Publications of the Oklahoma Biological Survey
2nd Series
Volume 11:1-16, 2011

CONSERVATION STATUS OF THE ENDANGERED OZARK BIG-EARED BAT (*CORYNORHINUS TOWNSENDII INGENS*) – A 34-YEAR ASSESSMENT

G. O. Graening[1*], Michael J. Harvey[2], William L. Puckette[3], Richard C. Stark[4], D. Blake Sasse[5], Steve L. Hensley[6], and Ronald K. Redman[2]

[1]*Department of Biological Sciences, California State University, Sacramento, CA 95819, USA*
[2]*Department of Biology, Tennessee Technological University, Cookeville, TN 38505, USA*
[3]*Poteau Public School District, 100 Mockingbird Lane, Poteau, OK 74953, USA*
[4]*Oklahoma Ecological Services Field Office, United States Fish and Wildlife Service, Tulsa, OK 74129, USA*
[5]*Arkansas Game and Fish Commission, Mayflower, AR 72106, USA*
[6]*Ozark Plateau National Wildlife Refuge, Unites States Fish and Wildlife Service, Vian, OK 74962, USA*

ABSTRACT.—Direct counts of Ozark big-eared bat *(Corynorhinus townsendii ingens)* in hibernacula and maternity roosts were analyzed from 1977 to 2010. We compiled data from 1,330 survey events at 268 sites: 77 sites known to be used in Arkansas, 84 in Oklahoma, 9 in Missouri, and 98 potential use sites. Survey techniques were standardized, and baseline population indices established. Rank correlation techniques of population indices (Mann-Kendall Test) at 19 essential sites revealed important demographic trends over this 34-year period: 7 colonies have a significantly increasing trend—3 maternity sites (Cave No. AD10, AD17/18, and CW29BT3) and 4 hibernacula (AD14/125, AD3, ADT1, and WA31T complex); 3 colonies are decreasing—the maternity sites AD125 and AD13/24/25, and hibernaculum MR0702/9702/979a; and the remaining essential sites are data deficient. Historic total abundance estimates of Ozark big-eared bats ranged widely from less than 100 in 1973 to 2,500 individuals in 1990; the current population estimate is 1,600 to 1,800 bats. When all site counts are pooled by year, trend analyses indicate an increase in all maternity and hibernaculum counts over the last 34 years. Confounding this apparent increase is the discovery of new maternity colonies and hibernacula. Human disturbance and habitat loss appear to be the most important limiting factors, as the behavior and life history of this species make it inherently vulnerable to anthropogenic disturbances. Colony protection (primarily via cave gating), habitat protection (via conservation easement and fee title acquisition), and landowner management agreements have been particularly effective, yet additional time is needed before this bat's conservation status can be upgraded.

INTRODUCTION

The challenge of protecting rare mammals from extinction is typified by the efforts to manage the Ozark big-eared bat (*Corynorhinus townsendii ingens* Handley 1955; Figure 1). Historical population baselines are lacking for most vertebrate species, which impedes the creation of appropriate restoration targets or management plans (Pauly 1995). Enigmatic species such as cave-dwelling bats are difficult to census or even to define in discrete population units (Ellison et al. 2003, Kunz 2003). Bat monitoring is further challenged by the lack of standardization of census methods (Kunz 2003). Where sufficiently large datasets of rare vertebrate population surveys do exist, biologists have relied too often upon linear regression to test against declining or increasing trends; this statistical method requires assumptions that are not often met in endangered species' time series (e.g. normally distributed errors, constant variance) and outliers may change results dramatically (USEPA 2006). Nonparametric rank correlation methods, used for decades in other disciplines such as hydrology (Hipel and McLeod 1994, USEPA 2006), are now increasingly used by zoologists to test for trends in time series; such ranking procedures are preferable when exact estimates of population size are not known, when data gaps are present, etc. (Thompson et al. 1998). Even with the use of the appropriate statistic, significant

Figure 1. Photograph of the Ozark big-eared bat roosting in a cave in Adair County, Oklahoma. Photo by Richard Stark.

*E-mail: graening@csus.edu

upward trends in population surveys over time are difficult to attribute specifically to population recovery/growth when such increases may also be due to improved survey methods or discovery of new subpopulations.

Recovery of rare mammals is also impeded by the specificity of their life history requirements and their vulnerability to human activities. In response to a petition by MJH and J. Hall, the United States Fish and Wildlife Service (USFWS) listed the Ozark big-eared bat as endangered due in large part to the few existing suitable subterranean roost habitats that met its biological needs, and to its extreme sensitivity to human disturbance, including simple visual counts at roosts (USFWS 1977). This study analyzed the current conservation status of this bat based on 34 years of monitoring and recovery efforts. We also report on the establishment of a standardized survey protocol, baseline population data, and survey trend analyses using a non-parametric rank procedure.

MATERIALS AND METHODS

Population surveys / roost counts. Ideally surveys are performed at each site during the maternity and hibernation seasons, but count frequency was reduced by shortages of personnel, weather conditions, denial of access by landowners, or reports of stress to certain colonies from caving activities (recreational or scientific). USFWS (1995) guidelines suggest that maternity roosts be annually surveyed externally, and that hibernation roosts (hibernacula) be surveyed internally at most every 2 years, with a limit of 5 minutes spent directly under any roost. We used the definition of a roost count as defined by Ellison et al. (2003): *"a generic term for how many bats were found in a particular location on a unique date. Methods used to obtain a 'count' varied...sometimes a count is a survey, or 'best guess' of the original investigator and is not a census."* A population is defined as a group of bats of the same species living in a specific area, and may consist of multiple colonies with spatial boundaries varying within and among years (Ellison et al. 2003). These "specific areas" are subterranean roosting sites, whose locations are protected by the use of an alpha-numeric code (provided by state cave registries maintained by the National Speleological Society).

Figure 2. Photograph of an Ozark big-eared bat colony in Devil's Den State Park, Arkansas. Photo by Harry Harnish.

Hibernating colonies were surveyed by counting bats using battery-powered helmet lights, ideally attenuated with infra-red filters (USFWS 1995). Where clusters were too dense to count individuals (Figure 2), ceiling coverage of the colony was estimated, and then multiplied by a density estimate of 180 bats/foot^2 (1,938 bats/m^2), which is thought to be more accurate than Grigsby and Puckette's (1982) estimate of 150 bats/foot^2. The hibernacula survey ignored any bats roosting independently in auxiliary (or limited use) sites, and assumed that neonates have matured into virile adults, and that male and female bats are equally represented—sex ratios are near unity for hibernating conspecifics and congenerics (Twente Jr. 1955; Rippy and Harvey 1965; Humphrey and Kunz 1976; Harvey et al. 1981).

Maternity colonies were surveyed between late May and mid-June before pups were volant by conducting emergence counts at cave entrances at the crespuscular period; declining ambient light was augmented by battery-powered incandescent lights fitted with infrared filters (wavelength > 700 nm) (Kunz 1982, Bagley and Jacobs 1985, USFWS 2008). Infrared light is not known to disrupt bat behavior (Hope and Bhatnagar 1979, Mistry and McCracken 1990). Passive night vision field glasses were used to count emerging bats, although we are testing videography as a supplemental interpretative device. Ozark big-eared bats are differentiated from other vespertilionids by their conspicuously large ears, larger body size, and distinctive flight pattern (USFWS 1984). A population index was derived by doubling the emergence count to account for solitary males, assuming a 1:1 sex ratio (USFWS 2008).

