

Articles

Use of Long-Term Opportunistic Surveys to Estimate Trends in Abundance of Hibernating Townsend's Big-Eared Bats

Theodore J. Weller,* Shawn C. Thomas, James A. Baldwin

T.J. Weller

U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station, Arcata, California 95521

S.C. Thomas

Carlsbad Caverns National Park, Carlsbad, New Mexico 88220

J.A. Baldwin

U.S. Department of Agriculture Forest Service, Pacific Southwest Research Station, Albany, California 94706

Abstract

The advent of broad-scale threats to bats such as white-nose syndrome and climate change highlights the need for reliable baseline assessment of their populations. However, few long-term, rigorously designed assessments of bat populations exist, particularly in western North America. Consequently, results of informal monitoring efforts are often the only data available upon which to base population assessments. We evaluated whether an opportunistic collection of surveys recorded over a 22-y period could be used to assess population trend of Townsend's big-eared bats (*Corynorhinus townsendii*) at Lava Beds National Monument in northern California. We used records of counts of hibernating bats conducted during 1991–2012 to estimate the number of bats in 52 individual caves as well as cumulatively. Seventeen of 22 caves surveyed in four or more years had an increasing trend in the number of hibernating bats. We estimated the cumulative annual growth rate over the period to be 1.79%. Stable or increasing number of hibernating Townsend's big-eared bats may be a result of management actions taken to limit disturbance of bats during maternity and hibernation seasons. We found no evidence that annual counts depressed the number of hibernating bats, thereby broadening monitoring options and the ability to link population trends to extrinsic factors. Our results demonstrate that opportunistically collected, long-term data sets may be useful for establishing first approximations of population trends for bats.

Keywords: bats; cave; *Corynorhinus townsendii*; hibernation; monitoring; population; winter

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* Corresponding author: tweller@fs.fed.us

Introduction

Assessing the status and trend of wildlife populations is fundamental to understanding their ecology and making informed conservation and management decisions. Successful monitoring programs require careful organization and planning, early involvement by a

statistician, and sample sizes suitable to achieve identified objectives (Morrison et al. 2001). However, finding the time or funding to design and implement a statistically robust monitoring program can be challenging (Sergeant et al. 2012), particularly prior to conspicuous population changes that often motivate such initiatives and liberate necessary funds. Nevertheless,



baseline information on the status and trend of wildlife populations is critical for quantifying changes in populations, particularly in response to ecological perturbations (Jones et al. 2009; Pederson et al. 2010).

The emergence of broad-scale threats to bat populations such as white-nose syndrome (Bleher et al. 2009; Cryan et al. 2013) and climate change highlights the need for reliable baseline assessment of bat populations (Frick et al. 2010b; Olson et al. 2011; Thogmartin et al. 2012) against which to compare impacted populations. Absent a well-designed, consistently applied, broad-scale monitoring program (O'Shea and Bogan 2003), baseline assessments of population status for North American bat species have relied on an amalgam of existing local efforts and historic data sets (Frick et al. 2010a; Thogmartin et al. 2012). There are a few examples of rigorously designed and analyzed intensive local efforts (Frick et al. 2007; Frick et al. 2010b; O'Shea et al. 2011). Typically though, assessments result from proactive steps by local entities, usually with insufficient funding, to characterize the status of one or more bat populations. In particular, a great deal of recent effort has been focused on establishing baseline population levels of hibernating bats prior to the anticipated arrival of white-nose syndrome (Olson et al. 2011). Many such efforts, however, lack the statistical rigor, funding, or consistent support associated with robust monitoring programs (Hayes et al. 2009; Sergeant et al. 2012). It is important to determine whether these efforts can assess baseline conditions and whether low-cost enhancements can increase their efficacy (McPherson and Myers 2009).

Corynorhinus townsendii, the Townsend's big-eared bat, is a cave- and mine-roosting species that is considered imperiled throughout its range in North America (Pierson et al. 1999; Ellison et al. 2003). Two eastern subspecies (*C.t. ingens* and *C.t. virginianus*) are listed as endangered under the U.S. Endangered Species Act (ESA 1973, as amended); and biologists suspect that populations of its western subspecies (*C.t. pallescens* and *C.t. townsendii*; Piaggio and Perkins 2005) are declining throughout their range in western North America (Pierson et al. 1999). Compared to other species in western North America, Townsend's big-eared bats are relatively conspicuous and hence have attracted a good deal of conservation attention and monitoring effort (Pierson et al. 1999; Ellison et al. 2003; Weller et al. 2009).

Lava Beds National Monument (LBNM) provides roosting habitat for one of the largest populations of Townsend's big-eared bats known from western North America (Pierson et al. 1999). Accordingly, LBNM has engaged in a typical, if longer duration than most, effort to monitor their numbers. In 1991, monument personnel began consistently recording results of roost searches for bats, especially Townsend's big-eared bats. LBNM personnel identified caves containing hibernating bats opportunistically and added them to an informal list of caves where counts of hibernating bats were conducted. The number of caves visited and number of surveys conducted varied annually according to staff availability, interests, and expertise. We were interested in whether we could use such data to evaluate the status and trend

of hibernating bats. Specifically, our objective was to assess the trend in the number of Townsend's big-eared bats hibernating at LBNM during the period 1991–2012. Further, we aim to use existing survey data from this period to improve the scope and reliability of future monitoring efforts while maintaining the flexibility necessary to respond to changes in personnel or funding. A secondary objective was to determine whether annual surveys reduced the number of bats at individual hibernacula (Kunz et al. 2009). If so, survey protocols could be altered accordingly; if not, it would broaden options for future monitoring and research (e.g., linking annual abundance to weather or disease).

