THE USE OF SWIMMING POOLS BY BATS IN A GAME RESERVE IN SOUTH AFRICA

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INTRODUCTION

Bats play an important role in ecosystems globally as they provide an array of essential services, including but not limited to, pollination (Tremlett et al. 2019), seed dispersal (van Toor et al. 2019), and pest control (Sow et al. 2020). For example, by suppressing stinkbugs bats save the macadamia industry in South Africa between $59 and $139/ha in agricultural damages (Taylor et al. 2017). Bats also contribute to local economies through ecotourism (Wiederholt et al. 2015). The bats in Carlsbad Caverns in the U.S., for instance, have an annual ecotourism value in excess of $3 million (Wiederholt et al. 2015). Moreover, the abundance and diversity of bats in an area are a good indicator of ecosystem health (Jones et al. 2009, Park 2015). In fact, many studies have shown that areas containing any taxonomic assemblages (such as invertebrates, birds, plants, fungi, fish, or mammals, particularly small mammals like bats) with a high diversity of both generalist and specialist species demonstrates a healthy, stable, and often structurally complex ecosystem (Sverdrup-Thygeson et al. 2017, Chisté et al. 2018, Mills et al. 2019). For example, a forest habitat with trees across a wide variety of age classes can support a high diversity of bird species (Edworthy et al. 2018). In other words, the more heterogeneous and complex the environment, the greater the variation in resources, which in turn means the area can support a larger number of species. Thus, for an area to support an abundant and diverse bat community, it must provide species-specific resources, such as roosting sites, foraging opportunities, water sources, mating opportunities, and movement corridors to access the aforementioned resources for a variety of bat species (Wilde et al. 2018, Cortes & Gillam 2020, Frick et al. 2020).

It is generally acknowledged by conservation practitioners that natural habitats tend to represent resource rich areas, with semi-natural habitats, in comparison, providing inferior and/or limited resource opportunities (Cassel et al. 2019). For example, the diversity and abundance of bee species in an ecosystem has been found to be positively correlated to the amount of natural habitat in the area (Spiesman et al. 2017). Conversely, the presence of semi-natural habitats in anthropogenically-dominated landscapes can substantially increase local species abundance and diversity. For instance, the preservation of semi-natural habitat benefits buff-tailed bumble bee (*Bombus terrestris*) colonies by increasing their access to a greater variety of flowering plants (Proesmans et al. 2019). Other studies have shown that species are capable of effectively using anthropogenic features in semi-natural environments as alternatives to their natural resources (Thomas & Jung 2019, Dammhahn et al. 2020). For example, a cave represents a natural resource used by roosting bats, while a wine cellar represents an anthropogenic equivalent (Baroja et al. 2019, Winter et al. 2020). Furthermore, some species, including a number of bat species, thrive in urban habitats (characterized here as non-natural) when they have been able to use such alternative resources (Páez et al. 2018, Nystrom & Bennett 2019). Given these findings, perhaps an ecosystem does not need to be entirely natural for it to support a high abundance and diversity of species, as is currently assumed. We, therefore, posed the question “Is it possible for anthropogenic features to enhance semi-natural or even natural habitats for bats?”

Typically, natural resources tend to represent the classic or traditional resources, defined here as resources that are preferentially selected by a specific species and it is only when these resources are unavailable or limited that a species will seek to use a less preferable option or alternative (Arias et al. 2020). For instance, the presence of an interconnected tree canopy is crucial to bats, particularly when they are commuting, because it reduces their risk of predation (Zurcher et al. 2010, Bennett & Zurcher 2013, Sieradzki & Mikkola 2020). In natural habitats, foraging and commuting bats are associated with forest edges, riparian corridors, and woodland glades (Angell et al. 2019, Trubitt et al. 2019). Yet in urban environments, bats can forage and commute effectively along tree-lined roads, hedgerows, the edges of wooded parkland, fence-lines, and even walls (Angell et al. 2019, Sołowczuk 2019, Martínez-Fonseca et al. 2020). These features offer a source of food (e.g., prey items) and function (i.e., provide cover) in a way that is akin to natural resources (Garland & Markham 2007).

To select suitable resources, animals depend on a combination of learned and innate criteria to establish resource quality and preference (Nielsen et al. 2013, Lillie et al. 2018). For example, rainbow trout (*Oncorhynchus mykiss*) that have never been exposed to predators, innately display antipredator behaviors, such as shoaling and sheltering (Mikheev et al. 2019). In contrast, Russel et al (2017) found that the common eastern bumble bee (*Bombus impatiens*) showed no innate preference for specific flowering plant species from which to collect pollen, but learned to select flowers with a higher abundance of pollen based on their color (Russell et al. 2017). Flower color represents a search criteria or perceptual cue, and animals may use one or more of these to select habitat, shelter, food items, water sources, and even mates (Gibson & Cocroft 2018). These criteria or cues can be visual characteristics, such as color, size, and shape (Kheradmand et al. 2018), but they can also be auditory (Niu et al. 2019), olfactory (Sörensen et al. 2019), tactile (Goller et al. 2017), and magnetic (Nyqvist et al. 2020).

If a habitat or resource meets the specific ‘search’ criteria of a species, they are deemed suitable. Thus, anthropogenic structures that fulfill these criteria could be selected by individuals. For example, rivers, streams, lakes, ponds, and even puddles are considered to be traditional water sources for bats; however, studies have shown that bats can drink at artificial reservoirs, wastewater treatment works, ornamental ponds, retention ponds, drainage ditches, cattle troughs, and even residential swimming pools (Hall et al. 2016, Korine et al. 2016, Russo et al. 2017, Nystrom & Bennett 2019, Agpalo 2020, Nelson & Gillam 2020). The use of these types of water resources indicates that they meet the search criteria by which bats select their water sources.

To date, the use of anthropogenic resources by wildlife in natural and semi-natural habitats is largely unknown (Korine et al. 2016) and there are few studies that suggest that anthropogenic features could improve or enhance such areas for wildlife (Newton et al. 2017, Switalski & Bateman 2017). Where species or communities of conservation concern are involved, any improvements to their habitats, whether it be natural or non-natural, could be of benefit to their persistence or recovery. Thus, the aim of this study is to assess the potential benefits of alternative resource use by wildlife in natural and semi-natural environments. We, therefore, conducted a study to explore the importance of artificial waters sources for wildlife in a semi-natural habitat. More specifically, we explored the species-specific use of swimming pools, as a foraging and drinking resource by bats in a game reserve in the Eastern Cape of South Africa. Our objectives included determining if bats were using these anthropogenic features as resources, if that resource use was related to foraging or drinking, if there were species-specific differences in pool usage, and if there were temporal differences in nightly and seasonal species-specific pool use.

The arrival of European colonists in 1652 resulted in the removal of nearly all natural grassland and savanna habitats in South Africa, which were replaced with cattle grazing pastures and agricultural fields (Russell & Ward 2016, Oliver & Oliver 2017). However, since the 1980s, South Africa, and the Eastern Cape in particular, has experienced a considerable amount of land-use change driven by the rapid shift from livestock farming to an expanding ecotourism industry (Achieng et al. 2020). To support the shift toward ecotourism-focused game reserves, many agricultural areas were encouraged to revert back to semi-natural habitats (Achieng et al. 2020).

The majority of these reserves are now managed specifically for their charismatic megafauna, such as the lion (*Panthera leo*), elephant (*Loxodonta africana*), Cape buffalo (*Syncerus caffer*), African leopard (*Panthera pardus pardus*), black rhinoceros (*Diceros bicornis*), and white rhinoceros (*Ceratotherium simum*; Hausmann et al. 2017). Despite this form of management, the complexity and diversity of habitats within these game reserves, along with their continued reversion to a more natural state, are likely to be dependent on the presence and abundance of naturally colonizing smaller species, such as bats. Thus, if bats are using swimming pools at tourist accommodations on game reserves, we hypothesize that the presence of such alternative resources would increase overall water availability in the area for bats. By demonstrating that the presence of anthropogenic features in semi-natural habitats could be of value to bats, this study may provide some of the first insights into how such features could be used to enhance game reserves and other semi-natural habitats for wildlife, thereby improving ecosystem health and stability.

METHODS

Study Area

This study was conducted on Amakhala Game Reserve in the Eastern Cape of South Africa (33°32′05.07″ S; 26°05′13.05″ E; Fig. 1). The game reserve is approximately 90 km north-east of Port Elizabeth and 42 km south-west of Grahamstown. In 1999, eight privately-owned lands, previously used for livestock farming were converted by the owners into a joint conservation venture (Achieng et al. 2020). Since this venture was formed, the area has been allowed and encouraged to return to a semi-natural thicket and savannah state. Amakhala Game Reserve now consists of ten properties comprising a total area of 85 km^2 with multiple vegetation types, including Kowie thicket, Mesic succulent thicket, coastal thicket, Karroid shrubland, savanna grassland, and open grassland (Fig. 2). These habitats are representative of the natural Albany Thicket Biome that formerly occurred in the area. This biome is predominately composed of subtropical thicket communities of spinescent shrubs, woody creepers, tall woody shrubs, geophytes, succulents, and various grass species (Smit et al. 2016, Gwate et al. 2018, Duker et al. 2020). Within the game reserve, there are several water sources that are available for wildlife, including the Bushman’s River, which runs through the north east portion of the property, and a number of brackish watering holes primarily found in the south western portion of the reserve (Fig. 1; Zengeni et al. 2016).

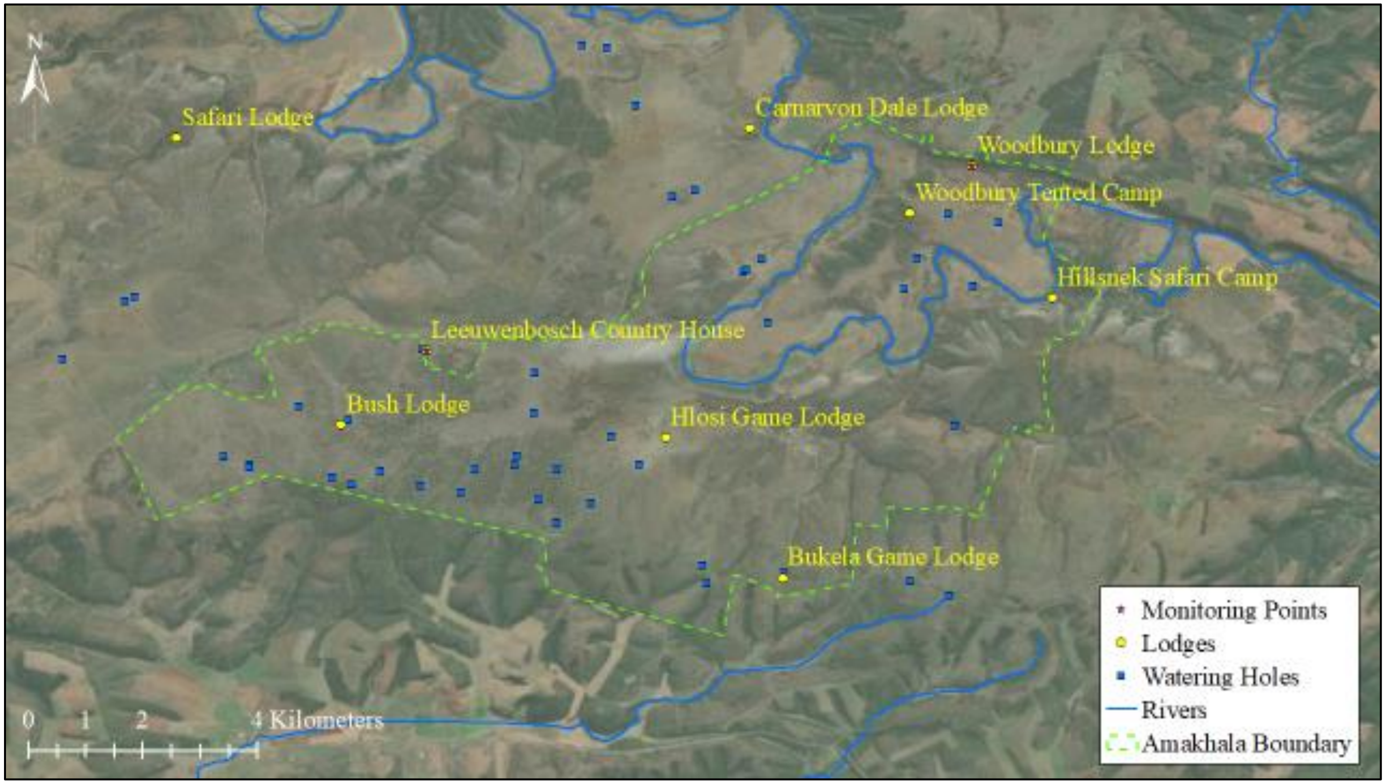

Figure 1: Map of Amakhala Game Reserve and surrounding area in the Eastern Cape of South Africa. Yellow points show the locations of tourist lodges with swimming pools, blue points indicate the locations of watering holes with in the reserve, and pink dots represent the locations of acoustic detectors at swimming pools.

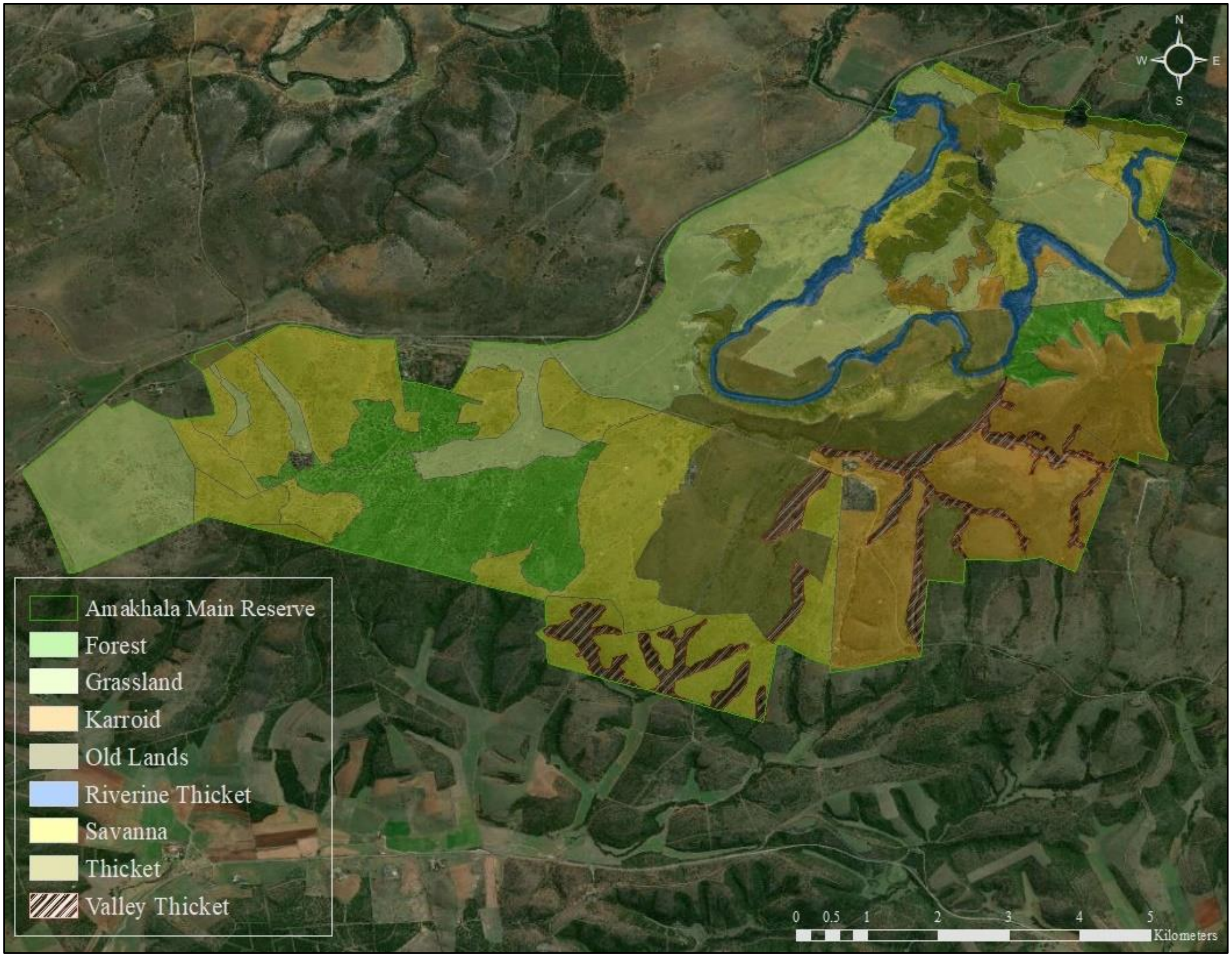

Figure 2: Map of vegetation types in Amakhala Game Reserve in the Eastern Cape of South Africa. Taken from Blanché (2021).

As an ecotourism-focused game reserve, the property manages populations of ostrich (*Struthio camelus),* cheetah (*Acinonyx jubatus*), lions, elephants, Cape mountain zebra (*Equus zebra zebra*), common warthog (*Phacochoerus africanus*), hippopotamus (*Hippopotamus amphibius*), South African giraffe (*Giraffa camelopardalis giraffa*), Cape buffalo, and several species of antelope, including common eland (*Taurotragus oryx*), greater kudu (*Tragelaphus strepsiceros*), gemsbok (*Oryx gazella*), waterbuck (*Kobus ellipsiprymnus*), black wildebeest (*Connochaetes gnou*), red hartebeest (*Alcelaphus buselaphus caama),* blesbok (*Damaliscus pygargus phillipsi*), impala (*Aepyceros melampus*), and springbok (*Antidorcas marsupialis*).

In addition, many smaller species from various taxonomic groups have naturally colonized within or migrated through the reserve, including birds, invertebrates, reptiles, amphibians, and mammals (Table 1). Some more common residents include the Cape girdled lizard (*Cordylus cordylus*), leopard tortoise (*Stigmochelys pardallis*), African darter (*Anhinga rufa*), pale chanting goshawk (*Melierax canorus*), red-necked spurfowl (*Pternistis afer*), three-banded plover (*Charadrius tricollaris*), giant kingfisher (*Megaceryle maxima*), pied kingfisher (*Ceryle rudis*), ant-eating chat (*Myrmecocichla formicivora*), common fiscal (*Lanius collaris*), bokmakierie (*Telophorus zeylonus*), Cape glossy starling (*Lamprotornis nitens*), red-billed oxpecker (*Buphagus erythrorynchus*), greater double-collared sunbird (*Cinnyris afer*), long-tailed widowbird (*Euplectes progne*), pin-tailed whydah (*Vidua macroura*), short-toothed blue butterfly (*Leptotes brevidentatus*), vervet monkey (*Cercopithecus pygerythrus*), black-backed jackal (*Canis mesomelas*), rock hyrax (*Procavia capensi*), aardvark (*Orycteropus afer*), Cape porcupine (*Hystrix africaeaustralis*), bushpig (*Potamochoerus larvatus*), springhare (*Pedetes capensis*), common duiker (*Sylvicapra grimmia*), bushbuck (*Tragelaphus sylvaticus*), black-backed jackal (*Canis mesomelas*), mountain reedbuck (*Redunca fulvorufula),* and yellow mongoose (*Cynictis penicillate*; Sinclair et al. 2011, Stuart & Stuart 2015, Branch 2016, iNaturalist.org 2020). While frequent migrants to the reserve include the African monarch butterfly (*Danaus chrysippus*), African migrant butterfly (*Catopsilia florella*), Eurasian buzzard (*Buteo buteo*), African hoopoe (*Upupa africana*), and African stonechat (*Saxicola torquatus*; Sinclair et al. 2011, Woodhall 2012).

As part of the tourist experience at the reserve, there are also ten lodges and camping facilities. Six of these facilities are located inside the reserve and four are in the surrounding area <4 km away. Nine of these facilities have swimming pools (Fig. 1 and Table 2) and Bush Lodge has additional plunge pools at each of its eight suites.

Table 1: Examples of species that have naturally colonized or migrate through Amakhala Game Reserve in the Eastern Cape of South Africa. Photos taken and provided by V. Bennett.

		
short-toothed blue (*Leptotes brevidentatus*)	vervet monkey (*Cercopithecus pygerythrus*)	black-backed jackal (*Canis mesomelas*)
		
yellow mongoose (*Cynictis penicillate*)	red-billed oxpecker (*Buphagus erythrorynchus*)	Cape glossy starling (*Lamprotornis nitens*)

Table 2: Descriptive summary of swimming pools or plunge pools at each of the lodges located within or near to Amakhala Game Reserve in the Eastern Cape of South Africa. Photos taken from www.amakhala.co.za/.

Lodge	Swimming Pool	Details
Bukela Game Lodge		*Shape*: Straight-edged *Dimensions*: 20 m^2 *Treatment*: Chlorine
Bush Lodge		*Shape*: Straight-edged *Dimensions*: 34 m^2 *Treatment*: Chlorine
		*Shape*: Straight-edged *Dimensions*: 2 m^2 *Treatment*: Chlorine
Carnarnvon Dale Lodge		*Shape*: Curved-edged *Dimensions*: 9 m^2 *Treatment*: Chlorine
Hillsnek Safari Camp		*Shape*: Straight-edged *Dimensions*: 36 m^2 *Treatment*: Chlorine
Hlosi Game Lodge		*Shape*: Straight-edged *Dimensions*: 20 m^2 *Treatment*: Chlorine

Lodge	Swimming Pool	Details
Leeuwenbosch Country House		*Shape*: Straight-edged *Dimensions*: 30 m^2 *Treatment*: Chlorine
Safari Lodge		*Shape*: Curved-edged *Dimensions*: 15 m^2 *Treatment*: Chlorine
Woodbury Lodge		*Shape*: Straight-edged *Dimensions*: 7 m^2 *Treatment*: Chlorine
		*Shape*: Straight-edged *Dimensions*: 20 m^2 *Treatment*: Chlorine
Woodbury Tented Camp		*Shape*: Curved-edged *Dimensions*: 13 m^2 *Treatment*: Chlorine
		*Shape*: Straight-edged *Dimensions*: 20 m^2 *Treatment*: Chlorine

Acoustic Surveys

For the main part of our study, we conducted a series of acoustic surveys at two of the lodges with swimming pools on the Amakhala Game Reserve; 1) Leeuwenbosch Country House and 2) Woodbury Lodge (Fig. 1 and Table 2). Acoustic detection of bat echolocation has emerged as the most commonly used method for surveying bats (Mac Aodha et al. 2018, MacEwan et al. 2020). This technique provides a practical and effective means to determine bat presence, bat activity patterns, identify resource use, and determine habitat quality (Frick 2013, Mac Aodha et al. 2018, Salvarina et al. 2018, Findlay & Barclay 2020). Acoustic detectors record the high frequency echolocation calls of bats that are active within ~35 m of a detector (Bakwo Fils et al. 2018). The calls not only can be used to identify species via the structure and frequency of the call, but also the type of activity being exhibited (Fig. 3; McAlexander 2013, Schimpp et al. 2018, Huzzen et al. 2020). Specific activities can be identified from four distinct call phases (Hulgard & Ratcliffe 2016, Bohn & Gillam 2018). The first phase is known as *commuting*, indicating that bats are travelling through an area on the way to another location (Bohn & Gillam 2018, Kerbiriou et al. 2019). For this activity, bats emit a series of pulses (or chirps) that coincide with the bats' downward wing strokes. Pulses are, therefore, seen to occur at regular intervals with the strength of the pulse steadily increasing as a bat gets closer to the detector, then steadily decreasing as it moves away. The second phase, known as the *search phase*, consists of consecutive pulses synchronized with wing beats, but the pulses vary in strength as the bat turns its head from side to side in search of, for example, prey (Kohles et al. 2020). The third phase is the *approach phase* and demonstrates either foraging activity or that a bat is approaching a static object or surface (i.e., when they are about to land at a roost site or come down to a water source to drink; Lewanzik et al. 2019, Stidsholt et al. 2020). In the *approach phase*, bats vary the interval between pulses (i.e., multiple pulses can occur in succession within a single wing beat as the bat pursues prey). Pulse strength tends to be constant, but the length of the frequency sweep (i.e., the range of frequencies (kHz) that occur within a pulse) increases as the bat gets closer. Finally, the presence of terminal buzz indicates that a bat has caught their prey, landed on a surface, or drank from the surface of water (Russo et al. 2016, Kloepper et al. 2019, Mayberry et al. 2019, Muñoz et al. 2019). These are known as feeding buzzes, landing buzzes, and drinking buzzes, respectively. For this *terminal buzz phase*, the pulse rate increases rapidly as the interval between successive pulses decreases (Hulgard & Ratcliffe 2016, Lewanzik et al. 2019). Thus, we can use feeding and drinking buzzes to ascertain whether bats are using swimming pools as a resource for either foraging and/or drinking.

