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"Free" food: nectar bats at hummingbird feeders in southern Arizona

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We report the results of an 11-year (2008–2018) community science project (also known as citizen science) designed to document the use of hummingbird feeders by two species of nectar-feeding bats, the lesser long-nosed bat (*Leptonycteris yerbabuenae*) and the Mexican long-tongued bat (*Choeronycteris mexicana*), in the Tucson area of southern Arizona. From 50 to > 100 households participated in this project each year. We supplemented their reports with occasional mist-netting of bats at 21 observer sites to determine age and sex composition of bats at feeders. Our results indicate that *L. yerbabuenae* was more widespread and common at feeders than *C. mexicana*, which occurred mainly at sites close to mountains. In the Tucson area, the geographic extent of feeder visitations by bats, mostly *L. yerbabuenae*, expanded since 2007 and by 2018, covered most of the city and its suburbs. Most bats of both species visited feeders between late August and late October with little year-to-year variation in timing; some individuals of both species continued to visit feeders during winter. The number of bats observed at many sites during September (the month of peak visitations) was relatively stable for at least 10 years; modal numbers of nightly visitors per site in most years was 6 – 10 bats. Capture data indicated that *L. yerbabuenae* that visited feeders in the Tucson area were not a random sample of the species' age and sex composition in southeastern Arizona, where their food plants are located in late summer and fall. In Tucson, most bats visiting feeders were subadult females (juveniles and yearlings). We suggest that hummingbird feeders have substantially increased food availability for nectar bats in southern Arizona prior to their migration south into Mexico. However, reasons for the increased use of feeders by *L. yerbabuenae*, particularly subadult females, beginning in 2007 are not yet clear.

Keywords: *Choeronycteris mexicana*, citizen science program, community science program, hummingbird feeders, *Leptonycteris yerbabuenae*, southern Arizona

Informamos acerca de los resultados de un proyecto de ciencia comunitaria (también conocida como ciencia ciudadana) de 11 años (2008–2018) diseñado para documentar el uso de bebederos de colibríes por parte de dos especies de murciélagos nectarívoros, el murciélago magueyero menor (*Leptonycteris yerbabuenae*) y el murciélago trompudo mexicano (*Choeronycteris mexicana*), en el área de Tucson, al sur de Arizona. Entre 50 y > 100 hogares participaron en este proyecto cada año. Complementamos los informes de los hogares con capturas ocasionales de murciélagos utilizando redes de neblina en 21 sitios de observación para así determinar la composición de edad y sexo de los murciélagos en los bebederos. Nuestros resultados indican que *L. yerbabuenae* estaba más ampliamente extendido y era más común en los comederos que *C. mexicana*, la cual última se encontraba principalmente en sitios cercanos a las montañas. En el área de Tucson, la extensión geográfica de las visitas a los bebederos por parte de los murciélagos, en su mayoría *L. yerbabuenae*, se expandió desde 2007 y en 2018 cubrió la mayor parte de la ciudad y sus suburbios. La mayoría de los murciélagos de ambas especies visitaron los bebederos entre finales de agosto y finales de octubre, con poca variación anual; algunos individuos de ambas especies continuaron visitando los bebederos durante el invierno. El número de murciélagos observados en muchos lugares durante septiembre (el mes de máximas visitas) fue relativamente estable durante al menos 10 años; el número modal de visitantes nocturnos por sitio en la mayoría de los años fue de 6 a 10 murciélagos. Los datos de captura indicaron que los *L. yerbabuenae* que visitaron los bebederos en el área de Tucson no eran una muestra aleatoria de la composición de edad y sexo de la especie en el sureste de Arizona, donde se encuentran sus plantas de alimentación a finales de verano y otoño. En Tucson, la mayoría de los murciélagos que visitaron los bebederos eran hembras subadultas (juveniles y de un año de edad). Sugerimos que los bebederos de colibríes han aumentado sustancialmente la disponibilidad de alimento para los murciélagos nectarívoros en el sur de Arizona antes de su migración al sur de México. Sin embargo, aún no están claras las razones del mayor uso de los bebederos por parte de *L. yerbabuenae*, especialmente las hembras subadultas, a partir de 2007.

Palabras clave: bebederos para colibríes, *Choeronycteris mexicana*, *Leptonycteris yerbabuenae*, programa de ciencia ciudadana, programa de ciencia comunitaria, sur de Arizona

Bats occur in most habitats on Earth, including many cities, towns, and villages. Many species have been urban-dwellers for millennia, using buildings as day roosts and nocturnal feeding and resting sites, and foraging in streets, yards, parks, and over water, at night (reviewed by Jung and Threlfall 2016). In the temperate zone, most urban bats are insectivores. Plant-visiting bats also are urban-dwellers or foragers in subtropical and tropical regions where they feed at native and non-native species of flowers and fruit (e.g., Jara-Servin et al. 2017; Laurindo and Vizentin 2020). Because urban habitats are important sources of roosts and food for many bats, conservation strategies for these species need to incorporate urban areas into their overall plans.

