POPULATION STRUCTURE AND DYNAMICS OF JUVENILE BRAZILIAN FREE-TAILED BATS (*TADARIDA BRASILIENSIS MEXICANA*) BANDED IN CENTRAL TEXAS

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By

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

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May 2001

Supervising Professor: John T. Baccus

During the summer months as many as 3 million Brazilian free-tailed bats (*Tadarida brasiliensis mexicana*) reside in an abandoned train tunnel at the Old Tunnel Wildlife Management Area, Kendall County, Texas. This study examined the population ecology of juvenile bats as it related to emergence patterns, sex ratios, and recruitment. To collect large numbers of bats efficiently a 1.8 m by 2 m double frame Harp trap was lowered in front of the south opening of the tunnel shortly after the start of the emergence. Banding occurred in late July and August of 1999 and 2000. Bands were placed on 4,000 and 3,625 bats, respectively. The sex of each juvenile banded and the dates of banding were recorded. Capture data showed no significant difference in the sex ratio in 1999, however the ratio was significantly male biased ($p < 0.001$) in 2000. Data from recaptures were analyzed using the Jolly-Seber method to estimate the juvenile population for both summers. Results show a decrease in the population from 1999 to 2000. Population trends, however, appear to be similar between the two summers.

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INTRODUCTION

The Brazilian free-tailed bat (*Tadarida brasiliensis mexicana*) is the most abundant bat species in Texas. Summer population estimates for the state range from 95.8 million to 103.8 million (Davis *et al.* 1962). Some migrate to Texas from Mexico as early as February and return south as early as September (Cagle 1950; Barbour and Davis 1969). The majority of spring migrants consist of pregnant females that form large maternity colonies primarily in caves, caverns, and sinkholes. These bats select for a small number of roost sites, which provide the narrow range of climatic conditions necessary for pre- and postnatal development (Kunz and Robson 1995). These sites are vulnerable to human disturbance and habitat destruction. The loss of natural roosting sites has resulted in an increase in the occupancy of man-made structures. In Texas, these structures include the Congress Avenue Bridge in Austin, Clarity Tunnel at Caprock Canyons State Park, and the Old Tunnel Wildlife Management Area (hereafter, Old Tunnel WMA) near Comfort. Abandoned mines and tunnels most closely simulate natural cave conditions (Fraze and Wilkins 1990; Belwood 1991); however, due to environmental fluctuations, these sites are considered sub-optimal for rearing young bats.

During the summer as many as 1.2 million to 3 million *T. b. mexicana* and about 3,000 cave myotis (*Myotis velifer*) reside in an abandoned train tunnel at the Old Tunnel WMA, Kendall County, Texas (Wallace and Lawyer 1996). The Old Tunnel WMA has been called a pseudomaternity colony because females display the characteristics found in maternity colonies, such as pregnancy and lactation; however, nonvolant young have not been found at this site (Bailey 1993; Wallace and Lawyer 1996; Harper 1997; Tanner 1999). Pregnant females residing at the Old Tunnel WMA presumably leave this site to give birth at unknown maternity roosts. Parturition occurs in mid-June, with more than 90% of pups being born within 15 days (Cagle 1950; Eads *et al.* 1957; Glass 1958; Short 1961; Davis *et al.* 1962; Svoboda and Choate 1987; Schmidly 1991). Females nurse their pups for six weeks, at which time the young bats have developed their wings and are volant (Pagel and Jones 1974; Wilkins 1989; McCracken and Gustin 1991; Kunz and Robson 1995). At this time juveniles fly with adult bats to the Old Tunnel WMA roost. Fraze and Wilkins (1990) reported this type of behavior in a Brazilian free-tailed bat colony near Belton-Salado, Texas.

The Old Tunnel WMA provides an excellent model for population studies because as a permanent summer roost, a large number of bats can be easily collected while exiting from the tunnel. Previous research at the Old Tunnel WMA focused on the structure and dynamics of the population of adult bats. To completely understand the ecology of the entire colony, a study designed to research similar aspects in the juvenile segment of the population began in 1999.

Sex ratios express the relative abundance of males to females in animal populations (Bolen and Robinson 1999). Bellrose *et al.* (1961) noted that sex ratios change in populations based on age structure. The primary sex ratio refers to the proportion of males to females at the time of fertilization. Based on statistical probability of genetic sex determination, this ratio is assumed 1:1. The sex ratio at parturition, or secondary sex ratio also is assumed 1:1. The tertiary sex ratio refers to the juvenile segment, defined here as those juveniles capable of flight. This stage is important because it indicates the proportion of each sex entering the breeding population. Finally, the quaternary sex ratio represents the sex ratio of the adult population. This ratio is often substantially biased toward one sex.

Studies on *T. b. mexicana* at a number of colonies in Texas reported biased sex ratios in adult populations. Behavioral differences in migration, roost selection, and emergence result in these unbalanced or skewed sex ratios (Krutzch 1955; Twente 1956; Eads 1957; Davis *et al.* 1962; Villa and Cockrum 1962). Males tend to remain in Mexico during the summer, whereas females migrate to northern latitudes (Davis *et al.* 1962; Villa and Cockrum 1962). In the United States, males form small bachelor colonies separate from the large, female-biased maternal roosts (Krutzch 1955; Twente 1956). Tanner (1999) reported changes in the quaternary sex ratio at different times during summer emergences from the Old Tunnel WMA. Therefore, accurate data on quaternary sex ratios are difficult to collect at summer locations.

Juvenile bats provide a good model for population studies because of 1) the abundance of juveniles in Texas during late summer, 2) ease of capture during an emergence, and 3) ease of sex determination based on external genitalia. Even (1:1) sex ratios have been reported for pre- and postnatal bats (Cagle 1950; Mohr 1952; Davis *et al.* 1962; Humphrey and Cope 1976; Wilkins 1989; Kunz and Robson 1995). Little information, however, exists on the tertiary segment of the population.

The tertiary sex ratio should not differ from unity unless natural or man-made factors influence deviations. Such factors include differential mortality in earlier age groups, differences in growth rates and/or differences in behavioral patterns with respect to migration, roost selection, or emergence. Biased ratios also can result from poor research design. Improper sex determination and/or erroneous sampling methods can produce unbalanced ratios.

Ecological studies often require some estimate of numbers within a given area (Thomas and LaVal 1988). Estimates at one point in time provide little information about the status of a population. A series of estimates, however, offers meaningful data as to the direction and magnitude of change a population might experience over a specified time (Lancia *et al.* 1996).

Mark-recapture techniques provide a method for estimating population size. Individuals are marked on one occasion and later the population is sampled to compare the numbers of marked to unmarked animals. The cohort of juvenile bats at the Old Tunnel WMA is considered an open population. Open populations constantly change in size because of births or immigrations and/or deaths or emigrations (Krebs 1999). The departure from the nursery roost and subsequent arrival of juvenile bats at the Old Tunnel WMA occurs over an extended period, causing fluctuations in the population size.

The objectives of my study were to 1) determine the timing of parturition of *T. b. mexicana* in central Texas, 2) determine the arrival date of juvenile *T. b. mexicana* at the Old Tunnel WMA, 3) estimate the tertiary sex ratio for *T. b. mexicana*, and 4) assess the recruitment of juvenile *T. b. mexicana* at the Old Tunnel WMA.

