The plight of the Endangered mountain gazelle *Gazella gazella*

Yoram Yom-Tov, Amir Balaban, Ezra Hadad, Gilad Weil and Uri Roll

Abstract The Endangered mountain gazelle *Gazella gazella* was once widespread throughout the Levant. Over the past 100 years its population fluctuated greatly as a result of various anthropogenic threats and disturbances. We review the dynamics of the mountain gazelle throughout this period in Israel, its last remaining stronghold, with c. 5,000 individuals. During the 20th century Israel's human population increased steadily at an annual rate of 2%; the population density is currently 430 persons per km² and is forecast to increase further. This presents an array of threats to the mountain gazelle, including habitat change, fragmentation and isolation by roads, railways and fences, poaching, road kills and predation by increasing populations of natural predators and feral dogs, sustained partly by anthropogenic food waste. These threats may act in synergy to amplify their effects. We present an overview of how these factors acted in the past and are currently threatening the survival of this species. We also review the policy and management actions, both implemented and still required, to ensure the persistence of the mountain gazelle. In addition, we analyse connectivity in the landscape, highlighting highly fragmented gazelle populations, and suggest potential interventions. The mountain gazelle exemplifies an ungulate with both great vulnerability to human pressures and a large breeding potential. As more regions, in Israel and elsewhere, are converted to human dominated landscapes, pressures on wildlife are increasing, and lessons from the mountain gazelle could prove valuable.

Keywords Anthropocene, *Gazella gazella*, hunting, Israel, land use, mountain gazelle, poaching, threat

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Yoram Yom-Tov (Corresponding author, orcid.org/0000-0002-9234-9431) School of Zoology, Tel Aviv University, Tel Aviv 6997801, Israel
E-mail yomtov@tauex.tau.ac.il

Amir Balaban Society for the Protection of Nature in Israel, Tel Aviv, Israel

Ezra Hadad Bet Shemesh, Israel

Gilad Weil Department of Geography, the Hebrew University, Jerusalem, Israel

Uri Roll (orcid.org/0000-0002-5418-1164) Mitrani Department of Desert Ecology, Ben-Gurion University of the Negev, Midreshet Ben-Gurion, Israel

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Introduction

Wild ungulate populations are declining as a result of habitat destruction and fragmentation, invasive species, hunting and poaching (Di Marco et al., 2014). There have been many attempts to alleviate this situation through conservation actions (Moehlman et al., 2016). The mountain gazelle *Gazella gazella* in the southern Levant exemplifies the plight of threatened ungulates globally, with increasingly altered landscapes and complex interactions with people (Game et al., 2014). If present trends persist, the mountain gazelle's survival may be in jeopardy.

Here we review the main human-driven changes in the Israeli mountain gazelle population during the past 100 years (Fig. 1). We focus on current drivers of threats and review policy and management practices employed for the species' conservation. To ensure the species' persistence, we recommend measures to alleviate the major threats.

The local setting

The spatial scope of this work includes the State of Israel, the Golan Heights and the Palestinian Authority in the West Bank, an area of c. 28,000 km² (Fig. 2). Most surveys and monitoring of mountain gazelles included in this review were carried out throughout this area, albeit at different intensities. For convenience we refer to this entire region as Israel (and refrain from making any political statement in so doing). The State of Israel per se comprises a land area of c. 22,000 km². Its human population has increased from c. 0.8 million in 1949 to 8.7 million in 2017 (Statistical Abstract of Israel, 2017). The population density is c. 430 persons per km², with c. 1,300 human settlements (Sorek & Perevolotsky, 2016). Since 1996 Israel's human population has increased at an average annual rate of 2%, the highest amongst OECD countries (Statistical Abstract of Israel, 2017). In the Mediterranean region, with an annual rainfall of 250–1,000 mm (Fig. 2), where most people reside, the maximum distance between human settlements is 5 km (Sorek & Perevolotsky, 2016).

