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Use of pinyon-juniper woodlands by bats in New Mexico

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Abstract

In recent years, the demand has grown for information on how to conserve bat populations in forested ecosystems. Many researchers have responded with studies of bats in forests, but few have studied bat communities in arid-adapted forest types, such as pinyon-juniper woodlands, which are widespread and abundant throughout the west. In this study, I evaluated the relative use and importance of pinyon-juniper woodlands to bats in west-central New Mexico by comparing bats captured in pinyon-juniper woodlands with those captured in ponderosa pine forest. I compared species richness and relative abundance of bats captured in these vegetation types and evaluated the relative importance of each based on its use as reproductive habitat by females. Bats were mistnetted over stock tanks in pinyon-juniper woodlands for 55 nights during 1995–1997 and in ponderosa pine forest for 22 nights in 1998–1999. Although overall capture rates (bats per net hour) were not different between study sites, more species were captured in pinyon-juniper woodlands. The bat community of this pinyon-juniper woodland was dominated by species typically found in upper elevation forests, but also included species from lower elevation shrublands and grasslands. A greater proportion of females was reproductively active in pinyon-juniper woodlands than ponderosa pine, suggesting that females prefer woodlands for rearing their young or that fecundity rates of females are higher in this vegetation type. Results of this study demonstrate that pinyon-juniper woodlands support abundant and diverse bat communities and provide important summer habitat to reproductive females. Thus, biologists and land managers should plan activities in pinyon-juniper woodlands with greater attention and consideration to bats and their habitat requirements.

Keywords: Bats; Pinyon; Juniper; Wildlife; Habitat

1. Introduction

Recognizing that bats contribute not only to biodiversity, but also to ecological processes such as insect control and nutrient cycling, public land management agencies and private landowners have become increasingly interested in protecting bat populations (Lacki, 1996; Marcot, 1996). To conserve bats, biologists and land managers must first understand the distributions, habitat associations, and habitat requirements of bats within their region of interest. Knowing which bat species occur in the target management area, when they are present, and their

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roost requirements in that vegetation type, managers may then design conservation strategies and mitigate potential effects of activities such as logging or mine closure.

Numerous studies have been conducted in the last 5–10 years to provide information on species-habitat associations and summer roost requirements of bats (e.g. Mattson et al., 1996; Vonhof and Barclay, 1996; Callahan et al., 1997; Crampton and Barclay, 1998; Menzel et al., 1998; Lacki and Schwierjohann, 2001; Weller and Zabel, 2001). These studies have shown that forests provide valuable summer foraging and roosting habitat to many bat species, that trees are often used as maternity roosts, and that bats select trees with specific characteristics. However, biologists still do not know the full range of resources and habitats used by bats because not all regions and forest types have been examined. Most studies in North America have focused on bats in mesic habitats such as western coniferous forests or eastern deciduous forests. Few have focused on bat communities in arid habitats, perhaps because these environments are thought to be marginal habitat for most species of bats (due to scarcity of water, sparse vegetation, etc.). Yet, arid-adapted vegetation types are widespread and abundant in the western U.S. (Barbour and Billings, 2000), and land managers need to know the degree to which these vegetation types are used by bats.

Pinyon-juniper woodlands are an arid-adapted, tree-dominated vegetation type that occupy over 55 million acres in 10 western states (Gottfried and Severson, 1993; Mitchell and Roberts, 1999). These openly-spaced woodlands rarely have continuous canopy cover and are composed of trees of small stature in a wide range of densities (Dick-Peddie, 1993; Brown, 1994). Pinyon-juniper woodlands are managed for a variety of purposes, including livestock forage, watershed health, fuelwood, pine nuts, Christmas trees, and wildlife habitat (USDA Forest Service, 1993; Shaw et al., 1994; Monsen and Stevens, 1999). These activities and many of the tools used to manage woodlands (e.g. chaining, roller drum chopping, or prescribed fire) can change the structure and composition of pinyon-juniper woodlands, thus affecting the type, quality, and quantity of resources available to wildlife. Although guidelines are available for managing wildlife habitat in pinyon-juniper woodlands, most are intended for terrestrial small mammals, birds, and big game and do not consider bats (e.g. Short and McCulloch, 1977; Evans, 1988; USDA Forest Service, 1993; Goodrich, 1999).