MATERIALS AND METHODS

The Old Tunnel WMA is located near the northern border of Kendall County (29° 41' 56" N, 98° 4' 39" W) 24 km southeast of Fredericksburg, Texas, and 18 km north of Comfort, Texas. The 4.2 ha tract was acquired in 1991 by the Texas Parks and Wildlife Department (TPWD) and is currently operated by this agency. The south opening of the tunnel and the adjacent valley are included within the property (Wallace and Lawyer 1996). The tunnel is approximately 280 m long and 6 m high with a ceiling width of 5 m. Vertical cliffs about 12 m high confine the south and north opening of the tunnel (Bailey 1993). The tunnel was constructed in 1913 to allow the shipping of goods from Fredericksburg to San Antonio. By 1942, the railroad company was bankrupt, and the rails were sold for scrap iron to the War Department (Schmidt 1973). According to anecdotal evidence, the tunnel soon became a roost site for bats.

During the evening emergence most bats exit the south opening, spiraling counter-clockwise to gain enough lift to carry them over nearby vegetation. To collect large numbers of bats efficiently, a 1.8 m by 2 m double frame Harp trap strung with six pound monofilament (Constantine 1958; Tuttle 1974; Kunz and Kurta 1988) was lowered in front of the south opening shortly after the start of an emergence. This was considered the optimal time for collecting juvenile bats once they had joined the Old Tunnel WMA population. The trap was raised and lowered using a rope and pulley system attached to a rotating iron bar mounted in the limestone rock above the tunnel opening. Once lowered, the trap was continuously moved side-to-side in such a manner as to cover the entire tunnel opening in one sweep. This technique was used to assure equal catchability by reducing the probability of permanent trap response.

Collections occurred two to three nights per week from June to mid-August 1999 and 2000. In 2000, collections occurred twice on several trap nights, once at the beginning of the emergence and a second time later in the emergence. Trapping did not occur on nights in which weather affected emergence behavior. These included nights with rain or excessive winds. Northern populations of roosting bats in Kansas and Oklahoma begin migrating south, on or about mid-August. To prevent bias due to these migrants, data collection ended on or near 20 August. Bats were identified by species and checked for relative age, sex, reproductive condition of females, and bands.

Examining the extent of the epiphyseal-diaphyseal fusion in the 4th metacarpal-phalangeal joint assessed relative age. Juvenile bats possess cartilaginous epiphyseal plates in the finger bones. These zones appear lighter than ossified parts of bones as lesser mineralization allows more light to pass through (Barbour and Davis 1969; Anthony 1988). Relative size and pelage colors also were considered in aging bats. Juveniles are noticeably smaller and possess a uniform gray pelage in comparison to the brownish pelage color of adult bats (Cagle 1950). Reproductive condition of females was designated as pregnant, lactating, or neither. Pregnancy was detected by swelling in the lower abdomen and lactation by diminished pelage around the mammae (Racey 1988).

Banding of juvenile bats occurred in late July and August 1999 and 2000. A split ring #2 band (Gey Band and Tag Co., Norristown, Pennsylvania) was placed on the right forearm of each juvenile. A green open celluloid band was used in 1999 and a blue aluminum band was used in 2000. Bands were loose and free to slide along the forearm causing minimal discomfort (Trapido and Crowe 1946). Information from recaptures included the date of recapture, band color, band number (if readable), any damage to the bat's wing caused by the band, sex, and reproductive condition of the bat.

Davis *et al.* (1962) reported increased milk production in female bats within a day of parturition. Timing of parturition, therefore, was based on the first appearance of lactating females on a collection night. The time of arrival of juvenile bats at the Old Tunnel WMA was determined by their first appearance in a collection.

Sex ratios were established for the juvenile population for 1998, 1999, and 2000. Research by Tanner (1999) provided data for 1998. Sex ratios were calculated per trap night, per year, and for the total number of juvenile bats caught. Results were tested for deviations from the expected 1:1 ratio using a G-test ($\alpha = 0.05$). Draper and Smith (1998) provided values for statistical significance.

Estimates for the juvenile population were calculated for 1999 and 2000 using the Jolly-Seber method. Estimates were established per trap night. Based on available data, estimates of population size cannot be obtained for the first sample, or for the last sample (Krebs 1999). Data from recaptures were analyzed using Krebs Ecological Methodology software.

RESULTS

In 1999, parturition was assumed to have occurred during 18 days from mid-June to early July. Lactating female bats first appeared in samples on 14 June. Pregnant female bats were last captured on 2 July. The first appearance of juvenile bats in samples occurred on 26 July.

In 2000, parturition was assumed to have occurred during 32 days from mid-June to mid-July. Lactating female bats first appeared in samples on 14 June. Pregnant female bats were last captured on 16 July. The majority of pregnant female bats, however, were captured before 5 July. Only 16 pregnant female bats were captured after this date. The first appearance of juvenile bats in samples occurred on 24 July.

During 1998, a total of 1,603 juvenile *T. b. mexicana* were captured on six trap nights. Of these, 55.1% (883) were males and 44.9% (720) females (Table 1). The percent composition of males in samples ranged from 43.7 to 60.0 and females ranged from 40.0 to 56.3 on individual capture nights.

Sex ratio calculations showed a significant male bias in samples for 1998 ($G = 8.30$, $p < 0.005$). However, males were only caught in significant proportions on 10 August ($p < 0.001$). Sex ratios for the remaining five nights did not deviate significantly from 1:1 (Table 1, Figure 1). Four of these nights showed a male bias in the samples. Only on 3 August did female abundance exceed male abundance.

A total of 4,310 juvenile bats were captured on 11 trap nights in 1999. Of these,

Table 1. Number of juvenile *Tadarida brasiliensis mexicana* captured per trap night at the Old Tunnel Wildlife Management Area, Texas, 1998. Sex ratios were tested for deviations from 1:1. Percent composition of males and females in each capture are shown in parenthesis.

Date	Males	Females	d.f.	G
29-Jul	132 (55.2)	107 (44.8)	1	2.62
31-Jul	114 (54.5)	105 (45.5)	1	0.37
3-Aug	45 (43.7)	58 (56.3)	1	1.65
7-Aug	153 (55.8)	121 (44.2)	1	3.75
10-Aug	270 (60.0)	180 (40.0)	1	18.12 ***
12-Aug	169 (53.1)	149 46.9)	1	1.26
Total	883 (55.1)	720 (44.9)	1	8.30 **

Significance levels are denoted as: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

