FINAL REPORT

SECTION 6

ENDANGERED SPECIES ACT

OKLAHOMA DEPARTMENT OF WILDLIFE CONSERVATION

FEDERAL AID PROJECT E-3

BIOLOGY OF THREATENED AND ENDANGERED SPECIES IN OKLAHOMA

STUDY 2 - MICRO- AND MACROHABITAT CHARACTERISTICS OF CAVES WITHIN THE RANGE OF THE OZARK BIG-EARED BAT IN EASTERN OKLAHOMA

APRIL 1, 1989 - SEPTEMBER 30, 1991

FINAL REPORT

STATE: OKLAHOMA **PROJECT NUMBER:** E-3

PROJECT TITLE: Biology of Threatened and Endangered Species in Oklahoma

JOB NUMBER: 2

JOB TITLE: Micro- and Macrohabitat Characteristics of Caves within the Range of the Ozark Big-eared Bat in Eastern Oklahoma.

PERIOD COVERED: 1 April 1989-30 September 1991

ABSTRACT

Over 100 caves in the Boston Mountains of northeastern Oklahoma and northwestern Arkansas have been identified as potential roost sites for the endangered Ozark big-eared bat (Plecotus townsendii ingens). However, maternity colonies and/or hibernating clusters only are known to occur in 5 caves (1 solely used as a hibernaculum; 2 solely used as a maternity roost; and 2 used as both a maternity cave and hibernaculum). We initiated this study to determine internal and external characteristics of caves that may influence patterns of cave use by Ozark big-eared bats. We estimated numbers of bats at 19 caves, including maternity sites and hibernacula, during 7 visits to caves in 1989 and 1990. At least one Ozark big-eared bat was found in 17 of 19 caves during at least 1 of the 7 cave visits. Numbers of bats present in a cave on the same day ranged from 0-485 individuals. Numbers of adult females using the 4 maternity caves (AD-010, AD-013, AD-017, and AD-125) were estimated at 838 in 1989 and 852 in 1990. This represented a 17-47% increase in numbers of females using these 4 caves since 1987 (n = 714) and 1988 (n = 580; see Clark, 1991).

Ozark big-eared bats selected specific microsites in caves, apparently in response to variations in temperatures. During summer, maternity colonies were located in areas with cooler temperatures than those found at random points in the caves or near solitary individuals. Solitary bats usually occurred near cave entrances at microsites with warmer temperatures than those at random points in caves. Relative humidity was not correlated to patterns of cave use by bats during summer or winter.

Hibernating clusters of Ozark big-eared were found in the coldest caves and at the coldest locations in those caves during winter months. However, solitary bats were found at microsites with warmer temperatures than those at random cave points. Bats were more active than expected during winter and shifted among hibernacula. For example, numbers of bats using one hibernaculum varied from 485 in November 1989 to 242 in December 1989 to 413 in February 1990. Furthermore, several Ozark big-eared bats were alert during each winter visit.

We did not find any relationship between cave use by Ozark big-eared bats and percent cover of major land-use types within radii of 1.0-6.0 km of each cave. Furthermore, degree of cave use was not related to percent cover of land-use types within subdivisions of elevation (upland and lowland), slope (0-5%; 6-10%, and >10%), or unique combinations of elevation and slope for areas within a 3.0-km radius of each cave. Average distances from caves to buildings or ponds in 4 quadrants (northeast, southeast, southwest, and northwest) did not differ between maternity caves and unused caves in summer or hibernacula and unused caves in winter. Lastly, no relationship was found between degree of cave use by bats and total length of permanent lotic habitats (creek and river courses) within a 3.0-km radius of each cave.

I. OBJECTIVE NUMBER: 2

Determine microhabitat (within cave) and macrohabitat (among caves) characteristics of caves that are available (used and unused) to Ozark big-eared bats for maternity roosts and hibernacula.

II. INTRODUCTION

The Ozark big-eared bat (Plecotus townsendii ingens) is a small insectivorous bat endemic to the Ozark Plateau of northeastern Oklahoma, northwestern Arkansas, and southwestern Missouri (Barbour and Davis, 1969; Caire et al., 1989; Handley, 1955, 1959; Kunz and Martin, 1982; Schwartz and Schwartz, 1981; Sealander and Heidt, 1990). The first record of this subspecies for the state was observed in a cave in Adair County, Oklahoma (Glass, 1961). Recent cave searches have failed to document any Ozark big-eared bats in Missouri (D. Figg, pers. comm.) and numbers have decreased in Arkansas (M. J. Harvey, pers. comm.). This subspecies was listed as endangered in 1979, primarily due to its localized distribution, reduced population size, and susceptibility to human disturbance (Bagley, 1984). Since Ozark big-eared bats are dependent on caves throughout the year and seem to be unable to exploit buildings and other anthropogenic habitats, they are especially susceptible to population declines (Barbour and Davis, 1969; Harvey, 1976; Humphrey and Kunz, 1976).

Clark (1991) recently completed studies that focused on 3 primary facets in the life history of Ozark big-eared bats: (1) activity patterns at a hibernaculum and maternity cave throughout the year; (2) prey availability and diet selection; and (3) habitat use by foraging females during summer. Population trends also were monitored at hibernacula during winter and maternity caves during summer. In contrast to numbers of Ozark big-eared bats in Missouri and Arkansas, the population in Oklahoma remained stable, or may have increased slightly during the past five years. Throughout the 1980's and early 1990's, William L. Puckette searched Adair, Cherokee, and Delaware counties, Oklahoma, and Crawford, Newton, and Washington counties, Arkansas, for caves used by Ozark big-eared bats. No study has compared internal and external characteristics of caves to the extent of their use by Ozark big-eared bats. Therefore, we initiated this study to determine if caves used by Ozark big-eared bats as maternity roosts and/or hibernacula could be differentiated from those not used (or used by only a few individuals) based on quantitative microhabitat and macrohabitat parameters.

III. STUDY AREA

This study was conducted in the Boston Mountains of Adair, Delaware, and Cherokee counties, Oklahoma, and Crawford, Newton, and Washington counties, Arkansas. The Boston Mountains are a subdivision of the Ozark Mountains and occupy ca. 1,295 sq km along its southwestern face (Huffman 1959). Numerous streams dissect the Boston Mountains, eroding the horizontal layers of bedrock in all directions (Sealander and Heidt 1990). Limestone caves, talus slopes, and bluffs of exposed rock provide numerous roosting sites for bats.