To develop management guidelines for bats, biologists and managers first need information on which species use pinyon-juniper woodlands as well as the degree, type, and season(s) of use. Some of this information may be gleaned from distributional and ecological studies of bats in the southwest and surrounding states (e.g. Jones, 1965; Black, 1974; Findley et al., 1975; Hoffmeister, 1986; Armstrong et al., 1994; Mollhagen and Bogan, 1997; Herder and Jackson, 2000). However, studies that have focused specifically on bats in pinyon-juniper woodlands are few and limited in effort or scope (Chung-MacCoubrey, 1996; Rabe, 1999; Chung-MacCoubrey and Bogan, 2003). The goal of this project was to evaluate the relative use and importance of pinyon-juniper woodlands to bats in west-central New Mexico by comparing bats captured in pinyon-juniper woodlands with those captured in ponderosa pine forest. I compared species richness and relative abundance of bats captured and evaluated the relative importance of each vegetation type based on its use as reproductive habitat by females. This project was part of a larger study examining the ecology and management of bats in pinyon-juniper woodlands.

2. Methods

2.1. Study area

This study was conducted on the Cibola National Forest in the Gallinas and San Mateo Mountains west of Magdalena, New Mexico. The San Mateo Mountains are situated approximately 20 km south of the Gallinas Mountains, and the two ranges are separated by the extensive grasslands of the San Augustin Plains. Vegetation of the Gallinas Mountains is composed primarily of pinyon-juniper woodland. The Gallinas study site ranges in elevation from 2133 to 2573 m and comprises Gallinas Peak (elevation 2573 m) in the northwest corner and areas to the east and south of the peak. Primary tree species in these woodlands are Colorado pinyon (*Pinus edulis*), one-seeded juniper (*Juniperus monosperma*) and to a lesser degree, alligator juniper (*J. deppeana*). The Gallinas

study site is bordered by juniper savanna and arid grassland at the lower elevations. The second study site was in ponderosa pine (*Pinus ponderosa*) forest in the northern San Mateo Mountains. This study area ranges in elevation from 2347 to 2682 m and is bordered at lower elevations by pinyon-juniper woodland and at higher elevations by mixed-conifer forest. Because cattle graze in both study sites, water is available year-round from several metal and earthen stock tanks, which are approximately 2.6–3.8 km apart.

2.2. Bat sampling

I used mistnetting data to characterize and compare bat communities (species richness, composition, and relative abundance) at each study site. Field crews mistnetted at water sources from June to early August in 1995–1999 using methods of Kunz and Kurta (1988). Nets were 5.5–12.8 m in length, were opened at dusk, and were closed after activity had substantially subsided. The same number of nets and net configuration were used each time a site was sampled. Netting conditions (temperature, humidity, wind, and cloud cover) were recorded at the beginning and end of netting. Temperature and humidity were measured with a sling psychrometer, and wind was estimated using the Beaufort scale. For all bats captured, species, sex, age (Anthony, 1988), reproductive status (Racey, 1988), and body measurements were recorded prior to release. Field crews did not distinguish between *Myotis ciliolabrum* and *M. californicus*, two species that may occur in pinyon-juniper woodlands, but are difficult to differentiate based on external characteristics (Bogan, 1974; Findley et al., 1975).

2.3. Data analysis

I used capture rate to compare relative abundance of species in the two study areas. I calculated capture rates for each species and gender and tallied the number of nights and sites at which each species was captured. I also calculated nightly capture rates for combined species at each study site. Nightly capture rates were calculated by dividing number of bats captured by number of net hours each night (e.g. 3 h × 2 nets = 6 net h). To further standardize these capture rates among nights, I only counted bats captured and net hours that occurred between setup time and 2315 h. To avoid biases introduced by misidentification of reproductive status (Cryan et al., 2000), I used data collected on or after 1 July to calculate capture rates for reproductive (i.e. pregnant, lactating, or postlactating) and nonreproductive adult females. Capture rates by reproductive status were calculated for species common in both study sites and for which reproductive females were captured. I tested for differences in overall capture rate of bats among years using ANOVA for the Gallinas data and Satterthwaite's *t*-test for the San Mateos data. Capture rates for each species and capture rates by reproductive status were compared between the Gallinas and San Mateos using independent two-sample *t*-tests or Satterthwaite's *t*-test when variances were not equal.