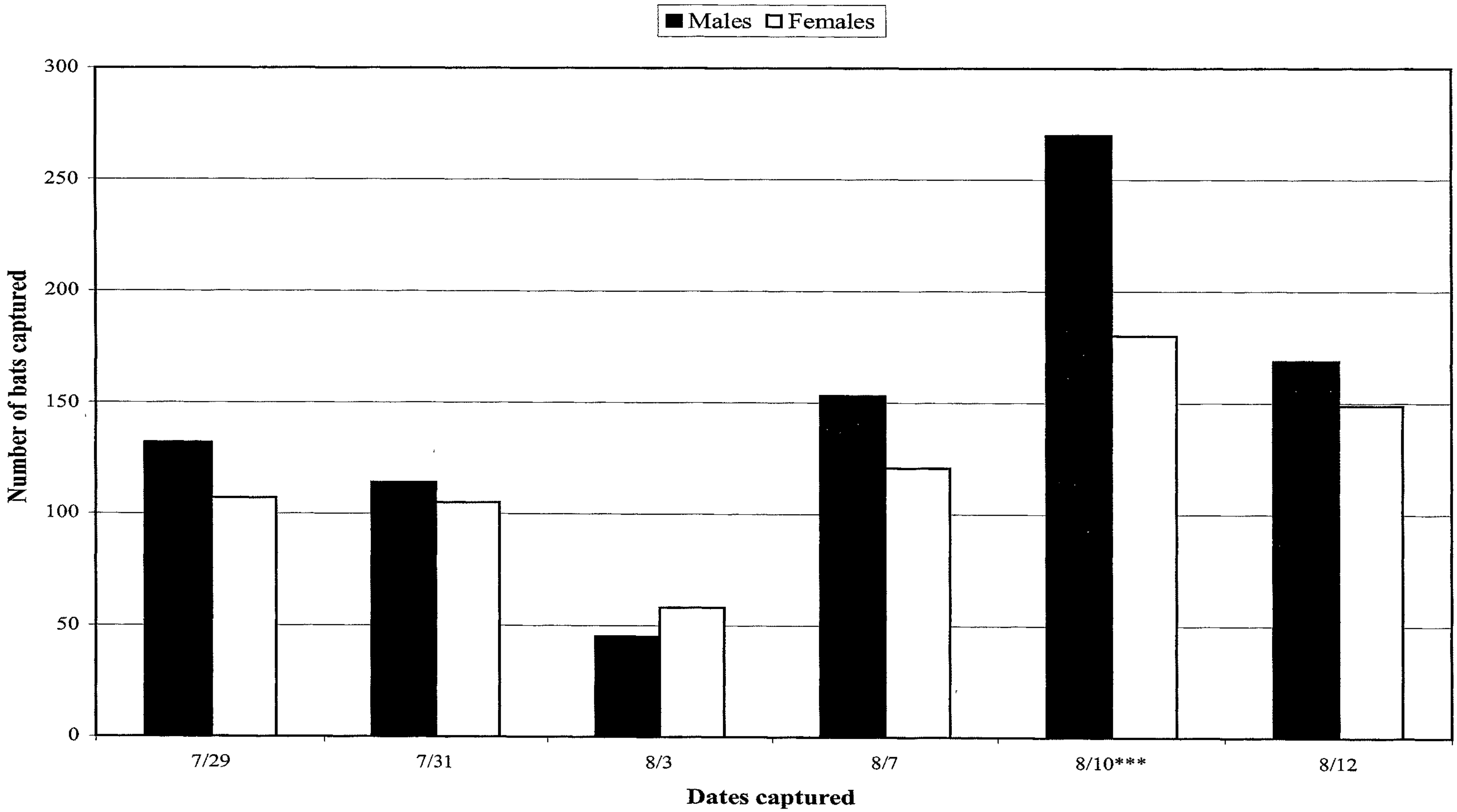

Figure 1. Number of juvenile *Tadarida brasiliensis mexicana* captured per trap night at the Old Tunnel Wildlife Management Area, Texas, 1998. Significance levels are denoted as: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

48.8% (2,105) were males and 51.2% (2,205) females (Table 2). The percent composition of males in samples ranged from 41.6 to 56.7 and females ranged from 43.3 to 58.4 on individual capture nights.

The 1999 sex ratio did not deviate significantly from 1:1 ($G = 2.32$, $p > 0.05$). The sex ratios, however, did vary among capture nights (Table 2, Fig. 2). Males were caught in significantly greater proportions on 28 June and 4 August ($p < 0.05$). The proportion of females was significantly greater on 13, 16, and 18 August. Sex ratios for the remaining six nights did not deviate significantly from 1:1.

During 2000, collections occurred twice on several trap nights, once at the beginning of the emergence and a second time later in the emergence. In early emergence samples (1/1), a total of 2,882 juvenile bats were captured on 12 trap nights. Of these, 59.7% (1,720) were males and 40.3% (1,162) females (Table 3). The percent composition of males in samples ranged from 47.1 to 83.6 and females ranged from 16.4 to 52.9 on individual capture nights.

Sex ratio calculations for early emergence samples (1/1) showed a significant male bias in 2000 ($G = 108.72$, $p < 0.001$). Males were caught in significantly greater proportions on eight of 12 capture nights. Females were captured in greater proportions on 9, 18, and 20 August, however, the sex ratio for these nights did not differ from 1:1 (Table 3, Fig. 3).

In late emergence samples (1/2), a total of 511 juvenile bats were captured on nine trap nights. Of these 59.7% (305) were males and 40.3% (206) were females (Table 4). The percent composition of males in samples ranged from 51.4 to 93.3 and females ranged from 6.7 to 48.6 on individual capture nights.

Table 2. Number of juvenile *Tadarida brasiliensis mexicana* captured per trap night at the Old Tunnel Wildlife Management Area, Texas, 1999. Sex ratios were tested for deviations from 1:1. Percent composition of males and females in each capture are shown in parenthesis.

Date	Males	Females	d.f.	G
26-Jul	39 (55.7)	31 (44.3)	1	0.92
28-Jul	156 (56.7)	119 (43.3)	1	4.99 *
2-Aug	290 (53.6)	251 (46.4)	1	2.81
4-Aug	199 (55.3)	161 (44.7)	1	4.02 *
6-Aug	225 (52.1)	207 (47.9)	1	0.75
9-Aug	236 (52.0)	218 (48.0)	1	0.71
11-Aug	145 (47.4)	161 (52.6)	1	0.84
13-Aug	219 (44.3)	275 (55.7)	1	6.36 *
16-Aug	253 (43.8)	325 (56.2)	1	8.99 **
18-Aug	198 (41.6)	278 (58.4)	1	13.51 ***
20-Aug	145 (44.8)	179 (55.2)	1	3.57
Total	2105 (48.8)	2205 (51.2)	1	2.32

Significance levels are denoted as: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