Methods

Study area

Lava Beds National Monument is located in northeastern California, approximately 250 km northeast of Redding, California, and 75 km southeast of Klamath Falls, Oregon. The monument contains the largest concentration of lava caves in the contiguous United States; LBNM staff had identified more than 750 caves by 2013. Lava Beds National Monument lies at the convergence of the Sierra-Klamath, Cascade, and Great Basin geographic provinces and ranges in elevation from 1,236 to 1,685 m. Accordingly, vegetation associations range from a low-elevation sagebrush steppe community dominated by bluebunch wheatgrass (*Pseudoroegneria spicata*) and basin or mountain big sagebrush (*Artemisia tridentata* subsp.), to an intermediate-elevation, mixed woodland community dominated by western juniper (*Juniperus occidentalis*) and mountain mahogany (*Cercocarpus ledifolius*), with ponderosa pine (*Pinus ponderosa*) coniferous forest occurring at the highest elevations. The climate of LBNM is considered high-elevation semiarid desert, with warm dry summers and cool winters. For the period from 1991 to 2012, average annual high temperatures were 16° C and average annual low temperatures were 2° C. The monument received an average of 37 cm of precipitation annually during this period, the majority of which was derived from snowfall.

Bat surveys

Personnel at LBNM began regularly documenting results of bat surveys in 1991. During winter surveys, personnel entered caves using headlamps and tallied all hibernating bats observed visually. Townsend's big-eared bats are, by far, the most prevalent species hibernating in LBNM caves and are generally easy to distinguish from other species of bats that occasionally hibernate in these caves (e.g., species in the genus *Myotis*) due to their conspicuously large ears (Figure 1). Townsend's big-eared bats at LBNM hibernate singly or in small groups, generally consisting of less than 20 individuals; LBNM personnel occasionally observe clusters of up to 40 individuals. Aggregations of this size are ideal for using visual counts to estimate number of individuals (Kunz 2003). On the other hand, it is likely that bats roosting singly or in small groups could be missed, particularly in larger caves or those with high



Figure 1. (A) Single Townsend's big-eared bat (*Corynorhinus townsendii*) hibernating with ears extended. (B) Example of winter hibernacula at a cave in Lava Beds National Monument depicting surveyor entering cave passing a sign indicating that cave is closed to the public.

ceilings. We assumed that error associated with missing small numbers of bats in individual caves was consistent over the monitoring period.

Estimating number of bats

We considered reports of surveys conducted between November 15 and March 15 to be counts of bats in a hibernaculum, defined as a cave bats use to overwinter while in a state of torpor. We assigned each survey a year according to the year in which the winter period ended. On 25 occasions, LBNM personnel counted an individual cave more than once during a single winter, but we only included results of a single count per year in our analyses. The count selected for inclusion was based on its reliability as judged from written comments. When counts appeared equally reliable ($n = 19$), we selected the count conducted closest to 15 January. On the few occasions when surveyors provided an estimate of minimum and maximum number of bats present ($n = 6$), we used the minimum value. We excluded caves that had been surveyed during winter but where no bats had ever been observed. Not all caves are suitable as bat hibernacula (Pierson and Rainey 1996; Sherwin et al. 2003).

We fit a log-linear model to each cave that was surveyed four or more times during 1991–2012 and for which 50% or more of the counts were non-zero. Specifically, we used the negative binomial distribution to model the case where counts for cave i followed a linear trend over time (McCullagh and Nelder 1989):

$$\ln(\text{mean}[\text{count}_i]|\text{year}) = a_i + b_i \times \text{year}$$

with $(\text{count}_i|\text{year}) \cong$ negative binomial (μ_i, k) where a_i and b_i are the respective intercept and slope for cave i ,

year is 1991, 1992, ..., 2012, and k and $\mu_i = e^{a_i + b_i \times \text{year}}$ are the negative binomial parameters with μ_i representing the predicted count for a particular year. We used negative binomial regression because count data did not meet assumptions of normality associated with other approaches (Humbert et al. 2009). We decided to censor estimates to attain plausible results for individual caves (Hill et al. 2007). The alternative was to allow estimates to extend to zero for caves in which a zero count had never been observed or attain maximum values that far exceeded the observed maximum count. We arbitrarily censored predicted counts to fall between 90% of the lowest count and 110% of the greatest count observed at a particular cave. For instance, if the lowest and highest observed counts at a cave were two and nine bats respectively, our prediction for that cave was bounded to fall between 1.8 and 9.9 bats. We used a t -test to evaluate whether the slope of year vs. predicted count for each cave differed from zero and evaluated the probability (P -value) of observing a more extreme estimate of the slope given that the true slope was zero.

