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Source: The Southwestern Naturalist, 66(4) : 333-338

Published By: Southwestern Association of Naturalists

URL: https://doi.org/10.1894/0038-4909-66.4.333

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THE SOUTHWESTERN NATURALIST 66(4): 333–338

SOME OBSERVATIONS OF SEVERE WEATHER EVENTS ON A LARGE URBAN POPULATION OF FREE-TAILED BATS (*TADARIDA BRASILIENSIS*)

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ABSTRACT—The effects of severe weather events associated with Hurricane Harvey (August 2017) and ice storms (February 2021) on a colony of free-tailed bats (*Tadarida brasiliensis*) are presented. The colony is located along Buffalo Bayou in Houston, Texas (Harris County; 29.76167, –95.39834). Flooding and freezing resulted in an increase in mortality. Changes in behavior after the flooding event included "false exodus," emergence of smaller groups, and a delayed emergence time from the roost. The primary change following the freeze was widespread mortality and extralimital movement. A specimen of *Dasypterus xanthinus* is anecdotally reported, representing an important range extension in Texas.

RESUMEN—Se presentan los efectos de los eventos climáticos severos asociados con el huracán Harvey (agosto de 2017) y las tormentas de hielo (febrero de 2021) en una colonia de murciélagos de cola libre (*Tadarida brasiliensis*). La colonia se encuentra a lo largo de Buffalo Bayou en Houston, Texas (condado de Harris; 29.76167, –95.39834). Las inundaciones y las congelaciones resultaron en un aumento de la mortalidad. Cambios en el comportamiento después de la inundación incluyeron "falso éxodo", salida de grupos más pequeños y la hora de emergencia retrasada desde el dormidero. El cambio principal después de la congelación fue la mortalidad generalizada y el movimiento fuera de su área límite. Un espécimen de *Dasypterus xanthinus* es registrado anecdóticamente, representando una importante extensión de rango en Texas.

Severe floods can significantly alter wildlife movement and behavior patterns and corresponding habitats through the destruction of native plant life, decimation of animal populations and disruption of food chains from both the quantity or quality of water, including volume, debris or additional chemicals (O'Shea et al., 2016). Bat populations in urban areas, especially colonies that roost under bridges or overpasses, may be at greater risk from floods because of their proximity to water (Allen et al., 2011). A significant flood can damage a colony by reducing the size of the population (Chamberlain and Leopold, 2002), forcing it to disperse (Gillam et al., 2010), or permanently destroying it.

Various bat species have been recorded overwintering in large groups within enclosed roosts to maintain a consistent ambient temperature >5°C to maintain circulation within the body (Davis et al., 1967). Bat populations in the subtropics will undergo torpor to conserve energy and water during the winter, as well as overwintering in large populations to maintain a consistent temperature across the whole colony. These adaptations allow bats to survive colder weather until more favorable conditions return (Rambaldini and Brigham, 2008). However, if cold weather continues longer than usual, bats in torpor may suffer from these longer hibernation intervals because calories consumed pre-torpor may be insufficient to thermoregulate for unexpected extensions (Geiser and Stawski, 2011). Bats that exit the roost to feed increases the chance of mortality as a result of lowered metabolic function and lack of food available while temperatures are low (Day and Tomasi, 2014).

Our objectives are to document the effects of severe weather events on a colony of resident free-tailed bats (*Tadarida brasiliensis*) roosting in Buffalo Bayou Park in Houston, Texas. Weather events include a major flooding event after Hurricane Harvey inundated the greater