Forward stepwise logistic regression was used to identify factors influencing the probability of capturing reproductive females versus males and nonreproductive females in these study sites. For the analysis, I used data from individuals of the most common species (*Eptesicus fuscus*, *M. evotis*, *M. thysanodes*, *M. volans*, and *M. ciliolabrum*/*californicus*) that were captured on or after 1 July. Variables entered into the model included mountain range, year, net site elevation, Julian day, bat species, and netting conditions (temperature, humidity, wind, and cloud cover at the start of netting). Statistical significance for predictor variables was set at $P \leq 0.05$. All tests were performed with SPSS statistical software (Version 10.1.4, Chicago, IL).

3. Results

3.1. Gallinas study site

In the Gallinas, seven steel-sided, aboveground stock tanks and one earthen stock tank were mistnetted. Four tanks contained water throughout the summers of 1995–1997 and were netted annually. Four tanks did not have water each year and were netted opportunistically. Tanks were netted an average of 2.25 times each summer (S.E. = 0.47, $n = 24$). Field crews captured 1222 bats of 10 species during 351 h of netting (15 nights in 1995, 28 nights in 1996, and 12 nights in 1997; Table 1). After the first two species were caught in the Gallinas, time intervals before the

Table 1
Summary of bats captured in pinyon-juniper woodland (Gallinas Mountains) and ponderosa pine forest (San Mateo Mountains) of west-central New Mexico, 1995–1999

Bat species	Gallinas[a] ($n = 55$)			San Mateos[a] ($n = 22$)		
	Total captured	Nights captured	Number of sites	Total captured	Nights captured	Number of sites
E. fuscus	499	52	8	179	18	7
M. ciliolabrum/californicus	330	44	7	13	8	6
M. evotis	176	44	7	94	19	7
M. volans	118	39	7	57	19	7
M. thysanodes	68	26	7	58	17	6
A. pallidus	11	8	4	–	–	–
L. cinereus	7	6	3	12	5	2
L. noctivagans	5	3	2	34	9	4
T. brasiliensis	7	3	3	–	–	–
M. yumanensis	1	1	1	–	–	–

[a] Numbers of nights mistnetted are in parentheses.

capture of additional species were 13, 38, 19, 52, and 4 net h, respectively (Fig. 1). According to the species accumulation curve, the cumulative number of species reached a plateau at 157 net hours. Bats of five species (*E. fuscus*, *M. ciliolabrum/californicus*, *M. evotis*, *M. volans*, and *M. thysanodes*) were captured frequently (i.e. >47% of nights) and at most sites in the study area (Table 1). Bats of the remaining five species were captured infrequently and at only 1–4 net sites. Nightly capture rate for all species combined was not different among years ($F_{2,52} = 0.207$, $P = 0.814$). Thus, average nightly capture rate for all years combined was 3.859 bats per net hour (S.E. = 0.324, $n = 55$, range = 0.188–11.455). For the five species commonly captured at this study site, females were captured at higher rates (1.1–4.9 times) than males, and reproductive females were caught at higher rates (2.7–9.2 times) than nonreproductive females (Table 2). Too few reproductive males (i.e. males with obvious testes) were captured to warrant a separate accounting from nonreproductive males.

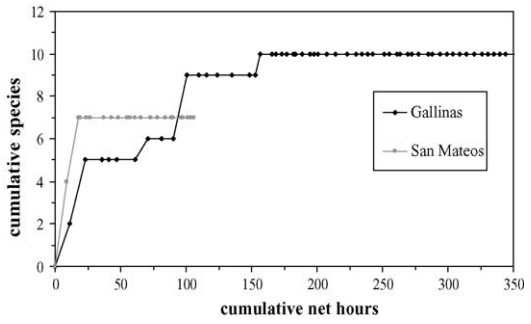

Fig. 1. Cumulative number of bat species captured based on net effort in pinyon-juniper woodland (Gallinas) and ponderosa pine forest (San Mateos) in New Mexico, 1995–1999.