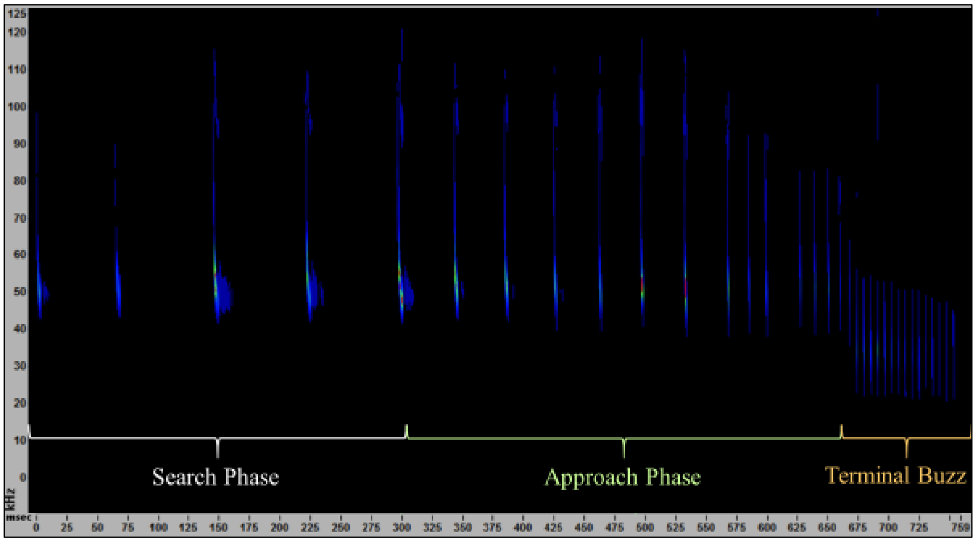

Figure 3: Spectrograph delineating the different ‘search’, ‘approach’ and ‘terminal buzz’ phases of activity observed in a bat echolocation call.

Acoustic monitoring, via passive detector surveys, is also a low maintenance method that can yield large amounts of data (Browning et al. 2017, Newson et al. 2017, Gibb et al. 2018). This technique involves using programmable ultrasonic acoustic detectors to collect large qualities of data unattended (Sugai et al. 2019). Passive acoustic detectors can be placed at a select location and left for up to a month, depending on battery life and data storage capabilities. Thus, we deployed passive detectors at the two study sites in Amakhala Game Reserve to collect year-round data on pool usage by various bats in the area. More specifically, we used SM4BAT FS acoustic bat detectors with an external U2 ultrasonic microphone from Wildlife Acoustics, Inc (Maynard, MA), designed to endure long-periods in the field with little maintenance. We placed one of these acoustic bat detectors at each study site in July 2018, where they remained until June 2021 (Fig. 4). Where possible, each detector was set up as close to the pool edge as possible (<10 m) with the microphone angled toward the pool.

Figure 4: Placement of acoustic detectors at A) Leeuwenbosch Country House and B) Woodbury Lodge swimming pools in Amakhala Game Reserve in the Eastern Cape in South Africa. Photo taken and provided by V. Bennett.

We set-up the detectors to record bat echolocation calls from 17:00 to 7:00, accommodating any variation in the timing of dusk and dawn, to ensure bat calls were recorded all year round. The detectors were set to trigger at frequencies between 10 kHz and 192 kHz with a 3-sec delay between recordings. We selected this range of frequencies to encompass the echolocation frequencies of known bat species within our study area (Monadjem et al. 2020). We also set the gain threshold at 12.0 dB with a trigger volume of 12.0 dB and any sound files were recorded in a 4-sec standard wav file (.wav) format. All files created were saved onto a 32 GB SD card with the sample rate at 256 kHz and rechargeable D-batteries were used to power the detectors. These SD cards and batteries were replaced each month, when possible.

Technicians in Amakhala downloaded all sound files recorded on the SD cards and made them accessible via Box (a file sharing software). We used a SonoBat Scrubber software (ver. 4, Sonobat^{TM}, Arcata, CA), which filtered out acoustic files containing noise (such as wind, rain, and stridulating insects). A ‘high call quality’ filter setting was applied to remove as many noise files as possible. Following this exercise, we first used Sonobat v. 3.4 bat call analysis software to manually confirm that the remaining sound files had bat echolocation calls within them. During this process, we initially grouped the calls into four activity-based categories; 1) approaching (see approach phase description above), 2) feeding buzz, 3) drinking buzz, and 4) other. Based on previous studies, we defined *feeding buzzes* as a sudden increase in pulse rate with the frequency range of the pulses shifting higher or lower collectively depending on species (Fig. 5A). In comparison, we defined *drinking buzzes* as a sudden increase in pulse rate with the frequency range of the pulses remaining similar to the search phase pulses often ending in a distinct splash as the bat touches the surface of the water, after which there is a characteristic silence before pulses resume (Fig. 5B; Russo et al. 2016, Kloepper et al. 2019, Agpalo 2020).

Next, we used the automated identification classifier for South African bats available in Kaleidoscope Pro Analysis Software (ver. 1.3.8, Wildlife Acoustics, Inc., Maynard, MA) to aid the identification of feeding and drinking buzzes to species. Species were then manually verified using Sonobat v. 3.4 bat call analysis software, as such automated software may have misidentified bat calls to species when call quality was low, there were multiple individuals of the same species present, or multiple species within a single call file (Frey-Ehrenbold et al. 2013, Lemen et al. 2015). For this manual identification, we used available call libraries, including those provided by Taylor (2000), Taylor et al. (2013), Monadjem et al. (2017), Monadjem et al. (2018), and Monadjem et al. (2020).

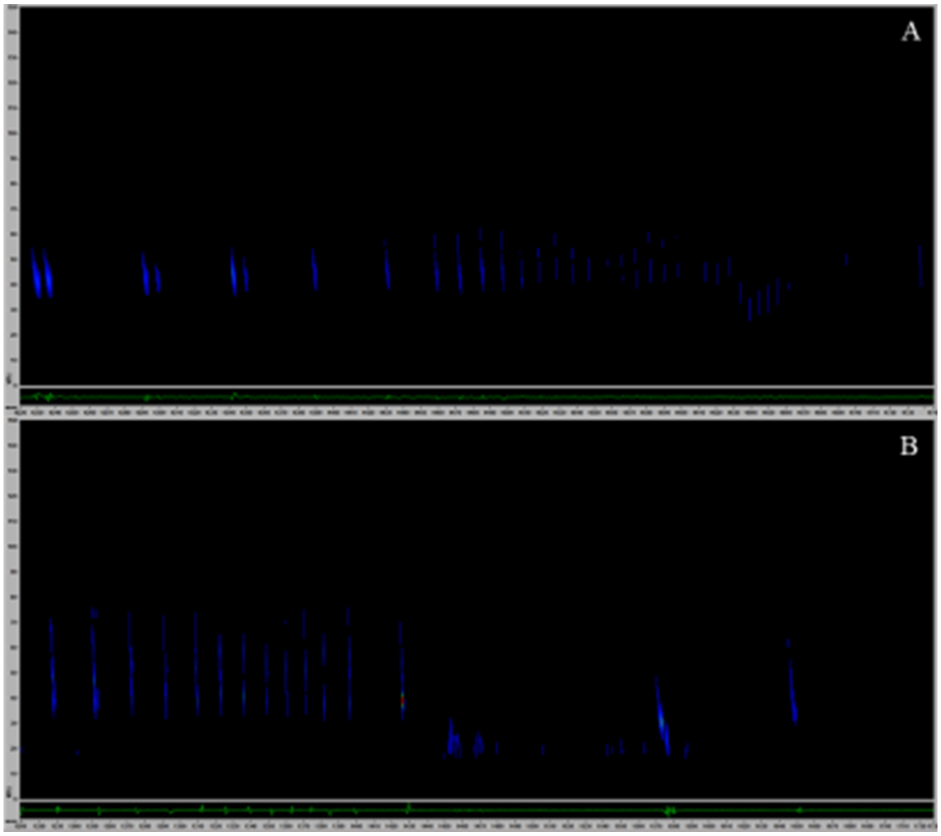

Figure 5: Spectrographs delineating the difference in structure between A) a feeding buzz and B) a drinking buzz emitted by a Cape serotine bat (*Neoromicia capensis*).

To further aid manual identification, we compiled a list of bat species that could be in our study area from the >70 bat species known to be in South Africa, including seven fruit-eating bat species and 65 insectivorous bat species (Taylor 2000). By also using sources, such as iNaturalist, an amateur naturalist reporting site (inaturalist.org), Taylor et al. (2013), Monadjem et al. (2017), and Monadjem et al. (2020), we confirmed that 23 of these bat species had distribution ranges that encompassed Amakhala Game Reserve and identified a further 11 species that could potentially be in the area. We then created an identification guide compiling information on the echolocation call characteristics of each of the 32 species (see Appendix A).

Once all calls were processed, we established a total of five dependent variables from the acoustic data. These included average number per survey night (i.e., the rate of calls recorded) of 1) bat calls, 2) approach phase calls, 3) feeding buzzes, 4) drinking buzzes, 5) and species-specific resources-related calls, which we defined as feeding buzzes and drinking buzzes.

Behavioral Observation Surveys

As the effectiveness of acoustic monitoring could have been influenced by a variety of factors, we conducted behavioral observation surveys to determine whether the placement of the SM4BAT FS acoustic detector (i.e., the distance from the pool) influenced the abundance of acoustic calls, activity, and species recorded. For example, as higher frequency bat calls attenuate more rapidly, feeding and drinking buzzes, which are often composed of short high frequency sweeps (Figs. 3 and 5), are less likely to be recorded effectively with increasing distance (Luo et al. 2014, Russo et al. 2016), hereafter referred to as activity bias. In addition, variations in the rate of attenuation across frequency ranges could also result in bats with high frequency echolocation calls being recorded less with increasing distance (Goerlitz 2018, Voigt et al. 2021), hereafter referred to as species bias. Finally, we conducted behavioral observations surveys to verify that the echolocation calls we associate with resource-related activity actually correspond with observed bat behaviors (i.e., a drinking buzz matched up with a bat making contact with the surface of the water).

Thus, in June 2021, we conducted behavioral observations at a swimming pool in Amakhala Game Reserve to verify whether foraging and drinking activity was effectively recorded in acoustic surveys. At Leeuwenbosch Country House (Fig. 1 and Table 2), we used an Axis Q1942-E 19mm ThermNetCam 30 FPS (Axis Communications, Lund, Sweden) thermal surveillance camera within the infrared spectrum of ~9,000-14,000 µm to observe bats actively flying in proximity to the pool located on this property. The thermal camera was set to the "Ice-and-Fire" false-color scheme setting (Fig. 6A), a resolution of 640 by 480 pixels, and a sampling rate of 30 frames per second. We positioned the camera ~10 m away from the pool with the lens angled to capture the entire surface of the pool in the field of view (Fig. 6B). To operate the thermal camera and record bat activity, we used a HP Compaq 8510w laptop computer via Ethernet cables and a Netgear ProSAFE 8-Port Fast Ethernet PoE Switch. The entire set up was powered by an available power source at the pool. Prior to each survey, we ensured that the time set on the SM4BAT FS acoustic bat detector at the pool (see *Acoustic Surveys* section above) was synchronized with the time set on the laptop, so that we could effectively match acoustic calls recorded with observed bat activity. In addition to the SM4BAT FS acoustic bat detectors present at the swimming pool, we used an iPad mini with an Echo Meter Touch ultrasonic microphone module from Wildlife Acoustics to record bat activity within 3 m of the surface of the swimming pool.

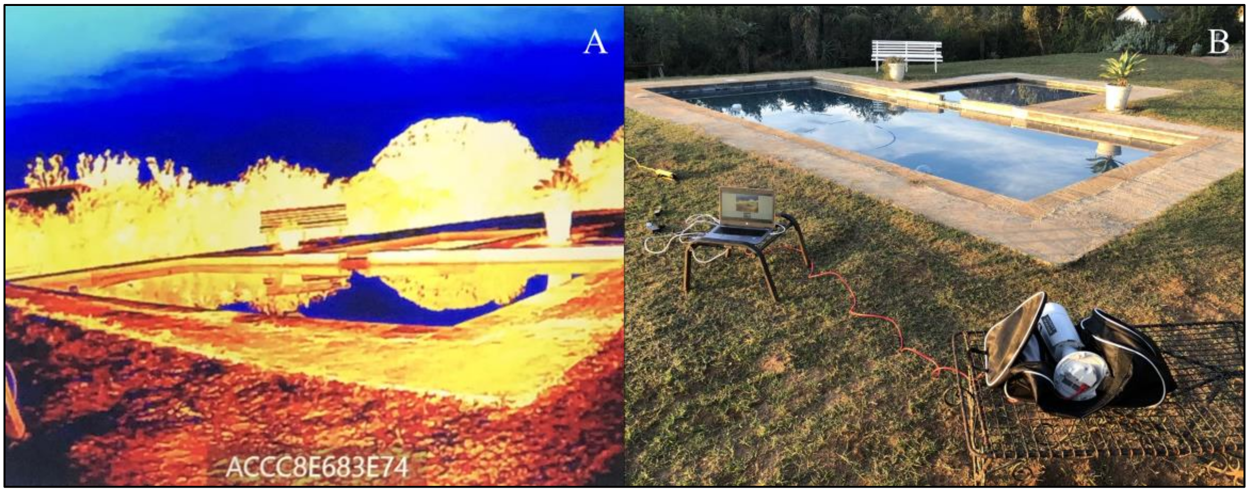

Figure 6: Behavioral observation survey A) thermal camera field of view and B) equipment set up at the swimming pool at Leeuwenbosch Country House in Amakhala Game Reserve.

At the start of each survey, we also recorded environmental conditions that could potentially influence bat activity, including temperature (°C), dew point (°C), humidity (%), barometric pressure (mb), wind direction (cardinal), average wind speed (km/h), wind gust speeds (km/h), moon phase, moon illumination (%), cloud cover (full, partial, or clear), and whether or not the moon was visible (Appendix B). To record these variables, we used two available apps: Weather Bug and Lunar Phase. All surveys were then undertaken 20 mins after sunset and lasted up to three hours. We selected this three-hour window, as preliminary analysis of the acoustic data showed that bat activity at the pool peaked during this time, which also supported the general consensus that bats are more likely to seek out water sources immediately after emergence (Korine et al. 2016).

Following each survey, we downloaded all footage recorded from the thermal camera and files were converted to .mp4 format using Prism Software (ver. 8.0.0, GraphPad Software, Inc., San Diego, CA). Once in .mp4 format, we used Vosaic video analysis software (ver. 1.1.3475, Nelnet, Inc., Lincoln, Nebraska) to identify and record the length of time individual bats were observed in the field of view. In addition, we marked and recorded any foraging behavior observed (i.e., the length of time individual bats were observed foraging in our field of view). For this, we defined foraging activity as a distinct zig-zagging flight in which bats make >2 changes in direction (i.e., turns) as they chased and captured prey (Huzzen et al. 2020). Finally, we marked and recorded the occurrence of drinking activity. More specifically, we counted the number of drinking events, defined here as a bat swooping down to the surface of the water with its body angled head-first towards the surface as it made contact with the water once or more as it passed over (Tuttle et al. 2006, McAlexander 2013, Kloepper et al. 2019). This activity often created ripples or a splash at the point of contact with the water, which we used to visually confirm contact (Kloepper et al. 2019).

Note that all acoustic files recorded on the SM4BAT FS and Echo Meter Touch during these surveys were processed as described above in the *Acoustic Surveys* section. Finally, to determine which species were observed using the swimming pool as a resource, we matched bats observed in the video footage with all resource-related acoustic calls identified to species that occurred within ±5 seconds of a bat flying into the field-of-view.

Analysis

Using this observational data along with acoustic data collected in these surveys from both the SM4BAT FS and Echo Meter Touch, we explored the location, activity, and species biases that could impact the frequency at which bats were recorded on the acoustic detectors and the effective identification of resource-related calls. To verify whether the bat detector was effectively recording bat activity over the swimming pool, we compared 1) the number of instances where bats were both observed actively flying in the field of view and acoustically recorded on the SM4BAT FS bat detector with 2) the number of instances bats were observed only. For this comparison, we used a two-tailed paired *t*-test and we applied the number of instances where bats were observed or acoustically recorded in 15 min intervals. We hypothesized that if the bat detector was not placed effectively (i.e., location bias), we would discern a significant difference between observed bat activity and the number of acoustic calls recorded. For example, if the microphone was not placed within an appropriate distance of the pool, we would observe more bats actively flying in the field of view with no corresponding acoustic call recorded. We then repeated this exercise using observed data and the acoustically recorded calls from the Echo Meter Touch. To further assess location bias, we compared the difference between number of bats observed with corresponding acoustic calls recorded on the SM4BAT FS (~10 m from the edge of the pool) with those observed and recorded on the Echo Meter Touch (3 m from the edge of the pool). Again, we used a two-tailed paired t-test.

To verify whether the bat detector was effectively recording specific foraging and drinking activity over the swimming pool, we first compared 1) the number of instances where bats were both observed foraging in the field of view and approach phase calls and feedings buzzes were recorded on the SM4BAT FS bat detector with 2) the number of instance bats were observed foraging only. Then we compared 1) the number of instances where bats were observed drinking in the field of view at the same time drinking buzzes were recorded on the bat detector with 2) the number of instances where drinking was observed only. Again, we used a two-tailed paired *t*-test to analysis the data. We hypothesized that if the bat detector was not placed effectively, we would observe a significant difference between observed foraging and drinking activity and acoustically recorded foraging and drinking activity (respectively; i.e., an activity bias). For example, if the microphone was not correctly angled towards the surface of the water or placed within an appropriate distance, we would observe more drinking events than drinking buzzes recorded.

To verify whether the bat detector was effectively recording species-specific bat activity over the swimming pool, we compared 1) the number of instances where bats were observed foraging or drinking in the field of view at the same time feeding or drinking buzzes were recorded on the SM4BAT FS bat detector for each species with 2) the total number of instances where bats were observed foraging or drinking only (note that these observations are not identified to species). We hypothesized that bat species with higher frequency echolocation calls, such as the Bushveld horseshoe (*Rhinolophus simulator*), would be recorded less often as their higher frequency calls (with a peak frequency of 80.1 ± 1.2 kHz) would attenuate faster, while more Egyptian free-tailed (*Tadarida aegyptiaca*) calls would be recorded as they have lower frequency calls (ranging from 20.5 to 38.3 kHz) that do not attenuate as quickly (Goerlitz 2018, Monadjem et al. 2020). As variations in species abundance may be a confounding variable driving the total number of bat observations and calls recorded, we conducted a Pearson's correlation to explore whether the number of feeding and drinking buzzes recorded when bats were observed was correlated to echolocation frequency (lo*f*).

Note that we conducted the analysis on the above behavioral observation data prior to the analysis of all the acoustic data at our two study sites. Subsequently, if any biases were confirmed, we were able to account for these accordingly when undertaking the acoustic survey analysis.

Analysis of Acoustic Monitoring Data

From the acoustic data collected, we investigated 1) if bats were using the swimming pools as a resource, 2) if bats were using the pools as a foraging resource specifically, 3) if they were using them as a drinking resource specifically, 4) whether specific pool use was species specific, 5) how nightly pool use varied overall and between species, and 6) how seasonal pool use varied overall and between species.

First, we used the presence of approach phase calls along with all terminal buzzes (i.e., resource-related calls) recorded to confirm whether bats were using swimming pools at the lodges in Amakhala Game Reserve as a resource. We then used the presence of feeding and drinking buzzes, specifically, to confirm whether bats were using the pools as a foraging and/or drinking resource, respectively. To further explore whether the use of the pools as a foraging resource was species-specific, we compared the number of feeding buzzes per night recorded for each species at both study sites using a one-way Analysis of Variance (ANOVA) with a post hoc Tukey test. We then explored whether the use of the pools as a drinking resource was species-specific by comparing the number of drinking buzzes per night recorded for each species at both study sites. For this, we used data only from complete survey nights (i.e., the bat detector successfully recorded from dusk until dawn).

To investigate whether the timing of nightly activity and, therefore, resource use varied, we first compared the number of feeding buzzes and drinking buzzes combined at both study sites for each hour from dusk until dawn. We used a one-way ANOVA with a post hoc Tukey test to determine whether variations in the number of feeding and drinking buzzes each hour were significantly different. To then assess whether the timing of nightly activity and, therefore, resource use varied by species, we compared the number of feeding buzzes and drinking buzzes combined for each species at both study sites for each hour from dusk until dawn. We used a two-way ANOVA with a post hoc Tukey test to determine whether variations in the number of feeding and drinking buzzes each hour were significantly different for each species. To further explore whether the timing of nightly species-specific activity was due to a particular resource (i.e., foraging or drinking), we compared the number of feeding buzzes and drinking buzzes separately for each species at both study sites for each hour from dusk until dawn. Again, we used a two-way ANOVA with a post hoc Tukey test to determine whether variations in the number of each type of buzz each hour were significantly different for each species.

To determine whether season influenced the resource use by species, we compared the number of resource-related calls recorded at both study sites for each season. For this, we defined summer as the months of December to February, fall as the months of March to May, winter as the months of June to August, and spring as the months of September to November. We used a one-way ANOVA with a post hoc Tukey test to determine whether variations in the number of feeding and drinking buzzes each season were significantly different. To then access whether season influenced the resource use by species, we compared the number of feeding buzzes and drinking buzzes combined for each species at both study sites for each season. We used a two-way ANOVA with a post hoc Tukey test, where possible, to determine whether variations in the number of feeding and drinking buzzes each season were significantly different for each species. To further explore whether the species-specific activity was due to a particular resource (i.e., foraging or drinking), we then compared the number of feeding buzzes and drinking buzzes separately for each species at both study sites for each season. Again, we used a two-way ANOVA with a post hoc Tukey test to determine whether the number of each type of buzz significantly varied seasonally between species.

For all statistical analyses undertaken, we used IBM SPSS Statistics (ver. 25, Armonk, NY) and $\alpha = 0.05$. In addition, all data was tested for normality to meet the assumptions of statistical tests conducted and log transformed where necessary.

