

Twenty-Five Years of Monitoring a Townsend's Big-Eared Bat (*Corynorhinus townsendii*) Maternity Roost

Author(s): Gary M Fellers Brian J Halstead

Source: Northwestern Naturalist, 96(1):22-36.

Published By: Society for Northwestern Vertebrate Biology

DOI: <http://dx.doi.org/10.1898/NWN14-12.1>

URL: <http://www.bioone.org/doi/full/10.1898/NWN14-12.1>

BioOne (www.bioone.org) is a nonprofit, online aggregation of core research in the biological, ecological, and environmental sciences. BioOne provides a sustainable online platform for over 170 journals and books published by nonprofit societies, associations, museums, institutions, and presses.

Your use of this PDF, the BioOne Web site, and all posted and associated content indicates your acceptance of BioOne's Terms of Use, available at www.bioone.org/page/terms_of_use.

Usage of BioOne content is strictly limited to personal, educational, and non-commercial use. Commercial inquiries or rights and permissions requests should be directed to the individual publisher as copyright holder.

TWENTY-FIVE YEARS OF MONITORING A TOWNSEND'S BIG-EARED BAT (*CORYNORHINUS TOWNSENDII*) MATERNITY ROOST

GARY M FELLERS

US Geological Survey, Western Ecological Center, Point Reyes National Seashore, Point Reyes, CA 94956 USA; gary_fellers@att.net

BRIAN J HALSTEAD

US Geological Survey, Western Ecological Center, Dixon Field Station, 800 Business Park Drive, Suite D, Dixon, CA 95620 USA

ABSTRACT—A *Corynorhinus townsendii* maternity roost located in an abandoned ranch house in central California was monitored for 25 y. Prior to the discovery of the bats in 1987, the house was broken into regularly and disturbance levels were quite high. Upon discovery of the roost, the house was fortified and vandalism was greatly reduced. The number of females and the number of volant young greatly increased during our study and was directly correlated with the decline in vandalism. Bats emerged from the house 43.6 (\pm 10.9 SD) min after local sunset. Bats emerged later in the evening during spring and fall, when it was warmer, and when it was windier. We also evaluated duration of emergence (47.11 [45.0–49.7] min), and seasonal patterns of re-entry into the roost. Several factors suggested that potential predation, most likely by owls, influenced both the timing and duration of evening emergences.

Key words: California, *Corynorhinus townsendii*, maternity roost, Point Reyes National Seashore, population trends, Townsend's Big-eared Bat, vandalism

Corynorhinus townsendii (Townsend's Big-eared Bat) is a rare and declining species throughout most or all of its range (Pierson and Rainey 1998). This species, like other *Corynorhinus*, is sensitive to human disturbance; simply entering a maternity roost can cause females to abandon their young, or move to a different site (Pearson and others 1952; Graham 1966). Pierson and Rainey (1998) conducted 4 y of extensive surveys for *C. townsendii* in California, including visits to all historic maternity colonies where >30 bats had been reported. They found that only 48% of historic colonies were occupied, and documented a 32% decline in the size of maternity colonies and a 44% decline in the number of available roosts. They concluded that *C. townsendii* roost sites are limited and the primary cause for declines was human disturbance. However, a California Department of Fish and Wildlife report (CDFW 2013) noted that *C. townsendii* can adapt to reoccurring and predictable human activity.

Corynorhinus townsendii was a US Fish and Wildlife Service species of concern (Category 2

candidate for listing) until that category was eliminated (USFWS 1985, 1994). Currently, *C. townsendii* has no federal protection, but in 2013 the State of California agreed to evaluate a petition to list *C. townsendii* as either threatened or endangered (CDFW 2013), and that process is on-going.

Though 82% of *C. townsendii* maternity roosts in California are located in caves or mines, most currently known maternity roosts in coastal regions are in anthropogenic structures (Pierson and Rainey 1998). Mazurek (2004) documented a *C. townsendii* maternity roost in a Coast Redwood (*Sequoia sempervirens*) in northwestern California, but it remains unclear how often such natural hollows serve as roost sites. In Marin County, there are 2 historic and 2 current *C. townsendii* maternity roosts. Both historic roosts are now gone. One of those was 2.1 km southeast of the town of Inverness; specimen records from this site at the Museum of Vertebrate Zoology at the University of California date back to 1941. That roost was in an old barn which had deteriorated to the point where by 1993 it was a hazard to enter.

Not long afterwards, the barn either collapsed or was removed by the private land owner. The most recent count at the roost was 75 bats on 25 August 1993 (G Fellers, pers. obs.). At that time of year, the roost would have included both females and their young; the number of females was likely about 40. That number matches an exit count of 40 bats by GMF on 18 April 1992. Because young are not born until May (Pearson and others 1952), the 1992 count presumably included only adult female bats.

The other historic roost was in the Olema Inn in the town of Olema. Pearson and others (1952) used that colony in their classic study of *C. townsendii* reproduction from 1947–1950. At some time between 1974, when the most recent Museum of Vertebrate Zoology specimen was collected, and 1983, the privately-owned inn was remodeled and bats were excluded from the attic (G Fellers, pers. obs.).

In 1987, E Pierson and GMF visited the Randall House, an old, abandoned ranch house at Point Reyes National Seashore, and found a maternity colony of *C. townsendii* in the attic. In 1990, GMF located another maternity roost in the attic of an old, but occasionally occupied house near the town of Bolinas, 6 km to the southwest of the Randall House. The house near Bolinas is seriously dilapidated with a failing foundation and a history of wood-boring beetles attacking the structural supports (G Fellers, pers. obs.). The last count at that roost was 244 females, which exited on 23 May 2006 (E Pierson, pers. comm.). Both these roost sites are in Marin Co., and are located on lands managed by Point Reyes National Seashore. Hence, the National Seashore manages the property with 2 of the 10 known maternity colonies of *C. townsendii* along the California coast (Pierson and Rainey 1998).

Pierson and others (1998) determined that only 4 of 39 *C. townsendii* maternity roosts in California had remained stable over the prior 40 y, and only 3 had increased in size at the time of their study. We initiated our study of the Randall House roost in 1988 with the goal of determining the status and population trend of the *C. townsendii* maternity colony. We also wanted to evaluate the impact of vandalism and roost disturbance, and factors affecting evening emergence.

METHODS

Study Area

The study was conducted at a *C. townsendii* maternity roost located in the attic of the Randall House, 8 km south of the town of Olema, Marin Co., California. The house is a 2-story ranch house constructed in the 1880s, the last remaining building from the original ranch complex. The house had been abandoned since 1974 and has been used as a *C. townsendii* maternity colony at least since the roost was discovered in 1987.

