COMMUNITY-BASED CLEAN-UP SCHEMES IN URBAN PARKS CAN IMPROVE WATER SOURCES FOR BATS

by

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ABSTRACT

Bats are essential to ecosystems, providing services like pollination, seed dispersal, and pest control, yet their populations are declining globally due to human-driven habitat loss. To counter these effects, conservationists promote strategies like enhancing habitats, even in urban areas. Yet to support healthy bat communities, they need to offer suitable resources such as water. Water access for bats depends on both availability and accessibility. Accessibility is often limited by "clutter"—physical obstructions such as vegetation, rocks, or debris that restrict bats' ability to drink in flight. Urban litter, primarily non-biodegradable items, degrades aquatic habitats, potentially restricting access for wildlife. Targeted litter removal, therefore, has the potential to reduce habitat degradation and improve access for species like bats. To investigate this, we implemented a community-based cleanup at select water sources in Fort Worth, Texas, from 2021 to 2024, recording bat activity with thermal and acoustic tools before and after cleanup to assess the impact of litter removal on bat drinking activity.

Post-clean up, overall bat presence increased significantly at both sites, with drinking activity increasing for hoary bats (*Lasiurus cinereus*), silver-haired bats (*Lasionycteris noctivagans*), and Mexican free-tailed bats (*Tadarida brasiliensis*), These findings reveal that litter does act as clutter, thereby limiting access to water for certain bat species with open-space flight patterns. Overall, our results highlight the value of litter-free water sources in urban environments for promoting bat species diversity and resource use. By demonstrating the positive impact of community clean-ups on bat activity, this project underscores the role of citizen-led conservation initiatives in fostering urban biodiversity, improving ecosystem health, and supporting local conservation strategies.

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INTRODUCTION

Bats play a crucial role in providing essential ecosystem services, including pollination (Flores-Abreu *et al.* 2019), seed dissemination (Sugiyama *et al.* 2018; da Silveira *et al.* 2024), and pest control (Tuneu-Corral *et al.* 2023). Despite being a service provider, bat populations are facing a global decline due to factors such as land-use change, intensive forestry and agricultural practices, and urbanization (Pretorius *et al.* 2021). To mitigate the adverse effects of these human-induced impacts, wildlife managers, and conservationists advocate for three broad strategies: 1) preventing further habitat loss and degradation, 2) reestablishing habitat, and 3) improving existing habitats (Donaldson and Elliott 2021; Aiello *et al.* 2023; Kosma *et al.* 2023). Although enhancing urban environments may not be a conventional conservation approach, research indicates that urban areas can still support stable and healthy bat communities (Caiza-Villegas *et al.* 2023), if suitable resources are readily available, including water sources (Lehrer *et al.* 2021; Lewanzik *et al.* 2022; Printz and Jung 2023).

Generally, water accessibility and availability determine the use of water sources by bats. Availability is associated with the abundance of water sources in an area (Adams and Hayes 2021) and requires that water be distributed amply across the landscape (Krauel and LeBuhn 2016; Amorim *et al.* 2018). However, water distribution is also associated with accessibility (i.e., the ability of bats to utilize a water source; Todd and Williamson 2019). One factor that can influence accessibility is level of clutter encroaching and limiting water surface area availability (Reyna-Hurtado *et al.* 2009; Magalhães de Oliveira *et al.* 2020; Harper 2024). Clutter is defined here as any physical obstruction present on the surface of the water or in immediate surrounding area. This includes vegetation, exposed rock, and debris; all of which can hinder bats from accessing the surface of the water while attempting to drink in flight (also referred to as drinking on the wing; Torrent *et al.* 2018). A study in the United Kingdom, for example, found that bats avoided rivers with dense overhanging tree canopy cover and rocks breaching the surface of the water (Todd and Williamson 2019). Similarly, one study determined that vegetation on the surface of water sources deterred bats from drinking, while another indicated that dense grass and scrub vegetation growing along banks led to a decrease in drinking activity (Ciechanowski *et al.* 2007; Jackrel and Matlack 2010). Yet, not all forms of clutter are natural. Two studies also confirmed that the presence of polystyrene and plastic objects created obstructions that hindered bats from drinking at water sources (Greenfeld *et al.* 2018; Rodriguez Hurtado and Sanchez 2022). It is studies such as these that demonstrate that anthropogenic forms of clutter, such as litter, can negatively impact water accessibility (Russo-Petrick and Root 2023) and in turn influence bat activity, abundance, and species diversity in an area (Beason *et al.* 2020).

In urban environments, higher population densities lead to increased litter generation particularly due to non-biodegradable single-use items, such as bottles, cans, plastic bags, polystyrene fast-food containers, cigarettes, and most recently disposable face masks, all of which have been recognized as harmful to wildlife (Ober and DeGroote 2011; Silva *et al.* 2021; Shah *et al.* 2023). Subsequently, the drainage systems associated with urban infrastructure facilitate the nonpoint source pollution of local water sources, as the litter from roads, parking lots, and other impervious surfaces wash into nearby water bodies where it accumulates (Koutnik *et al.* 2021; Xue *et al.* 2022). Due to the adverse effects of this accumulated litter, several studies highlight the importance of targeted interventions (Blettler and Mitchell 2021; Mallory *et al.* 2021). In particular, one study indicates that the removal of litter and other discarded objects from water sources can significantly reduce aquatic habitat degradation by 20-70% and improve habitat quality by approximately 15% (Gu *et al.* 2023). Moreover, three studies demonstrate that removing litter from water sources can not only benefit aquatic ecosystems, but also enhance accessibility for bats (Rosevelt *et al.* 2013; Vance *et al.* 2018; Bao *et al.* 2019). Therefore, a simple litter or trash cleanup scheme could potentially serve as an effective restoration activity for community groups.

To explore this concept, we assessed whether a community-based pond cleanup scheme could effectively improve water resource use by bats (i.e., result in an increase in drinking activities). For this, we first recorded bat activity at six water sources in local parks and neighborhoods in and surrounding the City of Fort Worth, Texas from 2021-2022 using thermal and acoustic technology. We then repeated the surveys from 2023-2024, while executing a monthly community-based cleanup scheme at two of the ponds. Finally, we compared levels of bat activity pre- and post-cleanup to determine if removing litter specifically increased drinking activity. The results from this study not only have the potential to inform the management of urban areas for bats and other wildlife, but also could contribute to efforts that improve urban community health and wellbeing through responsible waste management practices.

<u>METHODS</u>

Study Sites

Our study area, located within the Lower West Trinity watershed in Tarrant County, north central Texas, USA (32°41’21.17” N, 97°22’46.75” W; Fig. 1), predominately encompasses the City of Fort Worth. Fort Worth is one of the fastest growing cities in the United States, with a population exceeding 900,000 residents (UCSB 2020). We selected six water sources distributed across this area in local parks (Fig. 1) that were known to have an abundance and diversity of bats, including eastern red (*Lasiurus borealis*), hoary (*Lasiurus cinereus*), silver-haired (*Lasionycteris noctivagans*), tri-colored (*Perimyotis subflavus*), evening (*Nycticeius humeralis*), and Mexican free-tailed (*Tadarida brasiliensis*) bats (Nystrom and Bennett 2019; Hall *et al.* 2021; Bennett and Agpalo 2022). Moreover, each site selected provides essential resources for these species, including foraging opportunities, roosting sites, water resources, and connectivity (i.e., commuting corridors; Li and Wilkins 2014; Harms *et al.* 2020; Ruczynski and Bartón 2020; Toledo *et al.* 2020; Shao *et al.* 2022). Four of the six parks are owned and operated by City of Fort Worth Park and Recreation Department: Foster, Oakmont, Trinity, and Lake Como Parks. A fifth study site location was Rocky Creek Park, owned and operated by the U.S. Army Corps of Engineers, while the final study site, a retention pond known as Frat Pond, was located on the campus of Texas Christian University. Each study site is described below in order of potential for litter accumulation (best to worst; Table 1).

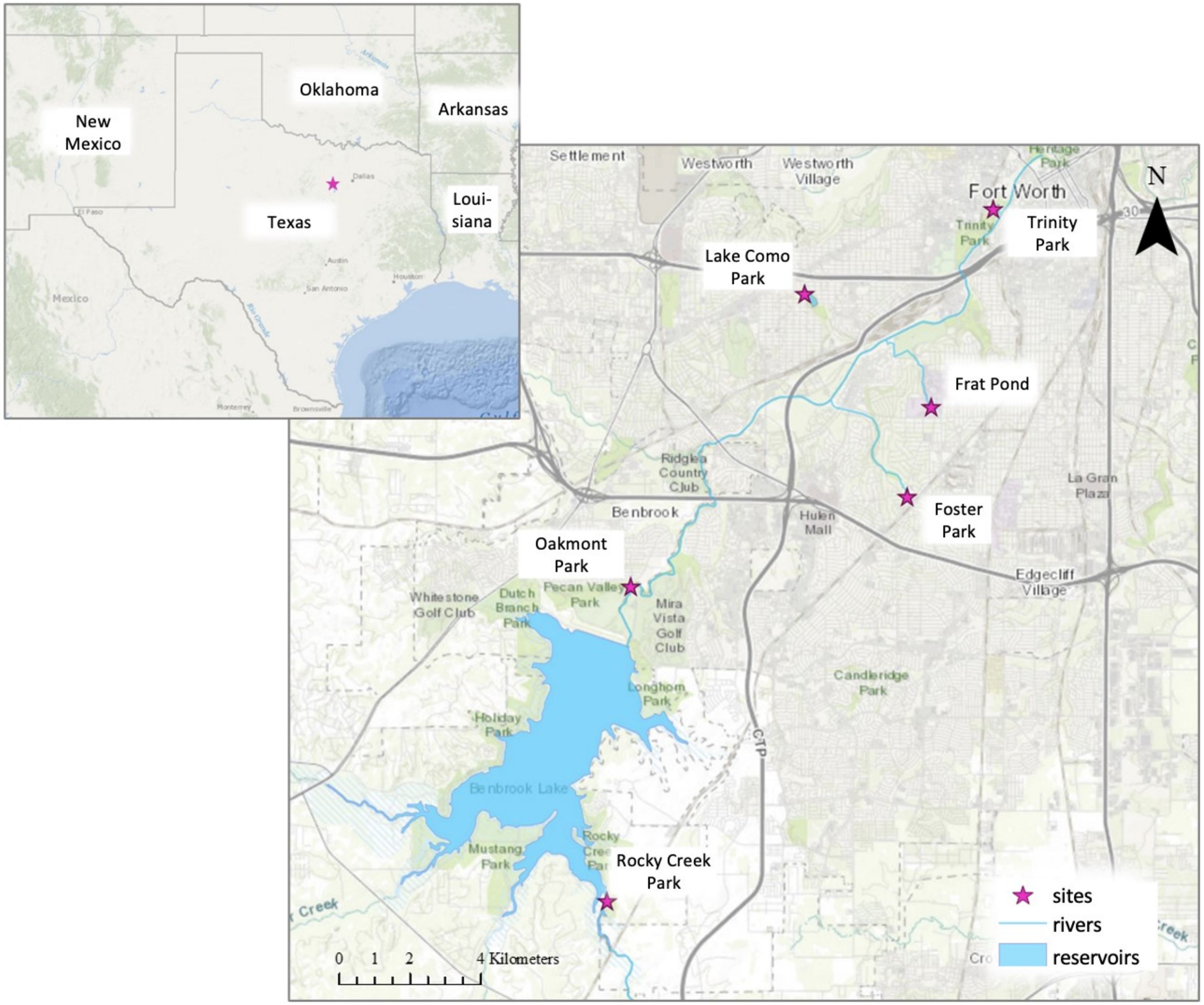
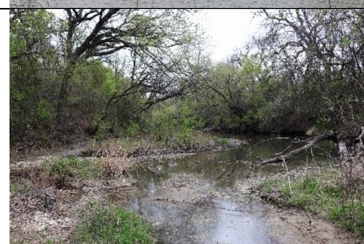
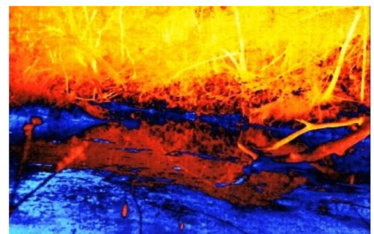
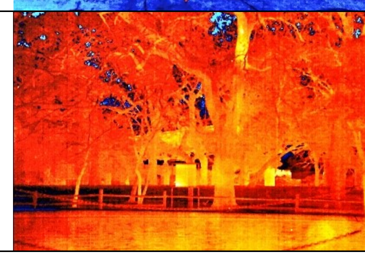
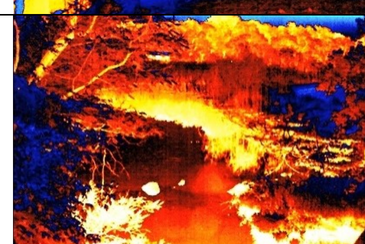
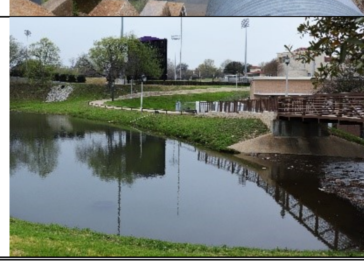


