FINAL REPORT

As Required by

THE ENDANGERED SPECIES PROGRAM

TEXAS

Grant No. E - 80

Endangered and Threatened Species Conservation

**Detection probabilities of karst invertebrates**

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29 October 2007

FINAL REPORT

**STATE:** Texas **GRANT NUMBER:** E - 80

**GRANT TITLE:** Endangered and Threatened Species Conservation

**REPORTING PERIOD:** 8/01/05 to 9/30/07

**PROJECT TITLE: Detection probabilities of karst invertebrates**

**OBJECTIVE(S):**

To determine the detection probability of five federally listed karst invertebrates during visual surveys.

**Significant Deviation:**

Initially five species were proposed for analysis. After it was found that only one of those five species had a large enough dataset for analysis, the search was expanded to 15 species. Of those only three had a large enough data matrix for analysis (see Attachment A, Table 1 for further details).

**Summary Of Progress:**

Please see Attachment A.

**Location:** Existing datasets analyzed in-house at Zara Environmental, Austin, Texas.

**Prepared by:** Craig Farquhar **Date:** 29 October 2007

**Approved by:** __________ **Date:** __________
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# DETECTION PROBABILITIES OF KARST INVERTEBRATES

*Chinquipellobunus madlae* from Headquarters Cave, Bexar County, Texas

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30 September 2007

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## Abstract

Troglobites, or species restricted to caves, commonly have small ranges and high levels of endemism, making them extremely sensitive to relatively small-scale habitat alteration that results from urbanization. Protection of federally listed endangered troglobites in central Texas focuses on caves that are occupied by the species. The determination of occupancy is based on presence/absence surveys for those taxa. Under current U.S. Fish and Wildlife Service recommendations, three surveys are used as a standard to determine presence or absence, and certain environmental and seasonal conditions must be met.

We used survey data from 23 caves on Camp Bullis Military Reservation, Bexar County, Texas that was collected from Fall 2003 to Spring 2007 (George Veni and Associates 2006) to create presence/absence matrices for three cave species, *Batrisodes uncicornis*, *Chinquipellobunus madlae*, and *Rhadine exilis*. Eleven environmental and seasonal covariates that have been suggested to affect detection probability (*p*) of these taxa were tested for fit to the detection data. *B. uncicornis* and *R. exilis* had weak likelihood scores for several covariates and thus were determined to have constant detection probabilities of 0.1226 and 0.1875. *C. madlae* was found to have a survey specific detection probability (average $p$ = 0.2424), also not tied to any of the measured covariates. The calculated detection probabilities were used to simulate the number of surveys needed to have a 5% chance of not detecting the species if they were present at the site. The number of surveys needed ranged from 10 to 22. These analyses suggest that the recommended environmental and seasonal conditions for surveying these species are not related to their detectability, and that a far greater quantity of surveys than the recommended three should be performed to determine absence. The results also indicate that a significant proportion of the time cave species are not available to be surveyed, and we hypothesize that they retreat into humanly inaccessible cracks connected to the cave. If this is the case, in addition to the caves themselves these mesocavernous spaces should be a priority for conservation.

## Introduction

Detection probability (*p*), or detectability, is the chance that a karst invertebrate will be observed if the cave is occupied by that species. In order for a species to be observed it must be both available (e.g. not hiding in a humanly inaccessible crack) and seen by the researcher. Occupancy (Ψ) is the proportion of sites that are occupied, or the proportion of areas where the species is present. Failure to take into account detection probabilities when using species counts can lead to underestimating cave occupancy, since non-detections in survey data do not necessarily mean that a species is absent unless the probability of detection is one (MacKenzie et al. 2002, Bailey et al. 2004). If the probability of detection is less than one, then surveys should be designed to account for imperfect detection.

Cave organisms are small (Figure 1) and live in an environment that is difficult to sample because of constricted crawlways, vertical drops, low oxygen levels, and an abundance of mesocaverns, or tiny cracks and voids connected to the cave but inaccessible to humans. For the sixteen species of federally listed terrestrial karst invertebrates in central Texas, recovery is based on protecting habitat around caves known to contain the species, therefore estimating occupancy of caves is of paramount importance. Monitoring the populations in these caves and conducting surveys in new caves are listed as key components to the recovery strategy (USFWS, 1994).

The U.S. Fish and Wildlife Service (2006) provides survey recommendations for these taxa and detail that permitted surveyors must have several years of experience with these or similar species under a permit holder. During the three surveys required to ascertain presence or absence of a species in a cave, certain environmental and seasonal conditions must be met. Thus far these conditions (number of visits, season, temperature, recent rain) have been determined based on non-quantified observations by researchers balanced with an estimation of observer impact on the environment (James Reddell and USFWS Bexar County Karst Invertebrate Recovery Team, pers. comm.).

Since newly found caves are rapidly being impacted by development, and the data from early counts of karst invertebrates are being relied upon for guidance of preserve designs, it is imminently important to estimate the utility of the recommended survey protocol with confidence. The focus of this study is to determine the detection probabilities for several terrestrial karst invertebrates, to assess whether certain environmental parameters affect detectability, and to use detectability to determine the number of surveys required to be confident in a determination of absence from a site.

## Methods

The original objectives and approach section of the proposal application, along with the significant deviations from the original proposal, can be found in Appendix A. This appendix was added in order to comply with "Final Report Guidelines for Section 6 Grants" but was excluded from the body of the report for clarity.

### *Study sites*

Caves on Camp Bullis Military Reservation, Bexar County, Texas were used for this study, and the raw dataset along with detailed information about each site is reported in George Veni and Associates (2006). Cave sites were subdivided into zones, and these individual zones are the survey units. Surveys were conducted three times per year, starting in the fall of 2003 and going to spring 2007, for a total of eleven sample events. Typically, at least 15 minutes were spent in each zone, but some larger zones were searched for up to an hour. Prior studies have used this method (Elliott, 1994) and it is consistent with U.S. Fish and Wildlife Service endangered species survey recommendations (2006).