The Randall House is <100 m from a perennial stream. Additional water is available from a number of ponds in the valley and several large reservoirs <10 km away. Vegetation in the valley is a mixture of grasslands that are actively grazed by cattle and a Douglas-fir forest (*Pseudotsuga menziesii*); there are some California Bay (*Umbellularia californica*) trees in moister canyon bottoms and a few second-growth redwoods. A more detailed description is given by Fellers and Pierson (2002).

When the *C. townsendii* maternity roost was discovered, the Randall House had been boarded up with plywood nailed over the windows and doors. This level of protection could easily be defeated with a hammer and crowbar, and the house was regularly broken into by local teenagers (LeeRoy Brook, Chief Ranger at Point Reyes National Seashore in 1987, pers. comm.). The park thought of the house as an attractive nuisance and had looked into having it removed from the site, converting it to a small visitor center or museum, or offering it to a local entrepreneur for renovation as an inn (John Sansing, Superintendent at Point Reyes National Seashore in 1987, pers. comm.). Once the maternity roost was discovered in 1987, the park fully committed to maintaining the house for bats, secured and fortified all doors and windows, reroofed the house to address water leaks, and periodically painted the exterior. As part of our study, we maintained a log of every time someone attempted to break into the house, and whether each attempt was successful.

Counting Techniques

All of the doors and windows of the house were completely boarded up except for a 15 × 61 cm opening on the front porch, which was

used by the bats for entering and exiting. To count bats, we set up a camp chair and a tripod-mounted night vision scope about 12 to 14 m from the front of the house so that we had a clear view of the exit opening and the covered porch. We used a Noctron IV night vision scope (Varo, Inc., Garland, Texas) to observe bats. Ambient light was augmented with a 6 v (lantern battery) flashlight covered with an infrared filter (Kodak Wratten 88A gel filter) over the lens to reduce potential disturbance to bats (Downs and others 2003); this light was positioned next to the night vision scope. A secondary light consisting of a 6×8 array of infrared LEDs was placed on the porch facing upwards. Exiting bats were recorded using a PDA (Personal Digital Assistant; Psion Organizer II, Model LZ64; www.pSION.com) that allowed us to generate a time-stamped record for each bat that exited or entered the roost.

Sources of Error

The Randall House was regularly used as a roost site by only 1 other species of bat, *Myotis californicus* (California Myotis). There were typically 5 to 15 *M. californicus* that emerged on evenings when we counted *C. townsendii*. The *M. californicus* could be distinguished by their size and much faster wing beats. Also, the *M. californicus* emerged earlier, so there was generally little or no temporal overlap between species. However, the most distinctive feature was the difference in vocalizations. Bat counts were nearly always conducted with a bat detector (Anabat; Titley Scientific, Columbia, Missouri; www.titley-scientific.com) set at a low volume so we could hear bat echolocation calls. *Myotis californicus* has a loud, buzzy call that is easily distinguished from the rather soft, quiet calls of *C. townsendii*. Hence, the bat detector served as a backup to our visual identifications.

We counted bats as they emerged from the house on 178 occasions, with 161 of those by GMF. Other observers were P. Kleeman (9 counts), E. Pierson (5), C. Corben (3), and W. Rainey (1). Hence, we had very few observers over the 25 y span of our study, and >90% of the counts were by 1 person. In the first 2 y, we conducted 3 double counts with 2 independent observers (GMF and E Pierson). Those counts differed by a mean of 4.5%. Because GMF had

limited experience counting emerging bats prior to this study, in marked contrast to EP, we presume that observer difference declined after the first few years, but that was not tested.

Data Analysis

We analyzed trends in counts of females (May and June counts) and females plus volant young (July and August counts) using linear regression. We used year of study as the independent variable, and the maximum net count from the two months (for females or females plus volant young) in that year as the dependent variable. To assess the effects of disturbance on bat counts, we correlated the number of successful plus attempted break-ins with female and female plus volant young counts using Pearson correlation coefficients.

Emergence time was evaluated relative to local sunset. Because the Randall House lies in a valley, we adjusted sunset times for San Francisco (35 km to the southeast) to reflect the time when the sun passed below the ridge to the west of the Randall House. We used astronomy software (The Photographers Ephemeris; photoephemeris.com) to determine the sun's azimuth at sunset for each evening we counted bats. The azimuth was then plotted using mapping software (National Geographic Topo!; www.software-maps.com) to determine the elevation and time at which the sun would pass behind the ridge (local sunset).

When *C. townsendii* begin to emerge, there are often a few bats that exit the roost notably early. Most of these bats reentered the roost after a brief flight near the house, but some departed the area. To account for these outliers, we defined the start of an emergence as the time when a net of 5 bats had emerged, and the end of an emergence when no bats had exited for more than 5 minutes. We evaluated factors that might affect both the emergence time relative to local sunset, and the duration of the emergence using a set of linear models. These factors included moon illumination, fog, minimum daily temperature, mean temperature and wind speed during the hour emergence began, barometric pressure, month as an ordinal variable, and a quadratic effect of month. Moon illumination was obtained from The Photographers Ephemeris software, fog was recorded at the Randall House at the time of the count, and

weather variables were obtained from the Barnaby weather station (<http://raws.dri.edu/ccaF.html>) 5.6 km to the northeast. We examined potential predictor variables for correlations, and only included variables with an absolute Pearson's correlation coefficient value of <0.50 with other variables in the full model. All continuous variables were standardized prior to analysis to make estimated model coefficients comparable. We analyzed the model in a Bayesian framework using Markov chain Monte Carlo methods. Model selection was done using indicator variables on model coefficients (Kuo and Mallick 1998; Royle and Dorazio 2008). Because posterior model probabilities are sensitive to the priors placed on model coefficients (Link and Barker 2010), we conducted a prior sensitivity analysis by placing 3 different uninformative priors on model coefficients ($N(0,10)$, $N(0,31.6)$, and $N(0,100)$). In all cases, indicator variables were given independent $Bern(0.5)$ priors. Missing continuous predictor variables were given $N(0,1)$ priors, and missing values for presence of fog were drawn from a $Bern(p_{fog})$ distribution, with p_{fog} given an uninformative $Beta(1,1)$ distribution. Goodness-of-fit was assessed with a Bayesian p -value and visual inspection of residual plots (Kéry 2010).