Figure 1: Location of the six water sources used in thermal and acoustic monitoring surveys conducted between 2021 to 2024 in Fort Worth, Tarrant County, Texas, USA. Taken from Harper 2024.

Table 1: Six study sites surveyed in Fort Worth, Texas, including the field-of-view for the thermal camera set up at each site. Taken from Harper 2024.

Location	Pond	Thermal View
Rocky Creek Park		
Oakmont Park		
Trinity Park Duck Pond		
Foster Park		
Lake Como Park		
Frat Pond		

Rocky Creek Park: Located on the shore of Benbrook Lake, the park is a 15.3 km^2 reservoir where the Clear Fork and the West Fork of the Trinity River join and are impounded by the Benbrook Dam. The park is one of seven that surround the reservoir that were created and maintained for recreation, primarily fishing, equestrian trail riding, and camping (USCOE 2022). Within the park there is a ~1 km^2 stretch of managed prairie intended to promote the conservation of native species (GPCR 2013). We selected a ~6,000 m^2 section of the Rocky Creek tributary next to a campground at the southern tip of the park.

Oakmont Park: This site is a ~0.5 km^2 riparian habitat that stretches along the Trinity River, 1.5 km from the Benbrook Dam on the northeastern edge of Benbrook Lake. The area surrounding includes the Pecan Valley golf course to the southwest and subdivisions of the city of Benbrook encompassing the rest of the park. Oakmont provides recreational opportunities for this surrounding community in the form of walking, running, fishing, and biking. The park itself is interspersed by mature trees, surrounding playgrounds within heavily manicured grassland with riparian habitat along the edge of the river comprising understory vegetation and additional trees. Within Oakmont Park, we selected a ~350 m^2 portion of the river located at the Art Cowsen Trailhead.

Trinity Park: Covering a ~1 km^2 of urban green space near downtown Fort Worth, the park is centered around the Trinity River and associated riparian habitat. Toward the north of the park there is a 4,840 m^2 pond, known as the Trinity Park Duck Pond, which we used in this study. This pond, which acts as a recreational duck pond for the surrounding highly developed downtown area, however the pond is a closed system and run-off from the surrounding area does not drain into the pond. We selected a ~570 m^2 area at the southern end of the pond as our survey site.

Foster Park: This park covers a 0.05 km^2 linear tree-lined green space centered around a drainage ditch and a ~1,700 m^2 retention pond. It is part of a park system (Kellis, Foster and Overton Parks) that lies within a suburban subdivision of ranch-style single-story housing (common to the region) built in the 1950s (FWPR 2014). This linear greenbelt of mature trees (>6 m in height) interspersed with a heavily manicured grassland interspersed paralleling a drainage ditch and associated riparian habitat comprising with understory vegetation and mature trees. For our surveys, we selected the retention pond towards the eastern end of the park from which stormwater enters from a small industrial area, rather than the surrounding neighborhood.

Lake Como Park: This site is a ~0.2 km^2 park centered around the 0.05 km^2 Lake Como waterbody. The park is located a few blocks south of Interstate 30 and west of Hulen Street. Built in 1952, the park provides recreational opportunities to the surrounding subdivisions; Como, Sunset Heights South, West Beyer, and East Libbey. The southern half of the park comprises heavily manicured grass, while the northern border of the lake predominately consists of dense understory and mature trees. Recreational activity in the area includes biking, fishing, walking, and running. Note that run-off from the surrounding neighborhoods and roads drain directly into the lake. Our study site comprised a ~650 m^2 linear section at northwestern end of the lake, next to a stormwater culvert and was bordered on both sides by mature trees and understory vegetation.

Frat Pond: Located on the campus of Texas Christian University, this ~6000 m^2 retention pond is bordered by shrubs and trees on its western edge and surrounded by heavily manicured grass on the eastern side. This large retention pond acts as drainage for the surrounding subdivisions and the campus community, including the Greek Village, soccer pitch, tennis courts, and athletics field. Tree-lined drainage ditches enter from the subdivision to the south and extends north from the pond to the Trinity (TCU 2015). At the pond, we selected a study site at its northern end where the pond flows into the tree-lined drain under a bridge and into a culvert.

Behavioral Surveys

To determine levels of bat activity at each survey site, we used thermal cameras and acoustic detectors to conduct behavioral observation and acoustic surveys from March to September 2021-2024 (the season when bats are active in north-central Texas; Bienz 2016; Smith 2019). To ensure the sites were surveyed consistently over this period, we surveyed each every 1-2 weeks with two technicians at each site. To accommodate any variation in bat activity associated with survey night, two sites were surveyed concurrently per night. We also postponed surveys until the next available night when winds exceeded 24 km/hr, it was raining, and/or temperatures <5°C (Bienz 2016).

At least 30 mins before starting surveys, we set up the equipment. First, we used thermal cameras within the infrared spectrum of ~9,000-14,000 micrometers; as recommended in Huzzen et al. (2020). Thermal camera set-ups consisted of an Axis Q1942-E 19mm ThermNetCam 30 FPS (Axis Communications, Lund, Sweden) surveillance camera placed on top 15-gal tote container and adjusted to a specified field-of-view using beanbags (Fig. 2). The thermal cameras themselves were set to the “Ice-and-Fire” false-color scheme setting, a resolution of 640 by 480 pixels, and a sampling rate of 30 frames per second. Note that no supplemental lighting was required. We positioned the cameras 10 m away from the edge of the water to create a field-of-view that captured the surface of the water and an area ~10 m above (Table 1). We kept the camera placement consistent between all survey sites (independent of water source size) to minimize any bias in data collection caused by variations in scale. Finally, to operate the thermal cameras and record bat activity, we used a laptop computer, Ethernet cables, a Netgear ProSAFE

8-Port Fast Ethernet PoE Switch, and a 300 W lithium battery which powered the laptop and thermal camera through the Netgear Ethernet switch (Fig. 2).

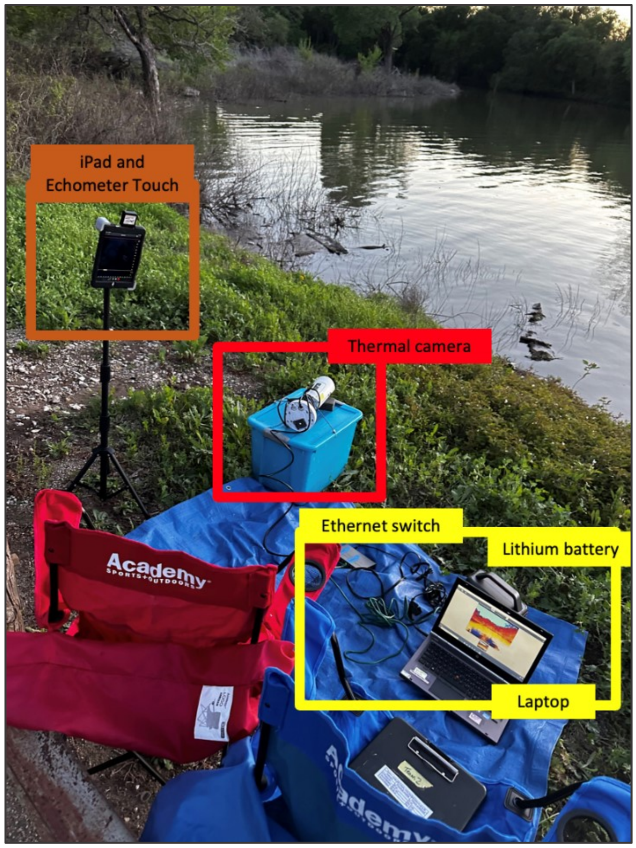


Figure 2: Annotated picture of equipment set-up used in thermal and acoustic monitoring surveys conducted between 2021 to 2024 in Fort Worth, Tarrant County, Texas, USA.