While there is no literature available regarding the home range size of any of the taxa we examined as part of this study, we feel these zones are independent of one another because of the lack of migration observed in other cave species, the low metabolisms typical of cavernicoles, and our personal observations on behavior. One aquatic cave limited species was used in a mark recapture study and found to have no migration between sites that were 6-10 m long and at least 15 m apart during a 24 hour sample interval (Knapp and Fong 1999). Cave organisms are repeatedly found to have low metabolisms (Poulson and White 1969, Wilhelm et al. 2006) which contributes to long periods of inactivity (e.g. Hendrickson et al. 2001). Most species are typically observed under the cover of rocks where they are probably waiting for prey or taking shelter. Some taxa, for example *Rhadine* beetles, appear more motile and are seen moving as far as 3-4 m during an observation period. Others, such as the harvestman *Chinquipellobunus* and other beetle *Batrisodes* are seen moving, but often extremely slowly or over very small areas (less than one meter). Some taxa such as pseudoscorpions are extremely rarely seen moving, but tend to remain perfectly still, clinging to the undersides of single rocks which they will not tend to move off of, even when disturbed (much less than one meter).

The zones used for each cave are illustrated in George Veni and Associates (2006). For most caves, the zone closest to the entrance was excluded because this is not an area that cave limited species are expected to be found. Table 1 summarizes how many zones were used for each taxon, and Appendix B indicates exactly what zones were used at what caves.

*Detection probabilities, Occupancy, and number of surveys*

The program PRESENCE (Proteus Wildlife Research Consultants, Dunedin, New Zealand) includes mark-recapture models modified by MacKenzie et al. (2002) for use with presence-absence data. It was used to analyze the fit of several models to the dataset. The first test was to determine whether our dataset that included multiple years and seasons could be considered closed during the period of the surveys, Fall 2003 to Spring 2007. Closure means the cave zone did not experience a change in occupancy by the species during the time interval of surveys and is an assumption of the occupancy models (MacKenzie et al. 2002). To determine closure three models were compared. The first model considered the detection probability as specific to each survey event, the second as specific to each season, and the third as constant across all survey events (Table 2). The models were compared using Akaike's Information Criterion (AIC) and AIC weights (Burnham and Anderson 2002). Once the assumption of closure was validated, detection probabilities were modeled as either constant among surveys, specific to individual surveys, or influenced by one of eleven covariates discussed below.

After model selection analysis, we determined the number of surveys needed to have a 5% chance of not detecting the species at sites where they are present, based on estimated probabilities of detection. For *Chinquipellobunus madlae*, we found that detectability varied with each survey. Therefore, we conducted a parametric bootstrapping simulation obtaining 1000 pseudo samples (Manly 1997). We used the formula

$$\prod_{i=1}^{s} (1-p_i),$$

where $p$ is the detection probability on survey $i$ and $s$ is the number of surveys (Jackson et al. 2006). For *Batrisodes uncicornis* and *Rhadine exilis*, whose detectability was constant across surveys, the calculations were based on the simpler formula

$1- (1-p)^s$,

where $p$ is the detection probability and $s$ is the number of surveys performed (formula 6.1 in MacKenzie et al. 2006). Simulations for each different number of surveys (2, 4, 6, etc.) were performed using the statistical software **R**, and consisted of 1,000 bootstrapped samples produced with a parametric and not a nonparametric bootstrapping algorithm. Then for each different number of surveys, the mean probability of failing to detect the species was calculated. For *Chinquipellobunus madlae*, the varying values of $p$ allowed us to create 95% confidence intervals (Figures 2-4).

*Covariates*

Detection probabilities were modeled as either constant among surveys, specific to individual surveys, or influenced by one of eleven covariates. Of these eleven covariates, four were unique to each cave site and seven were unique to each sample event. They were chosen based on personal observation, interviews with local cave biologists (James Reddell, Peter Sprouse), USFWS recommendations (2006), and other research (Schneider and Culver 2004).

The USFWS provides guidelines for recommended season and weather conditions for surveying for karst invertebrates (USFWS 2006). It is recommended to perform presence/absence surveys in the spring (March through June) and fall (September through January). Recommended weather condition criteria for sampling includes: 1) average weather (temperature and rainfall) for time of year; 2) surface air temperatures during the previous week between 4.4° C (40° F) and 37.8° C (100° F); 3) lack of drought conditions; 4) recent rainfall; and 5) absence of recent, extensive, local flooding (USFWS 2006).

Four site covariates were unique to each cave locality but did not differ among visits to the cave. These included cave length, cave depth, size of floor search area, and size of wall search area. Cave length was used because other researchers have found higher species richness associated with longer caves (Schneider and Culver 2004) with the logical explanation being that longer caves contain a bigger variety of habitats to support more species diversity. Cave depth was used because many central Texas caves are very shallow and therefore thought to have greater climactic variations including periods of drying and heating that would force organisms out of the majority of the passages and into small crevices or adjacent mesocaverns where they would be less detectable. Cave length and depth data were gathered from cave maps in George Veni and Associates (2006) that were created using standard cave mapping techniques (Dasher 1994) and data compilation in the program WALLS.

Size of search areas was not uniform, and given the possibility that a greater abundance of the species exists in a greater area, it is reasonable to expect that larger search areas would correspond to higher species detectability. Also, while these taxa can be found on the cave floor, walls, or ceiling, they are most often found on the floor probably due to the relative abundance of nutrients there. For this covariate we calculated the size of search area on the floor and walls using cave maps. Floor area was calculated by approximating rectangles or circles, and anything less than a 45 degree slope was considered a floor. Slopes greater than 45 degrees were considered walls. They do not tend to capture soil, leaf litter or rocks that are nutrients and habitat for species. Wall area was calculated using the formula for the sides of a cylinder, (2*pi*r)h. Ceiling area was not used in the analysis.

Seven sample covariates changed with each sampling event and included four continuous variables: search time, in-cave temperature, in-cave relative humidity and surface air temperature. The remainder corresponded with USFWS survey recommendations (USFWS 2006) and consisted of a yes/no determination for falling within the recommended surface temperature range, recommended sampling season, and a recent rain event.