Trend estimation from short time series is problematic (Humbert et al. 2009). Therefore we estimated counts for caves that had been surveyed one to three times or for which 50% or more of the counts were zero using the following equation:

$$\mu_i = e^{\ln \bar{x} + \bar{b}(y - \bar{y})}$$

where $\bar{x}$ is the mean count for a cave during previous surveys, $\bar{b}$ is the mean slope calculated for caves surveyed four or more times during 1991–2012, y is the year of interest and $\bar{y}$ is the mean year a cave was surveyed (e.g., for a cave surveyed in 2002 and 2006 the

mean survey year is 2004). We again bounded estimated counts to fall between 90% of the lowest and 110% of the greatest observed counts. We generated prediction intervals for each cave by selecting the middle 95% of the negative binomial distribution of our estimates. We limited prediction intervals to integer counts and censored lower limits at zero, but allowed upper limits to be unbounded (Table A2). We performed all programming for the negative binomial regression using PROC GLIMMIX, SAS software, Version 9.3 of the SAS System for Windows (SAS Institute, Inc., Cary, NC; Table A1, *Archived Material*).

To evaluate the accuracy of our estimation procedure, we used data from 1991 to 2011 to estimate the number of bats we expected to observe in individual caves in 2012 and compared them to the actual number counted during 2012 censuses. We estimated the annual total of hibernating bats in all caves by summing a combination of estimates and actual counts. For years and caves when a census was conducted, we used the count and assigned a zero standard error for that count. When a census was not conducted at a cave for a particular year we used the estimated count and its standard error. We estimated the standard error for the year as the square root of the sum of the squares of the individual standard errors. We estimated the annual rate of proportional change in the population as $e^m - 1$, where m was the slope of a linear regression between the log of the estimated total count versus year.

Results

Lava Beds National Monument personnel found hibernating bats in 52 of the 97 caves surveyed during the winters of 1991–2012. Among the 52 caves included in our analyses (Table A3), the mean number of caves searched annually was 11.9, but ranged from 0 to 34 (Table 1). In recent years, surveys have generally become more numerous, averaging 18.2 hibernacula counts per year during 2001–2012 (Table 1). Although LBNM personnel knew it to be a hibernaculum at an earlier date, they made the first recorded count of hibernating bats in cave L970 on November 22, 1990 when they counted 376 bats. Since 1990, cave L970 has been a high-priority site for hibernation counts and comprises a sizeable proportion of the hibernating bats counted at LBNM each winter (Table 1).

Seventeen of 22 caves (77%) surveyed in at least 4 y had a positive trend in the number of hibernating bats present over the period 1991–2012 (Figure 2; Table 2). This includes the 15 caves that registered the highest counts of bats. In 5 of the 15 caves with the highest counts, the P -values associated with the test of the slope being zero were very small ($P \leq 0.012$; Table 2). None of the five caves with decreasing trends had small associated P -values and the maximum count at any of these caves was 10 bats (Table 2; Figure 2). With few exceptions, observed counts fell within the 95% prediction interval for individual caves (Figure 2) indicating that there was no obvious lack of fit. The mean slope among caves surveyed at least 4 y was 0.0412, suggesting an

Table 1. Number of caves searched and total number of Townsend's big-eared bats (*Corynorhinus townsendii*) counted between November 15 and March 15 at Lava Beds National Monument, Siskiyou County, California, during the years 1991–2012. Cave L970 contained, by far, the largest number of hibernating bats in the monument.

Year	No. of caves	Cave L970 count	Total count
1991	5	376	438
1992	11	236	384
1993	1	—	1
1994	5	614	643
1995	2	469	512
1996	4	637	672
1997	0	—	—
1998	9	643	727
1999	1	—	2
2000	6	582	640
2001	13	530	665
2002	19	437	702
2003	18	586	811
2004	8	699	739
2005	25	551	733
2006	26	601	756
2007	10	505	620
2008	17	513	723
2009	5	607	665
2010	22	519	1,026
2011	21	541	1,117
2012	34	588	1,346

annual growth rate of approximately 4% for the most frequently surveyed caves.

In 2012, LBNM personnel conducted counts at 25 caves that had a non-zero count prior to 2012. Estimates based on data from 1991 to 2011 generally predicted counts well (Figure 3). However counts in most caves exceeded predictions in 2012; seven caves had their highest count in 2012 and another three equaled their previous high count. On average, 2012 counts at the 19 caves estimated to have less than 30 bats were within four bats (range 0.2–14.6) of estimates. Counts at five of six caves estimated to contain more than 34 bats were higher than expected in 2012. On average, counts at these six caves were within 21% of estimates, ranging from 3.9% lower than estimated in cave L970 to 54.7% higher than estimated at cave M270.

Cumulatively, we estimate that the number of hibernating bats in the 52 surveyed caves has increased from 834 (SE = 51) bats in 1991 to 1,427 bats (SE = 13) in 2012 (Figure 4). Size of prediction intervals were largest in years when cave L970 was not counted and generally inversely proportional to the total number of caves surveyed per year (Table 1; Figure 4). The estimated cumulative annual growth rate for the 52 caves over the period 1991–2012 was 1.79%.

Discussion

We found evidence of a positive trend in the number of Townsend's big-eared bats hibernating at LBNM during the period 1991–2012. Although only five caves had slopes that were statistically different from zero, the majority of individual caves, including those that housed the largest number of bats, exhibited positive estimated trends. Correspondingly, we estimated that the cumulative number of hibernating bats has increased since 1991. Our estimates relied on historic reports of hibernacula surveys and relatively few of the records and observations were made ourselves. As a result, we maintain a measure of uncertainty about the slope of the trend but are confident that the number of bats in the 52 surveyed caves has increased or, at the least, remained stable.