Bats exiting the roost sometimes flew back and forth on the porch and then re-entered the roost. We examined this behavior to evaluate whether it was more prevalent when young were present. Factors included moon illumination, minimum daily temperature, mean temperature and wind speed for the hour of emergence, and the presumed presence of young as a binary variable. Presence of young was based on the work of Pearson and others (1952) that documented which months of the year young were volant at a nearby roost in the town of Olema. We used mixed effects logistic regression to evaluate the ratio of re-entries to total exits for each count. We examined variables for correlations, and only included variables with an absolute Pearson's correlation coefficient value of <0.50 with other variables in the full model. An observation-level random effect was included in the model to account for extra-Binomial variation in the observed proportion of re-entries. As before, all variables were standardized prior to Bayesian analysis.

For the analysis of re-entry behavior, priors on model coefficients were $N(0,1.65)$, $N(0,3.16)$, and $N(0,10)$. In all cases, indicator variables were given independent $Bern(0.5)$ priors, and the standard deviation of the observation-level random effect was given a $U(0,10)$ prior. Goodness-of-fit was assessed with a Bayesian p -value and visual inspection of residual plots.

All models were analyzed by calling JAGS 3.3.0 (Plummer 2012) from R 3.0.1 (R Core Team 2013) using the package `rjags` (Plummer 2013). Posterior samples were drawn from 5 independent chains of 10,000 iterations each, after a burn-in of 10,000 iterations. Output was thinned by a factor of 5, resulting in posterior inference being drawn from a sample of 10,000 draws from the posterior distribution. Convergence was assessed with the Gelman-Rubin statistic (Gelman and Rubin 1992) and visual examination of history plots. Unless otherwise indicated, posterior distributions are summarized by their model-averaged posterior means (0.025 quantile–0.975 quantile) under the moderate set of priors. All other statistics were calculated using Statistix (Version 7, Analytical Software, Tallahassee, Florida) and $\alpha = 0.05$ to evaluate statistical significance.

RESULTS

When the *C. townsendii* maternity roost was discovered at the Randall House in 1987, the house had had a long history of being broken into (L Brook, pers. comm.). After the park fortified potential entrance points, attempts to break in gradually decreased along with the associated disturbance to the bats (Fig. 1A). Concomitantly, the number of females occupying the roost in May and June, before the young would be volant, increased from 95 bats in 1988 to 395 in 2012 ($y = 7.2x + 161.4$, $R^2 = 0.61$, Fig. 1B). The number of females plus volant young (July and August counts) increased from 176 to 512 over those same years ($y = 11.7x + 182.7$, $R^2 = 0.75$). These numbers reflect an 8.7% mean annual increase in the number of female *C. townsendii* occupying the maternity roost, and a 5.3% annual increase for volant young. A Pearson partial correlation between the number of young flying in July or August and disturbance, measured as attempted plus successful entries, at the Randall House was -0.60 , while the relationship with May or June counts was

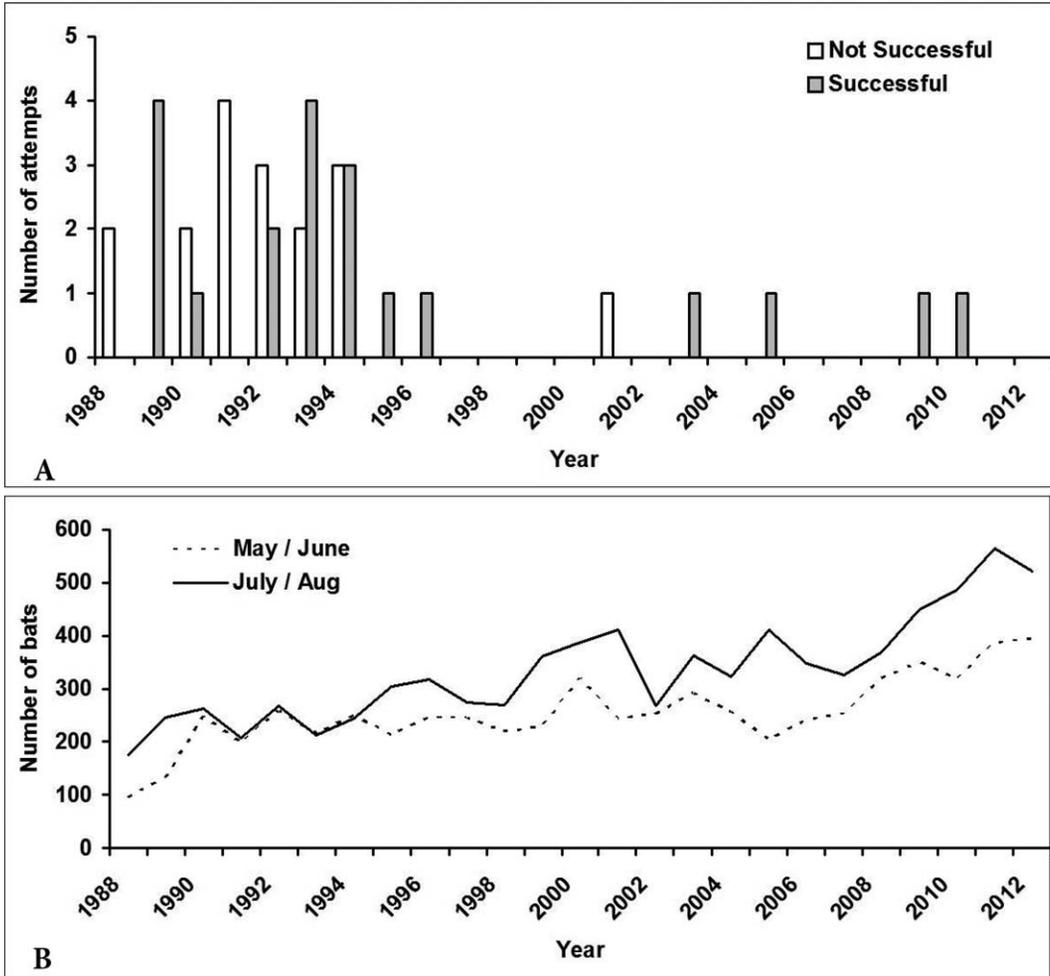


FIGURE 1. (A) Attempts to break into the Randall House, site of a *Corynorhinus townsendii* roost at Point Reyes National Seashore, California. (B) Annual number of adults (maximum count during May or June) and total *C. townsendii* (adults plus volant young; maximum count during July or August) emerging from roost at Point Reyes National Seashore.

-0.41. Hence, there were more *C. townsendii* in the maternity roost, and more volant young produced in years with less disturbance.

Prior to each evening’s emergence, we could look through the opening where the bats emerge and see *C. townsendii* flying without exiting. This behavior lasted 15 to 20 min before the 1st bat would typically exit, but unobserved flying within the house may have gone on for a longer time. We tried to assess this activity by quietly sitting in the upstairs bedroom where the bats emerged from the attic (GMF), and in the living room (E Pierson) where the bats exited through the window opening, but it

appeared that our presence intrigued the bats and caused them to repeatedly fly around us. As a result, we were not able to assess pre-emergence behavior from inside the house.