Search time was measured using wristwatches and recorded during in-cave surveys to the nearest minute. In-cave temperature and relative humidity were measured in each cave zone, or in an adjacent cave zone, using a fan-cooled wet and dry bulb psychrometer (Psychro-Dyne, by Industrial Instruments & Supplies, PO Box 416, County Line Industrial Park, Southampton, PA 18966) for wet and dry bulb measurements, and a watch or GPS mounted barometer (Helix, by Timex or Garmin Etrex GPS) to detect pressure. Surface air temperature was measured using the same instrument, approximately 5 m from the cave entrance in the shade. This is regionally accepted as a good method to measure small differences in a high humidity environment that are typically not detected by standard digital humidity meters.  Relative humidity is calculated from these three measurements using the formula in Appendix C. Recent rainfall is not specified by USFWS (2006), so for this study we used one inch or more of rain within ten days of the survey date.

*Species*

Initially fifteen species were considered for analysis, but of those only three were found to have adequate sample sizes for this analysis (Table 1). All of these localities were surveyed 11 times.

*Batrisodes uncicornis* is an eyed troglophilic (not restricted to caves, but can spend entire life cycle in a cave) pselaphid beetle (Figure 5) that occurs in caves throughout central Texas (Bexar, Blanco, Burnet, Comal County, Hays County, Kendall, Llano County, Travis County, and Williamson counties). This species is not endangered, but it is closely related to endangered *Texamaurops reddelli* and *Batrisodes texanus*. With a conservative interpretation members of the same family could be used as an analog for study. It is known to occur in 9 caves containing 21 zones that are regularly inventoried and part of this study (Appendix B).

*Chinquipellobunus madlae* is a troglobitic (restricted to caves) harvestman (Figure 6) that occurs in caves throughout central Texas (Bandera, Bexar, Comal, Edwards, Kendall, Kerr, Kinney, Medina, Terrell, Uvalde, and Val Verde counties) (Cokendolpher 2004). This species is not endangered, but it is related to endangered *Texella cokendolpheri*, *Texella reyesi*, and *Texella reddelli* harvestmen. *Chinquipellobunus madlae* is known to occur in 22 caves containing 61 zones that are regularly inventoried and part of this study (Appendix B).

*Rhadine exilis* is a federally listed carabid beetle (Figure 7) restricted to Bexar County, Texas. It is known from 21 caves that are regularly inventoried and part of this study, but also occurs more broadly in northern Bexar County both to the east and west of these sites. This range encompasses two other caves that are regularly inventoried. Since there is no obvious barrier between these caves and sites where the species is known from, these two additional caves were included in the analysis of this species for a total of 23 caves subdivided into 65 zones with 11 sample events (Appendix B).

## Results

The assumption of closure was met for all taxa, indicating that species do not colonize a site or become extinct from a site within the study period. Lower AIC values indicated the data for *Batrisodes uncicornis* were most consistent with constant detection probabilities and the data for the other two species varied by survey rather than being seasonal or constant (Table 2). After closure was met, data from all years were used to test whether detection probabilities were either constant among surveys, specific to individual surveys, or influenced by one of eleven covariates (Table 3). Of the three species, *Chinquipellobunus madlae* was the only dataset found to have a clear best model, which was that the detectability was different for every survey [notated as *p*(survey)]. Detection probabilities ranged from 0.0595 to 0.3769, with a mean of 0.2424, standard error of 0.0943 and coefficient of variation of 0.3887. The proportion of sites occupied (Ψ) was 0.85 with a standard error of 0.06. The other two species had several models that rose above the rest but were not distinct enough to choose between, and in those cases the most parsimonious of the higher ranking models were chosen. In the case of *Batrisodes uncicornis*, three models are highest and rank similarly: in-cave relative humidity, in-cave temperature, and wall area. For the first two variables, detection probabilities do not change much with a change in relative humidity (*p* between 0.0587 and 0.0594) or temperature (*p* between 0.0602 and 0.0606). For wall area, zones with high detection probabilities (>0.89) do have high surface areas of wall, however in the actual detection matrix there are no observed detections in these zones. Given the relatively few sites analyzed for this taxon (9 sites, see Table 1) and the low number of detections, none of these model selections were chosen, and instead the simplest model, constant probability of detection [notated as *p*(.)], was used. The constant detection probability was 0.1226, the proportion of sites occupied (Ψ) was 0.45 with a standard error of 0.16. In the case of *Rhadine exilis*, the top four models were search time, survey-specific, constant probability of detection, and floor area. As in *Batrisodes uncicornis*, the most parsimonious model, *p*(.), was selected. The constant detection probability was 0.1875 the proportion of sites occupied (Ψ) was 0.71 with a standard error of 0.07.

## Discussion

Many caves are surveyed to determine whether they are occupied by rare and endangered troglobites, and several researchers have examined accumulation curves and patterns of species richness in karst areas of West Virginia and Slovenia (Culver et al. 2004, Schneider and Culver 2004). These studies focused on determining the number of cave species in a region and how many caves would need to be sampled to obtain an accurate estimate of species richness for the area rather than for a single cave. Results included a lack of asymptotes or plateaus in species accumulation curves, with one explanation being that repeated visits are often necessary to collect all of the species found in a single cave (Schneider and Culver 2004). Culver et al. (2004) give an example of a new taxon being found after 6 visits, and two examples of new taxa being found after over a hundred visits to a cave. In the instance of Lakeline Cave, Williamson County, Texas, at least 45 biological surveys have been performed by experienced cave biologists of the entire cave (approximately 23 m long), and on approximately the 40th visit a new species of troglobitic pseudoscorpion was found. Clearly some species are commonly not available or not detected, however prior to this work no researchers have attempted to calculate detection probabilities or estimate the number of visits required to a single cave to find a troglobite.

The detection probabilities calculated herein suggest that modifications should be made to recommended survey techniques to confidently estimate occupancy. Even in taxa that are large and easy to see (*Chinquipellobunus madlae*, Figure 6), in our analysis of caves where they are known to occur, the proportion of sites occupied was 0.85 and the detection probability averaged only 0.24. With 10 visits recommended to confidently determining absence for this taxon, many more should be required of smaller, slower moving and more inconspicuous troglobites such as *Texella* species.

