

DETECTION PROBABILITIES OF KARST INVERTEBRATES

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Abstract

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 to test the validity of the survey protocols. Presence/absence matrices were created for three cave species, *Batrissodes unicoloris*, *Chiniquellobunus madlae*, and *Rhadine exilis*. Eleven environmental and seasonal covariates that have been suggested to affect detection probability were tested for fit to the detection data. *B. unicoloris* and *R. exilis* 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 $p = 0.2424$), and in no case was detectability tied to any of the measured covariates. Parametric bootstrapping was 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 results indicate that more surveys should be performed before determining absence from a site. The results also indicate that most 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.

Key words: cave ecology, cave management, endangered species, invertebrates, beetles, harvestmen, detection probability, Camp Bullis, Texas

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 nondetections 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 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 16 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 nonquantified 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.

Materials and Methods

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, during the spring (May), summer (July 15 – August 15), and fall (October). These started in the fall of 2003 and included spring 2007, for a total of eleven sample events. Prior studies have used this method (Elliott 1994) and it is consistent with U.S. Fish and Wildlife Service endangered species survey recommendations (2006).

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, which 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 it 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. 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 the harvestman, *C. madllae*, we found that detectability varied with each survey. Therefore, we conducted a parametric, bootstrapping simulation obtaining 1,000 pseudosamples (Manly 1997). We used the formula

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

where Π_i is the detection probability of the “ith” survey, p is the detection probability on survey i and s is the number of surveys (Jackson et al. 2006). For *Batrisesodes 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.

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). Site covariates included cave length, cave depth, size of floor search area, and size of wall search area. Seven sample covariates changed with each 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 and consisted of a yes/no determination for falling within the recommended surface temperature range, recommended sampling season and a recent rain event.

Species. *Batrisesodes uncicornis* is a troglophile (not restricted to caves, but can spend entire life cycle in a cave), and an eyed pselaphid beetle (Figure 1) that occurs in caves throughout central Texas. This species is not endangered, but it is closely related to endangered *Texamaurops red-*

delli and *B. texanus*. It is known to occur in nine caves containing 21 zones that were sampled 11 times.



Figure 1 *Batrisesodes uncicornis*, a tiny (2 mm), troglomorphic beetle, from B-52 Cave, Bexar County, Texas.

Chinquipellobunus madlae is a troglomorphic (restricted to caves) harvestman (Figure 2) that occurs in caves throughout central Texas. This species is not endangered, but it is related to endangered *Texella cokendolpheri*, *T. reyesi*, and *T. reddelli* harvestmen. *C. madlae* is known to occur in 22 caves containing 61 zones that were sampled 11 times.



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

Rhadine exilis is a federally-listed, troglomorphic carabid beetle (Figure 3) restricted to Bexar County, Texas. Survey results were used from 23 caves subdivided into 65 zones with 11 sample events.



Figure 3 Rhadine exilis, an endangered, troglobitic, ground beetle (1-1.5 cm), from Banzai Mud Dauber Cave, Bexar County, Texas.

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 *B. unicolornis* were most consistent with constant detection probabilities and the data for the other two species varied by survey rather than being seasonal or constant. 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. Of the three species, *C. madllae* was the only dataset found to have a clear best model, which was that the detectability was different for every survey. For *C. madllae*, the varying values of p allowed us to create 95% confidence intervals (Figure 4).