Bats emerged at a mean of 43.6 (± 10.9 SD) min after local sunset. Emergence time was potentially affected by a variety of environmental and celestial factors. A quadratic effect of month was included with a probability >0.999, regardless of the priors used (Table 1). Using the moderate and least restrictive priors resulted in the model with only a quadratic effect of month having the most support (Table 1). The most restrictive priors resulted in the best-

TABLE 1. Models for *Corynorhinus townsendii* emergence times relative to local sunset. An "X" indicates that the variable was included in the model. Unless otherwise specified or inappropriate, variables were measured for the hour of emergence. Only models with a posterior probability >0.05 in any model set are shown. Models are ranked in order of decreasing probability with SD = 31.6 priors on intercepts and coefficients.

Variable							Posterior probability ¹		
Mean wind speed	Mean temperature	Barometric pressure	Month	Month ²	SD = 100	SD = 31.6	SD = 10		
-	-	-	X	X	0.810	0.511	0.155		
-	X	-	X	X	0.100	0.197	0.184		
-	-	-	X	X	0.011	0.070	0.204		

¹ Posterior probabilities based on different sets of priors; standard deviations are prior standard deviations placed on the intercept and model coefficients.
² Quadratic effect of month.

supported model also including effects of mean temperature and wind speed at the hour of emergence (Table 1). Hence, *C. townsendii* emerged later in the evening in spring and fall (quadratic term = 5.67 [4.49–6.87]), when it was warmer (0.68 [0.00–3.43]), and when it was windy (0.19 [0.00–2.38]; Fig. 2, Fig. 3). Moon illumination, the presence of fog, daily minimum temperature, and barometric pressure played no significant role in the time of emergence, though bats emerged 6.3 min early on foggy nights (Fig. 2).

Mean duration of emergence was 47.11 (45.0–49.7) min. When examining factors that might influence duration, the best model, regardless of priors, was the null model which included no covariates (Table 2). The mean probability of re-entering the roost during the emergence was 0.13 (0.10–0.15). The best model for re-entry depended upon the priors used for model coefficients. Using more diffuse priors resulted in the selection of the null model with an observation-level random effect; more moderate priors resulted in a model with all fixed effects, but no random effect (Table 3). Moon illumination and warmer daily minimum temperatures increased the probability of a bat re-entering the roost (Fig. 4A–B). In contrast, warmer temperature at emergence and windier conditions, and the presence of young, decreased the probability of bats re-entering the house (Table 4; Fig. 4C–E).

We never observed any predation attempts as bats flew away from the roost, though we did observe or hear known bat predators on 11 occasions. These included Saw-whet Owls (*Aegolius acadicus*; calling on 4 evenings), Barn Owls (*Tyto alba*; calling twice, observed once), Great Horned Owls (*Bubo virginianus*; calling twice, observed 4 times), Spotted Owls (*Strix occidentalis*; calling once, observed once), and unidentified large owls (calling once, seen once). One of the Great Horned Owls we observed landed on the porch above the opening where the bats emerged. The porch roof blocked the owl from their view as bats exited through the window opening. However, we could not detect any change in behavior as they flew out from under the cover of the porch and proceeded to depart the area, and the owl did not attempt to pursue bats during the 5 min it was present. Additionally, both a Barn Owl and a Spotted Owl perched on a tree limb near

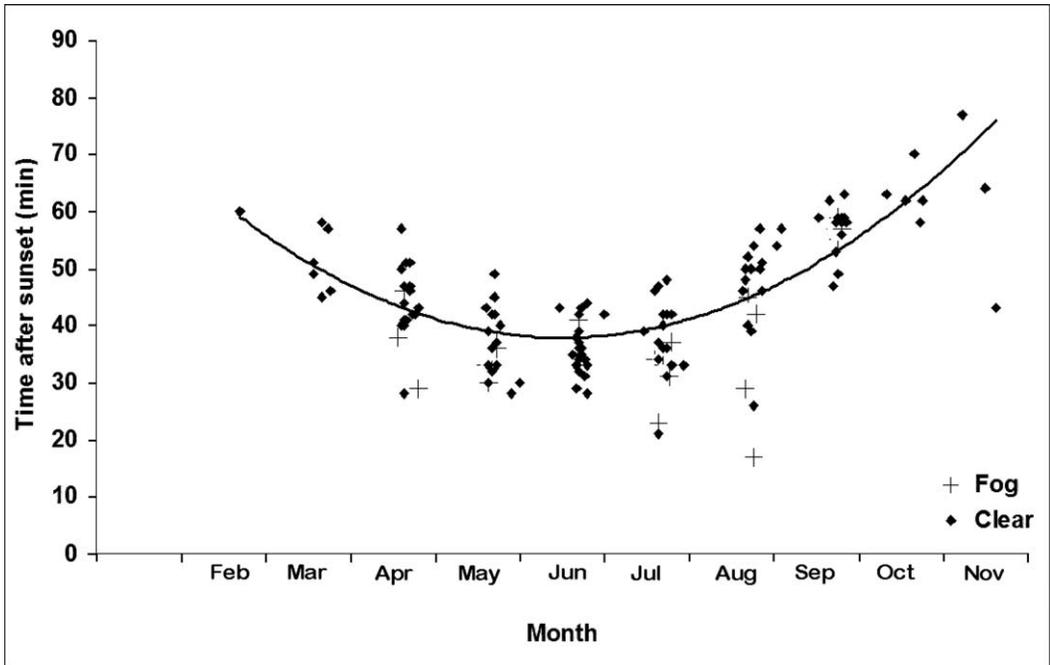


FIGURE 2. Time after sunset for *Corynorhinus townsendii* emergence from a maternity roost at Point Reyes National Seashore, California.

the house for a portion of different counts, but neither was seen to pursue bats during the 10 to 15 min that each was observed, even though bats could be seen flying within 10 to 20 m of the owls.

DISCUSSION

Population Trend

The number of females in the Randall House maternity roost increased at a mean annual rate of 8.7%, while the number of volant young increased by 5.3%. These increases run counter to the pattern seen for *C. townsendii* throughout California where, over the last 20 to 40 y, there has been a 52% decline in the number of maternity colonies, a 55% decline in the number of adult females at maternity roosts, and a 32% decrease in the average size of extant colonies. Of the historic maternity colonies, 27.8% decreased in size, 22.2% remained stable, and 16.7% increased in size (Pierson and Rainey 1998).