Residents of southern Arizona have developed a growing interest in observing nectar-feeding bats at their hummingbird feeders. Two species of nectar-feeding phyllostomid bats are seasonal residents in southern Arizona: the lesser long-nosed bat (*Leptonycteris yerbabuenae*, formerly *L. sanborni* or *L. curasoae*) and the Mexican long-tongued bat (*Choeronycteris mexicana*). In spring, migrant females of *L. yerbabuenae* return to several established maternity roosts in mines and caves in the Sonoran Desert of southwestern Arizona and northwestern Mexico. Each roost can contain hundreds to tens of thousands of individuals (Wilkinson and Fleming 1996; Cerro 2012; Medellín et al. 2018). During the maternity season, lesser long-nosed bats and their offspring feed primarily on the flowers and fruits of columnar cacti such as saguaro (*Carnegiea gigantea*), organ pipe (*Stenocereus thurberi*), and desert agave (*Agave deserti*). Prior to migrating south into Mexico in the fall, many of these bats appear in the upland grasslands and oak woodlands of southeastern Arizona, where they establish transitory roosts containing hundreds to thousands of individuals in mines and caves that they use for several weeks prior to migration (Ober and Steidl 2004; Cerro 2012; A. McIntire, Arizona Game and Fish Department, pers. comm.). During fall, their major food source is flowers of Palmer's agave (*Agave palmeri*), Parry's agave (*Agave parryi*), and other agaves (Ober and Steidl 2004; Scott 2004; Cerro 2012). Less is known about the roosting and feeding behavior of the Mexican long-tongued bat in Arizona. It also is migratory, and in the spring and summer, adult females form small maternity colonies of 5–15 bats in caves, mines, and rock crevices, primarily at elevations of 1,220–1,830 m; these roosts often are close to populations of agaves (Cryan and Bogan 2003).

Prior to 2007, nectar bats were known to be seasonal visitors to hummingbird feeders on the east side of Tucson, as well as in the Santa Catalina and Santa Rita mountain foothills in the Tucson valley. Following a notable failure of the *Agave* flower crop in 2006, members of the public began to report to the U.S. Fish and Wildlife Service (USFWS) in 2006 and 2007 that bats were visiting their hummingbird feeders in other parts of Tucson. In 2008, personnel from the Town of Marana, northwest of Tucson, the Arizona Game and Fish Department (AZGFD), the USFWS, and Bat Conservation International (BCI) expanded a community science program developed in 2004 to monitor bats at feeders in the Tucson metropolitan area (Wolf 2006). Here, we describe this program and report the results from the first 11 years (2008–2018). Our objectives were to: (1) determine the geographic distribution of both bat species at feeders in and around Tucson; (2) determine the seasonal occurrence (phenology) of nectar bats at hummingbird feeders and the pattern of nectar removal rates from two feeders during this season; (3) estimate the abundance of bats visiting hummingbird feeders in September (the month of peak visitations) each year; (4) estimate the age and sex composition of *L. yerbabuenae* visiting feeders based on mist-netting; and (5) compare this composition with other sites in southern Arizona. Because *L. yerbabuenae* was much more common and widespread than *C. mexicana* at hummingbird feeders in our study area, we focused on this species.

Materials and Methods

The study area.—We carried out this study in southern Arizona. Community scientists monitoring hummingbird feeders were located throughout southern Arizona but were concentrated in the greater Tucson area, including Marana, Saddlebrooke, Vail, and Green Valley (Fig. 1). Most of this area lies in the Arizona Upland and Semidesert Grassland Divisions of the Sonoran Desert (Turner and Brown 1994).

The community science program.—In 2008, the Town of Marana established a website for recording the following volunteer-provided information: name, address (minimally, zip code), and e-mail address; the number, kind, and location of hummingbird feeders at each site; and observations of nectar bats visiting their feeders. Volunteers were instructed to fill their feeders with a solution containing one part cane sugar to

