First record in over 40 years of the endemic *Gerbillus hesperinus* in Morocco using thermal imaging and live trapping in collaboration with mammalwatchers

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Abstract

The Moroccan Atlantic coast harbors a distinctive but poorly understood mammal fauna, including the endangered endemic gerbil *Gerbillus hesperinus*, a specialist of coastal sandy habitats not recorded for over 40 years. To assess its persistence, a multi-method survey integrating handheld thermal imaging with recording small mammal tracks and live trapping was conducted over seven nights in March 2026 near Essaouira. Across a sampling effort of 750 live trapping nights and 43.45 km of nocturnal thermal transects, we recorded five *G. hesperinus* and seven *G. campestris*. All *G. hesperinus* records were restricted to sandy, sparsely vegetated coastal dunes near the village of Ouassane. Detection was exceptionally low, potentially indicating a low population density. Morphological examination confirmed hairy foot-soles and revealed a field-identification trait: a grey patch below the eye in *G. hesperinus*, compared to the entirely white facemask of *G. campestris*. These findings confirm the persistence of *G. hesperinus* after more than four decades with no records, while also indicating a low population density in an extremely restricted range highly vulnerable to anthropogenic pressures such as invasive vegetation and recreational development. Consequently, we advocate for immediate conservation measures focused on the remaining dune habitats around Ouassane, as well as a formal reassessment of the species' current IUCN Red List status. More broadly, we showcase the potential of integrating thermal imaging citizen science to locate data-deficient small mammals.

Key words: North Africa, Citizen Science, Coastal Dunes, Cryptic Species, Atlantic Coast, Lost Species, Range restricted species, Mammal Conservation

1 Introduction

Morocco harbours a distinctive mammal fauna with several endemic and poorly known taxa. Despite increased attention in recent years (Aulagnier et al., 2017), significant gaps persist in the knowledge of the distribution and conservation status of many species. For example, the presence of *Mustela putorius* Linnaeus, 1758 and *Suncus etruscus* Savi, 1822 in Morocco remains unclear without recent records (Aulagnier et al., 2017). A notable case is the endemic *Gerbillus hesperinus* Cabrera, 1906, a member of a group of hairy-footed gerbils specialised to sandy Atlantic coastal dunes. The last confirmed records of *G. hesperinus* date back more than 40 years (pers. communication S. Aulagnier). While some publications suggest a wider historical distribution including Cape Tafelney, most historical records were from the immediate area surrounding Essaouira (Lay, 1975; Aulagnier et al., 2017). This area has since experienced extensive human development. A survey in 2012 failed to document any *G. hesperinus* (Ndiaye et al., 2012). The species' habitat has been described as coastal dunes with *Juniperus phoenicea* L. and *Retama monosperma* (L.)

Boiss. (Zyadi 1986). Such habitat still exists around Essaouira, particularly in the South towards Ouassane, but it is not known if the species occurs there. Of the Atlantic coastal gerbils, *G. hesperinus* is considered the most threatened species (Aulagnier et al., 2017; Denys & Bouarakia, 2022; Benazzou, 2025), due to its very restricted distribution. With no confirmed records in more than 40 years, it remains uncertain whether the species still survives in the wild.

Gerbils are challenging and time-intensive to survey. Population density can fluctuate, and reliable species identification often requires handling or genetic confirmation. Consequently, citizen-science and incidental records are rare for many species. Targeted live trapping has traditionally been the standard survey method for small mammals, including gerbils, but it is labour-intensive and often inefficient when population densities are low (Thomas et al., 2020). Recording of small mammal signs such as burrows and footprints can indicate areas of activity, but species-level identification is often difficult. Thermal imaging may offer a complementary approach for detecting small mammal presence. This technique is widely used by mammalwatchers (people looking for mammals as a recreational activity; Dinets and Hall, 2018) and has recently shown advantages over other traditional sampling methods such as tracking tunnels (Weinberger & Briner, 2025). In particular, thermal imaging allows larger areas to be surveyed more efficiently than conventional live trapping. Individuals can be located directly, photographed and if necessary, captured using hand nets, reducing by-catch associated with live traps and allowing animals to be processed immediately rather than remaining in traps. When combined with live trapping, thermal imaging can also guide strategic trap placement. Although this integrated approach represents a promising method for surveying small mammals, its application remains largely unexplored.

Despite the conservation importance of *G. hesperinus* and recent advances in survey techniques, the species has remained undocumented for more than 40 years. We combined thermal imaging with recording small mammal tracks and live trapping to investigate the persistence of *G. hesperinus* within its historical range. Specifically, we aim to document the persistence of *G. hesperinus*, characterise its habitat and associated small mammal community, and discuss its conservation status and potential threats.

2 Materials and Methods

2.1 Study species

Within the group of the Atlantic coastal gerbils, *G. hesperinus* represents the northernmost species, with most historical records around Essaouira (Aulagnier et al., 2017). *Gerbillus hesperinus* is geographically isolated by the High Atlas Mountains from *Gerbillus hoogstraali*

Lay 1975, which occurs further South in the Agadir region. Even further south, *Gerbillus occiduus* Lay 1975 replaces *G. hoogstraali*. All these species belong to the *Gerbillus* sub-genus clade. However, phylogenetic analyses indicate that *G. hesperinus* and *G. hoogstrali* are more closely related, forming sister clades (Granjon et al., 2018; Touria Benazzou, 2025). While there were some uncertainties about species status in the past, the carotype of *G. hesperinus* is distinctive among the other gerbil species, reported as 2n = 58, with the fundamental number reported as NF = 76 (Viegas-Pequignot et al., 1984) or NF= 78 (Ndiaye et al., 2012). Also, morphologically *G. hesperinus* is different from other gerbils, with hairy foot-soles, a head-body to tail ratio of around 115 %, a small brush at the tip of the tail and differences in skull structures (Aulagnier et al., 2017; Zyadi, 1986).
Within the surveyed region, the local Gerbillus assemblage is restricted to two sympatric species: *Gerbillus hesperinus* and *Gerbillus campestris Loche 1867*. These two species are readily differentiated in the field by the distinct presence of hair on the plantar surface of the hind feet soles in *G. hesperinus*, a trait absent in *G. campestris* (Supplementary Figure S1). Identifications were further supported with a combination of standard morphometric measurements (Aulagnier et al., 2017; Denys & Bouarakia, 2022; Aulagnier et al., 2025).