RESULTS

Survey Summary

Acoustic surveys were conducted from 19 July 2018 to 13 June 2021 for a total of 184 survey nights (159 complete survey nights and 25 partial). In this time, a total of 125,182 bat calls were recorded. Among entire survey nights, the number of calls recorded ranged from 14 to 2,559 per night, although across the entire survey period the average rate of activity recorded was 731.1 ± 659.4 per night. Comparing bat activity at the two study sites, we found that average activity per night was significantly higher at Leeuwenbosch Country House (736.3 ± 619.0 per night) than Woodbury Lodge (681.1 ± 995.2 per night (t=0.308, df=157, P=0.049; Table 3; Fig. 7). Seven bat species were identified, including *Laephotis botswanae*, *Neoromicia capensis*, *Miniopterus natalensis*, *Rhinolophus capensis*, *R. clivosus*, *R. simulator*, and *Taradrida aegyptiaca*.

Using all resource-related acoustic calls recorded to confirm whether bats were using the swimming pools on Amakhala Game Reserve as a resource, we identified 22,893 resource-related calls, of which 12,185 were approach phase calls, 1,356 were feeding buzzes, and 9,352 were drinking buzzes. Within a survey night, the number of resource-related calls ranged from 0 to 731 per night, with an average of 136.3 ± 151.4 per night across the survey period. Furthermore, resource-related calls were recorded at both study sites, although we found that these acoustic activities were significantly higher at Leeuwenbosch Country House (148.1 ± 154 per night) than at Woodbury Lodge (23.3 ± 39.1 per night; Table 3; Fig. 8; t=3.118, df=157, P<0.001).

Table 3: Summary of acoustic activity recorded at the two study sites in Amakhala Game Reserve in the Eastern Cape of South Africa.

	Leeuwenbosch Country House	**Woodbury Lodge**
Total number of survey nights	167 (144 complete) (23 partial)	17 (15 complete) (3 partial)
Total number of bat calls recorded	114,261	10,921
Maximum number of calls recorded per night	2,559	3,354
Average number of calls recorded per night ±SD	736.3 ± 619.0	681.1 ± 995.2

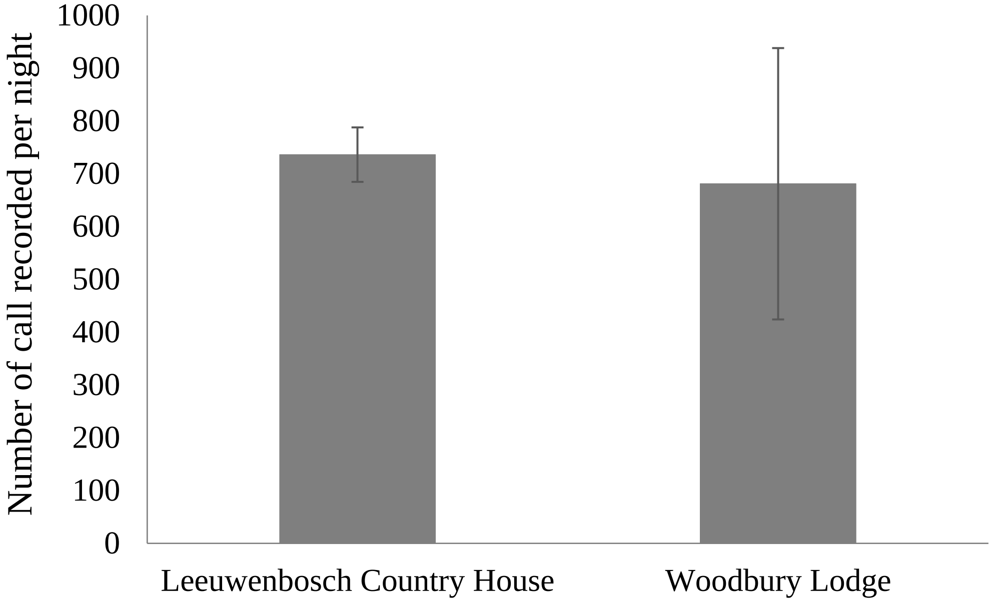

Figure 7: Average number of calls recorded at Leeuwenbosch Country House compared to Woodbury Lodge. Error bars show ± standard error of the nightly mean.

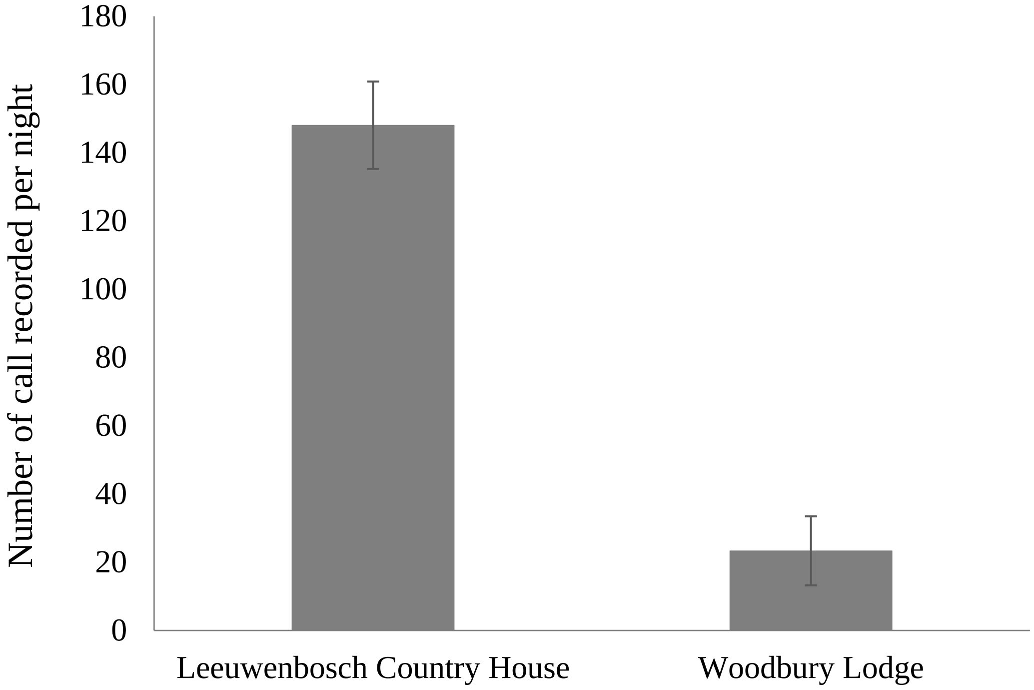

Figure 8: Average number of resource-related calls recorded at Leeuwenbosch Country House compared to Woodbury Lodge. Error bars show ± standard error of the nightly mean.

Behavioral observation surveys were conducted from 8 June 2021 to 13 June 2021, for a total of 6 survey nights at Leeuwenbosch Country House. In this time, a total of 449 bats were observed in the field of view, of which 105 were identified to be foraging activity and 267 drinking events were observed. During these surveys, a total of 1,082 calls were recorded on the SM4BAT (although this detector was not working on the first night of surveys) and 775 were recorded on the Echo Meter Touch (Appendix B). Across the survey nights, average number of calls recorded on the SM4BAT was 46.97/hr and for the Echo Meter Touch was 73.52/hr, foraging activity was 0.30/hr and 0.48/hr, and drinking activity averaged 3.58/hr and 4.21/hr respectively.

For the initial analysis of the observation and acoustic data, we determined there to be a significant decrease the number of instances where bats were both observed actively flying in the field of view and acoustically recorded on the SM4BAT FS detector compared to the number of instances bats were observed only (Fig. 9; t=4.009, df=45, P<0.001; ranging from 0 to 17 when both were recorded and 0 to 19 for observed only). For the Echo Meter Touch, we determined there to be a significant decrease the number of instances where bats were both observed actively flying in the field of view and acoustically recorded on this detector compared to the number of instances bats were observed only (Fig. 9; t=3.725, df=45, P=0.001; ranging from 0 to 16 when both were recorded and 1 to 24 for observed only). We then compared the number of instances where bats were both observed actively flying in the field of view and acoustically recorded on each detector and found no significant difference in the number of instances recorded on the SM4BAT FS and Echo Meter Touch (t=-0.678, df=45, P=0.502).

We found that the number of instances where bats were both observed foraging in the field of view and approach phase calls and feedings buzzes were recorded on the SM4BAT FS detector were no significant different between the number of instances bats were observed foraging only (ranging from 0 to 13) and bat were observed and recorded foraging on the detector (ranging from 0 to 3; Fig. 10; t=2.002, df=19, P=0.060). In contrast, we found that the number of instances where bats were observed drinking in the field of view at the same time drinking buzzes were recorded on the SM4BAT FS detector were significantly lower than the number of instances where drinking was observed only (Fig. 11; t=3.511, df=36, P=0.001; ranging from 0 to 17 when both were recorded and 0 to 6 for observed only).

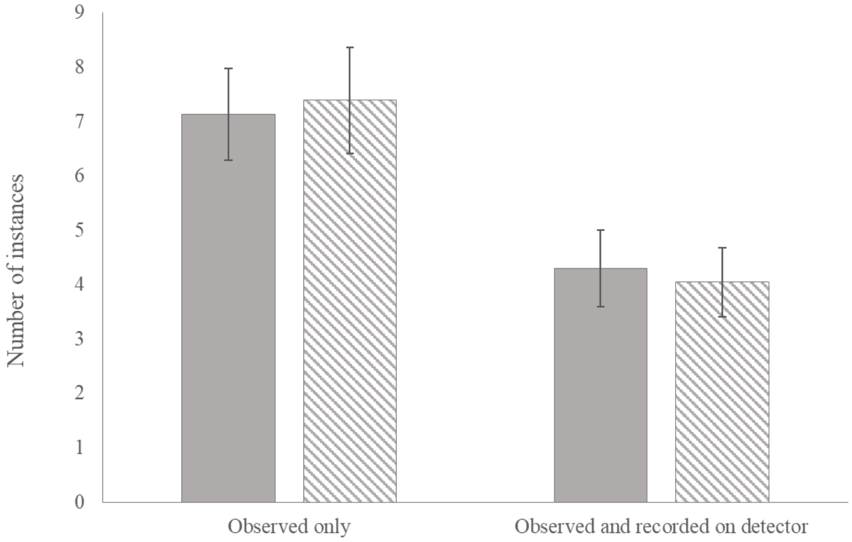

Figure 9: Average number of instances where bats were both observed actively flying in the field of view and acoustically recorded on the SM4BAT FS (solid bar) and Echo Meter Touch (striped bar) bat detectors compared to the average number of instances bats were observed only. Error bars show ± standard error of the mean for 15 min intervals.

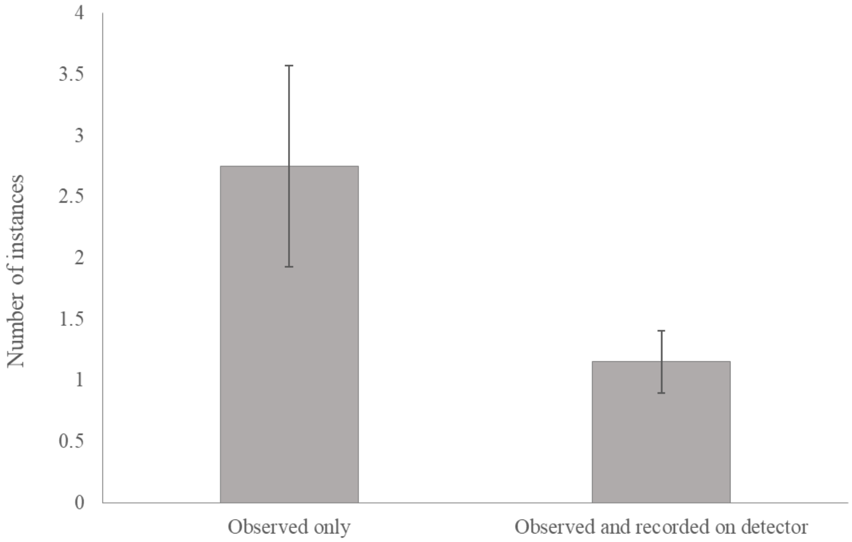

Figure 10: Average number of instances where bats were both observed foraging in the field of view and approach phase calls and feedings buzzes recorded on the SM4BAT FS bat detector compared to the average number of instances bats were observed foraging only. Error bars show ± standard error of the mean for 15 min intervals.

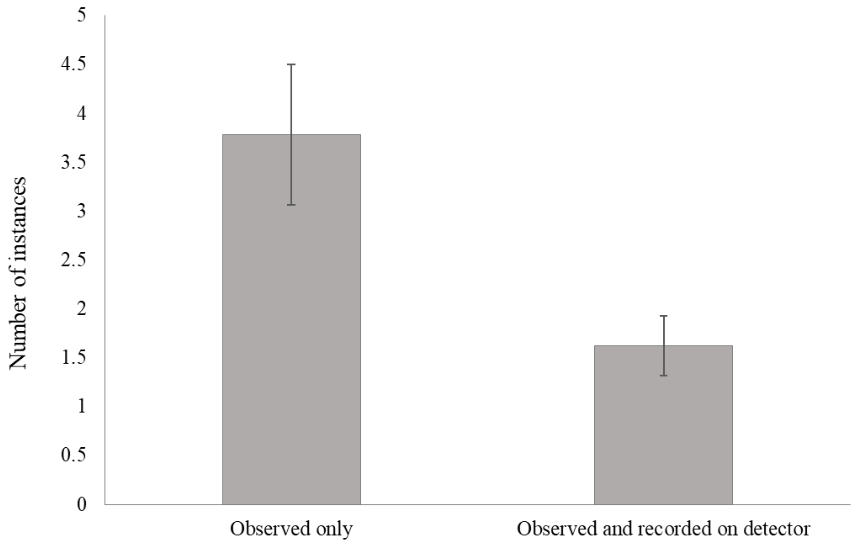

Figure 11: Average number of instances where bats were both observed drinking in the field of view and drinking buzzes recorded on the SM4BAT FS bat detector compared to the average number of instances bats were observed drinking only. Error bars show ± standard error of the mean for 15 min intervals.

In regard to species-specific bat activity over the swimming pool, we found that overall <30% of observed foraging (24 of 82) was associated with an approach phase call or feeding buzz. In particular, of the observed bats matched with *Laephotis botswanae* acoustic calls, <12% represented approach phase calls and feeding buzzes (2 of 17), while 50% of all calls identified to *Neoromicia capensis* and *Miniopterus natalensis* represented approach phase calls and feeding buzzes (20 of 40 and 2 of 4, respectively; Fig. 12). In addition, ~26% of the instances where bats were observed foraging were not associated with any acoustic calls.

For those bats observed drinking, we found that overall <30% of observed drinking (60 of 201) was associated with a drinking buzz. In particular, of the observed bats matched with a species-specific acoustic call, 43% represented drinking buzzes for *Laephotis botswanae* (15 of 35), 31% were from *Neoromicia capensis* (39 of 125), 46% were from *Miniopterus natalensis* (6 of 13) and none were from *Rhinolophus capensis* (0 of 8; Fig. 13). In addition, only 10% of the instances where bats were observed drinking were not associated with any acoustic calls.

In further exploring whether there was a relationship between feeding and drinking buzzes recorded and the frequency at which the bats echolocated, we found a strong negative correlation between the number of terminal buzzes recorded and frequency (r = -0.88). However, as there were only five data points, statistical significance could not be determined.

Based on the results of our initial analysis, we found there to be location, activity, and species biases influencing the frequency at which bats were recorded on the SM4BAT FS acoustic detectors and the effective identification of resource-related calls. Firstly, as we were able to discern a significant difference between observed bat activity and the number of acoustic calls recorded these results indicated the occurrence of location bias, in which the bat detector was not close enough to the swimming pool to effectively detect bat activity over the pool. Our results suggest that >60% of the bat activity over the two pool sites will not have been recorded on the SM4BAT FS acoustic detector.

Secondly, as we were able to discern a significant difference between observed drinking activity and acoustically recorded drinking activity, this revealed an activity bias, in which the bat detector may not have been placed effectively to detect all the instances where drinking activity occurred over the pool. Our results suggest that up to 70% of all drinking activity that occurs over our two pool sites will not have been recorded on the SM4BAT FS acoustic detector.

Finally, as we observed species-specific differences in the number of instances where bats were observed foraging or drinking in the field of view in relation to the number of resource-related calls recorded on the SM4BAT FS bat detector, we concluded that there was a species bias. *Laephotis botswanae*, for example, had foraging activity observed that was matched with non-resource-related acoustic calls (30 khz lo*f*), rather than its higher frequency feeding buzzes (35 khz). This result indicates that for this species there is likely to be an underestimate of the amount of foraging recorded at our two pool sites. Similarly, our initial analysis revealed differences in drinking activity observed and recorded for *Rhinolophus capensis*. Again, none of drinking activity observed was matched with drinking buzz (potentially >84 khz lo*f*), indicating that their drinking buzzes attenuated at even shorter distances. This result suggests that for this species no resource-related calls would be recorded at our two pool sites, despite the bats using them as a resource. Thus, we assumed for the following analysis of all the calls collected during acoustic monitoring that any calls recorded for horseshoe bats (*Rhinolophus* spp.) would represent resource use.

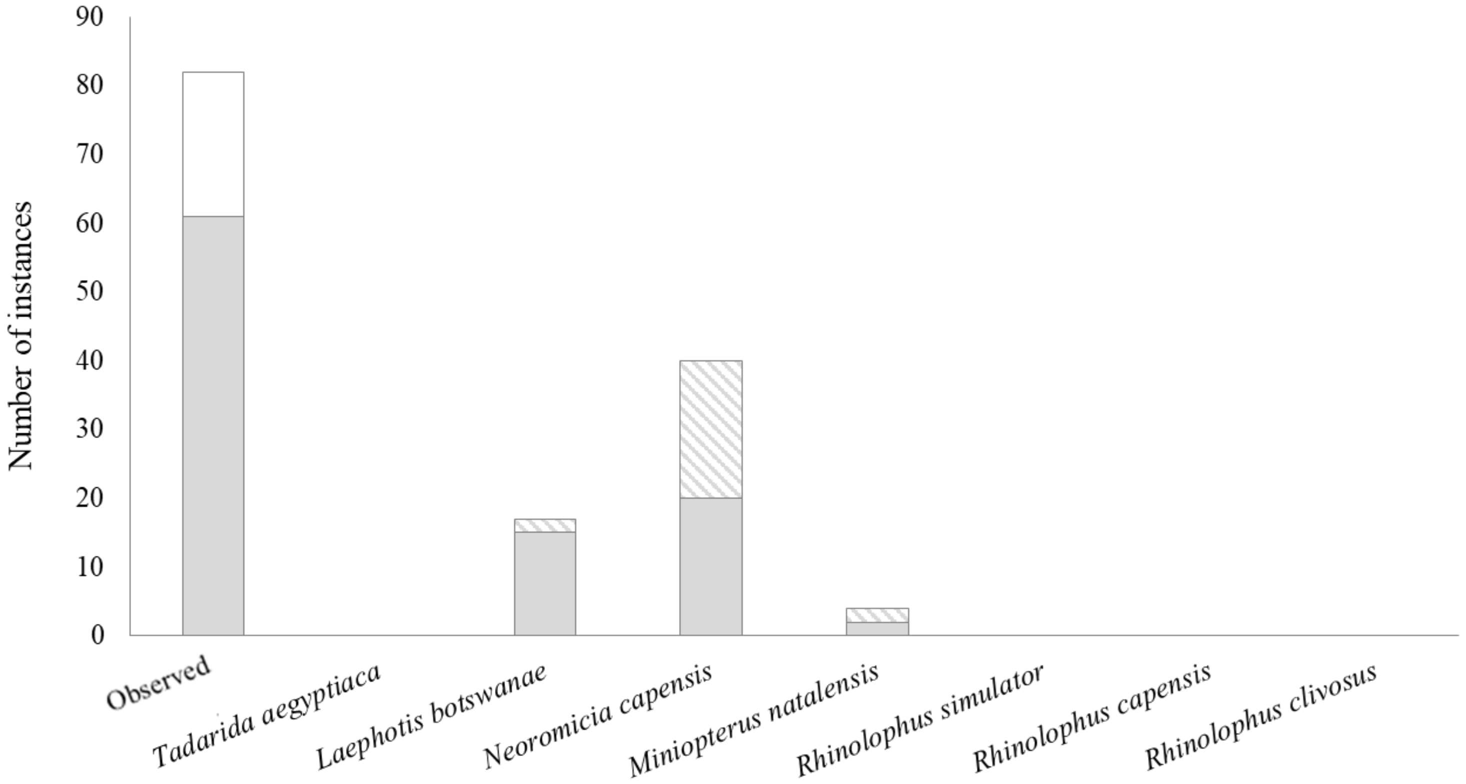

Figure 12: Observed bar shows the number of instances where bats were observed and acoustic calls were recorded on the SM4BAT FS bat detector (solid gray) and instances where bats were observed only (solid white). For each species, stripes show the number of instances where species-specific approach phase and feeding buzzes were recorded when bats were observed and solid gray shows instances where species-specific acoustic calls (excluding drinking buzzes) were recorded.

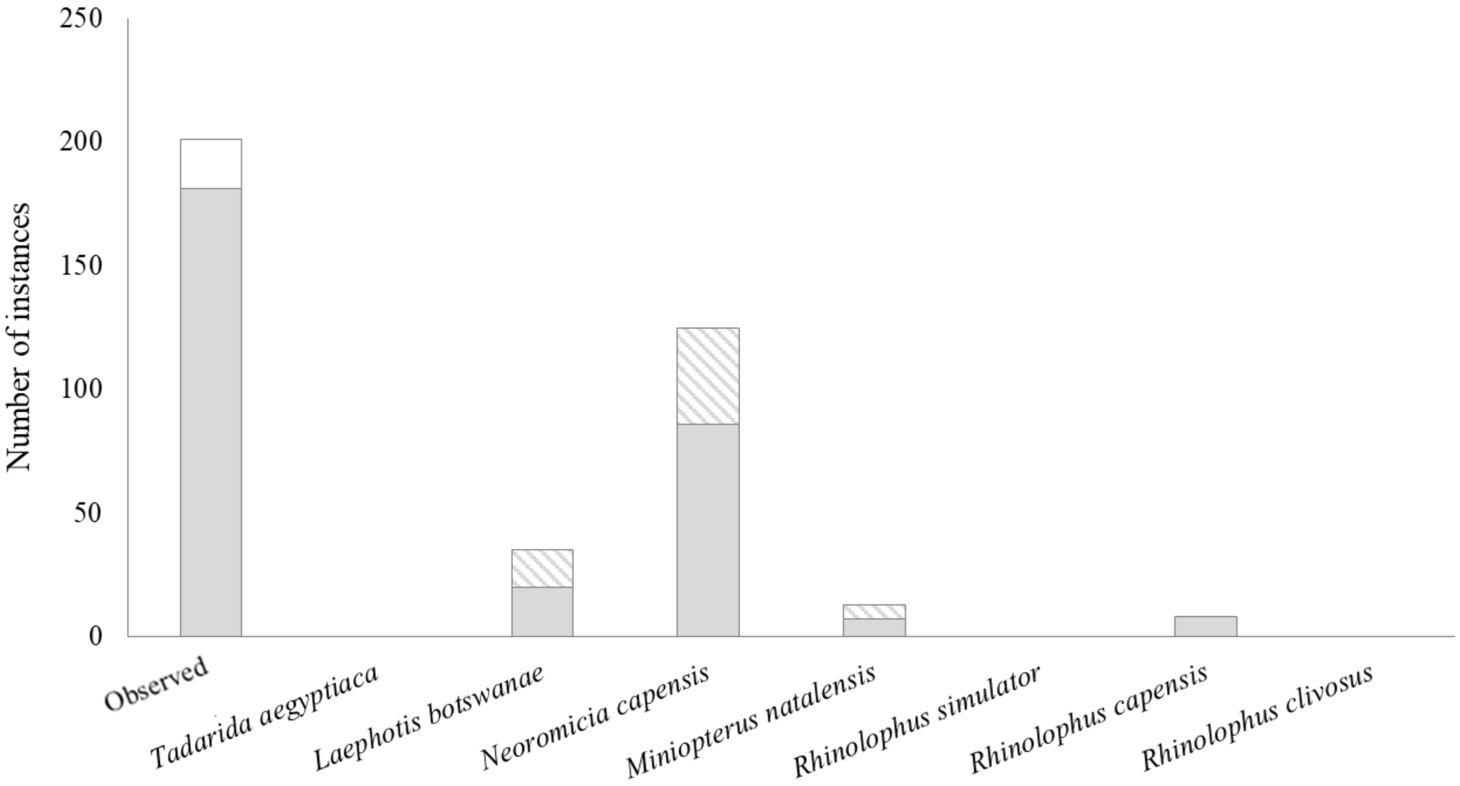

Figure 13: Observed column shows the number of instances where bats were observed and acoustic calls were recorded on the SM4BAT FS bat detector (solid gray) and instances where bats were observed only (solid white). For each species, stripes show the number of instances where species-specific drinking buzzes were recorded when bats were observed and solid gray shows instances where species-specific acoustic calls (excluding drinking buzzes) were recorded.