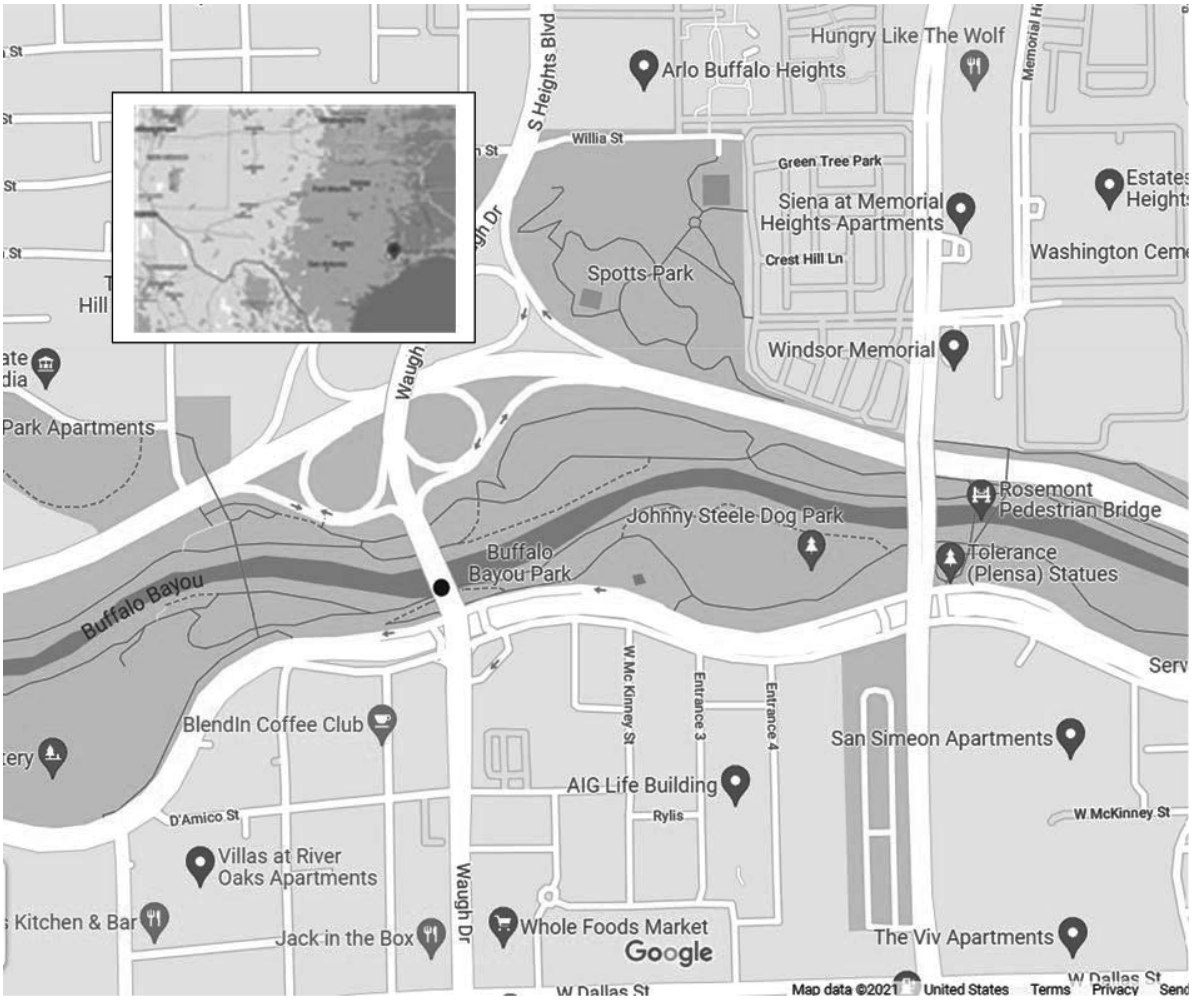

FIG. 1—Map showing the colony's location in Houston (dot on larger map) and Texas (dot on smaller map).

Houston area (August 2017) and a severe winter storm with below freezing temperatures lasting >2 days (February 2021). We hypothesize that both events had negative effects upon population size of the colony as well as behavior after both flooding and freezing of the area.

