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**SPATIAL AND TEMPORAL PATTERNS OF BAT USE OF WATER  
DEVELOPMENTS IN SOUTHERN ARIZONA**

**By**

**Amy Jo Kuenzi**

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**A Dissertation submitted to the Faculty of the  
SCHOOL OF RENEWABLE NATURAL RESOURCES**

**In Partial Fulfillment of the Requirements  
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**DOCTOR OF PHILOSOPHY  
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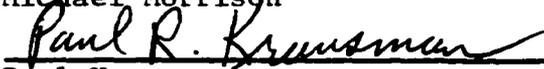
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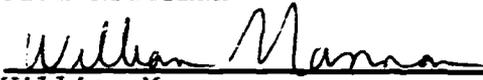
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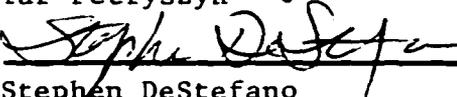
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## DEDICATION

To my father, Norbert James Kuenzi, for teaching me to appreciate nature, books,  
and differences in others.

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## ABSTRACT

I studied bat activity at 13 artificial and 4 natural water sources in southern Arizona from May 1995 through August 1996 using mist-nets and ultrasonic detectors. I used 2 indices of bat activity, capture rates, calculated from mist-netting data, and bat passes/30 minutes, calculated from ultrasound data. Both methods provided similar information on temporal patterns of bat activity. Indices of bat activity were highest during the reproductive season (May through August) compared to the non-reproductive season (September through April). Bat activity did not differ between any of the 2-week time periods within the reproductive season. During the reproductive season, bat activity was bimodal with peaks during the first 2 hours after sunset and the 2 hours preceding sunrise. During the non-reproductive season, bat activity was unimodal, with the majority of activity occurring within 2 hours of sunset.

I captured six bat species within the study area. Sex ratios tended to be male biased during the non-reproductive season but close to 1:1 during the reproductive season. Sex ratios did not differ between natural and artificial water sources for any of the bat species compared. Age ratios did differ significantly between natural and artificial water sites. A higher percentage of the total captures at natural water sources were juveniles compared to artificial water sources, possibly indicating higher reproductive output in areas surrounding natural sites.

Indices of activity during the reproductive season were significantly higher at natural compared to artificial water sources. However, this difference was not due to higher insect biomass at natural water sources. I developed stepwise multiple regression

models to explain variation in bat activity and species richness at water sources.

Elevation, type of water source and distance to the nearest cliff or rock outcrop were significant variables in explaining variation in overall capture rates at water sources. Type of water source was the only significant variable explaining variation in ultrasonic activity (passes/30 min), while distance to the nearest source of permanent water and size of the water source explained 33% of the variation in species richness.

## **INTRODUCTION**

**This dissertation is presented in the form of two complementary papers to be submitted to peer-reviewed journals. The papers will be submitted, in order of presentation, to The Journal of Wildlife Management, and The Wildlife Society Bulletin.**

## TEMPORAL PATTERNS OF BAT ACTIVITY IN SOUTHERN ARIZONA

### INTRODUCTION

In the past few decades, bats have been recognized as important predators of nocturnal insects (Whitaker 1995) and pollinators of some Sonoran Desert plants (McGregor et al. 1962, Flemming 1988). These factors, along with growing public awareness have resulted in an increased interest in bat conservation (Fenton 1997).

Among mammals their size, bats have low reproductive rates (Hill and Smith 1984), which makes populations slow to recover from high levels of mortality. Large population declines in some bat species have been documented (Humphrey 1978, Tuttle 1979, Richter et al. 1993). The potential for factors such as habitat alteration and/or environmental change to cause declines in bat abundance has led to the focus on bats by natural resource agencies. However, data necessary to develop meaningful conservation and management plans for bat species are often lacking. Even such basic information as species distribution is not available for many locations (Saugey 1991, Pierson 1998).

In addition, an essential component in understanding bat communities is knowledge of the way various species use habitat spatially and temporally, yet few studies have examined this aspect of bat biology (Hayes 1997). One of the hypotheses used to explain community structure involves interspecific competition and ecological differences among species (Hebert 1982, Grant and Schluter 1984, Schluter and Grant 1984). Understanding how species coexistence within local assemblages is one of the major areas of interest to community ecologists (Pianka 1981).

Mechanisms permitting species-coexistence probably have been achieved in a

number of ways including selection for morphological adaptations, spatial differences, varied patterns of foraging behavior, and food resource specialization. In many insectivorous bat communities, the majority of species are morphologically similar (Findley and Black 1983, Aldridge and Rautenbach 1987, Fenton 1990). Species with similar morphologies are assumed to be ecologically similar and this brings up the problem of explaining their coexistence (Saunders and Barclay 1992). There is evidence indicating that similar coexisting species may utilize some form of resource partitioning (Schoener 1974, Polis 1984).

Although data as to how coexisting species of bats partition space, food, and other resources is limited (Findley 1993), there are a few studies that provide some insight. Kunz (1973) used mist nets to study bat communities in three deciduous forest sites of Iowa. He suggested differences in capture time may indicate temporal allocation of foraging habitat but cautioned that differences could be due to varying proximity to roost sites. LaVal et al. (1977) used chemoluminescent light tags to observe foraging in 8 species of bats in Missouri. Species were found to vary in the types of habitat they used suggesting some allocation of foraging habitat. Similar results were obtained by Caire et al. (1984) in their study of 5 bat species in Oklahoma. Their data also suggested some spatial partitioning, with different species foraging at different heights and habitats within the study area.

In the Southwest, studies of bats have primarily focused on capturing individuals at water sources. Jones (1965) summarized the seasonal distribution of bats and presented a range of temperatures in which each species was active during his study of bat species of

the Mogollon mountains of southwestern New Mexico and adjacent southeastern Arizona. He also found significant differences in capture times between species suggesting temporal partitioning of resources.

Although many bat studies have been conducted in the Southwest, I could find only 1 study of bat communities (Bell 1980) that focused on the Sonoran Desert of southern Arizona. Bell used ultrasonic sensing equipment to examine habitat use patterns of bats in 3 habitat types: Lower Sonoran Desert, Upper Sonoran Desert, and riparian canyon forest in the Chiricahua Mountains in southeastern Arizona. He found the species present to be similar in all 3 habitats but foraging activity to be significantly higher in the riparian canyon forest compared to the other sites.

Many questions about bat ecology in the Sonoran Desert remain unanswered. Few studies have thoroughly investigated bat species activity throughout the entire foraging period (dusk to dawn). Access to water sources by different species may occur at the same or different times. Temporal partitioning among bats may be one mechanism whereby competition for resources has been effectively reduced. Data on species specific activity over the course of the foraging period is needed to determine if bat species in the Sonoran Desert partition resources temporally. This data will also be useful for designing inventory and monitoring programs for bat species (i.e., when to survey for specific species).

However, the determination of species specific activity over the course of the night may depend upon the techniques used to conduct the survey. The most commonly used bat survey methods are direct capture via mist-nets and ultrasonic detection of bat

echolocation calls (high frequency sounds emitted by insectivorous bats for orientation and prey capture). Although several recent studies (Kuenzi and Morrison 1998, O'Farrell and Gannon 1999) have compared the capabilities of these two techniques for determining species presence in an area, only two previous studies (Kunz and Brock 1975, Fenton et al. 1977) compared the two techniques ability for monitoring bat flight activity. Kunz and Brock (1997) found the two techniques yielded similar results. However, their study was only conducted at one site for a short period of time (6 nights). In another short term (1 month) study of African insectivorous bats, Fenton et al. (1977) found that most mist-net captures occurred within 1 hour of sunset but ultrasound data showed that bat activity occurred throughout the night. No study has yet compared the two techniques' ability for monitoring temporal variation in bat activity at a variety of sites and over longer periods of time.

My study was undertaken to determine bat species presence and temporal patterns of bat activity in the Sonoran Desert of southern Arizona as determined by mist-netting and ultrasonic detectors. My specific objectives were to (1) examine species composition, relative abundance and sex ratios of bat species utilizing water sources in the Sonoran Desert, (2) examine reproductive timing of these bat species, (3) examine the relationship between bat activity as determined by mist-netting and ultrasonic detectors, (4) determine if temporal patterns of resource partitioning exists among bat species present, and (5) examine the relationship between bat activity and environmental factors including moon phase, temperature and insect abundance. These results will contribute to the basic understanding of bat communities in the Sonoran Desert. They will also be used to

**develop recommendations for designing bat inventory programs and will provide baseline data on activity within this region.**

## STUDY AREA

My study was conducted on a 1,700 km<sup>2</sup> portion of the Barry M. Goldwater Air Force Range (BMGR), Maricopa County, Arizona. Vegetation in the study region is characteristic of the Lower Colorado River Valley and Arizona Upland subdivisions of the Sonoran desertscrub Biome (Turner and Brown 1982). The Arizona Upland subdivision is described as a mixed cactus (*Opuntia* spp.) desert interspersed with bursage (*Ambrosia* spp.), creosote bush (*Larrea tridentata*), catclaw (*Acacia greggii*), and paloverde (*Cercidium* spp.). Saguaro (*Cereus gigantea*) and organpipe (*Cereus thurberi*) cacti may also be present (Lowe and Brown 1973). The lower Colorado subdivision is characterized by creosote and bursage with blue paloverde (*C. floridum*), ironwood (*Olneya tesota*), mesquite (*Prosopis* spp.), and catclaw present in washes (Turner and Brown 1982).

The average daily temperature in the study region ranges from 10° C in the winter (December through February) to 30° C in the summer (June through August). Mean annual precipitation is approximately 23 cm (Sellers et al. 1985). Precipitation occurs mostly during two rainy seasons, late summer and winter (Reitan and Green 1968). The summer monsoons last from late July into September. Winter rains extend from December through March.

I surveyed bats at all 17 available water sources located in and around the Saucedá and Sand Tank mountain ranges. Water sources within each mountain range were separated by 1 to 5 km. Distance between the two mountain ranges was approximately 30 km. I did not have access to the two water sources found between the Saucedá and Sand

**Tank Mountains because of military activity.**

**Thirteen of the 17 water sources were artificial catchments that contained water year round. Each catchment consisted of a metal, asphalt, or fiberglass collection surface to capture runoff, a storage tank, and a drinking trough. All drinking troughs were less than 2.65 m<sup>2</sup> in size. Two of the water sources were tinajas (bedrock pools replenished seasonally by rainfall and runoff). These contained water on a seasonal basis and never had a surface area of > 2.5 m<sup>2</sup>. One source was a tinaja that had been modified by a concrete dam. This site contained water year round, but the amount of water fluctuated due to evaporation but never contained > 6 m<sup>2</sup> of open water. The remaining water source was a natural spring that flowed into a small pool with a surface area of approximately 2.75 m<sup>2</sup> (Appendix 1.1).**

## METHODS

Field work was conducted from mid-May 1995 through mid-August 1996. I did not conduct surveys during December 1995 due to logistical constraints. I also did not survey on nights with extreme weather conditions, or on the 2 nights preceding and following the full moon. I used two methods, live capture in mist-nets and ultrasonic detection of bat echolocation calls, to survey for bats.

### Mist-netting

I captured bats using 36-mm mesh, 50 denier, 2.1-m x 5.4-m mist-nets placed across or along the edges of each water source. The number of nets used per site varied with the size of the water source (range = 1 - 3). Nets were opened at sunset and were monitored continuously until sunrise. Captured bats were identified to species and data on body measurements, sex, reproductive condition of females, and age (juvenile vs. adult) were also recorded. I assessed reproductive condition by visual examination of the lower abdomen and mammary glands (Racey 1988). I aged bats based upon the degree of epiphyseal-diaphyseal fusion of wing bones (Anthony 1988). Bats could reliably be aged only during the reproductive season. Air temperature and time at capture were also recorded. All bats were marked using numbered, lipped, metal forearm bands (Lambournes Ltd., Herefordshire, England) and released after banding. Handling procedures were approved by the University of Arizona Animal Care and Use Committee (Protocol #95-164).

Mist-netting data were standardized by dividing the total number of bats captured

and the number of individuals of each species captured during each night and time session by net hours to obtain capture rates. I calculated net hours by multiplying the length of time nets remained open by the number of nets used.

#### Ultrasonic detection

Simultaneous with the use of mist-nets, I monitored bat echolocation calls at water sources continuously from sunset until sunrise using a heterodyne ultrasonic detector (Petterson Elektronik, Uppsala, Sweden, D100 model) set at 40 kHz. Although detection of echolocation calls cannot be directly translated into population estimates, they do provide an index of bat activity (Krusic et al. 1996, Vaughan et al. 1997, Betts 1998). I used the total number of bat passes during 30-minute time periods as my index of bat activity. I defined a pass as the sequence of a bat echolocation call on the detector from beginning to end. I recorded temperature to the nearest Celsius degree at the start of each time period using a digital thermometer. Observations on other environmental factors including moon phase and length of time the moon was up (based on time of moon rise, and time of moon set) were also recorded. Data from the 30-minute time periods were averaged over the course of the night to obtain a nightly ultrasound index of activity.

In addition to the heterodyne detector, I used a time-expansion ultrasonic detector (Petterson D140 model) linked to a tape recorder to record echolocation calls during each 30 minute time period. These recordings were digitized using SoundEdit™ 16 version 2.0.1. Sonograms were generated from digitized recordings using prototype computer software program developed by J. Szewczak (White Mountain Research Station, Bishop, California). Data on frequency composition, changes in frequency with time, harmonics,

and duration were obtained from these sonograms and visually compared with similar data from reference recordings of known species in order to determine species presence. Because of the similarity of their calls (Thomas 1988, Krusic et al. 1996), my identification of *Myotis* species was restricted to genus. In addition, not all of the echolocation calls I recorded could be identified to species. Calls detected and recorded vary depending upon factors such as direction of the microphone in relation to the bat, distance from the microphone to the bat, and instrument sensitivity (O'Farrell et al. 1999). I could only identify approximately 50% of the recordings made. Barclay (1999) cautioned that because rates of unusable sequences may not be distributed randomly among species, the relative abundance of species identified by their calls is likely inaccurate. Thus I did not use these data to compare relative abundance between species.

### Seasonal Effort

To examine seasonal trends in bat flight activity, I defined 2 seasons based on the biology of insectivorous bats in North America: reproductive season (May through August) and the non-reproductive season (late September through mid-April). Although copulation occurs in late autumn, fertilization in all the Vespertilionidae species present within the study area does not occur until late spring (Barbour and Davis 1969). Fertilization occurs immediately after copulation in one species, California leaf-nosed bat (*Macrotus californicus*), but embryonic development is delayed for 4-5 months (Neuweiler 2000). Therefore, I consider the reproductive season to be the time of highest energetic demands for females due to pregnancy and lactation.

With the exception of the two sites that did not contain water during the 1995

reproductive season and one site that was not located until the non-reproductive season, I collected data at each water source on 2-3 nonconsecutive nights during each of the 2 reproductive seasons and 1-2 nonconsecutive nights during the non-reproductive season.

### Insect Sampling

I sampled the aerial insect fauna during each bat survey using Malaise traps (Model 2875A Bioquip Products, Gardenia, California). Malaise traps are a non-attractant method of collecting flying insects (Morris 1960) and have fewer biases than attractant traps (Kunz 1988). Two Malaise traps were run simultaneously within 5-10 m of water sources from sunset to sunrise. Collecting jars were cleared at the end of each time session throughout the night. Insects were transferred to glassine envelopes, air dried the following day, and stored prior to identification.

Insects were examined under a dissecting microscope and classified to order. All samples were oven dried to a constant weight, and biomass (g) determined for each time session using an electronic balance. I standardized each sample by dividing biomass and the total number of insects in each order by sampling effort. Sampling effort was the number of hours both Malaise traps remained open during a time session. Biomass and insect numbers were then averaged within sites for each season.

### Statistical analyses

I performed all statistical analyses using either SPSS/PC+ v5.0.1 (Norusis 1992) or JMP (SAS Institute Inc., 1996). Data were transformed prior to analysis (using natural logarithm and square root transformations) to satisfy the assumptions of parametric tests. If these assumptions could not be met the appropriate nonparametric test was used.

Untransformed means are reported and used to plot all figures. Alpha of 0.05 was used in all statistical tests and data are presented as mean  $\pm$  1 standard error unless indicated otherwise.

I used chi-square goodness of fit tests (Zar 1984) to determine if sex ratios of captured bats differed from a 1: 1 ratio. Comparisons were made for individual species during the reproductive and non-reproductive seasons and for all species combined during each month of the study.

Nightly capture rates and ultrasound indices of activity (passes/30 min) were averaged within sites during each season. I used one-way Analysis of Variance (ANOVA) and Tukey's multiple comparisons procedure (Sokal and Rohlf 1987) to compare these measures of bat activity between seasons.

To examine temporal patterns of activity over the course of the reproductive season, I divided the season into 2-week time periods. Nightly capture rates and ultrasound indices of activity were averaged over 2-week time periods within each reproductive season. I used two-way ANOVA to examine the effects of year and time period on these indices of activity.

To examine temporal patterns of activity over the course of the night, I divided the night into 4 time sessions: session 1, sunset to 2 hours after sunset; session 2, 2 hours after sunset until 4 hours after sunset; session 3, was between time period 2 and 4 and changed duration over the course of the year; and session 4, 2 hours before sunrise until sunrise. Capture rates were calculated for each of the 4 time sessions during each night. These rates were then divided by the overall capture rate for that night to obtain the proportion

of captures that occurred during each time session. These proportions were then averaged at each site during a season. To obtain an ultrasound index of activity for each of the four nightly time sessions, I calculated the percentage of total passes that occurred during each time session. Since session 3 is longer than the other sessions, data were standardized by dividing by the length (in minutes) of each session prior to determining percentages.

Percentages were averaged at each site during a season. I used 2-way ANOVA to examine the effects of time session and season on these proportions.

Chi-square analysis (Zar 1984) was used to compare the proportion of insects in each order between the non-reproductive and both reproductive seasons combined. I used 2-way ANOVA to examine the effects of time session and season on several measures of insect abundance. I used one-way ANOVA to compare insect abundance between two-week time periods within both reproductive seasons combined. I combined data for this analysis because no insect data were collected from mid-May through mid-June in 1995.

