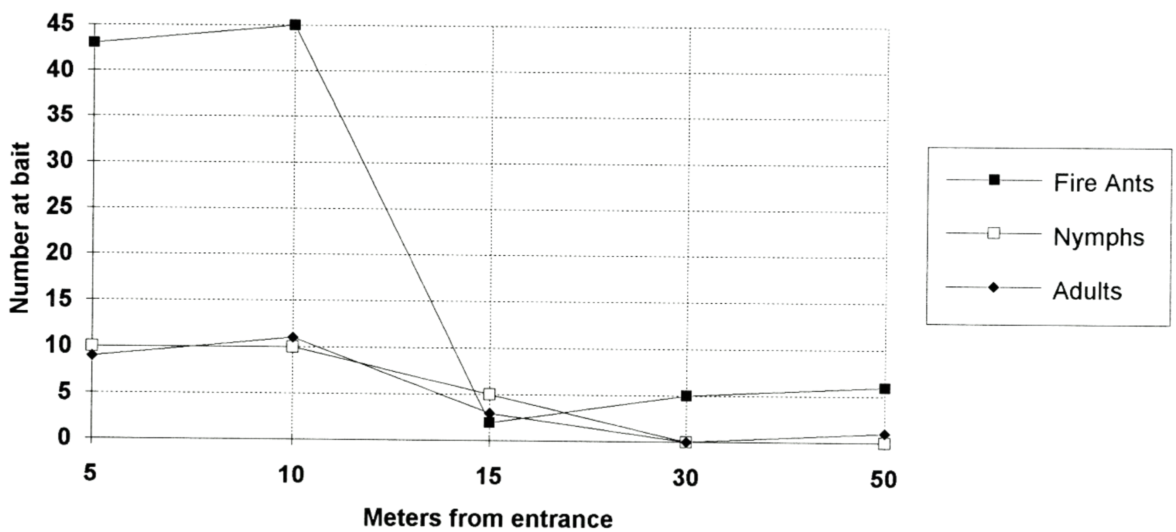


Fig. 36

Thor Cave, Crickets & Fire Ants at Bait Stations
(5 replicates, Aug., 1992 - May, 1993)

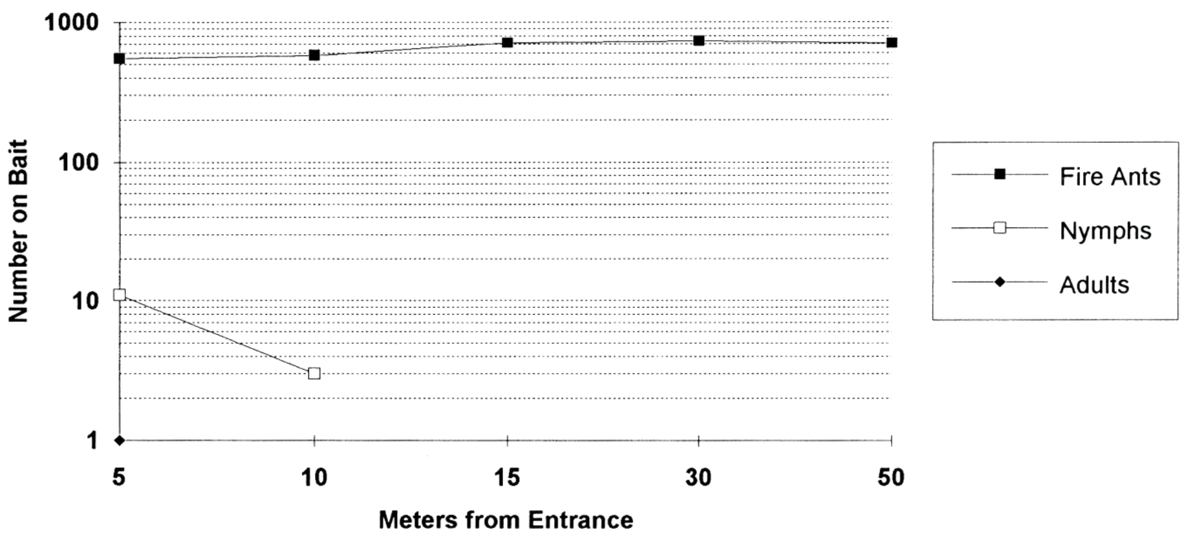


Fig. 37