Buffalo Bayou is a waterway that originates near the town of Katy, Texas (Ft. Bend County), and flows east for 85 km through downtown Houston (Harris County) to the northern reaches of Galveston Bay. A section of the river that passes through downtown Houston is a large municipal park, Buffalo Bayou Park, where several bridges span the water. The Waugh Bridge (Figs. 1 and 2a) spans north and south Buffalo Park via Waugh Drive and connects Allen Parkway to Memorial Drive. The underside of the bridge is divided into five sections, with crevices in each section that provide safe roosting sites for bats. The bridge was constructed in 1994, with total length 107 m, width 25 m, and height 14 m between the top of the bridge and the water at normal pool elevation (I. Marquez, pers. comm.). A colony of free-tailed bats has been present at the bridge based on initial sightings of bats made within a year of construction of the bridge (D. Foss, pers. comm.). Before Hurricane Harvey, it was estimated that approximately 250,000 free-tailed bats roosted under the Waugh Bridge (Winston et al., 2017). During the winter of 2021, an estimated 100,000 individuals were overwintering under the bridge (D. Foss, pers. comm.).

We collected data sporadically from the time of flooding through the end of the year, late August–December 2017. We made observations from late dusk to early nightfall to correspond with emergence times of bats from the bridge. We recorded durations and concentrations of emergences, as well as behavioral observations. We recorded durations by subtracting time of emergence terminations from time of first emergence from the bridge. We compared concentrations of emergences with a control emergence recording made in July 2017 using a handheld phone video recorder (Samsung Galaxy S4 [Samsung Group, Seoul, South Korea], 105 Challenger Road, Ridgefield Park, New Jersey 07660-0511) in addition to previous observations made at the site. In the absence of emergences, we detected the presence or absence of bats through audible vocaliza-

Fig. 2—a) Image of the Waugh Bridge, showing the five sections of the bridge, as well as long-running crevices. b) Floodwaters inundated Waugh Bat Colony by at least 1 m.

tions, clicks and wing beating, visible fresh guano beneath the bridge and ammonia odor.

In February 2021, near the end of the freeze event, local wildlife rehabilitators and bat naturalists visited the Waugh Bridge to collect injured bats to transport to various rehabilitation clinics for immediate care and eventual future release. These individuals also estimated the number of bats that perished as a result of the extreme weather event based on the presence of carcasses at the site. Local rehabilitators and naturalists also visited additional Houston metropolitan locations including sites in Fite/Pearland, Watonga Pinemont, Summerwood, Welsford, and Sugarland.

Before Hurricane Harvey, we observed the *T. brasiliensis* colony exiting the bridge roost every evening from spring through autumn, as well as during periods of winter. The roost site provides access to fresh water from the bayou below the structure and from nearby park fountains, and also provides a safe brooding site for bats.

On 25 August 2017, these conditions were altered as Hurricane Harvey made landfall along the Gulf Coast of Texas. Although the greater Houston area was not hit directly by the storm, the region received 0.9 m of rain resulting in area flooding. We observed bats dispersing from the bridge on 26–27 August, with individuals flying to the American General Building (2929 Allen Parkway) across the street, apparently seeking temporary shelter from the rising flood waters.

Table 1. Dates of post-flood emergence times of free-tailed bats (*Tadarida brasiliensis*) from Waugh Bridge (Houston, Texas).

Date	Time of flight (h)
4 September 2017	Bats did not emerge
6 September 2017	2005–2015
11 September 2017	1958–2005
24 September 2017	1940–2000
15 October 2017	1920–1950
11 November 2017	1803–1815
1 December 2017	1750–1758
11 December 2017	Bats did not emerge
29 December 2017	Individuals exited at 1818

On the morning of 29 August, controlled releases of water began from the Addicks Reservoir, one of two reservoirs used to prevent further flood damage from excessive rains downstream in Buffalo Bayou. These releases inundated the bayou causing significant flooding due to the complete deluge of the area, and completely submerged the bridge, including the bat roosting area (Fig. 2b). This event caused the bats to evacuate the bridge in the early afternoon. By 31 August, the storm had moved out of the area, although water levels along the bayou remained elevated. We found several dead bats around the bridge location and on the sidewalk beneath the bridge at this time. Although most of the carcasses were not salvageable as study skins and we could not determine gender, 20 individuals were vouchered at the Houston Museum of Natural Science as skeletal specimens (HMNS VM #1422–1441).

