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# Mammal diversity and temporal activity patterns in a Mediterranean botanical garden: evidence for urban refuge function

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**Abstract**
**Purpose:** Urbanization drives habitat loss and fragmentation, posing significant challenges for terrestrial mammals in Mediterranean ecosystems. Structurally complex urban green spaces, such as botanical gardens, can serve as refuges and micro-scale protected areas within human-dominated landscapes. This study evaluated the diversity of mammalian species and large-mammal activity patterns in the Ali Nihat Gökyiğit Botanical Garden (ANGBG), a semi-isolated urban green space in southern Türkiye.
**Method:** From March 2022 to May 2023, camera traps, live traps, mist nets, ultrasonic bat detectors, and field-sign surveys were used to document mammal taxa. Independent camera-trap records were used to analyze activity patterns through kernel density-based temporal overlap analyses.
**Findings:** A total of 29 taxa across six orders were either directly detected or assessed as potentially occurring based on habitat suitability and regional literature. Camera traps yielded 236 independent records over 281 sampling days, identifying seven large mammal species. Activity analyses revealed predominantly nocturnal patterns in wild boar (*Sus scrofa*), beech marten (*Martes foina*), and Indian crested porcupine (*Hystrix indica*). In contrast, red fox (*Vulpes vulpes*) displayed a flexible bimodal diurnal and crepuscular pattern. Kernel density-based temporal overlap analyses indicated moderate overlap between red fox and other species and high overlap among nocturnal taxa.
**Conclusion:** These results indicate that temporal niche differentiation may facilitate coexistence within this spatially constrained urban green space. Even small, well-managed botanical gardens can support diverse mammal communities and function as urban refuges under increasing anthropogenic pressure. Urban green spaces, therefore, represent important components of biodiversity conservation in Mediterranean cities.

**Keywords:** behavioral plasticity, camera trapping, Mediterranean region, mammal community, temporal activity, urban refuge

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## Akdeniz Bölgesi'ndeki bir botanik bahçesinde memeli çeşitliliği ve zamansal aktivite örüntüleri: kentsel sığınak işlevine ilişkin bulgular

**Özet**
**Amaç:** Kentleşme, Akdeniz ekosistemlerinde karasal memeliler için önemli tehditler oluşturan habitat kaybına ve parçalanmasına neden olmaktadır. Botanik bahçeleri gibi yapısal olarak karmaşık kentsel yeşil alanlar, insan baskısının yoğun olduğu peyzajlarda sığınak ve mikro-ölçekli koruma alanları olarak işlev görebilmektedir. Bu çalışma, Adana'da yer alan yarı-izole bir kentsel yeşil alan olan Ali Nihat Gökyiğit Botanik Bahçesi'nde (ANGBG) memeli tür çeşitliliğini ve büyük memelilerin aktivite örüntülerini değerlendirmeyi amaçlamıştır.

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**Metod:** Mart 2022 – Mayıs 2023 tarihleri arasında fotokapanlar, canlı kapanlar, sis ağları, ultrasonik yarasa dedektörleri ve arazi iz-gözlem çalışmaları kullanılarak memeli taksonları belirlenmiştir. Bağımsız fotokapan kayıtları kullanılarak aktivite örüntüleri kernel yoğunluk temelli zamansal örtüşme analizleri ile değerlendirilmiştir.
**Bulgular:** Toplam altı takıma ait 29 takson doğrudan tespit edilmiş veya habitat uygunluğu ile bölgesel literatür verilerine dayanarak potansiyel olarak değerlendirilmiştir. Fotokapanlar 281 örnekleme günü boyunca 236 bağımsız kayıt sağlamış ve yedi büyük memeli türü tespit edilmiştir. Yaban domuzu (*Sus scrofa*), kaya sansarı (*Martes foina*) ve oklu kirpi (*Hystrix indica*) ağırlıklı olarak gececil aktivite göstermiştir. Buna karşılık, kızıl tilki (*Vulpes vulpes*) çift tepe noktası gösteren gündüz ve alacakaranlık aktivite örüntüsü sergilemiştir. Zamansal örtüşme analizleri, kızıl tilki ile diğer türler arasında orta düzeyde, gececil türler arasında ise yüksek düzeyde örtüşme olduğunu göstermiştir.
**Sonuç:** Elde edilen bulgular, zamansal niş farklılaşmasının mekânsal olarak sınırlı bu kentsel yeşil alanda birlikte varoluşa katkı sağlayabileceğini göstermektedir. Küçük ve iyi yönetilen botanik bahçeleri, artan antropojenik baskı altında çeşitli memeli komünitelerini destekleyebilir ve kentsel sığınak işlevi görebilir. Bu nedenle kentsel yeşil alanlar Akdeniz kentlerinde biyolojik çeşitliliğin korunmasında önemli bileşenlerdir.

**Anahtar kelimeler:** davranışsal esneklik, fotokapan, Akdeniz Bölgesi, memeli komünitesi, zamansal aktivite, kentsel sığınak

## 1. Introduction

Human activities are causing rapid deterioration of ecosystems globally, resulting in the degradation and, in some cases, the complete destruction of natural habitats [1]. This ecological disruption has significantly affected the Anatolian Peninsula, which contains three of the 34 global biodiversity hotspots: the Caucasus, Mediterranean, and Irano-Anatolian regions [2]. Türkiye supports a rich vertebrate fauna due to its unique biogeographical position at the intersection of these regions [3]. Urbanization and agricultural expansion represent major pressures on these ecosystems. These anthropogenic pressures reduce the availability of natural prey and suitable habitats, resulting in population isolation and disruption of ecological processes. Among terrestrial vertebrates, mammals that require large, continuous, and well-protected habitats for foraging, reproduction, and shelter are particularly affected by these environmental changes [4]. While some mammal populations decline or face local extinction, others, especially generalist and opportunistic species, may thrive and expand their range in response to resource availability associated with urbanization [5].