For the acoustic surveys, we used a Song Meter SM4Bat acoustic detector with an external U2 ultrasonic microphone from Wildlife Acoustics (Maynard, Massachusetts) to record echolocation calls emitted by bats at the sites. The detector was placed at the edge of the water with its microphone angled toward the surface (Fig. 3). It should be noted that, although the microphone for the detector is directional, bat calls from outside the vicinity recorded on thermal cameras could be detected. The detector was set to trigger at the frequencies between 16 kHz and 192 kHz (a frequency range that encompasses the echolocation frequencies of known bat species within Fort Worth; Nystrom and Bennett 2019; Krejsa *et al.* 2020). In addition, we set the detector to have a 3-sec delay between recordings, a gain threshold of 12.0 dB with a trigger volume of 12.0 dB, and any sound files to be recorded as 4-sec standard wav files (.wav). We saved all files created onto a 64 GB SD card with the sample rate at 256 kHz and D-batteries were used to power the detectors.

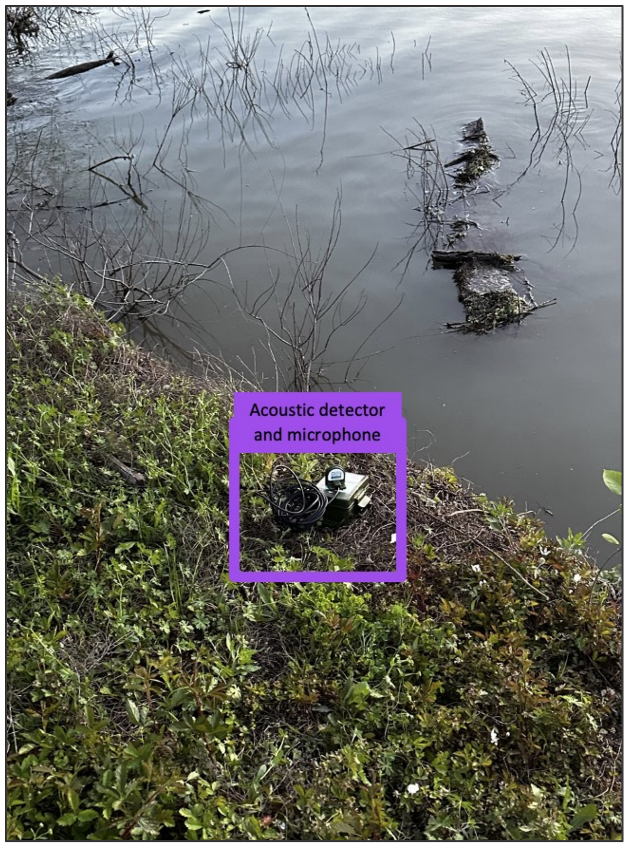


Figure 3: Annotated picture of equipment set-up used specifically in acoustic monitoring surveys conducted between 2021 to 2024 in Fort Worth, Tarrant County, Texas, USA.

Both thermal and acoustic surveys started 20 min after sunset and continued for ~1 hr to incorporate the primary period when local bats were actively searching for and drinking water (i.e., soon after the bats emerged from their roosts; McAlexander 2013). Each 1-hr survey was divided into six 10-minute sessions not only for the ease of processing the thermal camera footage, but also for survey technicians to reduce the occurrence of recording failures, delays, or equipment malfunctions. During surveys, we also used an iPad with an Echometer Touch ultrasonic microphone module from Wildlife Acoustics to determine if bats were flying in real-time. Any bats heard were recorded as back-up, along with any observations of bats in the thermal camera, in particular observations of bats drinking.

Note we also recorded the following data at the start of each survey using WeatherBug and Lunar Phase mobile applications: temperature (^{o}C), average wind speed (km/h), wind gust speed (km/h), wind direction (cardinal), humidity (%), dew point (^{o}C), barometric pressure (mb), cloud cover (full, partial, or clear), moon phase, moon illumination (%), and whether the moon was visible or not. These variables were recorded as they could potentially influence bat activity on a given survey night and could be used to account for the presence of outliers or anomalies in the data (Agpalo 2020).

Following each survey, we downloaded and converted all footage to .mp4 files using HandBrake Software (Version 1.5.1, Handbrake Team, GitHub, San Francisco, California), which we then input these into Vosaic video analysis software (Version 1.1.3686, Studiocode Business Group, Lincoln, Nebraska). Next, we observed the footage and manually logged the occurrence of bat activity in the field-of-view along a timeline (Fig. 4; see Bienz 2016 for further details). The csv. output file produced for each session provided the duration and time of each occurrence marked on the timeline.

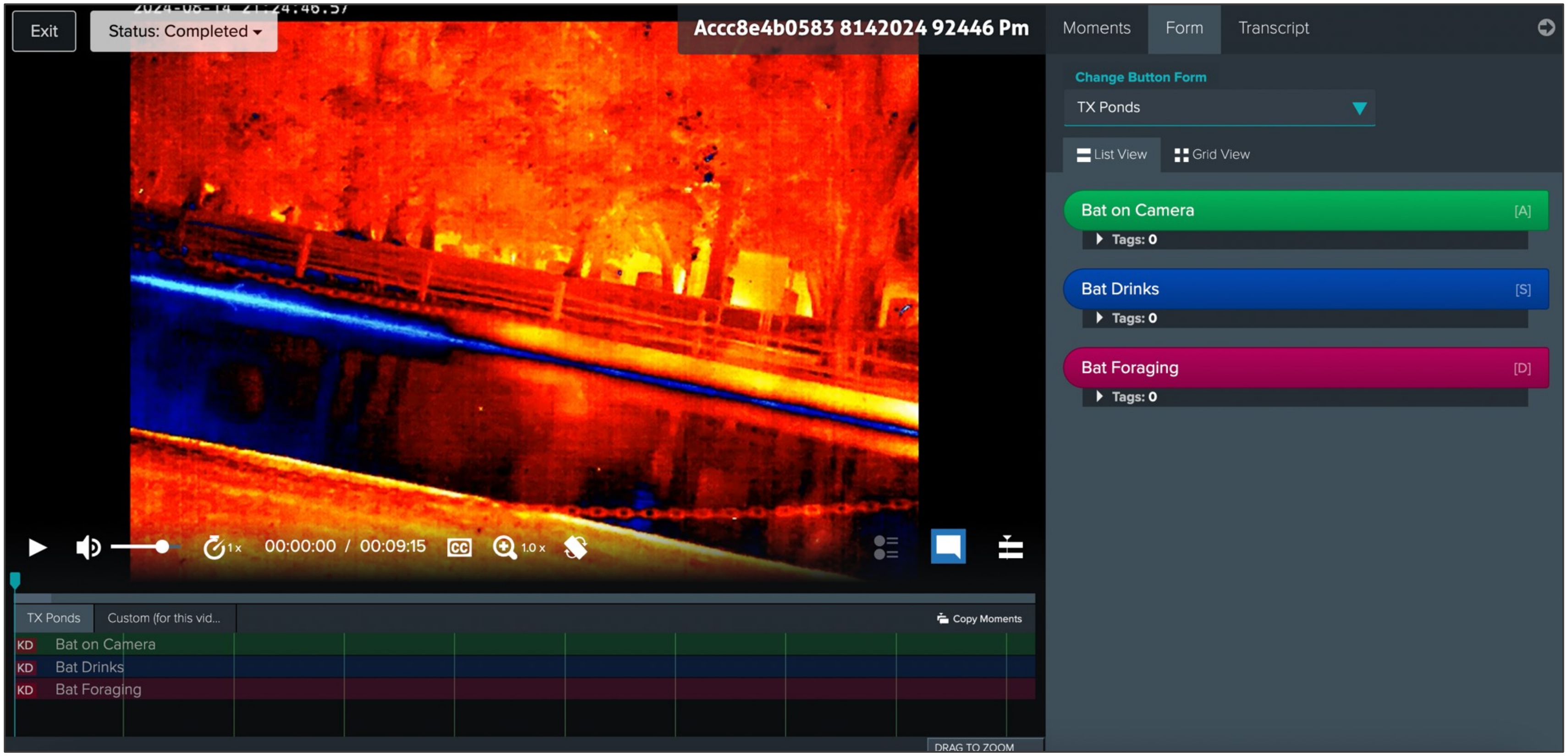


Figure 4: Example of Vosaic video analysis software viewing screen with customized activity buttons and timeline marked up with the occurrence of bats present and drinking in the field-of-view.

To determine the extent to which bats use each water source as a drinking resource, we recorded the total time (secs) bats were present in the field-of-view during the 1-hr surveys. Note that when multiple bats were observed in the field-of-view concurrently, we recorded the amount of time each individual bat was present and then summed the total time. For drinking activity, a drinking event was defined as a bat swooping down to the surface of the water with its body angled head-first facing towards the water and making contact with the surface ≥1 time as it passes over the water (Fig. 5; Tuttle *et al.* 2006; McAlexander 2013). This behavior often creates ripples or a splash at the point of contact with the water, which helped with identification (Kloepper *et al.* 2019). To determine drinking rate, we summed the number of drinking events to occur in the field-of-view during the 1-hr surveys.

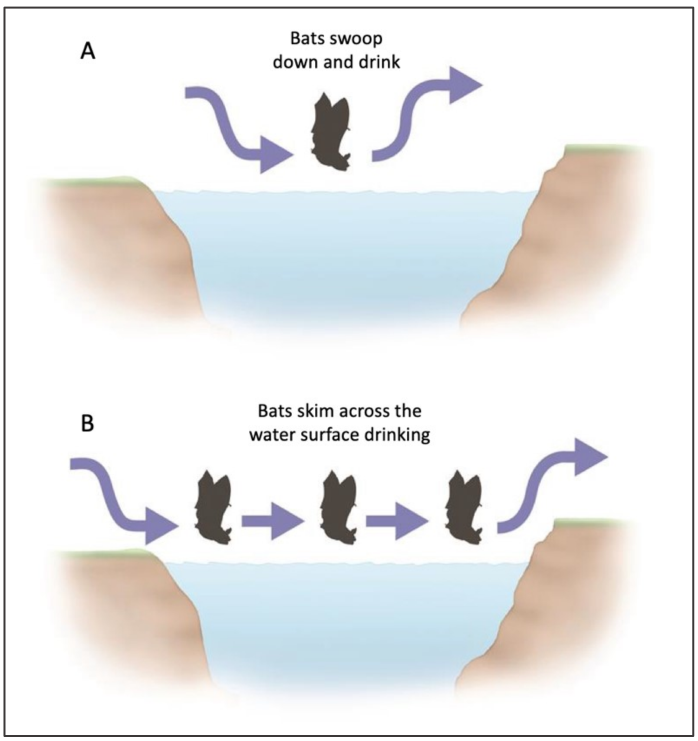


Figure 5: Illustration of drinking behavior at water sources by bats. (A) Drinking behavior in which the bat makes contact one time with the surface of the water. (B) Drinking behavior in which the bat skims the surface of the water. Modified from McAlexander 2013.