Over the past few decades, a common refrain has been that bat populations in general are in decline due to habitat loss, roost disturbance, and a variety of other factors (Pierson 1998; Hutson et al. 2001). Our results, in concert with several other recent studies of cave-roosting populations in North America, have found evidence of stable to increasing populations in the absence of disturbance (Sasse et al. 2007; Frick et al. 2010a; Langwing et al. 2012; Thogmartin et al. 2012; Wainwright and Reynolds 2013). Although analysis methods differed among studies we can compare our results to other recent trends in hibernating bat populations. Counts of *Myotis* spp. at a hibernaculum in Alberta increased 2.9% per year, which the authors attributed to reduced disturbance to bats that resulted from limitation on human visits during winter (Olson et al. 2011). Prior to onset of white-nose syndrome, hibernating populations for six species of bats in the northeastern United States were increasing an average of 8% per year (Langwing et al. 2012). We estimated that the cumulative number of Townsend's big-eared bats in 52 caves at LBNM increased by about 1.8% per year. The increasing number of hibernating individuals reaffirms LBNM as a population stronghold for Townsend's big-eared bats in a state (Pierson and Rainey 1998) and region (Pierson et al. 1999) where it is considered imperiled.

Potential ecological explanations for the increase in hibernating bats are unclear but could be related to changes in management policy at LBNM. Beginning in 1991, approximately 10 caves were closed during the maternity period to limit disturbance of maternity colonies by visitors. Lava Beds National Monument also closed winter hibernation sites to visitors, starting with a few sites in the 1990s and increasing to nearly 20 caves by 2012 (Figure 1). Limiting human visitation of caves during maternity or hibernation seasons has led to increased numbers of bats in roosts elsewhere (Sasse et al. 2007; Olson et al. 2011; Paksuz and Özkan 2012; Wainwright and Reynolds 2013). Lava Beds National Monument hosts a large summer population of Townsend's big-eared bats (Pierson and Rainey 1996); thus it is plausible that improved management of their summer habitat has increased the hibernating population at

LBNM. However, we do not know what proportion of bats that hibernate at LBNM also spend their summers at the monument.

We found no evidence that annual censuses of caves during hibernation depressed the number of bats hibernating in them. The two most frequently surveyed caves (L970 and M270) consistently housed large numbers of bats. Although there was high annual variability in counts both had positive, though not significant, estimated slopes over the 1991–2012 survey period and there was no evidence that counts in consecutive years decreased the number of hibernating bats (Figure 2). Further, during 2010–2012, LBNM personnel censused 19 caves in all 3 y. Counts in 12 were relatively consistent while in six others, including the caves with the second and fourth highest numbers of bats, counts increased 41–100%; only one cave exhibited a decrease and this was from nine to three bats. Although this particular 3-y period may not be representative, and may even represent an unusual period of population growth, it provides no indication that annual hibernation counts decreased the number of hibernating Townsend's big-eared bats. Existing guidance recommends that hibernaculum counts should be conducted no more than every 2 y so as to minimize disturbance to hibernating bats (Pierson et al. 1999; Kunz 2003; Kunz et al. 2009). For the population of Townsend's big-eared bats hibernating at LBNM we found no evidence that annual censuses were detrimental. Accordingly, we encourage others to reexamine their rationale for not censusing hibernacula annually. Annual counts provide a more sensitive measure of population change and provide improved opportunities to link changes in population size or structure to extrinsic factors such as weather (Warren and Witter 2002; Frick et al. 2010b; Olson et al. 2011; O'Shea et al. 2011) or disease introduction (Thogmartin et al. 2012; Frick et al. 2010a). On the other hand, where budgets are limited or concerns about disturbance are high, it is possible to elucidate multiyear trends without annual surveys (Humbert et al. 2009).

Cave L970 housed by far the largest number of bats and could be considered the preferred hibernaculum at LBNM. Under this scenario, we considered whether other caves may be acting as population sinks with higher than expected counts in years when cave L970 had its highest counts and may have been at capacity. In the 8 y since 2002, when 16 or more caves were surveyed, fewer bats than expected were counted at cave L970 in 4 y. In two of those years, more bats than expected were counted cumulatively in other surveyed caves and in 2 y fewer bats than expected were counted. Likewise in the 4 y when more bats than expected were counted at cave L970, more bats than expected were counted in other caves during 2 y and fewer bats than expected were counted in the other 2 y. Hence there appeared to be no relation between counts at cave L970 and other caves and thus no reason to believe that simply monitoring numbers of bats at cave L970 would be an accurate index for the number of bats hibernating in the sample of 52 caves.