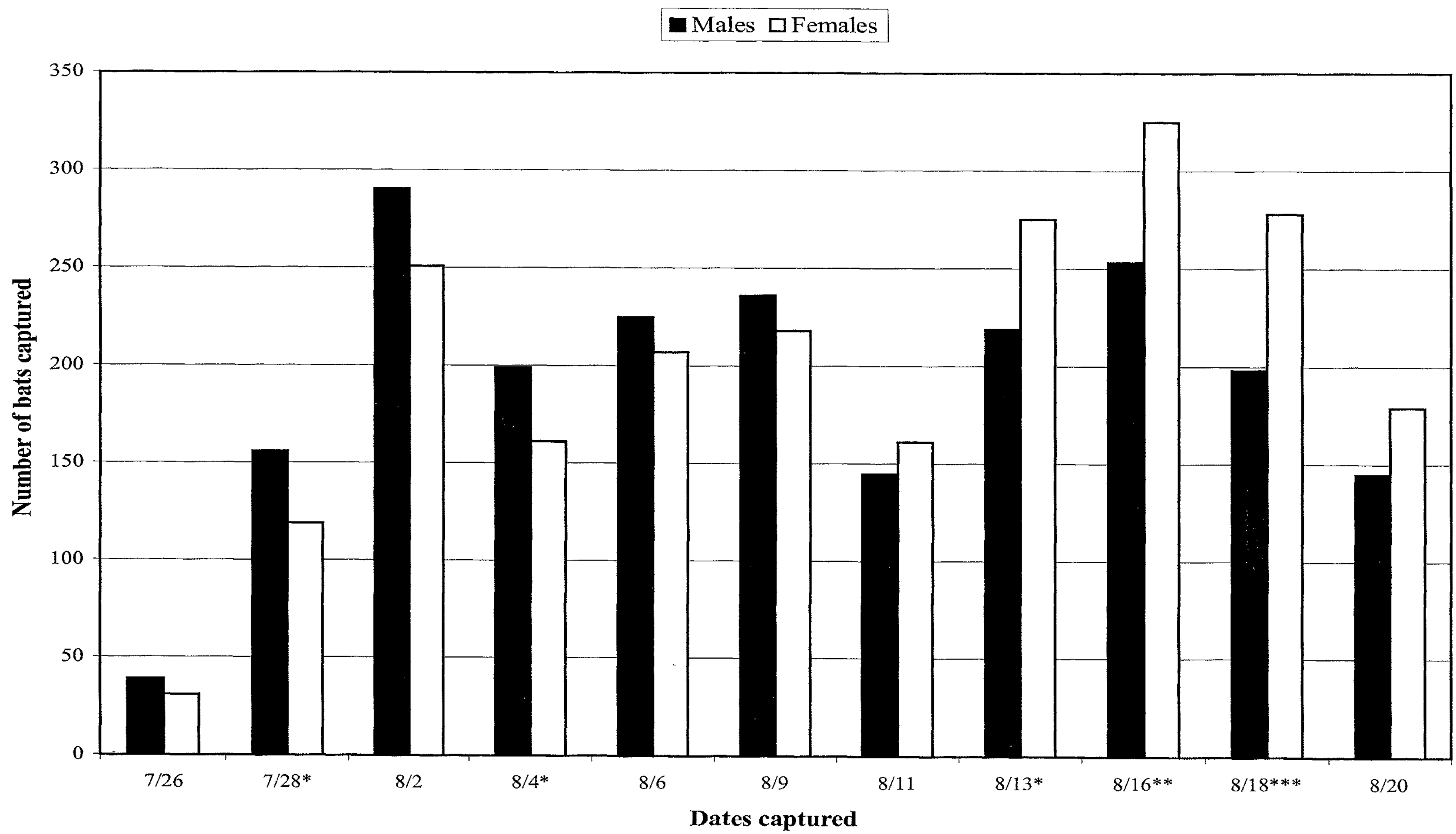

Figure 2. Number of juvenile *Tadarida brasiliensis mexicana* captured per trap night at the Old Tunnel Wildlife Management Area, Texas, 1999. Significance levels are denoted as: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

Table 3. Number of juvenile *Tadarida brasiliensis mexicana* captured in early emergence samples (1/1) per trap night at the Old Tunnel Wildlife Management Area, Texas, 2000. Sex ratios were tested for deviations from 1:1. Percent composition of males and females in each capture are shown in parenthesis.

Date	Males	Females	d.f.	G
24-Jul	153 (83.6)	30 (16.4)	1	90.41 ***
25-Jul	48 (73.8)	17 (26.2)	1	15.40 ***
26-Jul	136 (74.7)	46 (25.3)	1	46.52 ***
1-Aug	188 (66.7)	94 (33.3)	1	31.94 ***
2-Aug	197 (59.3)	135 (40.7)	1	11.65 ***
7-Aug	167 (76.6)	51 (23.4)	1	65.88 ***
9-Aug	189 (49.2)	195 (50.8)	1	0.09
11-Aug	188 (56.6)	144 (43.4)	1	5.85 *
14-Aug	117 (50.2)	116 (49.8)	1	0.04
16-Aug	112 (57.1)	84 (42.9)	1	4.01 *
18-Aug	104 (47.7)	114 (52.3)	1	0.46
20-Aug	121 (47.1)	136 (52.9)	1	0.88
Total	1720 (59.7)	1162 (40.3)	1	108.72 ***

Significance levels are denoted as: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

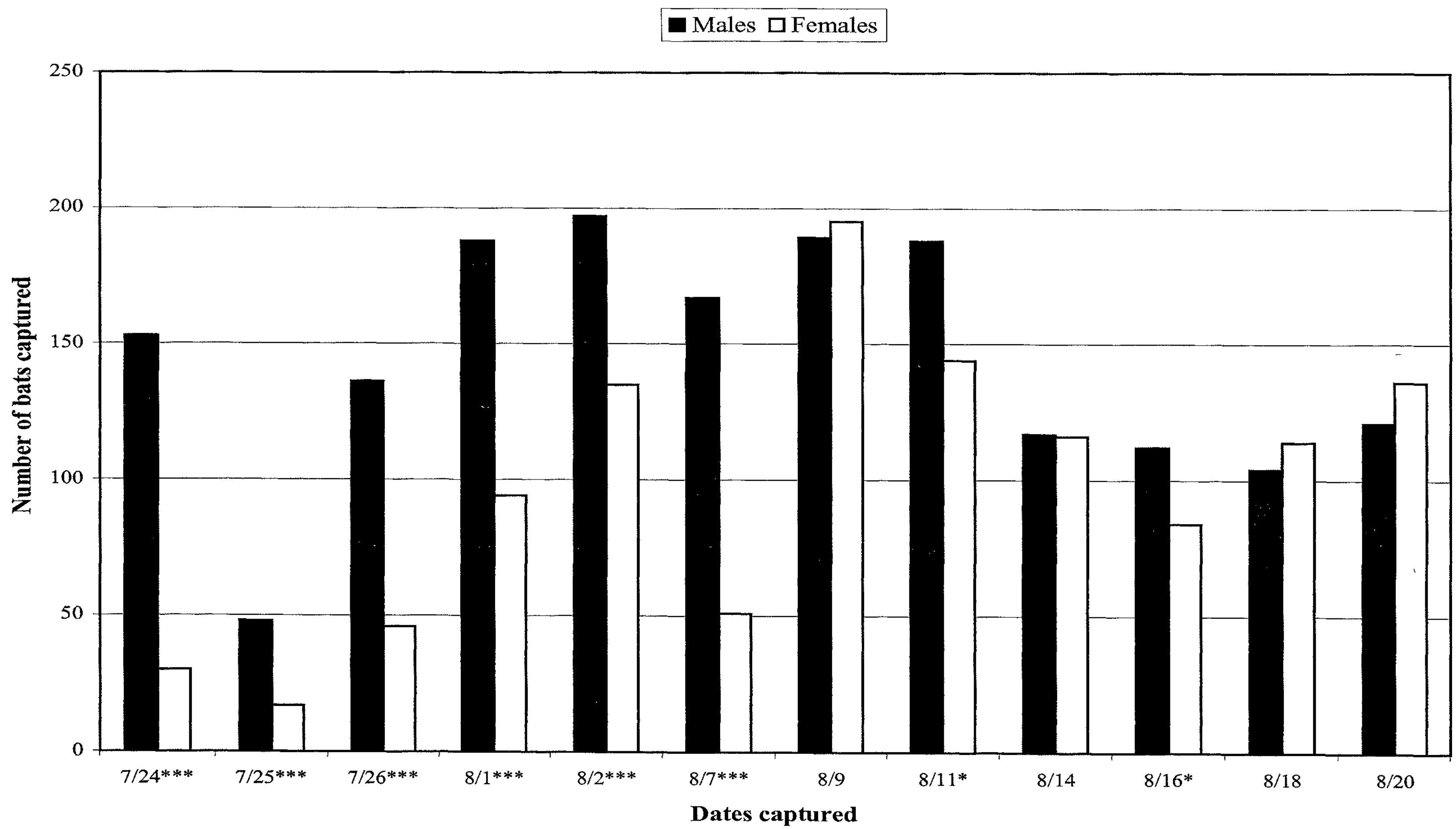

Figure 3. Number of juvenile *Tadarida brasiliensis mexicana* captured in early emergence samples (1/1) per trap night at the Old Tunnel Wildlife Management Area, Texas, 2000. Significance levels are denoted as: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

Table 4. Number of juvenile *Tadarida brasiliensis mexicana* captured in late emergence samples (1/2) per trap night at the Old Tunnel Wildlife Management Area, Texas, 2000. Sex ratios were tested for deviations from 1:1. Percent composition of males and females in each capture are shown in parenthesis.