2.2 Study Area

The study area was chosen based on past historical records and the presence of potentially suitable habitat in the region around the city of Essaouira extending to Cape Tafelney (Supplementary Figure S2). The Essaouira coastal region (Figure 1) is situated at the southern margin of the Moroccan Atlantic central plains and plateaus, bordering the westernmost extension of the High Atlas Mountains. The region is characterised by a hot, semi-arid climate (Chauveau et al., 2026), buffered by the Atlantic Ocean, with a mean annual precipitation of approximately 309 mm. Average maximum daily temperatures range from 19 °C in January to 27 °C in August (*Weather & Climate.com*, 2026).

The Moroccan Atlantic coast is heavily influenced by persistent north-easterly trade winds, which occur on average of 250 days per year (*Weather & Climate.com*, 2026). Driven by this high wind energy and the prolonged dry season, the coastal geomorphology of the Essaouira region is highly dynamic and strongly shaped by wind. This results in extensive sand dune fields aligned parallel to the shoreline, interspersed with highly mobile intrusive dunes continuously migrating inland (Flor-Blanco et al., 2013).

Within this semi-arid coastal system, the vegetative structure is predominantly anchored by *J. phoenicea*, alongside localized *Eucalyptus* plantations situated North of Ouassane and in fragmented forest patches surrounding the Essaouira agglomeration. Moving inland, the

coastal dune scrub transitions into open woodlands dominated by *Tetraclinis articulata* (Vahl) Mast. and *Argania spinosa* (L.) Skeels. Throughout this coastal-to-inland gradient, the understory and stabilizing shrub layer is characterized by the widespread occurrence of *R. monosperma*, *Acacia cyclops* A.Cunn. ex G.Don, and *Lycium ferocissimum* Miers. Furthermore, patches of *Carpobrotus* sp. extensively colonize and stabilize dune faces south of Essaouira, whereas *Nicotiana glauca* Graham is more frequently distributed toward the inland sectors.

2.3 Sampling Design

Within the study area, sampling focused on habitats considered most suitable for *G. hesperinus*, namely sandy dunes, and historical locations (pers. communication S. Aulagnier, Supplementary Figure S2). Most of these sites were situated in the immediate surroundings of Essaouira, with additional locations including one further inland along Oued Ksob (Ndiaye et al., 2012), two south of a golf course, and one 45 km south at Cape Tafelney (Lay, 1975). Urbanized, heavily modified, or severely degraded areas within and around the city were excluded from the sampling design. Additionally, outside of the historical range, we visited a sand dune area near Tamri with no previous records of a hairy-footed *Gerbillus* species (Aulagnier et al., 2017), but with potentially suitable habitat.

To maximise detection probability of *G. hesperinus*, we used a multi-method approach (Garden et al., 2007) combining live trapping, recording indirect small mammal activity and thermal imaging surveys. We also recorded other mammal species present.

2.3.1 Live Trapping

Live trapping was conducted in five plots, ranging from 40 to 80 traps per plot within the study area (Figure 1) chosen based on habitat suitability and past records. In each plot, we installed 4 to 8 parallel trapping lines with 10 traps with approximately 10-meter intervals. Traps were set along habitat structures expected to be used by small mammals during their movements. Most lines were in parallel, separated by approximately 25 meters. Line trap placement was sometimes modified to cover more microhabitats. Exact GPS location of all traps was recorded. To reduce trap type bias, three live trapping models were used randomly: Longworth traps, Large Sherman traps (length of 7.6 x 8.9 x 22.9 cm cm), and Extra-Large Folding Kangaroo Rat Sherman traps (length of 7.6 x 9.5 x 30.5 cm). All traps were provisioned with bedding material (hay and non-absorbent cotton wool) for thermoregulation and baited with a mixture of apples, dates, oats, seeds, and peanut butter. No pre-baiting was done. Traps were opened before sunset and checked and closed shortly

after sunrise to avoid capturing animals during the heat of the day. Each plot was sampled over two consecutive nights. All captured individuals were quickly handled and released at the exact same location where they were trapped. In total, the sampling effort represented 750 trap nights (61 h of effort, including trap preparation and cleaning, for a team of two). During scouting for live-trapping locations and trap maintenance, we recorded signs of small mammal activity, namely tracks.

2.3.2 Thermal imagery surveys

Within the study area, we conducted nocturnal thermal imagery surveys along transects targeting different micro-habitats and locations of past records. Surveys on foot started post-sunset and were timed to limit moonlight, thereby maximizing detectable small mammal activity (Prugh & Golden, 2014). Survey teams were composed of two to four investigators walking along the transects using one to three handheld thermal imaging devices. The walking speed was approximately 3-4 km/h but could be higher in more open areas. All visual encounters of active small mammals were documented with precise GPS coordinates, date, and time. Upon detection, we used torches to confirm a gerbil observation and used butterfly nets to capture the individual. Gerbils were slowly pushed towards a strategically placed net (e.g. between two bushes) until they walked on it and could be caught. All captured specimens were immediately handled and released at the capture site to minimize handling time and associated stress. In total, we covered 43.45 km (n = 17, mean length ± SD = 2.6 ± 1.6 km) of transect with thermal surveys (roughly 31.5h of effort for a team of two; Figure 1). During thermals survey, we recorded signs of small mammal activity, namely burrows, fresh and old, given away by their thermal signature, as well as occasionally small mammal tracks. We also noted different species and gerbils we could not identify to species level.

2.4 Sample collection and processing

All captured individuals were handled for measurement and sample collection first. They were subsequently photographed (if fit and not lactating) and released at their exact capture locations. Precise GPS coordinates and time of the capture was recorded. If possible, standard morphometric data were recorded on captured individuals, including head and body length, tail length, hind foot length, and body mass. Non-lethal biological samples (a minimal dermal tissue excision using an ear punch) were collected from each specimen and immediately preserved in 96% ethanol for subsequent genetic analyses.