The human population increase has led to a concurrent increase in the use of land for agriculture and infrastructure. In 2020, c. 15,000 km² of Israel's land area is natural, and agriculture occupies c. 4,000 km². Overall, 10.7% of Israel's area is urbanized (2,360 km²), 12 times higher than the global average (Sorek & Perevolotsky, 2016). In the Mediterranean region, 18% of the area is urbanized (Sorek & Perevolotsky, 2016). Motor vehicle density on the roads

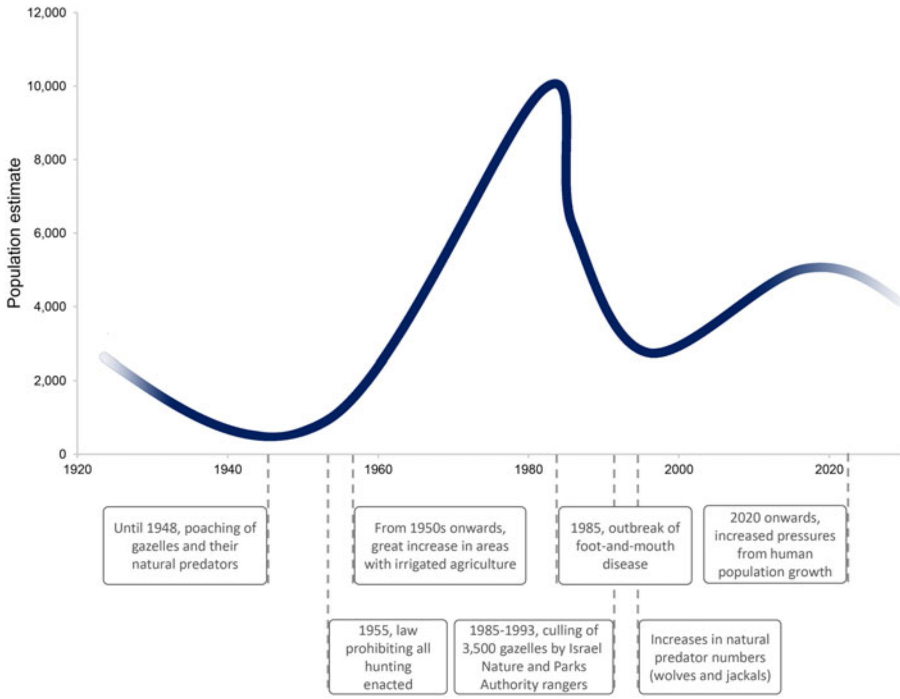

FIG. 1 Mountain gazelle *Gazella gazella* population dynamics since 1920, highlighting the main drivers of population change.

is the highest among OECD countries (Bar, 2017). It has been estimated that by 2040 Israel's population will have increased to c. 13 million people (Raz-Dror & Cost, 2017). Consequently, the area urbanized is likely to increase from 10.7 to 15.3% at the expense of agricultural and natural areas. This increase will mostly occur in the Mediterranean part of the country where mountain gazelles live and where urbanized areas are projected to encompass 25% of the total area.

Historical overview

The mountain gazelle is categorized as Endangered on the IUCN Red List (IUCN SSC Antelope Specialist Group, 2017). It was once widespread throughout the Levant, in Turkey, Syria, Lebanon, Jordan, Israel and possibly in Sinai, Egypt, but its main population now occurs in Israel (IUCN SSC Antelope Specialist Group, 2017). A small population of c. 200 individuals may exist in Hatay province in Turkey (Kankiliç et al., 2012), and a few individuals are occasionally observed in other areas of its former range (Mallon & Kingswood, 2001).

Traditional hunting of gazelles persisted to varying degrees up to the beginning of the 20th century (Bar-Oz et al., 2013). Until the demise of the Ottoman Empire at the end of World War I, hunting was unregulated and widespread (Talbot, 1960). This led to local extinctions or serious declines of several vertebrate species, including a massive decline in the gazelle population (Talbot, 1960; Dolev & Perevolotsky, 2002). After World War I, during the British mandate of Palestine, a Conservation of Game Animals law for the regulation of hunting was enacted but rarely enforced (Mendelssohn, 1974). Gazelle hunting and poaching therefore persisted, resulting in a continued decline to c. 500 individuals by 1948 (Mendelssohn, 1974).

