HABITAT SELECTION BY EXOTIC DAMA GAZELLES *(NANGER DAMA RUFICOLLIS)* IN TEXAS

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Abstract.–Habitat selection information is important for both breeding on Texas ranches and repatriation in Africa. This is especially true for the critically endangered dama gazelle *(Nanger dama)*. Exotic dama gazelles of the eastern subspecies *(N. dama ruficollis)* wearing GPS-radio collars were tracked for one year on two Texas ranches. Three adult and two subadult males were collared from a large (8,996 ha) pasture in west Texas. Next, collars went on all males plus all females released into a 202 ha Edwards Plateau pasture (seven adult females, one maturing male, and one to three adult males). On both sites, the gazelles favored the less steep terrain of the Ector soil series. Adult male core areas averaged 440 ha in west Texas (vegetation sparse) and 57 ha on the Edwards Plateau (dense food stands). These relationships allowed for estimation of the number of adult males that could be stocked in the larger pasture while still allowing room for the males to spread out. No special affinity for water sources was found, although dama gazelles do drink during hot weather when water is available. There was no consistent seasonal distributional change noted. On both Texas sites, the gazelles survive on natural browse. Where there are feeders, competition from larger animals kept gazelles out. For breeding or restoring populations, flat-to-gently rolling terrain with ample browse is best. Shade and water are important, and any supplemental feed requires access. There also needs to be enough favored habitat to accommodate the adult males without dangerous conflict.

Keywords: *Africa, endangered species, home range, Sahelo-Saharan Zone*

For both repatriation initiatives and breeding programs, there is a serious need for information on such topics as habitat selection (Mallon et al. 2019). This is especially true for the critically endangered dama gazelle *(Nanger dama)* from the Sahelo-Saharan region of Africa. This species formerly lived along the borders of the Sahara from the Atlantic coast to near the Nile River. By the early 1970s, it was extinct in the west, and currently only five small

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populations are known in the wild. Presently, planning is in progress to bolster the eastern subspecies, also known as addra *(N. dama ruficollis)*, in Chad. Here, numbers have fallen from an estimated 6,000 to 8,000 individuals in the mid-to-late 1970s to a total of less than 70 individuals in two isolated populations (Thomassey & Newby 1990; RZSS & IUCN Antelope Specialist Group 2014; Mungall 2018a).

In 1969, the Ouadi Rimé-Ouadi Achim Game Reserve was established in Chad in the area inhabited by one of these relict populations, providing a degree of protection that favors repatriation possibilities. Fortunately, stock for additions is available. Descendants of individuals originally caught in part of what became the game reserve (van den Brink 2018) constitute a substantial population of eastern dama gazelles (approximately 1,500 individuals as of 2015 (Mungall 2018b)) raised as exotics on Texas ranches (Fig. 1).

Figure 1. Collared eastern dama gazelles *(Nanger dama ruficollis)* in an area of tall, dense vegetation on an Edwards Plateau ranch, USA: two adult females on left, adolescent male on right (photo by Christian Mungall, courtesy of Stewards of Wildlife Conservation, TX).

A study of habitat selection among native dama gazelles in the wild would be advantageous in identifying attributes of the environment important for the gazelles. A start was made with a first release of western dama gazelles *(N. dama mhorr)* in 2015 from a captive breeding center in southern Morocco (Abáigar et al. 2019). Abáigar and her co-authors intend to publish important information about the flat terrain with *Acacia raddiana* trees where the gazelles localized although poaching events prevented long-term monitoring. More could be determined in a sampling of different parts of dama gazelle native habitat were it not for the difficult logistics, the scarcity of individuals, and the unsettled political situation in many parts of northern Africa. Texas offers environments similar to the African Sahel, and animals on Texas ranches live under conditions as close to those of natural habitat as can be found in the United States. Another reason that makes the secure study in Texas valuable is that continuation of the sizable Texas ranch population is important. It gives the species a safeguard against extinction so findings that assist management in Texas will help the species survive. This study was conducted on two sites: one of the few Texas ranches with dama gazelles in conditions with similarities to native dama gazelle habitat (an especially large Texas pasture with a semi-arid environment) and a much more limited pasture representative of many of the ranch pastures where dama gazelles are raised in Texas. This allows determinations from the present study to offer benefits both for conservation in the wild and for management of the many populations that give the species a safeguard in captivity.