2.5 Environmental data collection

We documented environmental conditions using cameras and field observation with the aim to document the microhabitat in each site. In addition, we evaluated larger landscape changes using Google Earth Pro and its timelaps function, based on the oldest satellite pictures with sufficient resolution available from 2003 (South) and 2007 (North)

2.6 Ethical Note

Live trapping, handling and taking of genetic samples of *G. hesperinus* were conducted under permits issued by the relevant Moroccan authorities (Permit No. 14/26 issued in Rabat, February 25th 2026, by the Agence National des Eaux et Forêts). Animals were handled for identification, measurements and genetic samples and released at their point of capture after processing. All procedures were designed to minimize stress and handling time.

3 Results

3.1 Survey effort

Within the whole study area, we recorded five *Gerbillus hesperinus* and seven *Gerbillus campestris* (Figure 2, 3, Supplementary Table S1). Three separate individuals of *G. hesperinus* were captured in traps, with one individual being captured twice. Two additional individuals were captured during the thermal surveys. All individuals of *G. hesperinus* were captured in the vicinity of Ouassane. All individuals of *G. hesperinus* we encountered showed a grey patch below the eye (Figure 3). Among the seven *G. campestris* individuals, three were captured in traps and four during the thermal surveys. *Gerbillus campestris* was recorded throughout the study area, specifically in the surroundings of Ouassane, south of the wind farm and near Tamri.

In the northern part of the study area around Essaouira (Figure 1), we conducted thermal surveys only. Despite the presence of potentially suitable habitat and historical records (Aulagnier et al., 2017), we did not detect *G. hesperinus*. One *G. campestris* was caught in a very sandy habitat very close to the coast, just South of Essaouira. North and East of Essaouira, we did not manage to catch any Gerbils, although signs of small mammal activity were observed in areas considered potentially suitable for *G. hesperinus*.

The central part of the study area extended south of Essaouira towards the Ouassane area. The inland area between the city and village was partly characterised by denser vegetation, where we conducted extensive surveys based on historical records from this region (Supplementary Figure S2). However, only *G. campestris* was captured at these sites. The

coastal area was characterised by coastal dunes with sparse vegetation. Around Ouassane, we recorded *G. hesperinus*, in a total area smaller than 2 km², measured using a minimum convex polygon.

Towards Essaouira, the coastal habitat showed similarities but was also characterised by higher levels of anthropogenic disturbance, including invasive plant species (*Eucalyptus* sp. and *Carpobrotus* sp.), recreational activities such as ATV use, and the presence of a golf course. Also there, we detected signs of small mammal activity but did not capture any individuals.

Further in the South, we visited two sites. Around Cape Tafelney, we assessed habitats during a visit based on a historical record (Lay, 1975). Only very limited areas were identified as potentially suitable habitat, restricted to small areas of sandy dunes.
In the coastal area north of Tamri-Idorane, we conducted extensive thermal surveys (4.81 km across two transects) due to a possible suitability of this region for Atlantic coastal sand gerbils, given its position between the known distributions of *G. hesperinus* and *G. hoogstraali*. No individuals of either species were detected, and only one *G. campestris* was caught in a highly sandy microhabitat.

In all areas, we recorded evidence of probable gerbil activity with tracks and new and old burrows. Other wild mammals recorded included Algerian Hedgehog, North African Elephant Shrew and Mediterranean Hare (Supplementary Table S2), in addition to domestic sheep and donkeys, as well as feral cats and dogs. The catch per unit effort (CPUE), calculated on the basis of unit effort being 100 trap nights = 0,54 captures/100 trap nights for *G. hesperinus,* including the recapture (0,93 including *G. campestris*). During the thermal surveys, we captured 0.05 *G. hesperinus* per km of transect and 0.14 *Gerbillus* per km with *G. campestris* included.

3.2 Habitat

Habitats with captured *G. hesperinus* (Figure 2) were characterised by sandy ground near the coast with little vegetation on the ground and few scattered shrubs (Figure 3).
Gerbillus hesperinus G3 (Table S1) was captured in an open sandy valley with sparse vegetation consisting primarily of linearly growing *R. monosperma*, interrupted by corresponding linear sandy patches. The whole sandy valley was situated between two rocky hills to the east and west and leading towards the coast to the South. To the West, we captured G6 in sandy coastal dunes with sparse cover, but the widest variety of plants among all *G. hesperinus* sites. Individuals G2, G5 and G7 were captured on a wide sand dune South of the road to Oussane with *R. monosperma*, *J. phoenicea* and other ground

vegetation. Here, we also captured *G. campestris* G4. *Gerbillus campestris* G0 was captured in an area with stony ground, including some larger stones with diameters above 30 cm, and taller vegetation including shrubs. G1 was captured in a very sandy area, with small bushes including *Lycium ferocissimum*, many human footprints and a resident pack of stray dogs. G9-G11 were captured in a site with both stony and sandy undergrounds, with large bushes, but also more open, sandy habitat patches with sparse vegetation. Individual G8 was caught outside of the core study area near Tamri in a very sandy habitat in a patch of knee-high, dense vegetation.

Historical satellite imagery (Google Earth Timelapse) indicated substantial changes in land use within the study area since the early 2000s. These changes included the construction of a golf course and wind farm first visible in satellite imagery from 2007 in coastal areas in the vicinity of historical records of *G. hesperinus*. In the field, the presence of invasive vegetation (such as *Eucalyptus sp., Carpobrotus sp., Lycium ferocissimum*), tourism infrastructure and recreational activities were evident in several areas, especially closer to Essaouira, but the exact timeline is unclear.