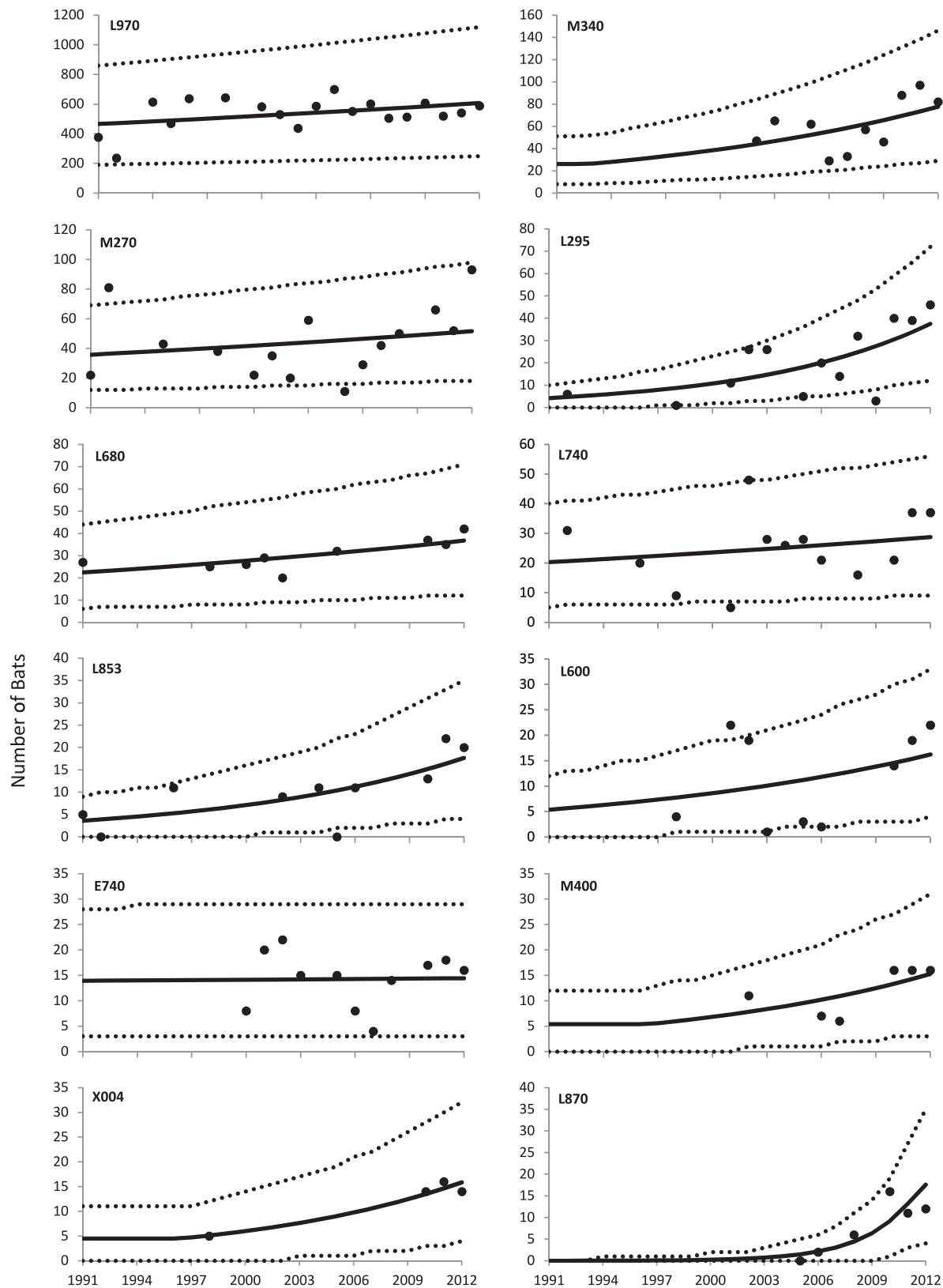


Figure 2. Estimated trend (solid line), upper and lower 95% prediction intervals (dotted lines), and number of Townsend's big-eared bats (*Corynorhinus townsendii*) counted (solid circles) during hibernacula surveys at 22 caves in Lava Beds National Monument, Siskiyou County, California, during 1991–2012. Caves are ordered top left to bottom right as largest to smallest observed counts.