Date	Males	Females	d.f.	G
25-Jul	42 (93.3)	3 (6.7)	1	40.34 ***
26-Jul	2 (66.7)	1 (33.3)	1	0.34
2-Aug	3 (75.0)	1 (25.0)	1	1.05
7-Aug	10 (52.6)	9 (47.4)	1	0.05
9-Aug	19 (51.4)	18 (48.6)	1	0.06
11-Aug	121 (58.5)	86 (41.5)	1	5.95*
14-Aug	80 (53.0)	71 (47.0)	1	0.54
16-Aug	9 (56.3)	7 (43.7)	1	0.25
18-Aug	19 (65.5)	10 (34.5)	1	2.84
Total	305 (59.7)	206 (40.3)	1	19.30 ***

Significance levels are denoted as: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

Sex ratio calculations for late emergence samples (1/2) showed a significant male bias in 2000 ($G = 19.30$, $p < 0.001$). The proportion of males was significantly greater on 25 July and 11 August (Table 4, Fig. 4). Females were not captured in a greater proportion on any of the nine capture nights.

Between 1998 and 2000, 9,306 juvenile bats were captured. Of these, 53.9% (5,013) were males and 46.1% (4,293) were females (Table 5). Data from 1998 and both sampling periods in 2000 showed a significant male bias. Data from 1999 showed no deviation from 1:1 (Table 5, Fig. 5). The overall sex ratio of juvenile bats for the three years differed significantly from 1:1 in favor of males ($G = 55.76$, $p < 0.001$).

During 1999, a total of 4,000 juvenile bats were banded and released. Of these, 0.73% (29) were recaptured between 4 August and 20 August. Population estimates were calculated per trap night from 2 August to 18 August (Table 6). The estimated population of juvenile bats ranged from 68,875 to 753,641 individuals (Fig. 6). Estimates showed a relatively small number of bats on 2 and 4 August. The population peaked on 6 August followed by a sharp decrease on 9 August. The population fluctuated from 9 August to 20 August. The lowest estimate occurred on 13 August.

During 2000, a total of 3,625 juvenile bats were banded and released. Of these, 0.61% (22) were recaptured between 26 July and 21 August. Population estimates were calculated per trap night from 25 July to 20 August (Table 7). The estimated population of juvenile bats ranged from 92 to 160,178 individuals (Fig. 7). Estimates showed a relatively small number of bats on 25 and 26 July with the lowest estimate on 26 July. The population peaked on 1 August followed by a sharp decrease on 2 August. The estimated population increased again on 9 August then continued to decline from

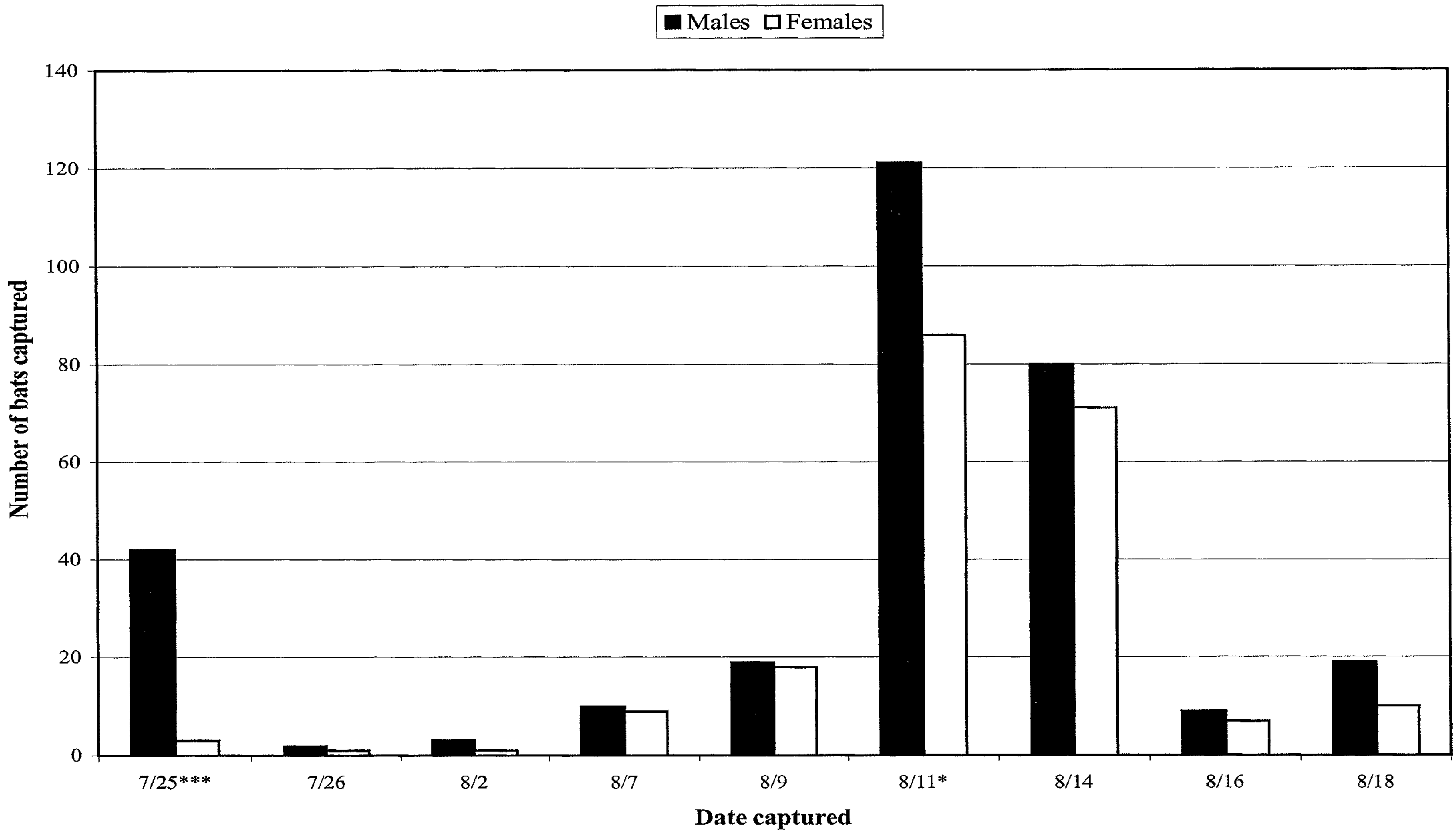

Figure 4. Number of juvenile *Tadarida brasiliensis mexicana* captured in late emergence samples (1/2) per trap night at the Old Tunnel Wildlife Management Area, Texas, 2000. Significance levels are denoted as: * = p < 0.05, ** = p < 0.01, *** = p < 0.001.

Table 5. Number of juvenile *Tadarida brasiliensis mexicana* captured per year at the Old Tunnel Wildlife Management Area, Texas. Sex ratios were tested for deviations from 1:1. Percent composition of males and females in each year are shown in parenthesis.

Year	Males	Females	d.f	G
1998	883 (55.1)	720 (44.9)	1	8.30 **
1999	2105 (48.8)	2205 (51.2)	1	2.32
2000 (1/1)	1720 (59.7)	1162 (40.3)	1	108.72 ***
2000 (1/2)	305 (59.7)	206 (40.3)	1	19.30 ***
Total	5,013 (53.9)	4,293 (46.1)	1	55.76 ***

Significance levels are denoted as: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$.