For the sound files recorded on the acoustic detectors, we first downloaded the files into SonoBat Scrubber software (Version 4, SonoBat, Arcata, California), which filtered out a majority of the acoustic files containing noise; such as stridulating insects. We then used SonoBat bat call analysis software (Version 3.03, SonoBat, Arcata, California) to manually identify bat echolocation calls among the remaining files to species (where possible) and activity (Fig. 6). For the latter, we defined four acoustically distinct activities (Fig.6 and 7; Nystrom and Bennett 2019): 1) commuting (e.g., bat that is moving through the area) characterized as consecutive, equally-spaced calls (i.e., individual chirps), which are constant, steadily decreasing, or steadily increasing in call strength. In addition, any sound file with <2 calls were categorized as commuting; 2) searching (i.e., when a bat is actively seeking a resource) described as consecutive, equally spaced calls that vary in strength due to the bat turning its head from side to side; 3) approaching (i.e., when a bat is moving towards a resource) which has call intervals that vary, trending toward becoming shorter, while the frequency bandwidth tends to increase; and 4) terminal buzz (i.e., a bat catches a prey item, lands, or comes in to drink) when the interval between successive calls decreases rapidly and the shape and bandwidth of these calls varies from those in the previous three activities (Agpalo 2020). Furthermore, we used distinct differences between terminal buzzes to determine if bats were using the water source as a drinking resource (drinking buzz). Drinking buzzes are discernable from feeding buzzes as the frequency of the terminal phase calls are equivalent to the preceding approaching phase frequencies, while feeding buzzes are seen to shift higher or lower in frequency (depending on species) compared to the previous approaching phase frequencies (Russo *et al.* 2016). Thus, for each call file we recorded 1) site, 2) date, 3) time, 4) number of bats, 5) species of each bat present, and 6) activity exhibited by each bat.

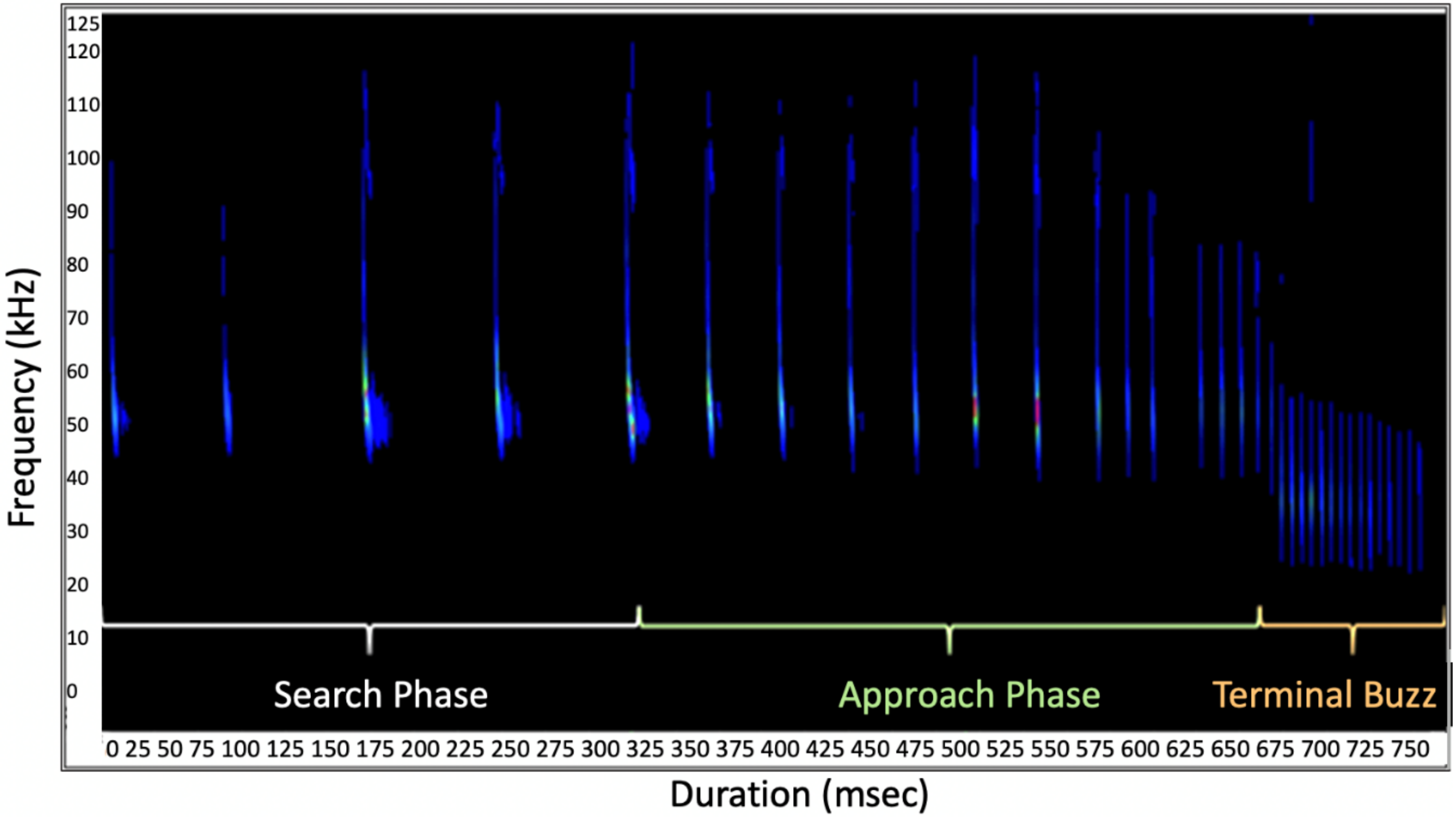


Figure 6: Spectrograph with examples of three of the acoustic activities exhibited by bats. Note *x* axis shows duration (ms) and *y* axis shows frequency (kHz).

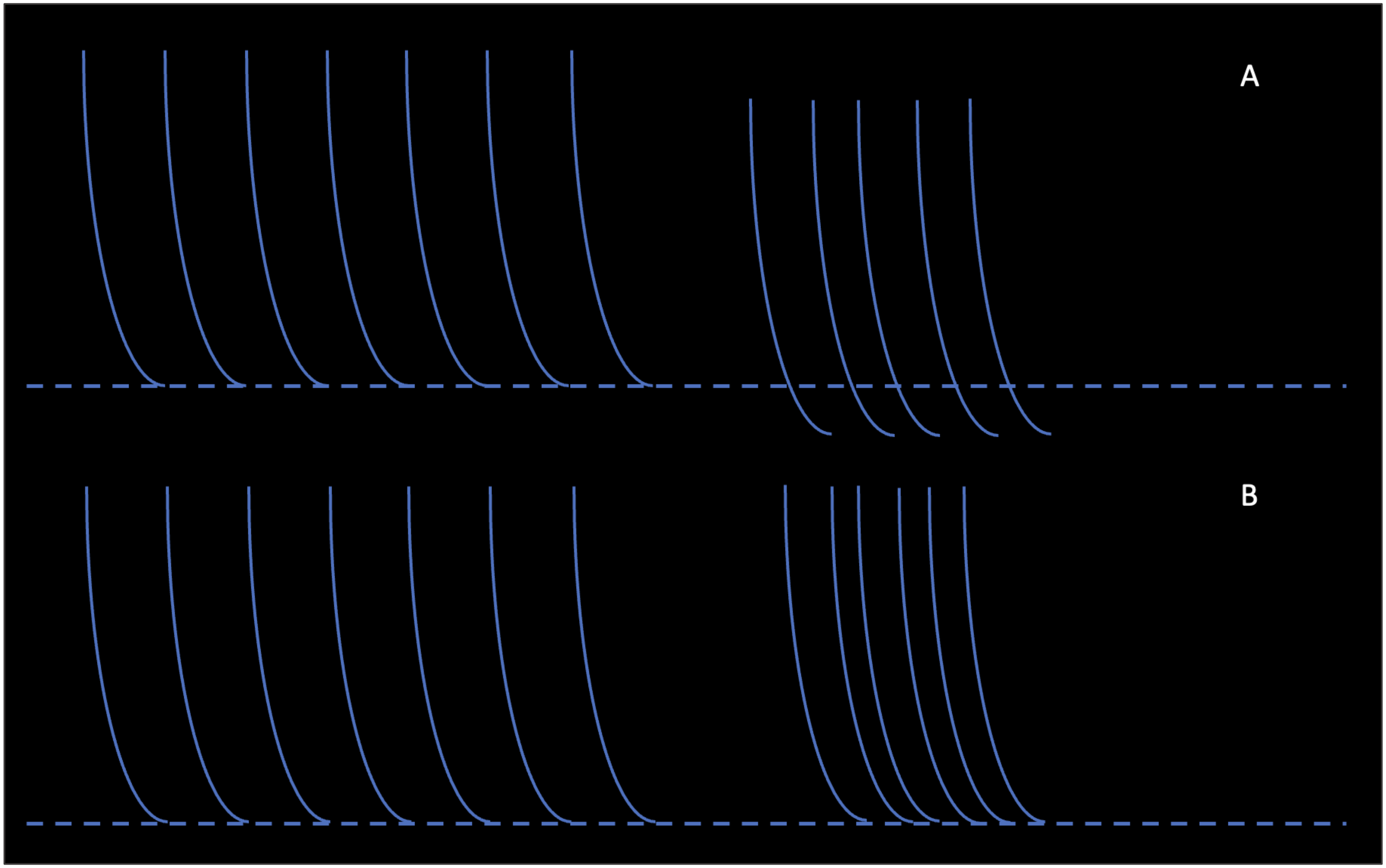


Figure 7: Examples of spectrographs delineating the difference in structure between A) a feeding buzz which exhibits a low frequency shift (in this example) and B) a drinking buzz.

Once processed, we had a total of six dependent variables from the behavioral observation and acoustic surveys. These included, observationally, (1) total time bats were observed and (2) number of bats observed drinking per pond per night. From the acoustic files recorded, bat echolocation calls were manually identified with acoustic software, where possible, to species (i.e., (3) total number of species present) and activity (i.e., (4) the total number of calls recorded). As drinking and foraging are acoustically distinct activities, we were also able to determine (5) the number of drinking calls per pond per night. Note this variable was only used as a backup if observed drinking activity data was compromised. Finally, we determined species-specific drinking activity using both the acoustic calls (i.e., (6) number of drinking calls per pond per night per species).