Botanical gardens, originally established for the protection, research, and exhibition of plant collections, have become increasingly important as wildlife habitats within urban environments [6]. As natural habitats are lost to urbanization, green spaces such as botanical gardens serve as refuges, supporting not only plant diversity but also terrestrial vertebrates, including amphibians, reptiles, birds, and mammals. With limited human intervention, these areas form relatively isolated ecosystems that offer protection from anthropogenic threats such as hunting and traffic [7]. Furthermore, they help mitigate the adverse effects of urbanization by providing food and shelter [8]. In response to urbanization, mammals increasingly use these protected areas as shelters and develop various adaptation strategies [9]. However, empirical evidence quantifying the refuge function of botanical gardens for mammals remains limited.

This study examines the diversity of mammal species in the Ali Nihat Gökyiğit Botanical Garden (ANGBG) in Adana province, using the ANGBG as a case study. The research aims to document mammal diversity and examine patterns of habitat use and activity within the garden. The primary hypothesis is that, despite their limited size, urban green spaces such as botanical gardens can provide critical habitats for mammals by mitigating the negative impacts of urbanization.

Additionally, it is hypothesized that large mammals using the botanical garden may adjust their activity patterns in response to urban conditions. To test this hypothesis, the daily activity patterns of large mammals were analyzed using camera trap data. The analysis assessed behavioral similarities and differences among species by evaluating their nocturnal, diurnal, and crepuscular activity patterns within the urban green space. These findings, together with data on species richness and behavioral patterns, provide valuable insights for the management of urban green spaces and the development of effective conservation strategies.

## 2. Materials and methods

### 2.1. Study area

ANGBG is located on the main campus of Çukurova University in the Sarıçam district of Adana, Türkiye, approximately 2.5 km from the city center (37° 3.014′ N, 35° 21.236′ E; Figure 1). The surrounding district has an urban population density of about 301 people/km² in 2023 [10]. The garden covers about 200 decares and is situated in a suburban area near Seyhan Dam Lake. The campus functions as a transitional buffer between the city's urban and rural areas. The garden contains diverse thematic collections, such as the Mediterranean Maquis Valley, Rock Garden, Palm Garden, and Medicinal and Aromatic Plants Garden.

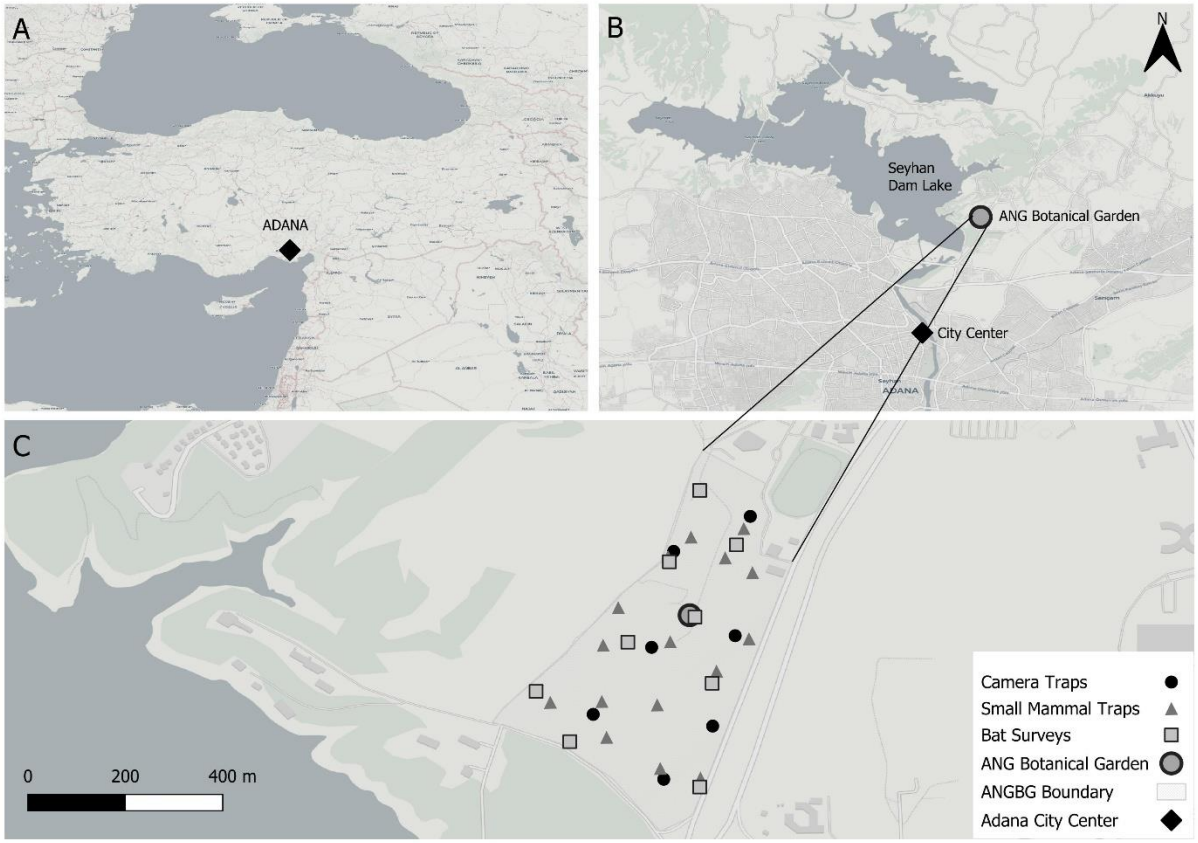



Figure 1. Location of the Çukurova University Ali Nihat Gökyiğit Botanical Garden (ANGBG) in southern Türkiye. (A) Geographic location of Adana Province within Türkiye. (B) Location of ANGBG in relation to Adana city center and Seyhan Dam Lake. (C) Detailed map of ANGBG showing sampling locations, including camera traps, small mammal traps, and bat survey sites