Wide valleys with deep, mesic soils dissect the broad plateaus of the Boston Mountains. Dominant vegetation in uplands include blackjack oak (Quercus marilandica), post oak (Q. stellata), winged elm (Ulmus alata), and black hickory (Carya buckleyi). Silver maple (Acer saccharinum), cottonwood (Populus deltoides), sycamore (Plantanus occidentalis), and a variety of oaks (Quercus sp.) occur in the lowlands. Sugar maple (A. saccharum), white oak (Q. alba), chinquapin oak (Q. muhlenbergii), and redbud (Cercis canadensis) dominate the north-facing slopes, protected ravines, and seepage zones along bluffs. Eastern red cedar, (Juniperus virginianus), winged elm, and several oak species occur in shallow soils along exposed limestone and chert bluffs.

IV. METHODS

Cave Searches.--Suitable geologic formations in Adair, Delaware, and Cherokee counties, Oklahoma and Crawford, Newton, and Washington counties, Arkansas were searched for caves during summer months of 1989-1990.

Population Estimates and Microhabitat Parameters.--We selected 19 caves (18 in Adair County, Oklahoma and 1 in Delaware County, Oklahoma), including all known maternity sites and hibernacula, to search for Ozark big-eared bats. We also collected internal microhabitat data from the caves during each visit.

All 19 caves were visited 7 times. Numbers of bats using each cave were estimated and data for microhabitat characteristics were collected in June (maternity colony formation), August (maternity colony break-up), and November 1989 (autumn swarming and/or formation of hibernating clusters), as well as in February (hibernation), May (prior to maternity colony formation), June (maternity colony formation), and November 1990 (autumn swarming and/or formation of hibernating clusters). We also assisted with the annual winter bat census in December 1989 (an effort to monitor long-term population trends). Data were collected at 3-8 random points within each cave and in close proximity to solitary individuals and clusters of Ozark big-eared bats. Temperatures were recorded for the cave floor, 10 cm above the cave floor, midway between the floor and ceiling of the cave, 10 cm below the cave ceiling, and the cave ceiling. Percent relative humidity also was recorded midway between the floor and ceiling of the cave. Air flow was insufficient to measure.

Macrohabitat Parameters.--Location for each of the 19 caves was plotted on 7.5-minute USGS topographic maps and digitized into a geographic information system (GIS). We used large scale black and white and natural color aerial photographs to estimate land-use surrounding each cave. Our initial analyses examined land-use surrounding caves within concentric circles with radii varying from 1.0 km to 6.0 km. We tested for differences in mean area of each land-use type between maternity caves and unused caves in summer and between hibernacula and unused caves in winter for the area encompassed by each concentric circle. Caves not used as a maternity site or hibernaculum were classified as unused, although occasional bats sometimes were present.

Eight major land-use categories were identified: (1) buildings and farmsteads; (2) cropfields; (3) orchards and nurseries; (4) rangeland; (5) rangeland with >35% groundcover of brush; (6) bottomland hardwoods in riparian areas; (7) forestland of shortleaf pine and oak (mixed stands) or oak-hickory dominated woodlands (>70% deciduous); and (8) water. Data for land-use were digitized into GIS for summary statistics.

The 18 caves in Adair County occur within a localized area (ca. 16 km by 27 km) and large concentric circles (radii of 4.0-6.0 km) used in the first analysis overlapped. We used a 3.0-km radius about each cave in later analyses to reduce overlap. Because 3.0 km is slightly less than the average distance traveled by females to foraging areas during late lactation (Clark 1991) we also could determine habitat availability to foraging bats more precisely. We deleted 4 caves infrequently used by Ozark big-eared bats from these later analyses of land-use to further reduce the degree of overlap between nearby caves. However, we included macrohabitat data for 2 additional caves that were further apart and infrequently used by Ozark big-eared bats to maintain adequate sample size for comparisons.

In addition to land-use, elevation and percent slope within a 3.0-km radius around each cave were digitized into GIS. We partitioned elevation into 2 classes, above (uplands) and below (lowlands) the elevation of caves. These data were unique for each cave as elevation and patterns of topographic relief were site specific. Percent slope was subdivided into 3 classes: (1) 0%-5%; (2) 6%-10%; and (3) >10%. We also estimated distances to nearest building and pond in 4 quadrants (northeast, southeast, southwest, and northwest) surrounding each cave and length of lotic habitats (creek and river courses) within a 3.0-km radius of each cave. Land-use, elevation, and slope data were referenced to a Universal Transverse Mercator grid system with a spatial resolution of 4 ha. Therefore, each 4-ha square would be assigned to the most prevalent habitat type (regardless if it comprised 25% or 75% of the square).

V. RESULTS

Cave Searches.--We found over 30 new caves and/or shelters in Adair and Delaware counties, Oklahoma during June, July, and August 1989 that may be used by bats. Solitary Ozark big-eared bats were found at 2 (AD-206 and AD-211) of these new sites.

During June, July, and August 1990, over 20 new caves and/or shelters with signs of Ozark big-eared bats were found in Adair and Delaware counties, Oklahoma and Crawford, Newton, and Washington counties, Arkansas. Ozark big-eared bats were found at 6 of these new sites (Oklahoma: AD-215; Arkansas: CW-2365, CW-2367, WA-3203, WA-3215, and WA-3302).

Population Estimates and Microhabitat Parameters.--During June 1989, we recorded 897 Ozark big-eared bats in the 19 caves (Table 1). We estimated that 838 bats were using the 4 maternity caves (AD-010, AD-013, AD-017, and AD-125), 218 more bats than the estimate in 1988. A large cluster of 40 bats (including males) and 15 additional bats were found in AD-003 (a hibernaculum). In addition to these 5 caves, solitary Ozark big-eared bats were found in 4 other caves. Solitary individuals occurred at sites with warmer temperatures than that of sites used as maternity roosts or at random points (Duncan's multiple-range test, $P < 0.05$; Table 2). Mean temperatures for all heights (floor to ceiling) at maternity clusters were not different from sites with no bats ($P > 0.05$). Relative humidity was similar among sites used by solitary bats, maternity clusters, and random points .

