Short Note

Mina Cansu Karaer, Tolga Kankılıç and Çağatay Tavşanoğlu*

Population status and recent threats to the northernmost isolated population of the endangered mountain gazelle (*Gazella gazella*)

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Abstract: The endangered mountain gazelle (*Gazella gazella*) has experienced significant habitat loss across its range in the Middle East. We modelled the population growth of the northernmost isolated population in Hatay, Türkiye, scientifically rediscovered in 2008, using a logistic growth model, and quantified habitat suitability and its change over three decades with CORINE Land Cover data. Although the population has shown notable growth, the observed S-shaped curve indicates approach to carrying capacity. Key threats to the population include habitat loss due to agricultural expansion, the Türkiye-Syria border wall restricting dispersal, and competition with domestic herbivores. Targeted conservation strategies are needed, including habitat restoration, preventing agricultural encroachment, and translocations to ensure further population growth and expansion.

Keywords: anthropogenic pressures; conservation management; *Gazella gazella*; habitat fragmentation; population growth

Gazelles (genus *Gazella*) are small bovids distributed across arid and semi-arid regions in Africa, the Middle East, and South and Central Asia (Lerp et al. 2013; Mallon and Kingswood 2021). Of the 24 recognised *Gazella* taxa (Groves and Grubb 2011; Lerp et al. 2013), most are listed as Endangered or have gone extinct (IUCN SSC Antelope Specialist Group 2017). The mountain gazelle (*Gazella gazella* Pallas, 1766; Figure 1a), an endangered gazelle species from the Middle East, has experienced intense human pressure since the Pleistocene-Holocene transition (Munro et al. 2022), and has seen a marked contraction in its range over the past century due to habitat fragmentation and anthropogenic disturbances (Yom-Tov et al. 2021). Historically, it occurred along the Mediterranean coast of the Middle East, from Adana (Türkiye) to the Sinai Peninsula (Egypt) (IUCN SSC Antelope Specialist Group 2017). However, current populations survive mainly in Israel, Palestine, and Golan Heights (IUCN SSC Antelope Specialist Group 2017; Yom-Tov et al. 2021; Figure 1c), with an isolated northernmost population in Hatay, Türkiye (Kankılıç et al. 2012; Figure 1c).

The southern main population of this species has fluctuated considerably over the past century, driven downward by uncontrolled hunting and disease outbreaks, then partially rebounding under conservation efforts (Kaplan 2002; IUCN SSC Antelope Specialist Group 2017; Yom-Tov et al. 2021). As of 2020, this population includes approximately 5,000 individuals (Yom-Tov et al. 2021), with a well-connected population of ca. 3,000 individuals residing in northern Israel and the Golan Heights, and ca. 1,500 around central Israel, and the West Bank (Yom-Tov et al. 2021). Once presumed extinct, the Hatay mountain gazelle population was scientifically rediscovered through genetic analyses (Kankılıç et al. 2012; Saatoğlu et al. 2019), demonstrating the urgency of protecting this isolated population. The establishment of the Hatay Mountain Gazelle Wildlife Development Area (hereafter, WDA) and recent conservation measures have facilitated population recovery (Akman et al. 2017; Çoğal and Sözen 2017). Nevertheless, multiple pressures continue to endanger this northernmost population, emphasizing the need to re-evaluate its status and address critical challenges.

When the Hatay mountain gazelle population was first scientifically rediscovered in 2008 (Kankılıç et al. 2012), it was estimated that around 200 individuals were present in

***Corresponding author: Çağatay Tavşanoğlu**, Division of Ecology, Department of Biology, Hacettepe University, Beytepe, 06800, Ankara, Türkiye, E-mail: ctavsan@hacettepe.edu.tr. https://orcid.org/0000-0003-4447-6492
Mina Cansu Karaer, Institute of Science, Hacettepe University, Beytepe, Ankara, Türkiye; Division of Ecology, Department of Biology, Hacettepe University, Beytepe, 06800, Ankara, Türkiye; Food and Agriculture Vocational School, Çankırı Karatekin University, Çankırı, Türkiye; and Institute of Preclinical Sciences, Veterinary Faculty, University of Ljubljana, Ljubljana, Slovenia
Tolga Kankılıç, Department of Biology, Sabire Yazıcı Faculty of Science and Letter, Aksaray University, Aksaray, Türkiye