I calculated correlation coefficients to examine the relationships between (1) nightly capture rates and activity (passes/30 minutes), (2) nightly capture rates and average temperature, minutes of moonlight (adjusted for moon phase), and insect biomass, and (3) activity and average temperature, minutes of moonlight (adjusted for moon phase) and insect biomass. I also examined correlations between biomass of insects and average temperature. Correlation coefficients were calculated within each season. Since nightly capture rates, ultrasound activity and insect abundance did not differ between the 1995 and 1996 reproductive seasons, data were combined prior to analyses.

## RESULTS

### Species Presence and Reproductive Status

I collected data on 82 nights (1,552 net hours) during the reproductive season (May through August), and 24 nights (522 net hours) during the non-reproductive season (September through April). I captured 718 individuals of six bat species during the reproductive season for an overall capture rate (all species combined) of 0.46 bats/net hour (Table 1.1, Appendix 1.2). During the non-reproductive season I captured a total of 48 individuals of five bat species for an overall capture rate of 0.09 bats/net hr (Table 1.1).

Pallid bats (*Antrozous pallidus*) and California leaf-nosed bats were the most common species captured at water sources on the Barry M. Goldwater Air Force Range. Western pipistrelle (*Pipistrellus hesperus*) was the third most common species captured during the reproductive season and the second most common captured during the non-reproductive season. Other species captured included big brown bat (*ptesicus fuscus*) and two species of *Myotis*, California myotis (*M. californicus*) and cave myotis (*M. velifer*). With the exception of the big brown bat, all species were captured during both the reproductive and non-reproductive seasons.

Recaptures were rare within the study area and occurred in only pallid bats and California leaf-nosed bats. Four of 300 (1.3%) pallid bats and 6 of 260 (2.6%) California leaf-nosed bats were captured on nights other than the night of their initial capture. Half of both species' recaptures occurred at sites other than the site of initial capture. The distance between these sites ranged from 1 to 4.5 km. In addition, one female California leaf-nosed bat was captured by another researcher during January 1997 at a mine adit

**Table 1.1. The number of bats captured by species and sex at 17 water sources on the Barry M. Goldwater Air Force Range, Arizona during the reproductive (May through August) 1995, 1996 and non-reproductive season (late September through mid-April) 1995-1996.**

Species	Reproductive season					Non-reproductive season				
	Males	Females	Total <sup>1</sup>	Sex ratio <sup>2</sup>	P <sup>3</sup>	Males	Females	Total <sup>1</sup>	Sex ratio <sup>2</sup>	P <sup>3</sup>
California leaf-nosed bat	118	136	260	0.86:1	0.2587	5	2	8	2.50:1	0.2568
California myotis	8	11	19	0.73:1	0.491	0	5	5	0:5	0.0253
Cave myotis	3	4	7	0.75:1	0.706	5	0	5	5:0	0.0253
Big brown bat	5	3	8	1.66:1	0.479	0	0	0		
Western pipistrelle	80	38	124	2.10:1	0.0001	7	5	13	1.40:1	0.5637
Pallid bat	172	123	300	1.39:1	0.0218	10	5	17	2.00:1	0.1963
Total	386	315	718	1.22:1	0.0073	27	17	48	1.58:1	0.1317

<sup>1</sup>Includes some individuals who were not identified to sex.

<sup>2</sup>Proportion of males to females.

<sup>3</sup>P-value from Chi-square goodness of fit test with 1 degree of freedom.

located on the Cabaza Prieta Wildlife Refuge (S. Schmidt, University of Arizona, unpublished data), approximately 75 km from the original capture site.

A significantly higher male:female ratio was found for western pipistrelles, pallid bats, and all species combined during both reproductive seasons (Table 1.1). This is due to significantly ( $P < 0.0001$ ) higher numbers of males captured in relation to females during May (Figure 1.1). The ratio of males to females was significantly greater than one during May for all three commonly captured species (Figure 1.2) (all  $P$ s  $< 0.02$ ). In all of these species, close to three times more males were captured compared to females during this month. Significantly higher numbers of western pipistrelle males compared to females were also captured during the month of June ( $P = 0.0278$ ). Pallid bat sex ratios did not differ from 1:1 for the remainder of the reproductive season while significantly more California leaf-nosed bat females than males were captured in July ( $P = 0.0002$ ).

There was a general trend of higher numbers of males to females captured during the non-reproductive season. This is likely due to significantly ( $P < 0.0001$ ) higher numbers of males ( $n = 9$ ) captured in relation to females ( $n = 0$ ) during September (Figure 1.1). However, when comparing the sex ratios of individual species, a statistically significant male biased sex ratio was only found for California myotis.

Reproductive females (pregnant, lactation, post-lactating) were captured in all 6 species (Table 1.2). The percentage of adult females reproductively active ranged from 68.9% for western pipistrelles to 100% for California leaf-nosed bats and big brown bats. Parturition likely began at the beginning of June for western pipistrelles, pallid bats, and California leaf-nosed bats (Figure 1.3). The first lactating pallid bat was captured during

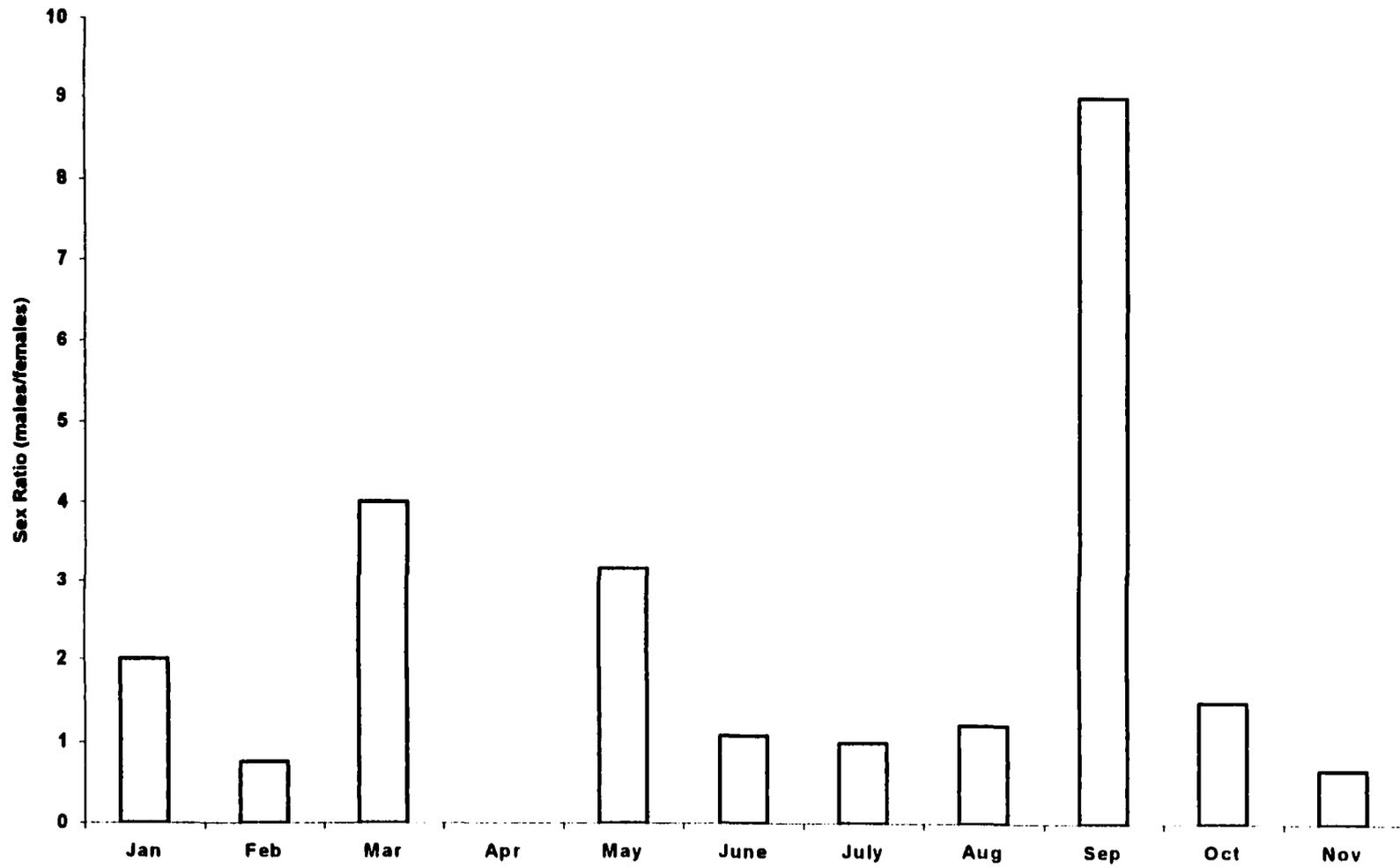
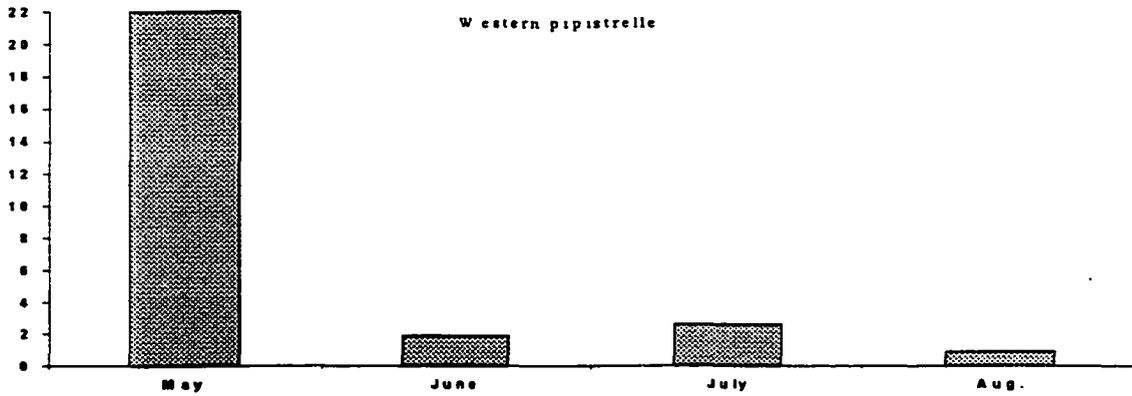
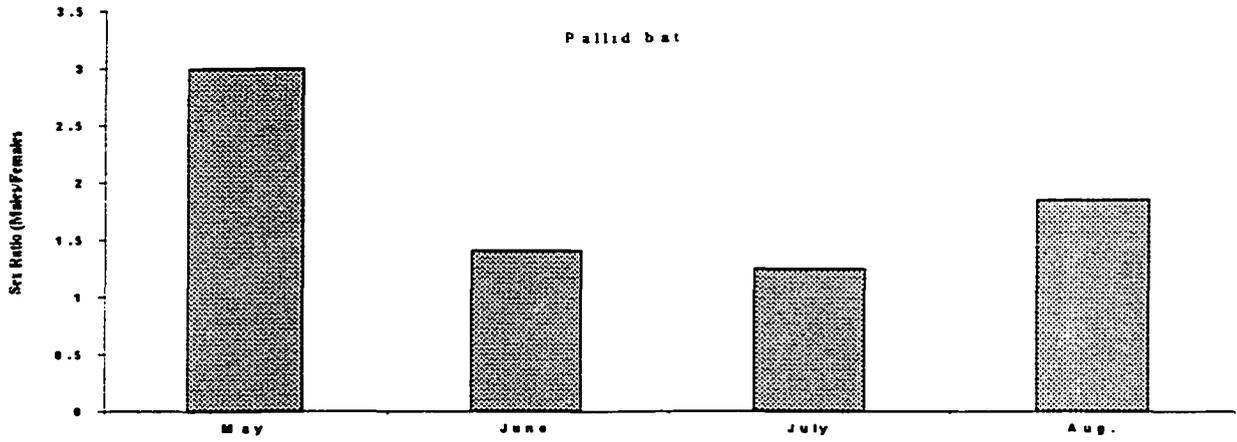
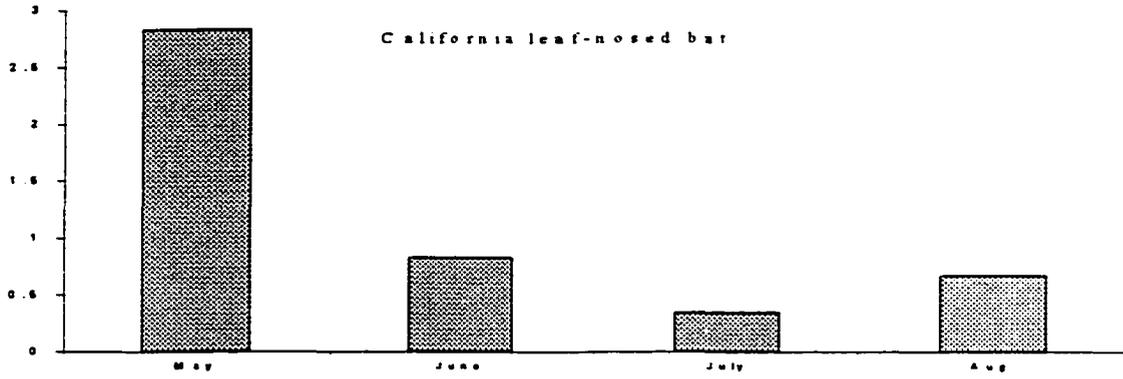


Figure 1. 1. Overall sex ratio of bats captured on the Barry M. Goldwater Air Force Range, Arizona, May 1995 through August 1996.

**Figure 1. 2. Sex ratios for California leaf-nosed bat, western pipistrelle, and pallid bats captured on the Barry M. Goldwater Airforce Range, Arizona during, May through August 1995, 1996.**



**Table 1.2. Reproductive status of adult female bats captured on the Barry M. Goldwater Air Force Range, Arizona, May-August 1995, 1996.**

<b>Species</b>	<b>Total captured</b>	<b>No. pregnant</b>	<b>No. Lactating</b>	<b>No. post-lactating</b>	<b>% reproductive</b>
California leaf-nosed bat	120	39	62	19	100.0
California myotis	10	3	5	0	80.0
Cave myotis	4	1	2	0	75.0
Big brown bat	3	0	2	1	100.0
Western pipistrelle	29	6	7	7	68.9
Pallid bat	83	3	52	21	91.6

the second week in June. Lactating California leaf-nosed bats and western pipistrelles began appearing the following week.

Juvenile western pipistrelles and pallid bats started appearing around the middle of July with juvenile California leaf-nosed bats appearing a week later (Figure 1.4). I continued to capture juveniles through August.

### Seasonal Activity

Overall capture rates and ultrasound activity (passes/30 min) did not differ significantly between the 1995 and 1996 reproductive season (Table 1.3). Both indices of activity, however, were significantly higher during both reproductive seasons compared to the non-reproductive season. Capture rates for pallid bats and California leaf-nosed bats were also significantly higher during the reproductive season compared to the non-reproductive season. No significant differences were found in the capture rates of western pipistrelles during the reproductive and non-reproductive season.

### Activity within the Reproductive Season

Overall capture rates, species-specific capture rates, and ultrasound activity did not differ significantly between 2-week time periods across years (Table 1.4). Significant year by 2-week time period interactions were found for pallid bats. This was due to two decreases in capture rates for this species in 1995 (end of May and beginning of August) in contrast to fairly level capture rates in 1996 (Table 1.4). A significant year by 2-week time period interaction was also found for ultrasound activity (passes/30 min). This was due to two peaks of ultrasound activity in 1995 (mid-May through mid-June, and mid-

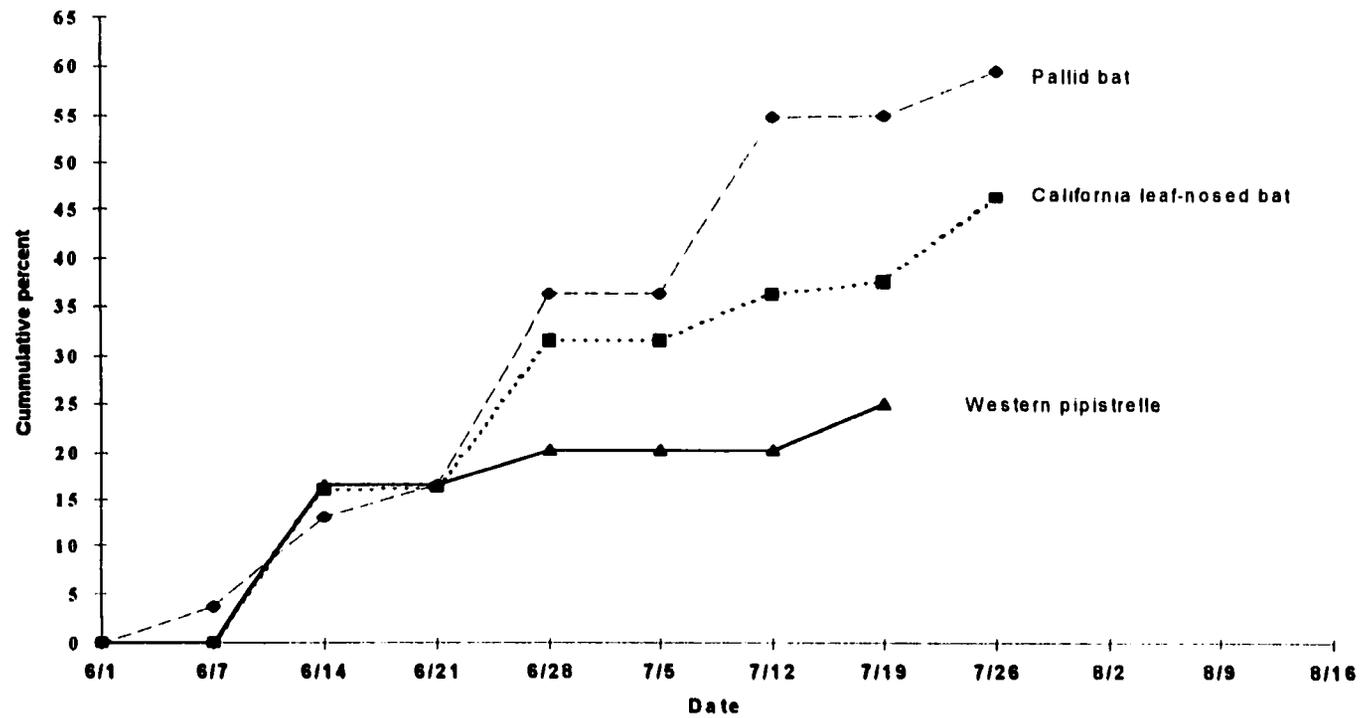


Figure 1.3. The cumulative percentages of captured bats that were lactating when captured during May through August, 1995, 1996 on the Barry M. Goldwater Air Force Range, Arizona.