Analysis of Acoustic Monitoring Data

Comparing the number of terminal buzzes recorded for each species at both swimming pool sites, we identified that seven species (including three *Rhinolophus spp*., i.e., species with echolocation frequencies >70 kHz) were using both swimming pools as a resource (Fig. 14). We also found there to be a significant difference in the use of pools by species (F=37.088, df = 6, p<0.001).

Excluding the *Rhinolophus spp*., we further identified that four species (including *Tadarida aegyptiaca*, *Laephotis botswanae*, *Neoromicia capensis*, and *Miniopterus natalensis*) were using both pools as a foraging resource and determined there to be a significant difference between these species (F=27.007, df = 3, p<0.001). *Neoromicia capensis* was recorded foraging at the pools more than any of the other species (Fig. 15).

For drinking activity specially, we found that three species used the swimming pool at Leeuwenbosch Country House as a drinking resource (including *Laephotis botswanae*, *Neoromicia capensis*, and *Miniopterus natalensis*) and no species used the swimming pool at Woodbury Lodge (Fig. 16). Moreover, we determined there to be a significant difference between these species with *Neoromicia capensis* and *Laephotis botswanae* being recorded drinking at the pools more often than *Miniopterus natalensis* (F=52.350, df = 2, p<0.001).

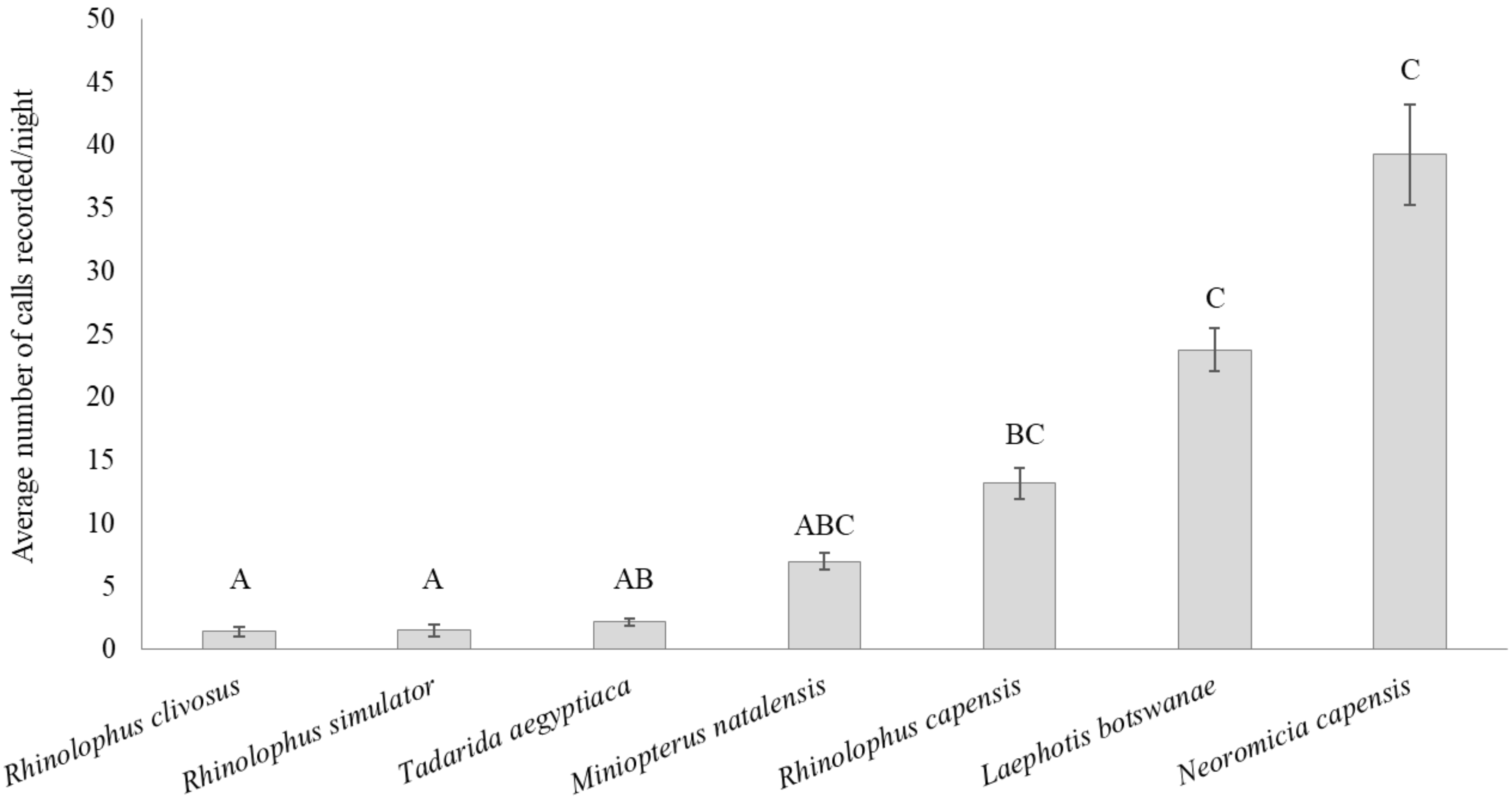

Figure 14: Average number of feeding and drinking buzzes recorded for each species at both study sites. Error bars show ± standard error of the mean for 15 min intervals. Letters indicate significant differences as shown in the posthoc Tukey test provided in Appendix C Table C1.

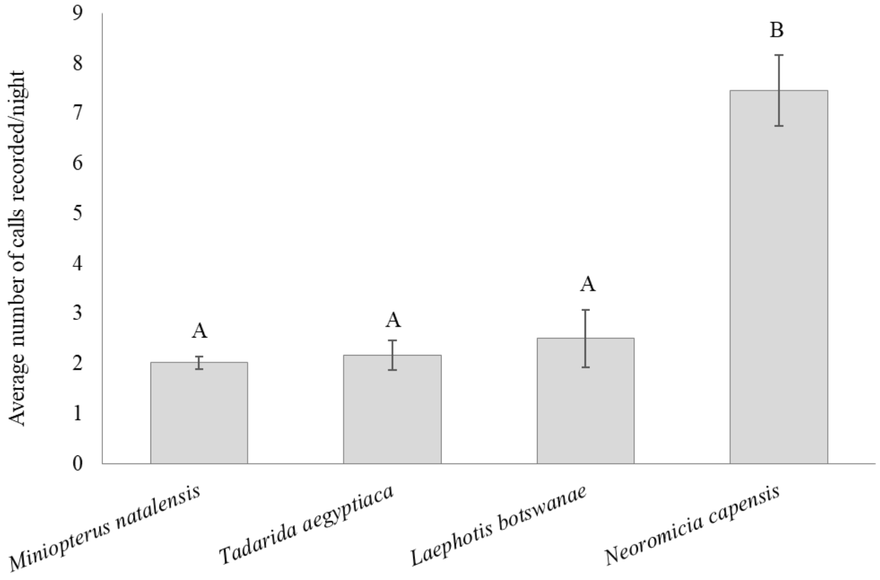

Figure 15: Average number of feeding buzzes recorded for each species at both study sites. Error bars show ± standard error of the mean for 15 min intervals. Letters indicate significant differences as shown in the posthoc Tukey test provided in Appendix C Table C2.

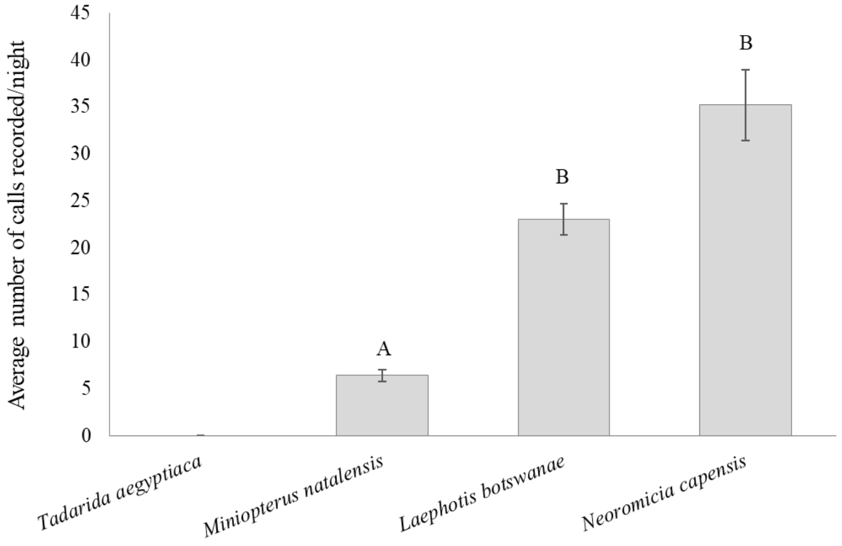

Figure 16: Average number of drinking buzzes recorded for each species at both study sites. Error bars show ± standard error of the mean for 15 min intervals. Letters indicate significant differences as shown in the posthoc Tukey test provided in Appendix C Table C3.

Comparing the average number of feeding and drinking buzzes recorded for each hour from dusk until dawn (including *Rhinolophus* spp.), we found there to be a significant difference in these resource-related calls recorded across the night with peaks one hour from dusk and then again in the hour before dawn (Fig. 17; *F*=13.789, *df* = 13, *p*<0.001). In assessing whether the timing of nightly activity and, therefore, resource use varied by species, we found there to be a significant difference in the hourly use of the swimming pools by species (Fig. 18; *F*=3.437, *df* = 49, *p*<0.001). We determined that *Neoromicia capensis* and *Laephotis botswanae* exhibited more activity in the hour after dusk and before dawn. While *Miniopterus natalensis, Tadarida aegyptiaca*, and *Rhinolophus capensis* appeared to be using the pools as a resource throughout the majority of the night. Note that few bats of any species were recorded mid-way through the days with the longest hours of darkness in winter months, and *R. simulator and R. clivosus* were not recorded enough to determine hourly activity patterns.

For specific resource-use activities, we found there to be no significant difference in the nightly patterns of foraging activities at the swimming pools by species (Fig. 19; *F*=0.491, *df* = 32, *p*=0.992). In contrast, we determined there to be a significant difference in the species-specific drinking activities across the night at the swimming pools (Fig. 20; *F*=3.195, *df* = 23, *p*<0.001). *Neoromicia capensis* tended to drink most often one to two hours from dusk and then again two hours before dawn, while *Laephotis botswanae* appeared to peak in activity the hour before dawn, and *Miniopterus natalensis* was consistently active throughout the night.

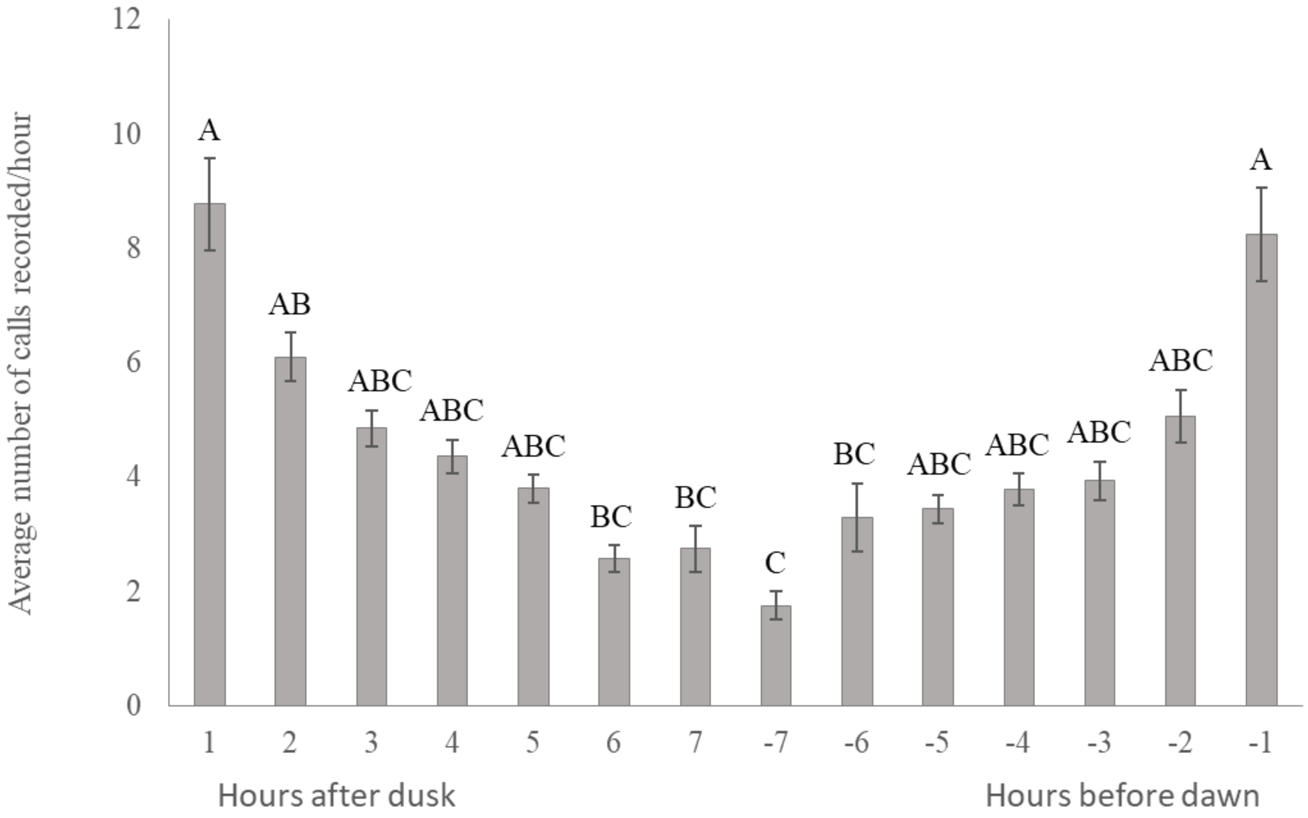

Figure 17: Average number of feeding and drinking buzzes for each hour from dusk until dawn (including *Rhinolophus* spp.). Error bars show ± standard error of the nightly mean. Letters indicate significant differences as shown in the posthoc Tukey test provided in Appendix C Table C4.

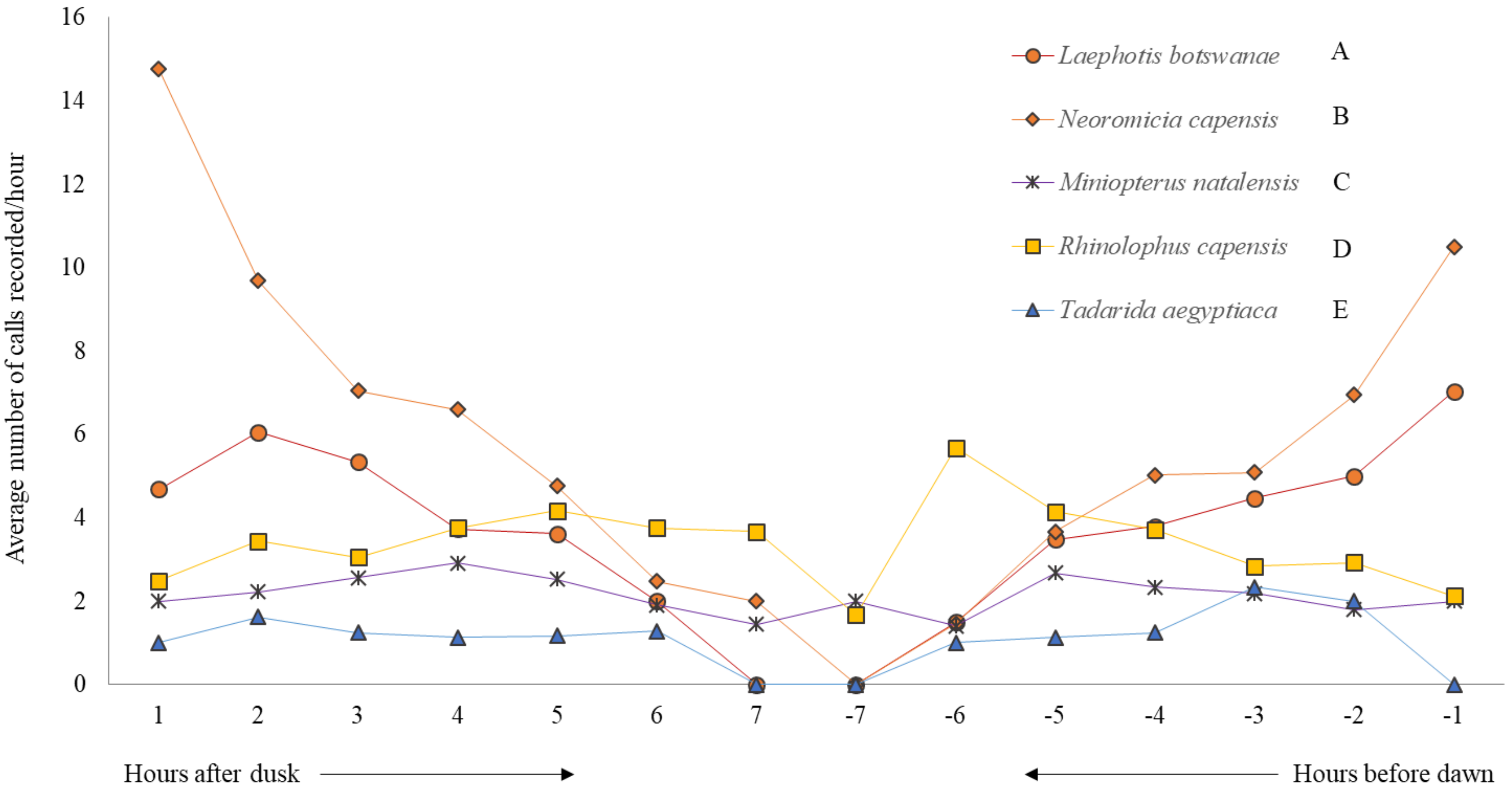

Figure 18: Average number of feeding and drinking buzzes for each hour from dusk until dawn by species, including *Rhinolophus* spp. Letters indicate significant differences as shown in the posthoc Tukey test provided in Appendix C Table C5.

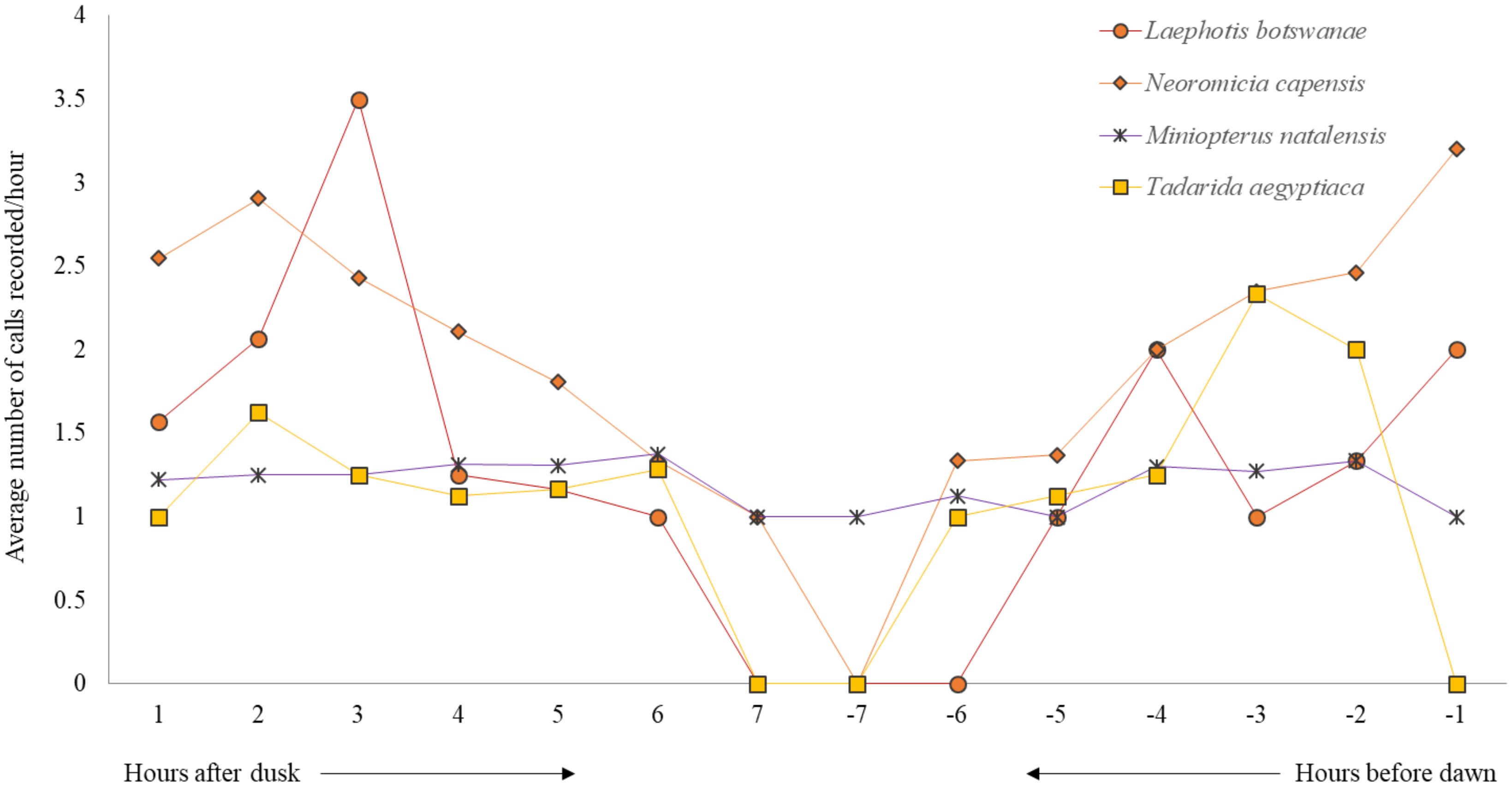

Figure 19: Average number of feeding buzzes for each hour from dusk until dawn by species.