3.2. San Mateos study site

In the San Mateos, four steel-sided and three earthen stock tanks were mistnetted. All tanks contained water throughout the summers of 1998–1999. Tanks were netted an average of 1.57 times per summer (S.E. = 0.34, $n = 14$). Field crews captured 447 bats of seven species during 106 h of netting (12 nights in 1998 and 10 nights in 1999; Table 1). The seventh species was captured at 18 net h, and no additional species were caught during the subsequent 88 net h, suggesting that the cumulative number of species had reached a plateau. Except for *M. ciliolabrum/californicus*, species that were commonly captured in the Gallinas were also common in the San Mateos (i.e. captured on most nights and at most sites; Table 1). Nightly capture rate for all species combined was not different between years ($t_{16} = 1.006$, $P = 0.329$). Thus, average nightly capture rate for the years combined was 4.973 bats per net hour (S.E. = 0.781, $n = 22$, range = 0.667–16.129). For five commonly captured species in the San Mateos, females were captured at higher rates (1.2–9.5 times) than males (Table 2). For *E. fuscus* and *M. thysanodes*, reproductive females were caught at higher rates than

Table 2
A comparison of capture rates of females vs. males and reproductive vs. nonreproductive females in pinyon-juniper woodland (Gallinas Mountains) and ponderosa pine forest (San Mateo Mountains) of west-central New Mexico, 1995–1999

Bat species	Gallinas		San Mateos	
	Females/ males	Reproductive/ nonreproductive females[a]	Females/ males	Reproductive/ nonreproductive females[a]
E. fuscus	3.898	9.187	9.477	6.765
M. ciliolabrum/californicus	2.825	3.435	1.173	–
M. evotis	1.104	2.730	1.650	0.935
M. volans	1.561	4.908	1.405	0.507
M. thysanodes	4.904	8.892	1.956	2.588

[a] Calculated only if both reproductive and nonreproductive females were captured.

nonreproductive females (Table 2). For *M. evotis* and *M. volans*, reproductive females were caught at lower rates than nonreproductive females. Few reproductive and no nonreproductive female *M. ciliolabrum/californicus* were captured after 1 July.

3.3. Between site comparisons

In the San Mateos, the number of species accumulated more quickly, but reached a plateau earlier and at a lower number than in the Gallinas (Fig. 1). Species captured in the San Mateos were a subset of those in the Gallinas (Table 1). Average nightly capture rates in the San Mateos and Gallinas were not significantly different ($t_{75} = -1.570$, $P = 0.121$), but capture rates for many individual species differed between sites. *E. fuscus* had the highest capture rates of all species at both sites (Table 3). *M. ciliolabrum/californicus*, the second most frequently captured species in the Gallinas, was replaced by *M. evotis* as the second most frequently captured species in the San Mateos. *M. evotis*, *M. thysanodes*, *M. volans*, and *L. noctivagans* were captured at higher rates and *M. ciliolabrum/californicus* and *Antrozous pallidus* at lower rates in the San Mateos (Table 3). At both study sites, most of the *L. cinereus* and *L. noctivagans* captured were males (84 and 100%, respectively), and the majority were captured between mid-May and the end of June.

3.4. Reproductive status of females

Higher ratios of reproductive to nonreproductive females and the greater probability of catching reproductive females at lower elevations indicate that reproductive females were more prevalent in the Gallinas (Tables 2 and 5). The higher ratios of reproductive to nonreproductive females result from

Table 3
A comparison of species capture rates (bats per net hour) between pinyon-juniper woodland (Gallinas Mountains) and ponderosa pine forest (San Mateo Mountains) of west-central New Mexico, 1995–1999