Materials & Methods

Two Texas study sites were used (Fig. 2). First, one year was spent in west Texas tracking dama gazelles on Stevens Forest Ranch in Terrell County, Texas (north of US Highway 90 between Dryden and Sanderson, 30.1189^{O}N, 102.2367^{O}W). A pasture encompassing 8,996 ha, unusually large for an exotics ranch, gave the animals a near free-

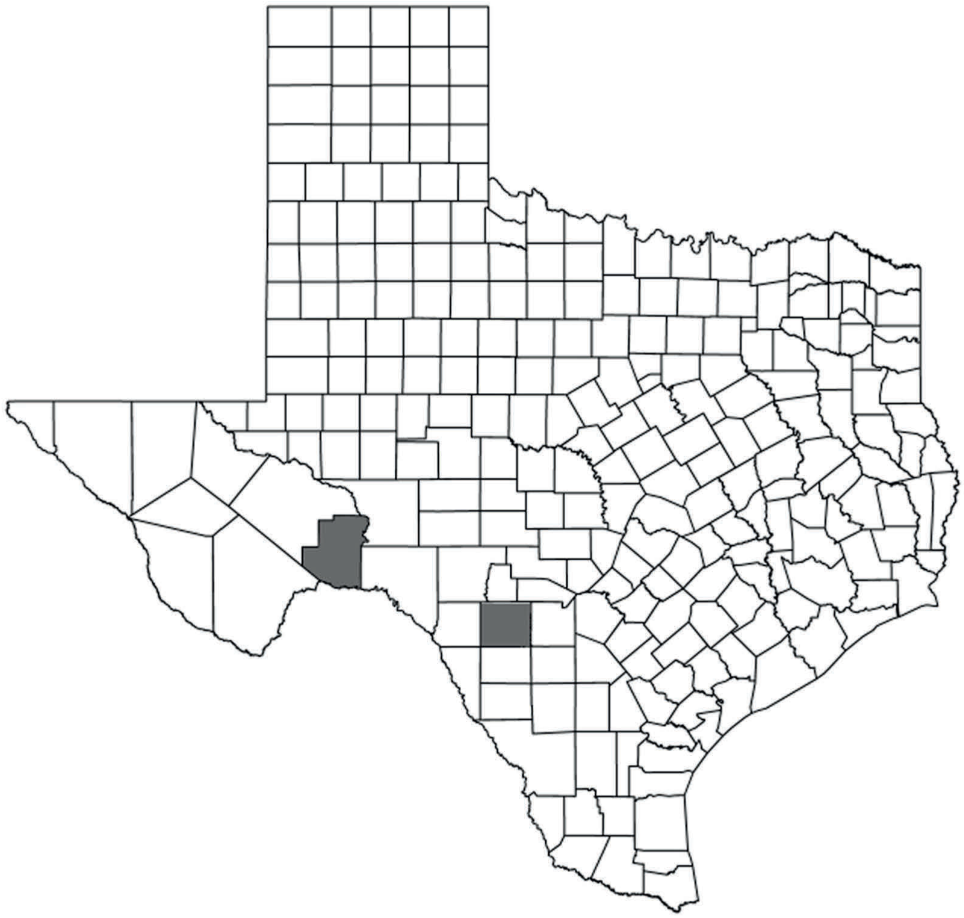

Figure 2. Locations of the study sites in Terrell County (left), west Texas, and in Uvalde County (right) on the edge of the Edwards Plateau, TX, USA.

ranging environment in which fences were not expected to be a limiting factor affecting the sites chosen or the amount of space used by the animals. Next, one year was spent on the Edwards Plateau (essentially the "Hill Country" of central Texas) tracking dama gazelles on Morani River Ranch in a Uvalde County pasture of 202 ha (north of County Road 405 near Uvalde, 29.3456^{O}N, 99.9885^{O}W). This is a more typical pasture size for Texas exotics ranches. Both pastures were high-fenced and contained a mixture of other ungulate species as well as the dama gazelles. In west Texas, exotics such as South African oryx *(Oryx gazella)* and blackbuck antelope *(Antilope* *cervicapra)* were frequently seen as well as native mule deer *(Odocoileus hemionus)* and the few domestic cattle. Other than raptors, potential predators were mainly coyotes *(Canis latrans)* and occasionally mountain lions *(Puma concolor)*. At the Edwards Plateau site, exotic scimitar-horned oryx *(Oryx dammah)* were numerous and blackbuck antelope, Grant's zebras *(Eguus quagga böhmi)* and domestic longhorn cattle were among the most conspicuous animals using areas near the dama gazelles. Terrestrial predators had been successfully fenced out.