Undisturbed *C. townsendii* populations tend to remain stable over time (Pearson and others 1952; Pierson and Rainey 1998). However, early

studies reported that *C. townsendii* was sensitive to disturbance at both hibernacula and maternity roosts (Graham 1966), with bats either abandoning roost sites altogether after handling or banding bats, or occupying roosts in much lower numbers after visits that involved no handling of bats (Pearson and others 1952). Range-wide assessments of *C. townsendii* roosts in California have concluded that the combination of disturbance and the loss of roost sites are the most important factors in the decline of this species throughout California (Pierson and Rainey 1998). Based on these findings, the state is considering formal listing of *C. townsendii* (CDFW 2013). Our study is unusual in recording all disturbances to a roost site as well as monthly roost counts for 25 y, thus providing a long-term assessment of how *C. townsendii* responds to reduced disturbance. The increase in the number of females occupying the roost and the increase in volant young suggest that the Randall House colony was below its potential size when we started the study, and that increased security and maintenance have had the expected positive effect. This serves as a good example of what can be done when a

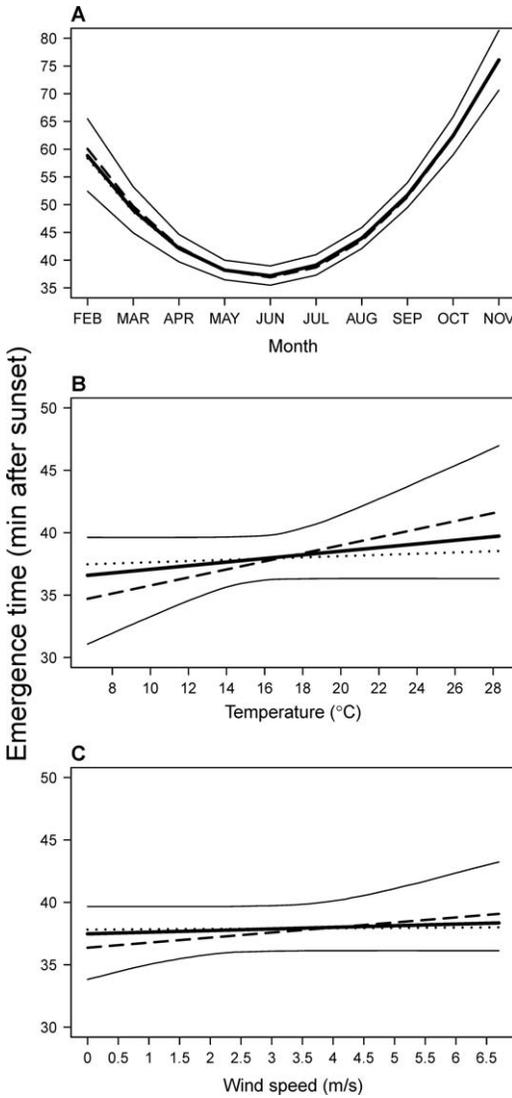


FIGURE 3. Model-averaged effect of (A) month (quadratic), (B) mean temperature, and (C) mean wind speed during the hour of emergence on emergence times of *Corynorhinus townsendii* at Point Reyes National Seashore, California, 1998–2012. Bold lines represent posterior means; fine lines represent 95% credible limits. Solid lines are based on $N(0,31.6)$ priors on model coefficients, the dashed line is based on $N(0,10)$ priors, and the dotted line is based on $N(0,100)$ priors. Credible limits for the most and least restrictive priors are omitted for clarity.

management agency gives a high priority to a species of concern, and suggests that better protection and reduced disturbance might lead to similar increases at other *C. townsendii* roosts.

TABLE 2. Models for *Corynorhinus townsendii* emergence duration. An “X” indicates that the variable was included in the model. Unless otherwise specified or inappropriate, variables were measured for the hour of emergence. Only models with a posterior probability >0.05 in any model set are shown. Models are ranked in order of decreasing probability with $SD = 31.6$ priors on intercepts and coefficients.

	Variable					Posterior probability ¹				
	Moon illumination	Fog	Daily minimum temperature	Mean wind speed	Mean temperature	Barometric pressure	Month	$SD = 100$	$SD = 31.6$	$SD = 10$
-	-	-	-	-	-	-	-	0.774	0.444	0.113
-	-	-	-	-	X	-	X	0.099	0.099	0.082
-	-	-	-	-	-	X	-	0.046	0.098	0.065
X	-	-	-	-	-	-	-	0.034	0.057	0.042
-	-	X	-	-	-	-	-	0.036	0.054	0.044
-	-	-	-	-	X	X	X	0.004	0.029	0.060

¹ Posterior probabilities based on different sets of priors; standard deviations are prior standard deviations placed on the intercept and model coefficients.