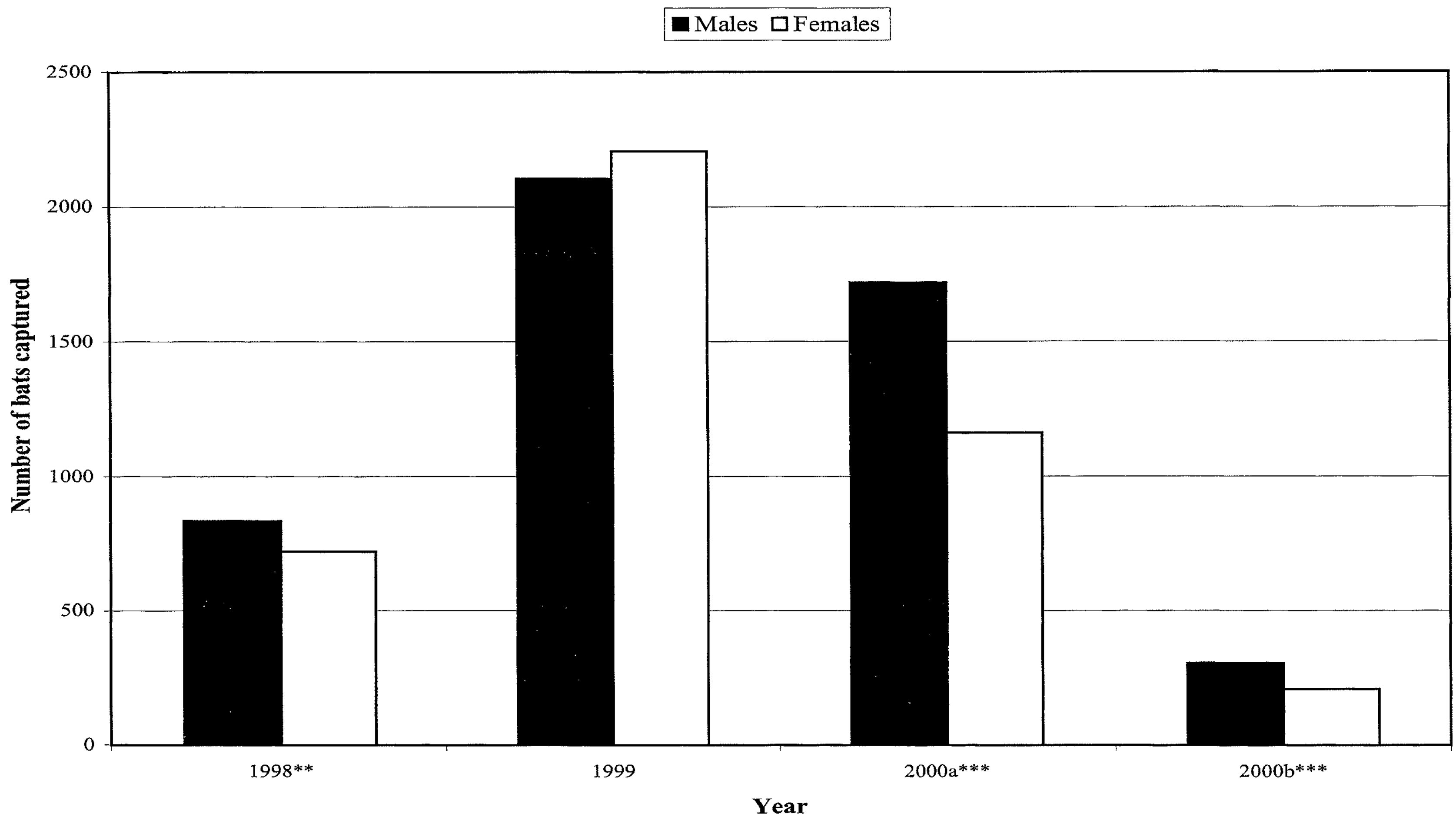

Figure 5. Number of juvenile *Tadarida brasiliensis mexicana* captured by year at the Old Tunnel Wildlife Management Area, Texas. Significance levels are denoted as: * = p < 0.05, ** = p < 0.01, *** = p < 0.001.
a: First Emergence / First Capture. b: First Emergence / Second Capture.

Table 6. Population estimates per capture night for juvenile *Tadarida brasiliensis mexicana* at the Old Tunnel Wildlife Management Area, Texas, 1999. The 95 % confidence intervals are shown along with estimates.

Date	Total Population		
	Low	Estimate	High
28-Jul	(a)	(a)	(a)
2-Aug	21,056	146,882	2,746,948
4-Aug	31,845	153,066	1,622,190
6-Aug	98,564	753,641	15,975,828
9-Aug	33,937	145,783	1,306,259
11-Aug	33,995	207,348	3,138,934
13-Aug	24,918	68,875	318,665
16-Aug	75,671	238,389	1,336,900
18-Aug	19,618	75,906	584,161
20-Aug	(a)	(a)	(a)

(a): No estimate can be made of this parameter from the available data.

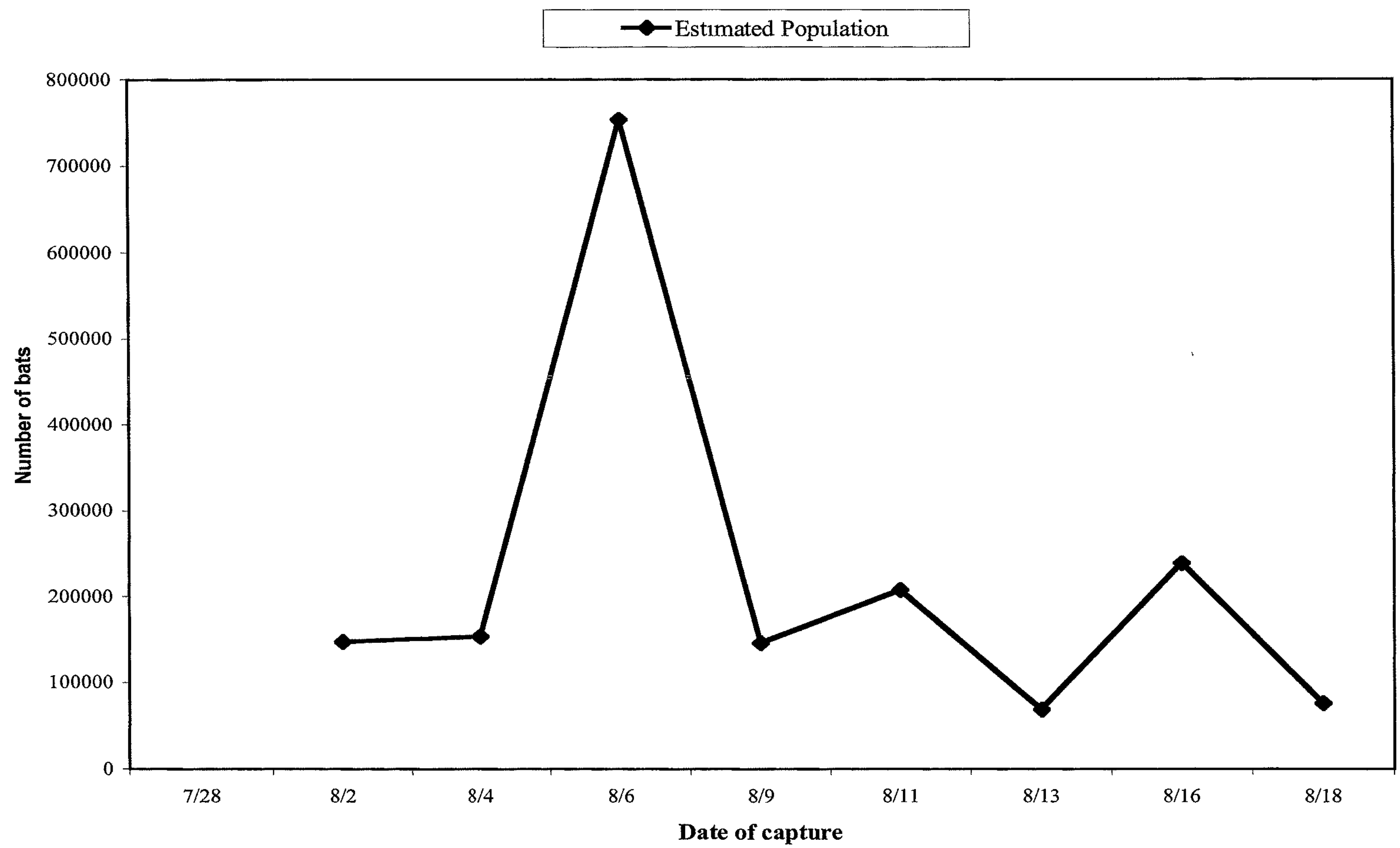

Figure 6. Population estimates for juvenile *Tadarida brasiliensis mexicana* per capture night at the Old Tunnel Wildlife Management Area, Texas, 1999.