The west Texas study site is similar to present-day dama gazelle native habitat: dry, rocky, scrub habitat. Some dama gazelles in their native Africa have retreated into rocky scrubland as habitation by pastoralists, livestock grazing, and access for poaching have increased (Newby et al. 2018). This part of Texas is classified as warm temperate semi-desert with mean minimum and maximum daily temperatures ranging from 1-16^{o}C (January) to 22-35^{o}C (July). Mean annual rainfall is 285 mm, falling mainly from May-October. In the Sahel of Africa, annual rainfall varies from 200-600 mm with extended dry periods. Hot season temperatures are similar or somewhat hotter than those in west Texas, and cool seasons are milder with temperatures rarely falling below 18^{O}C (Udvardy 1975).

Climate on the Edwards Plateau is classified as humid subtropical and is characterized by hot summers and mild-to-cool winters. Temperatures (as recorded by Mungall on Edwards Plateau dama gazelle sites) are likely to range from 7-24 ^{o}C in January and 22-38 ^{o}C in July. June to August is typically hot and dry until a series of heavy rains often in late August to early September. Light rains usually follow during the winter, but droughts are common. Annual precipitation is highly variable, averaging 651 mm (Texas State Historical Association 2019).

Both study sites are characterized primarily by rolling limestone hills associated with the Ector (Ec) soil series (USDA-NRCS 2012). As well as being prevalent on the west Texas study site, the Ector soil series extends through much of the Edwards Plateau. The terrain consists of limestone hills and plateaus with thin rocky soils. Elevation in the west Texas pasture ranges from 730-975 m. The east side, which was preferred by the gazelles, is primarily characterized by the Ec soil series. Slopes are less steep, and the terrain consists of plateaus with shallow valleys of alluvial soils of the Upton-Regan Lozier soil association (Uz). The north and west side of the ranch is rugged with rocky plateaus of the Ector-Rock Outcrop Complex soil series (Er) and steeply sloping, gravel valleys of the Sanderson-Upton soil association (Su). A central valley and rocky, dry creek bed bisect the ranch. Fig. 3 maps the soil types for the west Texas ranch and Table 1 gives their percentages and aerial extent. Estimated potential agricultural productivity is low: 1,500 kg/ha on the dominant Ector soils to as little as 670 kg/ha on the other sites (USDA-NRCS 2012).

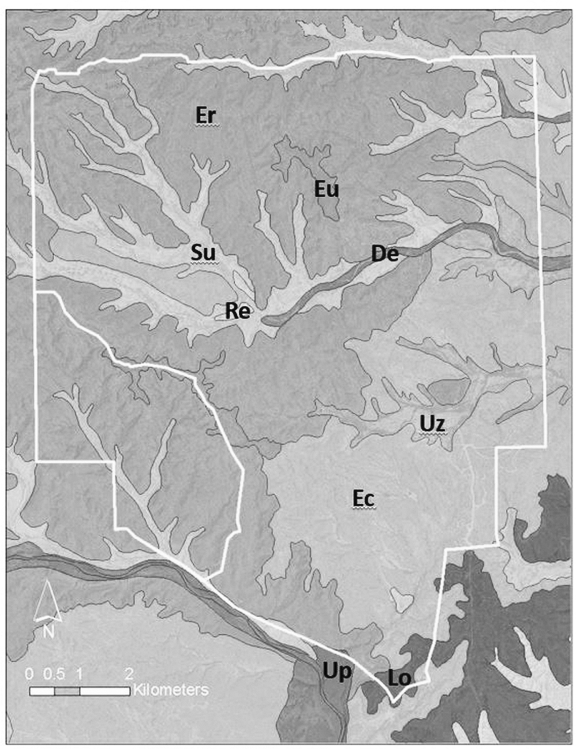

Figure 3. Soil types of the Terrell County, Texas, study site. Abbreviations: De=Dev Association; Er=Ector-Rock Outcrop Complex; Ec=Ector; Eu=Ector-Upton Association; Lo=Lozier; Re=Reagan Silty Clay Loam; Su=Sanderson-Upton Association; Up=Upton Very Gravelly Soils; Uz=Upton-Reagan-Lozier Association.

Table 1. Soil types in the west Texas study site with percentages and amounts. Soils derived from limestone (soil series as in USDA-NRCS 2012). S=slope.