Suggestions about appropriate sampling conditions for cave fauna come from qualitative observations by cave biologists, and in Texas have generally included seasonal and weather conditions that are thought to make the interior of these shallow caves more favorable for finding cave species. In our lengthy list of possible covariates, however, none clearly demonstrated an association with detectability of these species. For one of three taxa, detectability definitively varied with each survey event, indifferent of all the covariates tested. For the other two taxa, the distinction was less clear and confounded by a small number of detections in the matrix of observation events. Patterns of species detections appear irregular, and more work needs to be done both on the environment and experimentally on the species to determine if the environmental variables we measure during these studies are actually related to detection probability. For example, dataloggers in caves can demonstrate if seasonal, temperature, or rainfall variation on the surface is reflected in the cave environment at different endangered species localities. The other critical component is to use experimental manipulation of the taxa to determine if they respond to the magnitude of changes that actually occur within the cave.

Mitchell (1971) showed that a congener to one studied in this study, *Rhadine subterranea*, preferred temperatures below cave temperature in the summer then shifted to preferring near-cave temperatures in the winter. He also demonstrated this species perished or suffered behavioral abnormalities after exposure to high temperatures and low humidity. Mitchell (1971) focused on behavioral mechanisms that restrict cave species to their optimal environment, and if they have the capability to disperse overland. To accurately determine conditions for favorable species detection, it will be necessary to measure behavioral responses to normal small scale cave condition fluctuations for species that are targets for monitoring. Additionally, large datasets such as the one examined herein are needed to accumulate adequate sample sizes to distinguish between multitudes of environmental factors that may affect species presence. The analysis herein focused on USFWS recommendations for seasonal and climactic monitoring conditions (2006), but other parameters may be just as, if not more important (e.g. soil moisture, 2 cm soil temperature, time of day).

When the species analyzed herein are not available, the most obvious hypothesis is that they retreat into inaccessible cracks that are connected to the cave. These spaces, called mesocaverns (or sometimes called epikarst, voids, or unenterable caves), should then be considered a priority for conservation. Presently management focuses on caves and surface habitat immediately surrounding caves. Cave entrances and the surrounding surface area are important because they provide a nutrient source for cave ecosystems, but this suggests that a greater area of karst that is connected to caves may be where the species often reside. Knapp and Fong (1999) also concluded that the stygobites they studied occur primarily in a larger area of epikarst that is connected to the cave pools they could access, and considered the pools a small window into that habitat.

Beyond the original species description, and other basic taxonomic papers including a re-assignment of genus or update on list of caves known to contain the species, almost nothing is known of any of these species. The caves themselves have had some structural and hydrogeologic evaluation and studies of cave life in central Texas and beyond guide our general understanding of the biology, but there is no literature available on key aspects of biology or life history such as home range, life span, feeding habits, reproduction or behavior that may help interpret detection probability results. These are obvious gaps in our knowledge that may spur more broad-scale improvements to monitoring methods.

## Acknowledgements

Jackie Schlatter (Chief of Natural and Cultural Resources, Ft. Sam Houston, Texas) provided permission to use the dataset from Camp Bullis Military Reservation and coordination of the funding to collect the data. George Veni (Director, National Cave and Karst Research Institute) was the principal investigator and coordinator for all the research at Camp Bullis during the time these data were collected and always encouraged analyses to further the knowledge of these little studied systems. Cyndee Watson (USFWS) was involved in the project conception and provided many useful suggestions throughout the duration of the project. Rob Myers assisted with review and revisions of a draft version. James Reddell (Texas Memorial Museum) and Peter Sprouse (Zara Environmental LLC) provided suggestions of covariates to test. Kellie Cowan (Zara Environmental LLC) spent countless hours extracting and arranging the data for input into PRESENCE. Many people were involved in the in-cave data collection, including USFWS karst invertebrate permit holders Andy Gluesenkamp, Rob Myers, James Reddell, Marcelino Reyes, Peter Sprouse, Bev Shade and George Veni, and their observations and dedication created the large dataset used in this project and that will certainly be used for years to come. Funding for the analysis and this report was provided by Texas Parks and Wildlife through the Endangered Species Act Section 6 grant program of the U.S. Fish and Wildlife Service. In particular, Craig Farquhar (TPWD) did an outstanding job taking care of the administration of these funds. Matching funds and general support of the author were provided by Zara Environmental LLC and Texas State University.

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Table 1. Original list of taxa considered for analysis. Those in bold were the only ones with an adequate number of sites for analysis.

| Species (** = endangered) | Number of surveyed caves where taxon is known to occur (* = taxon could occur) | Number of cave zones used for analysis | Number of sample events | Size of data matrix |
|---|---|---|---|---|
| ***Batrisodes uncicornis*** | **9** | **21** | **11** | **231** |
| ***Chinquipellobunus madlae*** | **22** | **61** | **11** | **671** |
| *Cicurina bullis* | 5 | | 11 | |
| *Cicurina madlae* ** | 1 | | 11 | |
| *Cicurina pampa* | 2 | | 11 | |
| *Cicurina platypus* | 2 | | 11 | |
| *Eurycea latitans* | 3 | | 10 | |
| ***Rhadine exilis* **** | **21 (23*)** | **65** | **11** | **715** |
| *Rhadine infernalis* ** | 3 | | 11 | |
| *Rhadine persephone* ** | 2 | | 45 | |
| *Rhadine subterranea* | 2 | | 45 | |
| *Tartarocreagris reyesi* | 2 | | 11 | |
| *Texella elliotti* | 1 | | 11 | |
| *Texella hilgerensis* | 1 | | 11 | |
| *Texella reyesi* ** | 2 | | 45 | |

Table 2. Akaike's Information Criterion (AIC) and AIC weights of models used to determine whether the populations can be considered closed between Fall 2003 and Spring 2007. Occupancy (Ψ) was constant (.), detection probability (*p*) was either constant (.) or specific to surveys (survey), and colonization and extinction were constant (.). Models are listed in rank order according to their Akaike weights.