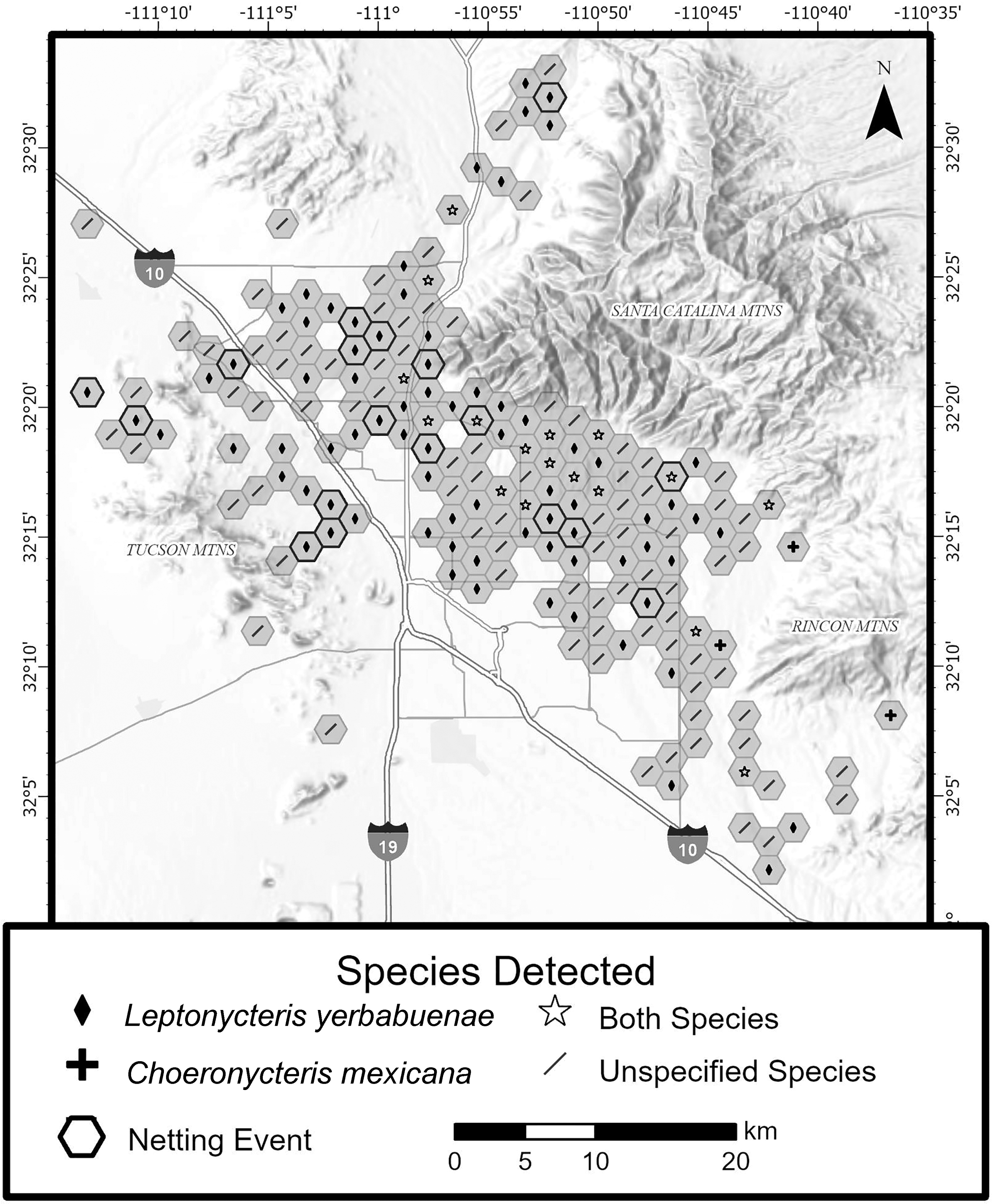

Fig. 1.—Map of verified sightings and captures of two species of nectar-feeding bats (*Leptonycteris yerbabuenae* and *Choeronycteris mexicana*) in the Tucson area, 2006–2018. Sites at which bat visitation was detected but bats were not identified are labeled “Unspecified Species.” Eighteen of the 21 netting sites are indicated by the bolded hexagons; the other three sites were located south and east of this area.

four parts water. They were encouraged to report their observations once or twice a week during the nectar bat season (typically late August to late October) and take digital photos of bat visitors so that they could be identified; most of these photos were reviewed by THF. After the bats migrated south, volunteers were asked to fill out a final summary form indicating dates of first and last arrivals of nectar bats, approximate dates of peak visitations, whether bats preferred particular designs of feeders (if multiple kinds were available), estimates of the number of bats visiting feeders at peak times (usually September), and general observations. Additional clarifying questions were added in later years to ensure that observations were being collected from each household in a standardized way. Examples of datasheets can be found at the AZGFD website (www.azgfd.com/wildlife/backyard-bats).

In addition to data entry forms, this website provided general information about the two species of nectar bats and how they can be distinguished (e.g., tail membrane present in *C. mexicana* and absent in *L. yerbabuenae*; rostrum longer and more narrow in *C. mexicana*). Prior to the beginning of the nectar bat season in August, this community science project was publicized throughout southern Arizona in press releases to a variety of regional news sources, social media, community e-mail distribution lists, and bird and bat enthusiast publications. From 50 to > 100 households joined this program each year in 2008 – 2018. Through 2018, 525 households participated in this project; 68 participated for at least 5 years, and 13 for at least 10 years. Although most volunteers lived in the greater Tucson area, we also received occasional reports from outlying areas such as Oracle and Mammoth to the north and Bisbee, Sierra Vista, Hereford, and the Nogales area, to the south and east.

Mapping verified bat sightings and sites of mist-netting.—To determine the distributions of the two species in the Tucson basin, we used volunteer-submitted photos and video clips to identify bats visiting hummingbird feeders in 2006 – 2018. We also identified bats captured in our netting program (see below). We classified reports of regular draining of hummingbird feeders overnight or of seeing bats using the feeders as "Unspecified" nectar bat detections. To create a map of these records, we aggregated them into 2 km diameter cells in a hexagonal tessellated grid using Esri ArcGIS Pro 2.4.3 (ESRI Inc. 2019). We distinguished four kinds of records: (1) sites visited only by *L. yerbabuenae*; (2) sites visited only by *C. mexicana*, (3) sites visited by both species; and (4) "unspecified" detections. We also indicated 18 of the 21 sites where we mist-netted bats; the other three sites were located south and east of this area (Fig. 1).

The netting program.—To determine the age and sex composition of the *L. yerbabuenae* population visiting feeders in the Tucson area, we used one to two 6-m mist-nets to capture bats in 40 sessions at 21 volunteer sites in August through October 2009–2018 (Fig. 1). Sixty-nine percent of these sessions occurred in September, the month of peak visitations; 22% occurred in October and the others occurred in August. Sites were chosen opportunistically based on volunteer reports and correspondence. Nets were opened near feeders from sunset (1930 – 2030 h MST) to about 2230 h. For each capture, we recorded species, sex, relative age, forearm length, mass, and reproductive condition. Females of *L. yerbabuenae* apparently do not breed until at least 2 years of age, as evidenced by the presence of young nonparous females in maternity roosts before births occur each spring (T. H. Fleming, pers. obs.). We recognized three age classes: juveniles (young of the year with partially ossified phalanges), yearlings (nonparous females and nonreproductive males with completely ossified phalanges), and adults (usually post-lactating females, but occasionally adult males). We also used body mass and pelage color to distinguish among age classes. Juveniles and yearlings, hereafter called subadults, weighed less than adults (Table 1) and had thin gray pelage; adults usually were brown. Adult females were significantly heavier than subadult females ($t_{56} = 7.27$, $P < 0.001$). To identify possibly recaptured individuals, we marked the head of each bat with a Sharpie pen (Newell Brands, Atlanta, Georgia) before releasing it. Many subadults and adults were distinguished easily based on pelage color in digital photos of bats visiting feeders. When handling bats, we followed the guidelines of the American Society of Mammalogists for use of wild mammals in research (Sikes et al. 2016).