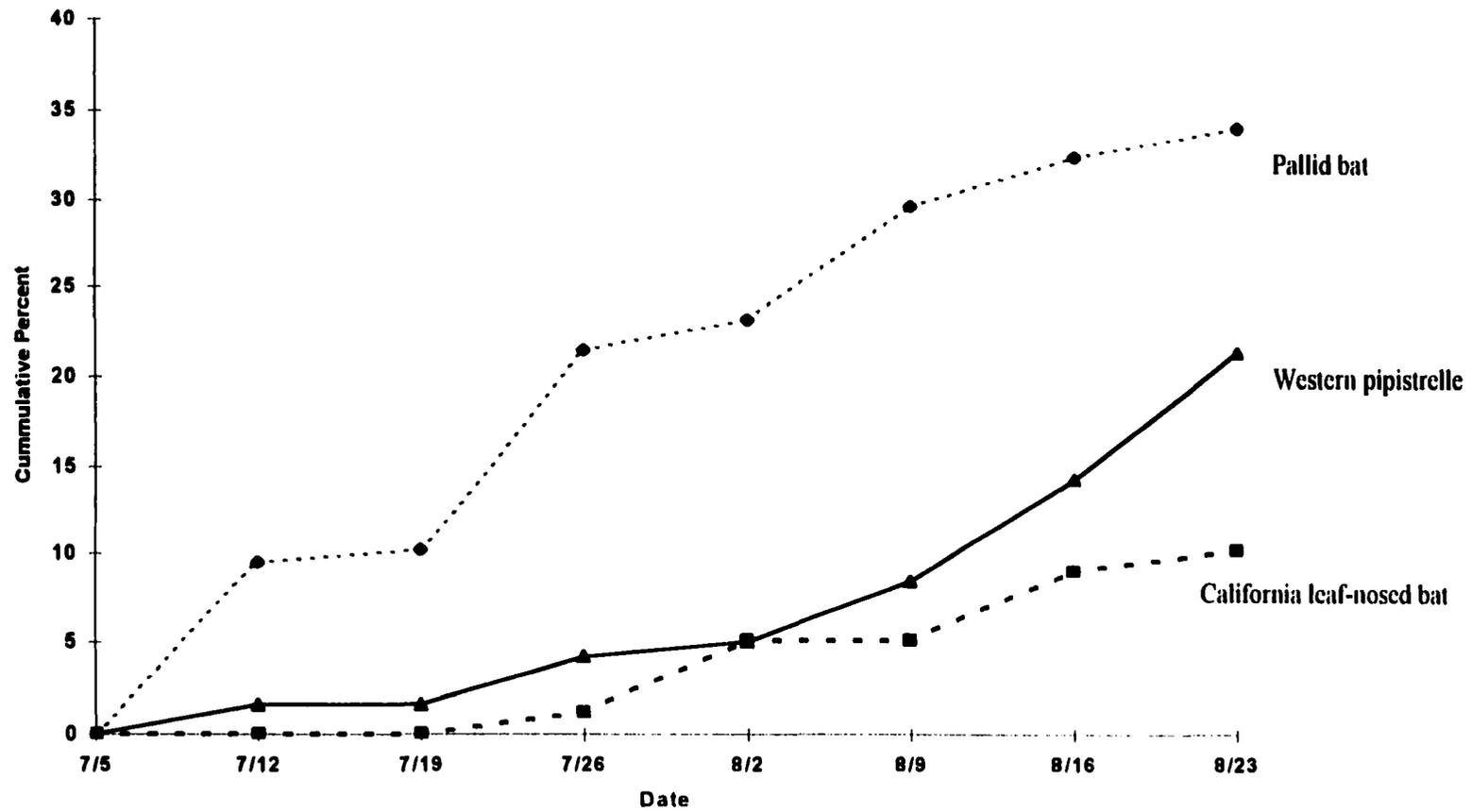


Figure 1.4. The cumulative percentages of captured bats that were juveniles during May through August, 1995, 1996 on the Barry M. Goldwater Air Force Range, Arizona.

**Table 1.3. Measures of bat activity ( $X \pm SE$ ) during the reproductive season (May through August) 1995, 1996 and the non-reproductive season (late September through mid-April) 1995-1996 at water sources on the Barry M. Goldwater Air Force Range, Arizona.**

Measure of activity	Reproductive season 1995 (n=14)	Reproductive season 1996 (n=17)	Non - reproductive season 1995-1996 (n=16)	<i>P</i> -value <sup>1</sup>
Total bats/net hr	0.57 $\pm$ 0.12 A	0.52 $\pm$ 0.12 A	0.10 $\pm$ 0.03 B	<0.0001
Pallid bat/net hr	0.22 $\pm$ 0.05 A	0.23 $\pm$ 0.09 A	0.03 $\pm$ 0.01 B	0.0018
Calif. leaf-nosed /net hr	0.18 $\pm$ 0.05 A	0.16 $\pm$ 0.04 A	0.01 $\pm$ 0.01 B	0.0015
W. pipistrelle/net hr	0.14 $\pm$ 0.05	0.11 $\pm$ 0.05	0.04 $\pm$ 0.02	0.1405
Passes/30 min	37.59 $\pm$ 9.73 A	24.49 $\pm$ 3.89 A	2.86 $\pm$ 0.75 B	<0.0001

<sup>1</sup>*P* associated with ANOVA of seasonal data. When  $P < 0.05$ , seasons with like letters were not significantly different based on Tukey's procedure.

**Table 1.4. Measures of bat activity ( $X \pm$  Standard error, (N)) over time within the reproductive season (May through August) at water sources on the Barry M. Goldwater Air Force Range, Arizona.**

Measure of Activity	Date	1995	1996	<i>P</i> -values <sup>1</sup>		
				Date	Year	Date x Year
Total bats/net hr	5/15 - 5/31	0.46 $\pm$ 0.18 (4)	0.64 $\pm$ 0.27 (9)	0.922	0.519	0.126
	6/1 - 6/15	0.53 $\pm$ 0.18 (7)	0.71 $\pm$ 0.25 (8)			
	6/16 - 6/30	0.45 $\pm$ 0.18 (3)	0.48 $\pm$ 0.11 (6)			
	7/1 - 7/15	0.55 $\pm$ 0.29 (4)	0.32 $\pm$ 0.23 (9)			
	7/16 - 7/31	0.79 $\pm$ 0.20 (10)	0.32 $\pm$ 0.16 (6)			
	8/1 - 8/18	0.39 $\pm$ 0.23 (8)	0.44 $\pm$ 0.10 (8)			
Calif. leaf-nosed/net hr	5/15 - 5/31	0.18 $\pm$ 0.15 (4)	0.27 $\pm$ 0.08 (9)	0.153	0.641	0.309
	6/1 - 6/15	0.27 $\pm$ 0.14 (7)	0.19 $\pm$ 0.13 (8)			
	6/16 - 6/30	0.28 $\pm$ 0.20 (3)	0.33 $\pm$ 0.07 (6)			
	7/1 - 7/15	0.19 $\pm$ 0.15 (4)	0.00 $\pm$ 0.00 (9)			
	7/16 - 7/31	0.22 $\pm$ 0.11 (10)	0.17 $\pm$ 0.12 (6)			
	8/1 - 8/18	0.11 $\pm$ 0.05 (8)	0.06 $\pm$ 0.04 (8)			
W. pipistrelle/net hr	5/15 - 5/31	0.19 $\pm$ 0.17 (4)	0.18 $\pm$ 0.14 (9)	0.199	0.299	0.117
	6/1 - 6/15	0.12 $\pm$ 0.06 (7)	0.19 $\pm$ 0.08 (8)			
	6/16 - 6/30	0.02 $\pm$ 0.02 (3)	0.01 $\pm$ 0.01 (6)			

Table 1.4 (Continued).

Measure of Activity	Date	1995	1996	<i>P</i> -values <sup>1</sup>		
				Date	Year	Date x Year
<b>W. pipistrelle/net hr</b>	7/1 - 7/15	0.03 ± 0.02 (4)	0.02 ± 0.01 (9)			
	7/16 - 7/31	0.10 ± 0.03 (10)	0.04 ± 0.03 (6)			
	8/1 - 8/18	0.23 ± 0.19 (8)	0.13 ± 0.04 (8)			
<b>Pallid bats/net hr</b>	5/15 - 5/31	0.00 ± 0.00 (4)	0.15 ± 0.07 (9)	0.396	0.316	0.037
	6/1 - 6/15	0.11 ± 0.05 (7)	0.22 ± 0.08 (8)			
	6/16 - 6/30	0.11 ± 0.09 (3)	0.14 ± 0.07 (6)			
	7/1 - 7/15	0.30 ± 0.13 (4)	0.29 ± 0.23 (9)			
	7/16 - 7/31	0.44 ± 0.11 (10)	0.11 ± 0.08 (6)			
	8/1 - 8/18	0.04 ± 0.02 (8)	0.25 ± 0.08 (8)			
<b>Passes/30 min</b>	5/15 - 5/31	40.8 ± 21.2 (4)	14.8 ± 4.9 (9)	0.583	0.256	0.024
	6/1 - 6/15	37.8 ± 14.1 (7)	38.3 ± 9.9 (8)			
	6/16 - 6/30	14.0 ± 5.9 (3)	17.5 ± 7.9 (6)			
	7/1 - 7/15	52.9 ± 18.5 (4)	15.3 ± 3.9 (9)			
	7/16 - 7/31	41.6 ± 13.5 (10)	12.9 ± 2.5 (6)			
	8/1 - 8/18	27.8 ± 15.1 (8)	43.2 ± 4.2 (8)			

<sup>1</sup>*P*-values from two-way analysis of variance.

July) in contrast to one peak in 1996 (early June).

#### Activity over the course of the night

Ultrasound activity (passes/30 min) occurred throughout the night during both reproductive seasons and non-reproductive seasons (Table 1.5). A significant time session by season interaction was found for ultrasound activity, indicating that the pattern of activity over the course of the night differed by season. During the non-reproductive season ultrasound activity was significantly higher during the first 2 hours after sunset (time session 1) compared to the rest of the night. During the 1995 reproductive season, a significantly higher percentage of bat passes were detected around sunset and sunrise (time sessions 1 and 4). In 1996, ultrasound activity did not differ between most time sessions. Activity during the 2 hours before sunrise (time session 4) though was significantly higher than that during the middle of the night (time session 3).

Similar to the ultrasound data, bat activity as determined by direct capture also occurred throughout the night with a significant time session by season interaction indicating that mist-netting activity over the course of the night differed by season (Table 1.5). During the non-reproductive season, a significantly greater proportion of captures (all species combined) occurred in the first 2 hours after sunset with declining percentages as the evening progressed. During the 1995 reproductive season, a significantly greater proportion of total captures (of all species combined) occurred in the 2 hours following sunset and the 2 hours preceding sunrise. No significant differences were found in 1996.

**Table 1.5. Average percentage of bat passes (standardized by length of time session) and average percentage of captures (standardized by effort) that occurred during different time periods of the night at water sources on the Barry M. Goldwater Air Force Range, Arizona. Data are presented as mean  $\pm$  1 standard error.**

Measure of activity	Season	N <sup>b</sup>	Time 1	Time 2	Time 3	Time 4	P-values <sup>a</sup>		
							Season	Time	Season X Time
Passes/30 min	Non-reproductive.	16	78.5 $\pm$ 5.0	13.0 $\pm$ 3.9	5.1 $\pm$ 1.6	3.4 $\pm$ 1.8	0.009	< 0.001	< 0.001
	1995 reproductive.	14	39.8 $\pm$ 3.9	19.5 $\pm$ 1.9	14.9 $\pm$ 1.8	25.8 $\pm$ 2.4			
	1996 reproductive	17	29.5 $\pm$ 3.0	20.5 $\pm$ 1.4	19.9 $\pm$ 2.5	30.1 $\pm$ 3.0			
Total bats/net hr	Non-reproductive.	16	68.2 $\pm$ 11.0	18.6 $\pm$ 7.8	10.6 $\pm$ 7.7	2.6 $\pm$ 2.6	0.207	< 0.001	< 0.001
	1995 reproductive.	14	34.3 $\pm$ 3.2	16.9 $\pm$ 3.0	17.1 $\pm$ 3.5	31.7 $\pm$ 3.5			
	1996 reproductive	17	18.5 $\pm$ 3.2	20.3 $\pm$ 5.2	25.0 $\pm$ 5.4	36.2 $\pm$ 5.1			
Calif. leaf-nosed bat/net hr	Non-reproductive.	16	37.5 $\pm$ 23.9	32.0 $\pm$ 19.4	30.5 $\pm$ 23.7	0.0 $\pm$ 0.0	0.880	0.334	0.143
	1995 reproductive.	14	32.2 $\pm$ 10.1	7.7 $\pm$ 2.5	32.2 $\pm$ 11.9	27.9 $\pm$ 7.31			
	1996 reproductive	17	13.2 $\pm$ 3.2	27.7 $\pm$ 8.4	31.9 $\pm$ 9.5	27.2 $\pm$ 7.7			
W. pipistrelle/net hr	Non-reproductive.	16	96.7 $\pm$ 3.3	3.3 $\pm$ 3.3	0.0 $\pm$ 0.0	0.0 $\pm$ 0.0	0.899	< 0.001	0.008
	1995 reproductive.	14	47.0 $\pm$ 9.9	8.3 $\pm$ 3.9	16.0 $\pm$ 10.8	28.7 $\pm$ 10.8			
	1996 reproductive	17	43.3 $\pm$ 12.6	13.8 $\pm$ 6.4	12.1 $\pm$ 5.9	30.8 $\pm$ 11.3			

**Table 1.5 (Continued).**

Measure of activity	Season	N <sup>b</sup>	Time 1	Time 2	Time 3	Time 4	P-values <sup>a</sup>		
							Season	Time	Season X Time
Pallid bat/net hr	Non-reproductive.	16	68.3 + 12.3	10.4 + 7.0	15.0 + 12.4	6.3 + 6.3	0.466	0.060	0.000
	1995 reproductive.	14	24.1 ± 7.4	14.8 ± 5.3	18.9 ± 5.1	42.2 ± 8.8			
	1996 reproductive	17	11.1 ± 3.9	21.5 ± 5.7	30.9 ± 7.7	36.5 ± 6.1			

<sup>a</sup>P-values from two-way analysis of variance. <sup>b</sup>Sample Size (Number of sites surveyed)..

The percentage of captures occurring during each time session did not differ significantly for California leaf-nosed bats during the non-reproductive season and either reproductive season (Table 1.5). Significant time by season interactions were found, however, for pallid bats and western pipistrelles. During the non-reproductive season, the percentage of western pipistrelle and pallid bat captures that occurred during the first 2 hours after sunset was significantly higher than those during the other three time sessions. No significant differences were found in western pipistrelle captures during either reproductive season. Pallid bat captures during the 1995 reproductive season were significantly higher 2 hours before sunrise compared to 2-4 hours after sunset (time session 2). In 1996 a significantly higher percentage of captures occurred during the middle of the night to sunrise (time sessions 3 and 4) compared with the first 2 hours following sunset (time session 1).

Although I could not identify all of the recordings made, most identifiable echolocation calls were recorded during the later part of the evening (time sessions 3 and 4) (Table 1.6). Again, western pipistrelle was the exception to this generalization with most of their calls being recorded just after sunset (time session 1) or just prior to sunrise (time session 4). During the non-reproductive season, most identifiable recordings came from the first 4 hours after sunset (time sessions 1 and 2). California leaf-nosed bat was one of the most common species captured yet these calls were rarely recorded or were recorded and were unidentifiable.

Big brown bats, cave myotis and California myotis were captured at too few sites

**Table 1.6. Percentage of ultrasound calls of each species detected on the Barry M. Goldwater Air Force Range, Arizona during different time periods of the night during the reproductive (May through August) 1995, 1996 and non-reproductive season (late September through mid-April) 1995-1996.**

<b>Species</b>	<b>Season</b>	<b>Time 1</b>	<b>Time 2</b>	<b>Time 3</b>	<b>Time 4</b>
<b>California leaf-nosed bat</b>	<b>Reproductive</b>	18.5 (12) <sup>1</sup>	21.5 (14)	30.8 (20)	29.2 (19)
	<b>Non-Reproductive</b>	0.0	0.0	0.0	0.0
<b><i>Myotis</i> species</b>	<b>Reproductive</b>	19.6 (9)	28.3 (13)	36.9 (13)	15.2 (7)
	<b>Non-Reproductive</b>	0.0	0.0	0.0	0.0
<b>Big brown bat</b>	<b>Reproductive</b>	38.1 (16)	9.5 (4)	23.8 (10)	28.6 (12)
	<b>Non-Reproductive</b>	0.0	0.0	0.0	0.0
<b>Western pipistrelle</b>	<b>Reproductive</b>	40.8 (304)	19.6 (146)	19.5 (145)	20.1 (150)
	<b>Non-Reproductive</b>	71.4 (15)	19.0 (4)	0.0	9.6 (0)
<b>Pallid bat</b>	<b>Reproductive</b>	17.7 (144)	23.7 (193)	37.3 (304)	21.3 (173)
	<b>Non-Reproductive</b>	70.6 (12)	17.6 (3)	0.0	11.8 (2)

<sup>1</sup>Number of identified recordings.

and in too few numbers to adequately examine temporal patterns of activity using average percent captures across study sites. However, when I examined when most of these rare individuals were captured, I found that the most occurred during the middle of night or predawn time session (Table 1.7).