Bat species	Gallinas			San Mateos			*P*
	n	Mean	S.E.	*n*	Mean	S.E.	
E. fuscus	55	1.532	0.143	22	1.583	0.412	0.908
M. ciliolabrum/californicus	55	1.010	0.141	22	0.122	0.044	<0.001
M. evotis	55	0.605	0.091	22	1.278	0.311	0.048
M. volans	55	0.369	0.049	22	0.877	0.231	0.042
M. thysanodes	55	0.250	0.056	22	0.755	0.162	0.007
A. pallidus	55	0.027	0.010	22	0.000	–	–
L. cinereus	55	0.024	0.011	22	0.065	0.028	0.170
L. noctivagans	55	0.023	0.016	22	0.293	0.109	0.022
T. brasiliensis	55	0.015	0.011	22	0.000	–	–
M. yumanensis	55	0.002	0.002	22	0.000	–	–

Table 4
A comparison of reproductive and nonreproductive female capture rates (bats per net hour) between pinyon-juniper woodland (Gallinas Mountains) and ponderosa pine forest (San Mateo Mountains) in west-central New Mexico, 1995–1999

Bat species	Reproductive females[a]						*P*	Nonreproductive females[a]						*P*
	Gallinas			San Mateos				Gallinas			San Mateos			
	n	Mean	S.E.	*n*	Mean	S.E.		*n*	Mean	S.E.	*n*	Mean	S.E.	
E. fuscus	34	1.045	0.129	13	0.784	0.391	0.415	34	0.114	0.025	13	0.116	0.064	0.969
M. evotis	34	0.212	0.041	13	0.462	0.261	0.362	34	0.078	0.024	13	0.494	0.167	0.029
M. thysanodes	34	0.095	0.032	13	0.402	0.213	0.179	34	0.011	0.008	13	0.155	0.063	0.041
M. volans	34	0.139	0.038	13	0.142	0.080	0.970	34	0.028	0.011	13	0.281	0.117	0.053
M. cilio/calif	34	0.495	0.096	13	0.062	0.035	<0.001	34	0.144	0.041	13	0.000	0.000	0.001

[a] Only netting data collected on or after 1 July each summer were used.

the lower capture rates for nonreproductive females in the Gallinas (Table 4). A comparison of capture rate ratios was not available for *M. ciliolabrum/californicus* because few reproductive females and no nonreproductive females were captured in the San Mateos (Table 4). Elevation, relative humidity, and bat species were significant in predicting the capture of reproductive females in both mountain ranges (Table 5). As elevation decreased from 2527 to 1975 m, the proportion of reproductive females increased. As humidity at dusk increased from 23 to 90%, the proportion of reproductive females increased. Because relative humidity was inversely correlated with ambient temperature (Pearson's correlation = -0.762, $P < 0.001$), temperatures at dusk were also cooler on nights when higher proportions of reproductive females were captured. The probability of catching a reproductive female was greater for *E. fuscus*, *M. ciliolabrum/californicus*, and *M. thysanodes* than *M. evotis*. Net site elevation and mountain range were correlated because lower elevation sites occurred in the Gallinas and higher elevation sites occurred in the San Mateos. Mountain range and year were correlated because sites were studied consecutively rather than concurrently. Nonetheless, elevation, the most detailed of the correlated variables, explained the greatest amount of variation in the model.

Table 5
Logistic regression model for the probability of capturing a reproductive female (vs. nonreproductive females and males) in the Gallinas and San Mateo Mountains of west-central New Mexico

Predictor Variable	Slope	S.E.	exp(*B*)	*P*
Elevation (m)	−0.004	0.001	0.996	<0.001
Humidity (%)	0.023	0.004	1.023	<0.001
Bat species				<0.001
M. evotis	0.000[a]			
M. volans	0.195	0.291	1.215	0.503
M. ciliolabrum/californicus	0.786	0.244	2.195	0.001
E. fuscus	1.210	0.221	3.354	<0.001
M. thysanodes	0.745	0.332	2.106	0.025

[a] Effects of individual bat species were measured against *M. evotis*.