The study area has a Mediterranean-type climate. Summers are hot and dry, while winters are mild and wet. The average annual precipitation is around 625 mm, with most rainfall between November and March. The wettest months are December (125.1 mm) and January (112.1 mm). The driest months are June (22.1 mm) and July (10.1 mm). Average temperatures range from 9.6°C in January to 28.8°C in August. The highest average maximum temperature is 33.9°C in July, while the lowest average minimum is 5.3°C in January (data from the Turkish State Meteorological Service, 1929-2024). These climatic conditions support a variety of plant species. The garden is located within the boundaries of the Seyhan Dam Lake Wildlife Development Area, which has been designated for waterbird conservation since 2006.

The garden is fully enclosed by fencing to limit entry. Access is controlled, and visiting hours (08:30–16:30) are restricted to reduce human disturbance and maintain ecological stability. Despite being close to a main road and university facilities, the area contributes to relatively low levels of anthropogenic disturbance for both plants and animals.

### 2.2. Mammal sampling

Mammal surveys were conducted from March 2022 to May 2023 to cover all seasons and avoid missing potential seasonal variations in mammal species presence and large mammal activity patterns. Despite the predominantly human-modified nature of the garden habitats, these areas represent ecologically distinct structures; therefore, sampling was carried out across all habitat types. An opportunistic field methodology was used, combining direct sightings, indirect signs (e.g., tracks and feces), passive infrared camera traps, live traps, mist nets, and ultrasonic detectors.

Medium- to large-sized mammals were reliably identified using passive infrared camera traps, a widely accepted method for monitoring terrestrial mammals of this size class. Species detected by camera traps in this study were classified as large mammals. Four camera traps (Juo Night Vision Camera Trap, JH-780, and Bushnell Trophy Camera, 119476) were deployed to detect these species and assess their activity patterns (Figure 1). Cameras were positioned at stations along 1 m-wide natural animal trails and remained at each station for at least one month. If no target species were recorded during that period, the camera was moved to another trail. Cameras that continued to capture target species remained at the same station, resulting in a total of seven stations throughout the study. Odors and

baits were not used to avoid attracting free-ranging domestic dogs, which could introduce bias. All camera traps were checked at least once per week for maintenance and data collection. In addition to camera traps, signs such as tracks and feces were recorded when observed to confirm species presence.

Small mammal surveys were conducted at 16 sites within the garden using Sherman live traps to identify species during late summer (Figure 1). Traps were placed in locations where evidence of small mammals, such as burrows, feces, or food remains, was observed. Sampling was carried out over three consecutive nights at each site, with a minimum of 10 traps per night. Traps were spaced 2 to 10 m apart, depending on site characteristics, and were set before dusk and checked within three hours of sunrise to minimize the risk of overheating. Each trap contained a small piece of cotton for insulation and a small amount of peanut butter as an attractant. Trap sites were marked with flags to prevent re-sampling of the same locations. Captured individuals were identified to the species level and released at the capture site. Because the objective was to determine species composition rather than estimate abundance or density, individuals were not marked or recaptured.

Bat surveys were conducted in nine randomly selected areas within the garden (Figure 1) during the peak bat activity period (May–August in the Mediterranean region). Three sampling methods were used to identify bat species: ultrasonic detectors, mist nets, and roost inspections. The sampling covered all habitat types in the garden and was carried out over three consecutive nights at each site. A Pettersson D500X Ultrasound Detector/Recorder and BatSound software were used to monitor bat activity. The detector was placed 3 to 5 m above the ground to ensure an optimal detection range and operated continuously from dusk until dawn. Two mist nets were placed along artificial ponds, flyways, and fruit trees, specifically targeting the Egyptian Fruit Bat [*Rousettus aegyptiacus* (E. Geoffroy, 1810)]. Nets were set at heights of 2.5 to 3 m and lengths of 3 to 8 m. They were checked every 3 to 10 minutes, and captured individuals were carefully removed and immediately released after identification. Additionally, roosting sites, including mature trees, rock crevices, and anthropogenic structures such as houses and other buildings, were inspected to further assess the presence of bats.

### 2.3. Activity pattern analysis of large mammals

Daily activity patterns of large mammal species were assessed by analyzing timestamps from camera trap photographs. Photographs of the same species taken by the same camera trap within a one-hour interval were considered a single independent record, assuming they likely represented the same individual [11]. Given the relatively small size of the garden and the likelihood that individuals could pass through multiple stations in a short period, all records of the same species captured by different camera traps within the same one-hour interval were treated as a single record to minimize spatial bias. Photographs containing multiple individuals of the same species were also recorded as a single event.

Filtered records were used to calculate Relative Capture Frequency (RCF), defined as the number of independent records per 100 camera trap days (CTDs) [12]. To examine daily activity patterns, the number of records for each species was summarized across two-hour intervals and visualized using separate histograms. Only species with more than ten independent records were included in the analysis to ensure statistical robustness. Each record was grouped into one of three temporal activity classes based on local sunrise and sunset times: diurnal (05:00–18:00), nocturnal (18:00–05:00), and crepuscular (04:00–06:00 and 17:00–19:00) [13]. Chi-square ($\chi^2$) tests were used to assess whether activity levels differed significantly among the three categories, with $\alpha = 0.05$ as the threshold for statistical significance.