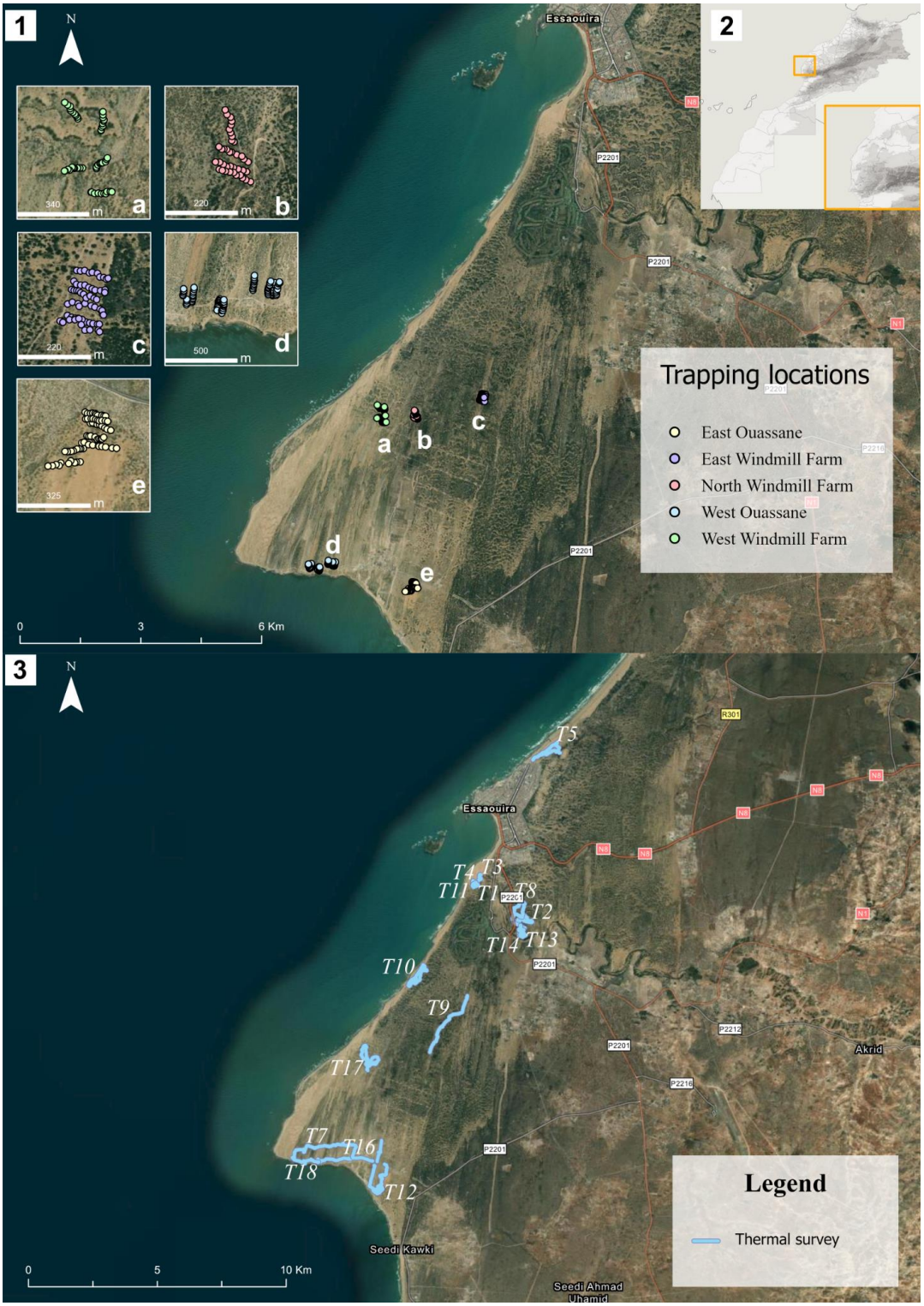


Figure 1: Study area with traplines and thermal survey transects. Panel 1 shows the location of the study area around Essaouira in Western Morocco, panel 2 and 3 respectively show an overview of the study area with the traplines (dots) and thermal transects (blue lines). Panel a through e are a detailed view of all trapping plots with individual traps positions. Basemap: Esri World Imagery 2026.

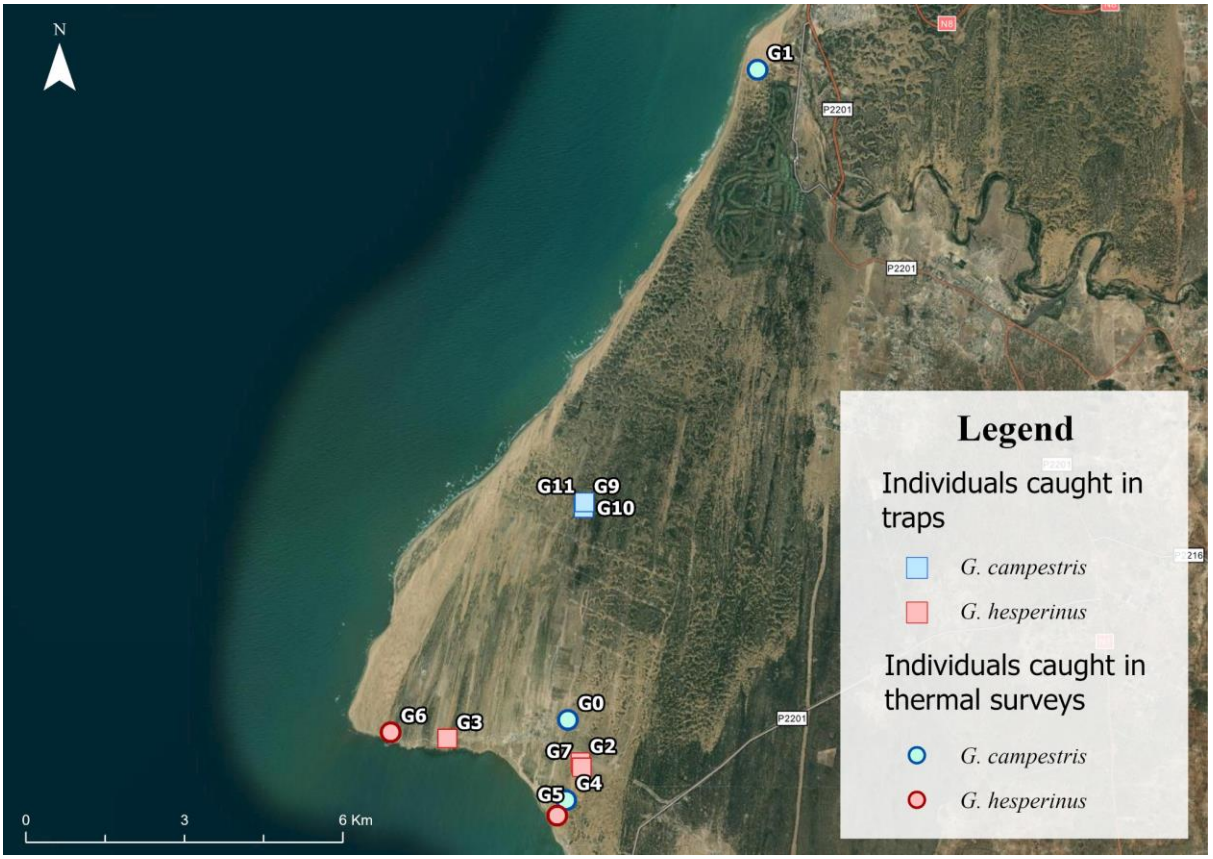


Figure 2: Map of caught Gerbils. *Gerbillus campestris* (blue), *Gerbillus hesperinus* (red). The symbol indicates if the animal was captured in a trap (square) or with a net during a thermal survey (circle). Basemap: Esri World Imagery 2026.