Pond Clean-up

To assess whether a community-based pond clean-up scheme could effectively improve water resource use by bats, two of our six sites were selected that consistently had visibly more litter and accumulated trash (Fig. 8). In comparison to the other four sites (hereafter referred to as *reference sites*), Lake Como Park was located at the mouth of a culvert that carries run-off from all the residential houses and roads in the surrounding neighborhood directly into the lake, while Frat Pond was a large retention pond that acted as drainage for the surrounding subdivisions and campus community. Moreover, a recent study into the water quality of our six study sites revealed that Lake Como Park and Frat Pond had the highest pollution potential due to their location in highly urban areas and watershed extent (Scott 2023). Subsequently, both experienced higher levels of litter accumulation and, in turn, surface clutter that potentially hindered bat drinking activity. We hypothesized that removal of litter from these two sites would result in an increase in bat drinking activity. Thus, at these sites we organized and executed a monthly community-based cleanup event starting at the end of February and continuing through to the end of August in 2023 and 2024. For this, we enlisted the help of four different organizations; the TCU Community Scholars, TCU Student Government Association, TCU Honors College Community Service, and the TCU chapter of the One Shade Greener (a national conservation and community engagement organization).

Figure 8: Photo of typical litter accumulation on the surface of Lake Como.

Using swimming pool skimmer nets, trash pickers, heavy-duty rubber gloves, and heavy-duty trash bags sponsored by Fort Worth Zoo, members of each of the relative organizations removed all visible debris and trash from the aforementioned water sources and immediate area surrounding (Fig. 9). The litter was then disposed of in accordance with City guidelines, for instance, sharps were placed in appropriate containers. As previously noted, clean-ups occurred monthly, with both sites being cleaned at the end of each month throughout the bat "activity" season.

Figure 9: Photos of organizations performing clean-ups conducted at Frat Pond (left) and Lake Como (right).

Analysis

To determine if the monthly removal of litter and debris at the sites increased the use of the water as a drinking resource for bats, we compared observed bat presence and drinking activity recorded in 2021 and 2022 (pre-clean up) with equivalent bat activity data collected in surveys conducted in 2023 and 2024 (post-clean up). For this analysis, we first conducted a preliminary assessment of the data to determine normalcy. We found that due to the occurrence of multiple survey nights with no activity recorded, the data was not normally distributed. In addition, further assessment of the data revealed that bat abundance in 2021 and 2022 in comparison to 2023 and 2024 was 67.3% higher across our reference sites, with the exception of Trinity Park Duck Pond (Fig. 10). Using a Kruskal–Wallis test, a non-parametric method, we confirmed that this difference was statistically significant (H=7.66, df=1, P=0.006). To account for this annual variation, which is to be expected (Staton and Poulton 2012), we adjusted observed bat presence and drinking activity at Lake Como and Frat Pond for 2023 and 2024 based on the aforementioned percentage difference between 2021 and 2022 combined and 2023 and 2024 combined at Rocky Creek, Oakmont, and Foster Parks.

Once adjusted, we used a non-parametric Mann-Whitney U test to compare pre-cleanup against post-cleanup data at Lake Como and Frat Pond. The assumptions of this test were that the data from these two groups was independent of each other and all the dependent variables were continuous. We also assumed that under the null hypothesis H_0, that bat activity would be similar between pre- and post-cleanups, while activity would vary pre- and post-cleanup in the alternative hypothesis H_1.

For all statistical analysis we used Minitab statistical software (version 22.1.0, Minitab, LLC State College, PA) and where $\alpha = 0.05$.

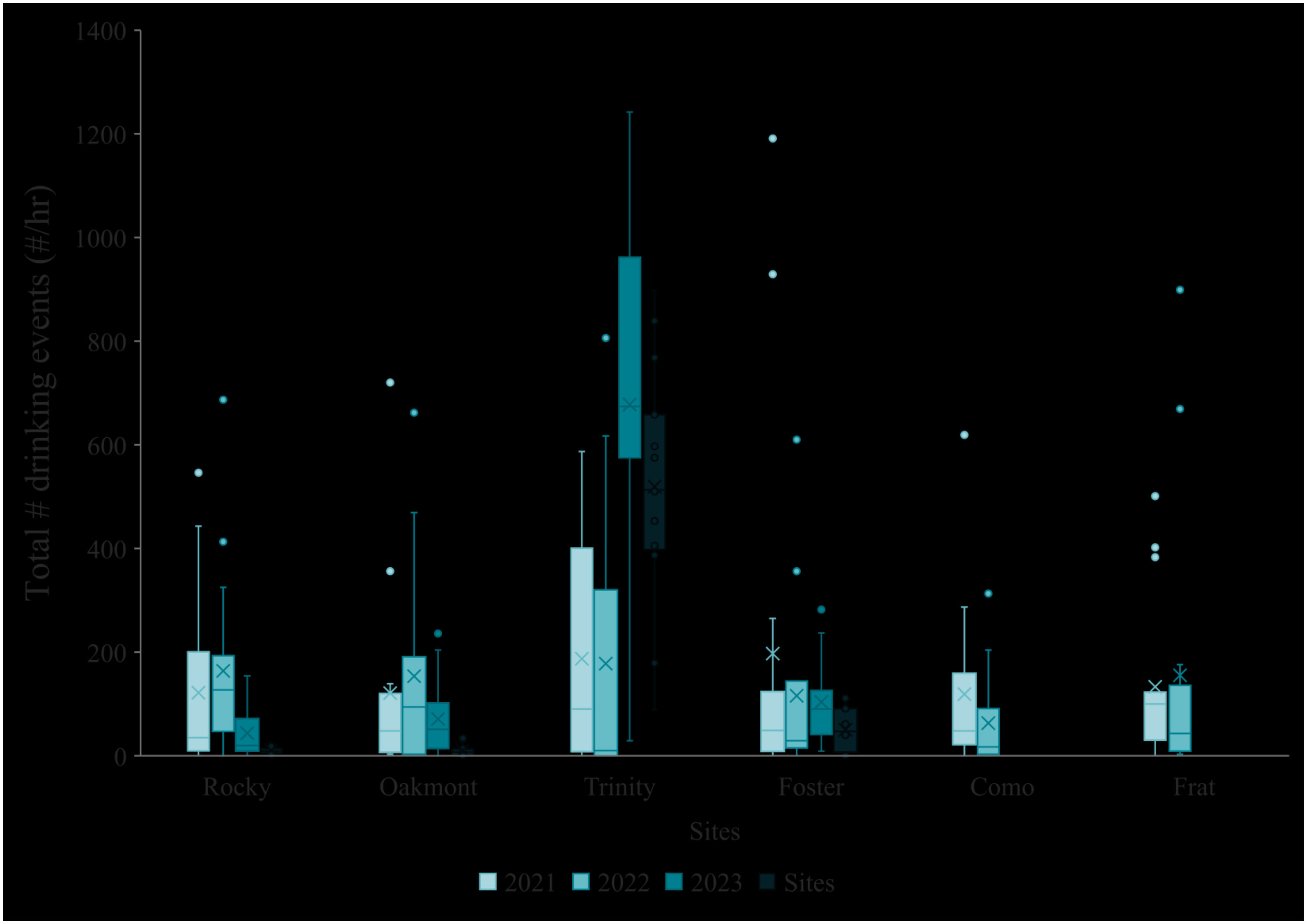


Figure 10: Number of bat calls recorded per night at Rocky Creek Park, Oakmont Park, Trinity Park Duck Pond, and Foster Park in 2021-2024, and Lake Como and Frat Pond in 2021-2022 in Tarrant County, Texas.

RESULTS

We successfully conducted behavioral observation and acoustic surveys at all six proposed survey sites from 23 March to 27 September 2021, 2 March to 21 September 2022, 8 March to 27 September 2023 and 4 March to 19 September 2024, for a total of ~60 1-hr surveys per site. We recorded bats to be present at all ponds and observed bats on 341 of the 351 surveys conducted. Among these surveys, we found that the total time bats were present in the field-of-view per pond per night averaged 67±173 SD sec (ranging from 0 sec to 32 min 9 secs). Lastly, we observed 2,418 drinking events across all six study sites on 183 of the 351 surveys conducted. For nights drinking occurred, the average drinking rate per pond per night was 7 ±15 SD (ranging from 1 to 108). From the acoustic surveys, we recorded 47,827 acoustic bat calls in proximity to the ponds in 322 surveys. We recorded an average of 138 ± 232 SD (ranging from 1 to 1,242) calls per pond per night and identified all 6 local bat species, although not all species were recorded at every pond surveyed. For instance, the hoary bat was only recorded at 2 of our 6 sites (Oakmont and Trinity Parks). On average this equated to 13 ±23 SD (ranging from 1 to 1,172) calls per species per pond per night. Across all ponds, we found that bat activity varied between the sites (Fig. 11) and over the bat activity season (Fig. 12).