Data acquisition and analyses. Data were compiled primarily from unpublished annual survey reports by WLP, MJH, RKR, H. Harnish (Devil's Den State Park, West Fork, Arkansas), and colleagues, but

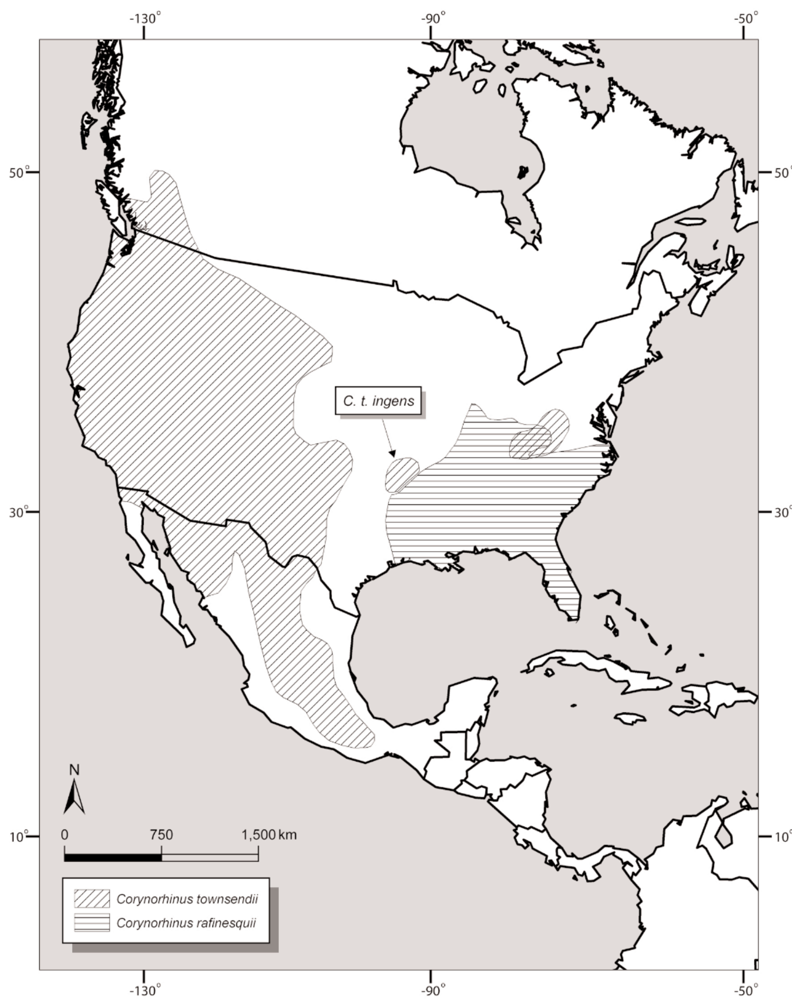

Figure 3. Current global range of Townsend's big-eared bat *(Corynorhinus townsendii)* and Rafinesque's big-eared bat *(C. rafinesquii)* in relation to North American countries (Piaggio and Perkins 2005; Medlin Jr. et al. 2006).

also museum collections and Natural Heritage Network databases maintained by the Arkansas Natural Heritage Commission, Oklahoma Biological Survey, and Missouri Department of Conservation. Corynorhinids collected in northwest Arkansas by Sealander Jr. (1951) were originally assigned to Rafinesque's big-eared bat (*C. rafinesquii* [Lesson 1827]); these were reassigned to *C. t. ingens* by Handley (1955). Since Handley's (1959) taxonomic revision, it is understood that these species' ranges do not overlap (Figure 3), although recent mist-netting studies of Arkansas bottomlands confirms their parapatry at the ecoregion boundary between the Ozark Plateaus and the Arkansas River Valley (Medlin Jr. et al. 2006).

Summary statistics of roost counts were performed using SPSS statistical software (version 15.0, SPSS, Inc.). Consistent with other bat survey data analyses (e.g. Ellison et al. 2003), a time series of counts required at least four annual counts (but not necessarily consecutive years) that were conducted using similar methods and at the same season of year. Where a roost count was reported as a range, the mean of the lower and upper bound was used. None of the counts included estimates of sampling-based variation, and most lacked replicate counting: both are suggested for future counts, where possible. The MAKESENS software created by Salmi et al. (2002) was used to perform the nonparametric Mann-Kendall Test (Kendall 1938, Mann 1945) and Sen's Slope Estimator Method (Sen 1968a,b), which tests for a monotonic trend in the time series and the magnitude of the trend, respectively, at significance level $\alpha = 0.05$. The Mann-Kendall test involves computing the Z statistic (or S statistic for time series with less than 10 observations), which is the difference between the number of pairwise differences that are positive minus the number that are negative (USEPA 2006). If Z is a large positive value and the probability value is less than 0.05, then there is evidence of an increasing trend in the data, and vice versa. The null hypothesis or baseline condition is that there is no temporal trend in the time series (USEPA 2006). The coefficient of variation (CV, ratio of standard deviation of a parameter estimate to its mean, expressed as a percent) was used to further evaluate potential trends because it is a dimensionless measure of precision and can compare data sets of unequal variance (Thompson et al. 1998; Ellison et al. 2003). Ellison et al. (2003) explains its application in bat roost count time series: *"in cases where CVs are relatively high, failure to reject the null hypothesis may be due to high variability in counts. In cases where CVs are low, the trend may be stable."* Where a time series did not have a significant upward or downward trend, we followed Ellison et al. (2003)'s use of an arbitrary CV cutoff point of 50% to interpret its meaning. Where the CV was less than 50%, the count was inferred to stabilize around a mean value; where a time series had a larger CV, we inferred that the counts were too variable to interpret any trend (until a later date when the time series dataset was large enough to reduced the CV). Sen's Slope Estimator Method provides a simple linear equation where the number of years between bat counts, year(x) – year(0), is multiplied by a slope Q (bats/yr) and a y-axis intercept B to yield the number of bats estimated for that future year(x).

Each site was assigned a bat use category refined from the recovery plan (USFWS 1995) definitions: 1) essential—a site particularly crucial to the continuing existence of Ozark big-eared bats, including major maternity and hibernacula sites, or other currently active, large roosts consistently being used by at least 10 bats; 2) limited use—sites used by singletons or small groups, typically less than 10, including "transient use" sites; 3) historic use—a site used by the Ozark big-eared bat in the past but for which recent surveys indicate is no longer used or where the habitat has become unsuitable for bats; or 4) potential use—a site having the requisite habitat parameters and the presence of bat guano accumulations with culled insect remains, especially moth wings, but no confirmed Ozark big-eared bat sightings. Geographic information system software (ArcGIS 9.3, Environmental Systems Research Institute, Inc.) was used to explore potential zoogeographical patterns.

RESULTS

Site inventory. Compilation of records from all known sources yielded a dataset of 1,330 Ozark big-eared bat survey events (including zero counts and observations of bat sign only). In total, 170 confirmed sites and 98 potential use sites were identified. Confirmed sites numbered 77 in Arkansas, 84 in Oklahoma, and 9 in Missouri (Figure 4), and were categorized further as 59 historic, 92 limited use, and 19 essential. Of the sites deemed essential (7 in Arkansas and 12 in Oklahoma), some are used as transitional fall roosts (AD16, CZ18), as maternity roosts (AD13, AD17, AD18, AD24, AD25, AD3, CW21BT1, CW29BT3, MR9702), as hibernacula (AD3, ADT1, WA31T complex), or for multiple functions (AD10, AD14, AD125, MR0702, and MR979a).