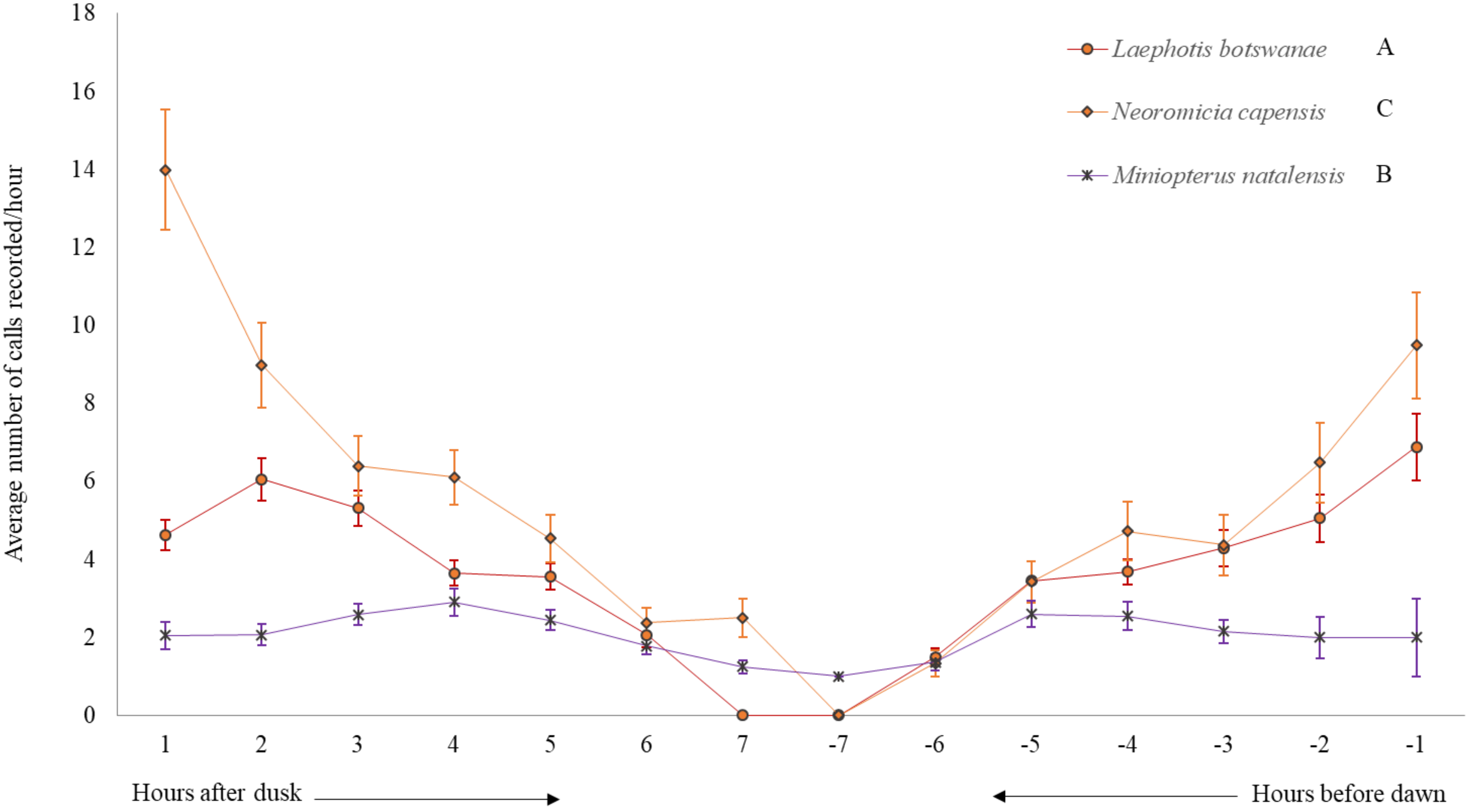

Figure 20: Average number of drinking buzzes for each hour from dusk until dawn by species. Error bars show ± standard error of the nightly mean. Letters indicate significant differences as shown in the posthoc Tukey test provided in Appendix C Table C6.

Comparing the number of feeding buzzes and drinking buzzes combined at both study sites for each season to determine whether season influenced the resource use by bats, we found there to be a significant difference between seasonal resource-related bat activity with peak pool use recorded in the summer (Fig. 21; F=35.290, df = 3, p<0.001). In assessing whether the seasonal activity and, therefore, resource use varied by species, we found there to be a significant difference between season and species resource use at the swimming pools with *Laephotis Botswana, Neoromicia capensis,* and *Miniopterus natalensis* being more active during Summer. The former two species also showed increased resource use in the Spring compared to both Fall and Winter. In contrast, *Rhinolophus capensis* exhibited seasonal peaks in resource use in the Winter and Spring, while *Tadarida aegyptiaca* appeared to actively use the pools all year round (Fig. 22; F=7.915, df=12, p<0.001).

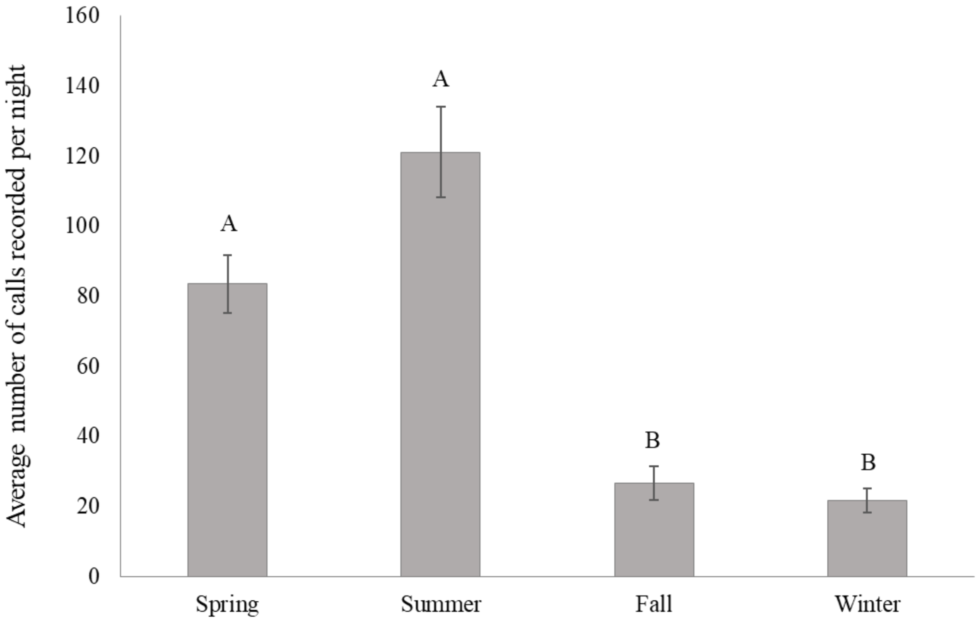

Figure 21: Average number of resource-related calls for each season, including *Rhinolophus spp*. Error bars show ± standard error of the nightly mean. Letters indicate significant differences as shown in the posthoc Tukey test provided in Appendix C Table C7.

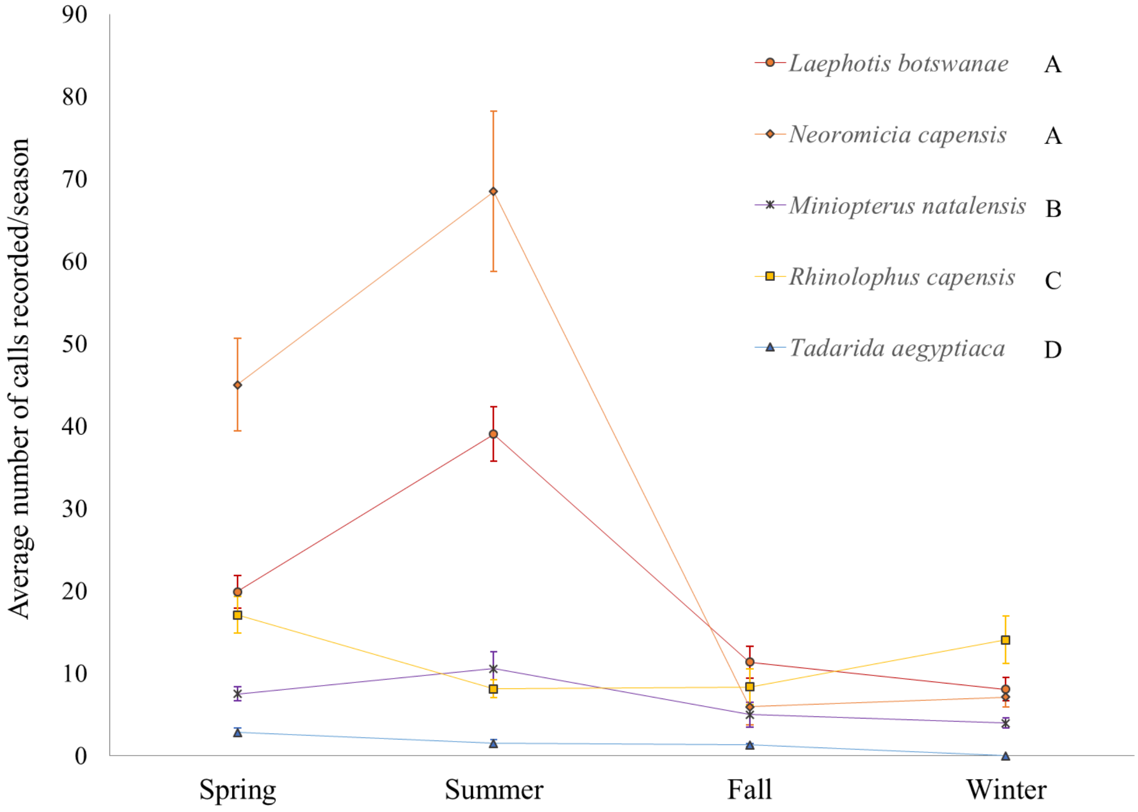

Figure 22: Average number of feeding and drinking buzzes for each season by species. Error bars show ± standard error of the nightly mean. Letters indicate significant differences as shown in the posthoc Tukey test provided in Appendix C Table C8.

For specific resource-use activities, we found there to be a significant difference in species-specific foraging activities seasonally at the swimming pools (Fig. 23; F=4.614, df = 8, p<0.001), with *Neoromicia capensis* actively foraging in Spring and Summer, *Laephotis Botswana* most active in the Winter, and *Miniopterus natalensis* and *Tadarida aegyptiaca* foraging over the swimming pools throughout the year. Similarly, we determined there to be a significant difference in species-specific drinking activities seasonally at the swimming pools (Fig. 24; F=4.773, df = 6, p<0.001), with *Neoromicia capensis* and *Laephotis Botswana* actively foraging in Spring and Summer and *Miniopterus natalensis* drinking at the pools year round.

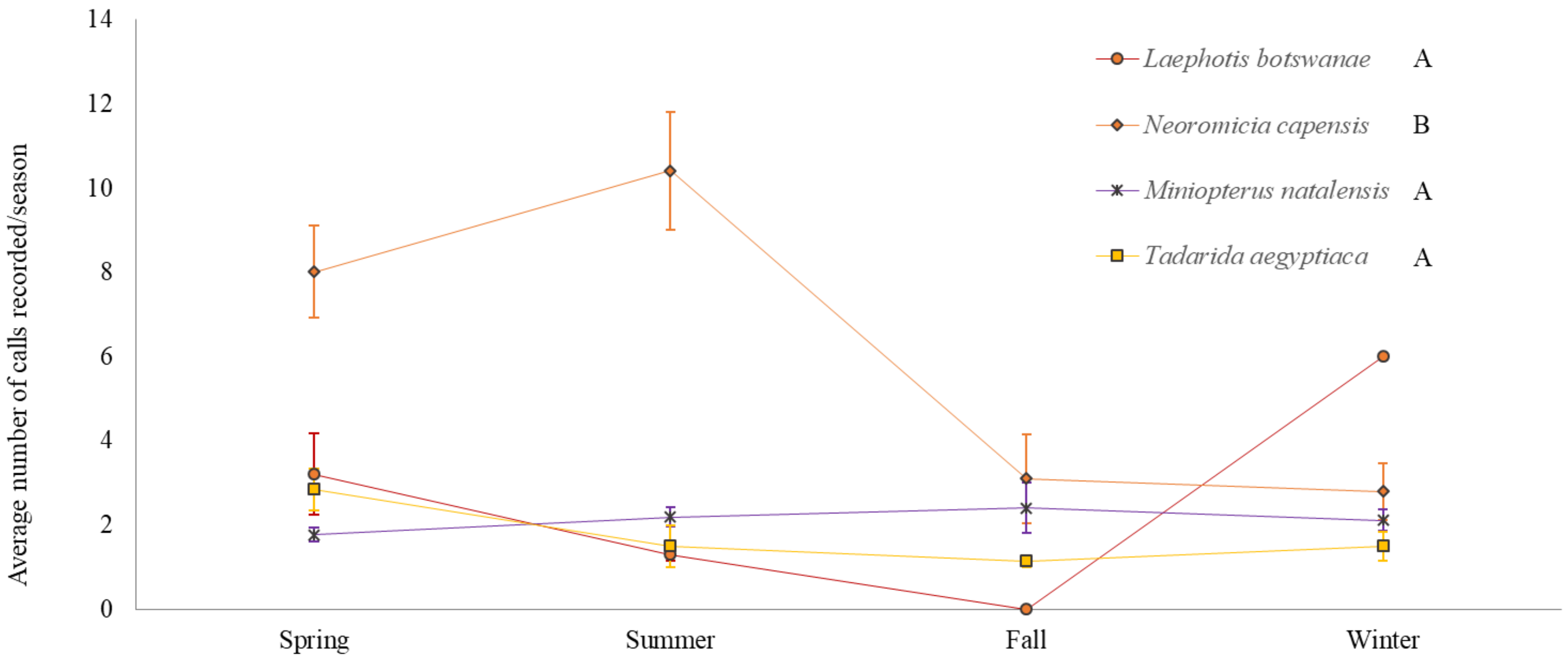

Figure 23: Average number of feeding buzzes for each season by species. Error bars show ± standard error of the nightly mean. Letters indicate significant differences as shown in the posthoc Tukey test provided in Appendix C Table C9.

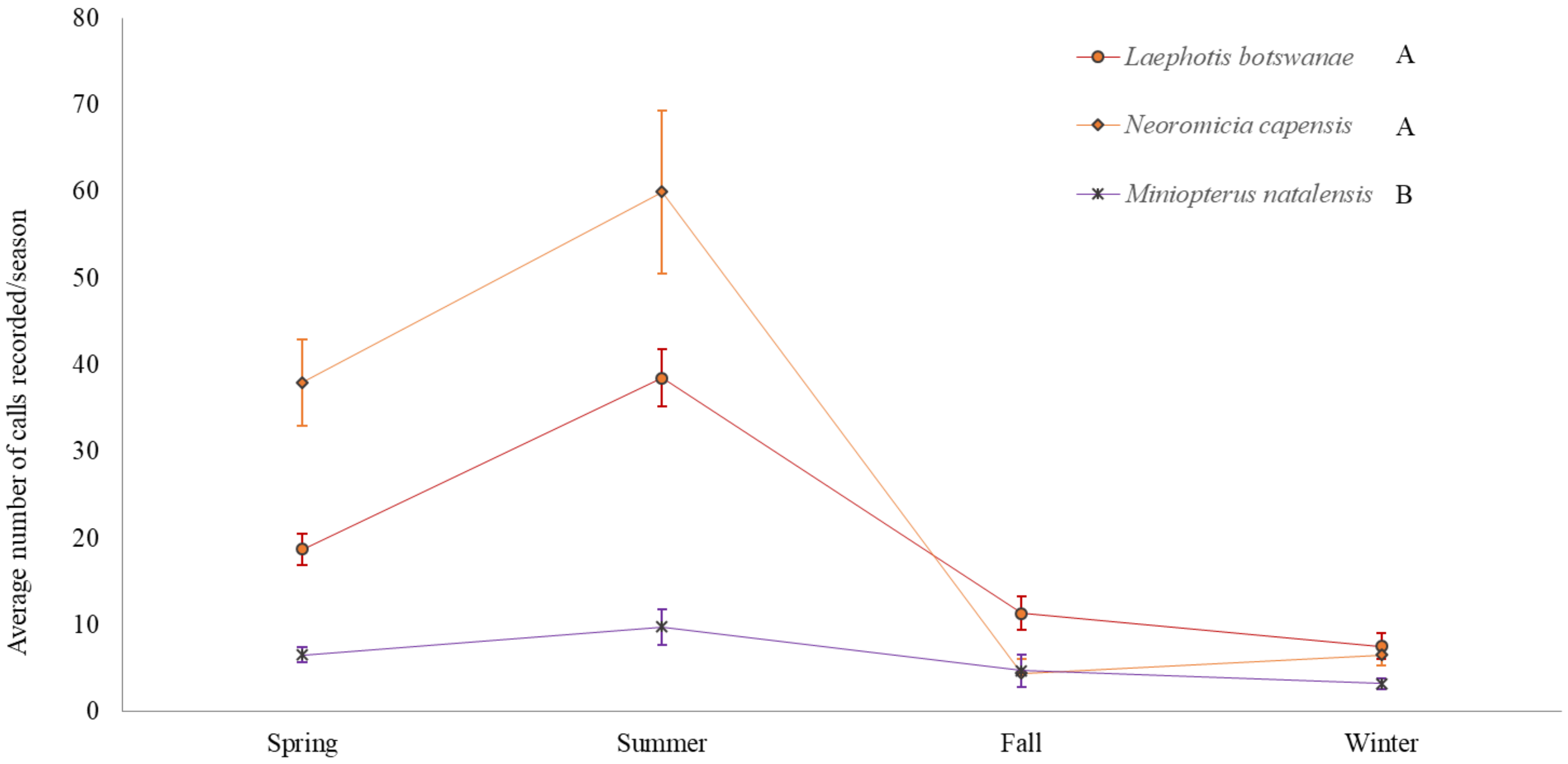

Figure 24: Average number of drinking buzzes for each season by species. Error bars show ± standard error of the nightly mean. Letters indicate significant differences as shown in the posthoc Tukey test provided in Appendix C Table C10.

DISCUSSION

This study revealed the use of swimming pools, as both a foraging and drinking resource, by seven different species of bat in a game reserve in the Eastern Cape of South Africa, confirming that bats will use anthropogenic water sources in a semi-natural environment as a resource (Korine et al. 2016). More specifically, we determined that *Laephotis botswanae, Neoromicia capensis*, and *Miniopterus natalensis* used swimming pools as both a foraging and drinking resource, and *Tadarida aegyptiaca* used the pools as a foraging resource only. These findings were also supported in the behavioral observation surveys and associated acoustic monitoring as *Laephotis botswanae*, *Neoromicia capensis*, and *Miniopterus natalensis* were found to use the pool at Leeuwenbosch Country House as a foraging and drinking resource. Furthermore, behavioral observation surveys informed us that *Rhinolophus capensis* used the pool as a drinking resource, which enabled us to treat all horseshoe bat (*Rhinolophus* spp.) calls as resource-related. While there are a number of studies that support our findings that bats can use anthropogenic water sources as a drinking resource in particular, all these studies appear to have been conducted in habitats that are considered degraded (Ciechanowski 2015, Korine et al. 2016, Salvarina 2016, Nystrom & Bennett 2019, Agpalo 2020). To our knowledge, our study is the first to demonstrate that bats use such resources in a semi-natural temperate environment.

Our study also demonstrated that among the bat species using swimming pools as a resource, nightly use varied temporally. We found that overall that the majority of pool use occurred in the first hour after dusk and the last hour before dawn. These findings are supported by a number of studies that have shown that bats are most active in the first three hours after dusk and the first three hours before dawn (Goodenough et al. , Milne et al. 2005, Frick et al. 2012, Korine et al. 2016). Moreover, studies have shown that many bat species immediately seek drinking resources after they emerge from their roosts (McAlexander 2013, Moir 2014, Kloepper et al. 2019), which often results in a peak in drinking activity at water sources within one hour after dusk, but this is dependent on species-specific emergence times and the distance bats need to travel from their roosts to a water source (Rainho & Palmeirim 2011, Fabianek et al. 2015).

We determined there was species-specific variations in nightly resource use patterns, with two species, *Laephotis botswanae* and *Neoromicia capensis*, appearing to drive observed peaks in activity. These species represented the two most commonly recorded, comprising 30% and 60% of the terminal buzzes recorded, respectively. While *Tadarida aegyptiaca*, *Miniopterus natalensis*, and *Rhinolophus capensis* were found to visit the swimming pools at lower frequencies throughout the night. Currently, there is not enough known about the ecology of these species to determine the reason for these differences in nightly resource-related activity as there has been little research on bat activity and ecology in the Eastern Cape (Doty & Martin 2013). However, one reason for these species-specific differences in nightly activity at resources may be competition avoidance. Studies have shown a number of species will visit water sources at different times to potentially avoid competing with each other for that resource (Adams & Thibault 2006, Beilke et al. 2021). Nevertheless, in acoustic monitoring we recorded multiple species in the same sound files, demonstrating that these species were actively flying and potentially using the pools as a resource in proximity to each other. For example, we recorded echolocation calls from *Laephotis botswanae* and *Neoromicia capensis* on the same sound files, as well as *Neoromicia capensis* and *Rhinolophus capensis,* and *Tadarida aegyptiaca* with *Laephotis botswanae*, *Miniopterus natalensis,* and *Neoromicia capensis*. Similarly, in behavioral observations and associated acoustic monitoring we identified four species, *Laephotis botswanae, Neoromicia capensis, Miniopterus natalensis,* and *Rhinolophus capensis* that were recorded over the swimming pools within 5 min of each other. Moreover, on 7 occasions we observed one species drinking at the swimming pool in Leeuwenbosch Country House and another species coming in a drinking within 1 min of that first instance. These observations indicate that these species are not competing for resources with each other and supports a study by Adams and Simmons (2002), which found that individual bats from eight different species appeared to take turns drinking at a water resource (equating it to airplanes in a holding pattern waiting to land on a runway). Lastly, in regard to nightly activity patterns, we found that species-specific activity did vary between foraging and drinking with *Laephotis botswanae* peaking in drinking 2 hrs after dusk and *Neoromicia capensis* 1 hr after dusk, immediately followed by a peak in foraging activity an hour after their respective peaks in drinking activity. In contrast, *Miniopterus natalensis* showed little variation in foraging and drinking activity, indicating this species is active throughout the night. This temporal trend indicates that the swimming pools potentially represent a preferred or selected, reliable water source that the bats in the area are dependent upon.