Soil site (abbreviation)	Description	Location	Available (%)	Amount present (ha)
Ector-Rock Outcrop Complex (Er)	Loamy, shallow, calcareous, stony soils with rocky outcrops; S=10-35%	Steep NW hills	46.09	4,146.26
Ector (Ec)	Loamy, shallow, calcareous, stony soils; S=5-20%	Less steep, E hills	29.85	2,685.31
Sanderson-Upton Association (Su)	Gravelly outwash deposits; S=0-5%	Central valley & valleys in Er complex	13.80	1,241.45
Upton-Reagan-Lozier Association (Uz)	Gravelly, silty outwash deposits; S= 0-5%	E valleys in Ec	5.35	481.29
Ector-Upton Association (Eu)	Loamy, shallow, stony soils; S=0-5%	Flat hill tops in Er & Eu soil types	2.12	190.71
Dev Association (De)	Flood plains of river valleys; Generally 50% limestone gravel and cobbles; S=0-1%	Central valley creek bed	1.35	121.44
Reagan Silty Clay Loam (Re)	Sediments washed off limestone uplands; S=0-3%	Patches of sediments in central & NE valleys	0.72	64.77
Lozier (Lo)	Very gravelly loam; S=1-12%	Small area in S tip of pasture	0.69	62.07
Upton Very Gravelly Soils (Up)	Gravelly, stony, outwash soils on hills; Slope 0 to 5%	Small area in S tip of pasture	0.03	2.70

The smaller Edwards Plateau pasture is more uniformly Ec soils with a broken network of steep slopes. There are small inclusions of Dev (De) soils in the east, Limestone Rockland (Ls) soils near the southeast fence, and Eckrant-Kavett Complex soils (EKc) in the southwest corner (Fig. 4, Table 2). Elevation ranges from 332 m on the eastern flat to 396 m for the central-to-northwestern hills. Estimated potential agricultural productivity of the dominant Ector soils is low at 1,500 kg/ha. Productivity in the valleys is 2,000 - 2,500 kg/ha due to slightly deeper soils and greater water availability, whereas productivity on the exposed limestone is estimated at only 1,100 hg/ha (USDA-NRCS 2012).

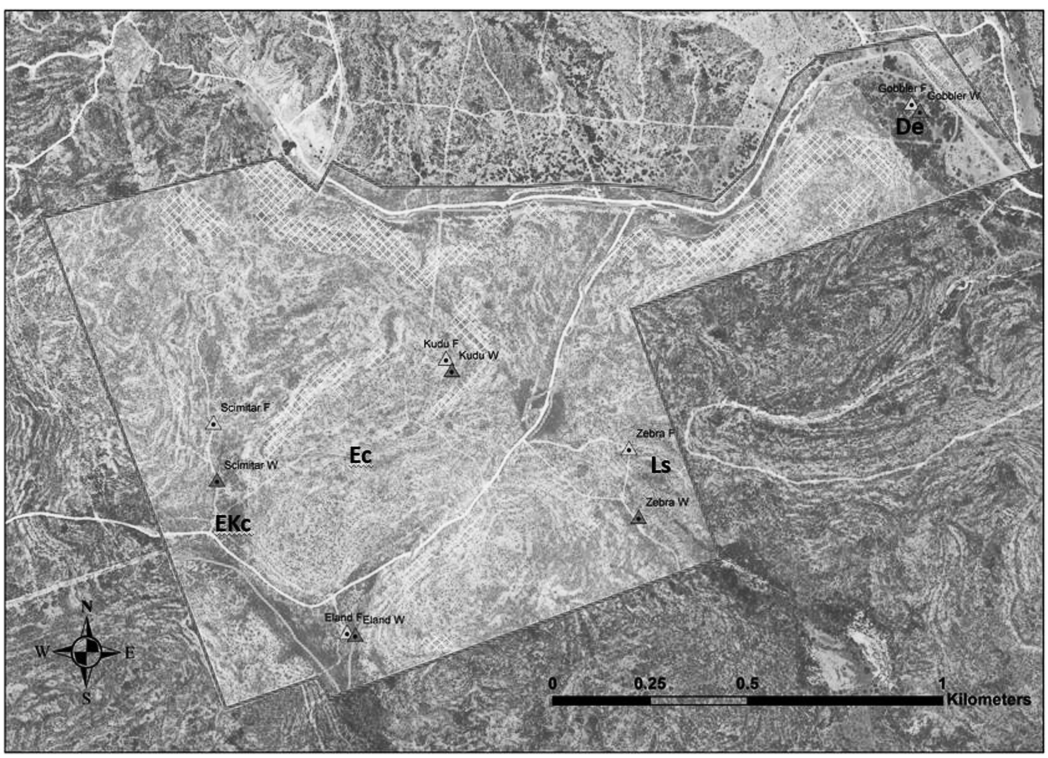

Figure 4. Soil types of the Edwards Plateau, Uvalde County, study site. Steep slopes are identified by cross hatching. Locations of supplemental feed and water are depicted by light and dark triangles, respectively. Abbreviations: De=Dev Association; Ec=Ector; EKc= Eckrant-Kavett Complex; Ls=Limestone Rockland.