Temporal overlap was quantified among large mammal species and between mammals and human activity. For pairwise overlap analyses, the time of each independent camera trap record was converted to radians, and coefficients of temporal overlap ($\Delta 1$) were estimated using kernel density functions in the R package overlap [14]. The $\Delta 1$ estimator, recommended for relatively small sample sizes, was applied to all species pairs with more than 10 independent records. Confidence intervals were obtained using 1,000 bootstrap resamples based on percentile estimates. To assess potential temporal conflict with human presence, mammal records were classified as occurring either within or outside the garden's public visiting hours (08:30–16:30). For each species and for all large mammals combined, the proportion of independent records that overlapped temporally with human activity was calculated.

Sampling efficiency of camera traps was assessed by analyzing the relationship between the total number of CTDs and the number of independent records across stations using Pearson's correlation coefficient (r), to determine whether longer camera deployment durations increased the likelihood of detecting species.

## 3. Results

### 3.1. Species composition

A total of 29 mammal species, representing 16 families and six orders, were recorded in ANGBG or assessed as potentially occurring based on habitat suitability and regional literature. These species comprised bats, small mammals, and large mammals. Table 1 lists all mammal species in this study, their scientific names, IUCN

conservation status (including Mediterranean assessments), and identification methods. Each species is categorized according to its status in the study area as one of the following: Detected (confirmed through field sampling), Likely (supported by literature and habitat suitability), Possible (marginal or uncertain occurrence), or Unlikely (outside the expected range or ecological context). This approach allows the integration of field-based evidence with regional ecological knowledge.

Table 1. Mammal species detected or assessed for potential occurrence in the Ali Nihat Gökyiğit Botanical Garden (ANGBG), including conservation status and identification methods

| ORDO/Family | Scientific Name | Common Name | Status in ANGBG | IUCN (G/M) * | Identification Method |
|---|---|---|---|---|---|
| **EULIPOTYPHLA** | | | | | |
| Erinaceidae | *Erinaceus concolor* Martin, 1838 | Southern White-Breasted Hedgehog | Detected | LC/LC | Direct observation, feces |
| Soricidae | *Crocidura leucodon* (Hermann, 1780) | Bicolored Shrew | Detected | LC/LC | Sherman trap |
| | *Crocidura suaveolens* (Pallas, 1811) | Lesser White-toothed Shrew | Detected | LC/LC | Sherman trap |
| **CHIROPTERA** | | | | | |
| Pteropodidae | *Rousettus aegyptiacus* (E. Geoffroy, 1810) | Egyptian Fruit Bat | Detected | LC/NT | Mist net |
| Rhinolophidae | *Rhinolophus euryale* Blasius, 1853 | Mediterranean Horseshoe Bat | Possible | NT/VU | Literature [15] |
| Vespertilionidae | *Pipistrellus kuhlii* (Kuhl, 1817) | Kuhl's Pipistrelle | Detected | LC/LC | Ultrasonic detector |
| | *Hypsugo savii* (Bonaparte, 1837) | Savi's Pipistrelle | Likely | LC/LC | Literature [16] |
| | *Myotis blythii* (Tomes, 1857) | Lesser Mouse-eared Myotis | Unlikely | LC/NT | Literature [17] |
| **LAGOMORPHA** | | | | | |
| Leporidae | *Lepus europaeus* Pallas, 1778 | European Hare | Detected | LC/LC | Camera trap, feces |
| **RODENTIA** | | | | | |
| Sciuridae | *Sciurus anomalus* Gmelin, 1778 | Caucasian Squirrel | Detected | LC/LC | Direct observation |
| Gliridae | *Dryomys nitedula* (Pallas, 1778) | Forest Dormouse | Detected | LC/LC | Sherman trap |
| Cricetidae | *Microtus guentheri* (Danford & Alston, 1880) | Günther's Vole | Detected | LC/LC | Sherman trap |
| | *Nothocricetulus migratorius* (Pallas, 1773) | Gray Dwarf Hamster | Detected | LC/LC | Sherman trap |
| Muridae | *Apodemus flavicollis* (Melchior, 1834) | Yellow-necked Field Mouse | Detected | LC/LC | Sherman trap |
| | *Apodemus witherbyi* (Thomas, 1902) | Steppe Field Mouse | Detected | LC/LC | Sherman trap |
| | *Rattus rattus* (Linnaeus, 1758) | Black Rat | Detected | LC/NE | Sherman trap |
| | *Rattus norvegicus* (Berkenhout, 1769) | Brown Rat | Possible | LC/NE | Literature [18] |
| | *Mus musculus* Linnaeus, 1758 | House Mouse | Detected | LC/LC | Sherman trap |
| | *Mus macedonicus* Petrov & Ružić, 1983 | Macedonian Mouse | Likely | LC/LC | Literature [18] |
| | *Meriones tristrami* Thomas, 1892 | Tristram's Jird | Unlikely | LC/LC | Literature [18] |
| Spalacidae | *Nannospalax* sp. | Blind Mole Rat | Detected | NE/NE | Burrow observation |
| Hystricidae | *Hystrix indica* Kerr, 1792 | Indian Crested Porcupine | Detected | LC/LC | Camera trap, feces |
| **CARNIVORA** | | | | | |
| Canidae | *Canis aureus* Linnaeus, 1758 | Golden Jackal | Detected | LC/NE | Camera trap |
| | *Vulpes vulpes* (Linnaeus, 1758) | Red Fox | Detected | LC/LC | Camera trap, direct observation |
| Mustelidae | *Meles meles* (Linnaeus, 1758) | Eurasian Badger | Detected | LC/NE | Camera trap |
| | *Martes foina* (Erxleben, 1777) | Beech Marten | Detected | LC/LC | Camera trap, direct observation |
| | *Mustela nivalis* Linnaeus, 1766 | Least Weasel | Detected | LC/NE | Camera trap, direct observation |
| Herpestidae | *Herpestes ichneumon* (Linnaeus, 1758) | Egyptian Mongoose | Detected | LC/LC | Camera trap |
| **CETARTIODACTYLA** | | | | | |
| Suidae | *Sus scrofa* Linnaeus, 1758 | Wild Boar | Detected | LC/LC | Camera trap, feces |