### Insect Abundance

I captured seven different orders of insects in Malaise traps during the reproductive season and five different orders over the non-reproductive season (Figure 1.5). Most individuals captured during both seasons were from the orders Lepidoptera and Diptera. The proportion of insects in each order, however, was significantly different between the non-reproductive season and both reproductive seasons combined ( $\chi^2_5 = 93.1$ ,  $P < 0.0001$ ). Lepidoptera and Diptera made up higher percentages of the total captures during the non-reproductive season, whereas Hymenoptera, Homoptera and Coleoptera were higher during the reproductive seasons.

There was a significant difference in insect biomass (g/hr) across seasons, with biomass being higher during both reproductive seasons compared to the non-reproductive season (Table 1.8). Insect biomass also differed significant across time sessions. During the non-reproductive and 1996 reproductive season, insect biomass was significantly higher during the first 4 hours after sunset (time sessions 1 and 2) compared to the rest of the night. Insect biomass during the 1995 reproductive season was significantly higher during the first four hours after sunset and the 2 hours preceding sunrise (time session 4) compared to the middle of the night (time session 3).

**Table 1.7. Percentage of individuals of each species captured on the Barry M. Goldwater Air Force Range, Arizona during different time periods of the night during the reproductive (May through August) 1995, 1996 and non-reproductive season (late September through mid-April) 1995-1996.**

Species	Season	Time 1	Time 2	Time 3	Time 4
California leaf-nosed bat	Reproductive	21.0 (4)	15.8 (3)	31.6 (6)	31.6 (6)
	Non-Reproductive	80.0 (4)	20.0 (1)	0.0	0.0
Cave myotis	Reproductive	28.6 (2)	28.6 (2)	42.8 (3)	0.0
	Non-Reproductive	20.0 (1)	80.0 (4)	0.0	0.0
Big brown bat	Reproductive	0.0	12.5 (1)	50.0 (4)	37.5 (3)
	Non-Reproductive	0.0	0.0	0.0	0.0

<sup>1</sup>Number of individuals captured

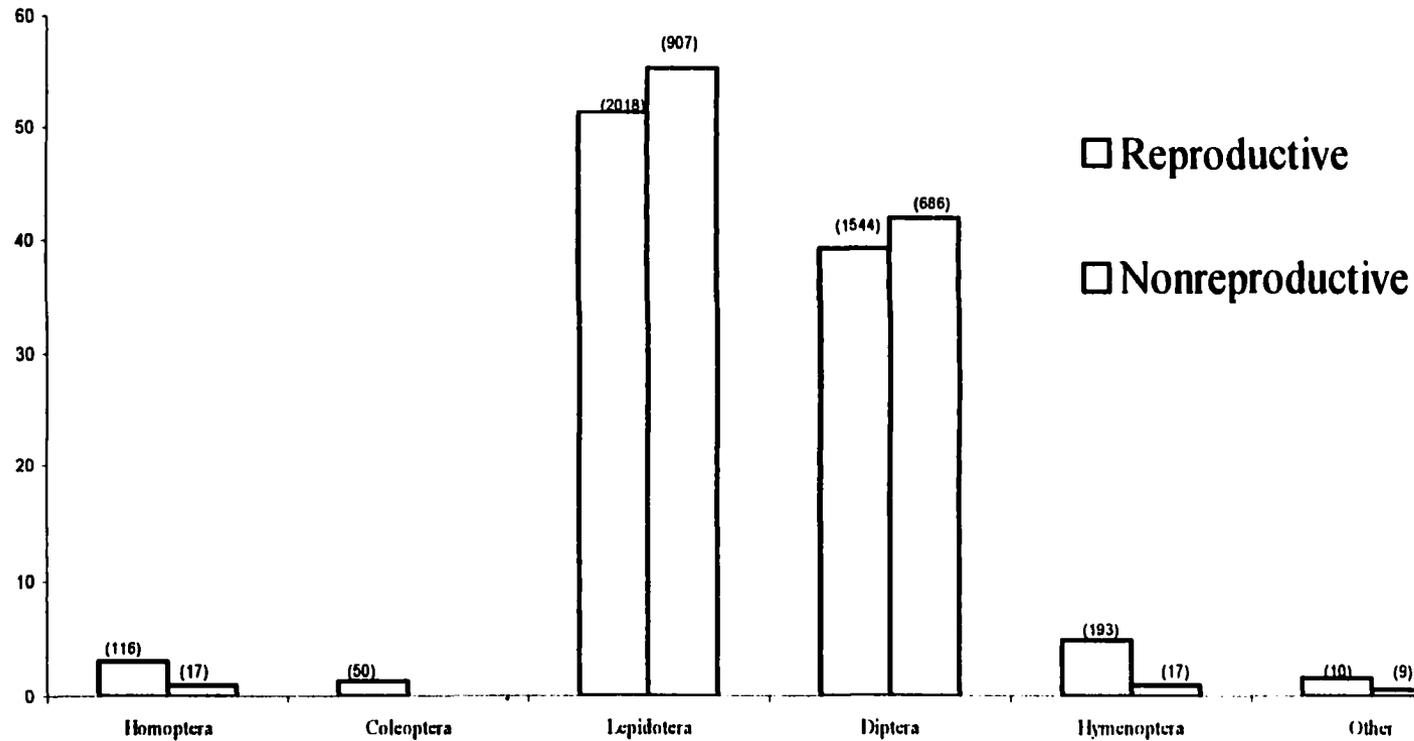


Figure 1.5. Percentage of insects in each order that were capture in Malaise traps on the Barry M. Goldwater Air Force Range, Arizona during the non-reproductive (mid-September 1995 through mid-April 1996) and both reproductive seasons combined (May through August 1995, 1996). The number of individuals captures is shown in parentheses above each order. The orders Collembola and Neuroptera were combined into the category "Other".

The number of Lepidoptera/hr and Diptera/hr also differed significantly across seasons with numbers being significantly higher during the reproductive seasons compared to the non-reproductive season (Table 1.8). Lepidoptera and Diptera numbers were also significantly different across time sessions. During both reproductive seasons and the non-reproductive season, significantly higher numbers of Lepidoptera and Diptera were collected during time 1.

Within the reproductive season, insect biomass (g/hr) was significantly higher in August compared to earlier in the season (mid-May through mid-July) (Table 1.9). Diptera (numbers/hr) did not differ between any of the two-week time periods. Lepidoptera (numbers/hr) were significantly higher in August compared to the middle to the end of May.

I found no significant linear relationship between insect biomass and the indices of bat activity derived from either the ultrasonic detectors ( $r = 0.166$ ,  $n = 70$ ,  $P = 0.169$ ) or mist-netting ( $r = 0.11$ ,  $n = 70$ ,  $P = 0.358$ ) during both reproductive seasons combined. During the non-reproductive season, insect biomass was positively correlated with activity derived from ultrasound data ( $r = 0.648$ ,  $n = 23$ ,  $P = 0.0008$ ) and mist-netting data ( $r = 0.497$ ,  $n = 23$ ,  $P = 0.0158$ ).

There was no significant linear relationship between insect biomass and minutes of moonlight during both reproductive seasons combined ( $r = 0.178$ ,  $n = 70$ ,  $P = 0.1400$ ) and the non-reproductive season ( $r = -0.352$ ,  $n = 23$ ,  $P = 0.1000$ ). Insect biomass was also not significantly correlated with temperature during either season ( $r = 0.057$ ,  $n = 70$ ,  $P = 0.639$  reproductive season,  $r = -0.388$ ,  $n = 23$ ,  $P = 0.0676$  non-reproductive season).

**Table 1.8. Measures of insect abundance during different time periods of the night at water sources on the Barry M. Goldwater Air Force Range, Arizona. Data are presented as mean  $\pm$  1 standard error.**

Measure	Season	N <sup>2</sup>	Time 1	Time 2	Time 3	Time 4	P-values <sup>1</sup>		
							Season	Time	Season X Time
Insect biomass (g/hr)	Non-reproductive	16	0.14 $\pm$ 0.02	0.08 $\pm$ 0.01	0.02 $\pm$ 0.01	0.03 $\pm$ 0.01	< 0.0001	< 0.0001	0.083
	1995 reproductive	14	0.16 $\pm$ 0.02	0.14 $\pm$ 0.02	0.09 $\pm$ 0.01	0.12 $\pm$ 0.01			
	1996 reproductive	17	0.13 $\pm$ 0.02	0.09 $\pm$ 0.01	0.06 $\pm$ 0.01	0.08 $\pm$ 0.01			
Total Lepidoptera/hr	Non-reproductive	16	8.6 $\pm$ 2.2	3.9 $\pm$ 1.2	1.2 $\pm$ 0.4	0.9 $\pm$ 0.4	< 0.0001	< 0.0001	0.354
	1995 reproductive	14	7.1 $\pm$ 1.3	3.4 $\pm$ 0.8	1.8 $\pm$ 0.3	2.3 $\pm$ 0.4			
	1996 reproductive	17	5.9 $\pm$ 1.1	2.9 $\pm$ 0.5	1.9 $\pm$ 0.4	1.9 $\pm$ 0.4			
Total Diptera/hr	Non-reproductive	16	10.7 $\pm$ 4.7	1.4 $\pm$ 0.5	0.4 $\pm$ 0.2	0.9 $\pm$ 0.5	< 0.0001	< 0.0001	0.127
	1995 reproductive	14	9.0 $\pm$ 7.2	1.7 $\pm$ 0.6	0.7 $\pm$ 0.2	0.7 $\pm$ 0.2			
	1996 reproductive	17	5.4 $\pm$ 0.12	2.7 $\pm$ 0.6	1.8 $\pm$ 0.4	1.9 $\pm$ 0.4			

<sup>1</sup>P-values from two-way analysis of variance.

<sup>2</sup>Sample Size (number of sites surveyed).

**Table 1.9. Measures of insect abundance across dates on the Barry M. Goldwater Air Force Range, Arizona, May through August 1995, 1996.**

Measure	Date	N <sup>1</sup>	X ± 1 standard error	P-value <sup>2</sup>
Insect Biomass (g/hr)	5/15 - 5/31	9	0.050 ± 0.004 A	< 0.0001
	6/1 - 6/15	8	0.046 ± 0.002 A	
	6/16 - 6/30	7	0.071 ± 0.013 A	
	7/1 - 7/15	10	0.071 ± 0.009 A	
	7/16 - 7/31	13	0.112 ± 0.017 AB	
	8/1 - 8/18	12	0.164 ± 0.032 B	
Lepidoptera (number/hr)	5/15 - 5/31	9	1.836 ± 0.583 A	0.0179
	6/1 - 6/15	8	1.540 ± 0.209 AB	
	6/16 - 6/30	7	2.608 ± 0.856 AB	
	7/1 - 7/15	10	2.136 ± 0.525 AB	
	7/16 - 7/31	13	2.675 ± 0.525 AB	
	8/1 - 8/18	12	5.929 ± 1.486 B	
Diptera (number/hr)	5/15 - 5/31	9	0.033 + 0.017	0.8501
	6/1 - 6/15	8	0.055 + 0.021	
	6/16 - 6/30	7	0.016 + 0.016	
	7/1 - 7/15	10	0.058 + 0.034	
	7/16 - 7/31	13	0.077 + 0.042	
	8/1 - 8/18	12	0.108 + 0.094	

<sup>1</sup>Sample size (number of sites surveyed). <sup>2</sup>P associated with one-way ANOVA, dates with the same letters were not significantly different based on Tukey's procedure.

### Activity in Relation to Environmental Factors

Ultrasound activity was not significantly correlated with minutes of moonlight in either the reproductive seasons combined ( $r = -0.023$ ,  $n = 79$ ,  $P = 0.844$ ) or the non-reproductive season ( $r = -0.181$ ,  $n = 24$ ,  $P = 0.397$ ). Capture rates for all species combined were also not significantly correlated with minutes of moonlight in either the reproductive season ( $r = -0.109$ ,  $n = 79$ ,  $P = 0.336$ ) or the non-reproductive season ( $r = -0.378$ ,  $n = 24$ ,  $P = 0.068$ ). Ultrasound activity was positively correlated with temperature during both the reproductive season ( $r = 0.293$ ,  $n = 79$ ,  $P = 0.009$ ) and the non-reproductive season ( $r = 0.491$ ,  $n = 24$ ,  $P = 0.015$ ). Capture rates for all species combined, however, were not significantly correlated with temperature during either season ( $r = 0.043$ ,  $n = 79$ ,  $P = 0.710$  reproductive season,  $r = 0.379$ ,  $n = 24$ ,  $P = 0.068$  non-reproductive season).

## DISCUSSION

I determined the presence of six species of bats utilizing water sources in southern Arizona during the reproductive season. All but one of these species was also present during the non-reproductive season. There are three other species that have been reported in southern Arizona during the reproductive season (Hoffmeister 1986): the lesser long-nosed bat (*Leptonycteris curasoae*), a federally endangered species (Shull 1988), the Mexican free-tailed bat (*Tadarida brasiliensis*), and the pocketed free-tailed bat (*Nyctinomops femorosacca*). It is unlikely, however, that these species were present in our study area and were missed by my survey techniques. Dalton et al. (1994) found scant evidence that the lesser long-nosed bat occurs in either the Sand Tank or Saucedá mountain areas of the BMGR. In addition, both the Mexican free-tailed bat and the pocketed free-tailed bat belong to the family Molossidae. Molossids have long narrow wings that enable them to fly quickly over long distances but make them less maneuverable in flight (Findley et al. 1972). Thus, these species need large surface areas ( $> 6 \text{ m}^2$ ) from which to drink (Cross 1986, LaVal 1973), areas larger than those available within the study area.

One of the biases associated with mist-netting is that repeated capture efforts at a site may allow some individuals to learn to avoid capture (Kunz et al. 1996, Kunz and Brock 1975). This may have occurred at my study sites as very few individuals were recaptured following their initial capture, a phenomena reported by others (LaVal 1970, Kunz 1973, LaVal and Fitch. 1977). Although, I have little data on how often individual bats use the same areas, radiotelemetry studies indicate that many species show fidelity to

foraging sites with individuals returning nightly (Brigham 1991, Hickey and Fenton, 1996, Rainey and Pierson 1996). Many species of bats, however, are opportunistic and will focus their feeding efforts on local concentrations of insects (Fenton and Morris 1976, Vaughan 1980). Since insect availability was highly variable within and between water sources at my study area it is likely that bats here do not show nightly fidelity to the same site. I do have some indication of this, half of my recaptures came from sites other than their original capture, indicating that at least some individuals use more than one water source within the study area.

All the species present at my study sites are insectivorous (Barbour and Davis 1969). Insectivorous bats in the United States generally hibernate during the late fall and winter. Some individuals and populations hibernate within their summer range, however, the majority of temperate bat species migrate relatively short distances (10-500 kilometers) between their summer and winter roosts (Griffin 1970). The California leaf-nosed bat is physiologically incapable of entering torpor (a controlled decrease of body temperature below normothermic levels) and is active year round throughout its range (Bell et al. 1986). Although my capture rates were very low, I did capture all species, with the exception of the big-brown bat, during the non-reproductive season, indicating that most bat species in my study area are at least partially active year round. O'Farrell et al. (1967) and O'Farrell and Bradley (1970) reported similar results for bat species in southern Nevada. Big brown bats have been netted in southern Arizona during many winter nights, indicating that if they do hibernate in Arizona it is probably for short periods of time (Hoffmeister 1986). My failure to capture this species during the non-

reproductive season may be an artifact of sample size as few individuals were ever captured suggesting that this species is rare within the study area.

O'Farrell and Bradley (1977) believe most bats probably arouse during the winter solely to drink. Water is an important factor to hibernating bats during arousal (Twente 1955) and humidity and available drinking water are conducive to winter activity (Kallen 1964). Although insect biomass was significantly lower during the fall and winter at my study sites, I did find a significant positive correlation between insect biomass and both ultrasound activity and overall capture rates during this time of the year suggesting that some foraging may occur during the fall and winter.

I captured slightly more male bats during the fall and winter than females. Male biased sex ratios have been reported for bat species inhabiting desert regions during the winter (Ruffner et al. 1979, O'Farrell and Bradley 1970, Cross 1965), while others have documented no difference in winter captures between the sexes (O'Farrell et al. 1967, Szewczak et al. 1998). Unequal sex ratios could be an indication that males and females are not wintering in the same areas. Sexual segregation is common in many bat species during the summer months but there is little evidence it occurs at other times of the year (Neuwelner 2000). It may be that males are more active than females during the fall and winter in the Sonoran Desert.

During the reproductive season adult male and females of many temperate bat species occupy geographically separated habitats. It has been speculated that males and non-reproductive females are able to inhabit areas of lower food availability because they do not have the high energetic demands of pregnancy and lactation (Kunz 1974, Thomas

1988) and because they can optimize energy and water savings by entering torpor daily (Hickey and Fenton 1996, Cryan et al. 2000). Pregnant females who enter torpor delay parturition which could leave their offspring with too short a season to acquire the fat stores needed for winter survival (Rydell 1989). I found no evidence that males move to different geographical areas during the summer months. With the exception of the month of May, sex ratios for the three most common species in my study site were equal during the reproductive season.

Sex ratios were skewed towards males during May but I do not feel that this is due to any geographical separation of the sexes. In May females are in the late stages of pregnancy. Although pregnancy is energetically demanding, many researchers have noted a reduction in foraging time towards the end of pregnancy (Kunz 1974, Racey 1982, Rydell 1993, Kunz et al. 1995). It is believed that the added weight of the fetus at this time reduces foraging efficiency making the energetic gains from foraging less than demands of flight (Kunz et al. 1995). This appears to be the case in southern Arizona as females were not captured as frequently as males at this time but later in the season sex ratios were roughly equal.

Reproductive condition has been shown to affect bat activity in an area (Anthony et al. 1981, Brigham 1989, Audet 1990, Barclay 1991, Wilkinson 1992). Lactating females of several bat species have been documented foraging for up to twice as long as pregnant and post lactating bats (Brigham 1991, Wilkinson 1992, Rydell 1993). Therefore, I hypothesised that I would see changes in bat activity over the course of the summer as the reproductive condition of females changed. Specifically, I expected to see

an increase of activity when females began lactating. At my study site, parturition occurred sometime in early to mid-June for western pipistrelles, pallid bats, and California leaf-nosed bats. I did not however, see a significant peak of activity at this time. Activity as measured by capture rates and ultrasound data was not significantly different though between 2-week time period across years.