4. Discussion

4.1. Bat community composition

Pinyon-juniper woodlands of the Gallinas support a diverse and abundant bat community. Although species accumulation curves in both study areas plateaued, not all species were necessarily caught, and the number of species identified in the Gallinas and San Mateos should be considered a conservative estimate. Many factors can influence netting results (e.g. weather, net placement, and moonlight), not all species are equally catchable, and additional species may have been identified with alternative methods such as acoustical monitoring (Kunz and Kurta, 1988; Kuenzi and Morrison, 1998; O'Farrell and Gannon, 1999). Nonetheless, data from this study suggest that arid, lower elevation pinyon-juniper woodlands may support bat communities that are as rich or richer in species and individuals as communities in higher elevation, tall coniferous forest. In New Mexico and Arizona, coniferous woodlands (pinyon-juniper and juniper savanna) are the most common forest type, covering approximately 8 million hectares (Conner et

al., 1990; Van Hooser et al., 1993). Other forest types combined (ponderosa pine, mixed-conifer, and subalpine forests) cover fewer acres (approximately 4.8 million hectares; Chambers and Holthausen, 2000). Thus, pinyon-juniper woodlands may represent a significant proportion of forested bat habitat in the southwest.

Previous studies have also found a high species richness in pinyon-juniper woodlands. In two studies of multiple mountain ranges in New Mexico, bat communities in pinyon-juniper woodlands included 16 species, over half of those found in New Mexico (Jones, 1965; Chung-MacCoubrey, 1996). In the White-Inyo Mountains of California and Nevada, pinyon-juniper woodlands supported the second most species-rich bat community of five vegetation types (Szewczak et al., 1998). Although fewer species were captured in pinyon-juniper woodlands than in grasslands of northern Arizona, results of this Arizona study may be misleading because total net effort in pinyon-juniper woodlands was small (12.25 h) and only 4% of the net effort in grasslands (Rabe, 1999).

A variety of bat species may use pinyon-juniper woodland because it is the transitional vegetation type between upper elevation, mesic forests and lower elevation, arid shrublands and grasslands. As such, it provides suitable habitat to species from both adjacent vegetation types. In a study of bats across multiple habitats in New Mexico, Jones (1965) captured a combination of 'highland' and 'lowland' forms in pinyon-juniper woodlands. Thirteen of the 16 species captured in woodlands were most abundant in either upper elevation coniferous forests or lower elevation xeric-shrub grassland. Similarly, bat species in the Gallinas included those captured in ponderosa pine forests of the San Mateos and additional species (*Tadarida brasiliensis*, *A. pallidus*, *M. yumanensis*) that are commonly captured at lower elevations (Jones, 1965; Findley et al., 1975).

Previous mistnet studies have identified species in pinyon-juniper woodlands and ponderosa pine forest that were not present in the Gallinas or San Mateos. The absence or minimal presence of these species may reflect a lack of critical resources, differences in geographic location, or net bias. Use of an area by a species is largely dependent on the presence of suitable foraging or roosting habitat (Humphrey, 1975; Fenton, 1997). For example, *P. hesperus*, *Corynorhinus townsendii*, *E. maculatum*, and *T. brasiliensis* have been captured in pinyon-juniper woodlands of California, Nevada, and the southwest (Jones, 1965; Findley et al., 1975; Szewczak et al., 1998; Rabe, 1999). However, these species may have been absent in the Gallinas due to the lack of preferred roost structures such as high cliffs, caves, large rock outcrops, and manmade structures (Findley et al., 1975). Although *M. occultus* has been captured in ponderosa pine forests of Arizona, this species was not captured in the San Mateo study area, likely due to the lack of large permanent bodies of water above which these species often feed (Findley et al., 1975; Lutch, 1996; Morrell et al., 1999). According to Findley et al. (1975), the San Mateo Mountains are at the periphery or are outside the distributional ranges of *M. auriculus*, *M. velifer*, and *Nyctinomops macrotis*, species that have been captured in ponderosa pine forests of Arizona (Lutch, 1996; Morrell et al., 1999). Low capture rates of *T. brasiliensis* in the Gallinas may be due to the absence of larger bodies of water from which this fast-flying, less maneuverable species may drink.