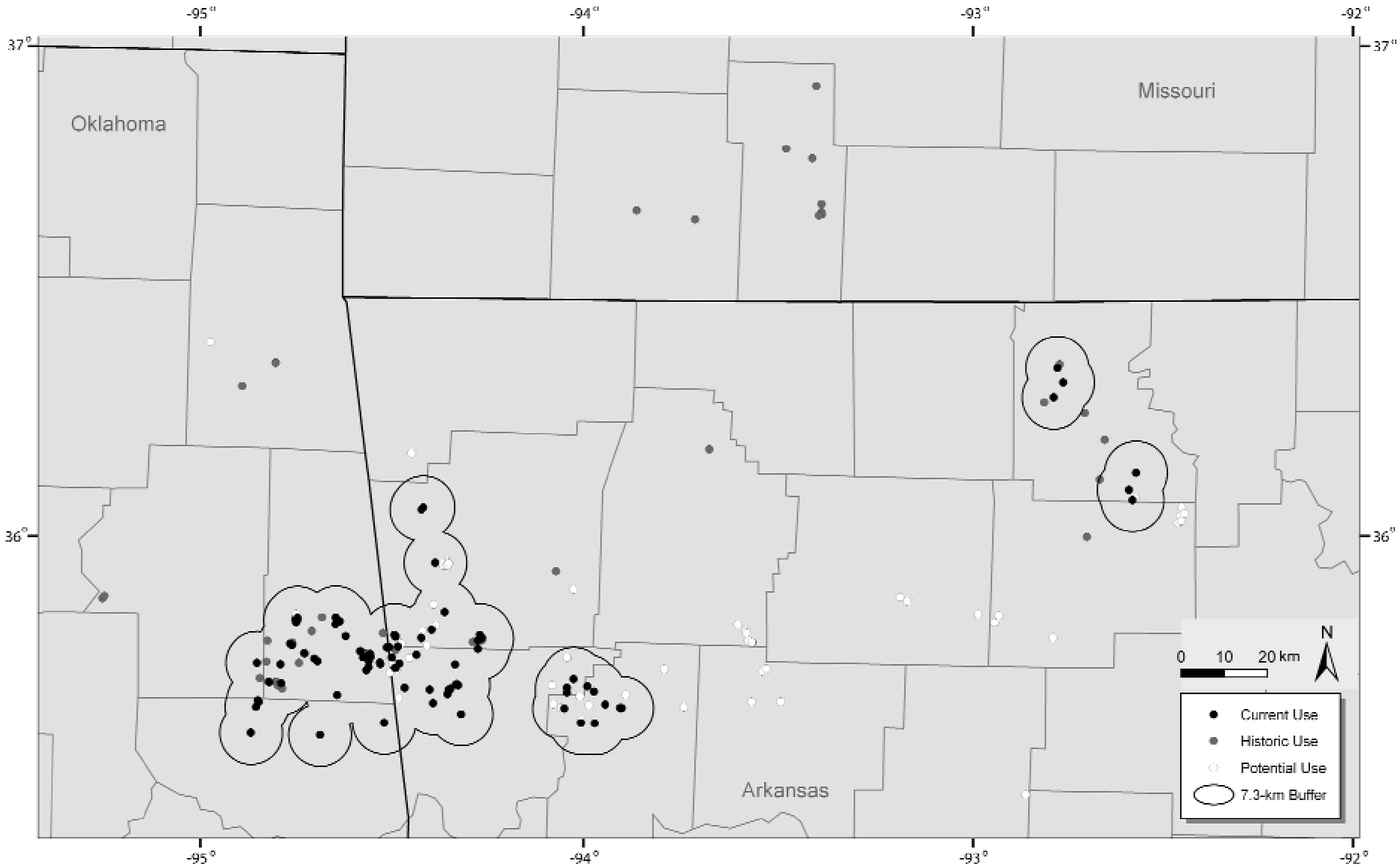

Figure 4. Current distribution of *C. t. ingens*: radial buffers of 7.3 km (maximum nightly foraging distance of the subspecies) around current sites (essential use and limited use), where dots show generalized locations with geographical uncertainty added to protect actual site locations.

Population trends at essential sites and rangewide. Trends of population counts were analyzed at each essential site grouping that housed relatively discrete colonies (Table 1, Figure 5, and Figure 6). Published total abundance estimates of Ozark big-eared bats range from 100 to 2,500 individuals, using various survey techniques and estimate methods (Harvey 1975, 1986, 1992, 1995, 1996, Humphrey and Kunz 1976, Harvey et al. 1978, Grigsby and Puckette 1982, Jacobs and Bagley 1983, Bagley 1984, 1985, 1987, Mathews and Mosely 1990, Harvey and Barkley 1990, Clark et al. 1997b, USFWS 1973, 1977, 1979, 1984, 1995, 2008). Total population estimates calculated for the last 5 maternity seasons were 1,900 bats in 2006, 1,600 in 2007, 1,800 in 2008, 1,500 in 2009, and 1,200 in 2010.

Over the four decades that colonies have been surveyed, there has been a significant increase in all pooled raw maternity counts and all winter counts (Figure 7). The mean of all pooled maternity counts (n = 33, $\bar{x}$ = 766 bats, CV = 48%) is significantly higher than the mean of pooled winter counts (n = 32, $\bar{x}$ = 496 bats, CV = 49 %), according to a Mann-Whitney U test for independent samples (n = 65, U = 250.500, z = -3.904, P = 0.001).

DISCUSSION

Current population status. Trend analyses of the entire 34-year data set suggest increasing trends for pooled maternity site counts and pooled hibernaculum site counts. These significant increases have been attributed to the discovery of cryptic populations resulting from increased field search efforts by WLP, MJH, and colleagues, and not necessarily to population growth or recovery (USFWS 2008). Figure 8 demonstrates the increase in total population size simply by the addition of new maternity sites to the running total.

Most of these individual datasets are highly variable, and may be due in part to movement between sites, making interpretations about the status of each colony difficult (Clark et al. 1997a). Our data and previous analyses show that total summer population counts are higher than total winter population counts even though juveniles are counted in winter, suggesting that some important hibernacula have not yet been located (USFWS 1995; Clark et al. 1997a).

While we have standardized the survey method, the majority of our data is from counts in only the last two decades. This is consistent with observations for Nearctic bats in general; the majority of observations

Table 1. Results of statistical trends analysis of bat counts of essential sites indicating habitat, survey dates, mean counts with variation, and trend analysis statistics.

Site Name (Habitat Type)	Survey Period	Mean Count (coefficient of variation, CV)	Maximum Count and Year	Population trends per year inferred by Mann-Kendall Test of Population Trends and Sen's Slope Estimator (n=number, Z = test score, p = significance level, Q = slope, B = y-intercepts of fitted line)
Maternity Sites				
AD10 (limestone cave)	1983 to 2010	255 bats (20%)	339 in 1998 and 338 in 2006	increase, 4 bats/yr (n = 27, Z = 2.7, p = 0.007, Q = 3.5, B = 215.0)
AD 13, 24, or 25 (limestone cave complex)	1984 to 2010	69 bats (46%)	148 in 1989	decrease, 2 bats/yr (n = 27, Z = -2.4, p = 0.015, Q = -1.8, B = - 103.3)
AD125 (limestone cave)	1987 to 2010	94 bats (87%)	276 in 1989	decrease, 3 bats/yr (n = 23, Z = -2.9, p = 0.004,Q = -6.5, B = 159.5)
AD17 + AD18 (limestone cave complex)		129 bats (41%)	252 in 2007	increase, 4 bats/yr (n = 27, Z = 3.3, p = 0.002, Q = 4.9, B = 26.2)
CW29BT3 (sandstone talus cave complex)	1997 to 2008	175 bats (39%)	300 in 2006 and in 2008	increase, 9 bats/yr (n = 10, Z = 3.0, p = 0.002, Q = 8.5, B = -70.8)
MR9702 + MR0702 + MR979a (limestone cave complex)	1978 to 2009	140 bats (61%)	336 in 2003	no trend (n = 31, p = 0.54)
WA5202 (limestone cave)	1995 to 2010	31 bats (52%)	53 in 2006	no trend (n = 16, p = 0.82)
All maternity sites combined	1978 to 2010	766 bats (48%)	1,497 in 2009	increase, 30 bats/yr (n = 33, Z = .9, p = < 0.001, Q = 30.0, B = 150.3)
Hibernacula				
AD10	1983 to 2010	33 bats (263%)	300 in 2009	no trend (n = 21, P = 0.497)
AD14 + AD125 (limestone cave complex)	1987 to 2010	48 bats (160%)	247 in AD125 in 1988 and 128 in AD14 in 2004	increase, 3 bats/yr (n = 22, Z = 3.2, p < 0.001, Q = 2.5, B = -6.6)
AD3 (limestone cave)	1981 to 2009	306 bats (30%)	435 in 2003 and 2009	increase, 10 bats/yr (n = 25, Z = 5.3, p < 0.001, Q = 9.5, B = 178.0)
ADT1 (sandstone talus cave)	1994 to 2010	10 bats (70%)	24 in 2006	increase, 1 bat/yr (n = 11, Z = 2.4, p = 0.012, Q = 0.8, B = 2.1)
CW21BT1a-g (sandstone talus cave complex)	1998 to 2010	9 bats (86%)	18 in 2010	no trend (n = 6, insufficient data)
MR0702 + MR9702 + MR979a	1979 to 2009	134 bats (67%)	420 in 1980	decrease of about 6 bats/yr (n = 27, Z = -3.6, p < 0.001, Q = -5.1, B = 206.9)
WA31T (sandstone crevice cave complex)	1975 to 2009	39 bats (75%)	116 in 2005	increase, 3 bats/yr (n = 30, Z = 4.6, p < 0.001, Q = 2.5, B = -9.4)
All hibernacula combined	1975 to 2010	439 bats (62%)	1,057 in 2010	increase, 12 bats/yr (n = 37, Z = 3.2, p < 0.001, Q = 12.4, B = 132.8)