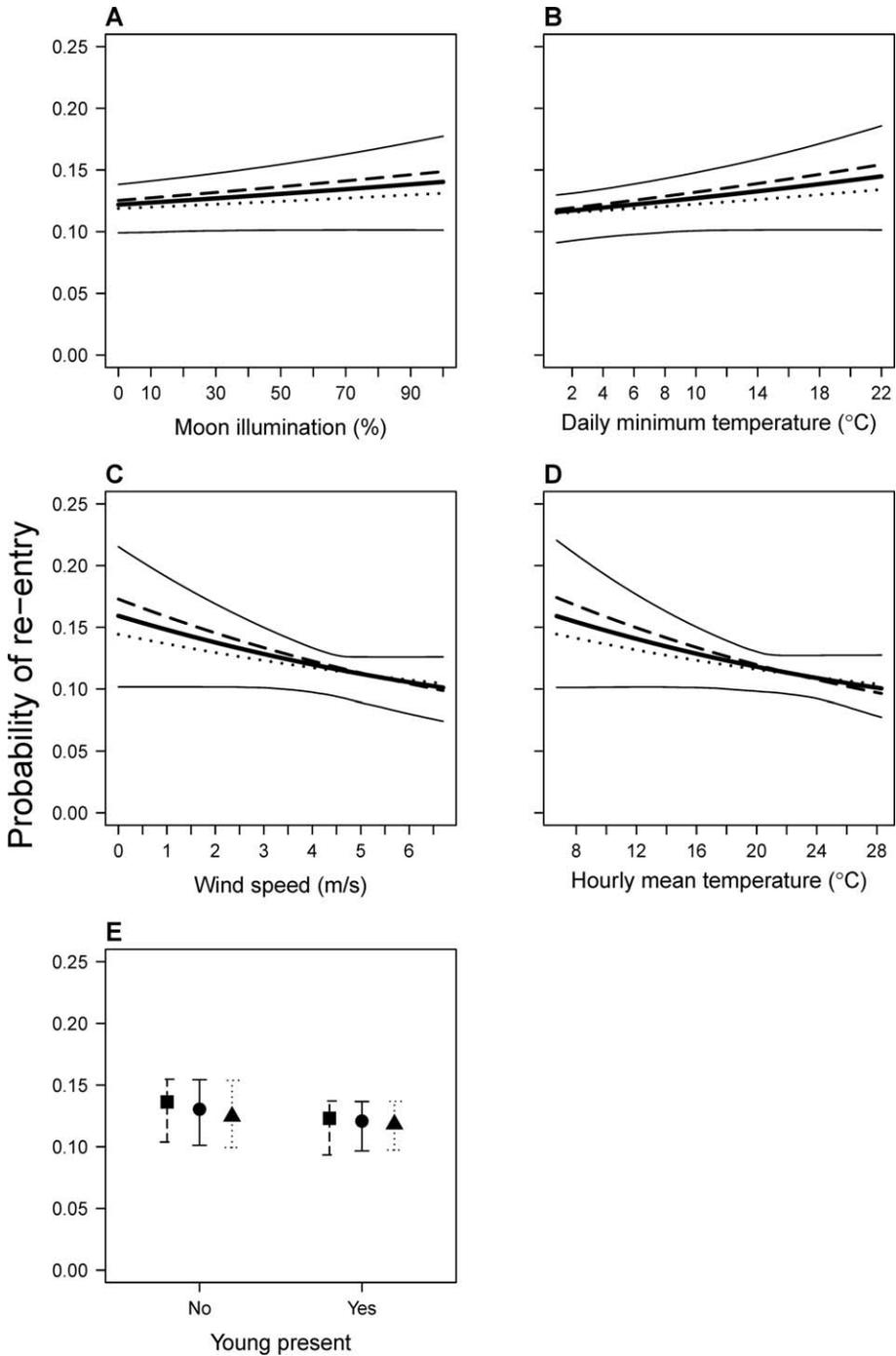


FIGURE 4. Model-averaged effect of (A) moon illumination, (B) daily minimum temperature, (C) hourly mean wind speed, (D) hourly mean temperature, and (E) presence of flying young on the probability of *Corynorhinus townsendii* re-entering a roost during emergence at Point Reyes National Seashore, California, 1998–2012. Bold lines represent posterior means; fine lines represent 95% credible limits. Solid lines (circle) are based on $N(0,3.16)$ priors on model coefficients, the dashed line (square) is based on $N(0,1.65)$ priors, and the dotted line (triangle) is based on $N(0,10)$ priors. Credible limits are omitted from the latter for clarity.

TABLE 4. Parameter estimates for the probability of *Corynorhinus townsendii* re-entering the roost during emergence at Point Reyes National Seashore, California, 1989–2012.

Parameter	Posterior mean	Posterior 95% CI
Intercept	-1.9	-2.18–-1.70
Wind speed at emergence	-0.13	-0.29–0.00
Temperature at emergence	-0.11	-0.26–0.00
Young present	-0.08	-0.25–0.00
Daily minimum temperature	0.08	0.00–0.20
Moon illumination	0.05	0.00–0.13
SD of observation-level random effect	0.45	0.00–0.93

suggested that differences in emergence times for *Tadarida brasiliensis* were consistent with a predator avoidance hypothesis, and that lactating females emerged earlier than other bats due to the higher energy demands of the lactating females. Likewise Frick and others (2012) suggested that emergence times were influenced by potential predation. We did not have individually marked bats, so we could not evaluate behavioral differences between adults and young. However, it was our impression that females and young *C. townsendii* emerged together. In July and August, when the young are first volant, there appeared to be a mix of strong flying bats, which we presumed were adult females, and less agile fliers, which we presumed were young bats. However, flight differences were subtle and we could not confirm our impressions with known-age individuals.

Corynorhinus townsendii is a slow-flying, but highly maneuverable species (Hayward and Davis 1964; Findley and others 1972) that begins its evening emergence well before complete darkness. Human observers can easily see the first bats depart the roost and fly across the evening sky. However, we never observed attempted predation on bats, even though owl species known to feed on bats were heard on 10 occasions and seen on 7 other occasions. Our observations included owls perched on the house or in nearby trees during the evening emergence. Perhaps the local owls only rarely or never prey on bats, though Fellers and Pierson (2002) reported that light-tagged *C. townsendii* from the same Randall House roost appeared to reduce their time in open grasslands, both when foraging and when travelling between the roost and foraging areas. Flight across open grassland was about 1 m above the ground and was always fast and usually in a straight line, though occasionally it was erratic or jerky. This behavior would suggest the bats might be

trying to reduce the risk of predation, though no predation attempts were seen during that study or our current one.

Corynorhinus townsendii emerge earliest during May and June. This is when the young are born and females are lactating (Pearson and others 1952). At that time, females need more time to forage in order to support the higher energy demands of lactation, and because females lose foraging time because they return to the roost 2 to 3 times a night to nurse their young (Clark and others 1993). Young become volant 2.5 to 3 wk after birth and join their mothers in foraging, even though the young may be sustaining themselves almost exclusively on their mother's milk (Pearson and others 1952). Later in the summer and into the fall, *C. townsendii* gradually emerge later after sunset. At this time, the females are finished nursing, and the young are presumably becoming more efficient at both flying and foraging. Because of these reduced energy demands, the bats can reduce their foraging time, emerge later, and reduce predation exposure in the early evening when predators can see the bats more easily. The same reasoning might explain why *C. townsendii* emerge later on warmer evenings. Warmer temperatures might allow their mostly lepidopteran prey (Whitaker and others 1977) to fly later into the night, and thus allow *C. townsendii* to emerge later, avoid predators at dusk, and still find sufficient food for the night.

Earlier emergence during lactation has been reported for Greater Horseshoe (*Rhinolophus ferrumequinum*) and Northern Bats (*Eptesicus nilssonii*; Duvergé and others 2000), Nyctalus Bats (*Nyctalus noctula*; Jones 1995), Hoary Bats (*Lasiurus cinereus*; Barclay 1989), Cave Bats (*Myotis velifer*; Kunz 1974), and Little Free-tailed Bats (*Tadarida pumila*; McWilliam 1989). Similar to our findings for *C. townsendii*, Duvergé and others (2000) found that emergence times for

Greater Horseshoe Bats became later when juveniles began foraging by themselves, and suggested that this was due to reduced energy demands on post-lactating females.