I also did not see an increase in activity in mid-July when juvenile bats became volant. However, the majority of bats captured in July and August were juveniles indicating that adult bats may have learned to avoid my nets by the time juveniles began to fly. This explanation though, does not explain why activity as indicated by the ultrasound detectors did not increase with juveniles entering the population. A more likely explanation would be that adult females at this time were in the late phases of lactation and may not have had to forage as frequently as they had earlier in the season. Thus, any increase in activity due to the presence of volant young was offset by a decrease in the activity of adult females.

An increase in insect abundance late in the reproductive season also did not seem to have any affect on activity as determined by mist-netting or ultrasonic detectors within my study area. Although others (Richards 1989, de Jong and Ahlen 1991, Hickey and Fenton 1996) have found activity to be positively correlated with insect abundance, I found no such relationship during the reproductive season. Although I detected feeding buzzes, high pulse repetition rates associated with attacks on prey (Fenton and Bell 1979), at all water sources, it is possible that individuals may have been coming to the water sources primarily to drink and were doing most of their foraging elsewhere. If this were

the case, than an increase in insect activity at water sources would not necessarily lead to an increase in bat activity. In addition, pallid bats have been documented alighting on the ground to feed on large flightless prey (Hermanson and O'Shea 1983). Since Malaise traps only collect flying insects they may not provide an adequate sample of insects available as food for this species.

I found no consistent pattern of temporal resource partitioning between species at my study site during the reproductive season. There was no difference in capture rates of California leaf-nosed bats or western pipistrelles between any time period of the night. Patterns obtained from ultrasound data were similar. Echolocation calls from both species were recorded during all time periods indicating periods of activity throughout the night. Although, the highest percentage of echolocation calls identifiable as California leaf-nosed bats were recorded during the 2 hours preceding sunrise (time session 4) the number of identifiable echolocation calls for this species was small. California leaf-nosed bats are in the family Phyllostomidae, a group of bats that are not readily studied with bat detectors because of their low intensity echolocation calls (Fenton 1997). Thus this species was probably not detected by the ultrasonic detector very frequently.

Temporal patterns of activity for pallid bats were also inconsistent. Most pallid bats were captured either in the post-sunset or predawn time sessions in 1995. In 1996 captures were highest in the middle of the night (time session 3) and during the predawn time session. The majority of the identifiable pallid bat ultrasound recordings also came from time sessions 3 and 4. In northern New Mexico and Arizona, most pallid bat activity was found to occur in the first 2 hours after sunset (Jones 1965). LaVal (1973),

however, found pallid bats to be active throughout the night in Texas with no distinct peaks of activity.

In general most activity, as determined by both ultrasound and mist-netting data (all species combined), was highest during the first 2 hours following sunset and the two hours preceding sunrise during the 1995 reproductive season. This bimodal pattern of activity with peaks at dusk and before dawn is typical of bats in many areas (Cockrum and Cross 1964, Jones 1965, O'Farrell and Bradley 1970, Ekert 1978) with activity during the post sunset period generally being higher than that of the predawn period (Kunz and Brock. 1975, Walsh and Mayle 1991, Hayes 1997). I, however, found unusually high activity during the predawn period despite low insect abundance. I speculate that bats at this time may be drinking at the water sources before returning to their day roost and that little foraging is occurring in these areas.

Within the non-reproductive season, the pattern of bat activity as determined by both mist-netting and ultrasound data was unimodal with most activity occurring during the first 2 hours following sunset, and almost no activity occurring later than 4 hours after sunset. This pattern of activity reflected the activity of insects, with insect biomass being highest during the first 2 hours after sunset (time session 1).

Bat activity increased with increasing temperature during both reproductive season and the non-reproductive season. Walsh and Mayle (1991) found that activity as determined by ultrasonic detectors increased with higher temperatures at preferred sites but had little effect at sites of low activity. Overall capture rates, however, were not significantly correlated with temperature during either season.

I found no relationship between moonlight and bat activity, as determined by both ultrasound and mist-netting data during any season. This contrasts with several studies that have found moonlight to suppress bat activity (Fenton et al. 1977, Reith 1982, Adam et al. 1994). However, many other studies have found no evidence that activity of insectivorous bats varies directly with intensity and/or duration of moonlight (Rydell 1991, Negraeff and Brigham 1995, Hayes 1997, Hecker and Brigham 1999). Although moonlight has been found to depress activity of nocturnal insects (Williams and Singh 1951), it had no affect on insect biomass collected in Malaise traps at my study sites during either the reproductive or non-reproductive season. Hardwick (1972) and Schafer (1976) found that insect activity relative to the lunar cycle varied by site and species. The majority of insects that I collected were from the order Lepidoteran (moths) and Hardwick (1972) found that noctuid moths exhibit no change in activity attributable to changes in lunar light.

## MANAGEMENT IMPLICATIONS

Mist-netting and ultrasonic detectors provided similar results in terms of temporal patterns of bat activity at my study sites in the Sonoran Desert of southern Arizona. Thus, it appears that either method could be used to address questions concerning bat activity at water sources within this region.

Not surprisingly I found significantly higher bat activity during the reproductive season compared to the non-reproductive season. Which season to survey during depends upon research objectives. However, my data can be used to develop guidelines for the best times to conduct bat surveys within each season.

During the reproductive season, I found no significant differences in bat activity during any of the 2-week time periods. Thus activity data collected anytime during the reproductive season should be representative of the rest of the season. However, it has been recommended that investigators try to avoid mist-netting females during late pregnancy and during early lactation in order to reduce stressing these individuals (Kunz et al. 1996). Most of the females I captured were pregnant during the end of May with parturition occurring at the beginning of June for western pipistrelles, pallid bats, and California leaf-nosed bats. Therefore, it may be better to focus mist-netting efforts later in the season such as the end of July. During this time, reproductive information could still be collected, as most females would be in late lactation, but with less stress to these individuals. In addition, adult to juvenile ratios could be assessed at this time, which would provide an index of reproductive output.

Most bat activity within the reproductive season occurred during the first 2 hours

after sunset and the 2 hours before sunrise. However, many bat studies are only conducted during the first 3-4 hours after sunset. Based on my results, it may be better to split this effort and conduct surveys at sunset and again prior to sunrise. Also many of the rare species (California myotis, Cave myotis, big brown bat) at my study sites were captured during the middle of the night. Therefore, if the objectives of a study are to determine species presence, all night surveys may be necessary to identify rarer species.

I did not gather data on activity patterns over the whole non-reproductive season therefore, I can not provide details on when is the best time to survey within this season. However, within this season, activity was significantly higher during the first 2 hours following sunset with little activity after this time. Most surveying effort should be concentrated during this time. The lack of information on basic geographic distributions, habitat associations, and population status of bat species is a major factor hindering the development of management procedures to protect bat populations. My study provides much needed information on the seasonal and spatial distribution of bats in a portion of the Sonoran Desert of southern Arizona. My data, collected using standardized methodology, also provides a baseline of bat activity upon which future studies can be compared. In addition, the information I gathered on temporal patterns of activity can be used in determining when to focus sampling efforts when designing inventory and monitoring programs.

**Appendix 1.1. Location and description of survey sites on the Barry M. Goldwater Range 1995-1996.**

Site	UTM <sup>a</sup>	Elevation (m)	Type	Size (m <sup>2</sup> )
Bender Springs 1	E371100, N3616700	910	Spring	2.75
Bender Springs 2	E372000, N3616200	840	Catchment	1.75
Big Horn	E366300, N3623300	550	Catchment	2.00
Javelina Mountain	E374200, N3623400	720	Catchment	2.10
Johnson Well 1	E372000, N3618600	780	Catchment	2.60
Johnson Well 2	E375300, N3614400	750	Catchment	2.25
Midway	E334800, N3621000	410	Catchment	2.60
Papago Mine	E357800, N3628400	550	Catchment	1.50
Ryan's Canyon 1	E346500, N3603600	660	Catchment	2.60
Ryan's Canyon 2	E347300, N3599200	660	Catchment	0.85
Ryan's Canyon 3	E343000, N3603100	610	Catchment	0.85
Ryan's Canyon 4	E339300, N3610100	545	Catchment	0.90
Sauceda Tank	E335200, N3614500	545	Tinaja	0 to 2.5
Thanksgiving Day Tank	E333200, N3613500	425	Mod. Tinaja	2 to 6.0
Tom Thumb 1	E350900, N3599100	725	Catchment	0.70
Tom Thumb 2	E349600, N3603500	660	Catchment	0.70
White Tank	E328300, N3600000	395	Tinaja	0 to 2.5

<sup>a</sup>Universal Transverse Mercator (UTM) Coordinates.

Appendix 1.2. Bats mist-netted at 17 water sources, Barry M. Goldwater Range, Arizona, 1995- 1996.

Site	Date	Net-hrs	Species	Female	Male	Unknown	Total
Bender Springs 1	13 Jun 95	17.7	Calif. leaf-nosed	1	0	0	1
			California myotis	1	1	0	2
			Western pipistrelle	5	2	0	7
			Pallid bat	3	2	0	5
	24 Jul 95	18.5	California myotis	0	1	0	1
			Big brown bat	2	2	0	4
			Western pipistrelle	1	3	0	4
			Pallid bat	5	13	1	19
	29 Sep 95	24.0	No captures	0	0	0	0
	13 Apr 96	22.0	Pallid bat	0	0	1	1
	10 Jun 96	19.0	California myotis	1	0	0	1
			Big brown bat	0	2	0	2
			Western pipistrelle	0	1	0	1
			Pallid bat	0	14	0	14
	13 Jul 96	19.0	Pallid bat	1	0	0	1
	6 Aug 96	20.0	Calif. leaf-nosed	1	0	0	1
Western pipistrelle			2	1	1	4	
Pallid bat			0	4	0	4	
Bender Springs 2	12 Jun 95	26.9	California myotis	1	1	0	2
			Western pipistrelle	1	4	0	5
			Pallid bat	0	7	1	8
	23 Jul 95	27.8	Western pipistrelle	1	1	0	2
			Pallid bat	2	22	0	24
	28 Sep 95	35.6	Cave myotis	0	1	0	1
			Pallid bat	0	1	1	2
	12 Apr 96	24.0	No captures	0	0	0	0
	9 Jun 96	28.5	Pallid bat	0	8	0	8
	14 Jul 96	9.0	Pallid bat	0	1	0	1
	7 Aug 96	30.0	Pallid bat	0	4	1	5
	Big Horn	9 Feb 96	26.0	No captures	0	0	0
6 Jun 96		19.0	Western pipistrelle	1	4	0	5
7 Jul 96		19.0	Western pipistrelle	0	1	0	1
Javelina Mountain	27 Jun 95	17.6	Cave myotis	1	0	0	1
			Western pipistrelle	1	0	0	1
	26 Jul 95	18.5	Western pipistrelle	2	1	0	3
			Pallid bat	0	1	0	1
	7 Feb 96	26.0	Western pipistrelle	0	1	0	1
	21 May 96	20.0	Cave myotis	1	0	0	1
Johnson Well 1	5 Jul 96	19.0	No captures	0	0	0	0
	21 May 95	12.0	Western pipistrelle	0	0	1	1
	8 Jul 95	17.7	Big brown bat	1	0	0	1
Pallid bat			0	4	0	4	

## Appendix 1.2 (Continued).

Site	Date	Net-hrs	Species	Female	Male	Unknown	Total		
Johnson Well 1	12 Aug 95	27.0	Cave myotis	0	1	0	1		
			Western pipistrelle	0	1	1	2		
			Pallid bat	0	1	0	1		
	20 Mar 96	24.0	Pallid bat	0	2	0	2		
			8 Jun 96	19.0	Western pipistrelle	0	1	0	1
	Johnson Well 2	10 Jul 96	19.0	Pallid bat	0	4	0	4	
				9 Aug 96	20.0	Pallid bat	0	1	0
No captures				0	0	0	0		
Johnson Well 2	14 Jun 95	17.7	Calif. leaf-nosed	15	1	0	16		
			Cave myotis	1	0	0	1		
			Western pipistrelle	1	3	0	4		
			Pallid bat	3	0	0	3		
	25 Jul 95	18.5	Calif. leaf-nosed	2	0	0	2		
			California myotis	1	0	0	1		
			Western pipistrelle	0	1	1	2		
			Pallid bat	4	7	0	11		
			13 Aug 95	11.0	Calif. leaf-nosed	2	1	0	3
	30 Sep 95	24.0	Western pipistrelle	1	1	0	2		
			Pallid bat	0	1	0	1		
			Calif. leaf-nosed	0	2	0	2		
			Cave myotis	0	4	0	4		
			Pallid bat	0	1	0	1		
	20 Apr 96	21.7	No captures	0	0	0	0		
	11 Jun 96	19.0	Calif. leaf-nosed	0	2	0	2		
			Western pipistrelle	0	1	0	1		
			Pallid bat	1	1	0	2		
	11 Jul 96	19.0	Cave myotis	0	1	0	1		
			Pallid bat	1	0	0	1		
	10 Aug 96	20.0	Calif. leaf-nosed	2	5	0	7		
			Big brown bat	0	1	0	1		
			Western pipistrelle	1	1	0	2		
			Pallid bat	0	4	0	4		
			6 Jul 95	17.7	Western pipistrelle	1	0	0	1
22 Jul 95	18.5	Pallid bat	3	2	1	6			
		Calif. leaf-nosed	0	1	0	1			
		Western pipistrelle	0	5	0	5			
28 Oct 95	26.0	Pallid bat	2	5	0	7			
		Pallid bat	1	0	0	1			
17 Feb 96	25.0	Western pipistrelle	0	1	0	1			
		Pallid bat	1	1	0	2			
7 Jun 96	19.0	Calif. leaf-nosed	10	9	0	19			
		Western pipistrelle	2	5	1	8			
Midway	6 Jul 95	17.7	Western pipistrelle	1	0	0	1		
			Pallid bat	3	2	1	6		
	22 Jul 95	18.5	Calif. leaf-nosed	0	1	0	1		
			Western pipistrelle	0	5	0	5		
			Pallid bat	2	5	0	7		
	28 Oct 95	26.0	Pallid bat	1	0	0	1		
	17 Feb 96	25.0	Western pipistrelle	0	1	0	1		
			Pallid bat	1	1	0	2		
	7 Jun 96	19.0	Calif. leaf-nosed	10	9	0	19		
			Western pipistrelle	2	5	1	8		

## Appendix 1.2 (Continued).

Site	Date	Net-hrs	Species	Female	Male	Unknown	Total	
Midway	7 Jun 96	19.0	Pallid bat	3	2	0	5	
	9 Jul 96	19.0	Western pipistrelle	0	1	0	1	
			Pallid bat	1	0	0	1	
	5 Aug 96	20.0	Calif. leaf-nosed	1	0	0	1	
			Western pipistrelle	1	0	0	1	
Pallid bat			0	3	0	3		
Papago Mine	20 May 95	10.0	Calif. leaf-nosed	0	1	0	1	
			California myotis	0	1	0	1	
			Western pipistrelle	0	7	0	7	
	7 Jul 95	17.0	Calif. leaf-nosed	7	4	0	11	
			California myotis	0	1	0	1	
			Western pipistrelle	0	1	0	1	
			Pallid bat	11	0	0	11	
	10 Jan 96	4.7	California myotis	1	0	0	1	
			Western pipistrelle	0	2	0	2	
	8 Feb 96	26.0	Western pipistrelle	2	0	0	2	
	5 Jun 96	19.0	Calif. leaf-nosed	0	1	0	1	
			Western pipistrelle	0	1	0	1	
	6 Jul 96	8.3	Pallid bat	0	2	0	2	
	14 Aug 96	6.0	Western pipistrelle	0	2	0	2	
			Pallid bat	1	0	0	1	
	Ryan's Canyon 1	7 Jun 95	17.9	No captures	0	0	0	0
		18 Jul 95	18.4	Pallid bat	2	1	0	3
1 Mar 96		12.0	No captures	0	0	0	0	
19 May 96		20.0	Calif. leaf-nosed	5	3	0	8	
			Cave myotis	1	0	0	1	
			Pallid bat	0	2	0	2	
27 Jun 96		19.0	Calif. leaf-nosed	5	0	0	5	
			Western pipistrelle	1	0	0	1	
			Pallid bat	3	1	0	4	
			No captures	0	0	0	0	
28 Jul 96	28.5	No captures	0	0	0	0		
Ryan's Canyon 2	9 Jun 95	35.8	No captures	0	0	0	0	
	19 Jul 95	18.4	Calif. leaf-nosed	2	1	0	3	
	10 Mar 96	25.5	Pallid bat	0	1	0	1	
	17 May 96	30.0	Calif. leaf-nosed	1	11	1	13	
	19 Jun 96	28.5	Calif. leaf-nosed	8	6	0	14	
	22 Jul 96	30.0	Calif. leaf-nosed	5	0	0	5	
			Western pipistrelle	1	0	0	1	
Pallid bat	1	0	0	1				
Ryan's Canyon 3	9 Jun 95	17.9	Calif. leaf-nosed	7	4	1	12	
	20 Jul 95	18.5	Calif. leaf-nosed	3	3	0	6	
			Pallid bat	0	3	0	3	
	15 Aug 95	20.0	Calif. leaf-nosed	1	0	0	1	