Pinyon-juniper woodlands should be added to the list of habitats with which *E. fuscus*, *M. evotis*, *M. volans*, *M. ciliolabrum*, and *M. thysanodes* are commonly associated. These species are reported to occur primarily in higher elevation, mesic forests of New Mexico (Jones, 1965; Findley et al., 1975; O'Farrell and Studier, 1980; Warner and Czaplewski, 1984; Manning and Jones, 1989; Kurta and Baker, 1990). Although authors have acknowledged that these species may occasionally be found in arid, lower elevation habitats, such as pinyon-juniper woodland, this study suggests that they occur in pinyon-juniper woodlands more frequently than predicted. These species were common and abundant in pinyon-juniper woodlands of the Gallinas and have been captured in pinyon-juniper woodlands in several other studies (Jones, 1965; Chung-MacCoubrey, 1996; Szewczak et al., 1998; Rabe, 1999; Chung-MacCoubrey and Bogan, 2003). Similar to the Gallinas, many pinyon-juniper woodlands may have a suitable quantity and distribution of food, water, and roosts to support these mesic-adapted species.

Data from this study contradict the characterization of *M. ciliolabrum* as a species most abundant in ponderosa pine forests (Jones, 1965; Findley et al.,

1975). After consultation in the field with M.A. Bogan during 1997, I concluded that most captures of *M. ciliolabrum/californicus* in the Gallinas and San Mateos were *M. ciliolabrum*. Thus, *M. ciliolabrum* was captured infrequently in ponderosa pine forests of the San Mateos, but frequently in pinyon-juniper woodlands of the Gallinas (the second most abundant species). Similarly, few *M. ciliolabrum* were captured in ponderosa pine forests of Arizona (Lutch, 1996; Morrell et al., 1999; Bernardos, 2001); yet it was the most abundant species captured in grasslands of Arizona (Rabe, 1999). These data suggest that *M. ciliolabrum* may be more common in lower elevation habitats and less common in upper elevation habitats of New Mexico than previously expected.

4.2. Importance to bats as reproductive habitat

In addition to supporting diverse and abundant bat communities, pinyon-juniper woodlands may also be preferred by reproductive females for rearing young. In another component of this project, I used radio-telemetry to locate day roosts of reproductive females and determined that females were rearing young within the study area in which they were captured (Chung-MacCoubrey, 2003; unpublished data). Thus, the greater proportion of reproductive females captured in the Gallinas may indicate that females prefer these pinyon-juniper woodlands as maternity roost habitat. Reproductive females have different habitat preferences and thermoregulatory strategies than males and nonreproductive females due to their higher energy requirements during the summer (Gittleman and Thompson, 1988; Thomas, 1988; Barclay, 1991). Reproductive females may actively select pinyon-juniper woodlands because these lower elevation habitats provide more favorable foraging and roosting conditions. Lower elevation habitats may be preferred because warmer temperatures at lower elevations are associated with higher prey densities and foraging efficiencies (Anthony et al., 1981; Hoying and Kunz, 1998; Cryan et al., 2000). Warmer temperatures of lower elevation habitats may also confer physiological and thermoregulatory advantages to females and their pups. Warmer temperatures facilitate gestation in females (and thus earlier parturition), facilitate growth of the pup, and minimize energy required to maintain homeothermy in adults and pups (McNab, 1982; Racey, 1982; Zahn, 1999). Earlier parturition dates are beneficial because they increase the amount of time available for females and their pups to accumulate fat stores, thus enhancing their chances of overwinter survival (Tuttle and Stevenson, 1982).

Males and nonreproductive females have fewer behavioral and physiological constraints because they do not carry the energetic burden of pregnancy and lactation. Males can reduce energy requirements during the summer by using torpor more frequently and deeply than females (Hamilton and Barclay, 1994; Grinevitch et al., 1995). Males are more tolerant of adverse conditions and may be found roosting in cooler habitats at higher elevations (Thomas, 1988; Barclay, 1991). In forests of the Pacific Northwest, South Dakota, and Alberta, greater proportions of males were captured at higher elevations, and greater proportions of females were captured at lower elevations during the summer (Fenton et al., 1980; Thomas, 1988; Barclay, 1991; Grindal and Brigham, 1999; Cryan et al., 2000). In high elevation, subalpine forests of Colorado, the majority of bats captured were nonreproductive females and males (Storz and Williams, 1996). The use of torpor as an energy-saving strategy may be disadvantageous for pregnant females because reduced body temperatures slow fetal growth rates and delay parturition (Racey, 1973; Racey and Swift, 1981). Thus, reproductive females may avoid higher elevation habitats because cooler temperatures increase thermoregulatory energy expenditures, require the periodic use of torpor, prolong gestation and lactation, and ultimately compromise reproductive success.