The establishment of the State of Israel in 1948 had substantial effects on wildlife following major political changes. Firstly, the Protection of Wild Animals law, enacted in 1955, stipulated that all wild, terrestrial, and volant vertebrates in Israel are protected, excluding a few species considered pests and some categorized as game (Mendelssohn & Yom-Tov, 1999). Secondly, following the 1948–1949 war, the human composition of the State of Israel changed considerably, and many communities with traditional hunting cultures were displaced (Abu-Saad, 2008). Thirdly, hunting and poisoning of predators of gazelles (golden jackal *Canis aureus*, wolf *Canis lupus*) during the British Mandate greatly reduced their numbers. Fourthly, within a few years c. 50% of agricultural areas became irrigated, providing gazelles with nutritious vegetation and drinking water year-round (Statistical Abstract of Israel, 2017). This latter change allowed gazelles to breed throughout the year, and females to give birth twice per year and to reach reproductive maturity within the first year of life (Mendelssohn, 1974; Mendelssohn et al., 1995). Consequently, between 1948 and the 1960s the gazelle population increased at an average annual rate of 8% (Yom-Tov, 2016). More substantial changes to gazelle populations occurred in the Golan Heights after this region was occupied by the State of Israel in 1967 (it was nearly devoid of gazelles and their predators prior to its occupation). During 1970–1971 c. 400 gazelles were translocated to the Golan Heights from Ramot

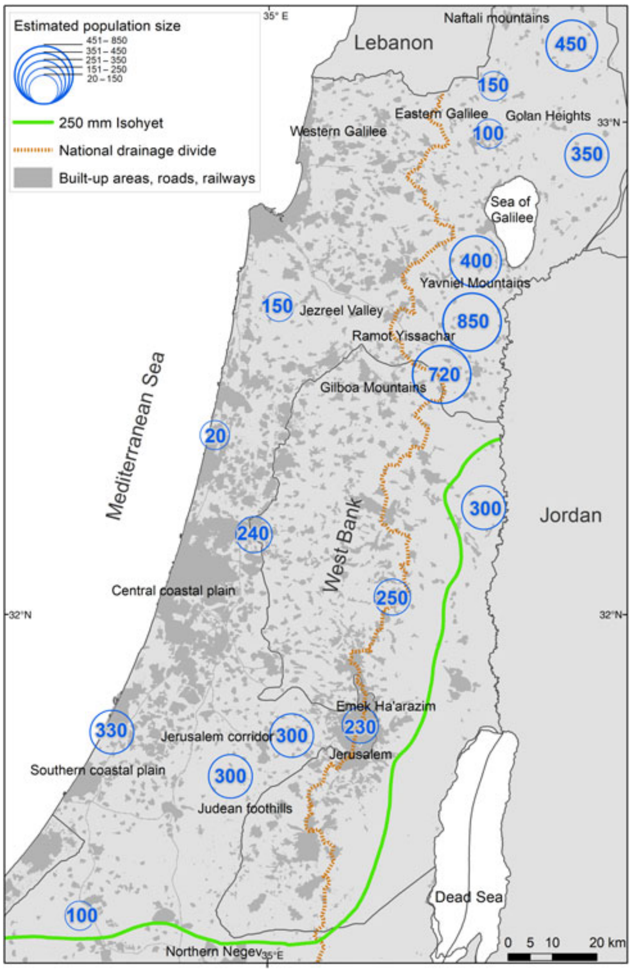

FIG. 2 The main concentrations of mountain gazelle populations in Israel, with the national drainage divide and the 250 mm isohyet delineating the Mediterranean region.

Yissachar (Fig. 2). These, together with 100–200 gazelles that inhabited the eastern shore of the Sea of Galilee, increased to c. 6,000 individuals by 1983. This represented an average annual rate of increase of 25% (Ayal & Baharav, 1985). Surveys conducted during the 1980s estimated the mountain gazelle populations in Israel (including the Golan Heights) numbered c. 10,000 (Kaplan, 1995, 2000). This was probably the peak size for the population in this region in modern times (Fig. 1).