## Appendix 1.2 (Continued).

Site	Date	Net-hrs	Species	Female	Male	Unknown	Total	
Ryan's Canyon 3	29 Mar 96	16.0	No captures	0	0	0	0	
	18 May 96	20.0	Calif. leaf-nosed	4	10	0	14	
			Pallid bat	0	2	0	2	
	26 Jun 96	19.0	Calif. leaf-nosed	3	1	0	4	
			Pallid bat	1	0	0	1	
	26 Jul 96	20.0	Calif. leaf-nosed	14	0	1	15	
Pallid bat			0	3	0	3		
Ryan's Canyon 4	10 Jun 95	26.8	Calif. leaf-nosed	7	0	0	7	
	21 Jul 95	18.5	Calif. leaf-nosed	1	0	0	1	
			Pallid bat	4	2	0	6	
	16 Aug 95	30.5	Calif. leaf-nosed	3	5	0	8	
			Pallid bat	1	0	0	1	
	30 Mar 96	25.5	Calif. leaf-nosed	2	1	0	3	
			Pallid bat	1	0	0	1	
	20 May 96	30.0	Western pipistrelle	0	1	0	1	
			Calif. leaf-nosed	1	1	0	2	
	28 Jun 96	28.5	Calif. leaf-nosed	3	4	0	7	
			Pallid bat	7	9	0	16	
	Sauceda Tank	14 May 96	10.0	Calif. leaf-nosed	10	2	0	12
				California myotis	0	5	0	5
				Western pipistrelle	1	1	0	2
Pallid bat				1	12	0	13	
23 Jun 96		10.0	Western pipistrelle	1	6	0	7	
			Pallid bat	0	2	0	2	
5 Jul 95		8.8	Western pipistrelle	3	2	0	5	
			Pallid bat	0	0	1	1	
27 Jul 95		9.3	Calif. leaf-nosed	6	4	1	12	
			Western pipistrelle	0	2	0	2	
18 Aug 95	10.2	Pallid bat	5	2	0	7		
		Calif. leaf-nosed	3	1	0	4		
24 Nov 95	14.0	Western pipistrelle	9	6	1	16		
		California myotis	3	0	0	3		
16 Feb 96	12.0	Western pipistrelle	1	2	0	3		
		Pallid bat	0	3	0	3		
13 May 96	10.0	Western pipistrelle	1	0	1	2		
		Calif. leaf-nosed	0	2	0	2		
		California myotis	1	0	0	1		
		Western pipistrelle	0	3	0	3		
		Pallid bat	1	1	0	2		
		Pallid bat	1	1	0	2		
12 Jun 96	9.5	Calif. leaf-nosed	1	3	0	4		
		California myotis	4	2	0	6		
		Western pipistrelle	2	4	0	6		
		Pallid bat	0	2	0	2		

## Appendix 1.2 (Continued).

Site	Date	Net-hrs	Species	Female	Male	Unknown	Total	
Thanksgiving Day	13 Aug 96	10.5	Western pipistrelle	1	2	0	3	
	13 Aug 96	10.5	Pallid bat	1	2	0	3	
Tom Thumb 1	23 Jun 95	17.6	Calif. leaf-nosed	2	10	0	12	
			Pallid bat	0	1	0	1	
	10 Aug 95	18.0	No captures	0	0	0	0	
	26 Oct 95	26.0	Calif. leaf-nosed	0	1	0	1	
	11 Mar 96	16.0	No captures	0	0	0	0	
	15 May 96	20.0	Calif. leaf-nosed	1	1	0	2	
	17 Jun 96	19.0	Calif. leaf-nosed	0	7	0	7	
	20 Jul 96	20.0	No captures	0	0	0	0	
Tom Thumb 2	24 Jun 95	17.6	Calif. leaf-nosed	2	1	0	3	
			Cave myotis	0	1	0	1	
			Pallid bat	4	1	0	5	
	11 Aug 95	12.0	Calif. leaf-nosed	1	1	0	2	
	27 Oct 95	26.0	Calif. leaf-nosed	1	2	1	4	
	12 Mar 96	16.0	No captures	0	0	0	0	
	16 May 96	20.0	No captures	0	0	0	0	
	18 Jun 96	19.0	Calif. leaf-nosed	0	2	0	2	
			Pallid bat	3	0	0	3	
	21 Jul 96	20.0	Calif. leaf-nosed	1	0	1	2	
	White Tank	25 Nov 95	13.5	California myotis	1	0	0	1
				Western pipistrelle	1	0	0	1
				Pallid bat	3	1	0	4
2 Mar 96		15.0	No captures	0	0	0	0	
12 Jul 96		17.5	Western pipistrelle	1	0	0	1	
			Pallid bat	25	12	0	37	
8 Aug 96		20.0	Western pipistrelle	1	0	0	1	
			Pallid bat	9	6	1	16	

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## BAT USE OF NATURAL AND ARTIFICIAL WATER SOURCES IN THE SONORAN DESERT OF SOUTHERN ARIZONA

### INTRODUCTION

Wildlife management in the arid southwestern United States has evolved around the belief that free-standing water is a limiting factor for many wildlife species, especially game animals (Payne and Bryant 1998). This belief has led to the construction of water sources throughout this region. In the Sonoran Desert of southwestern Arizona, water resources have been developed primarily within the last 50 years and have targeted large game animals such as desert bighorn sheep (*Ovis canadensis mexicana*) and desert mule deer (*Odocoileus hemionus eremicus*) (deVos and Clarkson 1990). The degree to which these developments are used by the target species and their potential influences, either negative or positive, has been the focus of numerous studies and much discussion (Hervert and Krausman 1986, deVos and Clarkson 1990, Broyles 1995, Krausman and Etchberger 1995, Broyles and Cutler 1999, Rosenstock et al. 1999).

Information on non-game species utilizing artificial water sources is not nearly as prevalent as it is for game species. Burkett and Thompson (1994) surveyed birds, mammals, invertebrates, and herpetofauna at developed water sources and paired non-water sites in southern New Mexico; they found no differences in animal species richness and composition between the two. Similar results were obtained by Cutler and Morrison (1998) at 2 sites in the Sonoran Desert of southern Arizona. Schmidt (1999) examined bat activity at three artificial water sources compared with nearby dry desert washes and dry random sites on the Cabeza Prieta National Wildlife Refuge in southwestern Arizona,

finding highest activity at water sources.

Water sources are commonly known to attract bats, and bat use of springs, livestock tanks, and washes in the west has been well documented (Jones 1965, 1966, O'Farrell et al. 1967, O'Farrell and Bradley 1970, Black 1974, Ruffner et al. 1979, Kuenzi et al. 1999). Water is important to insectivorous bats because of their high protein diet and high rates of evaporative water loss (McNab 1982, Carpenter 1986).

Water requirements are especially high for pregnant and lactating females (Kurta 1986, Kurta et al. 1989, 1990). Thus, increased availability of surface water could affect distribution, reproduction, and survival of bat populations. However, little information is available on bat species utilizing artificial water catchments. In order to understand the impact of artificial water on bat population demographics, studies must first examine if and how these water sources are used by bats and if bat use of artificial water sources differs from that of natural sources.

My study was initiated to gather data on bat species using both artificial water catchments and natural water sources in the Sonoran Desert of southwestern Arizona. The objectives of the study were to (1) examine species composition, age ratios, sex ratios, and relative abundance of bat species at natural versus artificial water sources and (2) determine the physical characteristics of water sources (i.e., size of open water, elevation, etc.) associated with bat species use or nonuse. These results will provide valuable information needed to develop sound management plans and to make informed decisions regarding water management in the desert Southwest. It will also provide some baseline data for future studies.

## STUDY AREA

My study was conducted on a 1,700 km<sup>2</sup> portion of the Barry M. Goldwater Air Force Range (BMGR), Maricopa County, Arizona. Average temperature in this region ranges from approximately 10° C in the winter to 30° C in the summer. The mean annual precipitation is approximately 23 cm (Sellers and Hill 1974) with most precipitation falling during the summer monsoons (July through September) and winter (December through March) rains (Reitan and Green 1968). Vegetation in the study region is characteristic of the Arizona Upland and the Lower Colorado River Valley subdivisions of the Sonoran Desertscrub Biome (Turner and Brown 1982).

I surveyed for bats at all available water sources (17) located in and around the Saucedo and Sand Tank mountain ranges within the study region. Elevation at water sources ranged from 395 to 910 m. Water sources within each mountain range were generally separated by 1 to 5 kilometers. Distance between the two mountain ranges was approximately 30 km. I did not have access to the two water sources found between the Saucedo and Sand Tank Mountains because of military restrictions.

Thirteen of the 17 water sources were artificial catchments consisting of a metal, asphalt or fiberglass collection surface to capture runoff, a storage tank, and a drinking trough. All drinking troughs were less than 2.65 m<sup>2</sup> in size and contained constant levels of water year round.

The remaining four water sources were natural sites. Two of these sites were tinajas (bedrock pools replenished seasonally by rainfall and runoff). These contained water on a seasonal basis and never had a surface area of more than 4 m<sup>2</sup>. One source was

a tinaja that had been modified by a concrete dam. This site contained water year round, but the amount of water fluctuated due to evaporation but was never contained more than 6 m<sup>2</sup> of open water. The remaining natural water source was a spring that flowed into a small pool with a surface area of approximately 2.75 m<sup>2</sup>.

## METHODS

I gathered data from mid-May through mid-August 1995, 1996 using both live capture in mist-nets and ultrasonic detection of bat echolocation calls. I did not collect data on nights with strong winds or heavy rains because of the potential for reduced bat activity (Bell 1980, Ekert 1982). I also did not collect data on the full moon, or on the two nights preceding and following the full moon for the same reason (Fenton et al. 1977, Reith 1982). With the exception of one artificial site that was inaccessible in 1995 and two natural sites that did not contain water in 1995, I collected data at each water source on 2-3 nonconsecutive nights during each of the 2 summers.

### Mist-netting

At each site I captured bats using 2.1-m x 5.4-m, 36-mm mesh, 50-denier mist-nets placed across or along the edges of water sources. The number of nets used per site varied with the size of the water source but ranged from 1 to 3. Nets were kept open from sunset until sunrise and were monitored continuously. I identified all captured bats to species and recorded the following data for each individual: time of capture; gender; reproductive condition of females; age (juvenile vs. adult); forearm length ( $\pm 1$  mm); and body mass ( $\pm 0.5$  g). Reproductive condition of females was assessed by visual examination of the lower abdomen and mammary glands (Racey 1988). I aged bats based upon the degree of epiphyseal-diaphyseal fusion of wing bones (Anthony 1988). All bats were banded using numbered, lipped, metal forearm bands (Lambournes Ltd., Herefordshire, England). Handling procedures were approved by the University of Arizona Animal Care and Use Committee (Protocol no. 95-164).

I standardized my mist-netting data by dividing the total number of bats captured and the number of individuals of each species captured during each night by net hours. Net hours were calculated by multiplying the length of time nets remain open each night by the number of nets used at that site. These capture rates were averaged by site within each field season.

Two-way analysis of variance (Sokal and Rohlf 1995) was used to assess the influence of season (1995, 1996) and water type (natural vs. artificial) on overall and species specific capture rates. Chi-square analysis (Zar 1984) was used to compare species specific age and sex ratios between natural and artificial water sources.

#### Ultrasonic detection

Simultaneous with the use of mist-nets, I monitored bat flight activity at a water source continuously from sunset until sunrise using a heterodyne ultrasonic detector (Pettersson elektronik, Uppsala, Sweden, D100 model) set at 40 khz. Flight activity was quantified as bat passes, with one bat pass being the sequence of a bat echolocation call on the detector from beginning to end. Bat passes were totaled over 30 minute time periods.

Data from these 30 minute time periods were averaged over the course of the night to obtain a nightly index of bat activity (mean passes/30 min.). These indices were then averaged by site within each field season. Two-way analysis of variance (Sokal and Rohlf 1995) was used to assess the influence of season (1995, 1996) and water type on bat activity.

In addition to the heterodyne detector, I used a time-expansion ultrasonic detector (Pettersson D140 model) linked to a tape recorder to record echolocation calls during

each 30 minute time period. These recordings were digitized using SoundEdit™ 16 version 2.0.1. Sonograms were generated from digitized recordings using prototype computer software program developed by J. Szewczak (White Mountain Research Station, Bishop, California). Data on frequency composition, changes in frequency with time, harmonics, and duration were obtained from these sonograms and visually compared with similar data from reference recordings of known species in order to determine species presence. Because of the similarity of their calls (Thomas 1988, Krusic et al. 1996), my identification of *Myotis* species was restricted to genus. In addition, approximately half of the recordings I made could not be identified to species either due to the poor quality or the incomplete nature of some of the recording (O'Farrell et al. 1999). Because rates of unusable sequences may not be randomly distributed among species, the relative abundance of species identified by their calls is likely inaccurate (Barclay 1999). Due to this bias, I did not use these data to compare relative abundance between species only to confirm species presence at a site.

### Insect Sampling

I used Malaise traps (Model 2875A, Bioquip Products, Gardenia, California) to sample the aerial insect fauna during each bat survey. Two traps were run simultaneously within 5-10 m of water sources from sunset to sunrise. Collected insects were transferred to glassine envelopes, air dried the following day, and stored prior to identification.

Insects were examined under a dissecting microscope and classified to order. Biomass was determined by weighing all collected insects from a night to the nearest 0.01g on an electronic balance. All samples were oven dried to a constant weight prior to

this final weighting. I standardized insect data by dividing biomass as well as the total number of insects in each order by sampling effort (number of hours both Malaise traps remained open). These standardized measures of insect abundance were then averaged by site within each field season.

I used two-way analysis of variance (Sokal and Rohlf 1995) to assess the influence of season (1995, 1996) and water type on insect abundance. Chi-square analysis (Zar 1984) was used to compare the proportion of insects in each order between natural and artificial water sources. I used Pearson's correlation (Zar 1984) to examine the relationship between average insect biomass collected at each site and elevation.

#### Characteristics of used versus non-used water sources

I described each site using the following variables: area of open water (m<sup>2</sup>); elevation (m); distance to nearest permanent water source (m); number of additional water sources within a 4 km radius; distance to nearest dry wash (m); distance to the nearest cliff or rock outcrop (m); plant species composition; and type of water source (natural, man made); area of open water at each site was measured directly. For water sources that varied in size, I used the average size for all statistical comparisons. I obtained elevation, distance to nearest permanent water source, distance to nearest dry riparian wash, number of additional water sources within a 1.61 km radius, and distance to nearest cliff or rock outcrop from USGS 7.5 minute topographical maps. Due to financial and time constraints it was impossible to locate roosts, therefore, I used distance to the nearest cliff or rock outcrop as an index of proximity to potential roost sites. Distance to the nearest dry wash was used as an index of proximity to a potential foraging area. Plant species composition

was determined by visual inspection of the area surrounding each site. A water source was classified as occurring in one of three categories (creosote flats, mixed cactus, or dry riparian) depending upon the dominant vegetation type surrounding it.

I did not consider a site used if a species was never mist-netted there or was not identified as being present based on the ultrasound data. Size of open water, elevation, distance to nearest additional water source (m), distance to nearest wash (m), number of additional water sources within a 1.61 km radius, and distance to the nearest cliff or rock outcrop were compared between used and non-used sites by separate T-tests (parametric or non-parametric) for each species. I did not test for differences between proportions of used versus non-used site in each of the 3 vegetation categories or the 2 water type categories because sample sizes were too small for testing using any type of contingency table analysis (Zar 1984). Comparisons were not made for pallid bats (*Antrozous pallidus*) because this species was captured at all but 1 site where its presence was later determined using ultrasonic data.

I used separate stepwise multiple regression analyses (Zar 1984) to determine the characteristics at water sources that were important in determining bat activity and species richness. I used 2 measures of bat activity: overall capture rate (bats/net hr) and passes/30 min. These measures were averaged by site over both seasons. Water source characteristics were tested for intercorrelation prior to analysis. The use of highly intercorrelated variables ( $r > 0.8$ ) in a regression model causes computational difficulties, increases standard errors of the regression coefficients, and biases estimators for the regression parameters (Wesolowsky 1976). If a pair of variables were found to be highly

intercorrelated one of the variables was removed from the regression analysis. The variable retained was the one deemed most biologically meaningful. Ease of measurement was also taken into consideration.

#### Characteristics of water sources used by different sexes within species

Chi-square analysis (Zar 1984) was used to determine if species specific sex ratios differed significant from a 1:1 ratio at each water source. Based on these analyses, I classified each water source as having either a male-biased sex ratio, a female biased sex ratio or an equal sex ratio for each bat species captured there. Size of open water, elevation, distance to nearest additional water source (m), distance to nearest wash (m), number of additional water sources within a 1.61 km radius, and distance to the nearest cliff or rock outcrop were compared between sites with male biased sex ratios, sites with female-biased sex ratios and sites with equal sex ratios using separate one-way ANOVA (parametric or non-parametric) for pallid bats (*Antrozous pallidus*) and California leaf-nosed bats (*Macrotus californicus*). Comparisons were not made for the remaining species because of inadequate sample sizes.

#### Statistical analysis

I performed all statistical analyses using JMP software (SAS Institute Inc. 1996). Data were tested for normality using Kolmogorov-Smirnoff goodness-of-fit test and equality of variances using the Bartlett-Box test (Zar 1984). Non-normal data was transformed using the appropriate equation (Zar 1984). Untransformed means  $\pm$  1 standard error are reported and used to plot all figures. If it was impossible to achieve a

normal distribution through transformation or if variances were found too be unequal the appropriate nonparametric test was used. Statistical significance was set at  $\alpha \leq 0.05$ .

## RESULTS

I captured 469 individuals of six species from artificial water sources in 64 trap nights (1,289 net hours) and 229 individuals of five species from natural water sources in 15 nights (210 net hours) (Table 2.1). With the exception of cave myotis (*Myotis velifer*), all species were captured at both natural and artificial water sources. California leaf-nosed bats (*Macrotus californicus*) and pallid bats (*Antrozous pallidus*) were the most common species captured at the artificial water sources. Both species were broadly distributed throughout the study region, occurring at 69% and 92% of the catchments surveyed respectively. Western pipistrelles (*Pipistrellus hesperus*) were also captured at a large percentage (77%) of catchments and was the third most commonly captured species. Pallid bats and western pipistrelles were also found to be present at 1 additional artificial water source each based on ultrasonic recordings (Appendix 2.1).

The most common species captured at natural water sources was the pallid bat, followed by the western pipistrelle. Both species were captured at all the natural water sources surveyed. Rare species captured at both natural and artificial sites were big brown bats and California myotis.

I found no significant differences in sex ratios between natural and artificial water sources for any of the bat species compared (Table 2.2). In most cases, slightly more males than females were captured at both natural and artificial water sources (Appendix 2.1). However, the ratio of males to females was only significantly greater than 1 for pallid bats ( $P = 0.0017$ ) and western pipistrelles ( $P = 0.0003$ ) at artificial water sources.