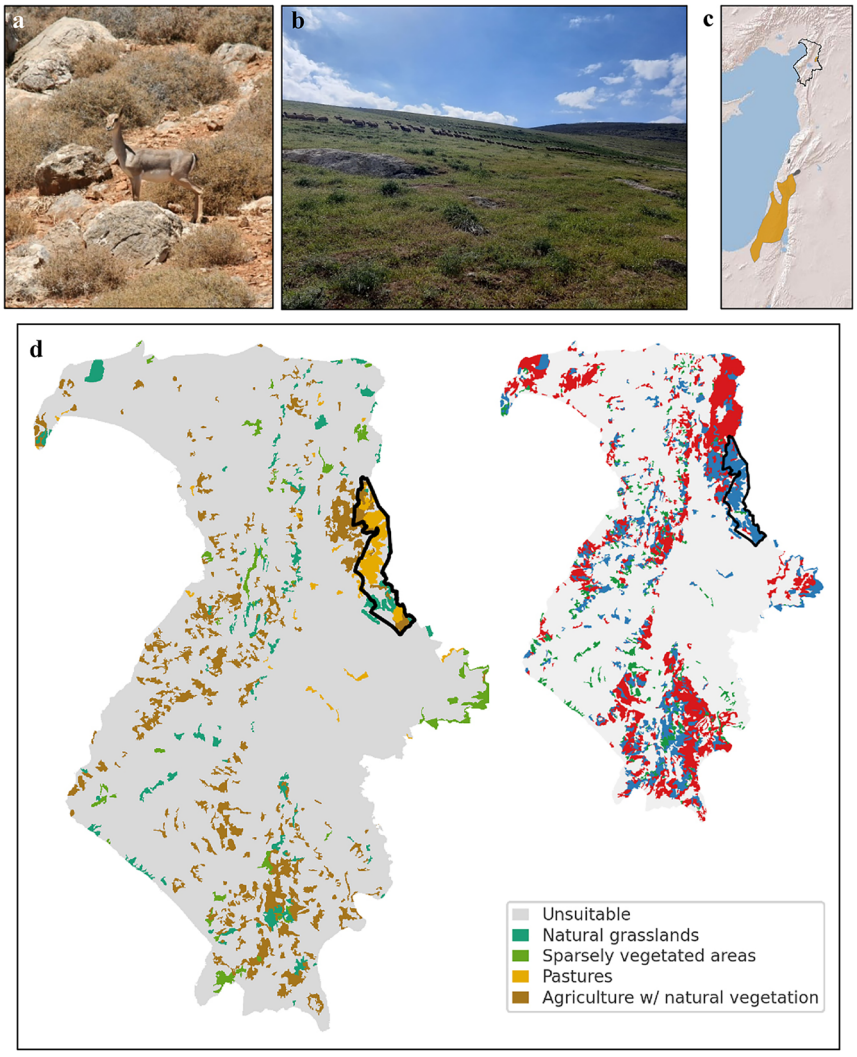

Figure 1: Distribution and habitat of the mountain gazelle (*Gazella gazella*). (a) A mountain gazelle in its natural habitat in Hatay, Türkiye. (b) A sheep flock in the study area. (c) Distribution range of *G. gazella* (IUCN SSC Antelope Specialist Group 2017); with the study population indicated by a red arrow, and Hatay Province outlined in black. (d) Habitat suitability (2018) and change (1990–2018) in Hatay Province from CORINE Land Cover; the Hatay Mountain Gazelle Wildlife Development Area is outlined in black. Inset map summarises 1900–2018 changes in suitable habitat (red = loss; green = gain; blue = unchanged).

the study area (Tolga Kankılıç, pers. observ.; IUCN SSC Antelope Specialist Group 2017; Yom-Tov et al. 2021). Despite intensive human pressures and habitat fragmentation, this small population persisted likely due to the local reverence for mountain gazelles as a sacred species and restricted access enforced by a military zone in the area, both of which have prevented hunting for decades. Alongside these protective factors, subsequent conservation initiatives following the scientific rediscovery of the population further promoted its growth over the past decade reaching ca. 1,500 individuals as of 2025 based on annual inventory counts (Figure 2). Given the observed growth in the Hatay mountain gazelle population, it can be inferred that the species action plan (Akman et al. 2017) has played a key role in ensuring its successful conservation.