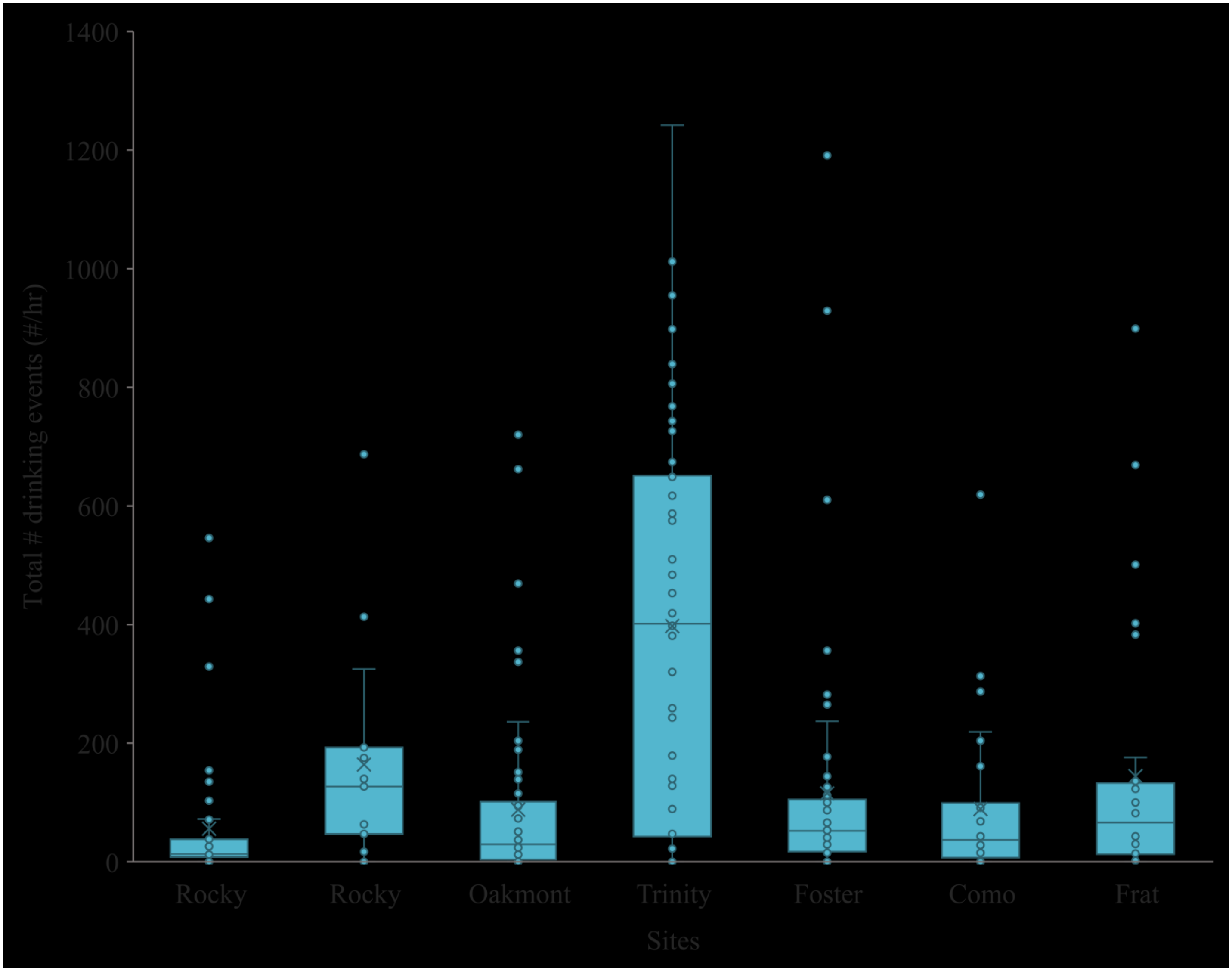


Figure 11: Number of bat calls recoded per night at Rocky Creek Park, Oakmont Park, Trinity Park Duck Pond, and Foster Park in 2021-2024, and Lake Como and Frat Pond in 2021-2022 in Tarrant County, Texas.

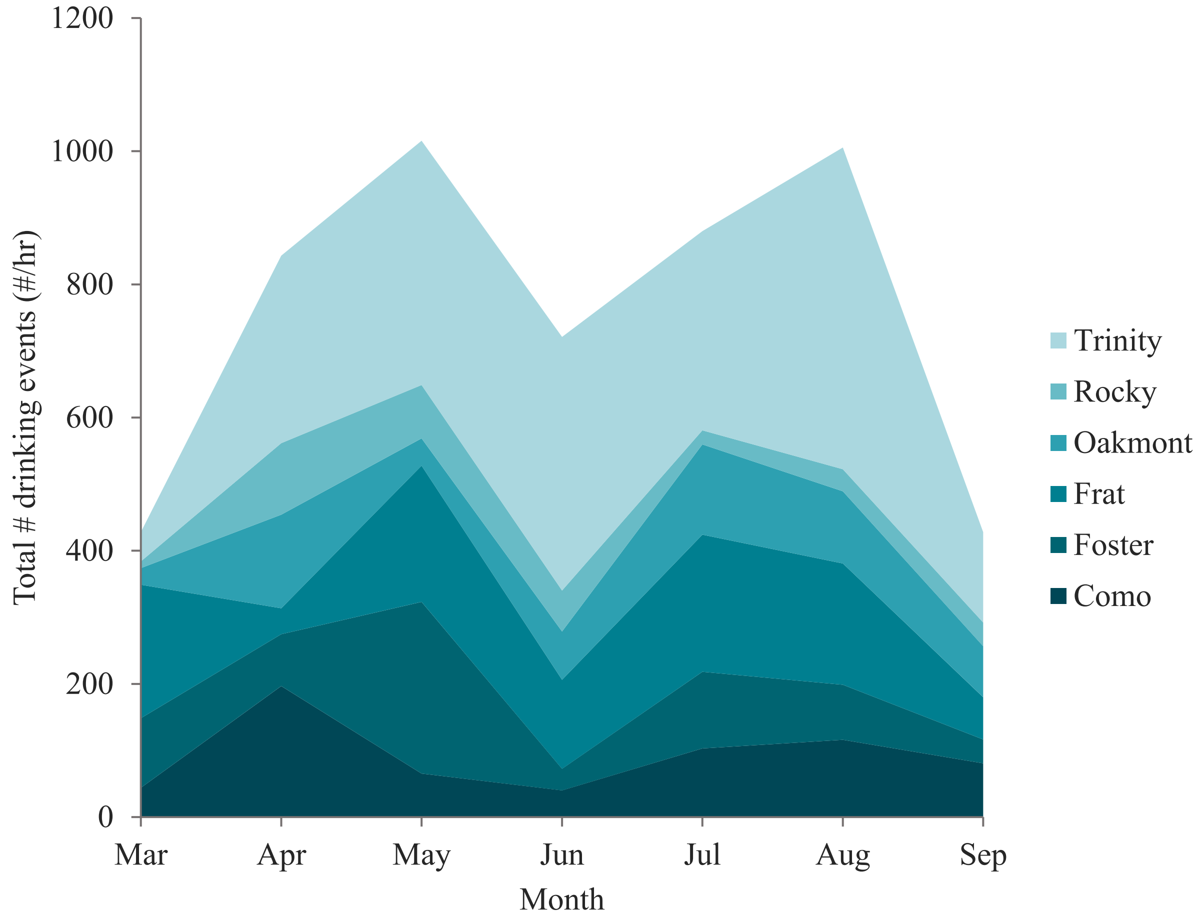


Figure 12: Number of bat calls recorded per night each month of the bat activity season at Rocky Creek Park, Oakmont Park, Trinity Park Duck Pond, and Foster Park in 2021-2024, and Lake Como and Frat Pond in 2021-2022 in Tarrant County, Texas.

From 28 February to 29 August 2023 and 26 February to 27 August 2024, we removed over two full 42-gallon trash bags of litter each month from the water at Lake Como and Frat Ponds for a total of 32 clean-ups (Fig. 13). A total of 10 volunteers from the TCU bat lab, 10 from the TCU Community Scholars Program, 11 from TCU Student Government Association and the TCU Honors College Community Service, and 58 from the TCU chapter of the One Shade Greener helped remove the trash from these two ponds monthly.

Figure 13: A collage of the clean-up process and average collection at each site.

Comparing the total time bats were observed in post-clean up with equivalent bat activity data collected in surveys conducted in pre-clean up, we found that more bats were observed among both of the ponds after litter was removed monthly during the bat activity season (Fig. 14). We confirmed that these observations were significantly higher (U=2592, P=0.004).

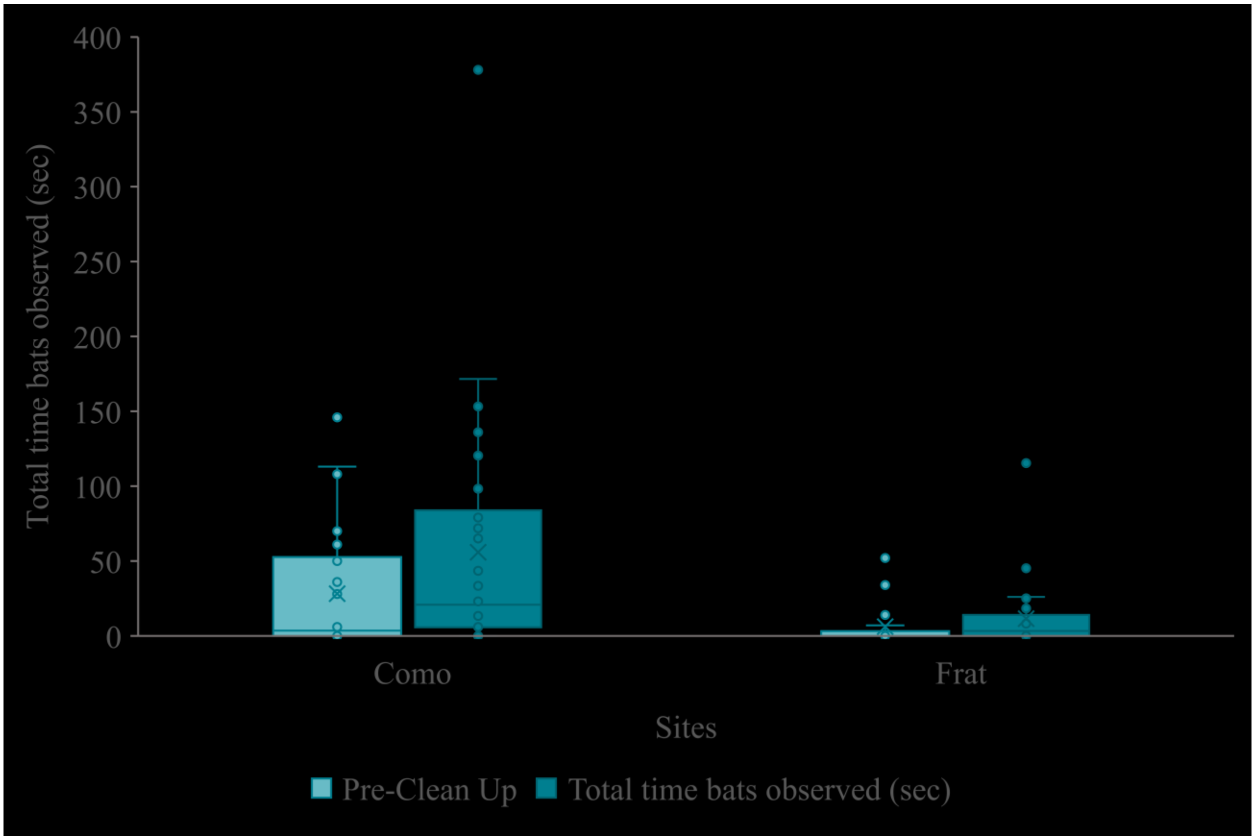


Figure 14: Total time bats were observed post-clean up (2023-2024) compared to with bats observed pre-clean up (2021-2022) at Lake Como and Frat Pond surveyed in Tarrant County, Texas.

Comparing the number of bats observed drinking per pond per night post-clean up with equivalent bat activity data collected in surveys conducted pre-clean up, we found that more bats were observed drinking at Frat Pond after litter was removed monthly during the bat activity season (Fig. 15). However, we confirmed that these observations were not significantly higher (U=784, P=0.254).