Table 7. Population estimates per capture night for juvenile *Tadarida brasiliensis mexicana* at the Old Tunnel Wildlife Management Area, Texas, 2000. The 95 % confidence intervals are shown along with estimates.

Date	Total Population		
	Low	Estimate	High
24-Jul	(a)	(a)	(a)
25-Jul	314	4356	262,148
26-Jul	58,955,479	92	147,819
1-Aug	12,966	160,178	7,054,654
2-Aug	3,120	28,056	810,241
7-Aug	2,089	24,531	1,060,341
9-Aug	4,519	49,408	1,889,562
11-Aug	4,899	28,056	399,247
14-Aug	1,951	9,539	110,081
16-Aug	28,824	161	198,542
18-Aug	2,670,689	147	39,490,103
20-Aug	611,466,054	130	1,761,007
21-Aug	(a)	(a)	(a)

(a): No estimate can be made of this parameter from the data available.

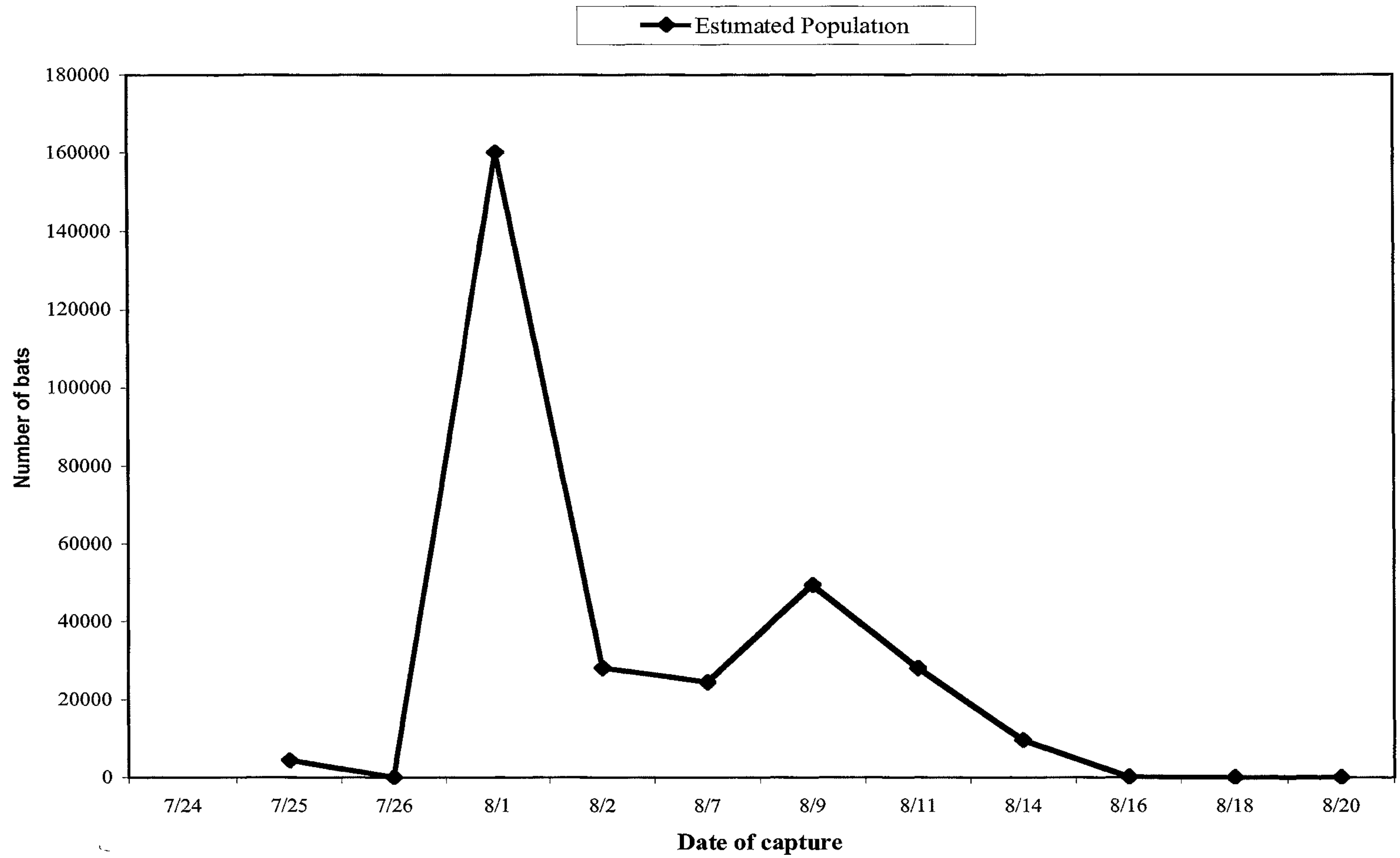

Figure 7. Population estimates for juvenile *Tadarida brasiliensis mexicana* per capture night at the Old Tunnel Wildlife Management Area, Texas, 2000.

11 August to 20 August.

In 2000, bats with green bands (1999) were reported roosting at other locations. One bat was observed in a building in downtown Austin, Texas, in April. Another bat was reported dead in Blanco, Texas, in late June.

During late summer, hundreds of bats were reported around the area of the Old Tunnel WMA, several of these possessed blue bands (2000). One bat was seen 8 km east of the Old Tunnel roost on 8 August. Another juvenile was reported in the vicinity of Boerne Lake, Boerne, Texas. Two ranches, both located approximately 8 km north of Comfort, Texas, observed several bats with blue bands on a number of occasions in late August. One of the ranchers reported close to 20 dead bats on his property, two of these # 2264 and # 2856, were banded juveniles from 2000. Another juvenile, # 1634, was found dead at Fort Martin, Fredericksburg, Texas, in August. In early September, juvenile bats with blue bands were observed in the parking garage of Southwest Texas State University, San Marcos, Texas.

DISCUSSION

The timing of parturition for *T. b. mexicana* collected at the Old Tunnel WMA was consistent between 1999 and 2000. Lactating female bats first appeared in samples on 14 June for both seasons. Parturition occurred during a three week period (mid-June to early July) with the majority of pups being born on or before 5 July. Previous studies conducted at nursery caves (Bracken Cave, Ney Cave, James River Cave, and Davis Cave) in the Edwards Plateau, Texas, report similar findings with respect to parturition (Cagle 1950; Eads *et al.* 1957; Short 1961; Davis *et al.* 1962).

Juvenile *T. b. mexicana* are weaned and volant by an age of six weeks (Pagel and Jones 1974; Wilkins 1989; McCracken and Gustin 1991; Kunz and Robson 1995). At this time, juveniles follow adult bats to the Old Tunnel WMA roost. The arrival of juvenile bats at the Old Tunnel WMA occurred on 26 July and 24 July in 1999 and 2000 respectively. The timing of arrival observed in this study corresponds with the arrival of juvenile *T. b. mexicana* at other man-made structures (Svoboda and Choate 1987; Fraze and Wilkins 1990).