During August 1989, 782 Ozark big-eared bats were observed in the 19 caves (Table 1). Numbers of bats had markedly increased at AD-010 and AD-017, probably due to natality. The maternity cluster at AD-013 had disbanded; because we did not video-tape emergence, no estimate could be made for bats using AD-125. Solitary bats occurred at warmer locations than maternity clusters or random points (Duncan's multiple-range test, $P < 0.05$; Table 3). Mean percent relative humidity at sites used by solitary bats and maternity clusters was not different from that of random points ($P > 0.05$).

We found 746 bats in the 19 caves in November 1989 (Table 1). We estimated that 485 bats were using AD-003, more than 200 over the previous high of 268 bats recorded in December 1987. We also found 83 bats in AD-010 and 170 bats in AD-016. Bats could not be counted at AD-125 as hibernating clusters typically occur behind a break-down area. Hibernating clusters occurred in caves with the coldest range of temperatures and at the coldest temperatures within these caves (Duncan's multiple-range test, $P < 0.05$; Table 4). Percent relative humidity did not differ among sites used by solitary bats, hibernating clusters, and random points ($P > 0.05$).

We recorded 249 bats in December 1989 (Table 1). Numbers in AD-003 dropped from 485 in November to 242 in December, only a single bat was found in AD-010, and no bats were found in AD-016. No microclimate data were collected during this census as different researchers conducted the December survey over a 2-week period.

During the census in February 1990, we recorded 509 individuals with bats occurring in 11 of 19 caves (Table 1). Numbers in AD-003 increased from 242 in December 1989 to 413 in February 1990 and numbers in AD-010 were similar to those in November 1989. Hibernating clusters of bats occurred at the coldest sites within each cave and mean temperatures at these sites were colder than that for random points and sites used by solitary individuals (Duncan's multiple-range test, $\underline{P} < 0.05$; Table 5). Percent relative humidity was similar among sites used by hibernating clusters, solitary individuals, and random points ($\underline{P} > 0.05$).

During May 1990, we observed 886 Ozark big-eared bats in the 19 caves (Table 1). We estimated that 586 bats were using the 4 maternity caves (AD-010, AD-013, AD-017, and AD-125). An additional 66 bats were using AD-018 at this time; AD-018 is an alternative maternity site when AD-017 is not used. More than 100 bats (including males) were found in AD-003 (a hibernaculum). A large aggregation of bats was found in AD-16. We believe that this cave is used as a transient roost for swarming before the formation of maternity colonies in summer and hibernating groups in late autumn. No significant differences were noted among random points, solitary bats, and large clusters of bats for ambient temperatures, surface temperatures, or relative humidity (Duncan's multiple-range test; $\underline{P} > 0.05$; Table 6). This was due in part to the variety of sites used by large clusters of bats. For example, many of the bats in AD-003 and a cool region of AD-010 were torpid and had curled ears, whereas other large aggregations, especially those in maternity caves, were more alert and active than those in hibernacula.

During June 1990, 872 Ozark big-eared bats were observed in the 19 caves (Table 1). Fourteen more females were at the 4 maternity caves in 1990 ($\underline{n} = 852$) compared to 1989 ($\underline{n} = 838$). Numbers of bats using AD-003, AD-016, and AD-018 had decreased between May and June 1990. Maternity clusters occurred at cooler portions of the caves than random points, or at sites with solitary bats (Duncan's multiple-range test; $\underline{P} < 0.05$; Table 7). No significant differences ($\underline{P} > 0.05$) were noted for the mean relative humidity at random points, solitary bats, and large clusters of bats. Maternity clusters typically occurred in mid to deep cave zones, whereas solitary individuals were found near the cave entrance (often in the twilight zone).

We found 622 bats in the 19 caves during our census in November 1990 (Table 1), 124 less than we found in November 1989. We estimated that 343 bats were using AD-003, 142 less than that found in November 1989. We also found 154 bats in AD-016 and 118 bats in AD-010. No estimate could be made for AD-125 as the chamber used as a hibernation site occurs behind a break-down area. Solitary individuals occurred at the warmest points of each cave, often near the cave entrance, and at significantly higher temperatures than found near hibernating clusters of bats (Duncan's multiple-range test; $\underline{P} < 0.05$; Table 8). Temperatures at random points were intermediate between those for solitary individuals and hibernating clusters. Hibernating clusters were found at the coldest points in the coldest caves. Percent relative humidity did not significantly differ ($\underline{P} > 0.05$) among sites used by solitary bats, hibernating clusters, and random points.

Macrohabitat Parameters.--Mean hectares of each land-use type for maternity caves and unused caves in summer are listed in Table 9. No significant difference (Duncan's multiple-range test; $\underline{P} > 0.05$) was noted between maternity and nonmaternity caves for any comparison of mean number of hectares for each land-use type within the six concentric circles (1.0-6.0 km radii) encompassing these caves. Forested areas comprised the largest portion (>50%) of each concentric circle around maternity and nonmaternity caves.

Mean hectares of each land-use type for hibernacula and unused caves in winter are listed in Table 10. No significant difference (Duncan's multiple-range test; $\underline{P} > 0.05$) was noted between hibernacula and caves not used as hibernacula for any comparison of mean hectares for each land-use type within the six concentric circles surrounding these caves. Forested habitats comprised >50% of the total area in each concentric circle surrounding hibernacula and caves not used as hibernacula.

The area encompassed by a 3.0-km radius is 2836 ha. Percent land-use for maternity sites and unused caves in summer and hibernacula and unused caves in winter are listed in Table 11. No difference was noted for any pairwise comparison of percent coverage for any land-use type for maternity caves and unused caves in summer (Duncan's multiple-range test, $\underline{P} > 0.05$). Likewise, no difference was noted for any land-use type when hibernacula were compared to unused caves during winter ($\underline{P} > 0.05$). Distances to nearest building and pond in each quadrant, or all quadrants combined, were not significantly different between maternity caves and unused caves during summer, or between hibernacula and unused caves during winter (Mann-Whitney $\underline{U}$-test, $\underline{P} > 0.05$; Table 12). Additionally, length of permanent creek and river courses within 3.0 km of caves were not different between maternity caves and unused caves in summer, or between hibernacula and unused caves in winter (Mann-Whitney $\underline{U}$-test, $\underline{P} > 0.05$; Table 12).