Wind was another factor that delayed evening emergence. *Corynorhinus townsendii* have relatively short, rounded wings and are not particularly fast fliers, but they are highly maneuverable. They feed primarily on moths (Whitaker and others 1977, 1981), which they obtain while slowly flying around the perimeter of trees (Fellers and Pierson 2002). Wind probably affects the activity of moths and other prey that are not strong fliers themselves. Hence, less food may be available on windy nights, but we did not try to evaluate this as part of our study. Adults, and especially newly volant young, would have more difficulty flying on windy nights, so they might be reluctant to leave the roost on nights with less favorable flying conditions.

Fog did not play a significant role in the time of emergence, even though we suspected it might. The Randall House is 5.6 km inland from the Pacific Ocean, with a 350-m ridge in between the roost and the ocean. Throughout much of the late spring through early fall, a fog bank develops along the coast and moves inland over the ridge in the late afternoon and evening. When it is foggy, it gets dark earlier because fog blocks light from the sun as it sets to the west of the fog bank. Though there is evidence that the frequency of fog has been declining since the early 20th century (Johnstone and Dawson 2010), this will likely have only a minor effect on *C. townsendii* emergence.

Re-entry Behavior

Twente (1955) described what he called light-sampling behavior for *C. townsendii* and *Antrozous pallidus* living in an Oklahoma cavern. Bats would fly from roost sites inside the cavern to points near the entrance where they remained for a few minutes before retreating back into the cavern; bats did not leave the cavern until it was dark. This is similar to our observations of bats flying inside the house before emerging. However, unlike the *C. townsendii* we studied, Twente did not see bats re-entering the cavern during the evening emergence. However, Duvergé and others (2000) reported Lesser Horseshoe Bats (*Rhinolophus hipposideros*) repeatedly

flying in and out of the roost before leaving 1 of the 2 roost entrances, but not at the other. The re-entry behavior occurred at the more exposed of the 2 entrances. They were unable to explain why bats acted differently at the 2 entrances or why the re-entry behavior occurred at the more exposed entrance. At the Randall House, the only entrance is through an opening in a boarded-up window on the porch. *Corynorhinus townsendii* often emerged, flew back and forth under the roof of the porch and then either departed or re-entered the house. Bats would be well-protected from predators such as owls until they left the porch. We could not tell whether the re-entry behavior was light sampling, mother-young social behavior, or something else. We originally posited that females emerged from the roost first and then flew back and forth on the porch while waiting for, or perhaps encouraging, their young to emerge, but re-entry did not coincide with the time when young first became volant and such behavior might be expected. A better understanding of this behavior would require individually marked bats that can be scanned as they pass through the roost opening.

The potential for predation appears to influence *C. townsendii* emergence behavior. Bats are more likely to re-enter the roost and delay their evening departure when the moon is more brightly illuminated. Temperature also has an influence, with bats re-entering the roost more frequently on nights when the minimum temperature that day was warmer. As with time of emergence, temperature may relate to the availability of prey, with prey being active later into the night on warmer days, hence allowing the bats to depart the roost at a more relaxed pace on those evenings when the temperature has been higher. Perhaps the most expected relationship was between re-entry and the presence of young. *Corynorhinus townsendii* emerged and immediately departed the roost more often during those months when young were present in the roost. Clark and others (1993) reported that lactating *C. townsendii* at a maternity roost in eastern Oklahoma returned 3 times during the night to feed their young. This would have put significant pressure on the females to begin foraging early, and not to linger during their exit from the roost.

Future of the Randall House Roost

Pierson and Rainey (1998) reported that 30 of 37 roosts had declined from historic population levels and that only 4 were stable and 3 had increased. The Randall House maternity roost was 1 of the 3 that was increasing at the time of their study, and it has continued to do so through 2013, 25 years after its discovery. Pierson and Rainey concluded that human disturbance had been the main cause for most declines. Since discovery of the Randall House roost, reducing human disturbance has been one of the main goals in the management of *C. townsendii* at Point Reyes National Seashore. Fortunately, the park fortified the house after the maternity roost was discovered and has continued to paint, roof, and repair damage to the house from vandals trying to break in. The park has also removed vegetation from around the house that might harbor Black Rats which are known to feed on roosting bats (Fellers 2000). These efforts are almost certainly the reason why this *C. townsendii* maternity roost has increased in size. Similarly, Weller and others (2014) summarized surveys at Lava Beds National Monument in northeastern California and concluded that reduced disturbance at *C. townsendii* cave roosts had led to an increase in numbers.

Pearson and others (1952) studied *C. townsendii* in the Olema Valley, where the Randall House is located, and concluded that the total population in the area was limited by roost sites surrounded by adequate food supply; we see no reason why that conclusion would not still be valid today. However, Pearson and others also concluded that the *C. townsendii* population (in the 1950s) was probably larger than when Europeans first arrived due to the availability of more buildings. This does not seem likely. Though much of the original habitat persists in the Olema Valley, it has undergone significant changes that almost certainly affect availability of both roosts and food. Coast Redwoods and Douglas-fir were heavily logged during the mid-1900s, and much of the forest on the west side of the valley has not returned to old-growth status. Old-growth redwoods and Douglas-fir, along with California Bay, provide roost sites for *C. townsendii* (Fellers and Pierson 2002; Mazurek 2004), and it seems likely that some of the tree hollows were large enough to harbor

small maternity roosts. While there are still quite a few ranch buildings in the valley, the classic old barns and associated wooden buildings are gradually deteriorating and falling down or being removed. More modern replacements tend to be constructed with less bat-friendly materials, such as metal, that do not provide good roosting sites or temperature regimes. Hence, the number and quality of tree roosts, roosts in man-made structures, and potential foraging areas appear to be lower than in the early 1800s.

Most of the east side of the valley is grazed by cattle; the vegetation is mostly open grassland with scattered Coast Live Oaks (*Quercus agrifolia*), California Bay, and small drainages with riparian vegetation. Before the arrival of Europeans, this part of the valley probably had more trees and less grassland, which would have provided more and better foraging areas for *C. townsendii*. A radiotracking study by Fellers and Pierson (2002) showed that *C. townsendii* spend little time over grasslands, an area that would make the bats more vulnerable to predation and offered relatively little foraging opportunity.

In this context, the Randall House is a classic, old abandoned ranch house that has one of the largest *C. townsendii* maternity roosts in California. Fortunately, the National Park Service has committed to maintaining the house for the benefit of the bats. Additionally, interest in *C. townsendii* may increase due to the current proposal to legally protect the bat by the State of California. If that happens, there will be added motivation to continue protecting the roost and monitoring the bats.

ACKNOWLEDGMENTS

E Pierson introduced me to the study of bats, and provided much help and assistance. Point Reyes National Seashore provided logistical support, a scientific research permit, and maintenance staff who periodically painted, roofed, and removed vegetation. Without the support of the park, it is highly unlikely that a bat colony would exist at the site today. P Kleeman, E Pierson, C Corben, and W Rainey conducted bat counts on nights when GMF was unavailable. J Fellers and P Kleeman provided useful comments on the manuscript. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the US Government.