***** IUCN categories follow the IUCN Red List (version 3.1): LC = Least Concern, NT = Near Threatened, VU = Vulnerable, DD = Data Deficient, NE = Not Evaluated. "G" indicates global assessment, and "M" indicates Mediterranean regional assessment (when available).

Large mammals were reliably recorded in ANGBG, primarily through camera traps, supplemented by indirect signs such as feces and direct observations. Herbivores included *Lepus europaeus*, found in semi-open scrublands, weedy patches, and field margins within suburban green areas, and *Sus scrofa*, which occurred in dense shrublands, wooded edges, and semi-open areas adjacent to protected green zones. Both species were confirmed using camera traps, with additional evidence provided by fecal records. Among rodents, *Hystrix indica* was a distinctive species detected on rocky slopes, bushy margins, and in semi-open areas with suitable ground cover and shelter; its presence was consistently verified by camera traps and fecal evidence. Carnivores were represented by several species. *Canis aureus* was detected in shrublands, field margins, and peri-urban ecotones adjacent to agricultural lands. *Vulpes vulpes* was among the most frequently recorded species, using shrub–grass mosaics, edge habitats, and semi-natural zones, and was confirmed by both camera traps and direct observations. In addition, *Meles meles* was recorded by camera traps, primarily in wooded patches and dense shrublands within the garden. *Martes foina* and *Mustela nivalis* were also detected, associated with rocky garden edges, wooded patches, dense ground vegetation, and rock piles near human-modified zones. Finally, *Herpestes ichneumon* was confirmed within the fenced garden and detected near habitat edges and linear landscape elements.

A diverse community of rodents and eulipotyphlans comprised the small mammal fauna of ANGBG. Confirmed rodents included *Sciurus anomalus*, which was directly observed in tree stands; *Dryomys nitedula*, captured in shrubby understory and stone piles; *Microtus guentheri* in open grassy fields; *Nothocricetulus migratorius* in semi-natural rocky clearings; *Apodemus flavicollis* and *A. witherbyi* in shrub–rock mosaics; *Rattus rattus* around building surroundings; and *Mus musculus* in anthropogenic structures. *Nannospalax* sp. was detected by observing its subterranean burrows in undisturbed green patches. Among eulipotyphlans, *Erinaceus concolor* was directly observed in shrub mosaics and semi-open areas, while *Crocidura leucodon* and *C. suaveolens* were captured in moist grassy edges and bushy undergrowth. Among taxa not directly confirmed, *Mus macedonicus* was considered likely due to the availability of open, grassy habitats. *Rattus norvegicus* was assessed as possible in highly urbanized areas and adjacent meadow-like patches. *Meriones tristrami* was regarded as unlikely; although reported in the regional literature, its distribution is associated with arid steppe and semi-desert habitats, which are absent from the study area.

Bats constituted a notable component of the mammalian fauna in ANGBG. *Rousettus aegyptiacus* was directly confirmed using mist nets, primarily occurring in urban green spaces with fruit trees and occasionally roosting in cavities of buildings within the garden. *Pipistrellus kuhlii*, detected through ultrasonic recordings, was another common species that frequently exploited illuminated areas near buildings and tree-lined corridors. Other species were inferred from habitat availability and regional literature. *Hypsugo savii* was considered likely, given the presence of building crevices and open, tree-dominated habitats suitable for foraging. *Rhinolophus euryale* was assessed as a possible species, based on the availability of potential roosting sites such as rocky crevices and anthropogenic structures. In contrast, *Myotis blythii* was regarded as unlikely; although reported in the regional literature, its preferred habitats, sparse woodlands and rocky slopes, are only marginally represented within the garden.

### 3.2. Temporal activity patterns of large mammals

During the one-year study period, a total of 236 independent camera trap records were obtained from 281 CTDs, representing seven large mammal species after filtering the camera trap photographs. Daily activity patterns were assessed for species with sufficient numbers of independent records (n > 10): *V. vulpes*, *M. foina*, *S. scrofa*, and *H. indica* (Table 2).

Table 2. Record numbers, RCF values, and first capture days of target species

| **Species** | **Record Number** | **RCF*** | **FCD**** |
|---|---|---|---|
| *Hystrix indica* | 101 | 35.94 | 1 |
| *Vulpes vulpes* | 69 | 24.56 | 18 |
| *Sus scrofa* | 41 | 14.59 | 6 |
| *Martes foina* | 15 | 5.34 | 54 |
| *Canis aureus* | 6 | 2.14 | 109 |
| *Meles meles* | 3 | 1.07 | 2 |
| *Herpestes ichneumon* | 1 | 0.36 | 246 |
| **Total** | **236** | **83.99** | |

* RCF: Relative Capture Frequency. RCF values are species-specific and therefore not additive.
** FCD: First Capture Day

*V. vulpes* showed activity across a broad time period, with most activity concentrated between sunrise and sunset. Most records were obtained between 06:00 and 20:00, showing a distinct bimodal daily activity pattern, with

activity peaking between 06:00 and 10:00 and 16:00 and 20:00. *M. foina* was recorded only at night and showed a typical nocturnal activity pattern. Most records were obtained between 20:00 and 04:00, with no daytime detections. *S. scrofa* displayed a predominantly nocturnal activity pattern. The highest number of records occurred between 20:00 and 02:00, with activity peaking around midnight and none during daylight hours. *H. indica* was also recorded only at night, with most records between 18:00 and 04:00. No *H. indica* activity was recorded from sunrise to sunset (Figure 2).