This increase in the gazelle population created, in some regions, conflicts with agriculture. Consequently, farmers exerted pressure on the Israeli Nature and Parks Authority (the Israeli governmental conservation organization) to reduce this conflict by culling gazelles (Schuster & Schuster, 1986), which took place during 1985–1993. Concurrently, in 1985 an outbreak of foot-and-mouth disease killed at least 3,500 gazelles within a few months, potentially because of their high local densities (Shimshony et al., 1986). Culling and foot-and-mouth disease, together with increased predation of fawns, poaching, and collisions with cars, caused major declines in gazelle numbers during the 1990s. By 2001 the population in Israel was estimated to be c. 3,000 individuals (Yom-Tov, 2003, 2013). This population is slowly recovering and is currently estimated to be c. 5,000 individuals (Fig. 1; Yom-Tov, 2016). This figure is twice that estimated in 2016 by IUCN (2017), probably because not all information was included in the IUCN estimate.

Current status of the gazelle population

Mountain gazelles in Israel prefer plains or hill landscapes with batha (low shrub), garrigue (higher shrub) or maquis plant communities. They can also be found in other habitats, such as mixed pine and broadleaf forests, mountainous terrain, semi-arid plains, sand dunes and agricultural field margins. Mountain gazelles often occur in steep terrain (hence their English name) and can withstand severe climatic conditions, but not deep snow (Mendelssohn et al., 1995).

Most gazelles occur east of the national drainage divide in the Naftali Mountains, eastern Galilee, Yavniel Mountains, Ramot Yissachar and Gilboa Mountains (Fig. 2; Yom-Tov, 2016). These populations, together with those in the Golan Heights, number c. 3,000 and their connectivity is generally high (Figs 2 & 3). All the above-mentioned areas are characterized by relatively low mean annual precipitation (300–400 mm) and batha and garrigue plant communities, which harbour many annuals during winter. Human density in these areas is relatively low and cultivated areas mostly comprise open fields with few irrigated plantations or orchards.

Another large concentration of gazelles occurs in the Judean foothills, the Jerusalem corridor, and around the city of Jerusalem, mostly west of the national drainage divide, where c. 850 gazelles reside (Fig. 2). In this area the mean annual precipitation is 500–550 mm and vegetation cover is generally higher than east of the national drainage divide (Zohary, 1959). Human density in this area is high and there are many agricultural settlements, with fields, vineyards and orchards providing the gazelles with green food and water throughout the year (Yom-Tov, 2016). Connectivity in these areas varies greatly. Other smaller populations occur throughout the Mediterranean region of Israel (Figs 2 & 3).

Analysing gazelle habitat connectivity

To analyse gazelle connectivity within the Israeli landscape, we first identified 41 core areas of gazelle populations that contain > 20 observations of gazelles (during 2007–2017) and are > 150 km². Figure 2 displays the core areas with the largest gazelle populations. We used three sources of data to identify gazelle population numbers: (1) annual regional counts, which are carried out each winter in the