Bat phenology and nectar removal.—To document the seasonal occurrence of nectar bats at feeders, we generated a set of cumulative yearly phenology curves depicting the temporal distributions of first and last visits based on volunteers' final reports. We calculated the median arrival and departure dates each year, combining data from all sites regardless of location. Geographic differences in date of first appearances at feeders likely exist in southern Arizona but will not be addressed here.

We also monitored nightly removal of sugar water from feeders to determine the dates and intensity of feeder visitations. For example, THF did this each year in 2010 – 2018 by recording to the nearest 25% the amount of liquid remaining in two feeders originally containing 0.47 liter each morning before refilling them. Observations, photographs, and netting indicated only *L. yerbabuenae* visited these feeders at night.

Bat abundance at feeders.—To determine the abundance of nectar bats visiting feeders, we asked volunteers to estimate the number of bats in their yards and visiting feeders simultaneously at the time of peak abundance, usually mid-to-late September; only one estimate per site was included in seasonal summary reports. Obtaining these data is challenging, even for experienced observers, because these bats fly quickly around yards while making short visits (< 1 s) to feeders. Several to many individuals can be seen taking turns visiting feeders at one time. To deal with this problem, we used an ordinal scale to

Table 1.—Body mass (g) of *Leptonycteris yerbabuenae* by age class and sex based on netting data collected in southern Arizona in August–October in 2014–2017, the years with the largest sample sizes.

Age class and sex	Sample size	Mean ± 1 *SE* (g)	Range (g)
Juvenile females	21	21.9 ± 0.40	18–25
Juvenile males	21	22.0 ± 0.49	19–27
Yearling females	12	22.9 ± 0.62	19–26
Yearling males	2	24.0	23–25
Adult females	25	26.6 ± 0.52	22–33
Adult males	3	26.0	23–30

estimate bat numbers in which 1 = 1 – 5 bats visiting feeders at peak numbers; 2 = 6 – 10 bats; 3 = 11 – 20 bats; and 4 = > 20 bats. In instances where volunteers reported an estimated range of bat counts, we used the maximum estimated value in our calculations. Each year we calculated a mean abundance score (± *SE*) per site. These abundance estimates were undoubtedly conservative because we often caught more bats than expected based on visual estimates.

Comparisons of bats at other sites in southern Arizona.—To determine whether the age and sex composition of *L. yerbabuenae* visiting feeders in the Tucson area reflected its composition throughout southeastern Arizona, we reviewed unpublished survey reports of mist-netting data by Arizona bat researchers on file in the Tucson office of the USFWS. We focused on reports from two areas in southern Arizona. The first was a large maternity roost located at Organ Pipe Cactus National Monument (ORPI), about 181 km southwest of Tucson. This roost is occupied from April through August and provides demographic information about *L. yerbabuenae* before the post-maternity and feeder visitation season begins; the six samples came from late July 2004 and 2005. The second area included six locations netted 10 times in southeastern Arizona; four of these sites were located in creek beds around the village of Portal; the other sites included feeders at the Southwestern Research Station (SWRS), 9.7 km west of Portal, and a post-maternity roost south of Sierra Vista in August and September 1999–2005. Distances between Tucson and Portal and Sierra Vista to the southeast are about 172 km and 97 km, respectively.

Statistical analysis.—All statistical summaries and analyses were done with PSI-Plot software (www.polysoftware.com) or program R (R Core Team 2017). Data summaries included means ± 1 *SE*. We used a parametric *t*-test to compare body mass data, and chi-square tests to compare the age and sex composition of netting samples from the Tucson area with those from ORPI and southeastern Arizona. We used a nonparametric Kruskal–Wallace one-way ANOVA to examine annual differences in abundance scores at volunteers' sites in 2009–2018. We used a nonparametric Kendall's tau correlation and a multiple pairwise Wilcoxon test with Bonferroni correction to examine the relationship between the number of feeders at a volunteer site and its abundance score for each of 10 years (2009–2018). We also used PSI-Plot to generate a smoothed curve based on polynomial regression of nectar removal scores at THF's two feeders versus date in each of 9 years (2010–2018).

Results

Distribution of nectar bats in the Tucson area.—*Leptonycteris yerbabuenae* was by far the most common nectar bat observed visiting hummingbird feeders in the greater Tucson area (Fig. 1). It was recorded alone at 75 sites (79%) and *C. mexicana* was recorded alone at three sites (3%); both species were recorded together at 17 sites (18%). *Leptonycteris yerbabuenae* was recorded throughout the Tucson area, whereas sites at which *C. mexicana* was recorded alone or with *L. yerbabuenae* tended to be in mountain foothills.

Nectar bat phenology and nectar removal.—The nectar bat season typically ran from late August until late October (Fig. 2). Arrivals and departures occurred over similar time intervals each year. Median arrival dates ranged from 14 August to 2