**Table 2.1. Number of bats captured by species at artificial and natural or modified natural water sources on the Barry M. Goldwater Air Force Range, Arizona, May through August 1995-1996.**

Species	Artificial			Natural		
	No. captured	% of total captures	% of sites	No. captured	% of total captures	% of sites
California leaf-nosed	220	46.9	69	29	12.7	75
California myotis	5	1.1	23	13	5.7	100
Cave myotis	7	1.5	46	0	0	0
Big brown bat	2	0.4	23	6	2.6	25
Western pipistrelle	61	13.0	77	63	27.5	100
Pallid bat	174	37.1	92	118	51.5	100
All combined	469	100.0		229	100.0	

Table 2.2. Sex of bat species captured on the Barry M. Goldwater Air Force Range, Arizona by type of water source, May through August 1995, 1996.

Species	Type	Males (%)	Females (%)	Total	<i>P</i> -value <sup>1</sup>
California leaf-nosed	Artificial	94 (43.5)	122 (56.5)	216	0.305
	Natural	15 (55.6)	12 (44.4)	27	
California myotis	Artificial	3 (60)	2 (40)	5	-----
	Natural	5 (38.5)	8 (61.5)	13	
Cave myotis	Artificial	3 (42.9)	4 (57.1)	7	-----
	Natural	0	0	0	
Big brown bat	Artificial	1 (50)	1 (50)	2	-----
	Natural	4 (66.7)	2 (33.3)	6	
Western pipistrelle	Artificial	42 (73.7)	15 (26.3)	57	0.238
	Natural	38 (62.3)	23 (37.7)	61	
Pallid bat	Artificial	106 (61.9)	65 (38.1)	171	0.220
	Natural	63 (54.3)	53 (45.7)	116	
All Combined	Artificial	249 (54.4)	209 (45.6)	458	0.683
	Natural	125 (56.0)	98 (44.0)	223	

<sup>1</sup>*P* associated with Fisher's exact test. When no value is given sample sizes were too small for significance testing.

Age ratios did differ significantly between natural and artificial water sites for California leaf-nosed bats, pallid bats and all species combined (Table 2.3). In all cases, a greater percentage of the total captures at natural water sites were composed of juveniles. The percentage of adult females of each bat species that were reproductively active (pregnant, lactating or post-lactating) was very similar at both the artificial and natural sites (Table 2.4). At both sites very few non-reproductive females were ever captured.

Overall capture rates, species-specific capture rates, and the number of passes/30 min did not differ significantly between the 1995 and 1996 field seasons (Table 2.5). In addition, no season by water type interactions were found for any of the comparisons made. Significant differences in capture rates between water types were found for all bat species combined, pallid bats, and western pipistrelles. In all cases, capture rates were higher at natural water sources. The number of passes/30 minutes was also significantly higher at natural water sources compared to artificial water sources.

Most insects captured at both artificial and natural water sources were either in the order Lepidoptera or Diptera (Figure 2.1). The proportion of insects in each order, however, was significantly different between natural and artificial water sources ( $\chi^2 = 63.1$ , 5 degrees of freedom,  $P < 0.0001$ ). Coleoptera, Homoptera, and Lepidoptera made up higher percentages of the total captures at the artificial sites while Diptera were more commonly captured at natural sites.

Insect biomass (g/hr), Lepidoptera abundance (number/hr), and Diptera abundance (number/hr) did not differ significantly between the 1995 and 1996 field season or between natural and artificial water sources (Table 2.6). The effect of type of water source was

Table 2.3. Age of bat species captured on the Barry M. Goldwater Air Force Range, Arizona by type of water source, May through August 1995, 1996.

Species	Type	Adults (%)	Juveniles (%)	Total	<i>P</i> -value <sup>1</sup>
California leaf-nosed	Artificial	204 (94.0)	13 (6.0)	217	< 0.0001
	Natural	14 (51.8)	13 (48.2)	27	
California myotis	Artificial	4 (80.0)	1 (20.0)	5	-----
	Natural	13 (100.0)	0 (0.0)	13	
Cave myotis	Artificial	5 (71.4)	2 (28.6)	7	-----
	Natural	0	0	0	
Big brown bat	Artificial	2 (100.0)	0 (0.0)	2	-----
	Natural	6 (100.0)	0 (0.0)	6	
Western pipistrelle	Artificial	49 (84.5)	9 (15.5)	58	0.1233
	Natural	44 (72.1)	17 (27.9)	61	
Pallid bat	Artificial	123 (72.4)	47 (27.6)	170	0.0111
	Natural	67 (57.8)	49 (42.2)	116	
All Combined	Artificial	387 (84.3)	72 (15.7)	459	< 0.0001
	Natural	144 (64.6)	79 (35.4)	223	

<sup>1</sup>*P* associated with Fisher's exact test. When no value is given sample sizes were too small for significance testing.

**Table 2.4. Number of adult female bats that were reproductively active (pregnant, lactation and/or post-lactating) by species at artificial and natural or modified natural water sources on the Barry M. Goldwater Air Force Range, Arizona, May through August 1995-1996.**

Species	Artificial			Natural		
	No. reproductive	Total captures	% of total	No. reproductive	Total captures	% of total
California leaf-nosed bat	114	114	100.0	4	4	100.0
California myotis	1	1	100.0	8	8	100.0
Cave myotis	3	4	75.0	0	0	0
Big brown bat	1	1	100.0	2	2	100.0
Western pipistrelle	10	13	76.9	10	16	62.5
Pallid bat	47	52	90.4	29	30	96.6
All combined	176	185	95.1	53	60	88.3

**Table 2.5. Measures of bat activity at natural and artificial water sources on the Barry M. Goldwater Air Force Range, Arizona, May through August 1995, 1996.**

Measure of activity	Season	Artificial	Natural	Season effect <sup>1</sup>	Water type effect <sup>1</sup>	Season x water <sup>1</sup>
		X ± 1 standard error (N)	X ± 1 standard error (N)			
Passes/30 min	1995	44.2 ± 2.9 (12)	100.9 ± 21.9 (2)	0.2860	0.0016	0.3895
	1996	18.5 ± 3.6 (13)	26.9 ± 7.3 (4)			
Total bats/net hr	1995	0.45 ± 0.09 (12)	1.29 ± 0.11 (2)	0.5230	0.0014	0.8376
	1996	0.32 ± 0.06 (13)	1.19 ± 0.27 (4)			
Ca. leaf-nosed/net hr	1995	0.16 ± 0.05 (12)	0.29 ± 0.27 (2)	0.5983	0.6298	0.5531
	1996	0.17 ± 0.05 (13)	0.11 ± 0.06 (4)			
W. pipistrelle/net hr	1995	0.08 ± 0.03 (12)	0.45 ± 0.14 (2)	0.5946	0.0042	0.8483
	1996	0.04 ± 0.02 (13)	0.32 ± 0.16 (4)			
Pallid bat/net hr	1995	0.18 ± 0.01 (12)	0.45 ± 0.20 (2)	0.6944	0.0221	0.5169
	1996	0.09 ± 0.02 (13)	0.65 ± 0.27 (4)			

<sup>1</sup>P-value associated with two-way analysis of variance.

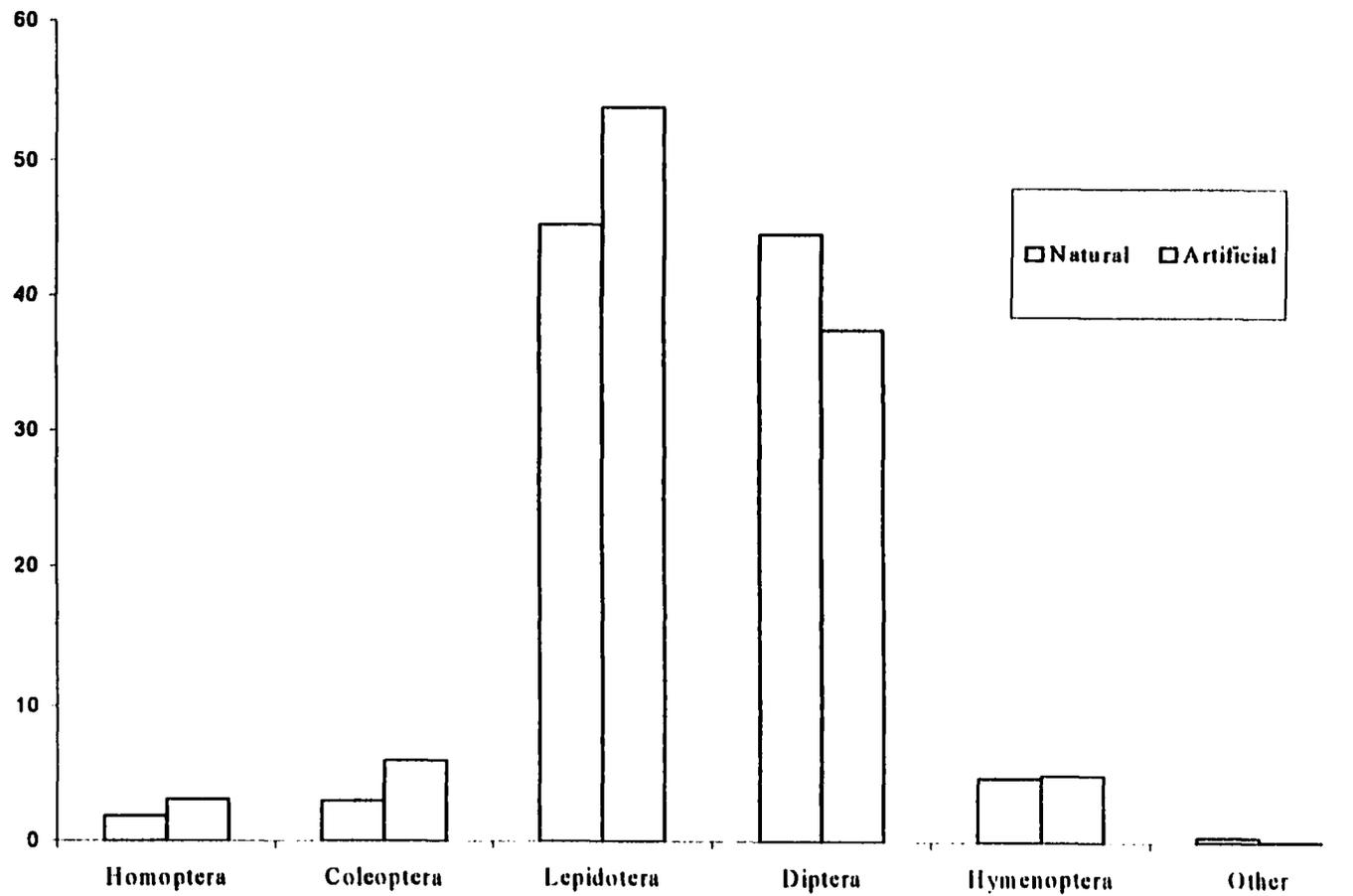


Figure 2.1. The percentage of insects captured in each order at artificial and natural water sources on the Barry M. Goldwater Air Force Range, Arizona, May through August 1995, 1996. The orders Collembola and Neuroptera were combined into the category "Other".

significant though for all orders of insects combined (number/hour). Significantly higher numbers of insects were captured in Malaise traps at the natural sites compared to the artificial sites. I found no significant relationship between average insect biomass collected at each site and elevation ( $r=0.368$ ,  $n = 17$ ,  $P=0.146$ ).

I found no significant differences between characteristics of used versus non-used water sources for California leaf-nosed bats and cave myotis (Table 2.7). Water sources used by California myotis and western pipistrelles were significantly larger than non-used sites. Sources used by California myotis were also significantly closer to rock outcrops than non-used sites. Water sources used by big brown bats were located at significantly higher elevations than non-used sites.

Elevation, type of water source (1 = natural, 2 = artificial), and distance to the nearest cliff or rock outcrop explained 81% of the variation in overall capture rates at water sources. This relation ( $F_{3,13} = 18.6$ ,  $r^2 = 0.81$ ,  $P < 0.0001$ ) is described by the equation:  $\ln(\text{capture rate}) = 1.4 - 0.002 (\text{elevation}) - 0.002 (\text{distance to cliffs}) - 0.432 (\text{type})$ . Type of water source alone explained 54% of the variation in capture rates (Table 2.8). Distance to the nearest cliff or rock outcropping explained an additional 9% and elevation an additional 16%.

Type of water source explained 47% of the variation in ultrasonic activity (passes/30 min). The relation ( $F_{3,13} = 13.3$ ,  $r^2 = 0.47$ ,  $P = 0.0024$ ) is described by the equation:  $\text{passes/30 min} = 38.6 - 16.8 (\text{Type of water source})$ . Distance to the nearest source of permanent water and size of the water source explained 33% of the variation in species richness. The relation ( $F_{3,13} = 3.51$ ,  $r^2 = 0.33$ ,  $P = 0.0582$ ) is described by the

**Table 2.6. Measures of insect abundance at natural and artificial water sources on the Barry M. Goldwater Air Force Range, Arizona, May through August 1995, 1996.**

Measure	Season	Artificial	Natural	Season effect <sup>1</sup>	Water type effect <sup>1</sup>	Season x water <sup>1</sup>
		X ± 1 standard error (N)	X ± 1 standard error (N)			
Biomass (g/hr)	1995	0.12 ± 0.01 (12)	0.12 ± 0.02 (2)	0.1731	0.5201	0.4934
	1996	0.07 ± 0.01 (13)	0.10 ± 0.02 (4)			
Total insects/hr	1995	5.2 ± 0.49 (12)	15.1 ± 10.4 (2)	0.5415	0.0026	0.7516
	1996	5.1 ± 0.61 (13)	8.9 ± 0.58 (4)			
Lepidoptera/hr	1995	3.4 ± 0.46 (12)	2.5 ± 0.29 (2)	0.5360	0.4992	0.0771
	1996	2.4 ± 0.45 (13)	4.4 ± 1.04 (4)			
Diptera/hr	1995	0.01 ± 0.01 (12)	0.47 ± 0.47 (2)	0.5886	0.1354	0.4137
	1996	0.04 ± 0.01 (13)	0.06 ± 0.03 (4)			

<sup>1</sup>P-value associated with two-way analysis of variance.

**Table 2.7. Comparison of characteristics at used versus non-used water sources by different bat species on the Barry M. Goldwater Air Force Range, Arizona, May through August 1995, 1996.**

Species	Characteristic	Used	Non-used	<i>P</i> -value from t-test
		$X \pm 1$ standard error (N)	$X \pm 1$ standard error (N)	
Ca. Leaf-nosed	Size (m <sup>2</sup> )	2.15 $\pm$ 0.47 (12)	2.19 $\pm$ 0.16 (5)	0.4807
	Elevation (m)	620.2 $\pm$ 40.6 (12)	655.7 $\pm$ 81.7 (5)	0.6688
	Distance to other water (m)	4902 $\pm$ 729 (12)	5137 $\pm$ 1562 (5)	0.8776
	Distance to wash (m)	145.8 $\pm$ 56.9 (12)	92.0 $\pm$ 53.6 (5)	0.9576
	Distance to rock outcrops (m)	184.6 $\pm$ 35.5 (12)	376.0 $\pm$ 134.1 (5)	0.3122
	No. other water sources	0.92 $\pm$ 0.19 (12)	1.0 $\pm$ 0.63 (5)	0.8225
California myotis	Size (m <sup>2</sup> )	3.06 $\pm$ 0.69 (6)	1.67 $\pm$ 0.26 (11)	0.0445
	Elevation (m)	668.7 $\pm$ 78.1 (6)	609.9 $\pm$ 38.1 (11)	0.4554
	Distance to other water (m)	4171 $\pm$ 1415 (6)	5407 $\pm$ 695 (11)	0.3895
	Distance to wash (m)	85.0 $\pm$ 46.8 (6)	154.5 $\pm$ 61.2 (11)	0.2874
	Distance to rock outcrops (m)	107.5 $\pm$ 35.8 (6)	313.6 $\pm$ 64.1 (11)	0.0332
	No. other water sources	1.33 $\pm$ 0.42 (6)	0.73 $\pm$ 0.24 (11)	0.4947
Cave myotis	Size (m <sup>2</sup> )	2.05 $\pm$ 0.35 (5)	2.21 $\pm$ 0.45 (12)	0.9128
	Elevation (m)	714.5 $\pm$ 24.6 (5)	595.7 $\pm$ 47.2 (12)	0.1389
	Distance to other water (m)	3712 $\pm$ 560 (5)	5496 $\pm$ 877 (12)	0.2306

Table 2.7 (Continued).

Species	Characteristic	Used X + 1 standard error (N)	Non-used X + 1 standard error (N)	P-value from t-test
Cave myotis	Distance to wash (m)	199.0 ± 104.6 (5)	101.3 ± 42.9 (12)	0.1514
	Distance to rock outcrops (m)	290.0 ± 105.1 (5)	220.4 ± 56.2 (12)	0.2874
	No. other water sources	1.20 ± 0.37 (5)	0.83 ± 0.27 (12)	0.3697
Big brown bat	Size (m <sup>2</sup> )	2.53 ± 0.15 (3)	2.08 ± 0.39 (14)	0.3341
	Elevation (m)	814.1 ± 48.3 (3)	591.3 ± 34.7 (14)	0.0132
	Distance to other water (m)	2298 ± 788 (3)	5544 ± 701 (14)	0.0585
	Distance to wash (m)	96.7 ± 61.1 (3)	137.1 ± 50.8 (14)	0.9494
	Distance to rock outcrops (m)	148.3 ± 64.6 (3)	260.7 ± 57.4 (14)	0.7028
	No. other water sources	1.7 ± 0.33 (3)	0.79 ± 0.24 (14)	0.0939
	Size (m <sup>2</sup> )	2.58 ± 0.35 (13)	0.79 ± 0.05 (4)	0.0005
W. pipistrelle	Elevation (m)	629.1 ± 46.5 (13)	635.6 ± 38.6 (4)	0.9424
	Distance to other water (m)	4994 ± 781 (13)	4895 ± 1409 (4)	0.9517
	Distance to wash (m)	157.3 ± 53.9 (13)	41.3 ± 13.9 (4)	0.5302
	Distance to rock outcrops (m)	257.3 ± 63.9 (13)	187.5 ± 16.1 (4)	0.9090
	No. other water sources	1.0 ± 0.28 (13)	0.75 ± 0.25 (4)	0.7633

**Table 2.8. Significant predictors of bat activity and species richness at 17 water sources on the Barry M. Goldwater Air Force Range, Arizona, May through August 1995, 1996 based on stepwise multiple regression models.**

<b>Dependent variable</b>	<b>Independent variables</b>	<b><i>P</i>-value</b>	<b><math>r^2</math></b>
<b>Capture rate (bats/net hr.)</b>	<b>Type of water source</b>	0.0008	0.5374
	<b>Elevation</b>	0.0168	0.6557
	<b>Distance to cliff</b>	0.0282	0.8107
<b>Ultrasonic activity (passes/30 min)</b>	<b>Type of water source</b>	0.0024	0.4706
<b>Overall Species Richness</b>	<b>Distance to other water</b>	0.0803	0.1899
	<b>Size of water source</b>	0.1038	0.3339

equation:  $\text{species richness} = 3.38 - 0.001 (\text{distance to water}) + 0.35 (\text{size of water source})$ . Distance to the nearest additional source of permanent water explained 19% of the variation in species richness while the addition of the variable size explained an additional 14% (Table 2.8).