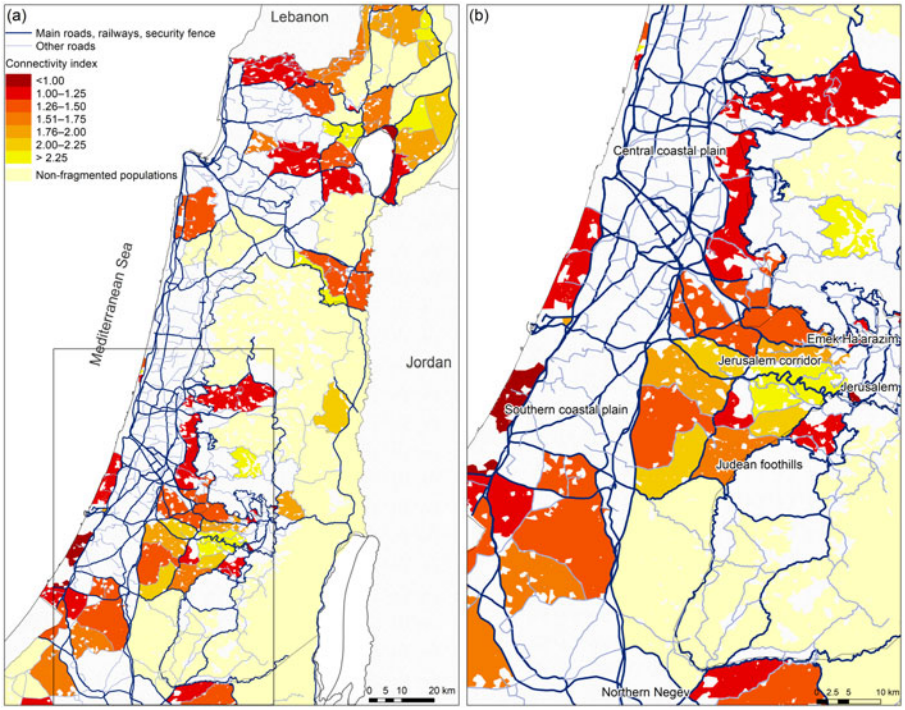

FIG. 3 Connectivity of the mountain gazelle population in (a) core regions in the Mediterranean region and (b) central Israel, where connectivity of gazelle populations is particularly hampered, with the main barriers preventing free movement between populations. The connectivity index is a function of permeability for gazelle movement to adjacent populations (see text for full details, and Supplementary Table 1).

main areas of gazelle concentrations, (2) occasional observations of gazelles routinely reported by Israel Nature and Parks Authority rangers (the database comprised 72,437 observations recorded during 1973–2018), and (3) observations and counts of gazelles by AB and EH in the Jerusalem corridor and Judean Mountains and foothills, respectively (Fig. 2).

For each core area we calculated the degree of fragmentation in two stages. Initially we used a map of land use (Sorek & Perevolotsky, 2016) to identify human dominated landscapes (i.e. built environments, roads, railways), and habitats that are permeable to gazelles such as natural vegetation and agricultural fields. Each pixel (150 m^2) was given a permeability score based on its property of enabling or hampering gazelle movement (see Supplementary Table 1 for permeability score values per land-use category). We then summed these scores outwards from each core area to create its connectivity area. For each connectivity area the permeability values were summed up to 6 km away from each core region, or up to a maximum of 6,000 permeability score units. In fragmented regions with high human disturbance, the 6,000 units threshold was reached before the 6 km limit, and thus the connectivity areas were smaller. We then calculated a connectivity index for each core area as (core area + connectivity area)/core area. Completely isolated core areas have an index value of 1, whereas higher index values indicate higher connectivity from the core areas outwards. Figure 3 displays the connectivity index for each core area, highlighting regions where gazelles reside and their connectivity.

This first stage did not take into consideration all possible causes of fragmentation, such as fences, most of which do not appear on the available maps. To account for such obstructions, we consulted with regional Israel Nature and Parks Authority rangers. In cases where obstruction to free movement of gazelles exists we changed the category of each core area by altering the relevant permeability scores and recalculating the connectivity index (Fig. 3). All spatial analysis was carried out in *ArcMap 10.3* (Esri, Redlands, USA).

Threats

A combination of several major threats limits the growth of the Israeli gazelle population and/or causes its decline.

Habitat destruction and change

The impact of human settlements on gazelles may extend beyond dwellings and is considerably greater than the actual loss of suitable grazing land. Gazelles have been recorded to perceive human presence as a threat, with an increased flight distance with higher human presence and a positive correlation of vigilance with extent of disturbance (Manor & Saltz, 2004, 2005). Gazelle pellet counts have indicated partial avoidance at least 700 m into natural habitats bordering human habitations (Manor & Saltz, 2005). Strong avoidance of human dwellings and their vicinity by gazelles has been confirmed using camera-traps (Sorek & Perevolotsky, 2016).

Habitat fragmentation and population isolation

Natural habitats in the Mediterranean region of Israel are highly fragmented. Along the central coastal plain, where several highways cross the landscape, this is particularly problematic. Furthermore, the security fence separating the State of Israel from the Palestinian Authority greatly limits the available habitat in this region for gazelles as it runs generally north–south, 15–30 km east of the Mediterranean coast (Fig. 3). Circa 1,000 gazelles inhabit areas of low or no connectivity (Fig. 3). In central Israel there are 11 populations disconnected from any other gazelles, living in de facto enclosures, and a further six populations have partial connectivity (Fig. 3; Supplementary Table 2). Continuous monitoring of these enclaved populations is needed to understand the nature and effects of fragmentation. Fragmentation and isolation have long been noted to have severe negative effects on wild populations (Caughley, 1994). These include, among others, the detrimental effects of demographic and environmental stochasticity, genetic effects of small populations and the Allee effect (Simberloff, 1988).