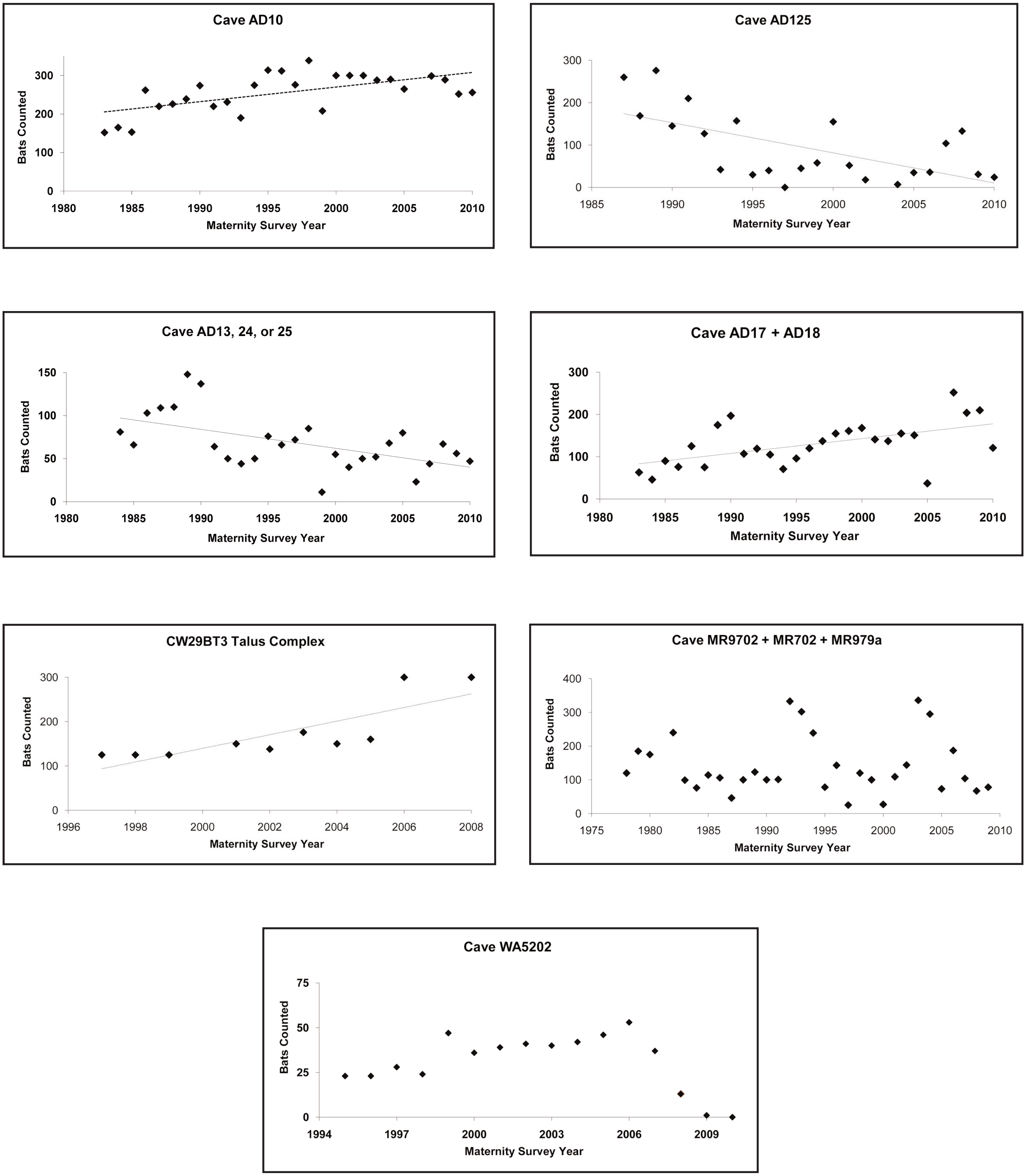

Figure 5. Time series of essential maternity sites; lines fitted where time series had significant trends.

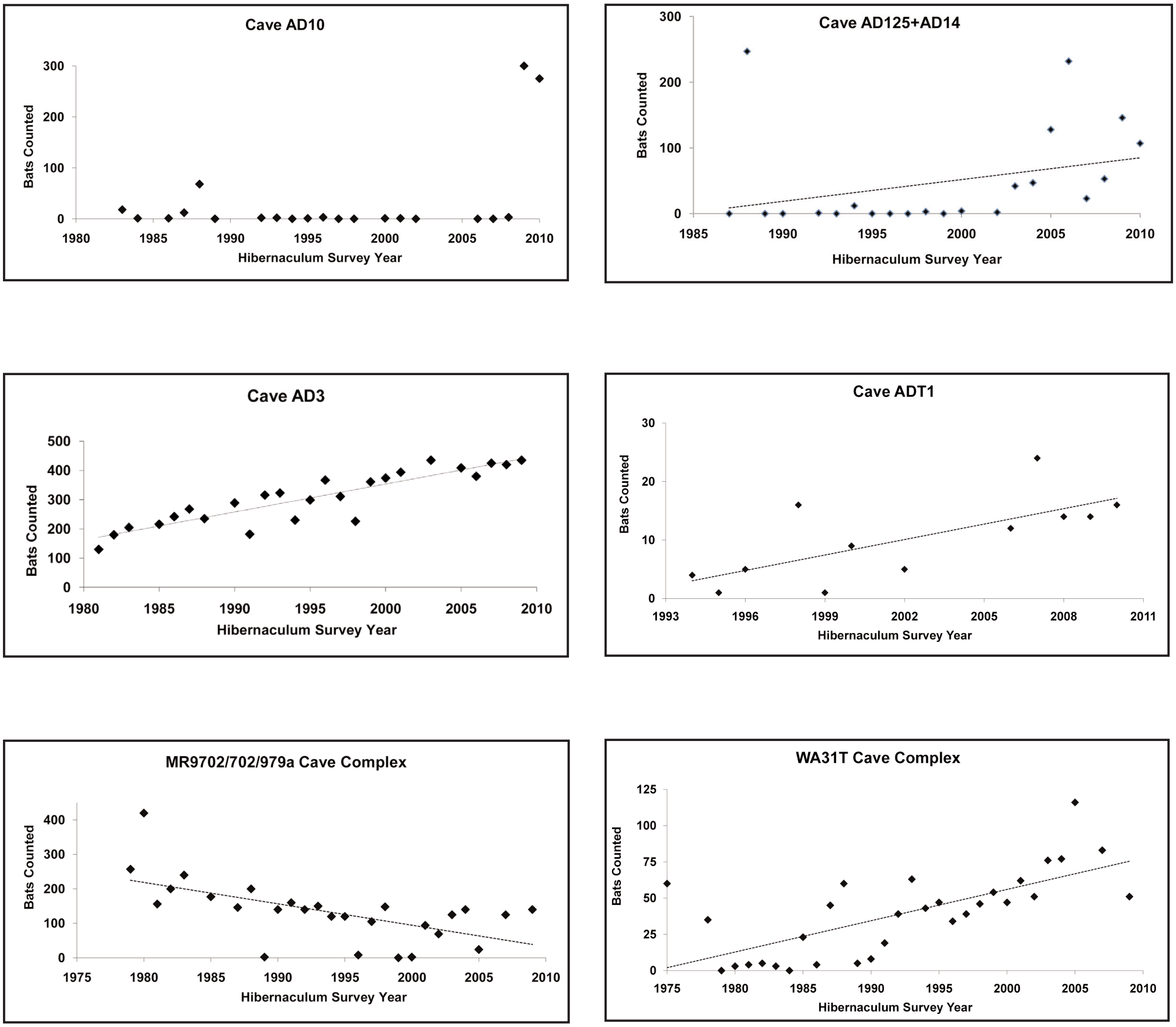

Figure 6. Time series of essential hibernacula; lines fitted where time series had significant trends.

were made after 1990; Ellison et al. (2003) attributed this to the increase in conservation interest in bat populations. Similar to the Ellison et al. (2003) analysis of bat population datasets nationwide, variance was high in bat counts and many survey data sets were not yet sufficiently long to detect a trend.

Current distribution / zoogeographic patterns. Handley (1955) reported the distribution of Ozark big-eared bats to be the “Ozark Highlands” (i.e. the Ozark Plateaus ecoregion). USFWS (1984, 1995) restricted the range to the western half of this ecoregion (northeastern Oklahoma, northwestern Arkansas, and southwestern Missouri). The Ozark big-eared bat has not been reported from Missouri since 1971 (unpublished data, Missouri Department of Conversation Natural Heritage database), and is currently understood to be extirpated from the state (Figg and Lister 1989, Elliott et al. 1999). Ozark big-eared bats are paradoxically absent from the eastern and northern portions of this ecoregion even though this area is rich in suitable cave habitat and no specific dispersal barriers have been identified.