Figure 3: Pictures of *Gerbillus hesperinus* (a) and habitat shots (b-d). Pictures: Rayane Vuillemin.

4 Discussion

Our study resulted in the rediscovery of *Gerbillus hesperinus*, a species lost to science for more than 40 years. Using a combination of thermal surveys, small mammal track recordings and live trapping, we were able to document five individuals in a week of combined effort. Although these findings confirm the persistence of this species, the few detections suggest that the species may occur at low population density and that the

remaining population may be small. Records were restricted to a very small 2 km² area around Ouassane. Our findings suggest *G. hesperinus* may be highly threatened, and emphasize the need for targeted monitoring and appropriate conservation measures to ensure the long-term persistence of this Moroccan endemic species.

4.1 Identification of *Gerbillus*

The identification of the two occurring species was straightforward based on the presence of long hairs on the foot-soles; however, we could only identify individuals we were able to capture. We exclude other possible species, such as *G. hoogstraali* and *Gerbillus amoenus* De Winton 1902 based on morphological measurements (Table S1). We also noticed a potential difference in the facemask pattern between *G. campestris* and *G. hesperinus* undescribed in literature to our knowledge. *G. hesperinus* consistently showed a grey patch below the eye (Figure 3), whereas *G. campestris* had an entirely white facemask. This characteristic could facilitate field-identification and support the use of passive monitoring approaches such as photo-boxes (Littlewood et al., 2021).

4.2 Occurrences of *G. hesperinus* and microhabitat

All our records of *G. hesperinus* were in the central part of our study area, around Ouassane, particularly to the West and Southeast of the village. In the Southeast, we recorded the species on a large sandy dune with sparse vegetation. West of the village, records were made in coastal sandy valley bottoms, a habitat seemingly extending further inland, but due to difficult access into the area, we could not obtain additional records. Further North of the study area, we did check several places with historical records, including an area closer in presumed habitat to the record from 1985 in a large inland sandy area, where we only trapped *G. campestris*. Also surveys closer to the coast and around Essaouira itself were not successful, only locating one *G. campestris* overall, in very sandy habitat. Of course, the absence of *G. hesperinus* from historically documented locations should be interpreted cautiously, as our surveys did not comprehensively cover the full range of potential habitats or seasonal variation in detectability. Nevertheless, our results suggest suitable habitat may be highly fragmented and restricted to specific dune systems.

The habitat where we recorded *G. hesperinus* corresponds to previous descriptions in the literature, notably the presence of *J. phoenicea* and *R. monosperma* (Aulagnier et al., 2017). Within the study area, individuals were only recorded in the seemingly highest-quality, most untouched open sandy habitats in the southern part of the survey region, particularly around Ouassane. In contrast, in coastal areas in the North, with apparently similar habitat and detection probability, but greater anthropogenic influence (characterized by paths and ATV tracks) and invasive plant species (*Carpobrotus* sp. and *Eucalyptus* sp.), we did not manage

to locate any *G. hesperinus*. Compared to where we found *G. hesperinus* in this survey, the inland habitats of the Ouassane peninsula, characterized by stony hills and sandy valley bottoms, seem less suitable with denser vegetation and a different plant community.

The occurrence of *G. campestris* in several habitats where *G. hesperinus* was absent, including sandy coastal environments, is noteworthy. While the two species occasionally occurred in close proximity, their ecological relationship remains unclear. *Gerbillus campestris* appears to have broader habitat tolerance and may be less dependent on unconsolidated sandy substrates. Possibly, habitat changes favouring soil compaction and dune stabilisation, such as livestock grazing, recreational vehicle tracks, paths, and the spread of invasive plants, may create conditions more suitable for *G. campestris* than for the more specialised *G. hesperinus*.

Further surveys are required to determine the true distribution limits of *G. hesperinus*, quantify habitat associations, and evaluate potential effects of interspecific interactions as well as anthropogenic habitat change.

4.3 Conservation of *G. hesperinus*

Gerbillus hesperinus should be considered a species of high conservation priority, due to its endemic status in Morocco and its restricted range. Although its conservation importance has previously been recognized (Aulagnier et al., 2017; Aulagnier, 2019; Denys & Bouarakia, 2022; Benazzou, 2025), to our knowledge, no targeted conservation measures or long-term monitoring programs have been implemented.

We did not record any *G. hesperinus* in locations with historical records. The species could have declined in the last 40 years due to loss of habitat surface, quality, and connectivity. The available historical satellite imagery shows substantial landscape modifications, including the construction of a golf course and a wind farm. In both these areas, historical vegetation structure and ground cover seem similar to habitats with historical records of *G. hesperinus*. Additionally, the golf course and wind farm may now act as a dispersal barrier between habitats. Furthermore, in areas with historical records, habitat availability may have decreased due to the spread of invasive plant species and tourism activities.

Our few observations also suggest a very low population density and one small remaining population only.