We examined differences in percent land-use between used and unused sites for upland and lowland areas. No significant difference was noted for any land-use class when maternity sites were compared to unused sites for either upland or lowland areas (Duncan's multiple-range test, $\underline{P} > 0.05$; Table 13). Similarly, no difference in percent land-use was found for any land-use class in uplands or lowlands when hibernacula were compared to unused sites ($\underline{P} > 0.05$; Table 14).

We tested for differences between used and unused caves for percent of total area in 3 slope categories for uplands and lowlands. No significant differences were found between maternity caves and unused caves during summer, or between hibernacula and unused caves during winter when pairwise comparisons were made for the percent of total area in each slope class (Duncan's multiple-range test, $\underline{P} > 0.05$; Table 15).

We also examined the interaction among elevation, slope, and land-use. We subdivided the data into 48 cells (8 land-use classes, 3 slope classes, and 2 elevations classes) to test for differences between unused and used caves during summer and winter. Only one significant difference was noted between maternity caves and unused caves. Percent of brushy rangeland in upland areas with slopes >10% was greater for maternity than unused caves (Duncan's multiple-range test, $\underline{P} < 0.05$). Similarly, only one significant difference was noted between hibernacula and unused sites. Percent of rangeland in lowland areas with >10% slopes was greater for hibernacula than caves not used in winter ($\underline{P} < 0.05$).

VI. DISCUSSION

Population Status.--We found at least one Ozark big-eared bat in 17 of 19 caves during this study. Numbers of Ozark big-eared bats using the 4 maternity caves were stable, or slightly increased, when compared to data from 1987 and 1988 (see Clark 1991). From November 1989 to November 1990, total numbers of bats using 2 hibernacula (bats in the third hibernaculum roost behind a break-down area and could not be counted) decreased from 568 to 461; however, numbers increased in one hibernaculum (AD-010), but decreased in the other (AD-003). Numbers of bats using AD-003 increased from 242, 268, and 235 in December 1986, 1987, and 1988 (Clark, 1991), respectively, to 485 and 343 in November 1989 and 1990, respectively. We were surprised to find only 242 bats in AD-003 in December 1989, when only 3-4 weeks earlier (November 1989) we found 485 bats and in February 1990 (6-7 weeks later) we counted 413 bats in this cave. This suggests that Ozark big-eared bats are more active in winter than expected.

One Ozark big-eared bat observed in AD-003 on 23 November 1990 was tagged with a green band. Seventeen (6 males and 11 females) Ozark big-eared bats were marked with green bands on 23 July 1981 at AD-010 (W. L. Puckette, pers. comm.). On five other occasions, bats with green bands were observed in caves other than AD-010 (2 in AD-003 on 31 December 1981; 1 in AD-002 on 23 May 1983; 1 in AD-003 on 23 December 1983; 1 in AD-003 on 26 December 1985; W. L. Puckette, pers. comm). AD-003 is ca. 7.0 km northwest of AD-010 and AD-002 is ca. 100 m north of AD-003.

Microhabitat Parameters.--Microclimate of roosts influences fetal and juvenile development, as well as overwintering success (see Humphrey, 1975) and we expected that Ozark big-eared bats would select specific roost sites within caves. However, we were surprised to find maternity clusters at cave locations with cooler temperatures than noted at random points, or near solitary bats. Adult females in late pregnancy and juvenile bats are poor thermoregulators (Studier and O'Farrell, 1972). Therefore, bats roosting in suboptimal temperatures have slower rates of fetal and neonatal growth and any delay in maturation of young may reduce their survival and/or natality (Humphrey, 1975). During winter, hibernating clusters of bats occurred at the coldest points in the coldest caves. Temperatures of hibernating bats are influenced by substrate temperature (McNab, 1974). Therefore, bats must select sites with temperatures sufficiently low to ensure the reduced metabolic rate will not exhaust fat reserves before hibernation is over (Humphrey, 1978). We did not find any relationship between patterns of cave use and relative humidity. Roosting behavior of Indiana bats (*Myotis sodalis*) during winter also was not influenced by relative humidity (Clawson et al., 1980). Temperatures and relative humidities we recorded near maternity and hibernating clusters were similar to those reported by Harvey (1986) for Ozark big-eared bats in Arkansas.

Macrohabitat Parameters.--We found no significant differences in land-use patterns between maternity caves and unused caves during summer and between hibernacula and unused caves during winter. This surprised us because Raesly and Gates (1987) found that both macrohabitat and microhabitat data were necessary to predict patterns of cave use by bats. Our inability to detect differences between used and unused caves may be the result of several, nonexclusive explanations. First, the scale of our analysis (4-ha resolution) may be insufficient to identify land-use patterns that influence cave use by Ozark big-eared bats. Second, vegetative parameters (composition, density, and vertical structure) surrounding cave entrances may be more important characteristics in cave selection by bats than overall land-use patterns. The presence of trees, shrubs, and herbaceous vegetation influences solar radiation striking cave entrances and air flow within caves. Third, not all suitable caves are currently being used for maternity sites or hibernacula due to the small population size. Last, patterns of cave use by Ozark big-eared bats may be more influenced by internal than external parameters.

VII. MANAGEMENT RECOMMENDATIONS

Our study suggests that the current status of Ozark big-eared bats in the Boston Mountains of northeastern Oklahoma and northwestern Arkansas is stable. However, loss of a single maternity cave or hibernaculum, due to human disturbance or cave collapse, may result in a population reduction of $\geq$20%. Therefore, human activity in known maternity caves and hibernacula should be limited to yearly censuses of bats (unless warranted to collect data important to the recovery of this subspecies).

The continued search for new caves that may serve as hibernacula and/or maternity sites should be continued. This is especially important given the differences in numbers of bats in summer and winter. For example, we estimated 852 adult females occurred in the four maternity caves during June 1990. If we assume equal numbers of adults males and females, the population size would be ca. 1700 bats (excluding recruitment of juveniles). However, we only found 622 bats (both males and females) during the census in November 1990, ca. 37% of that expected based on summer estimates. Ozark big-eared bats apparently are using caves, or sites within caves, that we have not found.