To understand the growth dynamics in the Hatay mountain gazelle population and to calculate its carrying capacity based on population data over years, we fit a logistic growth model using "*nls*" function in R (R Core Team 2021; the R code file is provided as Supplementary Material) in our study. Parameter estimates of population growth analysis (all $p < 0.0001$) were $K = 1{,}638$ (with 95 % confidence intervals of 1,501 and 1847), $r = 0.419$ (95 % CI = 0.280 and 0.411), and $xmid = 2018$ (95 % CI = 2017.3 and 2019.0). Robustness of the model was confirmed through 10-fold cross-validation ($R^2 = 0.98$), and a low residual standard error in our analysis (50.7, df = 10) further supported a strong model fit, accurately capturing the logistic (S-shaped) growth pattern between 2012 and 2025 (Figure 2). The observed S-shaped growth curve over the last 14 years (Figure 2), implies that the population had a moderate growth rate, reached half of its carrying capacity by 2018 but currently approached the carrying capacity, which suggested to be around 1,600 by model estimates. Understanding the causes of this slowing growth rate is therefore critical for determining the

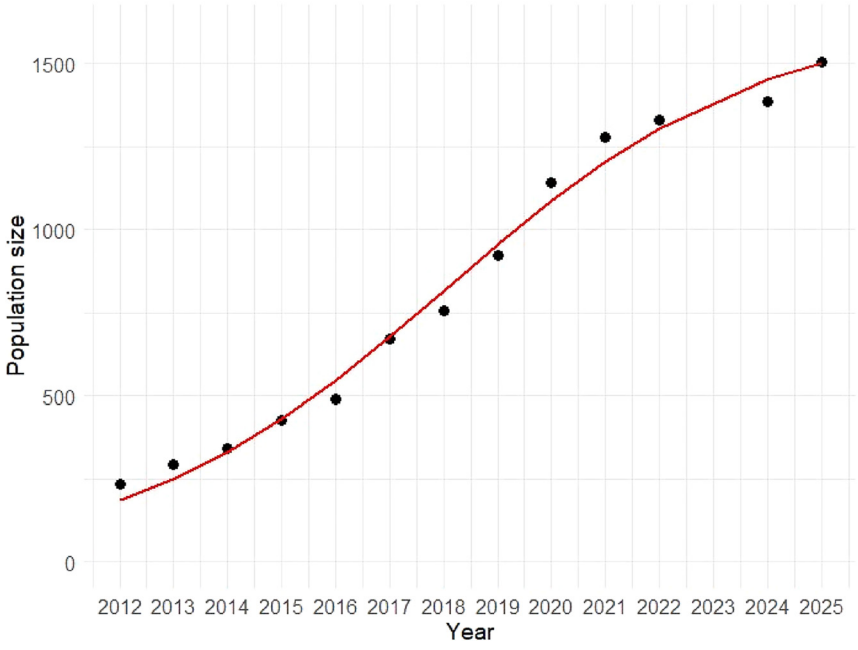

Figure 2: The population increase in the studied *Gazella gazella* population between 2012 and 2025, based on annual inventory counts by the Provincial Directorate of Nature Conservation and National Parks of Hatay, Türkiye. Note that no counts we recorded in 2023 due to the earthquake that affected the study region.

conservation status and needs of the Hatay mountain gazelle population.