Collisions with cars

The Israel Nature and Parks Authority database includes records of a total of 467 gazelles found dead or wounded on or next to roads during 2009–2017. These numbers increased significantly from 14 to 86 per annum during this period (linear regression; $R^2 = 0.83$, $F_{1,7} = 34.50$, $P = 0.0006$). This increase can be attributed to increases in the length and width of the roads, and traffic volume. However, greater awareness of Israel Nature and Parks Authority rangers during this period and an increase in some gazelle populations could have also contributed to the increase in collisions. During 2006–2014 c. 300 mountain gazelles were brought to the Hospital for Wild Animals, a third of which were victims of car accidents (i.e. an annual mean of c. 10). We view this as the lower boundary of the true toll of roads on gazelles as many may perish by the side of the road without being attended or recorded. Effects of collisions with cars can be particularly great along the central coastal plain of Israel, where gazelle populations are smaller and more fragmented, and road traffic is greater (Fig. 3).

Fragmentation constraints on behaviour

Fragmentation may prevent animals from behaving naturally. Gazelles exploit so-called green waves (sensu Merkle et al., 2016), moving seasonally according to food availability along mountain slopes or other gradients to track high quality forage (Geva, 1980). For example, in the Naftali Mountains in northern Israel, gazelles forage during winter on herbs at 250–450 m above sea level, predominantly in Batha habitats. As these herbs dry with the approach of summer, the gazelles move to lower elevations and forage on the green leaves of bushes and trees that grow in garrigue and maquis habitats (Geva, 1980). Increased fragmentation deprives gazelles of the opportunity of freely tracking food sources as these become available seasonally.

Predation

Predators affect prey either directly by killing individuals or indirectly by modifying the behaviour of the prey species (Lima, 1998). In Israel the main natural predators of gazelles, the wolf and golden jackal, are predominantly sustained by rubbish and agricultural products, complemented by wildlife such as rodents, hares *Lepus capensis* and partridges *Alectoris chukar*, but also by gazelle fawns and sometimes adult gazelles (Gingold et al., 2009). This has pronounced effects on some gazelle populations. For example, the population in the Golan Heights has probably become stagnant because of high predation pressure (Dolev et al., 2018).

In addition to their natural predators, gazelles are predated by the increasing population of the feral domestic dog *Canis familiaris*. The Israel Nature and Parks Authority estimates that tens of thousands of feral dogs roam Israel, often in packs of 4–8 that hunt and disturb wild animals, and have a detrimental effect on mountain gazelles (Manor & Saltz, 2004). Dog packs hunt gazelle fawns and significantly reduce gazelle breeding success via harassment of adults (Manor & Saltz, 2004; Gingold et al., 2009). The former practice of culling feral dogs has almost halted as a result of pressure from animal rights groups, and feral dog numbers are increasing (Y. Shkedy, pers. comm., 2019). As a result of the high human population density in the Mediterranean region of Israel, feral and domestic dogs can travel from settlements into neighbouring natural or semi-natural regions (Knesset Research and Data Center, 2015). Fragmentation further exacerbates the effects of predators. During their first month after birth young gazelles lie on the ground for most of the day while their mothers watch from a distance. Higher predator density increases the probability of fawns being discovered and killed by predators (possibly including wild boar *Sus scrofa*) during this period (Mendelssohn, 1974). Detection and predation of young gazelles may further increase in regions with intense cattle grazing, where there is less vegetation cover (Shamoon et al., 2017). Furthermore, predators have learned to chase gazelles towards fences and other barriers; frightened gazelles often collide with them, and die or fall stunned, making them easy prey (Yom-Tov, 2016). Predation pressure may further increase as gazelles are driven to be more nocturnal, to minimize contact with people, increasing their overlap in activity period with their principal nocturnal natural predators (Shamoon et al., 2018).