An analysis of vegetation surrounding all 19 caves is needed to assess for differences between used and unused caves. A smaller scale of resolution may reveal habitat differences and provide more insight on patterns of cave use by Ozark big-eared bats than did our large-scale analyses of landscape patterns and habitat coverage. This data also may reveal the impact that clearing nearby vegetation has on internal microclimates of caves.

Because Ozark big-eared bats used specific microsites within caves during both summer and winter, we urge caution when considering gating and/or fencing to reduce human access to caves. Roost temperatures appeared to be an important factor in microsite selection within caves. The construction of gates and/or fences may change patterns of air flow and, therefore, alter microclimates within the caves (see Bagley, 1984; Humphrey, 1978). Further, presence of gates may increase rates of predation as bats circle in front of the cave before entering (Tuttle, 1977; 1979).

Finally, the continued degradation of habitat on privately-owned lands needs to be addressed. Trees and other vegetation are being cleared near cave entrances and foraging sites, impacting both external and internal cave environments. Areas surrounding maternity caves, hibernacula, and other caves used by large aggregations of Ozark big-eared bats (e.g., transient roost caves) should be purchased or lease agreements should be established with landowners to prevent deleterious land-use practices.

VIII. PREPARED BY ______________________

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IX. DATE 15 November 1991

X. APPROVED BY ______________________

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Table 1. Numbers of Ozark big-eared bats observed by cave and month.

	1989				1990			
Cave	Jun	Aug	Nov	Dec	Feb	May	Jun	Nov
AD-003	55	0	485	242	413	106	12	343
AD-010	239[a]	402	83	1	74	185	274[a]	118
AD-012	1	0	1	0	1	0	2	1
AD-013	148[a]	10	1	1	0	125	137[a]	0
AD-015	0	0	0	3	5	0	0	1
AD-016	0	0	170	0	8	121	0	154
AD-017	175[a]	363	1	0	0	131	132[a]	1
AD-018	0	0	0	0	1	66	3	0
AD-025	0	0	0	0	2	0	1	0
AD-029	1	0	0	1	2	2	1	0
AD-051	0	1	1	0	0	1	0	1
AD-118	0	0	0	0	0	0	0	0
AD-125	276[a]	-[b]	-[b]	-[b]	-[b]	145[c]	309[a]	-[b]
AD-127	0	0	0	-[d]	1	0	0	0
AD-134	1	0	1	-[d]	1	1	0	0
AD-142	0	1	0	1	1	1	1	1
AD-167	1	0	3	0	0	2	0	0
AD-186	0	0	0	0	0	0	0	0
DL-21	0	5	0	0	0	0	0	2
Total	897	782	746	249	509	886	872	622

[a]Numbers estimated from viewing video tapes of emergence.
[b]Maternity and hibernating roosts occur behind a break-down area and numbers of bats could not be estimated.
[c]Bats occurred in cave in front of a break-down area.
[d]Caves not visited during annual count in December.

Table 2. Mean ambient and surface temperatures (^{o}C) and relative humidity (%) at locations within caves during June 1989.

	Mean[1]	SD	Minimum	Maximum	CV
No Bats					
Floor surface	13.9[b]	2.0	9.1	18.9	14.2
Floor ambient	14.5[b]	2.2	9.3	21.2	15.0
Midpassage ambient	15.8[b]	2.6	9.6	22.0	16.4
Ceiling ambient	16.3[b]	2.9	9.9	23.5	17.6
Ceiling surface	14.7[b]	2.3	9.0	19.4	15.6
Relative humidity	92.4[a]	3.3	85.0	98.0	3.5
Solitary Bats (<15 individuals)					
Floor surface	17.3[a]	1.8	15.2	18.9	10.3
Floor ambient	18.5[a]	2.4	15.9	21.2	12.8
Midpassage ambient	21.9[a]	2.3	18.9	24.4	10.4
Ceiling ambient	21.2[a]	1.5	19.5	22.7	7.2
Ceiling surface	19.3[a]	0.6	18.7	20.1	3.1
Relative humidity	90.5[a]	3.5	87.0	94.0	3.9
Maternity Clusters (≥15 individuals)					
Floor surface	12.8[b]	0.8	12.2	14.0	6.6
Floor ambient	13.4[b]	1.0	12.5	14.8	7.6
Midpassage ambient	13.9[b]	1.6	12.8	16.3	11.6
Ceiling ambient	13.7[b]	1.5	12.8	15.9	10.7
Ceiling surface	13.1[b]	1.4	12.1	15.1	10.6
Relative humidity	92.0[a]	1.8	90.0	94.0	2.0

[1]Means for each variable followed by the same letter not significantly different ($\underline{P} > 0.05$) among no bats, solitary bats, and maternity clusters.

Table 3. Mean ambient and surface temperatures (^{o}C) and relative humidity (%) at locations within caves during August 1989.

	Mean[1]	SD	Minimum	Maximum	CV
No Bats					
Floor surface	14.8[a]	2.1	9.5	19.5	14.0
Floor ambient	16.1[a]	2.2	10.7	20.5	13.7
Midpassage ambient	17.1[ab]	2.5	11.7	21.9	14.4
Ceiling ambient	17.3[ab]	2.6	11.2	21.9	14.8
Ceiling surface	15.6[ab]	2.4	10.0	20.4	15.1
Relative humidity	92.0[a]	3.0	85.0	98.0	3.3
Solitary Bats (<15 individuals)					
Floor surface	15.5[a]	0.4	15.1	15.9	2.6
Floor ambient	16.9[a]	0.7	16.3	17.7	4.4
Midpassage ambient	17.8[a]	0.5	17.2	18.1	2.9
Ceiling ambient	17.9[a]	1.3	16.4	18.9	7.4
Ceiling surface	16.3[a]	2.0	14.6	18.5	12.4
Relative humidity	91.3[a]	1.5	90.0	93.0	1.7
Maternity Clusters (≥15 individuals)					
Floor surface	13.1[a]	1.6	12.1	15.5	12.2
Floor ambient	14.7[a]	2.2	13.4	18.0	15.0
Midpassage ambient	14.6[b]	1.4	13.6	16.7	9.7
Ceiling ambient	14.5[b]	1.6	12.9	16.6	11.0
Ceiling surface	13.0[b]	1.0	12.0	14.4	7.9
Relative humidity	91.0[a]	4.5	86.0	97.0	5.0

[1]Means for each variable followed by the same letter not significantly different (*P* > 0.05) among no bats, solitary bats, and maternity clusters.