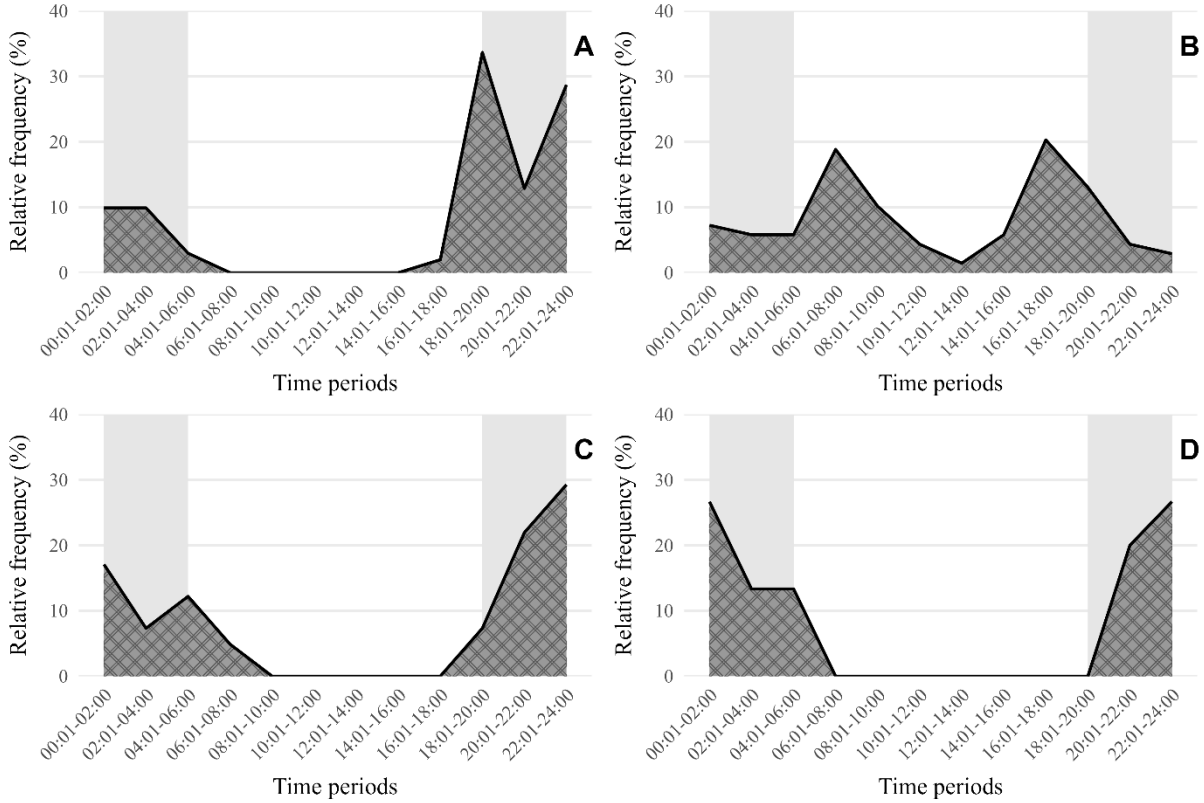



Figure 2. Daily activity patterns of large mammals recorded in ANGBG (n > 10 independent records). The x-axis shows two-hour time intervals over a 24-h cycle, and the y-axis represents relative activity frequency (%). The light-gray band marks nighttime (18:00–05:00), while the hatched dark-gray area indicates the intensity of activity. (A) *Hystrix indica*, (B) *Vulpes vulpes*, (C) *Sus scrofa*, (D) *Martes foina*

For all species included in the analysis, p-values were <0.05, indicating statistically significant differences among activity classes. According to the temporal distribution of records, *M. foina*, *S. scrofa*, and *H. indica* were classified as nocturnal or mainly nocturnal, whereas *V. vulpes*, although active at night, exhibited distinct diurnal–crepuscular activity peaks (Table 3).

Table 3. Daily activity preferences of target species (n > 10 independent records)

| | **Activity Class*** | | | |
|---|---|---|---|---|
| **Species** | **Nocturnal** | **Diurnal** | **Crepuscular** | **$\chi^2$ Values**** |
| *Hystrix indica* | 95.05 | 4.95 | 21.78 | 114.20 |
| *Vulpes vulpes* | 34.78 | 65.22 | 27.54 | 12.98 |
| *Sus scrofa* | 82.93 | 17.07 | 14.64 | 32.21 |
| *Martes foina* | 93.34 | 6.66 | 13.34 | 18.47 |

Crepuscular activity was calculated independently from nocturnal and diurnal activities
* Percentages (%) for activity classes of target species
** Chi-square values are significant at $P < 0.05$. df = 2 for all chi-square equations

Pairwise temporal overlap ($\Delta_1$) among large mammals revealed apparent differences in overlap patterns (Figure 3). Overlap ranged from $\Delta_1$ = 0.37 (*V. vulpes–M. foina*; 95% CI = 0.20–0.47) to $\Delta_1$ = 0.92 (*S. scrofa–M. foina*). Moderate overlap was observed between *V. vulpes* and *S. scrofa* ($\Delta_1$ = 0.42; 95% CI = 0.28–0.53) and between *V. vulpes* and *H. indica* ($\Delta_1$ = 0.45; 95% CI = 0.33–0.53), suggesting partial temporal segregation. In contrast, higher overlap was recorded among predominantly nocturnal species, including *H. indica–S. scrofa* ($\Delta_1$ = 0.75; 95% CI =

0.59–0.84) and *H. indica–M. foina* ($\Delta_1$ = 0.74; 95% CI = 0.52–0.80), indicating substantial sharing of nocturnal activity periods. *S. scrofa* and *M. foina* showed very high temporal overlap ($\Delta_1$ = 0.92); however, confidence limits should be interpreted cautiously because the bootstrap distribution was asymmetric under high overlap and unbalanced sample sizes.