Poaching

Despite laws prohibiting gazelle hunting in Israel, they are still hunted illegally. Using data on, and provided by, arrested poachers (R. Malka, pers. comm., 2019), we estimate that 300–1,300 gazelles are poached annually. Gazelles are shot with firearms, chased by off-road vehicles or trained dogs, and are spotted by poachers using night-vision goggles, and are also poached using iron foot-traps. Most poachers make private use of their bounty, but some do so for commercial purposes. In the northern Negev, an area characterized by plains and low hills, poachers may chase gazelles with off-road vehicles or Saluki dogs, until they are exhausted and thus easily caught (Israel Nature and Parks Authority rangers, pers. comms, 2019). Poaching is also carried out by migrant agricultural workers, mostly from Thailand, who hunt animals mainly using noose traps (Yom-Tov, 2003), with > 100 gazelles caught annually in this way (Leader & Boldo, 2008). Poachers are seldom caught and convicted, and those that are receive low fines and are seldom jailed, despite harsh laws that allow this punishment (Israel Nature and Parks Authority rangers, pers. comms, 2019).

Invasive plants

Invasive plant species pose another threat to gazelle habitats and food resources. In Emek Ha'Arazim west of Jerusalem, dense stands of the Chinese tree *Ailanthus altissima* have replaced much of the natural batha vegetation (authors, pers. obs.). Along the coastal dunes next to the Mediterranean Sea, extensive stands of the Australian shrub *Acacia saligna* and the North American composite *Hetherotheca subaxillaris* cover increasingly large areas and prevent the germination and/or spread of the annuals favoured as food by gazelles (Dufor-Dror, 2010). Although the effects of invasive plants are currently less significant than those of other threats, they could become more important as such plants spread.

Recommended conservation actions

Although Israel is the last stronghold of the Endangered mountain gazelle, some populations are in decline and others are unable to reach their carrying capacity despite the species' considerable reproductive potential. In addition to the systematic surveys of gazelles carried out by the Israel Nature and Parks Authority since the 1980s there is a need for more information on life history parameters, predation and poaching rates, to enable informed, science-based, policy and management of the species. Such research could be aided by geo-tagging of individuals and genetic analysis of isolated populations.

We make four recommendations to improve gazelle conservation (some are currently being explored or implemented by the Israel Nature and Parks Authority):

(1) To halt habitat destruction we advocate a ban on the establishment of new human settlements and greater restrictions on urban sprawl. Intensive agriculture should be promoted, and further conversion of natural habitats to agricultural fields or built areas should be prohibited. Subsidies that promote a high human birth rate need to be reconsidered.

(2) Effects of fragmentation and isolation should be minimized by constructing more efficient wildlife crossings in key areas. In some cases individuals should be translocated between populations to alleviate genetic bottlenecks. Ultimately, greater habitat connectivity at the regional and national planning levels needs to be promoted.

(3) To reduce the effects of predation, anthropogenic food sources for gazelle predators should be reduced, collected or removed (a method that has proved successful in initial trials; Dolev et al., 2018), and the control of feral dogs reinstated.

(4) To reduce poaching, dedicated Israel Nature and Parks Authority personnel with specialized equipment should be trained and tasked with locating and stopping poachers. Current laws should be changed to include obligatory minimum prison sentences for poaching, and educational programmes to promote conservation should be established in those regions with greater prevalence of poaching.

Outlook

Mountain gazelle populations in the southern Levant have undergone substantial, human-induced declines. This story offers several key lessons for other species and regions. The habitat of the mountain gazelle has been occupied by people for millennia. Although the species has survived persistent hunting and land-use changes its habitat is now being converted at an unprecedented scale. As the global human population increases and more natural areas are converted to human-dominated landscapes, the availability of natural habitats will become a greater limiting factor for the existence of this gazelle and for many other species (WWF, 2018).

The mountain gazelle faces several threats that can act in synergy when populations are fragmented, and knowledge of the biology and behaviour of the species is required to facilitate effective conservation action (Berger-Tal & Saltz, 2016). The story of the mountain gazelle highlights the importance of understanding the intricacies of conservation at different spatial scales, and the effects of fragmentation and associated factors in a conflict region with a complex socio-political situation.

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Conflict of interest None.

Ethical standards This research did not involve human subjects, experimentation with animals or collection of specimens, and otherwise abided by the *Oryx* guidelines on ethical standards.

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