Although difficult to quantify precisely, capture success was very limited, with only 3 captures (+ 1 recapture; +3 *G. campestris*) out of 750 trapping nights, and only 2 (+4 *G. campestris*) during 43 km/31.5 h of thermal surveys. In contrast, during a comparable survey for *G.*

hoogstraali near Souss-Massa conducted a few days later, we recorded multiple individuals of *G. hoogstraali* in a single night. *G. hoogstraali* is a species with a broadly similar ecology, yet our survey indicated a substantially different density. During a 45-minute thermal survey, we recorded several active individuals within a survey area of approximately 50 × 50 m. Traps placed directly adjacent to used burrows proved highly effective with two captures from ten traps within five hours, and an additional individual captured by hand net during the thermal survey. These three catches with a comparably small effort suggest the low *G. hesperinus* detections were unlikely to be solely a methodological artefact. This observation also suggests *G. hesperinus* may have more specific and higher habitat requirements than other Atlantic coastal gerbil species.

Population densities of both G. *hoogstraali* and *G. hesperinus* might have been temporarily elevated following the first substantial rainfall event in several years during 2025 and early 2026, potentially influencing these results. Further, species-specific differences in activity patterns and detection probabilities should be considered when interpreting these observations. Nevertheless, the population density of *G. hesperinus* seems very low.

Because our observations point towards a small remaining suitable habitat and a low population density and size, we recommend immediate conservation action to ensure the long-term survival of *G. hesperinus*. Conservation efforts should primarily focus on the remaining suitable habitat around Ouassane. Key measures should include regulation of the access to sensitive dune habitat to limit touristic activities, the prevention of large-scale construction around Ouassane and the control of invasive plant species. These actions should be accompanied by long-term monitoring programs to assess population trends and evaluate the effectiveness of conservation interventions. Finally, we also call for a reassessment of the IUCN Red List status of this species, which is currently classified as Endangered (EN) (Aulagnier, 2019), in light of the potentially very limited remaining suitable habitat, and potentially small population size.

4.4 Integrating thermal surveys and mammalwatchers to detect rare species

This study benefited from the involvement of mammalwatchers, whose motivation to participate in fieldwork and exchanges for opportunities to observe rare or interesting species provided valuable additional survey capacity. The widespread use of thermal imaging devices within this community has also increased their effectiveness in locating small mammals (pers. observation). Such collaborations have previously delivered interesting findings (Flannery et al. 2026) and could represent a mutually beneficial approach for further species searches or monitoring by facilitating both funding opportunities and field work. Thermal imaging has also recently gained wider application in scientific research

(Weinberger & Briner, 2025) and offers several advantages for small mammal surveys. In our study, advantages included comparatively large areas to be surveyed with relatively low effort compared to traditional trapping methods and the quick exclusion of non-target species, e.g. *Petrosaltator rozeti* Duvernoy, 1833. However, we still had to capture gerbils with a hand net to identify the species, a potentially risky procedure for the animal if not done carefully. Additionally, detection with thermal images and following capturing success can vary substantially across habitat types and species. Overall, in our study and with gerbils, the time investment per caught individual was broadly comparable between thermal surveys and live trapping.

Although our study was not specifically designed for comparing survey methods, it highlights the potential of combining conventional live trapping and small mammal sign surveys with thermal surveys. We recommend considering thermal imaging as a promising tool in small mammal research and monitoring.

Author contributions

The original idea for this search was from Rayane Vuillemin, who played a key role in the project realisation, conceptualisation, methodology and visualization together with Haytam Iallaten, Demian Hiß, and Valentin Moser. Haytam Iallaten, Demian Hiß, and Valentin Moser contributed jointly to formal analysis and writing of the original draft. Sidi Imad Cherkaoui organized the permits. Haytam Iallaten, Demian Hiß, Lorenz Achtnich, Hajar Boufrane, XabiClùa, Jeanne Magnin, Claudio S. Quilodrán, Rayane Vuillemin, Sandrine Wider and Valentin Moser contributed to the investigation through participation in the fieldwork. All authors contributed to reviewing and editing the manuscript.

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References

Aulagnier, S., Cuzin, F., & Thévenot, M. (2017). *Mammifères sauvages du Maroc: Peuplement, répartition, écologie*. Société française pour l'étude et la protection des mammifères.

Aulagnier, S. 2019. *Gerbillus hesperinus*. *The IUCN Red List of Threatened Species* 2019: e.T9128A90823992. Accessed on 01 October 2026.

Aulagnier, S., Haffner, P., Mitchell-Jones, T., Moutou, F., Zima, J., Borgese, J., Chevallier, J., Norwood, J., & Varela, J. M. (2025). *Field guide to mammals: Europe, North Africa and the Middle East* (Third edition). Bloomsbury Wildlife.

Chauveau, B., Pujol, A., & Mama, A. N. (2026). A Köppen–Geiger classification derivative tailored for numerical modeling of ecosystems within watershed dynamics. *Science of The Total Environment*, *1015*, 181445. https://doi.org/10.1016/j.scitotenv.2026.181445

Denys, C., & Bouarakia, O. (2022). *Les petits mammifères terrestres du Maroc, une biodiversité riche et méconnue* (Travaux de l'Institut Scientifique de Rabat).

Dinets, V. and Hall J. (2018). Mammalwatching: A new source of support for science and conservation. *International Journal of Biodiversity and Conservation. 10.* 10.5897/ijbc2017.1162.

Flannery, T.F., Aplin, K.P., Bocos, C., Koungoulos, L.G. and Helgen, K.M., (2026). Found alive after 6,000 years: modern records of an 'extinct'Papuan marsupial, Dactylonax kambuayai (Marsupialia: Petauridae), with a revision of the systematics and zoogeography of the genus Dactylonax. Contributions to the Mammalogy of New Guinea, 17-34.

Flor-Blanco, G., Flor, G., Lharti, S., & Pando, L. (2013). Morphological characteristics and sand volumes of different coastal dune types in Essaouira Province, Atlantic Morocco. *Geo-Marine Letters*, *33*(2), 101–115. https://doi.org/10.1007/s00367-012-0318-7

Garden, J. G., McAlpine, C. A., Possingham, H. P., & Jones, D. N. (2007). Using multiple survey methods to detect terrestrial reptiles and mammals: What are the most

successful and cost-efficient combinations? *Wildlife Research*, *34*(3), 218–227. https://doi.org/10.1071/WR06111

Granjon, L., Dobigny, G., Chevret, P., & Ndiaye, A. (2018). *Histoire évolutive et taxonomie intégrative dans le genre Gerbillus (Rodentia: Muridae)*.