To quantify habitat suitability and change for the Hatay mountain gazelle, we delineated the Hatay province (Türkiye) and the WDA and analysed CORINE Land Cover status layers for 1990 and 2018 (100-m raster, v2020_20u1; CLMS 2020). The 1990 layer was resampled to the 2018 grid using nearest neighbour within an equal-area projection (ETRS89-LAEA; EPSG:3035). We defined suitable habitat as natural grasslands, sparsely vegetated areas, pastures, and agriculture with natural vegetation, treating all other classes as unsuitable. We then computed 5×5 (1990 $\times$ 2018) transition matrices (km^2) for five categories (the four suitable types and a pooled "unsuitable" class) and mapped 2018 suitability with a loss-gain inset (1990 $\rightarrow$ 2018). All geoprocessing was implemented in R (R Core Team 2021) using the packages *terra* (Hijmans 2025), *sf* (Pebesma 2018), *tmap* (Tennekes 2018), and *magick* (Ooms 2025). In 2018, suitable habitat in Hatay amounted to 737.6 km^2 (13.4 % of the province), comprising agriculture with natural vegetation accounting for 449.6 km^2 (8.1 %), natural grasslands 131.5 km^2 (2.4 %), sparsely vegetated areas 85.2 km^2 (1.5 %), and pastures 71.6 km^2 (1.3 %) (Figure 1d; Supplementary Table S1). Within the WDA, suitable habitat stood at 85.1 km^2 (68.4 % of the WDA area), predominantly pastures (50.6 km^2; 40.7 %) and agriculture with natural vegetation (20.8 km^2; 16.7 %), with natural grasslands (13.8 km^2; 11.1 %) and negligible sparsely vegetated cover (<0.01 %). Outside the WDA, the remaining suitable area (652.5 km^2; 88.5 % of the province-wide suitable) is present mainly as agriculture-with-natural-vegetation and natural grasslands (Figure 1d). Province-wide, suitable area declined from 1,390.0 km^2 (25.2 %) in 1990 to 737.6 km^2 (13.4 %) in 2018 (loss 833.1 km^2; gain 180.8 km^2; net −652.3 km^2, -11.8 %) (Figure 1d; Supplementary Table S2). Taken together, the high proportion of suitability within the WDA and the net province-wide losses over three decades imply a restricted, WDA-centred distribution with few suitable patches elsewhere; this pattern is consistent with our field observations of Hatay mountain gazelles and previous camera-trap data (Çoğal and Sözen 2017).

Consequently, the primary driver behind the recent slowdown in population growth is the limited availability of suitable habitats across the region (Figure 1d). In Türkiye, the species historically occurred well north of its current range in Hatay (Kasparek 1986), whereas the neighbouring Syrian population, formerly contiguous with Hatay, was largely extirpated by poaching (Tolga Kankılıç, pers. observ., and anecdotal evidence by local communities), leaving its current status unknown. Today, the Hatay mountain gazelle population is confined to a narrow area bounded by human settlements and extensive agriculture to the west and south, extensive basaltic lava flows creating unsuitable substrates to the north, and the Türkiye–Syria border wall to the east (Figure 1d). The nearest mountain gazelle population lies far to the south in the Naftali Mountains, Israel (Yom-Tov et al. 2021), with no realistic potential for contact. Together with the loss of approximately half of the potential habitat in Hatay over the past three decades (Figure 1d), these constraints render natural range expansion highly unlikely.