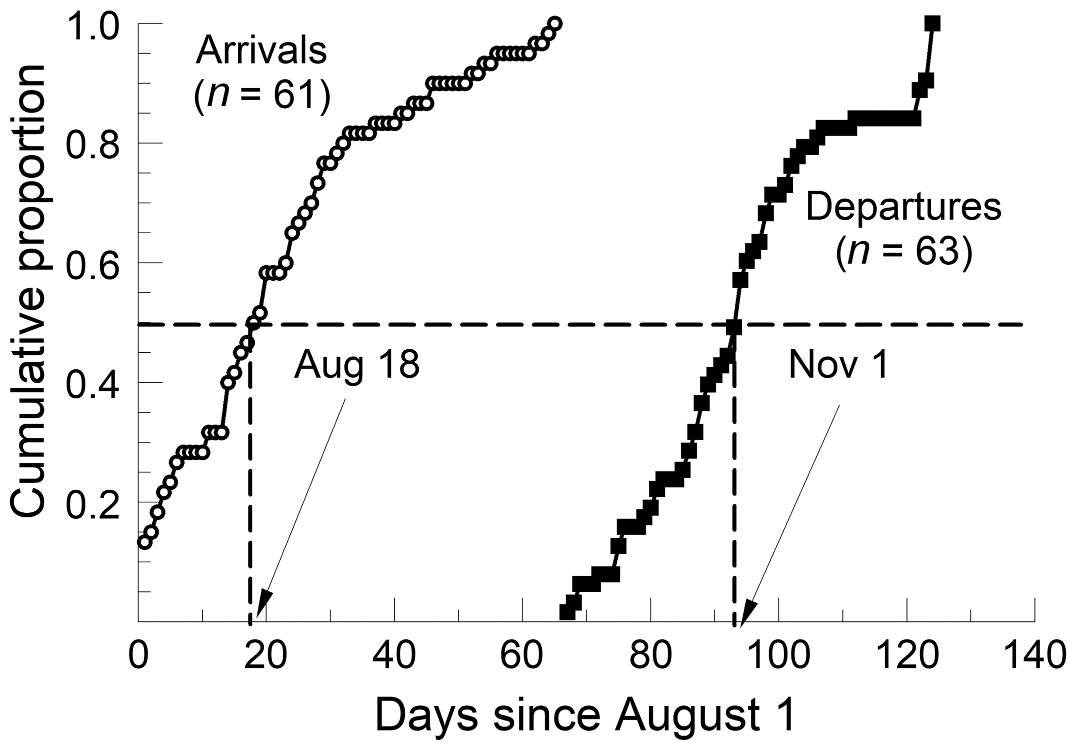

Fig. 2.—Typical cumulative phenology curves showing the median dates of arrival and departure of nectar bats (mostly *Leptonycteris yerbabuenae*) in 2018 based on all sites combined. Number of sites reporting data are indicated in parentheses.

September and clustered around August 18; median departure dates ranged from 12 October to 2 November and clustered around 22 October (Table 2). Volunteers reported that a few individuals of both species sometimes overwintered in Tucson and continued to visit feeders.

Dates of nectar removal in THF's yard reflected the nectar bat season. In 2010–2018 removal began on 17 August to 3 September and ended on 18 October to 3 November. Typical seasonal removal curves for 2 years are shown in Fig. 3. Feeding visits began earlier and more intensely in 2017 than in 2018; the feeding season was longer in 2018 (Fig. 3). In all years, the removal curves were unimodal with peaks occurring 20–30 days after feeding began. These peaks coincided with observations of peak numbers of bats visiting feeders each year (typically mid-to-late September).

Table 2.—Median arrival and departure dates of nectar bats (mostly *Leptonycteris yerbabuenae*) based on all volunteer sites in southern Arizona combined, with number of sites reporting.

Year	Median arrival date (*n*)	Median departure date (*n*)
2009	26 August (27)	12 October (22)
2010	2 September (37)	20 October (37)
2011	14 August (45)	22 October (49)
2012	22 August (24)	26 October (23)
2013	15 August (54)	28 October (55)
2014	20 August (56)	21 October (59)
2015	27 August (46)	2 November (46)
2016	17 August (69)	21 October (72)
2017	18 August (66)	22 October (63)
2018	18 August (61)	1 November (63)

Abundance.—Abundance of *L. yerbabuenae* per volunteer site was relatively stable in September between 2009 and 2018 (Fig. 4). Mean abundance class scores ranged from 2.07 in 2015 to 2.78 in 2013. Means did not differ significantly among years (H_9 = 11.83, P = 0.22). Within-year variation in abundance was low with a maximum *SE* of ± 0.28 in 2009 (Fig. 4). The actual reported number of bats at volunteer sites at peak visitation ranged from 1 to > 100. The modal abundance class score each year was 1 in 3 years, 2 in 6 years, 3 in 1 year, and 4 in 1 year (Table 3). In 2013 the modal abundance was both classes 2 and 4. These data indicate that many sites were being visited by many nectar bats in most years.

To determine whether the number of bats at each site each year was related to the number of hummingbird feeders at that site, we examined the relationship between number of feeders at a site (X) and its abundance class score (Y) for each of 10 years. Kendall's tau was positive in all 10 years, significant ($Ps \le 0.05$) in 3 years (2011 – 2012, 2016), and nonsignificant in the other 7 years. These results suggest that number of feeders at a site may play a role in attracting nectar bats to some sites in some, but not all, years.

Age structure and sex ratios.—Subadults (juveniles and yearlings) of *L. yerbabuenae* were by far the most common visitors to hummingbird feeders at most sites in most years in the Tucson area. Overall, captures at the 21 sites were dominated by subadults (mean proportion = 0.83 ± 0.05, *n* = 40 netting sessions; some sites were netted more than once in different years). Among subadults, juveniles were three times more common than yearlings (76% versus 24%; *n* = 359 captures).