Lay, D. M. (1975). *Notes on rodents of the genus Gerbillus (Mammalia: Muridae: Gerbillinae) from Morocco*. Field Museum of Natural History. https://doi.org/10.5962/bhl.title.4754

Littlewood, N. A., Hancock, M. H., Newey, S., Shackelford, G., & Toney, R. (2021). Use of a novel camera trapping approach to measure small mammal responses to peatland restoration. *European Journal of Wildlife Research*, *67*(1), 12. https://doi.org/10.1007/s10344-020-01449-z

Moores, R. & Brown, D. (2013). Range Extension, Identification and Habitat of Occidental Gerbil *Gerbillus occiduus*. *Go-South Bull.*, 10, 27–2

Ndiaye, A., Bâ, K., Aniskin, V., Benazzou, T., Chevret, P., Konečný, A., Sembène, M., Tatard, C., Kergoat, G. J., & Granjon, L. (2012). Evolutionary systematics and biogeography of endemic gerbils (Rodentia, Muridae) from Morocco: An integrative approach. *Zoologica Scripta*, *41*(1), 11–28. https://doi.org/10.1111/j.1463-6409.2011.00501.x

Prugh, L. R., and Golden, C. D. (2014). Does moonlight increase predation risk? Meta-analysis reveals divergent responses of nocturnal mammals to lunar cycles. *Journal of Animal Ecology*, *83*(2), 504–514. https://doi.org/10.1111/1365-2656.12148

Thomas ML, Baker L, Beattie JR, Baker AM. (2020) Determining the efficacy of camera traps, live capture traps, and detection dogs for locating cryptic small mammal species. *Ecol Evol,* 10(2):1054-1068.

Touria Benazzou. (2025). *Integrative taxonomy of Gerbillinae rodents in Morocco State of art in karyology, morphometric and phylogeny* (Hassan II Academy). Hassan II Academy. (Original work published Hassan II Academy Press)

Viegas-Pequignot, E., Benazzou, T., Prod'Homme, M., & Dutrillaux, B. (1984). Characterisation of a very complex constitutive heterochromatin in two Gerbillus species (Rodentia). *Chromosoma*, *89*(1), 42–47. https://doi.org/10.1007/BF00302349

Weather & Climate.com. (2026). World Weather & Climate Information. https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine,essaouira,Morocco

Weinberger, I. C., & Briner, T. (2025). Comparing thermal imagery and tracking tunnels to detect edible dormouse (Glis glis) and hazel dormouse (Muscardinus avellanarius). *European Journal of Wildlife Research*, *71*(6), 148. https://doi.org/10.1007/s10344-025-02031-1

Zyadi, F. (1986). *Etude de la répartition, du polymorphisme chromosomique et de la phylogénie de trois espèces de Rongeurs Gerbillidés (Gerbillus hesperinus, Gerbillus hoogstraali, Gerbillus occiduus)* [C.E.A Écologie, Génétique et Population]. Université Mohammed V.

Supplementary material



Figure S1: Comparative shots of the different footsole morphology between *Gerbillus campestris* (a) and *Gerbillus hesperinus* (b), with hair on the footsole present in *G. hesperinus*. Pictures Rayane Vuillemin.

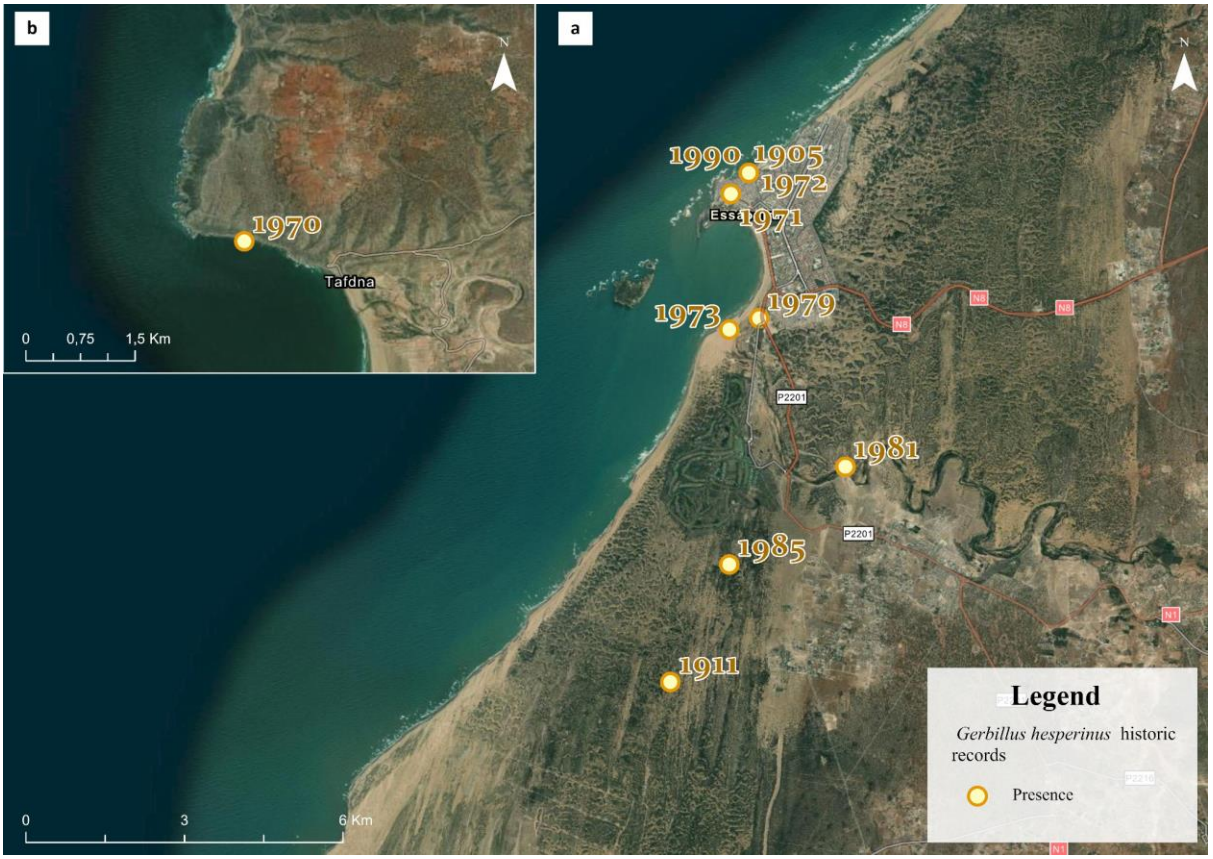


Figure S2: Historical records of *Gerbillus hesperinus* both in Essaouira region (a) and Cape Tafelney record (b) (most received through pers. communication S. Aulagnier). Ndiaye et al. (2012) found no presence of *G. hesperinus* at the 1981 location.