| Species/Model | AIC | Number of parameters | Akaike Weights |
|---|---|---|---|
| *Batrisodes uncicornis* | | | |
| Ψ(.), *p*(.) | 84.58 | 2 | 0.65 |
| Ψ(.), colonization(.), extinction(.), *p*(.) | 85.84 | 4 | 0.34 |
| Ψ(.), *p*(survey) | 94.88 | 10 | 0.01 |
| *Chinquipellobunus madlae* | | | |
| Ψ(.), *p*(survey) | 527.88 | 10 | 0.98 |
| Ψ(.), colonization(.), extinction(.), *p*(.) | 536.00 | 4 | 0.01 |
| Ψ(.), *p*(.) | 537.71 | 2 | 0.01 |
| *Rhadine exilis* | | | |
| Ψ(.), *p*(survey) | 432.59 | 10 | 0.63 |
| Ψ(.), *p*(.) | 434.69 | 2 | 0.22 |
| Ψ(.), colonization(.), extinction(.), *p*(.) | 435.40 | 4 | 0.15 |

Table 3. Akaike's Information Criterion (AIC), number of parameters (No. Par.) and AIC weights of models used to determine whether the detection probability (*p*) was either constant (.), specific to surveys (survey), or varied according to one of eleven potential covariates. Occupancy (Ψ) was constant (.). Models are listed in rank order according to their Akaike weights.

| **Species / Model** | **AIC** | **No. Par.** | **Akaike Weights** |
|---|---|---|---|
| *Batrisodes uncicornis* | | | |
| Ψ(.), *p*(in-cave temperature) | 87.59 | 3 | 0.31 |
| Ψ(.), *p*(wall area) | 87.68 | 3 | 0.29 |
| Ψ(.), *p*(in-cave relative humidity) | 88.42 | 3 | 0.20 |
| Ψ(.), *p*(floor area) | 90.49 | 3 | 0.07 |
| Ψ(.), *p*(search time) | 92.12 | 3 | 0.03 |
| Ψ(.), *p*(.) | 92.96 | 2 | 0.02 |
| Ψ(.), *p*(recent rainfall) | 94.06 | 3 | 0.02 |
| Ψ(.), *p*(cave depth) | 94.10 | 3 | 0.01 |
| Ψ(.), *p*(cave length) | 94.70 | 3 | 0.01 |
| Ψ(.), *p*(surface temperature) | 94.72 | 3 | 0.01 |
| Ψ(.), *p*(USFWS recommended temperature range) | 94.86 | 3 | 0.01 |
| Ψ(.), *p*(USFWS recommended temperature range) | 94.92 | 3 | 0.01 |
| Ψ(.), *p*(survey) | 104.55 | 12 | 0.01 |
| *Chinquipellobunus madlae* | | | |
| Ψ(.), *p*(survey) | 626.85 | 12 | 0.73 |
| Ψ(.), *p*(USFWS recommended temperature range) | 632.66 | 3 | 0.04 |
| Ψ(.), *p*(cave depth) | 632.78 | 3 | 0.04 |
| Ψ(.), *p*(recent rainfall) | 633.01 | 3 | 0.03 |
| Ψ(.), *p*(.) | 633.20 | 3 | 0.03 |
| Ψ(.), *p*(in-cave temperature) | 633.57 | 3 | 0.03 |
| Ψ(.), *p*(floor area) | 633.81 | 3 | 0.02 |
| Ψ(.), *p*(surface temperature) | 634.59 | 3 | 0.02 |
| Ψ(.), *p*(USFWS recommended season) | 634.92 | 3 | 0.01 |
| Ψ(.), *p*(wall area) | 634.93 | 3 | 0.01 |
| Ψ(.), *p*(in-cave relative humidity) | 635.01 | 3 | 0.01 |
| Ψ(.), *p*(search time) | 635.02 | 3 | 0.01 |
| Ψ(.), *p*(cave length) | 635.20 | 3 | 0.01 |
| *Rhadine exilis* | | | |
| Ψ(.), *p*(search time) | 519.07 | 3 | 0.18 |
| Ψ(.), *p*(survey) | 519.31 | 12 | 0.16 |
| Ψ(.), *p*(.) | 519.93 | 2 | 0.11 |
| Ψ(.), *p*(floor area) | 520.10 | 3 | 0.11 |
| Ψ(.), *p*(cave depth) | 520.87 | 3 | 0.07 |
| Ψ(.), *p*(USFWS recommended temperature range) | 521.17 | 3 | 0.06 |
| Ψ(.), *p*(surface temperature) | 521.43 | 3 | 0.05 |
| Ψ(.), *p*(cave length) | 521.72 | 3 | 0.05 |
| Ψ(.), *p*(recent rainfall) | 521.75 | 3 | 0.05 |
| Ψ(.), *p*(in-cave relative humidity) | 521.88 | 3 | 0.04 |
| Ψ(.), *p*(in-cave temperature) | 521.91 | 3 | 0.04 |
| Ψ(.), *p*(USFWS recommended season) | 521.93 | 3 | 0.04 |
| Ψ(.), *p*(wall area) | 521.93 | 3 | 0.04 |

Figure 1. A cave pseudoscorpion shown next to a penny, demonstrating their small size which certainly influences detection.