A significant positive correlation was found between CTDs and the number of independent records (r = 0.93, p = 0.002), indicating a strong positive relationship between sampling effort and detection rates.

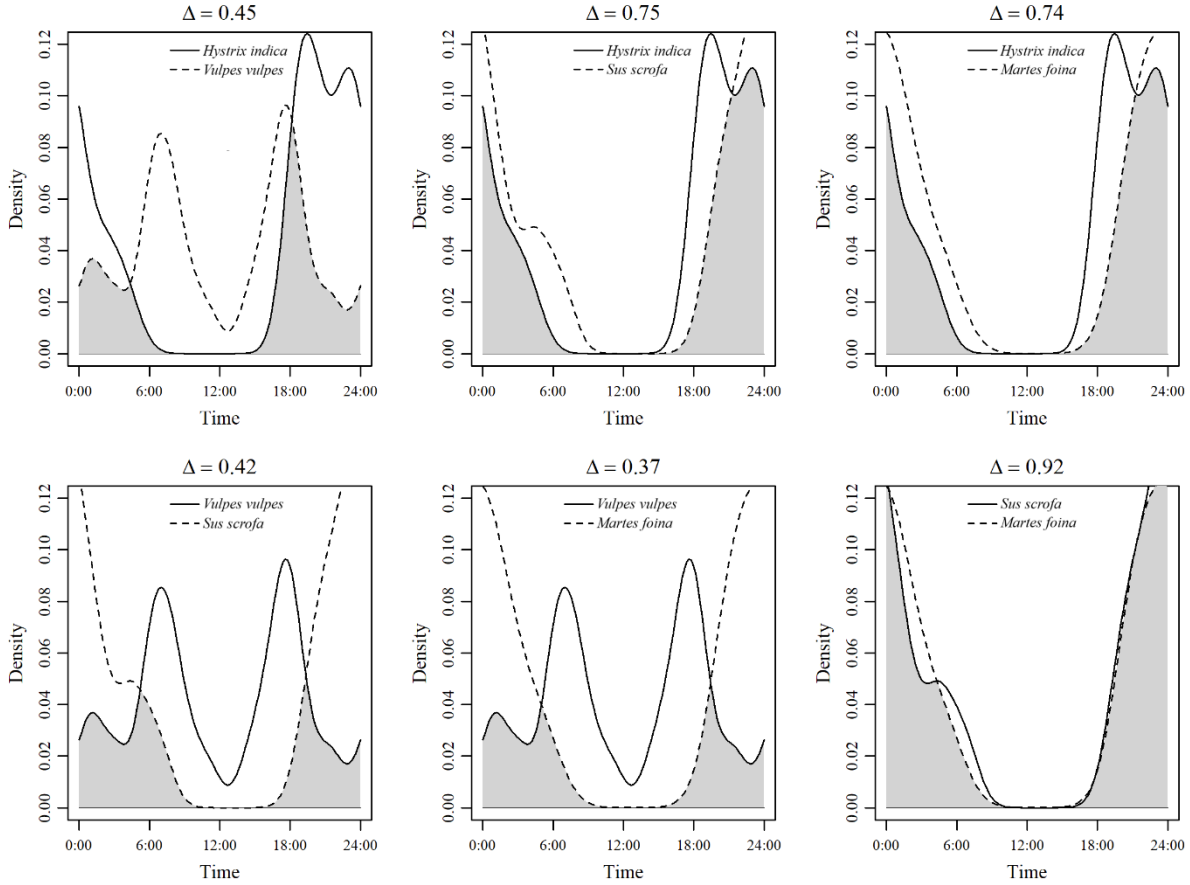



Figure 3. Comparative daily activity curves of large mammal species pairs recorded in ANGBG. Grey-shaded areas represent temporal overlap between species, while solid and dashed lines indicate kernel density estimates of daily activity patterns. Vertical tick marks along the x-axis indicate the timing of independent camera trap records for each species. Delta (Δ) values represent the coefficient of temporal overlap between species pairs

## 4. Discussion

This study shows that even small, semi-isolated urban green spaces can support diverse mammal communities. Although ANGBG covers only about 200 decares near Adana's urban core, field surveys and regional assessments indicated the presence or potential occurrence of 29 mammal taxa, including large mammals, small mammals, and bats. These findings support the view that botanical gardens provide ecological value beyond plant conservation by serving as urban refuges for vertebrate fauna [7].

The mammal assemblage observed in ANGBG demonstrates that botanical gardens with diverse vegetation, restricted access, and minimal human disturbance can serve as semi-natural islands within urban areas [7,8]. By providing shelter, food, and protection from threats such as hunting, traffic, and intensive land use, these gardens significantly contribute to urban biodiversity. They should be recognized as essential parts of urban ecological networks, not merely isolated green spaces [19]. The refuge provided by ANGBG results from both vegetation cover and reduced risks of human-caused mortality. Limited access, low hunting pressure, and less traffic create a controlled environment distinct from the surrounding city. In this way, ANGBG acts as a micro-scale protected area within a human-dominated landscape. However, persistence in these environments likely requires behavioral adaptation to urban disturbance. Activity patterns in large mammals suggest that species may adjust their behavior in response to ongoing human disturbance [20]. Therefore, ANGBG serves as both a spatial refuge and a behavioral filter, supporting species that can adapt their activity patterns to urban pressures.