Table S1: Location, trapping method and indicative measurements of each caught gerbil. Indicative measurements because the live gerbils were measured in the field and measurements might be imprecise. This is especially the case for body length.

Animal ID	Species	Date	X	Y	Survey type	Sex	Head body lenght (mm)	Tail lenght (mm)	Hindfoot lenght (mm)	Ear lenght (mm)	Weight (g)	Remarks
G0	*campestris*	8/3/2026	31,3898	-9,8052	Thermal	-	-	-	-	-	-	
G1	*campestris*	9/3/2026	31,4842	-9,7730	Thermal	-	64,8	77,8	-	-	-	
G2	*hesperinus*	10/3/2026	31,3836	-9,8031	Traps (Long Sherman)	F	-	110,5	24,8	13,7	26,85	
G3	*hesperinus*	10/3/2026	31,3871	-9,8257	Traps (Standard Sherman)	M	93,9	109,4	24,7	13,7	36,28	
G4	*campestris*	10/3/2026	31,3781	-9,8055	Thermal	-	87	125	25	-	-	
G5	*hesperinus*	10/3/2026	31,3759	-9,8071	Thermal	-	93	103	26	-	-	
G6	*hesperinus*	10/3/2026	31,3880	-9,8353	Thermal	-	90,9	107,4	27,6	13,8		
G7	*hesperinus*	11/3/2026	31,3829	-9,8029	Traps (Longworth)	M	87,7	103,4	26,2	-	-	swollen testicles
G2	*hesperinus*	11/3/2026	31,3834	-9,8028	Traps (Longworth)	F	95,4	112,4	-	-	25,03	
G8	*campestris*	12/3/2026	30,7227	-9,8447	Thermal	-	-	-	-	-	-	Outside of core study area, near Tamri
G9	*campestris*	14/3/2026	31,4214	-9,8024	Traps (Longworth)	F	89	120	24	-	-	
G10	*campestris*	15/3/2026	31,4206	-9,8025	Traps (Standard Sherman)		-	-	-	-	-	
G11	*campestris*	15/3/2026	31,4214	-9,8024	Traps (Standard Sherman)	-	-	-	-	-	-	

Table S2: Mammal observations in the study area. Observed gerbils could not be reliably identified without catching them. Based on the distribution they could either be *Gerbillus campestris* or *Gerbillus hesperinus*. Observations were made during thermal surveys as well as during setting of the traps.

Species	**Date and Time**	**Latitude**	**Longitude**
Lepus sp	2026-03-09 20:27:16	31,4828587	-9,7730608
Atelerix algirus	2026-03-09 23:37:00	31,385725	-9,80435753
Atelerix algirus	2026-03-11 00:27:36	31,3775845	-9,80535603
Gerbillus sp	2026-03-11 21:01:43	31,4685879	-9,75632286
Gerbillus sp	2026-03-11 21:54:19	31,4661884	-9,75667477
Gerbillus sp	2026-03-12 21:36:32	30,7637978	-9,82586289
Atelerix algirus	2026-03-08 22:46:48	31,3901825	-9,80563736
Gerbillus campestris	2026-03-08 23:02:36	31,3897648	-9,80520153
Petrosaltator rozeti	2026-03-10 20:58:55	31,3861866	-9,82672882
Lepus sp	2026-03-10 22:31:19	31,3882847	-9,83545876
Atelerix algirus	2026-03-10 22:45:16	31,3906498	-9,83373356
Gerbillus sp	2026-03-10 22:54:20	31,3907604	-9,83213234
Lepus sp	2026-03-10 23:43:49	31,3921452	-9,82129097
Lepus sp	2026-03-11 00:13:39	31,3924427	-9,81568718
Gerbillus campestris	2026-03-10 23:03:01	31,3781948	-9,80552101
Gerbillus hesperinus	2026-03-11 00:07:03	31,3759022	-9,80708981
Gerbillus sp	2026-03-09 20:52:39	31,4841747	-9,77295685
Gerbillus sp	2026-03-09 21:49:42	31,4841957	-9,77298546
Lepus sp	2026-03-10 06:09:58	31,3909321	-9,82077026
Gerbillus sp	2026-03-12 21:38:36	30,7226563	-9,84473705
Vulpes vulpes	2026-03-13 00:07:21	30,9510098	-9,69801998
Vulpes vulpes	2026-03-13 17:27:45	31,4206429	-9,80998421
Lepus sp	2026-03-13 21:58:50	31,4531708	-9,79014778
Lepus sp	2026-03-13 23:37:37	31,4475155	-9,79517269

small mammal	2026-03-09 20:26:14	31,4840622	-9,77148533
small mammal	2026-03-09 20:31:08	31,4848023	-9,77075768
Gerbillus sp	2026-03-09 21:36:15	31,4843712	-9,77299309
small mammal	2026-03-10 21:34:13	31,3759918	-9,8056221
Gerbillus sp	2026-03-10 21:54:08	31,3770447	-9,8044014
Gerbillus sp	2026-03-10 22:42:58	31,3781166	-9,80552959
Gerbillus sp	2026-03-11 00:02:27	31,3758831	-9,80705738
small mammal	2026-03-09 20:26:14	31,4840622	-9,77148533
small mammal	2026-03-09 20:31:08	31,4848023	-9,77075768
Gerbillus sp	2026-03-09 21:36:15	31,4843712	-9,77299309
small mammal	2026-03-10 21:34:13	31,3759918	-9,8056221
Gerbillus sp	2026-03-10 21:54:08	31,3770447	-9,8044014
Petrosaltator rozeti	2026-03-13 21:46:28	31,3876324	-9,81626225