An alternative explanation for the larger proportion of reproductive females in the Gallinas is that environmental conditions in lower elevation habitats influence reproductive status. Favorable foraging and roost conditions of lower elevations may increase fecundity rates by improving the condition in which females enter and emerge from hibernation. The ability of females to reproduce is largely affected by their condition, and females emerging from hibernation with critically depleted fat reserves may not ovulate in the spring and reproduce that year (Kunz et al., 1998). Juvenile females can become sexually mature by their first autumn (Racey, 1982; Tuttle and Stevenson, 1982) and may become pregnant the

following spring. Favorable foraging and roost conditions in lower elevation habitats may allow juvenile and adult females to store more fat in the fall, increase the likelihood of females ovulating in the spring, and ultimately increase fecundity rates for these females over that of their counterparts at higher elevations. As highly mobile, migratory animals, bats are capable of selecting favorable habitats to suit their energetic requirements, and increased fecundity of females at lower elevations is a likely outcome of roosting in favorable habitats. The larger proportion of reproductive females in pinyon-juniper woodlands of the Gallinas likely results from both of the mechanisms proposed, active habitat selection and habitat effects on fecundity rates.

A greater proportion of reproductive females were caught on cooler, more humid nights, suggesting that fewer nonreproductive females and males were out foraging under these conditions. While nonreproductive females and males may have reduced foraging activity and perhaps used torpor to save energy and water on these cooler nights (Webb et al., 1995; Chruszcz and Barclay, 2002), reproductive females may not have been able to forego drinking and foraging. Lactating females have higher energy and water requirements due to milk production (Kurta and Bell, 1989), and their water stress is exacerbated by arid conditions in low elevation habitats (Chruszcz and Barclay, 2002). Consequently, lactating females, which constituted a majority (62%) of the reproductive females in the regression analysis, may have been foraging and drinking on nights when nonreproductive females and males were not.

5. Conclusions

Careful management of bat habitat is critical due to the low reproductive rates of bats, the importance of suitable foraging and roost habitat to reproductive success (Racey, 1982) and the sensitive status of many bat species. Given the wide distribution of pinyon-juniper woodlands and the diversity and abundance of bats that may use it, particularly reproductive females, it is apparent that researchers and managers have underestimated the importance and value of this vegetation type to bats. Results of this and other studies suggest that millions of acres of pinyon-juniper woodlands throughout the southwest and other western states provide valuable summer habitat to bat populations and that land managers should consider the presence of these populations when planning activities in pinyon-juniper woodlands.

Additional studies are needed to identify how bat species composition varies with geographic location and characteristics of different pinyon-juniper woodlands. The Gallinas study site had a sufficient quantity and distribution of roosts, water, and prey to support a high proportion of mesic-adapted species and reproductive females. However, local characteristics of each pinyon-juniper woodland determine the distribution and availability of important resources and thus affect bat community composition and structure. Woodlands with a wider variety and distribution of water sources and roost structures likely support a greater diversity of bats (Humphrey, 1975; Geluso, 1978; Rabe et al., 1998; Szewczak et al., 1998; Schmidt, 2000). Such woodlands would contain a variety of tree species and forms, elements of adjacent vegetation types, and structures such as caves, mines, cliffs, and outcrops. Future studies should attempt to identify the type, amount, and distribution of roosts, water, and prey that determine bat community structure and overall use in pinyon-juniper woodlands. To develop management guidelines for bats in pinyon-juniper woodlands, studies are needed on habitat use and resource requirements of individual bat species in this vegetation type. Biologists and land managers may then predict the composition of bat communities, minimize the negative impacts of management activities on bat habitat, and conserve and protect bat populations in pinyon-juniper woodlands.

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