Using geographic information system software, each currently used site (essential or limited use) was given a radial buffer of 7.3 km (Figure 4); the longest tracked movement of the Ozark big-eared bat was 7.3

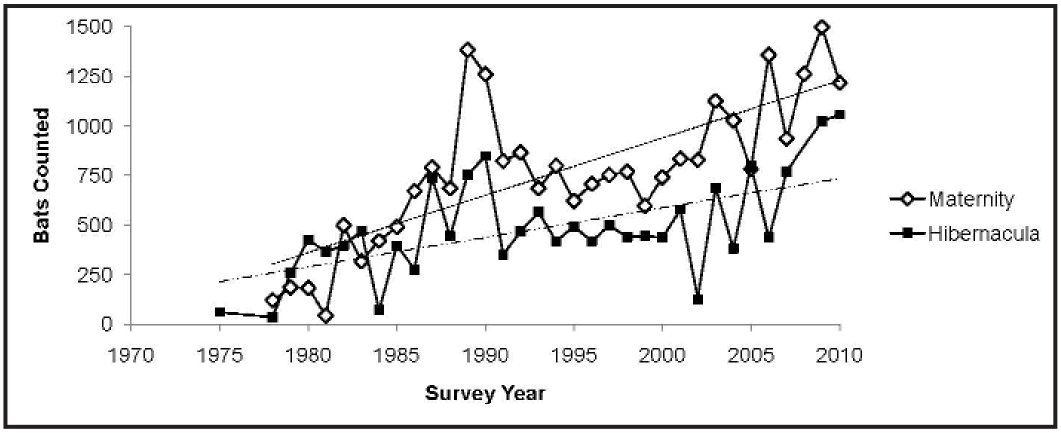

Figure 7. Significant increases detected in time series of all pooled colony site counts of *C. t. ingens* during maternity season and during hibernation.

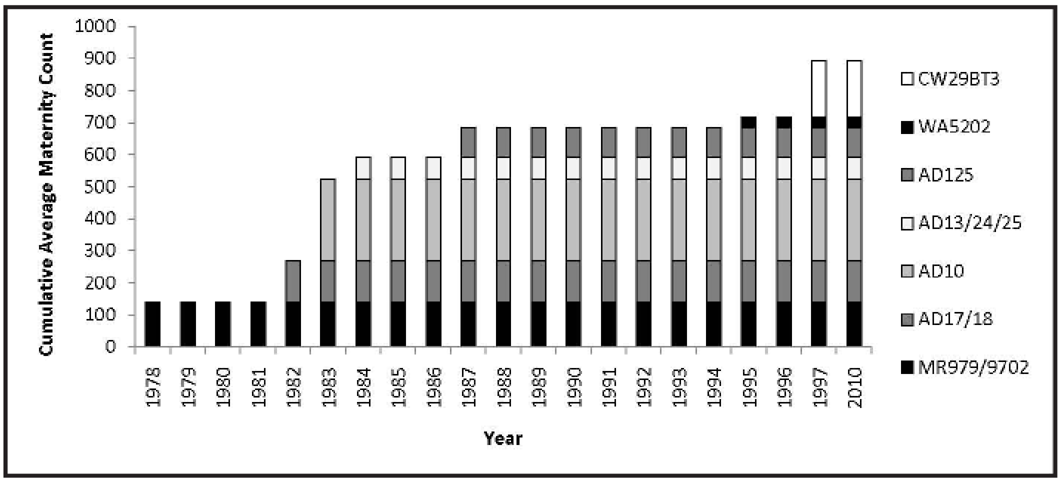

Figure 8. The significant increase in pooled maternity counts may be explained by the discovery of new maternity sites in 1982-1984, 1986, 1995, and 1998, which add greatly to the average yearly total of bats counted, regardless of the temporal trend in any particular colony.

km (Clark et al. 1993), although typical foraging distances traveled over a 24-hour period were within 2 km of the roosting site (Clark et al. 1993, Wethington et al. 1996, Wilhide et al. 1998). Any references (e.g. Wethington et al. 1996, Weyendt et al. 2005) attributed to Harvey (1992) stating that Ozark big-eared bats traveled up to 8 km in Arkansas are erroneous, as are references (e.g. USFWS 1995, Weyendt et al 2005) stating that Ozark big-eared bats moved up to 20 miles (32 km)—MJH was referring to banded Virginia big-eared bats in Harvey (1992).

These confirmed sites are neatly grouped by the 7.3 km radial buffers suggesting 3 discrete subpopulations: a cluster of essential and limited use caves within the Bull Shoals Reservoir watershed in Marion County, Arkansas, named the "Yellville population"; a large cluster of essential and limited use caves and crevices on the Arkansas/Oklahoma border within the watershed of the Illinois River/Lee Creek named the "Stateline population"; and a cluster of essential and limited use caves in the Frog Bayou/Mulberry River watershed. A fourth cluster of limited use caves and mines occurs in the Buffalo River watershed, but this cluster does not yet include any known essential maternity or hibernaculum sites. These 3 subpopulations might constitute a metapopulation, because the criteria defined by Hanski and Gilpin (1991) are probably met: the habitat occurs in discrete patches occupied by local breeding populations; even the largest (core) populations have a substantial extinction risk; habitat patches are not too isolated to prevent recolonization; and the dynamics of local populations are not known to be synchronized.

Radial buffers of 64 km, which represent a hypothetical maximum potential dispersal distance of the species, were also fitted around each confirmed site

(Figure 9). Barbour and Davis (1969) reported that the longest recorded movement for the Townsend's big-eared bat species complex was *"...up to 40 miles"* (64 km) in Kentucky and Virginia, and they cited other tracked movements of over 20 miles. Furthermore, Piaggio and Perkins (2005) documented gene flow in this species across distances greater than limitations invoked by their wing morphology or mark-recapture evidence; they suggested that this species can travel farther than previously documented, and cited a recent report of a western big-eared bat *(C. t. townsendii)* movement of over 150 km. Almost all of the remaining historic and potential use sites fall within these 64 km buffers, suggesting that the 3 subpopulations have the potential to disperse to numerous suitable patches of unoccupied habitat and establish satellite populations. Where this dispersal area is truncated by the extent of suitable geomorphology (the edge of the Boston Mountain Plateau to the south), we spatially described the current maximum range of this subspecies (Figure 9). However, Piaggio and Perkings (2005) suggested that dispersal to such suitable habitat is not the limiting factor of this species. Weyendt et al. (2005) performed a genetic study of 5 Ozark big-eared bats sites in Oklahoma, and confirmed that Ozark big-eared bats have high site fidelity. Weyendt et al. (2005) warned that such philopatry may impede colonization of proximal suitable habitat.

Threats. There is disagreement as to whether historic populations of Ozark big-eared bats have actually declined due to anthropogenic stresses (Barbour and Davis 1969, USFWS 1995), whether the subspecies is