On 4 September we made the first post hurricane observations at the Waugh Bridge site (Table 1). The bats began repopulating the roost site and vocalizations were audible under the bridge, although they did not exit the roost that evening. On 5 September we observed bats flying out of the fourth section of the bridge, confirming their utilization of part of the bridge. On 6 September we could see bats emerging from the second and fourth sections of the bridge at 2005 h, with the onset of sunset. We observed greater numbers than the previous evening, with the majority of the colony exiting by 2015 h. Observations made on 11 September revealed a population of bats ~20% larger compared with the previous week, with a larger group exiting the bridge at 1958 h. Fewer bats remained under the bridge after 2005 h than previous evenings, although most of the colony appeared to still be living in the fourth section of the bridge. We noted that bats, when exiting the roost site, would leave from one side of the bridge, circle around and fly under the second section of the bridge. We observed similar activity on the evening of 24 September, with activity initiating at 1930 h, the first group of bats emerging at

Table 2. Fates of bats from the winter storm from Waugh Bridge and other sites in the Houston (Texas) metropolitan area.

Colony	No. deceased	No. taken into rehab	No. re-released
Waugh	5,000	148	14
Fite/Pearland	1,500	?	?
Watonga/Pinemont	952	?	78
Summerwood	500	12	?
Welsford	150	?	?
Sugarland	2,245	44	32
Total	≥10,347	≥200–320	≥113–153

1940 h, and a second group emerging between 1950 and 2000 h.

We made further observations on 15 October, when the bats became active between 1850 and 1855 h. Vocalizations were heard from the first, second, and third sections of the bridge, although the bats did not begin to emerge until 1920 h. The bats moved to the second and third sections before flying out in a continuous stream, with two large bursts at 1932 and 1935 h, with most of the colony exited by 1950 h. Also, on this day we found more guano under the bridge than on previous evenings.

Visits made in November and December showed limited change in the bats' behavior. The colony still exited after sundown, although on two occasions (11 and 29 December) we heard the bats, but very few emerged from the bridge. Although the smell of ammonia and guano increased after the flood, the piles of guano were not as prominent as before Hurricane Harvey. Guano levels could have been affected by rainstorms that occurred after the flood or from routine municipal cleaning by the City of Houston maintenance crews.

Between 15 and 20 February, Texas was affected by three different winter storms (winter storms Shirley, Uri, and Viola) resulting in large parts of the state experiencing freezing weather, with a record low temperature of –11°C reported in Houston on 16 February. This weather event resulted in deaths of an estimated 5,000 bats (5% of the estimated colony population size) at the Waugh Bridge colony site (Table 2). Collection of surviving bats among the carcasses resulted in the transportation of 148 individuals to rehabilitation centers in the area, where 14 bats were rehabilitated and released within 1 month. Additional data for other sites in the Houston metropolitan area are also listed in Table 2. We collected no specimens because of our inability to store specimens in freezers as widespread electrical blackouts continued for several weeks in the area.

The time required for bats to exit the roost site at Waugh Bridge before the storm averaged 30 min, which is consistent with other findings for this species (Lee and McCracken, 2001). Duration of emergence immediately following the flood is not only shorter compared with observations made before the storm, but also compared with other populations of *T. brasiliensis* (Richard et al., 2009) not subjected to events of a storm catastrophe.

The most obvious deleterious effect of the flooding was the presence of many dead individuals, which is common for any population affected by a natural disaster (Chamberlain and Leopold, 2002). The majority of the dead bats appear to have been washed away, some adhered to the sidewalk under the bridge. The deceased individuals, combined with "population scatter," likely contributed to the bats not emerging from the bridge at all prior to 5 September, although some individuals had repopulated the bridge.

Several apparent behavioral differences were noted post-storm. For example, during mid-autumn bats made a "false exodus" from the bridge, immediately circling back to join other individuals in a different section of the bridge before the colony permanently emerged for the evening. The driving force behind this behavior is unknown; it is plausible that the bats active at the earliest times were waiting for numbers to build before making a mass exit from the bridge. The water level present at the bridge may have played a role in this observed behavior. More observations are needed to confirm that these behaviors are due to flood events rather than expected cyclic behavior of emergence.