Our study also revealed seasonal use of the swimming pools as a resource and in particular found that seasonal activity patterns were species-specific. *Laephotis botswanae* and *Neoromicia capensis* appeared to be active at the pools during Spring and Summer and the use of the pools in Summer by *Miniopterus natalensis*, indicates that these species may hibernate or migrate out of the area during the Fall and Winter months. *Neoromicia capensis* begins spermatogenesis starting in December, and our findings suggest that the Amakhala Game Reserve may represent an important habitat for these species during their summer activity period when they are breeding (Monadjem et al. 2020). Furthermore, the high volume of use by *Laephotis botswanae* and *Neoromicia capensis* during this period indicates that the swimming pools we surveyed represent an important water source for these species. More specifically, we found *Laephotis botswanae* and *Neoromicia capensis* drink significantly more in Spring and Summer than other species. In contrast, *Tadarida aegyptiaca* and *Rhinolophus capensis* appear to be year-round residents at the game reserve. This finding is supported by Taylor (2000), who found that *Rhinolophus capensis* only had small scale migrations (up to 10 km), and Toussaint et al. (2010) who found *Tadarida aegyptiaca* to reside year-round in Pretoria. Further studies would need to be conducted to determine whether the frequency of pool use by these species was correlated with their abundance and/or preference and availability of other water sources in the area. In addition, as we did not record *Tadarida aegyptiaca* drinking, which indicates that these species only using swimming pools as a foraging resource.

While our results confirm the use of pool by certain species, we have also shown them to be an underestimate of the potential usage of the swimming pools we surveyed. We acknowledge that based on the behavioral observation surveys and associated acoustic monitoring, the results of our passive acoustic monitoring underestimate the abundance and frequency of pool use by bats at our study sites by potentially 60%. Furthermore, the acoustic set-up we used did not effectively collect feeding or drinking buzzes bat species with echolocation frequencies >80 kHz. Thus, if we had not observed *Rhinolophus capensis* frequently drinking at the swimming pool at Leeuwenbosch Country House, we would not have known this was actively using the pool as a resource. Given the limited extent of our behavioral observation surveys and that we conducted these surveys during the winter, it is possible that we may have observed a larger number of high frequency species (such as *Rhinolophus clivosus* and *R. simulator*) using the pool as a foraging and drinking resource. We, therefore, recommend that further behavioral observation surveys be conducted in association with acoustic monitoring at least during different seasons and ideally across multiple years, to effectively ascertain the diversity of bats using the pool.

As we also noted a difference in the use of the swimming pools by bats between our study sites, this could be due to one of three reasons: 1) the placement of the acoustic detectors, 2) differences between the pools, and 3) the location of the pools. In our behavioral observation surveys and associated acoustic monitoring, we identified a bias in the placement of the detector caused by activity. Both distance from the pool and height above the pool influenced the number of resource-related acoustic calls recorded and influenced the number of foraging buzzes and drinking buzzes recorded. For example, the detector at Woodbury Lodge recorded no drinking buzzes while the detector at Leeuwenbosch Country House recorded ~140 drinking buzzes per survey night. In contrast, the detector at Woodbury Lodge recorded up to 89% more feeding buzzes than Leeuwenbosch. Given what we know about location bias, these differences between sites suggest that the microphones were placed at different heights and potentially angled differently, as we would expect more drinking buzzes to be recorded by microphones angled at the surface of the water and more foraging buzzes when the microphone is angled upwards. This finding is supported by studies that show bats forage 5-10 m above the surface of the water, while drinking buzzes are executed as the bats makes contact with the surface of the water (Korine et al. 2016, Agpalo 2020, Straka et al. 2020, Suksai & Bumrungsri 2020). This disparity in the ability of acoustic detectors to effectively detect feeding and drinking buzzes concurrently indicates that there is a need to refine acoustic monitoring for specific resource-related activities. Thus, we suggest that multiple microphones or multiple acoustic detectors be used when exploring resource use at water sources. In addition, our results indicated the need to place microphones within 1 m of the surface of a water source to effectively determine the rate at which these water sources are used by higher frequency bats.

We also acknowledge that the differences in characteristics, such as shape, size, lighting, and use by humans, could influence the frequency of foraging and/or drinking and the diversity of bat species accessing a swimming pool (Agpalo 2020). For example, the swimming pool at Woodbury Lodge is connected to the lodge and is more likely to be illuminated by lighting from the lodge, while the swimming pool at Leeuwenbosch is much more isolated and, therefore, not as well lit. Similarly, the amount of available surface area (determined by pool shape and size) could limit drinking activity by restricting bat maneuverability (Tuttle et al. 2006, Razgour et al. 2010, Korine et al. 2016). In this case, the swimming pool at Leeuwenbosch Country House has a greater surface area than the swimming pool at Woodbury Lodge by ~10 m^2. We, therefore, would expect more bat species to be able to drink at Leeuwenbosch Country House. We recommend that more surveys be conducted at swimming pools across Amakhala Game Reserve to determine which pool characteristics encourage and/or hinder resource use by local species of bat. Similarly, landscape connectivity and the presence of natural and semi-natural water sources in proximity are likely to influence the frequency of foraging and/or drinking and the diversity of bat species accessing a swimming pool. Landscape connectivity was considered important, as the presence of contiguous trees and linear features could increase pool accessibility for bats (i.e., >6 visible from the pool; Ancillotto et al. 2019, Agpalo 2020). We, therefore, recommend further studies that explore whether the surrounding habitat is driving bat activity and resource use at not only our two study sites, but other swimming pools located on Amakhala Game Reserve. The quality and availability of natural and semi-natural water sources throughout the game reserve could be influencing the use of swimming pools by bats at our study sites. During behavioral surveys, it was noted that large sections of Bushman’s River were dry, as a result of a drought that began in 2015, and subsequently was not available as a drinking resource (Mahlalela et al. 2020). Additionaly, the watering holes found throughout the game reserve are thought to contain brackish water as they are often filled with groundwater, which might lead to bats selecting alternative water sources. If this is the case, water quality testing of the watering holes could be useful in determining the reason why bats might be choosing swimming pools over natural and semi-natural water sources. Finally, we recommend similar studies be conducted at game reserves throughout the area to further substantiate our findings as to the use of swimming pools as water resources by bats in the area.

CONCLUSION

Similar to most places, bats in South Africa are subject to habitat loss and land-use change, and subsequently 17 species are listed as threatened, 5 species are listed as vulnerable, and 1 species is listed as critically endangered by the International Union for the Conservation of Nature (Doty & Martin 2013, IUCN 2021, O'Shea et al. 2016). Thus, if bats are using swimming pools at tourist accommodations on game reserves, we hypothesize that the presence of such alternative resources would increase overall water availability in the area for bats. By demonstrating that the presence of anthropogenic features in semi-natural habitats could be of value to bats, this study may provide some of the first insights into how such features could be used to enhance game reserves and other semi-natural habitats for wildlife, thereby improving their ecosystem health and stability.

APPENDIX A

Table A1: Acoustic characteristics of all the bat species to have ranges that encompass or are near to Amakhala Game Reserve in South Africa.

Scientific Name	Common Name	Low Frequency (kHz)	High Frequency (kHz)	Duration (ms)	Shape
Eptesicus hottentotus	Long-tailed serotine	32.0	42.0	5.5	hockey stick
Glauconycteris variegata	Variegated butterfly	30.0	64.0	2.3	hockey stick
Hypsugo anchietae	Anchieta's pipistrelle	50.0	85.0	2.1	hockey stick
Kerivoula argentata	Damara woolly	50.0	128.0	2.0	downward slash
Kerivoula lanosa	Lesser woolly	85.0	140.0	2.0	downward slash
Laephotis botswanae	Botswana long-eared	30.0	65.0	5.0	hockey stick
Miniopterus fraterculus	Lesser long-fingered	60.0	100.0	3.7	hockey stick
Miniopterus natalensis	Natal long-fingered	48.0	60.0	5.3	hockey stick
Mops midas	Midas free-tailed	12.0	17.0	16.5	shallow curve
Myotis tricolor	Temmink's myotis	30.0	86.0	3.3	downward slash

Scientific Name	Common Name	Low Frequency (kHz)	High Frequency (kHz)	Duration (ms)	Shape
Neoromicia capensis	Cape serotine	38.0	65.0	5.1	hockey stick
Nycteris hispida	Hairy slit-faced	.	80.8	2.0	slash
Nycteris thebaica	Egyptian slit-faced	.	90.0	1.7	slash
Pipistrellus hesperidus	Dusky pipistrelle	48.0	80.0	2.5	hockey stick
Rhinolophus capensis	Cape horseshoe	.	83.9	41.2	staple
Rhinolophus clivosus	Geoffroy's horseshoe	.	91.7	37.4	staple
Rhinolophus darlingi	Darling's horseshoe	.	87.1	39.5	staple
Rhinolophus simulator	Bushveld horseshoe	.	80.1	31.3	staple
Rhinolophus swinnyi	Swinny's horseshoe	.	106.6	22.2	right staple
Rousettus aegyptiacus	Egyptian rousette	10.0	60.0	.	clicks
Scotophilus viridis	Green house	30.0	60.0	10.0	hockey stick
Tadarida aegyptiaca	Egyptian free-tailed	20.0	30.0	9.6	hockey stick
Taphozous mauritianus	Mauritian tomb	.	25.9	7.4	pill

APPENDIX B

Table B1: Summary of behavioral observation surveys and acoustic monitoring at swimming pool at Leeuwenbosch Country House in Amakhala Game Reserve, South Africa.

Survey Information and Conditions						
Date:	6/8/2021	6/9/2021	6/10/2021	6/11/2021	6/12/2021	6/13/2021
Start Time:	1729	1725	1727	1728	1725	1727
Stop Time:	1916	2028	2001	2031	2027	2031
Cloud Cover (Full, Partial, or Clear):	Partial	Clear	Clear	Clear	Clear	Full
Wind Direction:	N	SSE	ESE	ESE	SM4	SSW
Average Wind Speed (km/h):	11	5	5	3	5	11
Wind Gust Speeds (km/h):	0	0	0	0	0	0
Temperature (^{o}C):	19	18	19	21	18	18
Dew point (^{o}C):	5	7	6	7	9	9
Humidity (%):	35	50	43	42	37	58
Barometric Pressure (mb):	1019.64	1021.67	1019.64	1012.87	1017.61	1016.93
Moon Phase:	Waning Crescent	Waning Crescent	New Moon	Waxing Crescent	Waxing Crescent	Waxing Crescent
Moon Visibility:	No	No	No	No	Yes	Yes

Moon Illumination (%):	3		0.6		0		1.3		4.5		9.5	
Summary of Observed Bat Activity												
Foraging:	20		10		22		25		7		21	
Drinking:	64		38		37		38		58		32	
Total Bats On Camera:	89		66		88		105		63		38	
Summary of Recorded Acoustic Calls												
Acoustic Detector:	SM4	EM	SM4	EM	SM4	EM	SM4	EM	SM4	EM	SM4	EM
Feeding Buzzes:	N/A	1	1	0	0	1	2	0	4	2	0	1
Drinking Buzzes:	N/A	22	9	10	11	10	14	5	16	7	12	5
Total Calls:	N/A	118	170	82	232	146	311	177	237	120	132	130

APPENDIX C

Table C1: Posthoc Tukey test results for the comparison of average number of feeding and drinking buzzes recorded and species at both study sites. * indicates significance.

Species		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Laephotis botswanae	*Miniopterus natalensis*	.57760*	0.06258	0.000	0.3925	0.7627
	Neoromicia capensis	-0.00862	0.05959	1.000	-0.1849	0.1676
	Rhinolophus capensis	.33374*	0.06020	0.000	0.1557	0.5118
	Rhinolophus clivosus	1.10247*	0.23407	0.000	0.4101	1.7949
	Rhinolophus simulator	1.04738	0.36617	0.066	-0.0357	2.1305
	Tadarida aegyptiaca	.97298*	0.09525	0.000	0.6912	1.2547
Miniopterus natalensis	*Laephotis botswanae*	-.57760*	0.06258	0.000	-0.7627	-0.3925
	Neoromicia capensis	-.58621*	0.06007	0.000	-0.7639	-0.4085
	Rhinolophus capensis	-.24386*	0.06068	0.001	-0.4233	-0.0644
	Rhinolophus clivosus	0.52488	0.23420	0.275	-0.1679	1.2176
	Rhinolophus simulator	0.46979	0.36625	0.860	-0.6136	1.5531
	Tadarida aegyptiaca	.39538*	0.09555	0.001	0.1127	0.6780
Neoromicia capensis	*Laephotis botswanae*	0.00862	0.05959	1.000	-0.1676	0.1849

	Miniopterus natalensis	.58621*	0.06007	0.000	0.4085	0.7639
	Rhinolophus capensis	.34236*	0.05758	0.000	0.1720	0.5127
	Rhinolophus clivosus	1.11109*	0.23342	0.000	0.4207	1.8015
	Rhinolophus simulator	1.05600	0.36575	0.061	-0.0259	2.1379
	Tadarida aegyptiaca	.98159*	0.09362	0.000	0.7047	1.2585
Rhinolophus capensis	*Laephotis botswanae*	-.33374*	0.06020	0.000	-0.5118	-0.1557
	Miniopterus natalensis	.24386*	0.06068	0.001	0.0644	0.4233
	Neoromicia capensis	-.34236*	0.05758	0.000	-0.5127	-0.1720
	Rhinolophus clivosus	.76873*	0.23357	0.018	0.0778	1.4596
	Rhinolophus simulator	0.71364	0.36585	0.448	-0.3685	1.7958
	Tadarida aegyptiaca	.63924*	0.09401	0.000	0.3612	0.9173
Rhinolophus clivosus	*Laephotis botswanae*	-1.10247*	0.23407	0.000	-1.7949	-0.4101
	Miniopterus natalensis	-0.52488	0.23420	0.275	-1.2176	0.1679
	Neoromicia capensis	-1.11109*	0.23342	0.000	-1.8015	-0.4207
	Rhinolophus capensis	-.76873*	0.23357	0.018	-1.4596	-0.0778
	Rhinolophus simulator	-0.05509	0.43013	1.000	-1.3274	1.2172
	Tadarida aegyptiaca	-0.12950	0.24496	0.998	-0.8541	0.5951

Rhinolophus simulator	*Laephotis botswanae*	-1.04738	0.36617	0.066	-2.1305	0.0357
	Miniopterus natalensis	-0.46979	0.36625	0.860	-1.5531	0.6136
	Neoromicia capensis	-1.05600	0.36575	0.061	-2.1379	0.0259
	Rhinolophus capensis	-0.71364	0.36585	0.448	-1.7958	0.3685
	Rhinolophus clivosus	0.05509	0.43013	1.000	-1.2172	1.3274
	Tadarida aegyptiaca	-0.07441	0.37323	1.000	-1.1784	1.0296
Tadarida aegyptiaca	*Laephotis botswanae*	-.97298*	0.09525	0.000	-1.2547	-0.6912
	Miniopterus natalensis	-.39538*	0.09555	0.001	-0.6780	-0.1127
	Neoromicia capensis	-.98159*	0.09362	0.000	-1.2585	-0.7047
	Rhinolophus capensis	-.63924*	0.09401	0.000	-0.9173	-0.3612
	Rhinolophus clivosus	0.12950	0.24496	0.998	-0.5951	0.8541
	Rhinolophus simulator	0.07441	0.37323	1.000	-1.0296	1.1784

Table C2: Posthoc Tukey test results for the comparison of average number of feeding buzzes recorded and species at both study sites. * indicates significance.

Species		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Laephotis botswanae	*Miniopterus natalensis*	-0.02334	0.07181	0.988	-0.2089	0.1622
	Neoromicia capensis	-.41240*	0.06746	0.000	-0.5867	-0.2381
	Tadarida aegyptiaca	-0.01153	0.08617	0.999	-0.2342	0.2111
Miniopterus natalensis	*Laephotis botswanae*	0.02334	0.07181	0.988	-0.1622	0.2089
	Neoromicia capensis	-.38906*	0.05247	0.000	-0.5246	-0.2535
	Tadarida aegyptiaca	0.01181	0.07501	0.999	-0.1820	0.2056
Neoromicia capensis	*Laephotis botswanae*	.41240*	0.06746	0.000	0.2381	0.5867
	Miniopterus natalensis	.38906*	0.05247	0.000	0.2535	0.5246
	Tadarida aegyptiaca	.40087*	0.07086	0.000	0.2178	0.5840
Tadarida aegyptiaca	*Laephotis botswanae*	0.01153	0.08617	0.999	-0.2111	0.2342
	Miniopterus natalensis	-0.01181	0.07501	0.999	-0.2056	0.1820
	Neoromicia capensis	-.40087*	0.07086	0.000	-0.5840	-0.2178

Table C3: Posthoc Tukey test results for the comparison of average number of drinking buzzes recorded and species at both study sites. * indicates significance.

Species		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Laephotis botswanae	*Miniopterus natalensis*	.61445*	0.06751	0.000	0.4556	0.7733
	Neoromicia capensis	0.02728	0.06323	0.903	-0.1215	0.1760
Miniopterus natalensis	*Laephotis botswanae*	-.61445*	0.06751	0.000	-0.7733	-0.4556
	Neoromicia capensis	-.58717*	0.06586	0.000	-0.7421	-0.4322
Neoromicia capensis	*Laephotis botswanae*	-0.02728	0.06323	0.903	-0.1760	0.1215
	Miniopterus natalensis	.58717*	0.06586	0.000	0.4322	0.7421

Table C4: Posthoc Tukey test results for the comparison of average number of feeding and drinking buzzes and each hour from dusk until dawn (includes *Rhinolophus* spp.). * indicates significance.

Hour		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
1 (1 hour after dusk)	2	0.092378	0.033036	0.226831	-0.01852	0.203278
	3	.14505*	0.034213	0.001887	0.030202	0.259904
	4	.18401*	0.03511	1.54E-05	0.06615	0.301872
	5	.24831*	0.034126	4.16E-11	0.133753	0.362872
	6	.36523*	0.044295	2.43E-13	0.216538	0.513928
	7	.31177*	0.080855	0.008857	0.040347	0.583193
	-7	0.424668	0.201625	0.697161	-0.25217	1.101504
	-6	.34793*	0.055745	4.59E-08	0.160797	0.535059
	-5	.27739*	0.037597	1.99E-11	0.151178	0.403599
	-4	.25670*	0.035145	3.4E-11	0.138724	0.374682
	-3	.23813*	0.037875	3.44E-08	0.110991	0.365277
	-2	.14001*	0.040983	0.041418	0.002436	0.277589
	-1	-0.01805	0.042747	1	-0.16155	0.125452
2	1	-0.09238	0.033036	0.226831	-0.20328	0.018522
	3	0.052675	0.032449	0.94022	-0.05625	0.161605
	4	0.091633	0.033393	0.254412	-0.02047	0.203731
	5	.15593*	0.032358	0.000133	0.047313	0.264557
	6	.27285*	0.042947	2.26E-08	0.128685	0.417025
	7	0.219392	0.080125	0.257667	-0.04958	0.488363
	-7	0.33229	0.201333	0.932382	-0.34357	1.008147
	-6	.25555*	0.05468	0.000268	0.071994	0.439106
	-5	.18501*	0.035999	2.63E-05	0.064163	0.305857
	-4	.16433*	0.03343	8.25E-05	0.052103	0.276548
	-3	.14576*	0.036289	0.004738	0.023936	0.267576
	-2	0.047635	0.039523	0.995502	-0.08504	0.180308
	-1	-0.11043	0.041349	0.296632	-0.24923	0.02838
3	1	-.14505*	0.034213	0.001887	-0.2599	-0.0302
	2	-0.05268	0.032449	0.94022	-0.1616	0.056254
	4	0.038958	0.034558	0.997681	-0.07705	0.154966
	5	0.103259	0.033558	0.113158	-0.00939	0.215912
	6	.22018*	0.043859	4.87E-05	0.072949	0.36741
	7	0.166717	0.080617	0.723466	-0.10391	0.437341
	-7	0.279614	0.20153	0.983418	-0.3969	0.956131

	-6	.20287*	0.055399	0.018049	0.016905	0.388844
	-5	.13233*	0.037082	0.02499	0.007852	0.256817
	-4	0.11165	0.034594	0.074025	-0.00448	0.227778
	-3	0.093081	0.037364	0.414455	-0.03235	0.218508
	-2	-0.00504	0.040511	1	-0.14103	0.130952
	-1	-.16310*	0.042295	0.008846	-0.30508	-0.02112
4	1	-.18401*	0.03511	1.54E-05	-0.30187	-0.06615
	2	-0.09163	0.033393	0.254412	-0.20373	0.020465
	3	-0.03896	0.034558	0.997681	-0.15497	0.077051
	5	0.064302	0.034472	0.845107	-0.05142	0.180021
	6	.18122*	0.044562	0.003871	0.031631	0.330812
	7	0.127759	0.081002	0.952016	-0.14416	0.399674
	-7	0.240657	0.201684	0.995921	-0.43638	0.917691
	-6	0.163917	0.055957	0.165792	-0.02393	0.35176
	-5	0.093377	0.037911	0.43449	-0.03389	0.220642
	-4	0.072692	0.035481	0.736363	-0.04641	0.191798
	-3	0.054123	0.038187	0.980038	-0.07407	0.182312
	-2	-0.044	0.041271	0.998691	-0.18254	0.094546
	-1	-.20206*	0.043024	0.00024	-0.34649	-0.05763
5	1	-.24831*	0.034126	4.16E-11	-0.36287	-0.13375
	2	-.15593*	0.032358	0.000133	-0.26456	-0.04731
	3	-0.10326	0.033558	0.113158	-0.21591	0.009393
	4	-0.0643	0.034472	0.845107	-0.18002	0.051418
	6	0.11692	0.043791	0.297008	-0.03008	0.263923
	7	0.063457	0.08058	0.999953	-0.20704	0.333958
	-7	0.176355	0.201515	0.999845	-0.50011	0.852822
	-6	0.099615	0.055346	0.876524	-0.08617	0.285405
	-5	0.029075	0.037002	0.999954	-0.09514	0.153288
	-4	0.008391	0.034508	1	-0.10745	0.12423
	-3	-0.01018	0.037284	1	-0.13534	0.114982
	-2	-0.1083	0.040438	0.292077	-0.24405	0.027446
	-1	-.26636*	0.042225	3.01E-08	-0.40811	-0.12461
6	1	-.36523*	0.044295	2.43E-13	-0.51393	-0.21654
	2	-.27285*	0.042947	2.26E-08	-0.41702	-0.12868
	3	-.22018*	0.043859	4.87E-05	-0.36741	-0.07295
	4	-.18122*	0.044562	0.003871	-0.33081	-0.03163
	5	-0.11692	0.043791	0.297008	-0.26392	0.030083
	7	-0.05346	0.085385	0.999997	-0.34009	0.233167
	-7	0.059435	0.203484	1	-0.62364	0.742512
	-6	-0.0173	0.062134	1	-0.22588	0.191272
	-5	-0.08784	0.046547	0.833672	-0.2441	0.068409
	-4	-0.10853	0.04459	0.455522	-0.25821	0.041154
	-3	-0.1271	0.046772	0.269254	-0.28411	0.029909