Table 4. Mean ambient and surface temperatures (^{o}C) and relative humidity (%) at locations within caves during November 1989.

	Mean[1]	SD	Minimum	Maximum	CV
No Bats					
Floor surface	12.1[a]	1.4	9.5	16.8	11.6
Floor ambient	12.4[a]	1.5	10.0	17.5	12.4
Midpassage ambient	13.4[a]	1.5	10.6	18.1	10.9
Ceiling ambient	13.3[a]	1.4	10.8	18.0	10.9
Ceiling surface	12.8[a]	1.4	9.7	17.0	11.0
Relative humidity	92.5[a]	4.0	79.0	98.0	4.3
Solitary Bats (<15 individuals)					
Floor surface	11.5[a]	0.7	10.5	12.5	6.2
Floor ambient	11.9[a]	0.6	11.3	13.0	5.1
Midpassage ambient	12.9[a]	0.6	12.2	13.6	4.6
Ceiling ambient	12.9[a]	0.6	12.3	13.7	4.3
Ceiling surface	12.4[a]	0.7	11.5	13.5	5.3
Relative humidity	93.5[a]	3.3	87.0	97.0	3.5
Hibernating Clusters (≥15 individuals)					
Floor surface	9.3[b]	0.8	8.5	10.6	8.3
Floor ambient	9.6[b]	0.9	8.6	11.0	9.8
Midpassage ambient	9.7[b]	0.8	8.8	10.6	8.3
Ceiling ambient	10.0[b]	1.0	9.2	11.5	9.5
Ceiling surface	9.8[b]	0.9	8.9	11.0	8.8
Relative humidity	93.3[a]	0.8	93.0	95.0	0.9

[1]Means for each variable followed by the same letter not significantly different ($P > 0.05$) among no bats, solitary bats, and maternity clusters.

Table 5. Mean ambient and surface temperatures (°C) and relative humidity (%) at locations within caves during February 1990.

	Mean[1]	SD	Minimum	Maximum	CV
No Bats					
Floor surface	10.6[a]	0.8	8.6	12.8	7.7
Floor ambient	10.8[a]	1.0	7.2	12.9	9.1
Midpassage ambient	11.3[a]	0.9	9.3	13.6	7.9
Ceiling ambient	11.4[a]	0.9	9.5	13.7	7.9
Ceiling surface	10.8[a]	0.8	9.1	12.9	7.7
Relative humidity	90.2[a]	3.8	78.0	98.0	4.3
Solitary Bats (<15 individuals)					
Floor surface	11.1[a]	0.5	10.5	12.3	4.4
Floor ambient	11.4[a]	0.5	10.8	12.5	4.6
Midpassage ambient	12.0[a]	1.0	11.0	13.9	8.1
Ceiling ambient	12.1[a]	0.9	11.0	13.8	7.6
Ceiling surface	11.3[a]	0.5	10.7	12.2	4.2
Relative humidity	92.0[a]	3.8	85.0	97.0	4.2
Hibernating Clusters (≥15 individuals)					
Floor surface	5.9[b]	1.7	5.1	8.9	27.9
Floor ambient	6.1[b]	1.6	5.3	9.0	26.4
Midpassage ambient	6.4[b]	1.4	5.5	9.0	22.5
Ceiling ambient	6.4[b]	1.3	5.8	8.8	20.5
Ceiling surface	6.1[b]	1.3	5.5	8.5	21.5
Relative humidity	88.2[a]	2.6	84.0	91.0	2.9

[1]Means for each variable followed by the same letter not significantly different ($P > 0.05$) among no bats, solitary bats, and maternity clusters.

Table 6. Mean ambient and surface temperatures (°C) and relative humidity (%) at locations within caves during May 1990.

	Mean[1]	SD	Minimum	Maximum	CV
No Bats					
Floor surface	11.7[a]	1.3	8.1	14.5	10.8
Floor ambient	12.2[a]	1.3	9.0	15.3	10.6
Midpassage ambient	13.4[a]	2.0	10.3	21.1	14.6
Ceiling ambient	13.4[a]	1.6	9.6	17.3	12.3
Ceiling surface	12.3[a]	1.3	8.3	15.1	10.9
Relative humidity	86.2[a]	6.2	72.0	97.0	7.2
Solitary Bats (<15 individuals)					
Floor surface	11.6[a]	2.1	8.0	13.1	18.1
Floor ambient	12.2[a]	1.7	9.4	13.5	13.8
Midpassage ambient	13.4[a]	1.8	10.6	15.0	13.5
Ceiling ambient	13.4[a]	2.2	9.6	14.8	16.5
Ceiling surface	12.2[a]	2.1	8.6	13.9	16.9
Relative humidity	88.2[a]	6.7	78.0	96.0	7.6
Large Clusters of Bats (≥15 individuals)					
Floor surface	10.8[a]	1.4	8.3	12.3	13.2
Floor ambient	11.3[a]	1.3	9.3	12.6	11.1
Midpassage ambient	12.1[a]	1.3	9.7	13.8	11.1
Ceiling ambient	12.0[a]	1.4	9.5	13.5	12.0
Ceiling surface	11.3[a]	1.5	8.4	12.9	13.5
Relative humidity	88.7[a]	3.2	83.0	94.0	3.7

[1]Means for each variable followed by the same letter not significantly different ($\underline{P} > 0.05$) among no bats, solitary bats, and maternity clusters.

Table 7. Mean ambient and surface temperatures (^{o}C) and relative humidity (%) at locations within caves during June 1990.