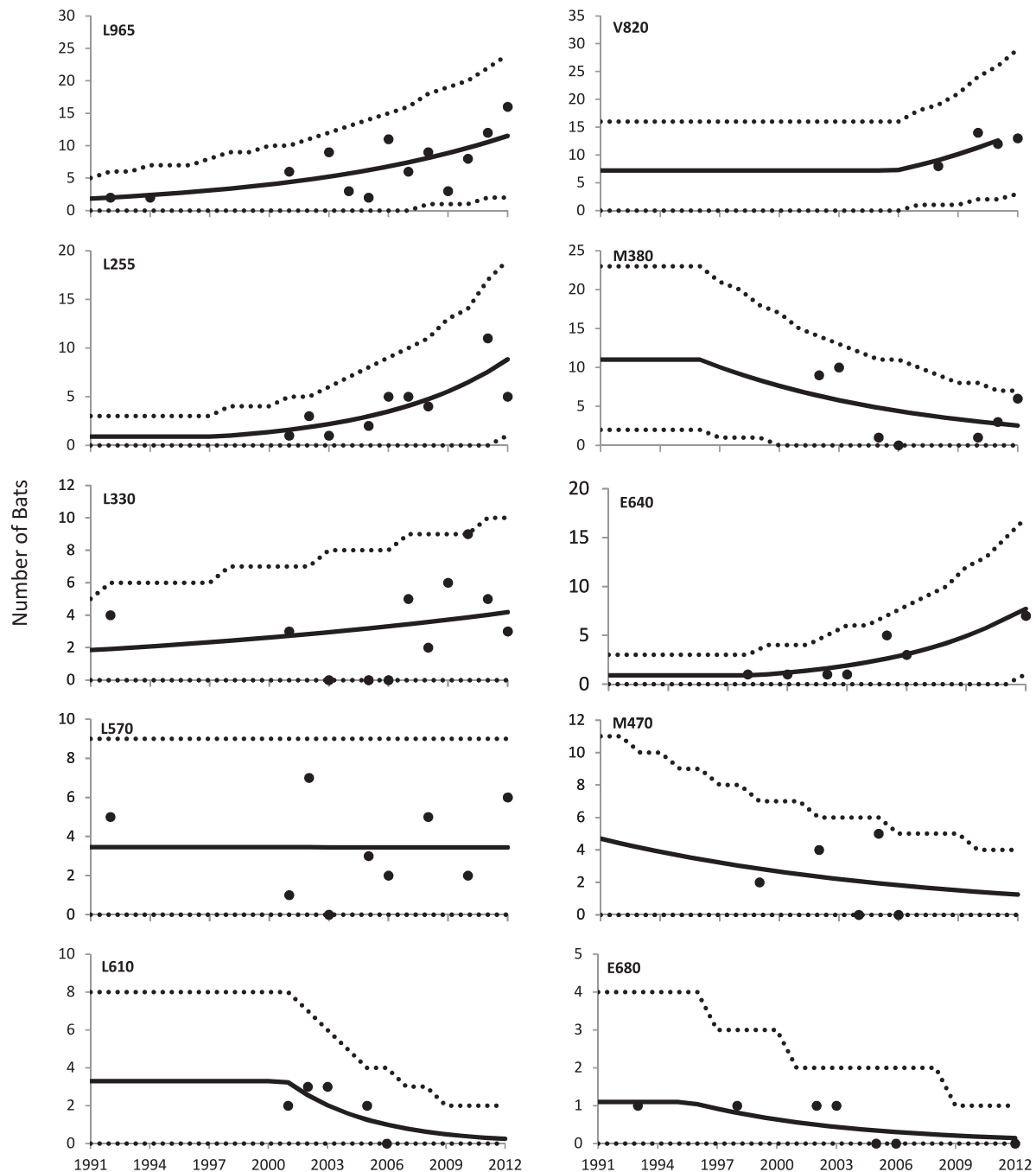


Figure 2. Continued.

It is possible that improved census practices in recent years have led to detection of a larger proportion of the bats hibernating in caves at LBNM. Locations of bats within caves that were discovered opportunistically in previous years were likely passed on to surveyors such that these locations were rigorously searched in later surveys. We do not know the extent of information sharing nor how much it may have improved accuracy of counts, but acknowledge that it would increase the number of bats counted in later surveys. The number of bats counted would also increase if early searches at a particular cave were only conducted in portions of the

cave but later efforts searched the entire cave complex. We suspect that this may have occurred in up to six cave complexes where it was not possible for us to determine whether the entire complex had been searched during earlier surveys. On the other hand, many of the caves at LBNM are relatively simple in structure and it is difficult to imagine a conscientious biologist overlooking more than a few bats. The slope of count trends in simple caves was similar to that of more complex caves, which provided a measure of confidence that the explanation for higher counts was due to increased numbers of hibernating bats rather than solely improved census accuracy.

Table 2. Estimates of change in number of Townsend's big-eared bats (*Corynorhinus townsendii*) hibernating in 22 caves at Lava Beds National Monument, Siskiyou County, California, between the years 1991 and 2012. The table presents number of years counted (*n*), slope (log-scale) of relationship between count and year and its associated standard error (SE), *t*-statistic (*t*) and probability (*P*). All tests had 158 degrees of freedom. Caves are listed in descending order of maximum observed count.

Cave	<i>n</i>	Slope	SE	<i>t</i>	<i>P</i>
L970	19	0.0126	0.0139	0.907	0.366
M340	10	0.0566	0.0366	1.546	0.124
M270	15	0.0175	0.0145	1.207	0.229
L295	13	0.1036	0.0245	4.223	<<0.001
L680	9	0.0235	0.0204	1.154	0.250
L740	13	0.0165	0.0194	0.849	0.397
L853	10	0.0756	0.0233	3.244	0.001
L600	9	0.0527	0.0327	1.612	0.109
E740	11	0.0017	0.0338	0.0493	0.961
M400	6	0.0670	0.0550	1.218	0.225
X004	4	0.0810	0.0483	1.678	0.095
L870	6	0.3630	0.1101	3.296	0.001
L965	13	0.0875	0.0301	2.905	0.004
V820	4	0.1098	0.1664	0.660	0.510
L255	9	0.1557	0.0609	2.557	0.012
M380	7	-0.0918	0.0601	-1.526	0.129
L330	11	0.0390	0.0385	1.012	0.313
E640	7	0.1574	0.0632	2.490	0.014
L570	9	-0.0003	0.0371	-0.008	0.993
M470	5	-0.0631	0.1385	-0.455	0.649
L610	5	-0.2348	0.2163	-1.085	0.279
E680	7	-0.1229	0.0986	-1.246	0.215