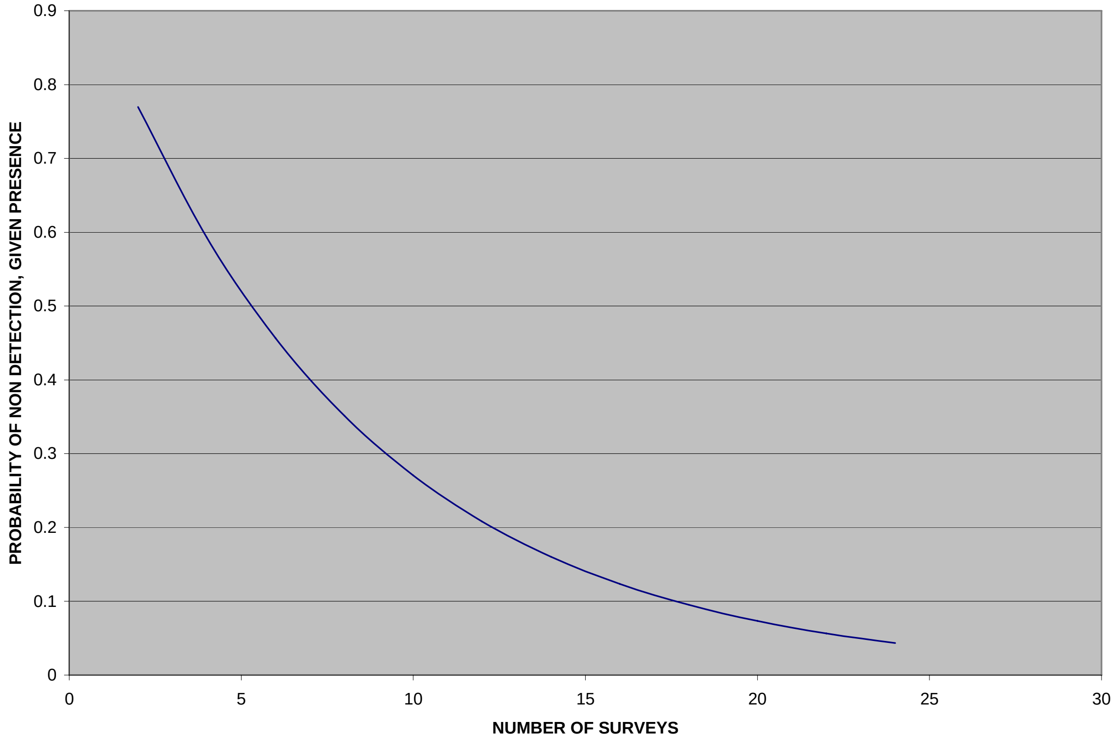


Figure 2. Simulations using the constant detection probabilities measured in *Batrisodes uncicornis* show that more surveys decrease the probability that this species will not be detected at sites where they are present. These findings suggest that 22 surveys are needed to be 95% confident that *B. uncicornis* is absent from a surveyed site.

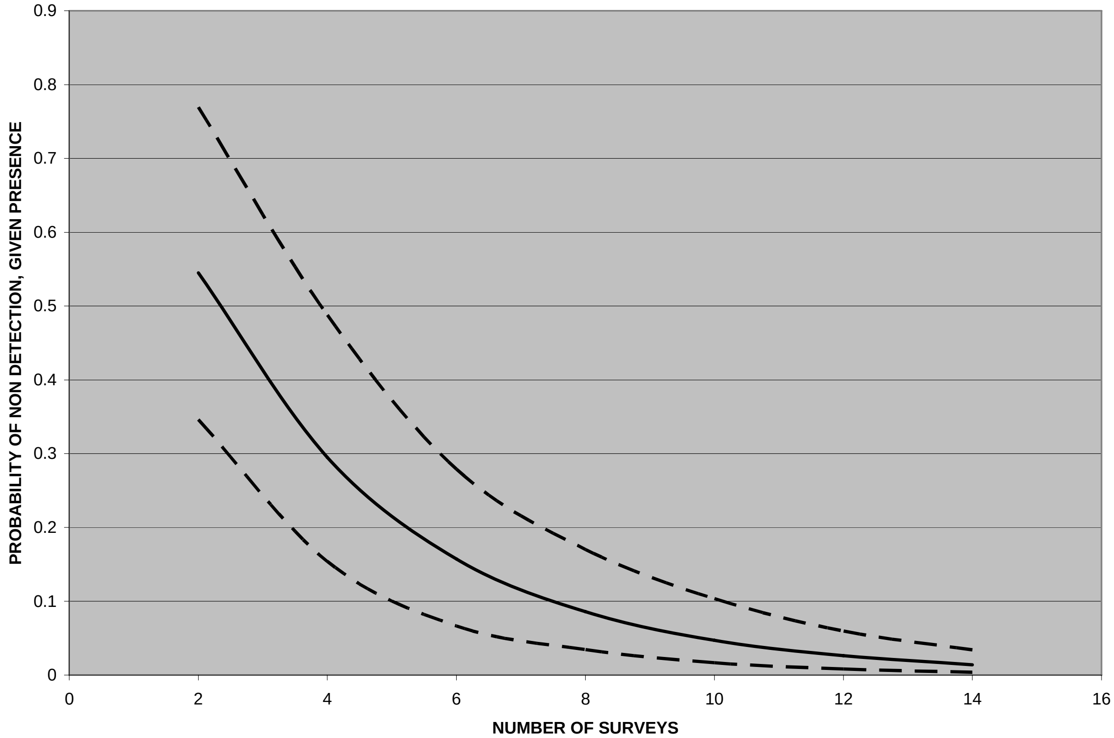


Figure 3. Simulations using the survey specific detection probabilities measured for *Chinquipellobunus madlae* show that more surveys decrease the probability that this species will not be detected at sites where they are present. Upper and lower 95% confidence intervals are shown as dashed lines. These findings suggest that 10-12 surveys are needed to be 95% confident that *C. madlae* are absent from a surveyed site.