	-2	-.22522*	0.049322	0.000442	-0.39079	-0.05965
	-1	-.38328*	0.050798	5.89E-12	-0.5538	-0.21276
7	1	-.31177*	0.080855	0.008857	-0.58319	-0.04035
	2	-0.21939	0.080125	0.257667	-0.48836	0.049579
	3	-0.16672	0.080617	0.723466	-0.43734	0.103907
	4	-0.12776	0.081002	0.952016	-0.39967	0.144156
	5	-0.06346	0.08058	0.999953	-0.33396	0.207043
	7	0.053463	0.085385	0.999997	-0.23317	0.340093
	-7	0.112898	0.214433	1	-0.60693	0.832727
	-6	0.036158	0.091848	1	-0.27217	0.344483
	-5	-0.03438	0.08211	1	-0.31002	0.241255
	-4	-0.05507	0.081017	0.999992	-0.32703	0.2169
	-3	-0.07364	0.082238	0.9998	-0.3497	0.202429
	-2	-0.17176	0.083715	0.734425	-0.45278	0.109266
	-1	-.32982*	0.084593	0.007515	-0.61379	-0.04585
-7	1	-0.42467	0.201625	0.697161	-1.1015	0.252169
	2	-0.33229	0.201333	0.932382	-1.00815	0.343568
	3	-0.27961	0.20153	0.983418	-0.95613	0.396902
	4	-0.24066	0.201684	0.995921	-0.91769	0.436377
	5	-0.17635	0.201515	0.999845	-0.85282	0.500112
	6	-0.05943	0.203484	1	-0.74251	0.623642
	7	-0.1129	0.214433	1	-0.83273	0.606932
	-6	-0.07674	0.20628	1	-0.7692	0.615721
	-5	-0.14728	0.202132	0.999981	-0.82582	0.531258
	-4	-0.16796	0.20169	0.999911	-0.84502	0.50909
	-3	-0.18653	0.202184	0.999721	-0.86524	0.492178
	-2	-0.28466	0.202789	0.981641	-0.9654	0.396088
	-1	-0.44272	0.203153	0.644905	-1.12468	0.23925
-6	1	-.34793*	0.055745	4.59E-08	-0.53506	-0.1608
	2	-.25555*	0.05468	0.000268	-0.43911	-0.07199
	3	-.20287*	0.055399	0.018049	-0.38884	-0.0169
	4	-0.16392	0.055957	0.165792	-0.35176	0.023927
	5	-0.09962	0.055346	0.876524	-0.2854	0.086175
	6	0.017305	0.062134	1	-0.19127	0.225881
	7	-0.03616	0.091848	1	-0.34448	0.272168
	-7	0.07674	0.20628	1	-0.61572	0.769201
	-5	-0.07054	0.057551	0.994708	-0.26373	0.122652
	-4	-0.09122	0.055979	0.938461	-0.27914	0.096693
	-3	-0.10979	0.057732	0.825828	-0.3036	0.084008
	-2	-.20792*	0.059818	0.034132	-0.40872	-0.00711
	-1	-.36598*	0.06104	2.1E-07	-0.57088	-0.16107
-5	1	-.27739*	0.037597	1.99E-11	-0.4036	-0.15118
	2	-.18501*	0.035999	2.63E-05	-0.30586	-0.06416

	3	-.13233*	0.037082	0.02499	-0.25682	-0.00785
	4	-0.09338	0.037911	0.43449	-0.22064	0.033887
	5	-0.02908	0.037002	0.999954	-0.15329	0.095138
	6	0.087845	0.046547	0.833672	-0.06841	0.244099
	7	0.034382	0.08211	1	-0.24126	0.310019
	-7	0.14728	0.202132	0.999981	-0.53126	0.825817
	-6	0.07054	0.057551	0.994708	-0.12265	0.263732
	-4	-0.02068	0.037944	0.999999	-0.14806	0.106689
	-3	-0.03925	0.040485	0.999521	-0.17516	0.096652
	-2	-0.13738	0.043407	0.088705	-0.28309	0.008338
	-1	-.29544*	0.045077	6.14E-09	-0.44675	-0.14412
-4	1	-.25670*	0.035145	3.4E-11	-0.37468	-0.13872
	2	-.16433*	0.03343	8.25E-05	-0.27655	-0.0521
	3	-0.11165	0.034594	0.074025	-0.22778	0.004478
	4	-0.07269	0.035481	0.736363	-0.1918	0.046413
	5	-0.00839	0.034508	1	-0.12423	0.107449
	6	0.108529	0.04459	0.455522	-0.04115	0.258213
	7	0.055067	0.081017	0.999992	-0.2169	0.327033
	-7	0.167964	0.20169	0.999911	-0.50909	0.845019
	-6	0.091224	0.055979	0.938461	-0.09669	0.279142
	-5	0.020685	0.037944	0.999999	-0.10669	0.148059
	-3	-0.01857	0.038219	1	-0.14687	0.109728
	-2	-0.11669	0.041301	0.212339	-0.25534	0.021954
	-1	-.27475*	0.043053	1.88E-08	-0.41927	-0.13023
-3	1	-.23813*	0.037875	3.44E-08	-0.36528	-0.11099
	2	-.14576*	0.036289	0.004738	-0.26758	-0.02394
	3	-0.09308	0.037364	0.414455	-0.21851	0.032347
	4	-0.05412	0.038187	0.980038	-0.18231	0.074066
	5	0.010179	0.037284	1	-0.11498	0.135339
	6	0.127099	0.046772	0.269254	-0.02991	0.284106
	7	0.073636	0.082238	0.9998	-0.20243	0.349701
	-7	0.186533	0.202184	0.999721	-0.49218	0.865245
	-6	0.109794	0.057732	0.825828	-0.08401	0.303596
	-5	0.039254	0.040485	0.999521	-0.09665	0.17516
	-4	0.018569	0.038219	1	-0.10973	0.146867
	-2	-0.09812	0.043648	0.594005	-0.24464	0.0484
	-1	-.25618*	0.045309	1.57E-06	-0.40828	-0.10409
-2	1	-.14001*	0.040983	0.041418	-0.27759	-0.00244
	2	-0.04763	0.039523	0.995502	-0.18031	0.085039
	3	0.005041	0.040511	1	-0.13095	0.141034
	4	0.043998	0.041271	0.998691	-0.09455	0.182543
	5	0.1083	0.040438	0.292077	-0.02745	0.244047
	6	.22522*	0.049322	0.000442	0.05965	0.39079

	7	0.171757	0.083715	0.734425	-0.10927	0.45278
	-7	0.284655	0.202789	0.981641	-0.39609	0.965398
	-6	.20792*	0.059818	0.034132	0.007114	0.408717
	-5	0.137375	0.043407	0.088705	-0.00834	0.283089
	-4	0.116691	0.041301	0.212339	-0.02195	0.255336
	-3	0.098122	0.043648	0.594005	-0.0484	0.244643
	-1	-0.15806	0.047937	0.060096	-0.31898	0.00286
-1 (1 hr before dawn)	1	0.018047	0.042747	1	-0.12545	0.161547
	2	0.110425	0.041349	0.296632	-0.02838	0.249231
	3	.16310*	0.042295	0.008846	0.021119	0.305082
	4	.20206*	0.043024	0.00024	0.057631	0.346486
	5	.26636*	0.042225	3.01E-08	0.124614	0.408106
	6	.38328*	0.050798	5.89E-12	0.212757	0.553804
	7	.32982*	0.084593	0.007515	0.045848	0.613787
	-7	0.442715	0.203153	0.644905	-0.23925	1.12468
	-6	.36598*	0.06104	2.1E-07	0.16107	0.57088
	-5	.29544*	0.045077	6.14E-09	0.144118	0.446753
	-4	.27475*	0.043053	1.88E-08	0.130227	0.419274
	-3	.25618*	0.045309	1.57E-06	0.104085	0.408278
	-2	0.15806	0.047937	0.060096	-0.00286	0.31898

Table C5: Posthoc Tukey test results for the comparison of average number of feeding and drinking buzzes each hour from dusk until dawn and species. * indicates significance.

Species		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Laephotis botswanae	*Miniopterus natalensis*	.2620*	0.023536	0	0.192575	0.33147
	Neoromicia capensis	-.0847*	0.019275	0.000233	-0.1416	-0.02784
	Rhinolophus capensis	.1253*	0.021122	7.1E-08	0.062989	0.187638
	Rhinolophus clivosus	.4785*	0.15335	0.030202	0.025961	0.930953
	Rhinolophus simulator	0.528629	0.216404	0.181289	-0.10992	1.167182
	Tadarida aegyptiaca	.4535*	0.049948	0	0.306092	0.60086
Miniopterus natalensis	*Laephotis botswanae*	-.2620*	0.023536	0	-0.33147	-0.19257
	Neoromicia capensis	-.3467*	0.022855	0	-0.41418	-0.2793
	Rhinolophus capensis	-.1367*	0.024432	5.1E-07	-0.2088	-0.06462
	Rhinolophus clivosus	0.216435	0.153841	0.798339	-0.23751	0.670379
	Rhinolophus simulator	0.266606	0.216752	0.88257	-0.37297	0.906187
	Tadarida aegyptiaca	.1915*	0.051435	0.003802	0.03968	0.343226
Neoromicia capensis	*Laephotis botswanae*	.0847*	0.019275	0.000233	0.027842	0.141596
	Miniopterus natalensis	.3467*	0.022855	0	0.279303	0.41418

	Rhinolophus capensis	.2100*	0.02036	0	0.149955	0.27011
	Rhinolophus clivosus	.5632*	0.153247	0.004541	0.110984	1.015368
	Rhinolophus simulator	0.613348	0.216331	0.069069	-0.02499	1.251686
	Tadarida aegyptiaca	.5382*	0.049631	0	0.391747	0.684643
Rhinolophus capensis	*Laephotis botswanae*	-.1253*	0.021122	7.1E-08	-0.18764	-0.06299
	Miniopterus natalensis	.1367*	0.024432	5.1E-07	0.064616	0.208801
	Neoromicia capensis	-.2100*	0.02036	0	-0.27011	-0.14996
	Rhinolophus clivosus	0.353143	0.15349	0.243877	-0.09977	0.806053
	Rhinolophus simulator	0.403315	0.216504	0.505426	-0.23553	1.042162
	Tadarida aegyptiaca	.3282*	0.050377	1.85E-09	0.179514	0.476811
Rhinolophus clivosus	*Laephotis botswanae*	-.4785*	0.15335	0.030202	-0.93095	-0.02596
	Miniopterus natalensis	-0.21643	0.153841	0.798339	-0.67038	0.23751
	Neoromicia capensis	-.5632*	0.153247	0.004541	-1.01537	-0.11098
	Rhinolophus capensis	-0.35314	0.15349	0.243877	-0.80605	0.099766
	Rhinolophus simulator	0.050172	0.264469	0.999996	-0.73021	0.830552
	Tadarida aegyptiaca	-0.02498	0.160025	0.999999	-0.49717	0.44721
Rhinolophus simulator	*Laephotis botswanae*	-0.52863	0.216404	0.181289	-1.16718	0.109925

	Miniopterus natalensis	-0.26661	0.216752	0.88257	-0.90619	0.372975
	Neoromicia capensis	-0.61335	0.216331	0.069069	-1.25169	0.024991
	Rhinolophus capensis	-0.40332	0.216504	0.505426	-1.04216	0.235532
	Rhinolophus clivosus	-0.05017	0.264469	0.999996	-0.83055	0.730209
	Tadarida aegyptiaca	-0.07515	0.221184	0.999878	-0.72781	0.577505
Tadarida aegyptiaca	*Laephotis botswanae*	-.4535*	0.049948	0	-0.60086	-0.30609
	Miniopterus natalensis	-.1915*	0.051435	0.003802	-0.34323	-0.03968
	Neoromicia capensis	-.5382*	0.049631	0	-0.68464	-0.39175
	Rhinolophus capensis	-.3282*	0.050377	1.85E-09	-0.47681	-0.17951
	Rhinolophus clivosus	0.024981	0.160025	0.999999	-0.44721	0.497173
	Rhinolophus simulator	0.075153	0.221184	0.999878	-0.57751	0.727811

Table C6: Posthoc Tukey test results for the comparison of average number of drinking buzzes each hour from dusk until dawn and species. * indicates significance.

Species		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Laephotis botswanae	*Miniopterus natalensis*	.2539*	0.02596	0.000	0.1930	0.3148
	Neoromicia capensis	-.0648*	0.02046	0.004	-0.1128	-0.0168
Miniopterus natalensis	*Laephotis botswanae*	-.2539*	0.02596	0.000	-0.3148	-0.1930
	Neoromicia capensis	-.3187*	0.02565	0.000	-0.3788	-0.2585
Neoromicia capensis	*Laephotis botswanae*	.0648*	0.02046	0.004	0.0168	0.1128
	Miniopterus natalensis	.3187*	0.02565	0.000	0.2585	0.3788

Table C7: Posthoc Tukey test results for the comparison of average number of feeding and drinking buzzes and season (includes *Rhinolophus spp*.). * indicates significance.

Species		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Spring	Summer	-0.20259	0.09032	0.116	-0.4368	0.0317
	Fall	.45853*	0.12349	0.002	0.1382	0.7788
	Winter	.70500*	0.08732	0.000	0.4785	0.9315
Summer	Spring	0.20259	0.09032	0.116	-0.0317	0.4368
	Fall	.66112*	0.13156	0.000	0.3199	1.0023
	Winter	.90759*	0.09840	0.000	0.6524	1.1628
Fall	Spring	-.45853*	0.12349	0.002	-0.7788	-0.1382
	Summer	-.66112*	0.13156	0.000	-1.0023	-0.3199
	Winter	0.24647	0.12952	0.231	-0.0895	0.5824
Winter	Spring	-.70500*	0.08732	0.000	-0.9315	-0.4785
	Summer	-.90759*	0.09840	0.000	-1.1628	-0.6524
	Fall	-0.24647	0.12952	0.231	-0.5824	0.0895

Table C8: Posthoc Tukey test results for the comparison of average number of feeding and drinking buzzes per season and species. * indicates significance.

Species		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Laephotis botswanae	*Miniopterus natalensis*	.5776*	0.05469	0.000	0.4158	0.7394
	Neoromicia capensis	-0.0086	0.05208	1.000	-0.1627	0.1454
	Rhinolophus capensis	.3337*	0.05261	0.000	0.1781	0.4894
	Rhinolophus clivosus	1.1025*	0.20457	0.000	0.4973	1.7076
	Rhinolophus simulator	1.0474*	0.32002	0.019	0.1007	1.9941
	Tadarida aegyptiaca	.9730*	0.08325	0.000	0.7267	1.2192
Miniopterus natalensis	*Laephotis botswanae*	-.5776*	0.05469	0.000	-0.7394	-0.4158
	Neoromicia capensis	-.5862*	0.05250	0.000	-0.7415	-0.4309
	Rhinolophus capensis	-.2439*	0.05303	0.000	-0.4007	-0.0870
	Rhinolophus clivosus	0.5249	0.20468	0.139	-0.0806	1.1304
	Rhinolophus simulator	0.4698	0.32009	0.764	-0.4771	1.4167
	Tadarida aegyptiaca	.3954*	0.08351	0.000	0.1483	0.6424
Neoromicia capensis	*Laephotis botswanae*	0.0086	0.05208	1.000	-0.1454	0.1627
	Miniopterus natalensis	.5862*	0.05250	0.000	0.4309	0.7415

	Rhinolophus capensis	.3424*	0.05033	0.000	0.1935	0.4912
	Rhinolophus clivosus	1.1111*	0.20400	0.000	0.5076	1.7146
	Rhinolophus simulator	1.0560*	0.31965	0.017	0.1104	2.0016
	Tadarida aegyptiaca	.9816*	0.08182	0.000	0.7395	1.2236
Rhinolophus capensis	*Laephotis botswanae*	-.3337*	0.05261	0.000	-0.4894	-0.1781
	Miniopterus natalensis	.2439*	0.05303	0.000	0.0870	0.4007
	Neoromicia capensis	-.3424*	0.05033	0.000	-0.4912	-0.1935
	Rhinolophus clivosus	.7687*	0.20413	0.003	0.1649	1.3726
	Rhinolophus simulator	0.7136	0.31974	0.280	-0.2322	1.6595
	Tadarida aegyptiaca	.6392*	0.08216	0.000	0.3962	0.8823
Rhinolophus clivosus	*Laephotis botswanae*	-1.1025*	0.20457	0.000	-1.7076	-0.4973
	Miniopterus natalensis	-0.5249	0.20468	0.139	-1.1304	0.0806
	Neoromicia capensis	-1.1111*	0.20400	0.000	-1.7146	-0.5076
	Rhinolophus capensis	-.7687*	0.20413	0.003	-1.3726	-0.1649
	Rhinolophus simulator	-0.0551	0.37592	1.000	-1.1671	1.0570
	Tadarida aegyptiaca	-0.1295	0.21408	0.997	-0.7628	0.5038
Rhinolophus simulator	*Laephotis botswanae*	-1.0474*	0.32002	0.019	-1.9941	-0.1007

	Miniopterus natalensis	-0.4698	0.32009	0.764	-1.4167	0.4771
	Neoromicia capensis	-1.0560*	0.31965	0.017	-2.0016	-0.1104
	Rhinolophus capensis	-0.7136	0.31974	0.280	-1.6595	0.2322
	Rhinolophus clivosus	0.0551	0.37592	1.000	-1.0570	1.1671
	Tadarida aegyptiaca	-0.0744	0.32618	1.000	-1.0393	0.8905
Tadarida aegyptiaca	*Laephotis botswanae*	-.9730*	0.08325	0.000	-1.2192	-0.7267
	Miniopterus natalensis	-.3954*	0.08351	0.000	-0.6424	-0.1483
	Neoromicia capensis	-.9816*	0.08182	0.000	-1.2236	-0.7395
	Rhinolophus capensis	-.6392*	0.08216	0.000	-0.8823	-0.3962
	Rhinolophus clivosus	0.1295	0.21408	0.997	-0.5038	0.7628
	Rhinolophus simulator	0.0744	0.32618	1.000	-0.8905	1.0393

Table C9: Posthoc Tukey test results for the comparison of average number of feeding buzzes per season and species. * indicates significance.

Species		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	**Upper Bound**
Laephotis botswanae	*Miniopterus natalensis*	-0.0233	0.06655	0.985	-0.1953	0.1486
	Neoromicia capensis	-.4124*	0.06252	0.000	-0.5740	-0.2508
	Tadarida aegyptiaca	-0.0115	0.07986	0.999	-0.2179	0.1948
Miniopterus natalensis	*Laephotis botswanae*	0.0233	0.06655	0.985	-0.1486	0.1953
	Neoromicia capensis	-.3891*	0.04862	0.000	-0.5147	-0.2634
	Tadarida aegyptiaca	0.0118	0.06951	0.998	-0.1678	0.1914
Neoromicia capensis	*Laephotis botswanae*	.4124*	0.06252	0.000	0.2508	0.5740
	Miniopterus natalensis	.3891*	0.04862	0.000	0.2634	0.5147
	Tadarida aegyptiaca	.4009*	0.06567	0.000	0.2312	0.5706
Tadarida aegyptiaca	*Laephotis botswanae*	0.0115	0.07986	0.999	-0.1948	0.2179
	Miniopterus natalensis	-0.0118	0.06951	0.998	-0.1914	0.1678
	Neoromicia capensis	-.4009*	0.06567	0.000	-0.5706	-0.2312

Table C10: Posthoc Tukey test results for the comparison of average number of drinking buzzes per season and species. * indicates significance.

Species		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Laephotis botswanae	*Miniopterus natalensis*	.6145*	0.05802	0.000	0.4780	0.7509
	Neoromicia capensis	0.0273	0.05433	0.870	-0.1005	0.1551
Miniopterus natalensis	*Laephotis botswanae*	-.6145*	0.05802	0.000	-0.7509	-0.4780
	Neoromicia capensis	-.5872*	0.05659	0.000	-0.7203	-0.4540
Neoromicia capensis	*Laephotis botswanae*	-0.0273	0.05433	0.870	-0.1551	0.1005
	Miniopterus natalensis	.5872*	0.05659	0.000	0.4540	0.7203

REFERENCES

ACHIENG, T., K. MACIEJEWSKI, M. DYER, AND R. BIGGS. 2020. Using a Social-ecological Regime Shift Approach to Understand the Transition from Livestock to Game Farming in the Eastern Cape, South Africa. LAND 9:97.

ADAMS, R. A. AND J. A. SIMMONS. 2002. Directionality of Drinking Passes by Bats at Water Holes: is there Cooperation? Acta Chiropterologica 4:195-199, 195.

ADAMS, R. A. AND K. M. THIBAULT. 2006. Temporal resource partitioning by bats at water holes. Journal of Zoology (1987) 270:466-472.

AGPALO, E. 2020. Improving Urban Habitats for Bats: What Makes a Bat-Friendly Residential Swimming Pool? ProQuest Dissertations Publishing.

ANCILLOTTO, L., L. BOSSO, V. B. SALINAS-RAMOS, AND D. RUSSO. 2019. The importance of ponds for the conservation of bats in urban landscapes. Landscape and Urban Planning 190:103607.

ANGELL, R. L., S. D. LANGTON, M. A. MACDONALD, J. SKATES, AND K. A. HAYSOM. 2019. The effect of a Welsh agri-environment scheme on bat activity: A large-scale study. Agriculture Ecosystems & Environment 275:32-41.

ARIAS, M., S. A. GIGNOUX-WOLFSOHN, K. KERWIN, AND B. MASLO. 2020. Use of Artificial Roost Boxes Installed as Alternative Habitat for Bats Evicted from Buildings. Northeastern Naturalist 27:201-214.

BAKWO FILS, E. M., A. MANGA MONGOMBE, D. E. TSALA, AND J. L. TAMESSE. 2018. Acoustic identification of five insectivorous bats by their echolocation calls in the Sahelian zone of Far North Cameroon. The Journal of Basic and Applied Zoology 79:28.

BAROJA, U., et al. 2019. Pest consumption in a vineyard system by the lesser horseshoe bat (*Rhinolophus hipposideros*). PLoS One 14:e0219265.

BEILKE, E. A., R. V. BLAKEY, AND M. O. K. JOY. 2021. Bats partition activity in space and time in a large, heterogeneous landscape. Ecology and Evolution 11:6513-6526.

BENNETT, V. J. AND A. A. ZURCHER. 2013. When corridors collide: Road-related disturbance in commuting bats. The Journal of Wildlife Management 77:93-101.

BLANCHÉ, L. A. 2021. Displacement of Wildlife Due to Anthropogenic-Induced Edge Effects in Small Game Reserves. ProQuest Dissertations Publishing.

BOHN, K. M. AND E. H. GILLAM. 2018. In-flight social calls: a primer for biologists and managers studying echolocation. Canadian Journal of Zoology 96:787-800.

BRANCH, W. 2016. A Pocket Guide to the Snakes and other reptiles of Southern Africa.

BROWNING, E., R. GIBB, P. GLOVER-KAPFER, AND K. JONES. 2017. Passive acoustic monitoring in ecology and conservation.

CASSEL, K. W., J. P. VANEK, G. A. GLOWACKI, T. S. PREUSS, AND C. K. NIELSEN. 2019. Multiscale habitat factors influence the occupancy and turnover of the suburban herpetofauna of Chicago, Illinois, USA. Herpetological Conservation and Biology 14:438-454.

CHISTÉ, M. N., et al. 2018. Intensive land use drives small-scale homogenization of plant- and leafhopper communities and promotes generalists. Oecologia 186:529-540.

CIECHANOWSKI, M. 2015. Habitat preferences of bats in anthropogenically altered, mosaic landscapes of northern Poland. European Journal of Wildlife Research 61:415-428.

CORTES, K. M. AND E. H. GILLAM. 2020. Assessing the use of rivers as migratory corridors for temperate bats. Journal of Mammalogy 101:448-454.

DAMMHAHN, M., V. MAZZA, A. SCHIRMER, C. GÖTTSCHE, AND J. A. ECCARD. 2020. Of city and village mice: behavioural adjustments of striped field mice to urban environments. Scientific Reports 10:13056.

DOTY, A. C. AND A. P. MARTIN. 2013. Assessment of bat and avian mortality at a pilot wind turbine at Coega, Port Elizabeth, Eastern Cape, South Africa. New Zealand Journal of Zoology 40:75-80.