Our work adds to a number of recent studies that have demonstrated that survey data, even those collected irregularly over space and time, can be profitably exploited to establish baseline population trends for bats (Sasse et al. 2007; Frick et al. 2010a; Olson et al. 2011; Langwing et al. 2012; Thogmartin et al. 2012; Wainwright and Reynolds 2013). Data resulting from poorly designed monitoring programs is generally considered an unreliable foundation for the basis of management decisions (Hayes et al. 2009; Sergeant et al. 2012). The use of historic data, in particular, is typically not considered reliable enough to establish trends (Hayes et al. 2009). Nevertheless, we were able to demonstrate that such data can sometimes be profitably exploited to this end. The best exhibition of this was the close fit we observed between predicted and realized counts in 2012 (Figure 3). We attribute our success to the relatively sustained level of effort over a 22-y period. It is remarkable, and somewhat fortuitous, that hibernacula monitoring at LBNM persisted due to the efforts of a series of dedicated champions over the years, especially without a formalized institutional memory (Sergeant et al. 2012). Most ad hoc monitoring programs are of shorter durations. Ellison et al. (2003) assembled all the

publicly available data on counts of bats at roosts and found that 72% of site records represented single visits and only 9% represented time series of 4 y or more. Hence, the assembled data on Townsend's big-eared bats from LBNM are especially unique and robust relative to data sets available for any species of bat in western North America.

Sustained monitoring efforts, even those without an a priori analysis plan, can sometimes be used to draw inference about baseline population trends in the absence of better data sets (Frick et al. 2010a; Langwing et al. 2012; Thogmartin et al. 2012). Although we support the use of properly designed monitoring efforts, we also encourage others to examine data collected ad hoc over long time periods both for its utility in designing efficient monitoring efforts in the future but also for its potential to provide first estimates of baseline populations trends (McPherson and Myers 2009). The latter is a major data gap for most bat populations, particularly in western North America (O'Shea and Bogan 2003; Weller et al. 2009; Olson et al. 2011).

Although we found an overall trend of increasing counts among the 52 caves surveyed at LBNM over the 22 y surveyed, we cannot necessarily conclude that the number of hibernating bats, as a whole, has increased over this period. There are several reasons for this. First, the caves surveyed were opportunistically selected from a larger number (>750) of caves in the monument, most of which have not been surveyed. Inference to the population as a whole would require caves to be selected from a statistical framework. We speculate that many of the unsurveyed caves support one to five hibernating bats, but this remains to be quantified. It is also likely that several other large hibernacula remain to be discovered. For example cave L865, which houses the second largest number of Townsend's big-eared bats (126–191 individuals), was only identified by researchers as a hibernaculum in 2010, and LBNM personnel only identified cave L795, with 45 bats, as a hibernaculum in 2012. The extent to which other unsurveyed caves support large numbers of hibernating bats, and the annual variability among counts are also important to know.

Future monitoring at LBNM is aimed at quantifying trends in the Townsend's big-eared bat population as a whole rather than in the 52 caves surveyed to date. Beginning in 2011, the majority of census activity has been conducted during a single week in mid-January rather than throughout the winter. This modification reduced opportunities for intercave movement by bats that would impact estimates of the number of hibernating bats (Sherwin et al. 2003; Thogmartin et al. 2012). Beginning in 2013, LBNM personnel expanded the sample frame of caves available for hibernation surveys to include all of the more than 750 caves within the monument. A "probability proportional to size" sampling approach is utilized by researchers for previously censused caves that provides higher probability of selection for caves according to number of bats observed in recent years. In this manner, it will be possible for LBNM personnel to simultaneously minimize variation in annual estimates, characterize the overall