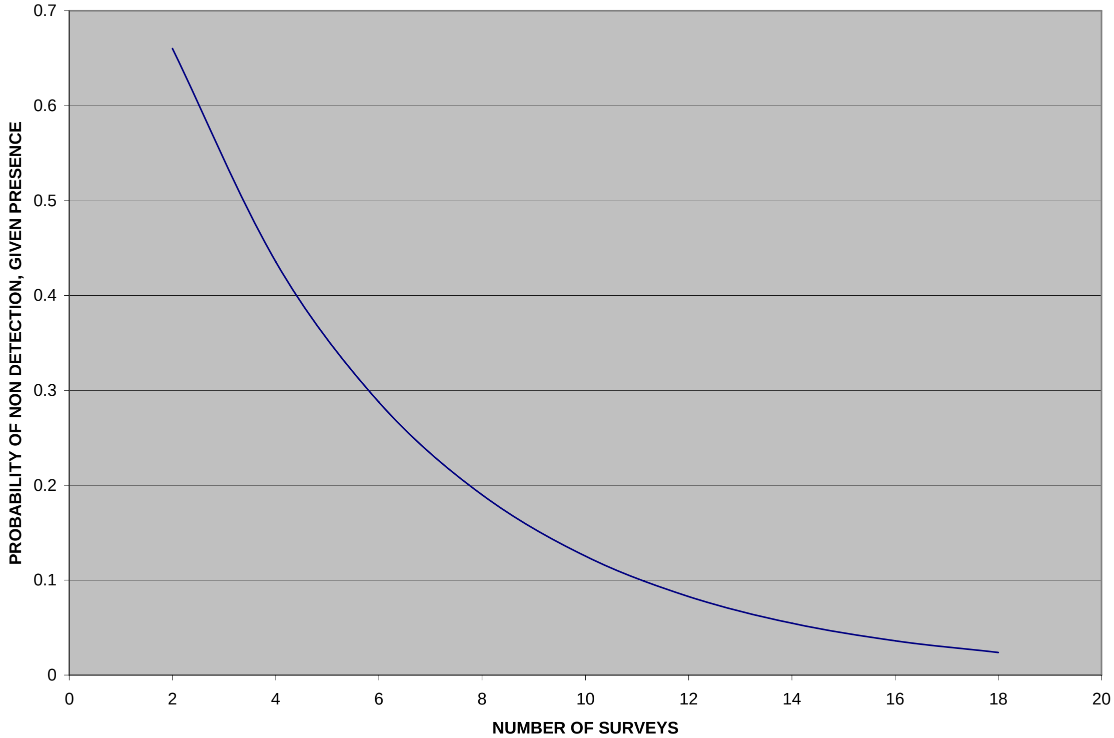


Figure 4. Simulations using the constant detection probabilities measured in *Rhadine exilis* show that more surveys decrease the probability that this species will not be detected at sites where they are present. These findings suggest that 14 surveys are needed to be 95% confident that *B. uncicornis* is absent from a surveyed site.

Figure 5. *Batrisodes uncicornis*, a tiny (2 mm) troglophilic beetle, from B-52 Cave, Bexar County, Texas.

Figure 6. *Chinquipellobunus madlae*, a troglobitic harvestman (2-3 cm), from Flying Buzzworm Cave, Bexar County, Texas.

Figure 7. *Rhadine exilis*, an endangered troglobitic ground beetle (1-1.5 cm), from Banzai Mud Dauber Cave, Bexar County, Texas.

Appendix A. Objective and Approach inserted exactly as in Project Statement in order to comply with "Final Report Guidelines for Section 6 Grants." This section is separated because it does not follow the exact approach actually used, see section on "Significant Deviations" in this appendix for explanation.

*Objective*

This study will determine the detection probability of five federally listed karst invertebrates during visual surveys. The detection probabilities will be used to create an estimation of the number of site surveys needed to be 95% confident that conclusions of absence are valid. They will also be used to assess environmental parameters that improve likelihood of species detection and estimate an appropriate survey interval for long term monitoring at known endangered species localities.

Data will be used from two datasets that are readily available. The first originates from the Lakeline Mall Habitat Conservation Plan and includes at least twelve years of monitoring data conducted up to four times per year at three caves (Elliott 2000, Myers et al. 2005). This dataset covers two of the Austin area federally listed karst invertebrates, the ground beetle Rhadine persephone and the harvestman Texella reyesi. The second databaset originates from the Camp Bullis management plan (Veni 2005) and covers three of the Bexar County listed species, Rhadine exilis, Rhadine infernalis and the meshweaver spider Cicurina madla. Matching hours will be used to extract data from these sources.

Analysis will involve occupancy models (MacKenzie et al. 2002) in the program PRESENCE formulated explicitly for estimating detection probabilities and sampling effort required to detect cryptic wildlife. This program uses an information-theoretic model selection approach that assesses whether environmental parameters correlate with presence or absence of karst invertebrates. More precisely, Akaike Information Criteria (AIC) (Burnham and Anderson 1998) is used in PRESENCE to assess the weight of each model. The model with the highest AIC weight is selected as the model that indicates the parameters influencing detection and the number of surveys needed to determine absence with a high degree of confidence (90%, 95%).

Additionally, a workshop for the program PRESENCE will be held at Texas State University in spring of 2006 and attendance at this workshop by the author will be used as matching hours.

Results will be compiled from the occupancy models to determine the number of surveys required to have 95% confidence of species absence. The environmental parameters of in-cave and exterior temperature and humidity that improve detection will be defined. Recommendations for monitoring intervals will be examined and discussions of existing datasets will follow in light of these new values. These data will be submitted for publication in a peer-reviewed journal. More details are provided in the Approach section.

Appendix A, continued. Objective and Approach inserted exactly as in Project Statement in order to comply with "Final Report Guidelines for Section 6 Grants." This section is separated because it does not follow the exact approach actually used, see section on "Significant Deviations" in this appendix for explanation.

*Approach*

1. Extract species count data from existing datasets (Elliott 2000, Myers et al. 2005, Veni 2005) for the following five species: *Rhadine persephone*, *Texella reyesi*, *Rhadine exilis*, *Rhadine infernalis* and *Cicurina madla*. These data are currently in a variety of formats, including digital spreadsheets, word processing documents and some only exist in paper formats. Care will be taken with data transfer and also with documenting the origin of different datasets. Any differences in observation method, even if they are slight, will be noted and associated with the data cells. This step will be done with matching hours.
January – March 2007

2. Extract in-cave and exterior temperature and humidity data from existing datasets mentioned above. As described above, these datasets exist in a variety of formats, and at times different tools were used to collect the same data. For example humidity can be calculated in a variety of ways, including dry-wet bulb aspirated psychrometers and resistance-type electrical hygrometers. Additionally, ambient pressure can be measured with a variety of instruments. These methods will be associated with the data cells. This step will be done with matching hours.
March – May 2007

3. Attend workshop at Texas State University in San Marcos on the program PRESENCE. This workshop will be being given by the authors of the program who have published extensively on the topic of detection probability (MacKenzie and Kendall 2002, MacKenzie et al 2002, 2003). This step will be done with matching hours.
Spring 2006 (final dates to be announced)

4. Perform analysis of these datasets using the software PRESENCE. This involves running multiple iterations of the dataset with various model parameters and also multiple simulation runs. This allows the user to choose the model with the highest AIC weight and obtain likelihood values for each parameter.
June – August 2007