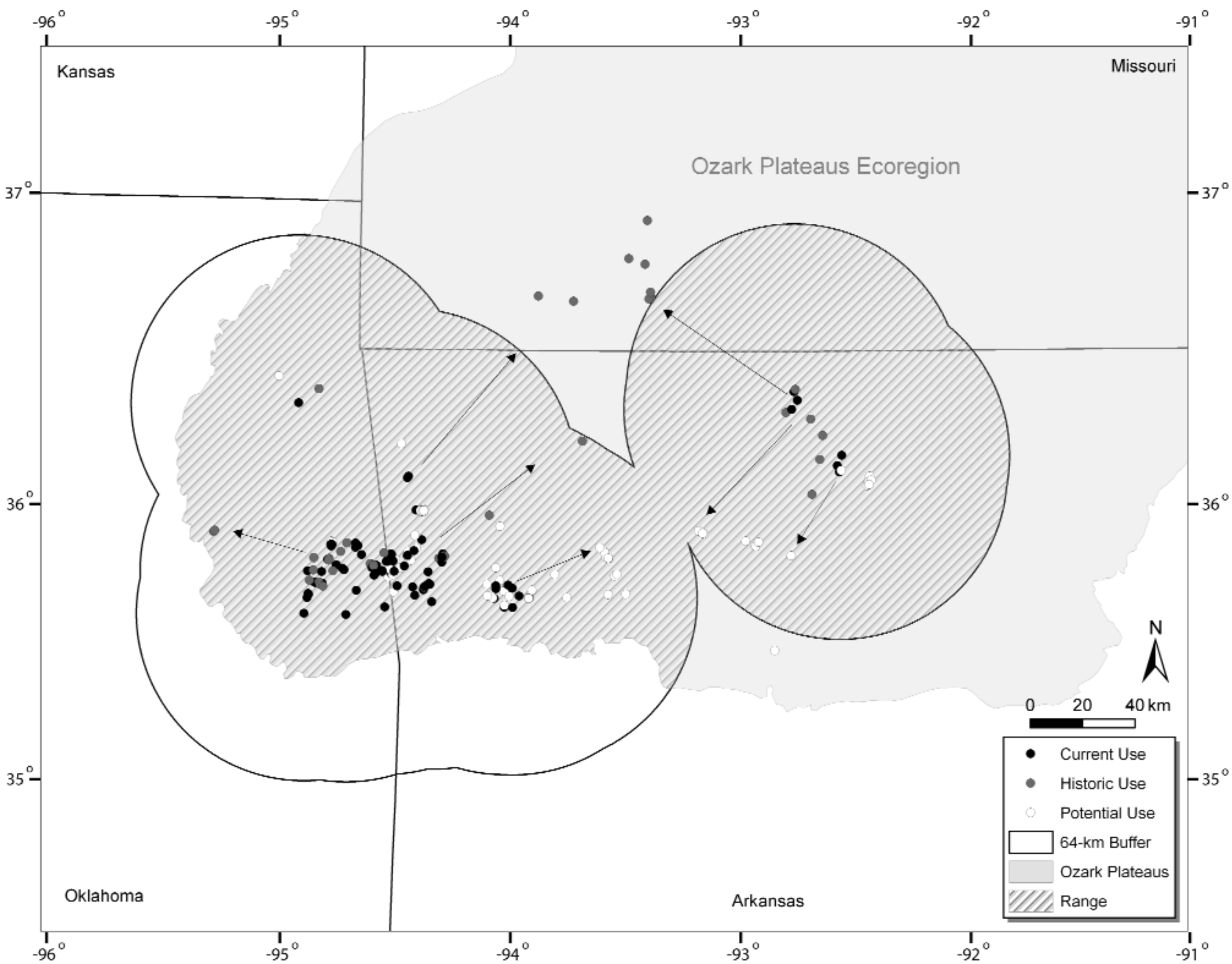

Figure 9. Potential dispersion of *C. t. ingens* to potential use sites suggested by arrows, with 64-km radial buffers around all current (essential and limited use) sites, representing the current maximum range (stippled area) of the subspecies within the Ozark Plateaus Ecoregion (solid gray).

simply rare (Sealander 1951), or whether it is an isolated "relict" due to climate change since the Pleistocene epoch (Handley 1959, Humphrey and Kunz 1976, Kunz and Martin 1982). The primary stressors causing population decline are understood to be human disturbance of colonies and loss of habitat (Harvey 1975, USFWS 1984). The behavior and life history strategies of *C. townsendii* make it inherently vulnerable to human disturbance at roosting sites. The bats are frequently encountered by cavers because the bats prefer to roost in the twilight zone, in places easily reached by flying such as open ceilings, and on low hanging ceilings where cold air is trapped (Barbour and Davis 1969, Humphrey and Kunz 1976). The bats are aroused easily, and Humphrey and Kunz (1976) reported that disturbance of hibernating pale lump-nosed bats *(C. t. pallescens)* could result in increased mortality due to depletion of fat reserves, a phenomenon well documented for other bats (reviewed by Davis 1970). Townsend's big-eared bats are disturbed by flashlights and cave visitation; disturbed colonies have been documented to move to more remote portions of caves, exit caves, or abandon sites permanently, often to less optimal sites (Barbour and Davis 1969).

Corynorhinids are also sensitive to research activities. After mistnetting and the fitting of radio transmitters on Ozark big-eared bats in AD125, Clark and Clark (1995) reported lowered maternity counts for the next 6 years. Yet, Clark et al. (1997a) reported tolerance of Ozark big-eared bats to later research activities. Humphrey (1969) and Humphrey and Kunz (1976) report that pale lump-nosed bats were extremely sensitive to disturbance by human visitation, and in 2 instances in Cimarron County, Oklahoma, the colony abandoned the roosting site after disturbance from their mark/recapture research, and subsequent population censuses decreased. However, wing bands and mark / recapture techniques have improved since these early studies, and mark / recapture techniques should be reconsidered for corynorhinid population monitoring. With at least 19 specimens catalogued in museums (Sealander 1951, Glass 1961), scientific collection may have historically impacted the subspecies. Voucher specimen collection has long since been replaced with visual identification techniques and non-lethal tissue sampling for genetic analyses.

Although often cited as a major threat, loss of habitat is not specifically documented for Ozark big-eared bats. Yet the southern Ozark Plateaus ecoregion is experiencing one of the nation's fastest human population increases (United States Census Bureau 2001; Oklahoma Department of Commerce 2002), and has resulted in rapid urbanization of potential bat foraging habitat. Climate change should be considered an important future threat because any changes in regional humidity or temperature could change the microclimate in subterranean roosts and render them unsuitable to colonial bats (Newson et al. 2009). Predation by other mammals, birds, and reptiles is another mortality factor for the species (Handley 1959, Clark et al. 1990) and has substantially impacted certain western corynorhinid populations (see Pearson et al. 1952). There is no documentation yet of any disease in this subspecies, including white nose syndrome (Blehert et al. 2008).

Conservation efforts. Here we summarize efforts to date to implement recovery actions specified in the Recovery Plan. Protection of cave entrances and bat flyways are obvious and necessary actions, but development of other best management practices has been hampered by scientific uncertainty of this subspecies' habitat requirements. Wethington (1994) and Wethington et al. (1996) recommend that protection efforts be focused upon lands within 8 km radii of all used caves. Wethington et al. (1996, 1997) reported no preference of Ozark big-eared bats in foraging habitat or land use, and conclude that previous studies documenting habitat preferences (Clark 1991, Clark et al. 1993) were attributable primarily to variations in prey availability. Prather and Briggler (2002) concluded that no landscape-level variables significantly affected occupancy. Dodd (2006) noted a preponderance of forest tree-associated moths in the diet, suggesting that the maintenance of this vegetation community type is important. Wilhide et al. (1998) recommended preserving existing vegetation structure (primarily forest), and Dodd et al. (2008) recommended preserving habitat heterogeneity to maximize moth prey resources and protecting forested riparian corridors for foraging habitat.

Colony disturbance has been reduced by modification of research techniques and by restricting recreational access to important caves. Early gate designs (e.g. external placement, vertical bars) caused gray bat *(Myotis grisescens)* colony abandonment; improved designs (e.g. placement in aphotic zone, emphasis on horizontal bars) increased retention of gray bats, and gate design continues to evolve (Martin et al. 2000). Gates may alter microclimates or increase predation (Clark et al. 1996; Martin et al. 2006), and some sites are impractical to gate because they have extremely large or numerous openings. Diligent monitoring and maintenance of these gates places a considerable and perpetual stewardship burden on conservation agencies.

The search for additional Ozark big-eared bats populations focuses upon escarpments / blufflines within 7 km of known habitats. Another focus area should be mining districts: mines have not been sufficiently inventoried for bat populations (Tuttle and Taylor 1998). Ozark big-eared bats are occasionally seen roosting in mines within the Buffalo River watershed (C. Bitting, US National Park Service, pers. comm.), and their westerly conspecifics are known to populate mines in large numbers (Kunz and Martin 1982, Tuttle and Taylor 1998).

Gray bat fatalities from insecticide exposure prompted USFWS biologists to investigate this threat in other endangered bat species. Martin (1992) detected aliphatic hydrocarbons, polycyclic aromatic hydrocarbons, and heavy metals in Ozark big-eared bat guano in caves AD10 and AD17, and concluded that bats were being exposed to a variety of environmental contaminants. Adornato (2005) detected organochlorine pesticide residues in eastern pipistrelle *(Periomyotis subflavus)* tissue and gray bat guano in caves of the Ozark Plateau National Wildlife Refuge. Sasse (2005) analyzed gray bat guano collected from 4 caves in Arkansas and detected organochlorine pesticide residues in all of the sites. Sasse (2005) and Martin (2007) recommended continued periodic monitoring of pesticide residues in guano and carcasses of dead bats.

Significant progress has been made toward permanent protection of Ozark big-eared bat habitat. The Ozark Plateau National Wildlife Refuge was established in 1986 by SJH with a focus upon protecting endangered species dependent upon caves (including AD10, AD14, AD18, and AD125), and now consists of 8 units with 3,748 acres in a combination of fee title, conservation easements, and management agreements. USFWS also cooperates with the Cherokee Nation (who owns caves AD17, AD51, and AD65), the City of Tulsa (cave DL4), the National Speleological Society (caves AD3, CZ18 and CZ19), and private landowners (caves AD13, AD16, AD24, AD25, ADT1, CW21BT1, WA5202) to protect endangered bats. The Arkansas Natural Heritage Commission (ANHC) and The Nature Conservancy continue to expand protection for the foraging area of the Yellville subpopulation, and are implementing a site conservation plan for the MR0702/9702/979a cave complex which are protected within ANHC's 536-acre Slippery Hollow Natural Area, the Conservancy's 450-acre preserve, and by private landowner management agreements. Arkansas Department of Parks and Tourism manages the Ozark big eared-bats within the 2,000-acre Devil's Den State Park. Cave CW29BT3 is protected within USFS' Ozark National Forest. In all, 72 confirmed sites are protected. However, some sites are still lacking protection measures: for example, only 21 of the 161 confirmed sites are gated (or fenced or wired with alarms).