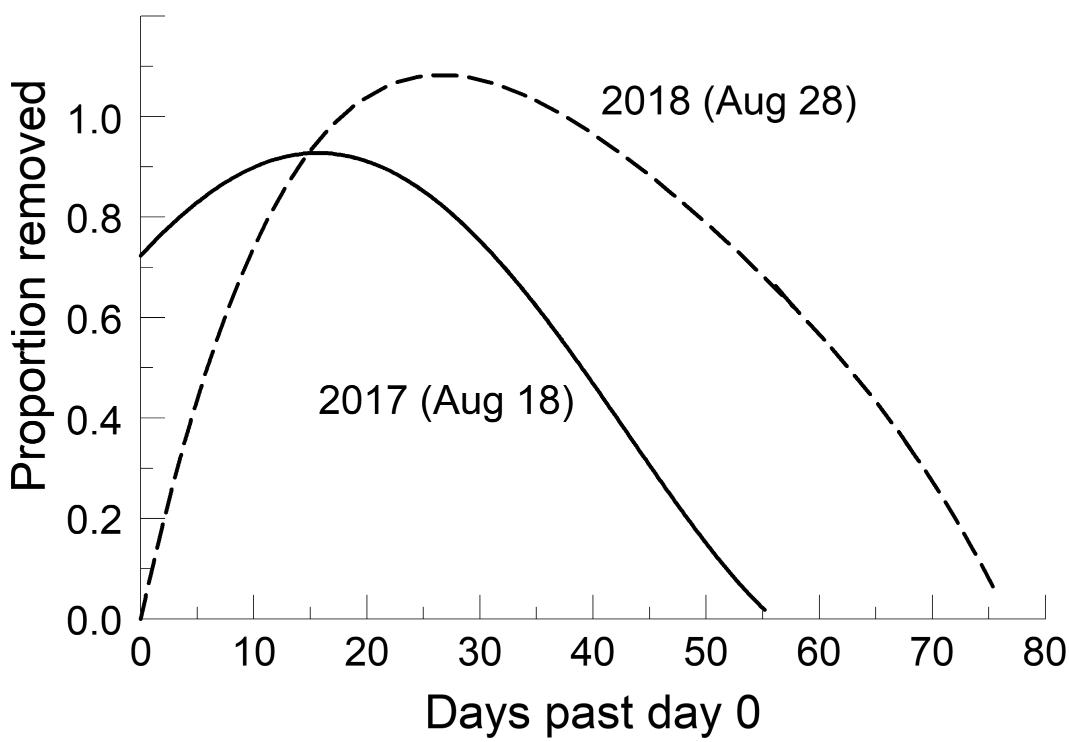

Fig. 3.—Smoothed polynomial curves based on proportion of liquid removed from two feeders at one site each day while they were being visited by *Leptonycteris yerbabuenae* in 2017 and 2018. Total volume in the two feeders was 0.47 liter. Beginning removal dates are indicated in parentheses. Correlation coefficients for these curves are: 2017: $r = 0.75$, *d.f.* = 54, $P < 0.001$; 2018: $r = 0.89$, *d.f.* = 73, $P < 0.001$.

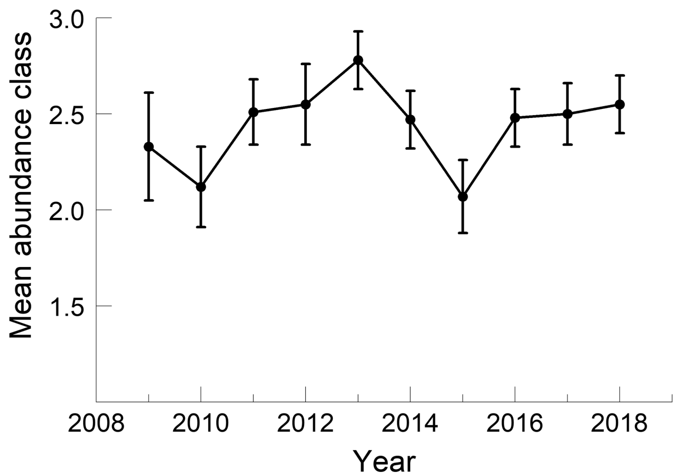

Fig. 4.—Mean abundance class score (± 1 *SE*) per observer site at peak numbers of nectar bats (mostly *Leptonycteris yerbabuenae*) visiting hummingbird feeders in southern Arizona, 2009–2018. Annual sample sizes ranged from 18 in 2009 to 51 in 2018. Class scores are: 1 = 1–5 bats, 2 = 6–10 bats, 3 = 11–20 bats, 4 = >20 bats.

Subadults outnumbered adults by a factor of 6.3 in the 418 captures (359 subadults [86%] versus 59 adults [14%]).

A striking temporal shift occurred in the frequency of adult *L. yerbabuenae* in our Tucson area captures during this study. In 2010, captures at all five feeder sites (100%) were adult-dominated (i.e., had ≥ 67% adult captures), whereas only two of 21 feeder sites (10%) were adult-dominated in 2011 – 2018. Subadults basically replaced adults of this species at feeders from 2011 on. We saw this shift at two of the five sites that yielded adult-dominated captures in 2010; only one of three sites sampled in both years remained adult-dominated in 2011.

In contrast to netting data from feeders in the Tucson area, netting events in southern Arizona showed that subadult lesser long-nosed bats did not outnumber adults in southeastern Arizona in summer and early fall. Six samples from the maternity roost at ORPI in July were similar to those from Tucson, and proportion of subadults (mostly juveniles) averaged 0.86 ± 0.04. In contrast, the 10 samples from southeastern Arizona were adult-dominated, and proportion of subadults averaged 0.38 ± 0.10. The distribution of age and sex classes in the Tucson and southeastern Arizona netting samples differed significantly (χ^2_3 = 140.8, P < 0.001; Table 4). Subadults were about twice as common in the Tucson samples than in the samples from southeastern Arizona (77% versus 36%).

Sex ratios also varied among locations (Table 4). In the Tucson area, females outnumbered males among subadults by a factor of 2.2 and among adults by a factor of 4.4. At the ORPI maternity roost, the sex ratio was 1:1 among subadults, and no adult males were caught (Table 4). In southeastern Arizona, the sex ratio among both subadults and adults also was 1:1 (Table 4). The female-biased sex ratio among subadults was significantly greater in Tucson than in the other two areas (χ^2_2 = 33.0, P < 0.001).