5. Write up results of the analysis. This report will include specific data such as the number of surveys required to have 95% confidence of species absence. The report will define environmental parameters of in-cave and exterior temperature and humidity that improve detection. Also it will provide recommendations for monitoring intervals. These new data will be discussed in light of existing datasets to assess their utility for a variety of conservation problems. For example, one problem is uncertainty about the range of these species. In many cases there are caves that have been surveyed only one or two times and not found to contain listed species. The discussion will cover how this dataset is applicable to new caves and provide some estimate as to whether the number of surveys provides an acceptable confidence level that the species actually does not occur there. Another example of a conservation problem to discuss is the appropriate or ideal weather conditions for species detection, an issue that is touched on in many survey reports but never quantified. Assigning relative confidence to these observations is of immediate

utility.  Finally, a quantified look at trends of long-term monitoring projects is a landmark for conservation of caves.  These data provide feedback to determine if varying levels of surface disturbance, configuration and size of preserves and presence of exotic species are impacting the cave community.  In Lakeline Cave, part of the Lakeline Mall HCP, many surveys have been performed each year for morte than a decade.  During these surveys there have been large intervals where the endangered species has not been observed.  The regression line for the observations is decreasing, but not significantly.  Does this mean that conservation measures are inadequate to maintain the species, or is the negative sloping regression line simply an artifact of sampling?
September – November 2007

6. Submit paper to peer-reviewed journal.  An example of a target journal is the Journal of Wildlife Management.  These months will be used to answer reviewer comments and make suggested changes.  Acceptance into the journal can not be guaranteed, but submission will be complete by the end of the year of funding.
November – December 2007

Appendix A, continued. Significant deviations from original Objective and Approach inserted in order to comply with "Final Report Guidelines for Section 6 Grants."

*Significant deviations*

Initially five species were proposed for analysis.  After it was found that only one of those five species had a large enough dataset for analysis, the search was expanded to 15 species.  Of those only three had a large enough data matrix for analysis (see Table 1).

Appendix B. Table of cave localities and zones used for the analysis of three species. An asterisk indicates that the species is known to occur at that cave, the letter "R" indicates that the cave is within the range of the species and was used in the analysis, and "NP" means the species is not present at that site and was not used in the analysis.

| **Cave Name** | **Cave Zone** | ***Rhadine exilis*** | ***Chinquipellobunus madlae*** | ***Batrisodes uncicornis*** |
|---|---|---|---|---|
| B-52 Cave | 2 | * | * | * |
| | 3 | * | * | * |
| | 4 | * | * | * |
| | 5 | * | * | * |
| Backhole | 2 | * | * | NP |
| | 3 | * | * | NP |
| | 4 | * | * | NP |
| Boneyard Pit | 2 | * | * | NP |
| | 3 | * | * | NP |
| | 4 | * | * | NP |
| | 5 | * | * | NP |
| Bunny Hole | 1 | * | * | NP |
| | 2 | * | * | NP |
| | 3 | * | * | NP |
| Cross the Creek Cave | 2 | * | NP | * |
| Dos Viboras Cave | 2 | * | NP | NP |
| Eagles Nest Cave | 2 | * | * | NP |
| | 3 | * | * | NP |
| | 4 | * | * | NP |
| Flying Buzzworm Cave | 2 | R | * | NP |
| 40 mm Cave | 1 | * | * | * |
| | 2 | * | * | * |
| Headquarters Cave | 2 | * | * | NP |
| | 3 | * | * | NP |
| | 4 | * | * | NP |
| | 5 | * | * | NP |
| | 6 | * | * | NP |
| | 7 | * | * | NP |
| Hilger Hole | 1 | * | * | NP |
| | 2 | * | * | NP |
| Hold Me Back Cave | 2 | * | * | * |
| | 3 | * | * | * |
| | 5 | * | * | * |
| Isocow Cave | 2 | * | * | NP |
| | 3 | * | * | NP |
| | 4 | * | * | NP |
| | 5 | * | * | NP |
| Low Priority Cave* | 1 | R | * | NP |
| | 2 | * | * | NP |
| MARS Pit | 2 | * | * | * |
| | 3 | * | * | * |
| | 4 | * | * | * |

Appendix B, continued. Table of cave localities and zones used for the analysis of three species. An asterisk indicates that the species is known to occur at that cave, the letter "R" indicates that the cave is within the range of the species and was used in the analysis, and "NP" means the species is not present at that site and was not used in the analysis.

| **Cave Name** | **Cave Zone** | ***Rhadine exilis*** | ***Chinquipellobunus madlae*** | ***Batrisodes uncicornis*** |
|---|---|---|---|---|
| MARS Shaft | 2 | * | * | NP |
| | 3 | * | * | NP |
| Pain In The Glass Cave | 1 | * | * | NP |
| | 2 | * | * | NP |
| | 3 | * | * | NP |
| | 4 | * | * | NP |
| Platypus Pit | 2 | * | * | * |
| | 3 | * | * | * |
| | 4 | * | * | * |
| | 5 | * | * | * |
| Poor Boy Baculum Cave | 2 | * | * | NP |
| | 3 | * | * | NP |
| | 4 | * | * | NP |
| Root Canal Cave | 2 | * | * | NP |
| | 3 | * | * | NP |
| | 4 | * | * | NP |
| | 5 | * | * | NP |
| Root Toupee Cave | 2 | * | * | * |
| Strange Little Cave | 1 | * | * | * |
| | 2 | * | * | * |
| | 3 | * | * | * |
| Up The Creek Cave | 1 | * | NP | NP |
| | 2 | * | NP | NP |
| **Total** | | **65** | **61** | **21** |

Appendix C. Formula used to calculate relative humidity.

First, a vapor pressure related to wet-bulb temperature ( $e_w$ ) and a saturated vapor pressure ($e_s$ ) is calculated using the equations below (where e is the number e=2.718...):

$$e_s = 6.112 \times e^{17.67 \times T / T + 243.5} \qquad e_w = 6.112 \times e^{17.67 \times T_W / T_W + 243.5}$$

Then, an actual pressure ( $e_a$ ) is calculated:

$$e_a = e_W - p_{sta} \times (T - T_W) \times 0.00066 \times (1 + (0.00115 \times T_W))$$

Finally, relative humidity (RH) is calculated:

$$RH = \frac{e_a}{e_s} \times 100$$

( T ): Air Temperature in degrees Celsius
($T_W$ ): Wet Bulb Temperature in degrees Celsius
( $P_{sta}$ ): Station Pressure in millibar (mb) or hectoPascal (hPa)