LITERATURE CITED

- BARCLAY RMR. 1989. The effect of reproductive condition on the foraging behavior of female Hoary Bats, *Lasiurus cinereus*. Behavioral Ecology and Sociobiology 24:31–37.
- [CDFW] CALIFORNIA DEPARTMENT OF FISH AND WILDLIFE. 2013. Evaluation of the petition from the Center for Biological Diversity. 27 p. Available at: <https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=65594>.
- CLARK BS, LESLIE JR DM, CARTER TS. 1993. Foraging activity of adult female Ozark Big-eared Bats (*Plecotus townsendii ingens*) in summer. Journal of Mammalogy 74:422–427.
- DOWNES NC, BEATON V, GUEST J, POLANSKI J, ROBINSON SL, RACEY PA. 2003. The effects of illuminating the roost entrance on the emergence behaviour of *Pipistrellus pygmaeus*. Biological Conservation 111:247–252.
- DUVERGÉ PL, JONES G, RYDELL J, RANSOME RD. 2000. Functional significance of emergence timing in bats. Ecography 23:32–40.
- FELLERS GM. 2000. Predation on *Corynorhinus townsendii* by *Rattus rattus*. Southwestern Naturalist 45: 524–527.
- FELLERS GM, PIERSON ED. 2002. Habitat use and foraging behavior of Townsend's Big-eared Bat (*Corynorhinus townsendii*) in coastal California. Journal of Mammalogy 83:167–177.
- FINDLEY JS, STUDIER EH, WILSON DE. 1972. Morphologic properties of bat wings. Journal of Mammalogy 53:428–444.
- FRICK WF, STEPANIAN PM, KELLEY JF, HOWARD KW, KUSTER CM, KUNZ TH, CHILSON PB. 2012. Climate and weather impact timing of emergence of bats. PLoS ONE 7(8):e42737.
- GELMAN A, RUBIN DB. 1992. Inference from iterative simulation using multiple sequences. Statistical Science 7:457–472.
- GRAHAM RE. 1966. Observations on the roosting habits of the big-eared bat, *Plecotus townsendii* in California limestone caves. Cave Notes 8:17–22.
- HAYWARD B, DAVIS R. 1964. Flight speeds in western bats. Journal of Mammalogy 45:236–242.
- JOHNSTONE JA, DAWSON TE. 2010. Climatic context and ecological implications of summer fog decline in the coast redwood region. Proceedings of the National Academy of Sciences 107:4533–4538.
- JONES C. 1965. Ecological distribution and activity periods of bats of the Mogollon Mountains area of New Mexico and adjacent Arizona. Tulane Studies in Zoology 12:93–100.
- JONES G. 1995. Flight performance, echolocation and foraging behaviour in noctule bats *Nyctalus noctula*. Journal of Zoology 237:303–312.
- KÉRY M. 2010. Introduction to WinBUGS for Ecologists: A Bayesian approach to regression, ANOVA, mixed models and related analyses. Burlington, MA: Academic Press. 302 p.
- KUNZ TH. 1974. Feeding ecology of a temperate insectivorous bat (*Myotis velifer*). Ecology 55:693–711.
- KUO L, MALLICK B. 1998. Variable selection for regression models. Indian Journal of Statistics 60: 65–81.
- LINK WA, BARKER RJ. 2010. Bayesian inference: With ecological applications. London, UK: Academic Press. 339 p.
- MAZUREK MJ. 2004. A maternity roost of Townsend's Big-eared Bats (*Corynorhinus townsendii*) in coast redwood basal hollows in northwestern California. Northwestern Naturalist 85:60–62.
- MCWILLIAM AN. 1989. Emergence behaviour of the bat *Tadarida (Chaerophon) pumila* (Chiroptera: Molossidae) in Ghana, West Africa. Journal of Zoology 219:698–701.
- PEARSON OP, KOFORD MR, PEARSON AK. 1952. Reproduction of the Lump-nosed Bat (*Corynorhinus rafinesquei*) in California. Journal of Mammalogy 33:273–320.
- *PIERSON ED, RAINEY WE. 1998. The distribution, status and management of Townsend's Big-eared Bat (*Corynorhinus townsendii*) in California. California Department of Fish and Game, Bird and Mammal Conservation Program Report 96–7. 49 p. Available at: http://dfg.ca.gov/wildlife/nongame/publications/bm_research/docs/96_07.pdf.
- *PLUMMER M. 2012. JAGS Version 3.3.0 user manual. 40 p. Available at: http://blue.for.msu.edu/CSTAT_13/jags_user_manual.pdf.
- *PLUMMER M. 2013. rjags: Bayesian graphical models using MCMC. 56 p. Available at: <http://cran.r-project.org/web/packages/rjags/index.html>.
- R CORE TEAM. 2013. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. Available at: <http://www.R-project.org>.
- REICHARD JD, GONZALEZ LE, CASEY CM, ALLEN LC, HRISTOV NI, KUNZ TH. 2009. Evening emergence behavior and seasonal dynamics in large colonies of Brazilian Free-tailed Bats. Journal of Mammalogy 90:1478–1486.
- ROYLE JA, DORAZIO RM. 2008. Hierarchical modeling and inference in ecology: The analysis of data from populations, metapopulations and communities. London, UK: Academic Press. 444 p.
- TWENTE JW. 1955. Some aspects of habitat selection and other behavior of cavern-dwelling bats. Ecology 36:706–732.
- [USFWS] US FISH AND WILDLIFE SERVICE. 1985. Endangered and threatened wildlife and plants;

* Unpublished

- animal candidate review for listing as endangered or threatened species. Federal Register 50:37965.
- [USFWS] US FISH AND WILDLIFE SERVICE. 1994. Endangered and threatened wildlife and plants; animal candidate review for listing as endangered or threatened species. Federal Register 59:58988.
- WELLER TJ, THOMAS SC, JA BALDWIN. 2014. Use of long-term opportunistic surveys to estimate trends in abundance of hibernating Townsend's Big-eared Bats. Journal of Fish and Wildlife Management 5:59-69.
- WHITAKER JR JO, MASER C, KELLER LE. 1977. Food habits of bats of western Oregon. Northwest Science 51:46-55.
- WHITAKER JR JO, MASER C, CROSS SP. 1981. Food habits of eastern Oregon bats, based on stomach and scat analyses. Northwest Science 55:281-292.

*Submitted 3 June 2014, accepted 30 October 2014.
Corresponding Editor: Paul Cryan.*