	Mean[1]	SD	Minimum	Maximum	CV
No Bats					
Floor surface	14.3[ab]	2.3	9.2	21.0	16.1
Floor ambient	15.0[ab]	2.4	10.6	22.1	15.8
Midpassage ambient	16.4[ab]	3.0	10.2	24.3	18.3
Ceiling ambient	16.5[a]	2.9	10.1	23.9	17.8
Ceiling surface	15.0[ab]	2.7	9.5	21.4	18.0
Relative humidity	89.5[a]	5.0	77.0	97.0	5.6
Solitary Bats (<15 individuals)					
Floor surface	15.1[a]	1.7	12.8	17.6	10.9
Floor ambient	15.7[a]	1.9	12.9	18.6	12.1
Midpassage ambient	17.4[a]	2.1	15.2	21.4	12.2
Ceiling ambient	17.5[a]	1.7	15.9	20.6	9.5
Ceiling surface	15.8[a]	1.5	14.4	18.3	9.4
Relative humidity	88.0[a]	5.6	77.0	94.0	6.4
Maternity Clusters (≥15 individuals)					
Floor surface	12.6[b]	0.7	11.7	13.4	5.6
Floor ambient	12.9[b]	0.4	12.4	13.3	3.4
Midpassage ambient	14.0[b]	0.7	13.1	14.9	5.3
Ceiling ambient	13.8[b]	1.0	12.9	15.1	7.1
Ceiling surface	12.9[b]	0.6	12.5	13.7	4.5
Relative humidity	89.3[a]	4.0	86.0	95.0	4.5

[1]Means for each variable followed by the same letter not significantly different ($\underline{P} > 0.05$) among no bats, solitary bats, and maternity clusters.

Table 8. Mean ambient and surface temperatures (^{o}C) and relative humidity (%) at locations within caves during November 1990.

	Mean[1]	SD	Minimum	Maximum	CV
No Bats					
Floor surface	11.3[a]	1.0	9.5	14.5	9.3
Floor ambient	11.8[a]	1.1	9.8	14.9	9.1
Midpassage ambient	12.8[a]	1.1	10.4	16.4	8.5
Ceiling ambient	12.8[a]	1.2	10.6	16.2	9.2
Ceiling surface	11.7[a]	1.4	9.8	19.7	12.3
Relative humidity	86.2[a]	6.2	71.0	98.0	7.2
Solitary Bats (<15 individuals)					
Floor surface	11.9[a]	0.4	11.4	12.5	3.5
Floor ambient	12.4[a]	0.4	11.6	12.9	3.3
Midpassage ambient	13.4[a]	0.8	12.5	15.1	6.1
Ceiling ambient	13.4[a]	0.7	12.8	14.9	5.6
Ceiling surface	12.2[a]	0.5	11.5	13.1	4.3
Relative humidity	90.7[a]	8.0	76.0	97.0	8.8
Hibernating Clusters (≥15 individuals)					
Floor surface	7.1[b]	2.0	5.5	10.1	28.1
Floor ambient	7.3[b]	1.8	5.9	10.5	24.9
Midpassage ambient	8.2[b]	2.3	6.2	11.5	27.7
Ceiling ambient	7.6[b]	2.7	5.6	12.0	34.8
Ceiling surface	7.3[b]	2.6	5.2	11.6	35.3
Relative humidity	86.9[a]	2.1	83.0	89.0	2.4

[1]Means for each variable followed by the same letter not significantly different ($\underline{P} > 0.05$) among no bats, solitary bats, and maternity clusters.

Table 9. Mean land-use (ha) for a habitats within a 1.0, 2.0, 3.0, 4.0, 5.0, and 6.0-km radius about maternity caves and unused caves during summer.

	Radius About Cave (km)					
Land-use	1.0	2.0	3.0	4.0	5.0	6.0
Maternity						
Buildings	0.0	0.0	3.2	7.2	19.6	31.6
Cropfields	0.0	1.6	2.4	3.2	7.2	16.0
Orchards	0.0	0.0	4.8	48.8	72.0	80.8
Rangeland	8.0	42.4	113.6	171.6	245.4	407.6
Rangeland[a]	60.8	346.4	1032.8	1892.0	2930.4	4385.6
Hardwoods[b]	1.6	12.0	24.0	32.0	52.0	79.2
Forest[c]	252.0	864.0	1628.0	2834.2	4467.6	6439.2
Water	1.6	1.6	26.4	39.2	55.2	79.2
Nonmaternity						
Buildings	0.6	22.6	59.9	98.9	108.5	112.9
Cropfields	0.0	5.4	6.9	12.9	24.3	43.4
Orchards	0.0	7.7	26.9	61.7	84.3	102.3
Rangeland	20.1	86.9	162.4	272.1	385.5	600.3
Rangeland[a]	79.4	332.3	820.0	1550.6	2405.1	3547.7
Hardwoods[b]	0.6	4.9	14.0	32.3	51.4	77.1
Forest[c]	223.5	802.9	1707.3	2958.9	4719.4	6923.1
Water	0.0	2.6	8.9	12.0	35.2	72.4

[a]Rangeland with >35% groundcover of brush.
[b]Bottomland hardwoods in riparian habitats.
[c]Forestland with shortleaf pine and oak (mixed stands) and oak-hickory dominated woodlands (>70% deciduous).

Table 10. Mean land-use (ha) for a habitats within a 1.0, 2.0, 3.0, 4.0, 5.0, and 6.0-km radius about hibernacula and unused caves during winter.

	Radius About Cave (km)					
Land-use	1.0	2.0	3.0	4.0	5.0	6.0
Hibernacula						
Buildings	0.0	2.7	5.3	9.3	24.7	28.7
Cropfields	0.0	0.0	1.3	2.7	6.7	16.0
Orchards	0.0	0.0	6.7	24.0	24.0	37.3
Rangeland	0.0	6.7	32.0	67.3	130.3	324.7
Rangeland[a]	65.3	264.0	826.7	1588.0	2420.0	3593.3
Hardwoods[b]	0.0	1.3	6.7	16.0	44.0	80.0
Forest[c]	258.7	986.7	1926.7	3289.0	5163.3	7381.0
Water	0.0	6.7	30.7	32.0	40.0	61.3
Nonhibernacula						
Buildings	0.6	19.3	52.4	87.1	96.4	103.3
Cropfields	0.0	5.3	6.5	11.8	22.3	40.0
Orchards	0.0	6.8	23.8	64.8	91.8	107.8
Rangeland	20.1	88.1	171.6	279.1	389.6	591.8
Rangeland[a]	76.3	349.5	885.3	1650.3	2566.5	3801.0
Hardwoods[b]	1.0	7.8	18.5	35.3	53.0	77.3
Forest[c]	225.8	787.6	1641.6	2858.1	4557.4	6685.9
Water	0.5	1.5	10.3	16.8	40.6	76.6

[a]Rangeland with >35% groundcover of brush.
[b]Bottomland hardwoods in riparian habitats.
[c]Forestland with shortleaf pine and oak (mixed stands) and oak-hickory dominated woodlands (>70% deciduous).