Conservation status. Important recovery accomplishments have occurred over the past 3 decades since federal designation of the Ozark big-eared bat as endangered. Gray bat colonies have rebounded from similar conservation efforts over the same time period (Martin 2007, Sasse et al. 2007). This provides optimism that continued implementation of conservation measures for the Ozark big-eared bat will continue to facilitate recovery. Yet our current population estimate is 1,600 to 1,800 total individuals. In their most recent status review, USFWS (2008) concluded that the overall population has stabilized since 1997—the year when the latest essential maternity site (CW29BT3) was added to the annual surveys, and the time period for which the time series is most complete. However, USFWS (2008) found that the recovery criteria have not been fully met and therefore upgrading the bat's status to threatened or recovered was not yet warranted. Additional study is needed to determine the limiting factors of the Ozark big-eared bat, and additional recovery time is needed for this animal to proliferate.

ACKNOWLEDGMENTS

The views described herein are those of the authors, and do not necessarily reflect the views of the USFWS. Funding for these conservation efforts have been provided over several decades primarily by the USFWS (Oklahoma and Arkansas Ecological Services Offices and the Ozark Plateau National Wildlife Refuge) and the US Forest Service Ozark National Forest; financial support has also been provided by The Nature Conservancy's Oklahoma and Arkansas Field Offices, Arkansas Game and Fish Commission, Oklahoma Department of Wildlife Conservation, Oklahoma State University, Rogers State University, Northeastern State University, and Tennessee Technological University. The MAKESENS software was made available courtesy of the Finnish Meteorological Institute at Helsinki. We are grateful to the landowners who graciously allow access to caves on their properties and who continue to protect the bat colonies. We are indebted to the colleagues that assisted with surveys over the years, but there are too many to list here. We thank M. Brigham (University of Regina) and anonymous reviewers for constructive comments.

LITERATURE CITED

Adornato TG. 2005. OK – Assessment of contamination in caves located at the Ozark Plateau National Wildlife Refuge, Oklahoma, Final Report, Project ID:1261-2N46. Environmental Contaminant Program, On-refuge Investigations Sub-activity. United States Fish and Wildlife Service, Region 2, Tulsa Oklahoma.

Bagley FM. 1984. 1984 Range-wide survey of Ozark and Virginia big-eared bat maternity colonies. Jackson Endangered Species Field Office, United States Fish and Wildlife Service, Jackson, Mississippi.

Bagley FM. 1985. 1985 Range-wide survey of Ozark and Virginia big-eared bat maternity colonies. Jackson Endangered Species Field Office, United States Fish and Wildlife Service, Jackson, Mississippi.

Bagley FM. 1987. 1986 Range-wide survey of Ozark and Virginia big-eared bat maternity colonies. Jackson Endangered Species Field Office, United States Fish and Wildlife Service, Jackson, Mississippi.

Bagley FM, Jacobs J. 1985 Census techniques for endangered big-eared bats proving successful. Endang Spec Tech Bull 10:5-7.

Barbour R, Davis W. 1969. Bats of America. The University Press of Kentucky, Lexington,Kentucky.

Blehert DS, Hicks AC, Behr M, Meteyer CU, Berlowski-Zier Br M, Buckles EL, Coleman JTH, Darling SR, Gargas A, Niver R, Okoniewski JC, Rudd RJ, Stone WB. 2008. Bat White-Nose Syndrome: An Emerging Fungal Pathogen? Science 323(5911): 227.

Clark BS. 1991. Activity patterns, habitat use, and prey selection by the Ozark big-eared bat *(Plecotus townsendii ingens)*. PhD dissertation, Oklahoma State University, Stillwater, OK.

Clark BK, Clark BS, Leslie Jr. DM. 1990. Ozark big-eared bat eaten by eastern woodrat. Prairie Naturalist 22(4):273-274.

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(2):422-427.

Clark BS, BK Clark. 1995. Final Report - Habitat use by Ozark big-eared bats at The Nature Conservancy's Lee Creek Woodland in Adair County. Contract Number OKFO19940413-02, Project Period - June 15, 1994 to December 31, 1995. Department of Biological Sciences, Southeastern Oklahoma State University, Durant, Oklahoma. 4 pp.

Clark BK, Clark BS, Leslie Jr. DM, Gregory MS. 1996. Characteristics of caves used by the endangered Ozark big-eared bat. Wildlife Society Bulletin 24(1):8-14.

Clark BK, Clark BS, Leslie, Jr. DM. 1997a. Seasonal variation in use of caves by the endangered Ozark big-eared bat *(Corynorhinus townsendii ingens)* in Oklahoma. American Midland Naturalist 137:388-392.

Clark BS, Puckette WL, Clark BK, Leslie Jr. DM.. 1997b. Status of the Ozark big-eared bat *(Corynorhinus townsendii ingens)* in Oklahoma, 1957 to 1995. Southwestern Naturalist 42:20-24.

Davis WH. 1970. Hibernation: ecology and physiological ecology. In: WA Wimsatt (ed) Biology of Bats. Academic Press, New York, p 265-300.

Dodd, LE. 2006. Diet and prey abundance of the Ozark big-eared bat *(Corynorhinus townsendii ingens)* in Arkansas. MS thesis, University of Kentucky, Lexington, KY

Dodd LE, Lacki MJ, Rieske LK. 2008. Variation in moth occurrence and implications for foraging habitat of Ozark big-eared bats. For Ecol Manag 255:3866-3872.

Elliott WR, Lister KB, Shiver MA. 1999. A Survey for Ozark big-eared bats *Corynorhinus townsendii ingens* and a cave crayfish *Cambarus aculabrum* in southern Missouri. Missouri Department of Conservation.

Ellison LE, O'Shea TJ, Bogan MA, Everette AL, Schneider DM. 2003. Existing data on colonies of bats in the United States: summary and analysis of the U.S. Geological Survey's bat population data base. in: O'Shea TJ, Bogan MA (eds) Monitoring trends in bat populations of the United States and territories: problems and prospects. United States Geological Survey, Biological Resources Discipline, Information and Technology Report, USGS/BRD/ITR—2003-0003. p 127-237.

Figg DE, Lister KB. 1989. Status and distribution of the Ozark big-eared bat *(Plecotus townsendii ingens)* in Missouri: Final Report – Surveys and Investigations Projects. Project No. SE-01-16 (1988-89) Jobs No. 1 and 2. Endangered Species Coordinator, Region 3, U.S. Fish and Wildlife Service, Twin Cities, Minnesota.

Glass BP. 1961. Two noteworthy records of bats for Oklahoma. Southwestern Naturalist 6(3&4):200-201.

Grigsby EM, Puckette WL. 1982. A study of three species of endangered bats in Oklahoma. Report for Contract No. 14-16-0002-81-202. United States Fish and Wildlife Service, Albuquerque, New Mexico.

Handley Jr. CO. 1955. New bats of the genus *Corynorhinus.* Jour Wash Acad Sci 45:147-149.

Handley Jr. CO. 1959. A revision of American bats of the genera *Euderma* and *Plecotus*. Proc US Nat Mus 110:95-246.

Hanski I, Gilpin M. 1991. Metapopulation dynamics: brief history and conceptual domain. Bio Jour Linn Society 42:3-16.

Harvey MJ. 1975. Endangered chiroptera of the south eastern United States. In: Proceedings of the 29th Annual Conference of the Southeastern Association of Game and Fish Commissioners, p 429-433.

Harvey MJ. 1986. Arkansas bats: a valuable resource. Arkansas Game and Fish Commission, Little Rock, AR.

Harvey MJ. 1992. Bats of the eastern United States. Arkansas Game and Fish Commission and United States Fish and Wildlife Service.

Harvey MJ. 1995. Management of endangered bat caves in Arkansas. In: 1995 National Cave Management Symposium Proceedings, p 150-154.

Harvey MJ. 1996. Status and management of endangered bats in Arkansas. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 50:246-253 .

Harvey MJ, Kennedy ML, McDaniel VR. 1978. Status of the endangered Ozark big-eared bat *(Plecotus townsendii ingens)* in Arkansas. Proc Ark Acad Sci 32:89-90.

Harvey MJ, Cassidy JJ, O'Hagan GG. 1981. Endangered bats of Arkansas: distribution, status, ecology, and management. Report to Arkansas Game and Fish Commission, United States Forest Service, and National Park Service. Memphis State University, Memphis, Tennessee.

Harvey MJ, Barkley SW. 1990. Management of the Ozark big-eared bat, *Plecotus townsendii ingens*, in Arkansas. Proc Ark Acad Sci 44:131-132.

Hipel KW, Mcleod AI. 1994. Time series modeling of water resources and environmental systems. Elsevier, Inc., Amsterdam, Netherlands.

Hope GM, Bhatnagar KP. 1979. Electrical response of bat retina to spectral stimulation: comparison of four microchiropteran species. Experientia 34:1189-1191.