Tertiary sex ratios in bats often differ from unity in favor of males. Cagle (1950) noted significantly greater proportions of juvenile male *T. b. mexicana* ($G = 6.694$ $p < 0.01$) sampled in August from Ney Cave, Bandera County, Texas. Juvenile male *T. b. cynocephala* sampled in a warehouse near New Orleans, Louisiana, were found in significantly greater proportions ($G = 4.29$, $p < 0.05$) in July 1968

(Pagel and Jones 1974). Male biased sex ratios ($G = 42.17$, $p < 0.001$) also were reported for juvenile *T. b. mexicana* in an abandoned mine, south-central Colorado, August, 1983 (Svoboda and Choate 1987). Other studies have observed male biased tertiary sex ratios (Twente 1955; Constantine 1967; Milligan and Brigham 1992) however, data were not found to be significant.

Secondary sex ratios in *T. b. mexicana* from numerous studies show no difference from unity (Cagle 1950; Mohr 1952; Davis *et al.* 1962; Humphrey and Cope 1976; Wilkins 1989; Kunz and Robson 1995). Assuming a 1:1 sex ratio of pups at birth, biases in tertiary sex ratios must occur between parturition and volancy. Explanations for biased sex ratios include differences in mortality, growth rates, and/or behavior. No reports, however, support differences in growth rate or mortality as evidence for skewed ratios.

Adult bats display behavioral differences with respect to migration, roost selection, and emergence (Krutzch 1955; Twente 1956; Eads *et al.* 1957; Davis *et al.* 1962; Villa and Cockrum 1962). These differences cause biased quaternary sex ratios within emergences, between trap nights and in overall composition. Little information, however, exists concerning these behaviors in juvenile bats.

Differences within a given emergence result in the timing in which males and females exit the roost. Previous studies conducted at the Old Tunnel WMA reported greater proportions of adult female bats emerging earlier in the evening, with adult males emerging later (Harper 1997; Tanner 1999). Data from late emergence samples show similarities in behavior for juvenile bats (Table 4, Fig. 4). Male bats were caught in greater proportions in all late emergence (1/2) samples taken.

The timing of arrival of juvenile males and females to alternate roost sites can cause skewed sex ratios between trap nights. Schowalter and Gunson (1979) noted juvenile male big brown bats (*Eptesicus fuscus*), left the maternity roost earlier than females. This type of behavior in *T. b. mexicana* at the Old Tunnel WMA would imply greater proportions of males in samples during July and early August with ratios nearing 1:1 or becoming female biased in mid to late August samples. Data from 1999 and early emergence (1/1) samples in 2000 support this behavior (Table 1, Fig. 1, Table 2, Fig. 2).

In 1999, male bats were caught in greater abundance from 26 July to 8 August. Samples from 11 August to 20 August show a greater proportion of female bats. During 2000, early emergence samples (1/1) show similar results. Juvenile male bats were caught in significantly greater proportions from 24 July to 7 August and on 11 August and 16 August. The remaining trap nights showed no significant difference from 1:1 with female bats being caught in greater proportions on 9, 18, and 20 August.

Hermanson and Wilkins (1986) reported males congregating with other males separate from females when sharing the same roost. Such congregations may influence the exit from which bats emerge, resulting in biased sex ratios. Unlike most natural caves, the Old Tunnel WMA roost has two available exits. The north exit is on private property and is covered by dense vegetation. Juvenile bats were not collected from the north end of the tunnel. Differences in the juvenile composition exiting either end of the tunnel could potentially skew tertiary sex ratios.

Different roosts appear to serve different functions in the life history of *T. b. mexicana*. In Texas, large caves are utilized as maternity sites (Barbour and Davis 1969) whereas, man-made roosts serve primarily transient individuals (Davis and Cockrum 1963) and resident bats (Eads *et al.* 1957; Davis *et al.* 1962; Fraze and Wilkins 1990).

The overall sex ratio for juvenile *T. b. mexicana* sampled at the Old Tunnel WMA roost was significantly male biased (Table 5, Fig. 5). *Tadarida brasiliensis mexicana* of both sexes temporarily use transient roosts as stop over sites during migration. Sex ratios can vary widely for these roosts (Cockrum 1969). Twente (1955) noted young, male *Myotis* bats gathering in fall pre-movement clusters, which included relatively few females. The Old Tunnel WMA might serve as a transient roost primarily for juvenile males.

Wallace and Lawyer (1996) estimated over 1 million adult bats residing at the Old Tunnel WMA. Of these, 50% to 70% were pregnant females (Harper 1997; Tanner 1999). Based on the proportion of pregnant females, estimates of juvenile bats ranging from 500,000 to 1 million were expected.

Population estimates of juvenile *T. b. mexicana* were calculated for both 1999 and 2000. In 1999, the estimated population was within the range of expected results (Table 6, Fig. 6). The population estimate for most nights was above 100,000 with the highest estimate, 753,641, on 4 August. During 2000, population estimates were much lower, with only one night above 150,000 (Table 7, Fig. 7). The decline in the population estimate for 2000 is potentially due to climatic conditions and not mortality.

Field work in 2000 occurred during a substantial drought event. Increasing temperatures and low trap success contributed to the drop in the estimated population of juvenile bats using the Old Tunnel WMA roost. Temperatures in excess of 41° C during 2000 may have caused bats to select cooler roosts. Henshaw (1960) reported changes in roosting behavior with increasing temperature. Bats increasingly occurred in open roosts in August 2000. Reports of bats roosting on porches, houses, and in parking garages were common. Several individuals reported bats with blue bands (2000).

Fewer bats exited the tunnel during nightly emergences in 2000. Bats avoided the trap, reducing the overall trap success. As a result, fewer individuals and fewer recaptures caused difficulties in establishing accurate population estimates.

The population trends for both 1999 and 2000 appear similar. The timing of parturition (Table 6, Fig. 6) caused initial fluctuations among trap nights. As expected, juveniles were caught in low numbers in early samples. Because 90% of pups are born within 2-3 weeks (Cagle 1950; Eads *et al.* 1957; Glass 1958; Short 1961; Davis *et al.* 1962; Svoboda and Choate 1987; Schmidly 1991), the majority of juvenile bats become volant and arrive to the Old Tunnel WMA at about the same time. The population increased dramatically in early August.

The subsequent decrease and fluctuation in estimates were potentially due to a lack of site fidelity and to migration. Juvenile bats are inefficient flyers compared to adults; therefore, they may select for roosts closer to nearby foraging sites. The recovery of banded individuals from the Old Tunnel WMA in the surrounding areas support the use of alternative roosts.

Migrating bats begin moving to southern latitudes in mid-August. Man-made structures are often used as transient roosts for *T. b. mexicana* as stop over sites during migration (Davis and Cockrum 1963; Cockrum 1969; Fraze and Willkins 1990). The use of the Old Tunnel as a transient roost for juvenile bats also would explain fluctuations in population estimates.

The sex ratio estimate for the population of juvenile *T. b. mexicana* is the result of behavioral differences in migration, roost selection, and emergence between males and females. Population trends were similar between the two years despite the decline in estimated numbers in 2000. Lower estimates in 2000 were not the result of increased mortality, but rather the probable selection for cooler roosts by *T. b. mexicana*. Future studies at the Old Tunnel WMA should include: 1) monitoring long-term trends in both the sex ratio and population of juvenile *T. b. mexicana*, 2) examing the population composition of bats emerging from the north end, and 3) examining the roosting behavior of juvenile bats within the tunnel.

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