Another contributing factor to the population slowdown and the observed S-shaped growth pattern may be increasing pressure from natural predators (Tolga Kankılıç, pers. observ.; interviews with local shepherds and NGOs). Leopards (*Panthera pardus*), caracals (*Caracal caracal*), and wolves (*Canis lupus*) are well-documented predators of mountain gazelles (Mendelssohn et al. 1995), but the former two species have not existed in the study region at least for decades, and wolves have been very rare (Çoğal and Sözen 2017). However, recent observations of increased wolf predation within the WDA suggest that wolves have recolonized the area. In addition, the region hosts several other mammals, including red foxes (*Vulpes vulpes*), hyenas (*Hyaena hyaena*), and jackals (*Canis aureus*) (Çoğal and Sözen 2017), which are natural predators of mountain gazelle fawns (Arnon et al. 2025b; Mendelssohn et al. 1995). The presence of wolves as top predators in the WDA suggests that conservation actions over the past 15 years for mountain gazelles have also benefited other wildlife species. Accordingly, natural predators likely exert a regulatory effect on mountain gazelle population growth within the WDA. Given that both top-down and bottom-up processes can regulate mammalian herbivores (Grange and Duncan 2006; Shalmon et al. 2020), predators in the WDA may help sustain grassland carrying capacity by reducing gazelle grazing and browsing over the long term. The Anatolian mouflon (*Ovis gmelini anatolica*) in central Anatolia provides an instructive parallel. Following strict fencing and the removal of wolves (Özüt 2009), the population grew rapidly as conservation began and approached carrying capacity (Sezen et al. 2004), but subsequently overshot within the restricted habitat and then declined markedly (Özüt 2009), plausibly due to stress, disease, and malnutrition (Ünal et al. 2016). However, human activities can also modulate predator-prey dynamics as shown in recent studies of the southern population of *Gazella gazella*, where elevated predation has been linked to anthropogenic food subsidies and visitor disturbance (Arnon et al. 2025b; Zukerman et al. 2024).

In recent years, expanding settlements and agricultural lands, the establishment of quarries and cement factories, and the construction of water canals and roads have further diminished the remaining habitat of mountain gazelles (Table 1). Such developments are also likely to increase habitat fragmentation. Because mountain gazelles favour grassland and steppe vegetation, the spread of human land use confines them to the current distribution area and limits their ability to disperse more widely. Although some agricultural fields (e.g., lentil and chickpea) provide supplemental forage and are often adjacent to the grasslands in the WDA, large-scale agricultural expansions pose a significant barrier to movements of mountain gazelles and may further isolate this already vulnerable population.

Table 1: Threats to the mountain gazelle population in the study area (Hatay province, Türkiye), their potential impacts on the population, and a comparison of threat intensity between the past (15 years ago) and the present.

Threat	Impacts	Change in intensity	Reason of change
Habitat-related threats			
Human land use	Habitat loss and fragmentation; restricted dispersal	Increased	Expanded agricultural activity; construction of new irrigation canals
Conversion of rangelands to croplands	Habitat loss; heightened competition with domestic sheep	Increased	Increased agricultural activity resulting in rangeland loss
Afforestation of natural steppe habitats with pines	Habitat loss	Ceased	No afforestation has been carried out for many years
Direct anthropogenic threats			
Poaching	Killings of gazelles by humans (in Syria)	Ceased	No passage from Türkiye to Syria due to the border wall
Human-gazelle conflict	Rising negative attitudes among locals towards gazelles	Increased	Gazelles grazing on lentil/chickpea fields; growing gazelle numbers
Physical barriers			
State border wall	Restricted dispersal	Novel	Construction of a border wall between Türkiye and Syria in 2016
Biological interactions			
Competition with domestic herbivores	Reduced food availability for gazelles	Increased	Larger flocks of sheep
Stray dogs	Killing of gazelles, especially fawns	Decreased	Municipalities no longer release stray dogs into the area
Parasite transfer from domestic herbivores	Higher parasite loads in gazelles	Unknown	Possible threat; insufficient data for past comparison
Physiological stress			
Stress levels	Diminished health and reproductive success in individuals	Increased	Multiple ongoing threats in this table

Information is based on continuous observations by Tolga Kankılıç between 2008 and 2024, and interviews with local shepherds and NGOs. "Increased" and "Decreased" indicate that the threat existed in the past and its intensity has since risen or declined, respectively. "Novel" indicates that the threat did not exist in the past but emerged in recent years. "Ceased" indicates that the threat used to exist but is no longer observed today.

Another key driver of habitat fragmentation in the region is the 4 m-high Türkiye–Syria state border wall (Table 1). Constructed between 2016 and 2018, it isolates mountain gazelles in

Türkiye from any remaining individuals on the Syrian side, thereby preventing access to potentially suitable habitats across the border. Although the number and distribution of mountain gazelles in Syria remain unknown, comparable physical barriers were shown to reduce both the genetic diversity and demographic stability of wildlife populations (Linnell et al. 2016). Notably, intensive poaching on the Syrian side was reported prior to the construction of the wall, therefore the absence of cross-border movement may confer short-term protection for mountain gazelles in Türkiye. Establishing a transboundary protected area could alleviate habitat constraints and foster population growth (Liu et al. 2020), but recent military conflicts and political instability in Syria make this unlikely in the near future.