Table 3.—Abundance class numbers of *Leptonycteris yerbabuenae* per volunteer site at peak visitation periods (in September). Data represent one estimate per site. Class numbers are: 1 = 1 – 5 bats; 2 = 6 – 10 bats; 3 = 11 – 20 bats; 4 = > 20 bats. Modal classes are in bold.

Year	Number and proportion of sites reporting			
	Class 1	Class 2	Class 3	Class 4
2009	**6 (0.33)**	4 (0.22)	4 (0.22)	4 (0.22)
2010	**9 (0.36)**	7 (0.28)	6 (0.24)	3 (0.12)
2011	8 (0.22)	9 (0.24)	**13 (0.35)**	7 (0.19)
2012	2 (0.10)	**9 (0.45)**	5 (0.25)	4 (0.20)
2013	5 (0.11)	**14 (0.30)**	13 (0.28)	**14 (0.30)**
2014	8 (0.18)	**17 (0.38)**	11 (0.24)	9 (0.20)
2015	**10 (0.36)**	9 (0.32)	6 (0.21)	3 (0.11)
2016	9 (0.20)	**16 (0.35)**	11 (0.24)	10 (0.22)
2017	6 (0.15)	**16 (0.40)**	10 (0.25)	8 (0.20)
2018	9 (0.18)	**19 (0.37)**	9 (0.18)	14 (0.27)

Other observations.—In their final reports, volunteers sometimes noted that *L. yerbabuenae* often arrived at feeders in groups or "swarms" and took turns feeding. When not actually feeding, these groups constantly circled around yards and entered and left yards together. In our netting sessions, we never captured the same bats twice, suggesting that different groups of bats were visiting feeders during the night. Observers also reported that the time of bat arrivals each night sometimes varied from year to year. In some years, bats arrived and began feeding shortly after sunset (1930 – 2030 h MST). In other years, they began feeding after 2130 h. For example, in THF's yard in September, bats arrived early in 2008, 2009, 2012, and 2014; they arrived much later (often after 2200 h) in 2010, 2011, and 2015 – 2017.

Discussion

Roost censuses conducted by the AZGFD over the past 25 years indicate that nectar-feeding bats, especially the lesser long-nosed bat *L. yerbabuenae*, are common in southern Arizona from mid-April to late October (A. McIntire, Arizona Game and Fish Department, pers. comm.). Based on the results of our community science project, many of these bats have become frequent visitors to hummingbird feeders in the Tucson area in August through October before migrating south into Mexico.

While most of the nectar bats visiting hummingbird feeders in the Tucson area were *L. yerbabuenae*, hummingbird feeders in this area and other parts of southern Arizona (e.g., SWRS) also were visited by *C. mexicana*. *Leptonycteris yerbabuenae* was much more common than *C. mexicana* at feeders in this study, in part because of the locations of hummingbird feeders that many volunteers monitored (Fig. 1). These differences reflect differences in the roosting and foraging behavior of these species. *Leptonycteris yerbabuenae* is a highly gregarious bat that often commutes long distances from its day roosts to its feeding areas (Horner et al. 1998; Ober and Steidl 2004; Medellín et al. 2018). In contrast, *C. mexicana* is not highly gregarious and likely forages relatively close to its montane day roosts. As a result, feeders located in montane areas (e.g., foothills of the Santa Catalina and Rincon Mountains and

Table 4.—Sex ratios of *Leptonycteris yerbabuenae* in mist-net samples from three areas in southern Arizona. Proportions (in parentheses) are based on within-age classes. Subadults include juveniles and yearlings. ORPI = Organ Pipe Cactus National Monument.

Location and number of netting sites	*n* subadult females	*n* subadult males	*n* adult females	*n* adult males
Tucson (21 feeder sites)	247 (0.69)	112 (0.31)	48 (0.81)	11 (0.19)
ORPI (one maternity site)	72 (0.44)	90 (0.56)	31 (1.00)	0
SE Arizona (one feeder and five nonfeeder sites)	26 (0.48)	28 (0.51)	49 (0.52)	45 (0.48)

towns such as Oracle and Mammoth, north of Tucson) were more likely to attract this species than were feeders located farther away from mountains (e.g., in central and western Tucson, east of interstate highway 10 (I-10); Fig. 1).

In addition to differences in the relative abundances of the two species at hummingbird feeders, the community science program also revealed that the major feeder visitation season ran from late August to late October with relatively little year-to-year variation. Most visits occurred between 18 August and 22 October with a peak in mid-to-late September. This predictability appears to be independent of annual variation in weather conditions (temperature and rainfall) and annual production of native *Agave* flowers, which can vary substantially among years in southern Arizona (Ober and Steidl 2004; Cerro 2012). This predictability is reminiscent of the highly predictable arrival schedules of many north temperate migratory birds (e.g., Bokony et al. 2019; Horton et al. 2019; Lehikoinen et al. 2019). Factors that determine the phenology in Arizona's two nectar bats largely are unknown but likely include the flowering phenology of *Agave* spp. along the migration pathways used by *L. yerbabuenae* as they move within Mexico and Arizona in late summer and early fall (Fleming et al. 1993; Moreno-Valdez et al. 2004).

This study also revealed that relatively large numbers of *L. yerbabuenae* visit urban feeders during late summer and fall. Modal nightly numbers of bats per site at peak visitation were at least 6 – 10 in all but 3 years. Despite a high per site constancy, the total number of individuals visiting feeders in the Tucson area has likely increased since 2007, particularly in central and western parts of the city. For example, it was not reported to visit feeders west of I-10 until 2013 but is now reported to be a common visitor to feeders at some locations in the Tucson Mountains (Fig. 1; J. Tyburec, Bat Survey Solutions, pers. comm.).