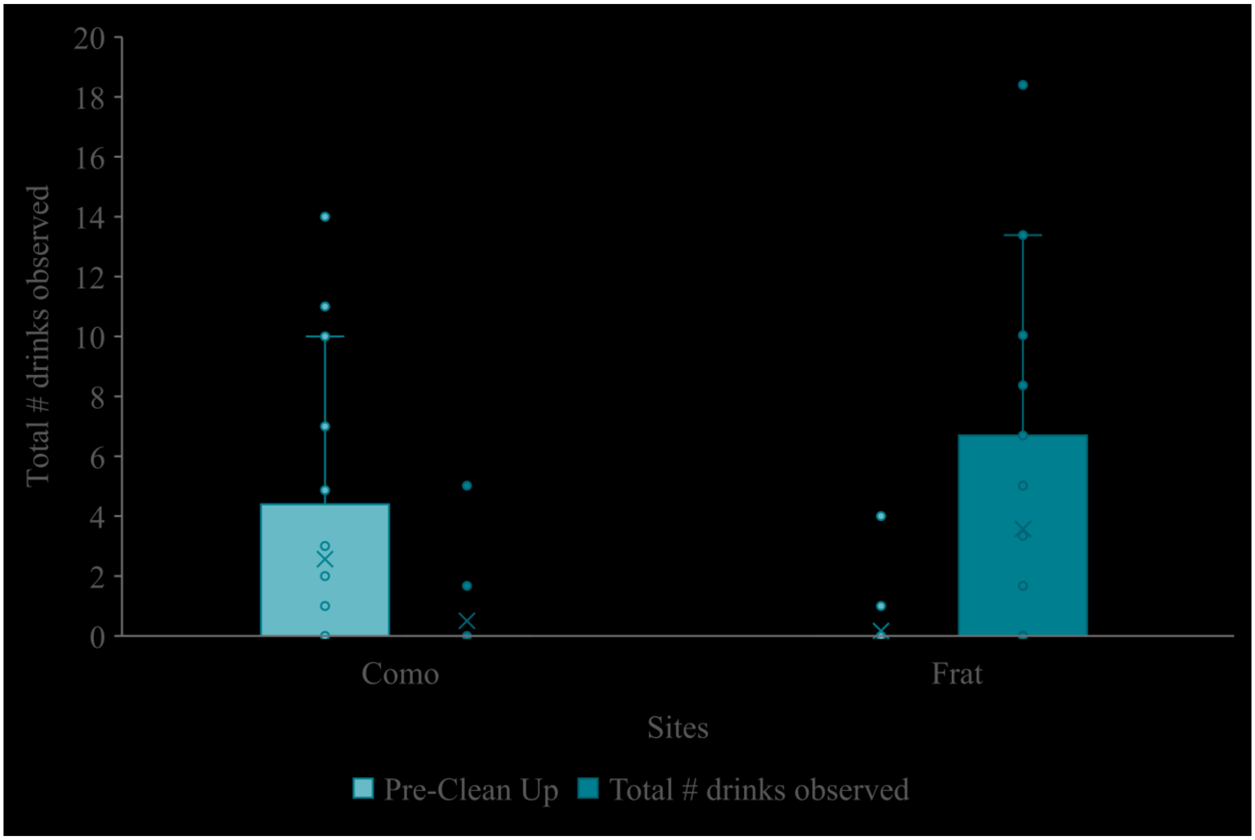


Figure 15: Total time bats were observed drinking per pond per night post-clean up (2023-2024) compared to with bats observed pre-clean up (2021-2022) at Lake Como and Frat Pond surveyed in Tarrant County, Texas.

Comparing the total number of species present post-clean up with equivalent bat activity data collected in surveys conducted pre-clean up, we found that more species were observed among the ponds after litter was removed monthly during the bat activity season (Fig. 16). We confirmed that these observations were not significantly higher (*U*=3149, *P*=0.803).

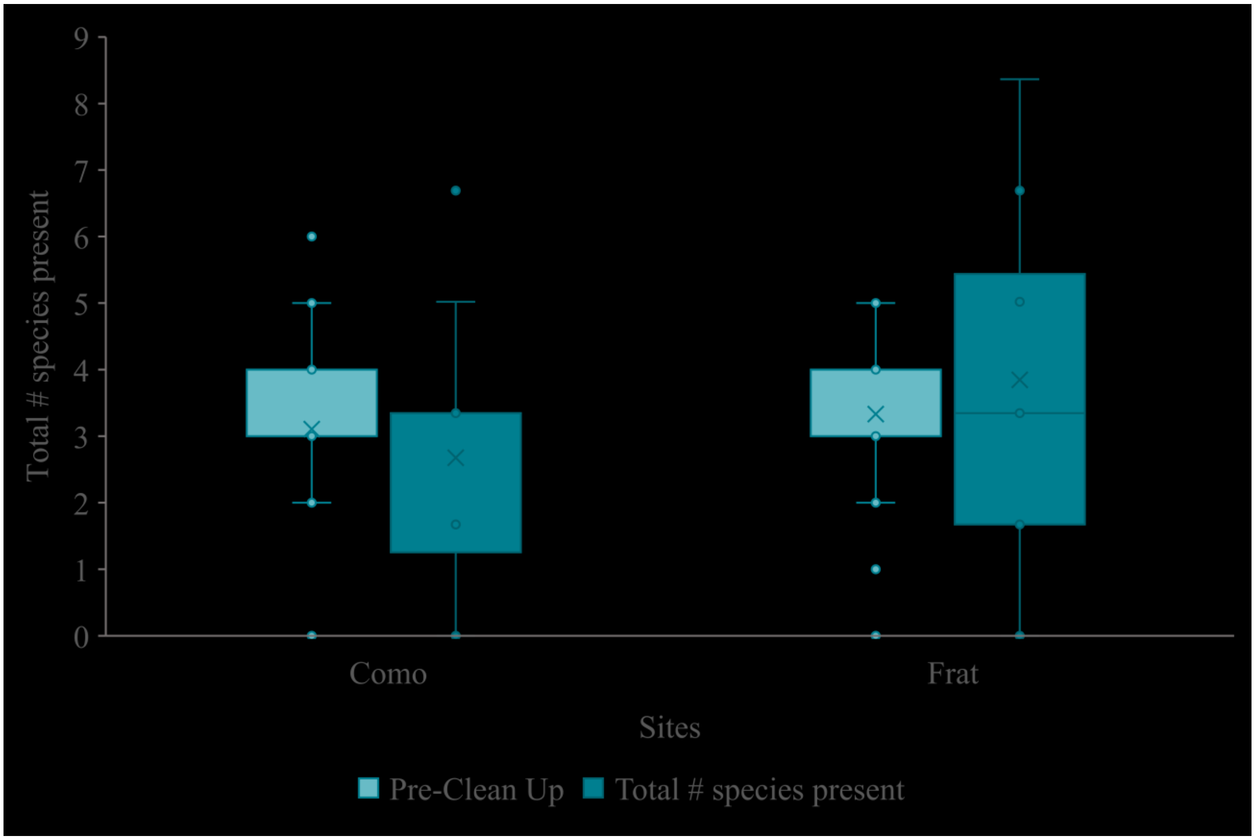


Figure 16: Total species of bats observed post-clean up compared to with bats observed pre-clean up at Lake Como and Frat Pond surveyed in Tarrant County, Texas.

Comparing the total number of drinking calls recorded per species post-clean up with equivalent bat activity data collected in surveys conducted pre-clean up, we found that more drinking buzzes were recorded for both hoary and silver-haired bats in the post-clean up years, and for Mexican-free tailed bats at Lake Como (Fig. 17). We confirmed that these observations were significantly higher for these species (Tables 2 and 3).

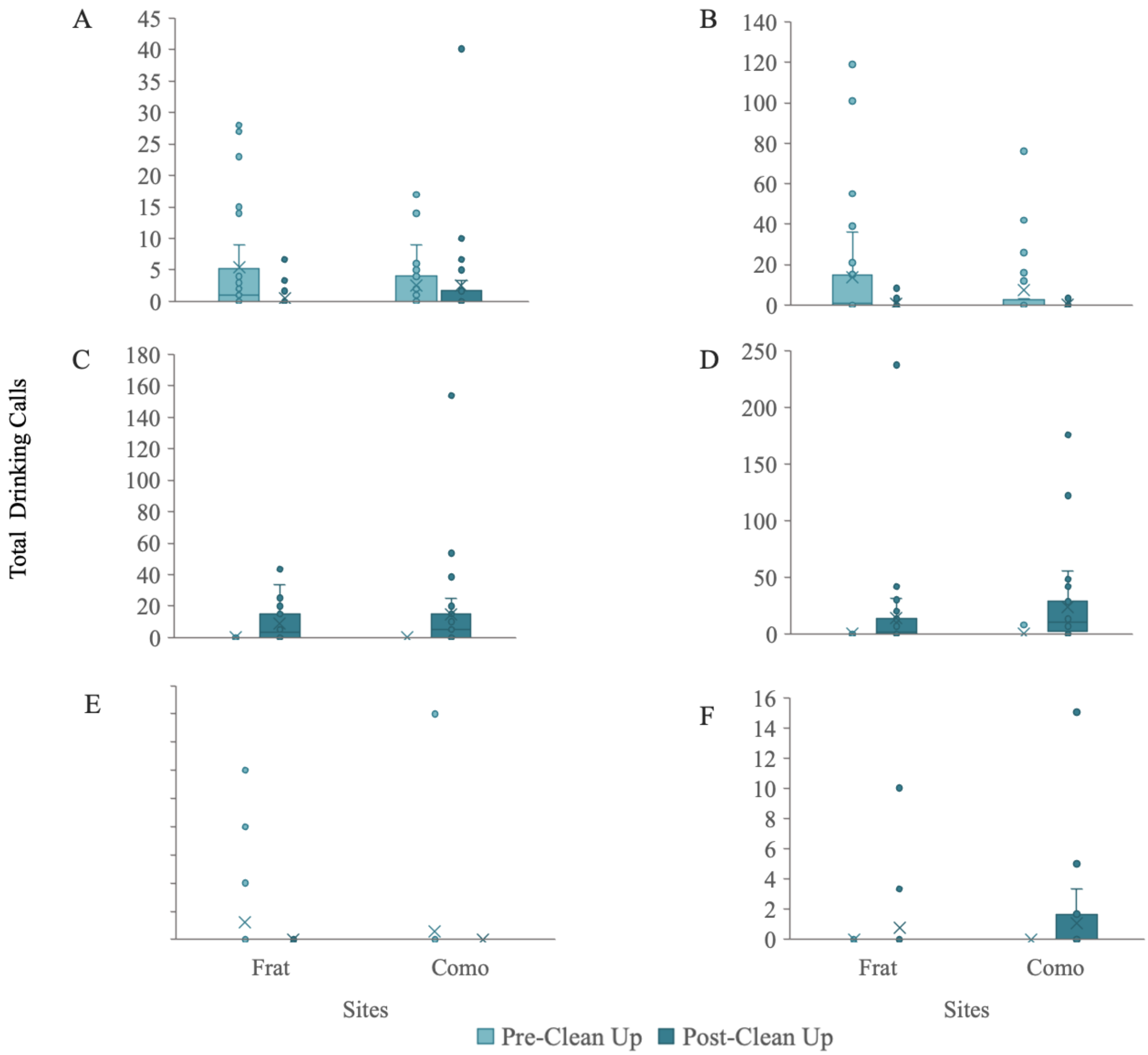


Figure 17: Total number of bat drinking calls per species (A) eastern red bat (*Lasiurus borealis*), (B) evening bat (*Nycticeius humeralis*), (C) hoary bat (*Lasiurus cinereus*), (D) silver-haired bat (*Lasionycteris noctivagans*), (E) tricolored bat (*Perimyotis subflavus*), and (F) Mexican free-tailed bat (*Tadarida brasiliensis*) recorded post-clean up (2023-2024) compared to with bats observed pre-clean up at Lake Como and Frat Pond surveyed in Tarrant County, Texas.