DUKER, R., R. M. COWLING, M. L. VANDER VYVER, AND A. J. POTTS. 2020. Site selection for subtropical thicket restoration: mapping cold-air pooling in the South African sub-escarpment lowlands. PeerJ.

EDWORTHY, A. B., M. K. TRZCINSKI, K. L. COCKLE, K. L. WIEBE, AND K. MARTIN. 2018. Tree cavity occupancy by nesting vertebrates across cavity age. The Journal of Wildlife Management 82:639-648.

FABIANEK, F., M. A. SIMARD, AND A. DESROCHERS. 2015. Exploring Regional Variation in Roost Selection by Bats: Evidence from a Meta-Analysis. PLoS One 10:e0139126-e0139126.

FINDLAY, S. V. AND R. M. R. BARCLAY. 2020. Acoustic Surveys for Bats are Improved by Taking Habitat Type into Account. Wildlife Society Bulletin 44:86-93.

FREY-EHRENBOLD, A., F. BONTADINA, R. ARLETTAZ, AND M. K. OBRIST. 2013. Landscape connectivity, habitat structure and activity of bat guilds in farmland-dominated matrices. Journal of Applied Ecology 50:252-261.

FRICK, W. F. 2013. Acoustic monitoring of bats, considerations of options for long-term monitoring. Therya 4:69-78.

FRICK, W. F., T. KINGSTON, AND J. FLANDERS. 2020. A review of the major threats and challenges to global bat conservation. Annals of the New York Academy of Sciences 1469:5-25.

FRICK, W. F., et al. 2012. Climate and Weather Impact Timing of Emergence of Bats. PLoS One 7:e42737.

GARLAND, L. AND S. MARKHAM. 2007. Is Important Bat Foraging and Commuting Habitat Legally Protected?

GIBB, R., E. BROWNING, P. GLOVER-KAPFER, AND K. E. JONES. 2018. Emerging opportunities and challenges for passive acoustics in ecological assessment and monitoring. Methods in Ecology and Evolution 10:169-185.

GIBSON, J. S. AND R. B. COCROFT. 2018. Vibration-guided mate searching in treehoppers: directional accuracy and sampling strategies in a complex sensory environment. Journal of Experimental Biology 221:jeb175083.

GOERLITZ, H. R. 2018. Weather conditions determine attenuation and speed of sound: Environmental limitations for monitoring and analyzing bat echolocation. Ecology and Evolution 8:5090-5100.

GOLLER, B., P. S. SEGRE, K. M. MIDDLETON, M. H. DICKINSON, AND D. L. ALTSHULER. 2017. Visual Sensory Signals Dominate Tactile Cues during Docked Feeding in Hummingbirds. Frontiers in Neuroscience 11:622.

GOODENOUGH, A. E., L. DEANS, L. WHITELEY, AND S. PICKERING. Later is Better: Optimal Timing for Walked Activity Surveys for a European Bat Guild. Wildlife Biology 21:323-328.

GWATE, O., S. K. MANTEL, A. R. PALMER, AND L. A. GIBSON. 2018. Biophysical controls of water vapour and energy fluxes: Towards the development of biome scale predictive models of evapotranspiration in the Albany Thicket, South Africa. Ecohydrology 11:e2031.

HALL, L. K., C. T. LAMBERT, R. T. LARSEN, R. N. KNIGHT, AND B. R. MCMILLAN. 2016. Will climate change leave some desert bat species thirstier than others? Biological Conservation 201:284-292.

HAUSMANN, A., T. TOIVONEN, V. HEIKINHEIMO, H. TENKANEN, R. SLOTOW, AND E. DI MININ. 2017. Social media reveal that charismatic species are not the main attractor of ecotourists to sub- Saharan protected areas. Scientific Reports 7:763-769.

HULGARD, K. AND J. M. RATCLIFFE. 2016. Sonar sound groups and increased terminal buzz duration reflect task complexity in hunting bats. Scientific Reports (Nature Publisher Group) 6:21500.

HUZZEN, B. E., A. M. HALE, AND V. J. BENNETT. 2020. An effective survey method for studying volant species activity and behavior at tall structures. PeerJ (San Francisco, CA) 8:e8438.

INATURALIST.ORG. 2020. iNaturalist. https://www.inaturalist.org. Accessed on September 15, 2020.

IUCN. 2021. The IUCN Red List of Threatened Species. Version 2021-3. https://www.iucnredlist.org. Accessed on March 29, 2022.

JONES, G., D. JACOBS, T. H. KUNZ, AND P. RACEY. 2009. Carpe noctem: The importance of bats as bioindicators. Endangered Species Research 8:93-115.

KERBIRIOU, C., Y. BAS, I. LE VIOL, R. LORRILLIERE, J. MOUGNOT, AND J. F. JULIEN. 2019. Potential of bat pass duration measures for studies of bat activity. Bioacoustics (Berkhamsted) 28:177-192.

KHERADMAND, B., J. CASSANO, S. GRAY, AND J. C. NIEH. 2018. Influence of visual targets and landmarks on honey bee foraging and waggle dancing. Insect Science 27:349-360.

KLOEPPER, L. N., A. M. SIMMONS, AND J. A. SIMMONS. 2019. Echolocation while drinking: Pulse-timing strategies by high- and low-frequency FM bats. PLoS One 14:e0226114.

KOHLES, J. E., G. G. CARTER, R. A. PAGE, AND D. K. N. DECHMANN. 2020. Socially foraging bats discriminate between group members based on search-phase echolocation calls. Behavioral Ecology 31:1103-1112.

KORINE, C., R. ADAMS, D. RUSSO, M. FISHER-PHELPS, AND D. JACOBS. 2016. Bats and Water: Anthropogenic Alterations Threaten Global Bat Populations. Pp. 215-241 in Bats in the Anthropocene: Conservation of Bats in a Changing World (Voigt CC and Kingston T eds.), Springer International Publishing, Cham.

LEMEN, C., P. W. FREEMAN, J. A. WHITE, AND B. R. ANDERSEN. 2015. The Problem of Low Agreement among Automated Identification Programs for Acoustical Surveys of Bats. Western North American Naturalist 75:218-225.

LEWANZIK, D., A. K. SUNDARAMURTHY, H. R. GOERLITZ, AND E. DERRYBERRY. 2019. Insectivorous bats integrate social information about species identity, conspecific activity and prey abundance to estimate cost–benefit ratio of interactions. Journal of Animal Ecology 88:1462-1473.

LILLIE, K. M., E. M. GESE, T. C. ATWOOD, AND S. A. SONSTHAGEN. 2018. Development of on-shore behavior among polar bears (*Ursus maritimus*) in the southern Beaufort Sea: inherited or learned? Ecology and Evolution 8:7790-7799.

LUO, J., K. KOSELJ, S. ZSEBŐK, B. M. SIEMERS, AND H. R. GOERLITZ. 2014. Global warming alters sound transmission: differential impact on the prey detection ability of echolocating bats. Journal of the Royal Society Interface 11:20130961.

MAC AODHA, O., et al. 2018. Bat detective-Deep learning tools for bat acoustic signal detection. Journal of Computational Biology 14:e1005995-e1005995.

MACEWAN, K., S. SOWLER, J. ARONSON, AND C. LÖTTER. 2020. South African Best Practice Guidelines for Pre-construction Monitoring of Bats at Wind Energy Facilities. South African Bat Assessment Association.

MAHLALELA, P. T., R. C. BLAMEY, N. C. G. HART, AND C. J. C. REASON. 2020. Drought in the Eastern Cape region of South Africa and trends in rainfall characteristics. Climate Dynamics 55:2743-2759.

MARTÍNEZ-FONSECA, J. G., M. CHÁVEZ-VELÁSQUEZ, K. WILLIAMS-GUILLEN, AND C. L. CHAMBERS. 2020. Bats use live fences to move between tropical dry forest remnants. Biotropica 52:5-10.

MAYBERRY, H. W., P. A. FAURE, AND J. M. RATCLIFFE. 2019. Sonar strobe groups and buzzes are produced before powered flight is achieved in the juvenile big brown bat, *Eptesicus fuscus*. Journal of Experimental Biology 222:jeb209163.

MCALEXANDER, A. M. 2013. Evidence that bats perceive wind turbine surfaces to be water. Texas Christian University, Fort Worth, Tex.

MIKHEEV, V. N., A. F. PASTERNAK, A. Y. MOROZOV, AND J. TASKINEN. 2019. Innate antipredator behavior can promote infection in fish even in the absence of predators. Behavioral Ecology 31:267-276.

MILLS, C. G., R. J. ALLEN, AND R. A. BLYTHE. 2019. Resource spectrum engineering by specialist species can shift the specialist-generalist balance. Theoretical Ecology 13:149-163.

MILNE, D. J., A. FISHER, RAINEY, AND C. R. PAVEY. 2005. Temporal Patterns of Bats in the Top End of the Northern Territory, Australia. Journal of Mammalogy 86:909-920.

MOIR, M. I. 2014. The Habitat Use, Temporal Distribution and Preferred Weather Conditions of Tadarida aegyptiaca and Neoromicia capensis, and Its Application to Wind Farm Development in South Africa. ProQuest Dissertations Publishing.

MONADJEM, A., I. CONENNA, P. J. TAYLOR, AND M. C. SCHOEMAN. 2018. Species richness patterns and functional traits of the bat fauna of arid southern Africa. Hystrix-Italian Journal of Mammalogy 29:19-24.

MONADJEM, A., J. T. SHAPIRO, F. MTSETFWA, A. E. RESIDE, AND R. A. MCCLEERY. 2017. Acoustic Call Library and Detection Distances for Bats of Swaziland. Acta Chiropterologica 19:175-187, 113.

MONADJEM, A., P. TAYLOR, C. FDP, AND C. SCHOEMAN. 2020. Bats of southern and central Africa: a biogeographic and taxonomic synthesis.

MUÑOZ, A. E., G. OSSA, T. ZAVIEZO, AND C. BONACIC. 2019. Diversity and foraging activity of bats in cultivated and uncultivated areas in agroecosystems of a Mediterranean-climate hotspot. Neotropical biodiversity 5:36-40.

NELSON, J. J. AND E. H. GILLAM. 2020. Influences of Landscape Features on Bat Activity in North Dakota. The Journal of Wildlife Management 84:382-389.

NEWSON, S. E., Y. BAS, A. MURRAY, AND S. GILLINGS. 2017. Potential for coupling the monitoring of bush-crickets with established large-scale acoustic monitoring of bats. Methods in Ecology and Evolution 8:1051-1062.

NEWTON, E. J., B. R. PATTERSON, M. L. ANDERSON, A. R. RODGERS, L. M. VANDER VENNEN, AND J. M. FRYXELL. 2017. Compensatory selection for roads over natural linear features by wolves in northern Ontario: Implications for caribou conservation. PLoS One 12:e0186525.

NIELSEN, S. E., A. B. A. SHAFER, M. S. BOYCE, AND G. B. STENHOUSE. 2013. Does Learning or Instinct Shape Habitat Selection? PLoS One 8:e53721.

NIU, H., W. CHU, X. YI, AND H. ZHANG. 2019. Visual and auditory cues facilitate cache pilferage of Siberian chipmunks (*Tamias sibiricus*) under indoor conditions. Integrative Zoology 14:354-365.

NYQVIST, D., C. DURIF, M. G. JOHNSEN, K. DE JONG, T. N. FORLAND, AND L. D. SIVLE. 2020. Electric and magnetic senses in marine animals, and potential behavioral effects of electromagnetic surveys. Marine Environmental Research 155.

NYSTROM, G. S. AND V. J. BENNETT. 2019. The importance of residential swimming pools as an urban water source for bats. Journal of Mammalogy 100:394-400.

O'SHEA, T. J., P. M. CRYAN, D. T. S. HAYMAN, R. K. PLOWRIGHT, AND D. G. STREICKER. 2016. Multiple mortality events in bats: a global review. Mammal Review 46:175-190.

OLIVER, E. AND W. H. OLIVER. 2017. The Colonisation of South Africa: A unique case. Hervormde Teologiese Studies 73:1-8.

PÁEZ, D. J., O. RESTIF, P. EBY, AND R. K. PLOWRIGHT. 2018. Optimal foraging in seasonal environments: implications for residency of Australian flying foxes in food-subsidized urban landscapes. Philosophical Transactions Biological Sciences 373:20170097.

PARK, K. J. 2015. Mitigating the impacts of agriculture on biodiversity: bats and their potential role as bioindicators. Mammalian Biology 80:191-204.

PROESMANS, W., G. SMAGGHE, I. MEEUS, D. BONTE, AND K. VERHEYEN. 2019. The effect of mass-flowering orchards and semi-natural habitat on bumblebee colony performance. Landscape Ecology 34:1033-1044.

RAINHO, A. AND J. M. PALMEIRIM. 2011. The Importance of Distance to Resources in the Spatial Modelling of Bat Foraging Habitat. PLoS One 6:e19227.

RAZGOUR, O., C. KORINE, AND D. SALTZ. 2010. Pond characteristics as determinants of species diversity and community composition in desert bats. Animal Conservation 13:505-513.

RUSSELL, A. L., A. L. RUSSELL, C. R. NEWMAN, C. R. NEWMAN, D. R. PAPAJ, AND D. R. PAPAJ. 2017. White flowers finish last: pollen-foraging bumble bees show biased learning in a floral color polymorphism. Evolutionary Ecology 31:173-191.

RUSSELL, J. M. AND D. WARD. 2016. Historical Land-use and Vegetation Change in Northern Kwazulu-Natal, South Africa. Land Degradation & Development 27:1691-1699.

RUSSO, D., L. ANCILLOTTO, L. CISTRONE, AND C. KORINE. 2016. The Buzz of Drinking on the Wing in Echolocating Bats. Ethology 122:226-235.

RUSSO, D., L. CISTRONE, N. LIBRALATO, C. KORINE, G. JONES, AND L. ANCILLOTTO. 2017. Adverse effects of artificial illumination on bat drinking activity. Animal Conservation 20:492-501.

SALVARINA, I. 2016. Bats and aquatic habitats: a review of habitat use and anthropogenic impacts. Mammal Review 46:131-143.

SALVARINA, I., D. GRAVIER, AND K.-O. ROTHHAUPT. 2018. Seasonal bat activity related to insect emergence at three temperate lakes. Ecology and Evolution 8:3738-3750.

SCHIMPP, S. A., H. LI, AND M. C. KALCOUNIS-RUEPPELL. 2018. Determining species specific nightly bat activity in sites with varying urban intensity. Urban Ecosystems 21:541-550.

SIERADZKI, A. AND H. MIKKOLA. 2020. A Review of European Owls as Predators of Bats.

SINCLAIR, I., P. HOCKEY, N. ARLOTT, W. TARBOTON, AND P. HAYMAN. 2011. Birds of Southern Africa: The Region's Most Comprehensively Illustrated Guide. Princeton University Press.

SMIT, I. P. J., M. LANDMAN, R. M. COWLING, AND A. GAYLARD. 2016. Expert-derived monitoring thresholds for impacts of megaherbivores on vegetation cover in a protected area. Journal of Environmental Management 177:298-305.

SOŁOWCZUK, A. 2019. Determinants of the Performance of Bat Gantries Installed to Carry Bat Commuting Routes over the S3 Expressway in Poland. Symmetry (Basel) 11:1022.

SÖRENSEN, I., M. AMUNDIN, AND M. LASKA. 2019. Meerkats (*Suricata suricatta*) are able to detect hidden food using olfactory cues alone. Physiology & Behavior 202:69-76.

SOW, A., et al. 2020. Birds and bats contribute to natural regulation of the millet head miner in tree-crop agroforestry systems. Crop Protection 132:105127.

SPIESMAN, B. J., A. BENNETT, R. ISAACS, AND C. GRATTON. 2017. Bumble bee colony growth and reproduction depend on local flower dominance and natural habitat area in the surrounding landscape. Biological Conservation 206:217-223.

STIDSHOLT, L., R. MÜLLER, K. BEEDHOLM, H. MA, M. JOHNSON, AND P. T. MADSEN. 2020. Energy compensation and received echo level dynamics in constant-frequency bats during active target approaches. Journal of Experimental Biology 223:jeb217109.

STRAKA, T. M., P. E. LENTINI, L. F. LUMSDEN, S. BUCHHOLZ, B. A. WINTLE, AND R. VAN DER REE. 2020. Clean and Green Urban Water Bodies Benefit Nocturnal Flying Insects and Their Predators, Insectivorous Bats. Sustainability 12:2634.

STUART, C. AND M. STUART. 2015. Stuarts' Field Guide to Mammals of Southern Africa: Including Angola, Zambia & Malawi. Penguin Random House South Africa.

SUGAI, L. S. M., T. S. F. SILVA, J. W. RIBEIRO, AND D. LLUSIA. 2019. Terrestrial Passive Acoustic Monitoring: Review and Perspectives. Bioscience 69:15-25.

SUKSAI, P. AND S. BUMRUNGSRI. 2020. Water bodies are a critical foraging habitat for insectivorous bats in tropical agricultural landscapes of central Thailand. Wārasān Songkhlā Nakharin 42:521-532.

SVERDRUP-THYGESON, A., O. SKARPAAS, S. BLUMENTRATH, T. BIRKEMOE, AND M. EVJU. 2017. Habitat connectivity affects specialist species richness more than generalists in veteran trees. Forest Ecology and Management 403:96-102.

SWITALSKI, A. B. AND H. L. BATEMAN. 2017. Anthropogenic water sources and the effects on Sonoran Desert small mammal communities. PeerJ 5:e4003.

TAYLOR, P. J. 2000. Bats of souther Africa. Guide to biology, identification and conservation. University of Natal Press, Pietermaritzburg.

TAYLOR, P. J., E. MATAMBA, J. N. STEYN, T. NANGAMMBI, M. L. ZEPEDA-MENDOZA, AND K. BOHMANN. 2017. Diet Determined by Next Generation Sequencing Reveals Pest Consumption and Opportunistic Foraging by Bats in Macadamia Orchards in South Africa. Acta Chiropterologica 19:239-254, 216.

TAYLOR, P. J., S. SOWLER, M. C. SCHOEMAN, AND A. MONADJEM. 2013. Diversity of Bats in the Soutpansberg and Blouberg Mountains of Northern South Africa: Complementarity of Acoustic and Non-Acoustic Survey Methods. South African Journal of Wildlife Research 43:12-26, 15.

THOMAS, J. P. AND T. S. JUNG. 2019. Life in a northern town: rural villages in the boreal forest are islands of habitat for an endangered bat. Ecosphere (Washington, DC) 10:n/a-n/a.

TOUSSAINT, D. C., A. E. MCKECHNIE, AND M. VAN DER MERWE. 2010. Heterothermy in free-ranging male Egyptian Free-tailed bats (*Tadarida aegyptiaca*) in a subtropical climate. Mammalian Biology: Zeitschrift für Säugetierkunde 75:466-470.

TREMLETT, C. J., M. MOORE, M. A. CHAPMAN, V. ZAMORA-GUTIERREZ, AND K. S. H. PEH. 2019. Pollination by bats enhances both quality and yield of a major cash crop in Mexico. The Journal of Applied Ecology 57:450-459.

TRUBITT, R. T., T. J. HOVICK, E. H. GILLAM, AND D. A. MCGRANAHAN. 2019. Habitat associations of bats in a working rangeland landscape. Ecology and Evolution 9:598-608.

TUTTLE, S. R., C. L. CHAMBERS, AND T. C. THEIMER. 2006. Potential effects of livestock water-trough modifications on bats in northern Arizona. Wildlife Society Bulletin 34:602-608.

VAN TOOR, M. L., M. T. O’MARA, M. ABEDI-LARTEY, M. WIKELSKI, J. FAHR, AND D. K. N. DECHMANN. 2019. Linking colony size with quantitative estimates of ecosystem services of African fruit bats. Current Biology 29:R237-R238.

VOIGT, C. C., D. RUSSO, V. RUNKEL, AND H. R. GOERLITZ. 2021. Limitations of acoustic monitoring at wind turbines to evaluate fatality risk of bats. Mammal Review 51:559-570.

WIEDERHOLT, R., et al. 2015. Optimizing conservation strategies for Mexican free-tailed bats: a population viability and ecosystem services approach. Biodiversity and Conservation 24:63-82.

WILDE, L. R., L. GÜNTHER, F. MAYER, M. KNÖRNSCHILD, AND M. NAGY. 2018. Thermoregulatory Requirements Shape Mating Opportunities of Male Proboscis Bats. Frontiers in Ecology and Evolution 6.

WINTER, R., J. MANTILLA-CONTRERAS, AND S. SCHMIDT. 2020. Usage of buildings in the life cycle of two endangered *Rhinolophus* species in the Mediterranean region: implications for roost protection. European Journal of Wildlife Research 66.

WOODHALL, S. 2012. Field Guide to Butterflies of South Africa. Penguin Random House South Africa.

ZENGENI, R., V. KAKEMBO, AND N. NKONGOLO. 2016. Historical rainfall variability in selected rainfall stations in Eastern Cape, South Africa. South African Geographical Journal 98:118-137.

ZURCHER, A. A., D. W. SPARKS, AND V. J. BENNETT. 2010. Why the Bat Did Not Cross the Road? Acta Chiropterologica 12:337-340.

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Personal Background

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Education

2001	Diploma, Burleson High School, Burleson, TX
2018	Associates of Arts, Tarrant County College
2020	Bachelor of Science, Environmental Science, Texas Christian University
2022	Master of Science, Environmental Science, Texas Christian University

Experience

2020-Present	Teaching Assistantship, Texas Christian University
2019-2020	Undergraduate Research Assistant, Texas Christian University
2007-2017	Nuclear Electrician’s Mate, United States Navy

Presentations

McGee, J. and V. Bennett. 2022. The use of swimming pools by bats in a game reserve in South Africa Michael and Sally McCracken Student Research Symposium. Texas Christian University. Fort Worth, TX.

McGee, J. and V. Bennett. 2021. The use of swimming pools by bats in a game reserve in South Africa. 100th Annual Meeting of the American Society of Mammalogists. Virtual.

Awards

2021	$3,000 - ENSC graduate research grant award, Department of Environmental Sciences, Texas Christian University
2021	$1,500- SERC graduate research grant award, College of Science and Engineering, Texas Christian University
2021	Student Travel award - 100th Annual Meeting of the American Society of Mammalogists
2020	$400 - Newland Award, Texas Christian University

ABSTRACT

THE USE OF SWIMMING POOLS BY BATS IN A GAME RESERVE IN SOUTH AFRICA

By James McGee, M.S., 2022
School of Science and Engineering
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Thesis Advisor:	Dr. Victoria J. Bennett, Associate Professor of Environmental Science
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Wildlife is generally thought to preferentially select natural resources over anthropogenic resources and will only select these anthropogenic resources when preferred natural resources are unavailable or limited and the use of such resources in natural and semi-natural habitats is not yet well understood. Therefore, we explored the use of artificial water sources by bats in a semi-natural habitat by conducting acoustic monitoring surveys at two swimming pools on Amakhala Game Reserve in South Africa from 2018 to 2021 and behavioral observations at one of the swimming pools in 2021. Seven of 23 locally known species were identified in 22,893 recorded resource-related calls, including 1,356 feeding buzzes and 9,352 drinking buzzes. Furthermore, behavioral observation revealed that this is an underestimate of actual resource-related activity as ~70% of observed drinking activity was not acoustically recorded. This study illustrates how anthropogenic features could provide value to wildlife in a semi-natural habitat.