I found no significant differences between characteristics of water sources with male biased sex ratios, female biased sex ratios and equal sex ratios for California leaf-nosed bats (Table 2.9). Water sources with male-biased sex ratios of pallid bats were located significantly closer to other sources of permanent water compared to water sources used by female pallid bats. These sites also had a significantly higher number of additional water sources nearby.

**Table 2.9. Comparison of characteristics at water sources with male-biased sex ratios, female-biased sex ratios and no difference in sex ratios (both) by different bat species on the Barry M. Goldwater Air Force Range, Arizona, May through August 1995, 1996.**

Species	Characteristic	Males	Females	Both	<i>P</i> <sup>1</sup>
		X ± 1 standard error (N)	X ± 1 standard error (N)	X ± 1 standard error (N)	
Ca. leaf-nosed	Size (m <sup>2</sup> )	3.35 ± 2.65 (2)	2.42 ± 0.17 (2)	1.78 ± 0.44 (8)	0.844
	Elevation (m)	636.4 ± 90.9 (2)	704.5 ± 46.9 (2)	595.1 ± 56.3 (8)	0.504
	Distance to other water (m)	3207 ± 707 (2)	3610 ± 110 (2)	5649 ± 996 (8)	0.307
	Distance to wash (m)	5.0 ± 5.0 (2)	405.0 ± 195.0 (2)	116.3 ± 55.4 (8)	0.109
	Distance to rock outcrops (m)	110.0 ± 90.0 (2)	162.5 ± 62.5 (2)	208.8 ± 47.3 (8)	0.676
	No. other water sources	1.0 ± 0.00 (2)	1.5 ± 0.50 (2)	0.75 ± 0.25 (8)	0.359
Pallid bat	Size (m <sup>2</sup> )	1.99 ± 0.44 (4)	1.40 ± 0.40 (4)	3.51 ± 0.68 (5)	0.066
	Elevation (m)	784.1 ± 63.9 (4)	536.4 ± 54.7 (4)	556.9 ± 66.2 (5)	0.065
	Distance to other water (m)	2169 ± 825 (4)	7002 ± 1217 (4)	5037 ± 1119 (5)	0.038
	Distance to wash (m)	45.0 ± 16.6 (4)	88.8 ± 55.9 (4)	177.0 ± 112.5 (5)	0.909
	Distance to rock outcrops (m)	118.7 ± 41.9 (4)	168.8 ± 27.7 (4)	189.0 ± 64.2 (5)	0.504
	No. other water sources	2.0 ± 0.41 (4)	0.25 ± 0.25 (4)	1.0 ± 0.32 (5)	0.032

<sup>1</sup>*P*-value associated with Student's t-test.

## DISCUSSION

I documented five bat species using both artificial and natural water sources in southern Arizona. Cave myotis was only detected at artificial water sources. However, the presence of this species was rare, therefore, the failure to detect this species at natural sites is likely an artifact of sample size rather than avoidance of natural water sources. Others (Hoffmeister 1986, Cockrum 1981) have commonly observed this species at natural water sources in other parts of southern Arizona.

I captured slightly more males than females at both natural and artificial water sources, but the ratio of males to females was only significantly greater than one for pallid bats and western pipistrelles at artificial water sources. Several studies (Thomas 1988, Barclay 1991) have suggested that male-biased sex ratios during the summer months could indicate lower quality habitat in terms of food availability. The reasoning behind this is that males do not have the high energetic demands of pregnancy and lactation and can inhabit areas with cooler temperatures and lower insect abundance. However, sex ratios did not differ significantly with type of water source for any of the bat species I compared indicating similar patterns of male and female use at natural and artificial sources.

Some desert species (i.e, Mexican free-tailed bats, lesser long-nosed bat) can survive for extended periods in the lab without free water (Carpenter 1969). However, the high temperature and low humidity conditions during summer months results in high evaporative losses during flight, likely making drinking necessary (Geluso 1980). Water requirements also increase in females during pregnancy and lactation (Kurta et al. 1989).

The majority of adult females I captured at both natural and artificial water sources were

pregnant or lactating indicating the reproductively active females will use both types of water sources.

I found a higher proportion of juveniles to adults at natural water sources suggesting that reproductive success may be higher in areas surrounding natural water sources. It also suggests that maternity roost may be located closer to natural water sources compared to artificial sources. Many species of crevice, cave, and mine roosting bats return to the same roost sites year after year to raise their young (Lewis 1995). It seems reasonable to assume that in desert areas, these traditional roost sites have historically been located near natural water sources. Roost sites located closer to water sources may have higher productivity as one factor influencing juvenile survival is proximity of foraging/watering sites to the roost (Altringham 1996).

Ultrasonic activity (number of passes/30 minutes) and capture rates for pallid bats, western pipistrelles, and all species combined were also significantly higher at natural water sources compared to artificial water sources. Several studies have found a strong positive correlation between bat activity and insect abundance (Richards 1989, de Jong and Ahlen 1991, Hickey and Fenton 1996). Thus, differences in activity between the two types of sources could be related to differences in aerial insect abundance. Lepidoptera and Diptera were the most common orders of insects captured at both artificial and natural water sources. Both of these orders constitute a significant portion of the diet of many insectivorous bats (Ross 1967, Whitaker 1972, Black 1974, Warner 1985, Griffith and Gates 1985, Brack and LaVal 1985). However, I did not find any significant differences in total insect biomass, Lepidoptera abundance (number/hr), and Diptera abundance

(number/hr) between natural and artificial sites. One potential bias with the use of Malaise traps is that this technique only samples aerial insect fauna (Kunz 1988). Pallid bats and California leaf-nosed bats also feed on non-volant prey gleaned from the ground or vegetation (Vaughan 1959, Hermanson and O'Shea 1983, Bell et al. 1986). Therefore, there may be differences in non-volant insect abundance that might explain the differences in at least pallid bat capture rates between artificial and natural water sources.

The differences in activity and capture rates between the two types of water sources may also be related to how much foraging is actually occurring at each of these sites. Schmidt (1999) made photographic and visual observations of bat behavior at three artificial water developments 75-100 km south of my study area and concluded bats were visiting these sites to drink rather than forage. Although I detected feeding buzzes, high pulse repetition rates associated with attacks on prey (Fenton and Bell 1979), at both natural and artificial water sources, I did not quantify these buzzes. Therefore, although I have some indication that bats are foraging around both natural and artificial water sources, it is unknown how much of their foraging time is spent around each type of site. Because water at my artificial sites is contained in drinkers, these sites were not any more heavily vegetated than the surrounding landscape. With the exception of the natural spring, the same was true for the natural tinajas. However, all of my natural water sources were located in dry desert washes which did support more vegetation and which have been found to have higher ultrasonic bat activity than random sites (Schmidt 1999). Only one of the artificial water sources was located in a dry desert wash. Therefore, bats may be spending more of their foraging time at

natural sites because of the denser vegetation found in these areas. Others (Racey and Swift 1985, Furlonger et al. 1987, Walsh et al. 1995) have documented bats focusing their foraging activity in more vegetated areas.

An additional factor that may affect bat activity in an area is the availability and location of roost sites (Kunz 1982). All of the species present within the study area roost in rocky crevices or caves (Orr 1954, Cross 1965, Barbour and Davis 1969, Vaughan and O'Shea. 1976). I found that water sources used by California myotis were significantly closer to cliffs or rock outcrops than unused sites and distance to nearest cliff or rock outcrop was a significant variable in explaining variation in overall capture rates between sites. However, distance to the nearest cliff or rock outcropping was not a significant variable in explaining variation in ultrasonic activity (passes/30 min). Several authors (see Fenton and Morris 1976, Bell 1980) have suggested that capture rates at water sources may provide more information about drinking behavior while ultrasonic data may provide more information on foraging behavior. The positive relationship between overall capture rates and proximity to potential roost sites may be more a factor of more bats concentrating to drink soon after exiting or just prior to returning to roost site rather than distance. The lack of a relationship between ultrasonic activity and proximity to potential day roosts may indicate that distance does not have as strong an influence on where bats forage. Information on how far individuals will travel between roosting areas and foraging sites is limited. Pierson (1998) summarized known maximum one-way distances from roost to foraging areas for nine bat species, finding that bats adapted for long distance flight (e.g., molossids and lasiurines) traveled the farthest (up to 30 km). Even Yuma

myotis (*Myotis yumanensis*) which are adapted for short-distance maneuverable flight (Norberg 1987) will travel up to 16 km to feed (Pierson 1998). There is also some evidence (Hirshfeld et al. 1977) that the availability of night roost sites may have a larger affect on foraging activity in an area than the availability of day roosts. Hirshfeld et al. (1977) found that desert bats often used trees and shrubs as night roosts, allowing individuals to remain in close proximity to foraging sites throughout the night before returning to less exposed day roosts that likely provided better protection from temperature extremes.

Another factor that was important in explaining overall capture rates at sites was elevation. Higher capture rates at lower elevations are often the result of differences in insect abundance. Nocturnal insect abundance decreases with increasing elevation (Wellington 1945). However, I found no relationship between insect abundance and elevation within my study region. Thus, the effect of elevation on capture rate may be more related to the availability of maternity roost sites with favorable temperature and moisture regimes, or the availability of foraging areas. Because very young bats do not thermoregulate roost temperature is very important in reproductive success (Kunz 1987). Distance to the nearest additional source of permanent water was a significant factor in explaining variation in species richness. The number of species captured at a site increasing with decreased distance to additional water. Although several authors (Jones 1966, Cockrum et al. 1996) have noted that abundance at water sources is influenced by the number of additional water sources in an area, I could find no studies that examined the influence of additional water sources on species richness. At a landscape level, close

sources of additional water may be a factor influencing roost site selection, particularly in areas with ephemeral water sources. Thus, areas with a backup source of water may have more suitable roost sites available for a wider variety of bat species. Size of the water source was also a significant factor in explaining variation in species richness, with more species utilizing larger water sources. Bat species vary in flight maneuverability, thus, less maneuverable species may be unable to use some of the smaller water sources.

Water sources used by California myotis were significantly closer to cliffs or rock outcrops than unused sites indicating that availability of roosts may be what is influencing their use of particular water sources. In addition, water sources used by this species as well as western pipistrelles, were significantly larger than non-used sites. Because both of these species are highly maneuverable (Norberg 1987), the use of larger bodies of water is somewhat surprising. Water sources used by big brown bats were located at significantly higher elevations than non-used sites. Others (Kurta and Baker 1990, Szewczak et al. 1998) have documented that the big brown bat is generally more abundant at higher elevations. I found no significant differences in characteristics at used versus unused sites for California leaf-nosed bats and cave myotis indicating that there may be other factors influencing these species presence at a site.

One potential concern with bats using artificial water sources is water quality at these sources and the affects water quality might have on bat species. I did not gather data on water quality during this study but I did notice that both artificial water sources and natural tinajas within the study area were stagnant and contained algae during the summer months. Blooms of potentially noxious or toxic blue-green algae have been

documented at natural tinajas (Kubly 1990) and high levels of hydrogen sulfite have been documented at both natural tinajas (Kubly 1990) and artificial water developments (Schmidt and DeStefano 1996). Although, both natural and artificial water sources have been found to be a source of disease for some animals including, ungulates (Cunningham 1989) and birds (Straus 1966, Fraser 1986), exactly what water qualities conditions are detrimental, tolerable, or healthy for wildlife, remains an open issue (Broyles. 1995).

## CONCLUSION

In the Sonoran Desert naturally occurring water sources are rare and are generally limited to springs and ephemeral tinajas (Brown and Johnson 1983). Artificial water sources have been added to this landscape and their presence greatly outnumbers natural sources in many locations within southern Arizona (Broyles 1997) including my study area. Unfortunately, there are no historical data on bat populations within this area thus, it is impossible to know what affect the addition of artificial water sources has had on bat population numbers. Given the scarceness of natural water sources in my study area, it is possible that the introduction of artificial water sources allowed some species to utilize roosts that might previously have been unavailable to them due to the costs of commuting large distances to watering/foraging areas. However, the higher activity I observed at natural sites could also be an indication that bats remain loyal to traditional roost sites and will not switch to other roosts.

The Game and Fish Department maintains about 800 water developments in Arizona, spending close to a million each year on maintenance and construction (deVos and Clarkson 1990). Unfortunately, guidelines to monitor the effects of these developments on wildlife and criteria to judge their efficiency are rare (Broyles and Cutler 1999). Information on bat use of water developments is necessary for wildlife managers to develop sound management plans and to make informed decisions regarding water management. My data provides baseline information on bat species utilizing both natural and artificial water sources in southern Arizona. It also indicates that use and perhaps reproductive output is higher at natural sources. Future studies,

especially impact assessment type studies, are needed to examine the ecological impacts of artificial water sources on bat species. Specific questions that I would like to see addressed include the following. Do artificial and natural sources differ in water quality? What affect does water quality have on bat species' reproduction and survival? How far do individuals in this area travel between watering/foraging and roosting areas? How much foraging is occurring at both natural and artificial water sources? What effect does addition or removal of water sources have on bat populations? Addressing these questions will lead to a better understanding of the ecological effects of artificial water developments on bat populations. Such an understanding is crucial in evaluating the effectiveness of artificial water developments as a wildlife management tool.

Appendix 2.1. Bats mist-netted at 17 water sources, Barry M. Goldwater Air Force Range, Arizona, May through August 1995-1996.

Site <sup>1</sup>	Elevation (m)	Vegetation	Species <sup>2</sup>	Males		Females	
				Adult	Juvenile	Adult	Juvenile
Bender Springs 1 (N)	910	Dry riparian	Calif. leaf-nosed bat	0	0	2	0
			California myotis	2	0	2	0
			Big brown bat	4	0	2	0
			Western pipistrelle	5	2	6	2
			Pallid bat	26	7	7	2
Bender Springs 2 (A)	840	Mixed cactus	California myotis	1	0	1	0
			Western pipistrelle	4	1	2	0
			Pallid bat	29	12	1	1
Big Horn (A)	550	Creosote	Western pipistrelle	5	0	1	0
			Pallid bat *	0	0	0	0
Javelina Mountain (A)	720	Creosote	Cave myotis	0	0	2	0
			Western pipistrelle	1	0	3	0
			Pallid bat	0	1	0	0
Johnson Well 1 (A)	780	Mixed cactus	Cave myotis	0	1	0	0
			Big brown bat	0	0	1	0
			Western pipistrelle	2	0	0	0
			Pallid bat	9	1	0	0
Johnson Well 2 (A)	750	Mixed cactus	Calif. leaf-nosed bat	4	5	17	4
			California myotis	0	0	0	1
			Cave myotis	0	1	1	0
			Western pipistrelle	5	0	2	1
			Pallid bat	7	6	6	3
Midway (A)	410	Creosote	Calif. leaf-nosed bat	10	0	11	0
			Western pipistrelle	10	1	3	1

**Appendix 2.1 (Continued).**

Site <sup>1</sup>	Elevation (m)	Vegetation	Species <sup>2</sup>	Males		Females	
				Adult	Juvenile	Adult	Juvenile
Midway (A)	410	Creosote	Pallid bat	6	6	6	3
Papago Mine (A)	550	Mixed cactus	Calif. leaf-nosed bat	6	0	7	0
			California myotis	2	0	0	0
			Western pipistrelle	8	3	0	0
Ryan's Canyon 1 (A)	660	Mixed cactus	Pallid bat	1	1	11	1
			Calif. leaf-nosed bat	3	0	10	0
			Cave myotis	0	0	1	0
			Western pipistrelle	0	0	0	1
Ryan's Canyon 2 (A)	660	Mixed cactus	Pallid bat	3	1	4	1
			Calif. leaf-nosed bat	18	0	16	0
			Western pipistrelle	0	0	1	0
Ryan's Canyon 3 (A)	610	Mixed cactus	Pallid bat	0	0	1	0
			Calif. leaf-nosed bat	18	0	30	2
			Pallid bat	7	1	1	0
Ryan's Canyon 4 (A)	545	Mixed cactus	Calif. leaf-nosed bat	12	0	18	2
			Western pipistrelle *	0	0	0	0
			Pallid bat	7	5	15	4
Sauceda Tank (N)	545	Dry riparian	Calif. leaf-nosed bat	5	0	0	0
			California myotis	1	0	1	0
			Western pipistrelle	13	1	1	0
			Pallid bat	7	1	3	1
Thanksgiving Tank (N)	425	Dry riparian	Calif. leaf-nosed bat	5	5	2	8
			California myotis	2	0	5	0
			Western pipistrelle	9	1	8	5

Appendix 2.1 (Continued).

Site <sup>1</sup>	Elevation (m)	Vegetation	Species <sup>2</sup>	Males		Females	
				Adult	Juvenile	Adult	Juvenile
Thanksgiving Tank (N)	425	Dry riparian	Pallid bat	4	3	3	4
Tom Thumb 1 (A)	725	Dry riparian	Calif. leaf-nosed bat	18	0	3	0
			Pallid bat	1	0	0	0
Tom Thumb 2 (A)	660	Mixed cactus	Calif. leaf-nosed bat	4	0	4	0
			Cave myotis	1	0	0	0
			Pallid bat	1	0	7	0
White Tank (N)	395	Dry riparian	Western pipistrelle	0	0	2	0
			Pallid bat	3	15	17	17

<sup>1</sup>Type of water source is shown in parentheses, A = artificial, N = natural. <sup>2</sup>\* indicates species was detected from ultrasonic data.

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