Humphrey SR. 1969. Disturbance and bats. Okla Underg 2(2):42-44.

Humphrey SR, Kunz TH. 1976. Ecology of a Pleistocene relict, the western big-eared bat *(Plecotus townsendii)*, in the southern Great Plains. Journal of Mammalogy 57:470-494.

Jacobs J, Bagley F. 1983. 1983 rangewide survey of Ozark and Virginia big-eared bat maternity colonies. Jackson Endangered Species Office, United States Fish and Wildlife Service, Jackson, Mississippi.

Kendall MG. 1938. A new measure of rank correlation: Biometrika 30:81-93.

Kunz TH. 1982. Little brown bat (capture and census techniques). In: Davis DE (ed) Handbook of census methods for terrestrial vertebrates. CRC Press, Boca Raton, Florida, p 124-126.

Kunz TH. 2003. Censusing bats: challenges, solutions, and sampling biases. In: O'Shea TJ, Bogan MA (eds) Monitoring trends in bat populations of the United States and territories: problems and prospects. United States Geological Survey, Biological Resources Discipline, Information and Technology Report, USGS/BRD/ITR—2003-0003. p 9-19.

Kunz TH, Martin RA. 1982. *Plecotus townsendii.* Mamm Spec 175:1-6.

Mann HB. 1945. Nonparametric tests against trend. Econometrica 13:245-259.

Martin DB. 1992. Contaminant studies on endangered bats in northeastern Oklahoma. US Fish and Wildlife Service, Oklahoma Ecological Services Office, Tulsa, Oklahoma.

Martin KW, Puckette WL, Hensley SL, Leslie Jr. DM. 2000. Internal cave gating as a means of protecting cave-dwelling bat populations in eastern Oklahoma. Proc Okla Acad Sci 80:133-137.

Martin KW, Leslie Jr. DM, Payton ME, Puckette WL, Hensley SL. 2006. Impacts of passage manipulation on cave climate: conservation implications for cave-dwelling bats. Wildl Soc Bull 34(1):137-143.

Martin CO. 2007. Assessment of the population status of the gray bat *(Myotis grisescens)*: status, review, DOD initiatives, and results of a multi-agency effort to survey wintering populations at major hibernacula, 2005-2007. Publication Number ERDC/EL TR-07-22. Army Endangered Species Research Program, Engineer Research and Development Center, United States Army Corps of Engineers.

Mathews JR, Mosely CJ. 1990. Ozark big-eared bat: *Plecotus townsendii ingens*. In: Mathews JR, Mosely CJ (eds) The official World Wildlife Fund guide to endangered species of North America Walton Beacham Publishing, Inc., Washington, District of Columbia, p 527-529.

Medlin Jr. RE, Brandebura SC, Fokidis HB, Risch TS. 2006. Distribution of Arkansas' bottomland bats. Jour Ark Acad Sci 60:189-191.

Mistry S, McCracken G. 1990. Behavioural response of the Mexican free-tailed bat, *Tadarida brasiliensis mexicana*, to visible and infrared light. Animal Behav 39:598-599.

Newson SE, Mendes S, Crick HQP, Dulvy NK, Houghton JDR, Hays GC, Hutson AM, MacLeod CD, Pierce GJ, Robinson RA. 2009. Indicators of the impact of climate change on migratory species. End Spec Res 7:101-113.

Oklahoma Department of Commerce. 2002. Population projections for Oklahoma: 2000-2030. Oklahoma City, Oklahoma.

Pauly D. 1995. Anecdotes and the shifting baseline syndrome of fisheries. TREE 10(10):430.

Pearson OP, Koford MR, Pearson AK. 1952. Reproduction of the lump-nosed bat *(Corynorhinus rafinesquii)* in California. Journal of Mammalogy 33:273-320.

Piaggio AJ, Perkins SL. 2005. Molecular phylogeny of North American long-eared bats (Vespertilionidae: *Corynorhinus*); inter-and instraspecific relationships inferred from mitochondrial and nuclear DNA sequences. Mol Phylog Evol 37:762-775.

Prather JW, Briggler JT. 2003. Use of small caves by Ozark big-eared bats *(Corynorhinus townsendii ingens)* in Arkansas. American Midland Naturalist 148:193-197.

Rippy CL, Harvey MJ. 1965. Notes on *Plecotus townsendii virginianus* in Kentucky. Journal of Mammalogy 46:499.

Salmi T, Määttä A, Anttila P, Ruoho-Airola T, Amnell T. 2002 Detecting trends of annual values of atmos pheric pollutants by the Mann-Kendall Test and Sen's Slope Estimates—the Microsoft Corporation Excel 1997 template application MAKESENS. Publications on air quality. No. 31. Finnish Meteorological Institute, Helsinki, Finland. 34 pp.

Sasse DB. 2005. Pesticide residues in guano of gray bats *(Myotis grisescens)* in Arkansas. Jour Ark Acad Sci 59:214-217.

Sasse DB, Clawson RL, Harvey MJ, Hensley SL. 2007. Status of populations of the endangered gray bat in the western portion of its range. Southeastern Naturalist 6:165-172.

Sealander Jr. JA. 1951. Lump-nosed bat in Arkansas. Journal of Mammalogy 32:465.

Sen PK. 1968a. Estimates of the regression coefficient based on Kendall's tau. Jour Am Stat Assoc 63:1379-1389.

Sen PK. 1968b. On a class of aligned rank order tests in two-way layouts. Annals of Mathem Stat 39:1115-1124.

Thompson WL, White GC, Gowan C. 1998. Monitoring vertebrate populations. Academic Press, San Diego, California.

Tuttle M, Taylor D. 1998. Bats and mines. Resource Publication No. 3. Bat Conservation International, Inc., Austin, Texas.

Twente Jr. JW. 1955. Aspects of a population study of cavern-dwelling bats. Journal of Mammalogy 36(3):379-390.

United States Census Bureau. 2001. Census 2000 Brief - Population Change and Distribution: 1990 – 2000. CK2BR/01 – 2.

United States Environmental Protection Agency. 2006. Data quality assessment: statistical methods for practitioners. EPA QA/G-9S. Coopublished with the Office of Environmental Information, Washington, DC.

United States Fish and Wildlife Service. 1973. Threatened wildlife of the United States. United States Department of the Interior. Resource Publication No. 114.

United States Fish and Wildlife Service. 1977. Endangered and threatened wildlife and plants: proposed endangered listing and critical habitat determination for the Virginia and Ozark big-eared bats. Fed Reg 42(232):61290-61292.

United States Fish and Wildlife Service. 1979. Endangered and threatened wildlife and plants: listing of Virginia and Ozark big-eared bats as endangered species, and critical habitat determina tion. Fed Reg 44(232):69206-69208.

United States Fish and Wildlife Service. 1984. A recovery plan for the Ozark big-eared bat and the Virginia big-eared bat. Prepared by Bagley FM. United States Fish and Wildlife Service Region 3, Twin Cities, Minnesota.

United States Fish and Wildlife Service. 1995. Ozark big-eared bat *(Plecotus townsendii ingens* [Handley]) Revised Recovery Plan. Prepared by Hensley S, Scott C. Tulsa, Oklahoma.

United States Fish and Wildlife Service. 2008. Ozark big-eared bat *(Corynorhinus townsendii ingens)* 5-year review: summary and evaluation. Prepared by Stark R. Oklahoma Ecological Services Office, Tulsa, Oklahoma.

Wethington TA. 1994. Foraging activity, habitat use, and cave selection by the endangered Ozark Big-eared bat *(Plecotus townsendii ingens)*. MS thesis, Oklahoma State University, Stillwater, OK.

Wethington TA, Leslie Jr. DM, Gregory MS, Wethington MK. 1996. Prehibernation habitat use and foraging activity by endangered Ozark big-eared bats *(Plecotus townsendii ingens)*. American Midland Naturalist 134(2):218-230.

Wethington TA, Leslie Jr. DM, Gregory MS, Wethington MK. 1997. Vegetative structure and land use relative to cave selection by endangered Ozark big-eared bats *(Plecotus townsendii ingens)*. Southwestern Naturalist 42(2):177-181.

Weyandt SE, Van Den Bussche RA, Hamilton MJ, Leslie Jr. DM. 2005. Unraveling the effects of sex and dispersal: Ozark big-eared bat *(Corynorhinus townsendii ingens)* conservation genetics. Journal of Mammalogy 86(6):1136-1143.

Wilhide JD, McDaniel VR, Harvey MJ, White DR. 1998. Telemetric observations of foraging Ozark big-eared bats in Arkansas. Jour Ark Acad Sci 52:113-116.