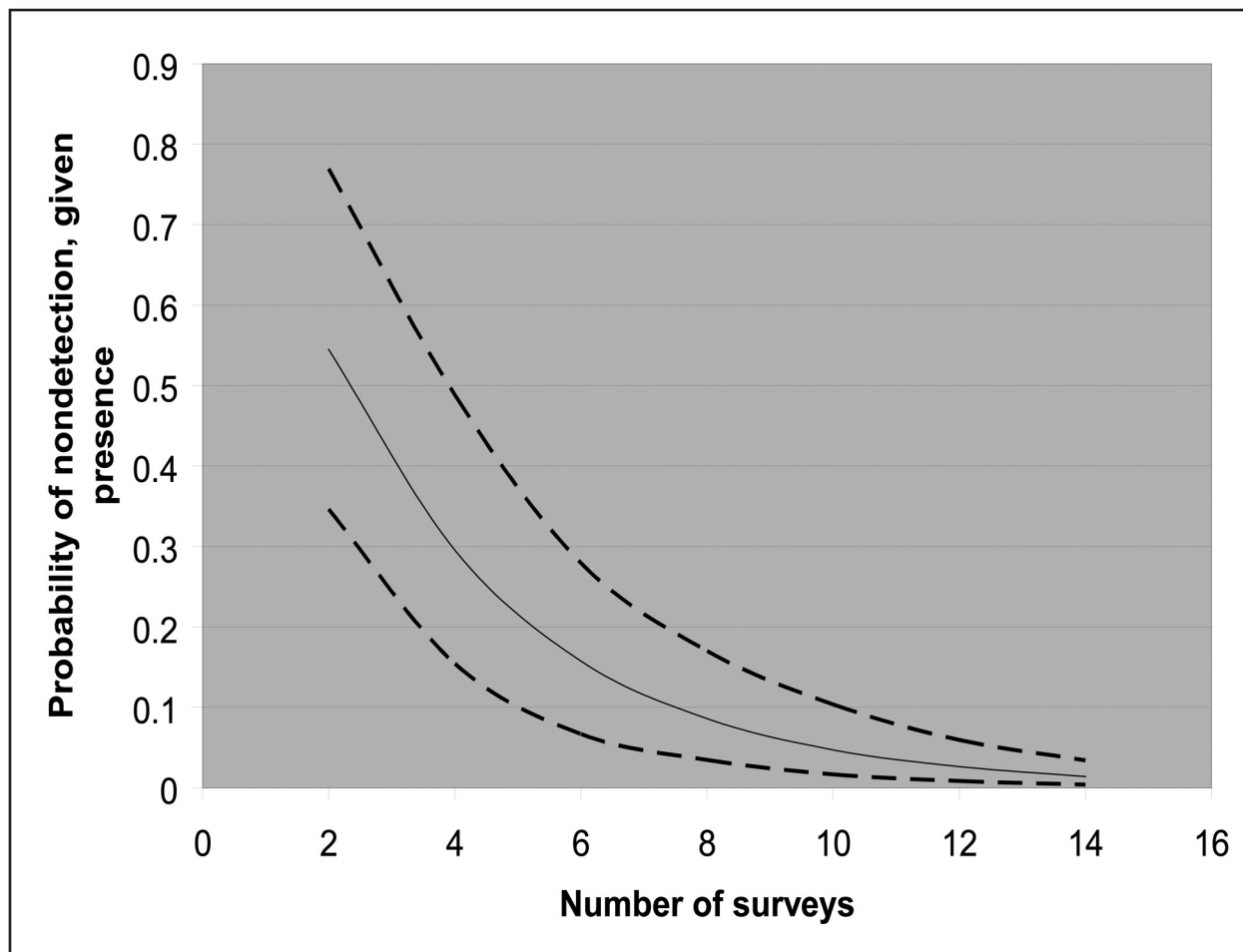


Figure 4 Simulations using the survey-specific detection probabilities measured for *C. madllae* show that more surveys decrease the probability that this species will not be detected at sites where they are present. Upper and lower 95% confidence intervals are shown as dashed lines. These findings suggest that 10-12 surveys are needed to be 95% confident that *C. madllae* are absent from a surveyed site.

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, constant probability of detection, was chosen. In the case of *B. unicolornis*, 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 *R. exilis*, the constant detection probability was 0.1875, the proportion of sites occupied (Ψ) was 0.71 with a standard error of 0.07.

Parametric bootstrapping yielded the following recommended number of surveys for *B. unicolornis*—22, *C. madlae*—10–12, and *R. exilis*—14. These are the recommended number of surveys to conduct to reduce the probability of nondetection, given presence, to 5%.

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 have 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 six visits, and two examples of new taxa being found after >100 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 (*C. madlae*, Figure 2), 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 10–12 visits recommended to confidently determine 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.

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.

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Literature Cited

- Bailey, L.L., T.R. Simons, and K.H. Pollock. 2004. Estimating site occupancy and species detection probability parameters for terrestrial salamanders. *Ecological Applications*, 14(3):692–702.
- Burnham, Kenneth P. and David R. Anderson. 2002. *Model Selection and Multi-Model Inference: A Practical Information-Theoretic Approach*. Springer-Verlag, New York, New York, USA. 488 pp.
- Culver, D.C., M.C. Christman, B. Sket, and P. Trontelj. 2004. Sampling adequacy in an extreme environment: species richness patterns in Slovenian caves. *Biodiversity and Conservation*, 13:1209–1229.
- Elliott, William R. 1994. Community ecology of three caves in Williamson County, Texas: A three year summary. Annual report submitted to Simon Development Co., Inc., U.S. Fish and Wildlife Service, and Texas Parks and Wildlife Department, 46 pp.
- Jackson, Jacob T., Floyd W. Weckerly, Todd M. Swannack, and Michael R.J. Forstner. 2006. Inferring absence of Houston toads given imperfect detection probabilities. *Journal of Wildlife Management*, 70(5):1461–1463.
- Knapp, S.M., and D.W. Fong. 1999. Estimates of Population Size of *Stygobromus emarginatus* (Amphipoda: Crangonyctidae) in a Headwater Stream in Organ Cave, West Virginia. *Journal of Cave and Karst Studies*, 61(1): 3–6.
- MacKenzie, D.I., J.D. Nichols, G.B. Lachman, S. Droege, A. Royle, and C.A. Langtimm. 2002. Estimating site occupancy rates when detection probabilities are less than one. *Ecology*, 83(8): 2248–2255.
- MacKenzie, Darryl I., James D. Nichols, J. Andrew Royle, Kenneth H. Pollock, Larissa L. Bailey, and James E. Hines. 2006. *Occupancy Estimation and Modeling: Inferring Patterns and Dynamics of Species Occurrence*. Elsevier Inc., Amsterdam. 324 pp.
- Manly, Brian F.J. 1997. *Randomization, Bootstrap, and Monte Carlo Methods in Biology*. 2nd ed., Chapman & Hall, New York. 399 pp.

- Schneider, K. and D.C. Culver. 2004. Estimating subterranean species richness using intensive sampling and rarefaction curves in a high density cave region in West Virginia. *Journal of Cave and Karst Studies*, 66(2):39–45.
- U.S. Fish and Wildlife Service. 1994. Recovery Plan for Endangered Karst Invertebrates in Travis and Williamson Counties, Texas. Albuquerque, New Mexico. 154 pp.
- U.S. Fish and Wildlife Service. 2006. USFWS Section 10(a) (1) (A) Scientific Permit Requirements for Conducting Presence/Absence Surveys for Endangered Karst Invertebrates in Central Texas. Fish and Wildlife Service, 10711 Burnet Road, Suite 200, Austin, Texas 78758. March 8, 2006. 21 pp.
- Veni, George, and Associates. 2006. Hydrogeological, Biological, Archeological, and Paleontological karst investigations, Camp Bullis, Texas, 1993–2006. Report for Natural and Cultural Resources, Ft. Sam Houston, by George Veni and Associates, San Antonio, Texas, 2,421 pp.