The presence of mammal species across multiple trophic levels demonstrates a simplified but functionally coherent food web within ANGBG. Large herbivores, such as *S. scrofa* and *L. europaeus*, benefit from dense shrub cover, reduced human disturbance, and abundant local plant resources. In contrast, omnivorous and carnivorous species use both natural prey and anthropogenic food sources [21]. This trophic structure shows that ANGBG provides habitat for individual species and supports key ecological processes, including energy transfer and trophic interactions. By supporting herbivores, mesocarnivores, and omnivores in a spatially limited, human-dominated landscape, the garden acts as a localized ecological node that may help mitigate the effects of habitat fragmentation. In this context, botanical gardens can function as ecological stepping stones, promoting species persistence and movement across fragmented urban environments, even with limited spatial extent [1].

The mammal assemblage in ANGBG consists mainly of species that tolerate or adapt to human-modified environments. Commonly detected taxa, including *V. vulpes*, *S. scrofa*, *M. foina*, and *H. indica*, have broad diets and behavioral flexibility, which likely support their persistence in the garden [21]. In contrast, species associated with extensive steppe systems, forest interiors, or large natural habitats were not detected or rarely observed in our surveys. These findings indicate that the mammal community in ANGBG is a subset of the regional fauna shaped by local urban conditions, habitat configuration, and resource availability, rather than fully reflecting the surrounding landscape.

Small mammals and bats reflect the selective nature of urban habitats within ANGBG. Species associated with shrub cover, rocky substrates, and diverse microhabitats were frequently observed, suggesting the availability of varied ground-level conditions. In contrast, species associated with open steppe habitats or specialized ecological needs were not detected in our surveys. Bat assemblages showed a similar trend, with records dominated by species that tolerate urban environments and use artificial structures and fragmented foraging areas [22]. The presence of urban-adapted bats suggests that ANGBG offers suitable roosting and foraging opportunities in a heavily modified landscape, while also highlighting the limited suitability for more specialized species.

Our results show that *S. scrofa*, *M. foina*, and *H. indica* were primarily nocturnal, while *V. vulpes* displayed both crepuscular and diurnal activity peaks. These activity patterns reflect species-specific responses to human disturbance in ANGBG, with temporal adjustments supporting their persistence in a small, frequently visited urban green space [23]. The nocturnal behavior of *S. scrofa* and *H. indica* suggests that nocturnal activity may be associated with daytime human disturbance in urban and peri-urban areas. The exclusively nocturnal activity of *M. foina* suggests temporal avoidance of humans rather than habitat-structure limitations [24]. In contrast, the bimodal activity of *V. vulpes* indicates greater behavioral flexibility, which may explain its frequent detection and success in human-dominated landscapes [23].

Temporal overlap analyses suggest that large mammals in ANGBG may coexist through partial temporal segregation. Moderate overlap between V. vulpes and other species suggests some temporal partitioning, which may reduce direct encounters and competition [25]. In contrast, high overlap among nocturnal species such as *S. scrofa*, *H. indica*, and *M. foina* indicates shared use of nighttime hours, likely due to differences in diet, spatial use, or microhabitat selection rather than strict temporal separation [20]. These findings highlight the role of temporal niche adjustment in structuring mammal communities in small urban green spaces. Temporal adjustment may facilitate coexistence in limited urban habitats.

## 5. Conclusions

This study shows that small urban botanical gardens can support considerable mammal diversity and serve as functional refuges within highly modified landscapes. At ANGBG, species composition and activity patterns indicate that mammals adapt their spatial and temporal habitat use in response to urban pressures [9]. These results highlight the importance of integrating faunal considerations into botanical garden management by maintaining habitat heterogeneity, minimizing nighttime disturbance, reducing artificial lighting, and regulating visitor access [7]. In Mediterranean regions facing rapid urban expansion and ongoing habitat fragmentation, small protected green spaces may play a vital role in sustaining local biodiversity and should be recognized as key elements of urban ecological networks [19]. The findings suggest that small, well-managed urban green spaces can exert a disproportionate ecological influence relative to their size [5]. However, several limitations should be noted. The study was limited to a single botanical garden and did not compare results with adjacent rural habitats. Temporal activity analyses focused only on large mammals detected by camera traps, potentially excluding finer-scale behaviors of smaller species. As a result, these findings should be generalized cautiously beyond similar Mediterranean urban contexts. Future research comparing mammal composition, activity, and behavior in areas surrounding the garden and in nearby rural landscapes could provide further insight into how urbanization gradients influence mammal communities.

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**Author contributions:** Burak Akbaba designed the study. Burak Akbaba and Şafak Bulut conducted field surveys. Burak Akbaba, Şafak Bulut, Ahmet Karataş, and Halil Çakan contributed to data evaluation and interpretation. Burak Akbaba performed statistical analyses and drafted the manuscript. Halil Çakan provided logistical support and critical revision of the manuscript. All authors read and approved the final manuscript.

**Ethical statement:** Small mammals and bats were temporarily captured using live traps and mist nets and were released immediately after identification. No invasive procedures or experimental manipulations were performed. Therefore, this study does not require formal approval from an ethics committee.

**Data Availability Statement:** The raw data supporting the findings of this study are available from the corresponding author (B.A.) upon reasonable request and within ethical boundaries.

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