Additional threats may also affect the growth rate, health, and overall status of the mountain gazelle population in Hatay (Table 1). One of the main threats is the presence of sheep herds in the WDA (Figure 1b): grazing by domestic herbivores intensifies competition for grasses and forbs (Arnon et al. 2025a; Karaer 2024), heighten the risk of interspecific parasite transmission (Karaer et al. 2024a; Karaer et al. 2025), and thus increases stress levels (Karaer et al. 2024b) (Table 1). In the Israeli mountain gazelle population, an outbreak of foot-and-mouth disease killed over 3,500 individuals within a few months in 1985 (Shimshony et al. 1986; Yom-Tov et al. 2021). A similar scenario could unfold in Hatay, as there is no regular parasitic monitoring, and the rapid population growth, accompanied by intensive inbreeding, may compromise disease resistance (Shimshony et al. 1986). Finally, as the Hatay mountain gazelle population continues to expand, the likelihood of human-gazelle conflict also rises, particularly when gazelles feed on nearby agricultural fields (Table 1).

The sustained growth of the Hatay mountain gazelle population over the past 15 years demonstrated the effectiveness of recent conservation actions. However, the slowdown since 2018, together with intensifying human-driven threats and an elevated risk of human–gazelle conflict, highlights the need to re-evaluate and refine current conservation strategies. Because scarcity of suitable habitat is the main limiting factor for this northernmost mountain gazelle population, we strongly recommend translocating individuals from the core area to historically occupied but currently uninhabited sites that retain suitable habitat, to promote population growth and range expansion. Such translocations are critical for the future of the Hatay mountain gazelle population, which is subject to multiple anthropogenic pressures within a restricted range. Similar herbivore translocations have been successfully conducted in Türkiye, including the Anatolian mouflon (*O. gmelini anatolica*; Özüt 2009) and European fallow deer (*Dama dama*; Durmuş 2019). Preventing further agricultural encroachment into mountain gazelle habitat is critical to mitigate additional habitat loss. Restoring croplands that formerly supported steppe grassland or pasture through ecological restoration could increase carrying capacity and sustain continued population growth. Restricting new infrastructure (e.g., roads, irrigation canals, industrial facilities, quarries) is likewise essential to safeguard remaining habitat and ensure the long-term viability of this endangered population. Monitoring predator populations is also needed to quantify the regulatory effects of predation on Hatay mountain gazelle population dynamics, and protecting these predators is crucial given their role in regulating the gazelle population and maintaining mammalian diversity and ecosystem functioning within the WDA.

Given limited opportunities for natural range expansion and the risk of inbreeding at low population size, genetic diversity could be enhanced in the future via assisted gene flow through small, phased translocations (e.g., mixed-sex cohorts sourced from southern populations). Where suitable release sites are lacking, establishing a second, geographically separate breeding centre or reintroduction site could reduce extinction risk from stochastic events (e.g., disease outbreaks). In conclusion, habitat restoration, targeted translocations, and the preventing further habitat loss should be the key conservation measures to secure continued growth of the Hatay mountain gazelle population.

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Research ethics: Fieldwork was carried out with permission from the General Directorate of Nature Conservation and National Parks of Türkiye (no: 8037146, date: 08.12.2022).

Informed consent: Not applicable.

Author contributions: M.C. Karaer: methodology, investigation, formal analysis, writing, original draft preparation, review and editing. T. Kankılıç: conceptualization, project administration, methodology, investigation, formal analysis, writing, review and editing. Ç. Tavşanoğlu: conceptualization, project administration, methodology, investigation, formal analysis, visualization,

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Data availability: R code used in population growth analysis (including the raw population count data) is given as Supplementary Material.

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