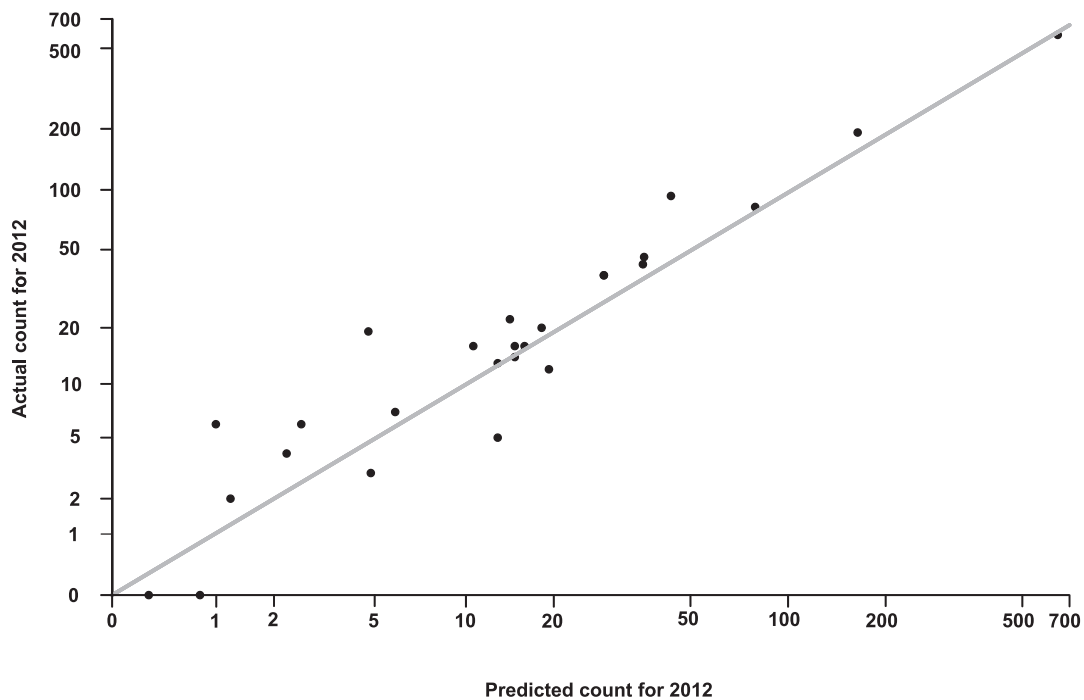


Figure 3. Relationship between number of Townsend's big-eared bats (*Corynorhinus townsendii*) estimated to be present based on counts in 1991–2011 and actual number of bats counted in 25 caves at Lava Beds National Monument, Siskiyou County, California, during 2012.

status of the large number of unsurveyed caves, and recruit new caves that may harbor large numbers of hibernating bats into the surveyed population. These changes do not necessarily require an increase in the number of caves surveyed nor even a commitment to survey a minimum number of caves annually. Hence, with a few improvements in study design, the scale of inference will increase dramatically without concomitant increases in survey effort.

Archived Material

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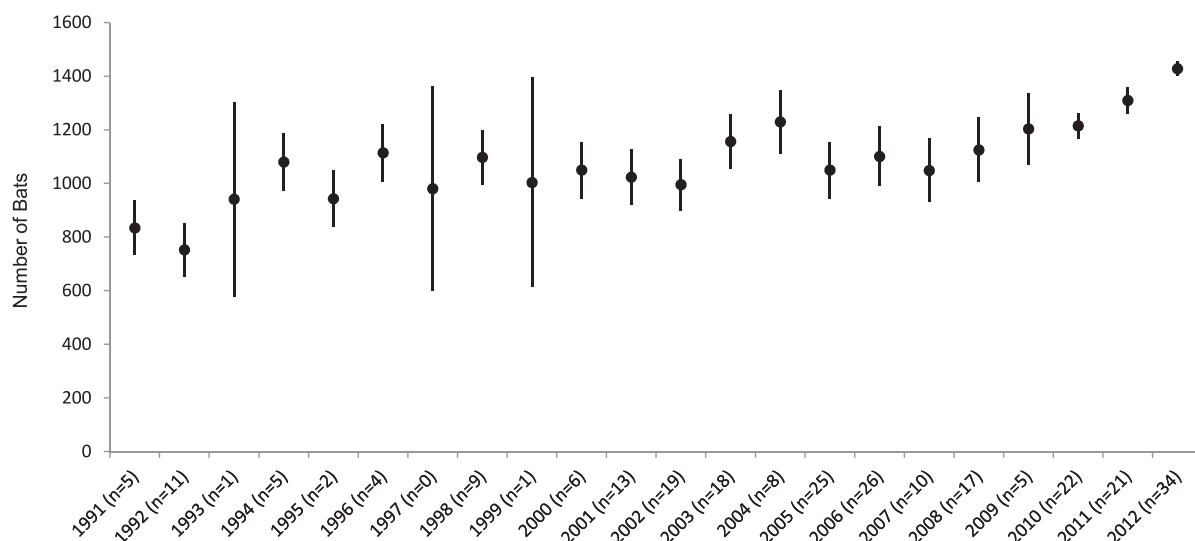


Figure 4. Estimates, with 95% prediction intervals, for the total number of Townsend's big-eared bats (*Corynorhinus townsendii*) hibernating in 52 caves at Lava Beds National Monument, Siskiyou County, California, during 1991–2012. The total number of caves surveyed each year is denoted as n on the x-axis.

Table A1. SAS (SAS Institute, Inc., Cary, North Carolina) code for analysis of hibernation counts of Townsend's big-eared bats (*Corynorhinus townsendii*) at Lava Beds National Monument 1991–2012. Code contains the raw data (counts for each year and cave) used in the analysis.

Found at DOI: <http://dx.doi.org/10.5061/dryad.th08v> (11 KB TXT)

Table A2. Worksheets that contain results of analyses estimating number of Townsend's big-eared bats (*Corynorhinus townsendii*) hibernating in individual caves at Lava Beds National Monument 1991–2012. Worksheet "All" contains slope, intercept, predicted number of bats, variance and upper and lower predicted limits for each cave and year. Worksheet "Parameter Estimates" provides estimate of slope, its standard error, degrees of freedom (df), *t*-value, and *P*-value (Probt) for 22 caves that were surveyed for 4 y or longer.

Found at DOI: <http://dx.doi.org/10.5061/dryad.th08v> (1 KB XLS)

Table A3. Raw data. Number of Townsend's big-eared bats (*Corynorhinus townsendii*) counted in 52 individual caves during each year from 1991 to 2012 at Lava Beds National Monument, Siskiyou County, California.

Found at DOI: <http://dx.doi.org/10.5061/dryad.th08v> (437 KB CSV)

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