Table 11. Mean percent land-use for a habitats within a 3.0-km radius about maternity caves and hibernacula and unused caves during summer and winter, respectively.

	Maternity		Unused Summer		Hibernacula		Unused Winter	
Land-use	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Buildings	0.1	0.1	2.8	5.9	0.2	0.2	2.5	5.6
Cropfields	0.1	0.1	0.3	0.6	0.0	0.1	0.2	0.5
Orchards	0.2	0.3	1.3	2.8	0.2	0.4	1.2	2.7
Rangeland	4.7	6.7	6.4	8.2	1.1	1.6	7.1	8.1
Rangeland[a]	34.7	16.8	24.9	19.1	28.4	15.0	27.1	19.8
Hardwoods[b]	0.2	0.4	2.3	6.7	0.3	0.6	2.1	6.5
Forest[c]	59.4	22.3	61.5	24.7	68.5	17.3	59.2	24.8
Water	0.6	1.2	0.6	1.3	1.1	1.9	0.5	1.1

[a]Rangeland with >35% groundcover of brush.
[b]Bottomland hardwoods in riparian habitats.
[c]Forestland with shortleaf pine and oak (mixed stands) and oak-hickory dominated woodlands (>70% deciduous).

Table 12. Average distance (km) to the nearest building and pond in each of 4 quadrants (NE = 0-90°; SE = 91-180°; SW = 181-270°; and NW = 271-360°) surrounding each cave and length (km) of permanent lotic habitats (creeks and stream courses) within a 3.0-km radius around each cave.

	Buildings					Ponds					
Cave Type	NE	SE	SW	NW	Total	NE	SE	SW	NW	Total	Lotic
Maternity											
Mean	1.6	1.7	0.8	1.2	1.3	1.4	1.6	1.2	0.8	1.2	7.2
SD	0.8	1.1	0.5	0.7	0.6	1.0	0.8	1.4	0.6	0.8	6.3
Nonmaternity											
Mean	0.9	0.9	1.3	1.0	1.0	0.9	1.5	1.1	1.2	1.2	6.2
SD	0.6	0.6	0.6	0.7	0.4	0.7	1.5	0.7	0.7	0.7	3.2
Hibernaculum											
Mean	1.2	1.3	1.0	1.5	1.3	1.2	1.3	2.1	1.5	1.5	3.9
SD	0.8	0.9	0.5	0.9	0.5	1.1	0.8	1.2	1.0	0.8	3.7
Nonhibernaculum											
Mean	1.0	1.1	1.2	1.0	1.1	1.0	1.6	0.9	1.0	1.1	7.0
SD	0.7	0.8	0.6	0.6	0.4	0.8	1.4	0.6	0.6	0.7	3.9

Table 13. Mean percent land-use for maternity and unused caves in summer by elevation (uplands = above cave; lowlands = below cave).

	UPLANDS				LOWLANDS			
	Maternity		Unused		Maternity		Unused	
Land-use	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Buildings	0.1	0.1	1.0	3.1	0.0	0.0	1.8	5.4
Cropfields	0.0	0.0	0.1	0.4	0.1	0.1	0.1	0.4
Orchards	0.0	0.0	0.3	0.4	0.2	0.3	1.0	2.5
Rangeland	2.5	3.7	4.4	5.6	2.2	3.1	2.0	2.6
Rangeland[a]	15.3	4.3	13.5	13.4	19.4	15.1	11.4	13.6
Hardwoods[b]	0.0	0.0	2.1	6.5	0.2	0.4	0.2	0.3
Forest[c]	45.9	30.3	50.5	27.5	13.5	8.4	10.9	7.1
Water	0.6	1.1	0.0	0.1	0.0	0.1	0.6	1.3

[a]Rangeland with >35% groundcover of brush.
[b]Bottomland hardwoods in riparian habitats.
[c]Forestland with shortleaf pine and oak (mixed stands) and oak-hickory dominated woodlands (>70% deciduous).

Table 14. Mean percent land-use for hibernacula and unused caves in winter by elevation (uplands = above cave; lowlands = below cave).

	UPLANDS				LOWLANDS			
	Hibernacula		Other		Hibernacula		Other	
Land-use	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Buildings	0.1	0.2	0.9	3.0	0.1	0.2	1.6	5.2
Cropfields	0.0	0.0	0.1	0.4	0.0	0.1	0.1	0.4
Orchards	0.0	0.0	0.3	0.4	0.2	0.4	0.9	2.4
Rangeland	0.4	0.4	4.7	5.4	0.7	1.2	2.4	2.8
Rangeland[a]	12.6	6.2	14.3	12.8	15.8	14.7	12.8	14.3
Hardwoods[b]	0.1	0.2	2.0	6.3	0.2	0.4	0.2	0.3
Forest[c]	54.6	26.6	48.2	28.4	13.9	9.5	11.0	7.0
Water	0.0	0.0	0.2	0.6	1.1	1.9	0.3	1.0

[a]Rangeland with >35% groundcover of brush.
[b]Bottomland hardwoods in riparian habitats.
[c]Forestland with shortleaf pine and oak (mixed stands) and oak-hickory dominated woodlands (>70% deciduous).

Table 15. Mean percent of total area above (uplands) and below (lowlands) maternity caves, hibernacula, and other unused caves.

	UPLANDS			LOWLANDS		
CAVE TYPE	0-5%	6-10%	>10%	0-5%	6-10%	>10%
Maternity						
Mean	19.6	24.3	20.5	25.4	9.5	0.7
SD	3.3	12.4	11.8	19.6	6.8	0.7
Nonmaternity						
Mean	30.8	25.8	15.4	21.3	6.1	0.6
SD	18.6	8.3	13.5	21.5	4.4	0.7
Hibernaculum						
Mean	17.8	29.4	20.7	22.4	8.9	0.8
SD	4.5	9.7	14.5	21.4	5.4	0.8
Nonhibernaculum						
Mean	30.3	24.5	15.8	22.3	6.4	0.6
SD	17.7	9.0	13.0	21.2	5.1	0.6