Table 2: Mann-Whitney U test results comparing bats observed drinking per species post-clean up with observations pre-clean up at Lake Como in Tarrant County, Texas. * shows significance.

Species	**Change Post-Clean Up**	***U*-value**	***P*-value**
Eastern red bat (*Lasiurus borealis*),	Decrease	885.00	0.002*
Evening bat (*Nycticeius humeralis*)	Decrease	814.00	0.021*
Hoary bat (*Lasiurus cinereus*)	Increase	586.00	0.006*
Silver-haired bat (*Lasionycteris noctivagans*)	Increase	478.00	0.000*
Tricolored bat (*Perimyotis subflavus*)	No significant difference	718.00	0.452
Mexican free-tailed bat (*Tadarida brasiliensis*)	Increase	611.00	0.020*

Table 3: Mann-Whitney U test results comparing bats observed drinking per species post-clean up with observations pre-clean up at Frat Pond in Tarrant County, Texas. * shows significance.

Species	**Change Post-Clean Up**	***U*-value**	***P*-value**
Eastern red bat (*Lasiurus borealis*),	Decrease	1100.5	0.000*
Evening bat (*Nycticeius humeralis*)	Decrease	1083.00	0.001*
Hoary bat (*Lasiurus cinereus*)	Increase	675.00	0.003*
Silver-haired bat (*Lasionycteris noctivagans*)	Increase	723.00	0.004*
Tricolored bat (*Perimyotis subflavus*)	No significant difference	963.50	0.159
Mexican free-tailed bat (*Tadarida brasiliensis*)	No significant difference	840.00	0.305

DISCUSSION

Our study revealed that community-based clean-up schemes at water sources in neighborhood parks can benefit bat presence, resource use, and species drinking activity. Overall, we found that bat presence increased by 90% at Lake Como and 48% at Frat Pond, and observed that drinking only increased at Frat Pond, when these water sources were cleared of litter regularly. In fact, Frat Pond had no records of bats drinking at the site until a clean-up scheme was initiated. These results parallel equivalent studies highlighting the benefits of clear, litter-free water sources for wildlife, especially in urban and semi-urban environments where such resources are limited and more susceptible to litter accumulation (Ciechanowski 2002; Tuttle *et al.* 2006; Greif and Siemers 2010; Nyberg *et al.* 2023).

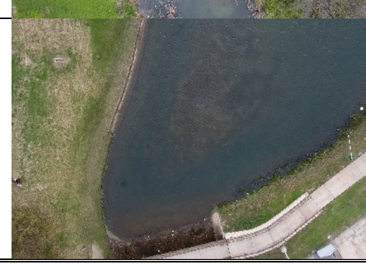
Our study also revealed that resource use was species- and site-specific, with some species benefitting more from litter removal than others. More specifically, we observed more silver-haired and hoary bat drinking activity at both sites post clean-up. At Lake Como drinking increased 109-fold and 16-fold increase for these species, respectively. We also observed an increase in Mexican free-tailed bat drinking at Lake Como, but not Frat Pond. In contrast, drinking activity decreased by >90% for eastern red and evening bats at both sites. On further analysis, we posit that these species-specific differences are likely being driven by wing morphology and associated maneuverability.

Of our six local species, the three that appeared to benefit from the clean-up scheme represented the larger and less maneuverable species. For instance, hoary bats are not only the second largest species of bat in the United States, they are known to be open-space flyers with wing morphology comprising high aspect ratios and wing loading (Rolseth *et al.* 1994). These features indicate that hoary bats have low maneuverability and avoid flying in cluttered environments, preferring to commute over the top of canopies (Norberg and Rayner 1987; Jung *et al.* 1999; Menzel *et al.* 2005). Similarly, Mexican-free tailed bats are our second largest bat out of the six local species, and again, open flyers due to their relatively high aspect ratio and wing loading (Iriarte-Díaz *et al.* 2002). Known for their fast, long-distance flying in open environments, they are particularly maladapted to cluttered environments. For example, during Hurricane Harvey in 2017 increasing flood water under the Waugh Bridge in Houston, Texas led to an estimated 5,000 Mexican free-tailed bat fatalities. These bats were unable to effectively escape from their roost under the bridge once water levels started raising, as they did not have the clearance they needed (McSweeny and Brooks 2022). Lastly, silver-haired bats represent the third largest local bat species and while they are considered edge-specialists they typically avoid cluttered environments.(Rogers *et al.* 2022). With moderate wing loading, they forage along canopy edges, but are not as maneuverable as smaller bat species due to their higher aspect ratio (Norberg and Rayner 1987; Kunberger and Long 2022).

This species-specific trend is further highlighted when comparing the total number of drinking buzzes recorded before and after litter removal at both study sites. Notably, hoary and silver-haired bats were either absent or recorded in single digits before litter was removed (n = 0 and 8, respectively, at Lake Como; n = 0 and 3, respectively, at Frat Pond). Post-cleanup, the number of drinking buzzes increased substantially at both sites (n = 94 and 313, respectively, at Lake Como; n = 59 and 220, respectively, at Frat Pond). Moreover, litter removal at Lake Como appeared to enhance water resource use for these two species more than at Frat Pond. As noted earlier, site-specific factors likely influenced these results. One key difference is size: the surveyed section of Frat Pond was 57% larger than Lake Como (Table 4). As Lake Como is smaller and more enclosed, this may have exacerbated the impact of litter accumulation, particularly for these species that are more sensitive to clutter.

In contrast, our smaller local bats, the eastern red, evening, and tri-colored bats, are all edge-space foragers that are adapted for flight in semi-cluttered environments. For instance, eastern red and tricolored bats have moderately low aspect ratios and lower wing loading that allow them to be more maneuverable in flight than the silver-haired bat (Canals *et al.* 2005; Hoofer *et al.* 2006). Evening bats, on the other hand, have similar aspect ratios to silver-haired bats, but have lower wing loading, indicating that they have greater maneuverability as they fly through tree canopies rather than along their edges (Jones 1967). Based on these three species' wing morphology and flight capabilities, contrary to our results we would not expect to observe a decrease in drinking activity once litter had been removed. However, this outcome is likely to be an artifact of our survey technique. We selected a 10 m by 10 m field-of-view for our thermal cameras that focused on the largest part of the water source at each site, which did not necessarily encompass the edge of the water and subsequent tree-lines. Small edge flyers, such as eastern red and evening bats, have a higher perceived risk of predation and are therefore more likely to access resources in proximity to features that offer cover (Mikula *et al.* 2016). However, when required resources are unavailable near edges, potentially due to the presence of clutter, edge flying bats may resort to utilizing less preferred, lower-quality, or higher-risk alternatives, such as sections of a water source in open areas (Mekonen 2020; Vásquez *et al.* 2020). This compensatory behavior could explain the decrease in observed drinking activity recorded post-clean up, as the removal of litter that had accumulated around the edges of the site likely shifted their drinking activity toward the now clutter-free edges and away from the open area within our field-of-view.

Table 4: Variations between the six study sites surveyed in Fort Worth, Texas, including size of site at capacity, type of water source, and aerial view taken by Peyton Harper using an unmanned aerial vehicle.

	Description	Aerial view
Rocky Creek Park	***Size at capacity (m^2):*** 3,600 m^2 ***Type***: River tributary	
Oakmont Park	***Size at capacity (m^2):*** 440 m^2 ***Type:*** River	
Trinity Park Duck Pond	***Size at capacity (m^2):*** 851 m^2 Type: Recreational pond	
Foster Park	***Size at capacity (m^2):*** 1,200 m^2 ***Type***: Retention pond	
Lake Como	***Size at capacity (m^2):*** 800 m^2 ***Type:*** Recreational lake	
Frat Pond	***Size at capacity (m^2):*** 1,400 m^2 ***Type:*** Retention pond	

While our study demonstrates a clear pattern of increased water resource use following litter clean-ups, several limitations should be considered. First, distinguishing the effects of litter removal from natural seasonal variation in bat activity can be challenging, as bat populations naturally fluctuate, potentially influencing the results. To address this, we recommend that future surveys focusing on specific variables (such as litter removal, water quality, or surface area) carefully account for seasonal variations and the potential interactions among multiple environmental factors.

Our study also highlights the impact any form of clutter on water resource use by bats. We, therefore, recommend that further research consider and explore other types of clutter that can fragment and degrade water resources, such as floating platforms, fountains, increasing algae blooms, and encroachment by surrounding vegetation. Similarly, future studies should also investigate the role of artificial lighting, noise, and other urban factors (Bunkley *et al.* 2015; Cravens and Boyles 2019; Zou *et al.* 2024), which all have the potential to degrade resource quality and subsequently limit their availability and accessibility.

CONCLUSION

The findings of this study suggest that community-based clean-up schemes can support local bat populations by effectively improving water resource accessibility (e.g., increasing drinking activity). By acknowledging the impact of litter in urban water bodies, we can better understand the extent to which clutter influences essential resource use by bats. Moreover, bats may serve as indicators of water availability for other urban wildlife species and provide valuable insights into the ecological health of local parks and adjacent neighborhoods. This understanding can aid in identifying and prioritizing areas of environmental concern in Fort Worth and other urban areas across the United States. Lastly, our study not only informs local wildlife conservation strategies, but also contributes to broader human and community health initiatives.

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