Another change in behavior pre-storm versus post-storm is the emergence of bats in smaller groups or as individuals post-storm, rather than the larger continuous group exodus pre-storm. Although the groups could be relatively large and close together during some evening viewings, some observations on other nights were of smaller groups with longer lags between exiting. During emergence, the bats remained in tight groups regardless of the numbers of individuals. There was minimal consistency among emerging group size, and emergences diminished as temperatures declined, similar to emergence reports of *T. brasiliensis* populations at Carlsbad Cavern, New Mexico (Hristov et al., 2010). Additionally, later in the autumn, bats exited the bridge after sundown, compared with earlier emergences that occurred at dusk, as observed before Hurricane Harvey.

The fatalities from the winter of 2021 are likely a result of several factors including reduced body fat, dehydration, pneumonia, organ damage, and frostbite that have been reported in previous studies (Spenrath and LaVal, 1974; D. Foss, K. Rugrodem, and M. Rhodes, pers. comm.). Low body fat due to winter torpor, lack of feeding, and early arousals, combined with being near the end of winter, resulted in the bats not having enough time to rebuild fat stores (e.g., Geluso, 2008). Dehydration was most likely due to the bats remaining in the roost to maintain body temperature, which prevented flying down to drink the water below the bridge in the bayou (Stegeman, 1954). There is the possibility of frostbite damage to external features (e.g., ears, tails, or

appendages) of bats, although there are limited occurrences of this reported within the affected colonies (Mulder and Janssen, 2016). Pneumonia has been recorded in a variety of mammals in the wild and captivity (Canfield and Cunningham, 1993), including bats, which can result in pulmonary lesions, possibly as a result from a traumatic event (Farina and Lankton, 2018). More in-depth research is needed, because there have been few projects studying the effects of cold weather on the health of bats.

Data from several colonies revealed >10,000 bats died in the Houston area alone during the winter storm event in 2021 (Table 2), and the numbers probably exceeded this figure. An estimated 200–300 injured bats were taken into rehabilitation at various locations throughout Texas, of which approximately one-half recovered enough to be released (Table 2; K. Rugrodem, M. Rhodes, S. Webb, and A. Estrada, pers. comm.). These numbers reported are for only the Houston Metropolitan area; the effects of these winter storms were statewide and beyond, so the numbers are likely to be staggering when evaluating the entire geographic scope.

The winter storm not only affected populations of free-tailed bats, but other species anomalies were reported. One bat rehabilitation site received several uncommon species from the Houston area, including one northern yellow (*Dasypterus intermedius*), one western yellow (*D. xanthinus*), one Seminole (*Lasiurus seminolus*), two southeastern myotis (*Myotis austroriparius*), and two evening (*Nycticeius humeralis*; K. Rugroden and M. Rhodes, pers. comm.) bats. The *D. xanthinus* specimen represents an important range extension record for Harris County, Texas, and more importantly for the entire eastern half of the state. Previous reports of this species are seldom east of extreme western counties of Big Bend and the Trans-Pecos regions of Texas (Decker et al., 2020). Strong forces exerted upon this individual bat during the extreme winter storm in February 2021 likely led to presence outside its' typical distributional range.

Future monitoring of the Waugh Bridge colony, including video and audio recordings, will help estimate current population size and fluctuations in population numbers, as well as seasonal changes and trends. We will make additional observations to verify whether behavioral changes are a reaction to the flood, seasonal temperature fluctuations, or other possible factors (Wolff et al., 2009; Fidiam and Iudica, 2011).

We are grateful to D. Schmidly for significantly improving this manuscript through extensive comments. We also wish to give special thanks to D. Foss from Texas Department of Parks and Wildlife for providing information on the colony during weather events in 2017 and 2021. Additionally, Bat Naturalists and Wildlife Rehabilitators S. Jurek, K. Rugroden, A. Estrada, S. Webb, and M. Rhodes helped provide data on numbers affected and ailments due to the winter storm. D.M.B. wishes to thank several lab associates for their hours of observations at the bat bridge, including K. and J. Winston, T. McSweeny, A. Bickham Baird, C. Geiselman, as well as S., L., and M. Brooks. We wish to dedicate this article in memory of Robert J. Baker, Batman and friend.

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Submitted 28 September 2019. Accepted 26 July 2022.
Associate Editor was Troy Ladine.