Reasons for this expansion currently are unknown but may involve at least two (nonexclusive) explanations. First, the total population of *L. yerbabuenae* in southern Arizona in late summer and early fall may have increased since 2007. Data collected by the AZGFD, however, do not support this (A. McIntire, Arizona Game and Fish Department, pers. comm.). Second, a larger proportion of this population now visits urban feeders than it did a decade or more ago, perhaps because of urban expansion and the loss of *Agave* habitat in southern Arizona. Urban expansion has been modest around Tucson, except for the Town of Marana; it has been greater around Sierra Vista southeast of Tucson (S. Richardson, pers. obs.). The extent to which this expansion has affected *Agave* populations, however, has not been documented. Further study is needed to determine whether nectar bats are being driven into urban areas as their native feeding habitats are being reduced in size.

Netting results indicated that the age and sex composition of *L. yerbabuenae* visiting hummingbird feeders in the greater Tucson area differed significantly from the population in the uplands of southeastern Arizona, where most of the flowering *Agave* occur in late summer and fall. The population structure was strongly skewed toward subadult females. Individuals netted at both feeder and nonfeeder sites in southeastern Arizona included more adults than subadults, and the sex ratio in subadults there and at the ORPI maternity roost was 1:1. We do not know why subadult females were the most common sex–age class at feeders in the greater Tucson area, but there is evidence suggesting that the predominance of subadult females at feeders is a recent occurrence. For example, Lowery et al. (2009) reported catching 32 individuals at hummingbird feeders at 13 sites in Tucson in 2007–2008; 29 (91%) were adults, including 17 males, and three were subadults (9%). Similarly, our captures of *L. yerbabuenae* at five sites in 2010 were adult-dominated. But from 2011 on, captures at most sites have been dominated by subadults. We do not know why this apparent shift has occurred.

Results of the Lowery et al. (2009) radiotracking study provide information about where *L. yerbabuenae* visiting feeders in Tucson are roosting. In 2007–2008 bats visiting these feeders were roosting in four caves or mines in mountains around the Tucson basin: the Santa Catalinas (N of the urban area), Rincons (E), and Empires (S); no roosts were located in the Tucson Mountains W of Tucson (Fig. 1). Radiotagged bats traveled 10–40 km from their day roosts to feeders in 2007 and 2–24 km in 2008. As also reported by Horner et al. (1998), sizes of their foraging areas were large, averaging 400 ha in 2007 and 504 ha in 2008. Tagged bats showed high site fidelity (over the few days of monitoring) and arrived at feeders shortly after sunset. Finally, in addition to feeding primarily at hummingbird feeders, these bats also fed at flowers of species of non-native, fall-blooming *Stenocereus* and *Cereus* cacti found at low densities in urban landscapes. We also occasionally saw pollen on the faces of bats that we netted, and THF has photographed *L. yerbabuenae* visiting flowers of the non-native columnar cactus *Cereus repandus* in his neighborhood.

Although young *L. yerbabuenae* were the most common visitors to hummingbird feeders in Tucson, it is not clear how they located them. One explanation is that experienced adult bats led inexperienced bats to these resources. But this did not appear to be true based on our results. Photographs, observations, and bat captures, jointly indicated that young inexperienced and possibly yearling bats arrived at feeders at the beginning of each nectar bat season and were not led by adult females. The cues these bats use to find feeders require further investigation, but group foraging in this species likely increases its chances of finding widely scattered, low-density resource patches just as group foraging likely increases the chances of bats finding naturally occurring flowers in low-density populations of *Agave* and columnar cacti (Howell 1979; Horner et al. 1998; Ober et al. 2005; Egert-Berg et al. 2018).

Our results indicated that in the late summer and fall adults and subadults of *L. yerbabuenae* fed in separate areas. Many young bats visited hummingbird feeders in the Tucson area, whereas most adults did not. This spatial separation likely was not based on intraspecific aggression with adults preventing young bats from feeding at *Agave* flowers, their main food in late summer and fall away from urban areas. We saw no aggression when mixed age classes fed together at hummingbird feeders. Unlike hummingbirds, *L. yerbabuenae* is not territorial when feeding (Fleming et al. 2020). Adults do not defend flowering plants (e.g., around flowering columnar cacti—Horner et al. 1998), so the explanation for this age-based geographic separation is not apparent and certainly deserves further study.

Year-to-year variation in the time of arrival of bats at hummingbird feeders (i.e., shortly after sunset or much later) suggests that some bats may be using different day roosts in different years. Radiotracking studies and observations indicate that time of arrival of *L. yerbabuenae* at feeding areas is positively correlated with distance between day roosts and feeding areas (Fleming et al. 1998; Horner et al. 1998; Ober and Steidl 2004). It therefore appears that in some years, bats are roosting farther away from urban feeders than in others. If true, we speculate that these bats might have a series of day roosts to choose from in different years. Location and protection of all these roosts should be a research and management priority.

The results of this study highlight the importance of developing community science projects to gather larger amounts of data than would be possible by a typical academic lab or by a small group of agency scientists. This economy of scale now is well-recognized and is the basis for many kinds of community science projects worldwide (e.g., Allen et al. 2019; Callaghan et al. 2019; Dosemagen and Parker 2019; He et al. 2019; Phillips et al. 2019; Snyder et al. 2019). In our study, one of the important payoffs, in addition to all of the data gathered, is that it introduced many people to nectar-feeding bats, an amazing group of animals. Bats still are largely mysterious and potentially frightening to the general public but, as many of our volunteers have indicated, this project taught them how interesting and ecologically and economically beneficial nectar bats are. Because these bats are quite tolerant of people watching them from close range as they feed, they have gained many enthusiastic admirers and supporters from this project, sometimes as a result of bat-watching neighborhood parties. This is a priceless benefit that people gain from participating in community science projects.

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