Table 2. Soil types in the Edwards Plateau, Uvalde County, study site with percentages and amounts. Rocky limestone hills throughout (soil series as in USDA-NRCS 2012).

Soil site (abbreviation)	Description	Location	Available (%)	Amount present (ha)
Ector (Ec)	Very shallow, stony, calcareous, clay loam soil over fractured limestone bedrock	Dominant ecological type	87.13	176.00
Eckrant-Kavett Complex (EKc)	Soils slightly deeper	Shallow valley in SW corner	5.44	11.00
Dev (De)	Limestone cobbles mixed with very gravelly clay loam soil	Around ephemeral creek in E	4.95	10.00
Limestone Rockland (Ls)	Exposed limestone	In SE & in small areas on hill tops	1.98	4.00
Other	Steepest slopes on the northern sides of the hills	Steep slopes	~ 0.50	1.00

Vegetation of the sites is characterized as mixed shrubland (Figs. 5 & 6). Shrub density is highest on the more mesic Edwards Plateau site but species diversity is greatest on the west Texas ranch. The west Texas pasture has a diverse array of low growing shrubs also typical of the nearby Edwards Plateau ecoregion and characterized by small leaves and often thorny stems. These include shrubs like brasil *(Condalia hookeri)*, elbow bush *(Forestiera pubescens),* mescat acacia *(Vachellia (=Acacia) constricta),* catclaw acacia *(Senegalia greggii)* and lotebush *(Ziziphus obtusifolia).* Shrubs on the west Texas study site are interspersed with prickly pear (*Opuntia* spp.), yuccas (*Yucca* spp.), and cacti typical of the Trans-Pecos region: Spanish dagger *(Y. torreyi)* and ocotillo *(Fouquieria splendens)* are conspicuous. In the valleys, greater water availability and deeper soils

Figure 5. Main soil and vegetation types of the Terrell County, Texas, study site: (top) Ector soils dominated by open growth of low shrubs, selected habitat of dama gazelles; (bottom) Ector-Rock Outcrop Complex soils showing rock ridges and steep slopes, not well used by dama gazelles (soil series as in USDA-NRCS 2012).

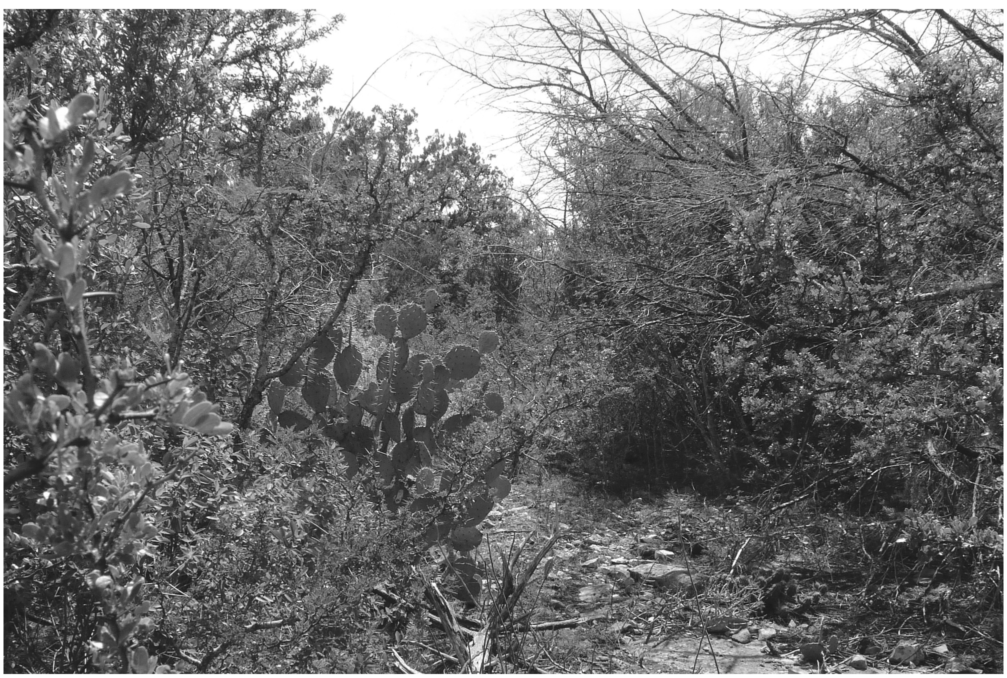

Figure 6. Main soil and vegetation types of the Edwards Plateau, Uvalde County, study site: (top) Ector soils dominated by denser growth of low shrubs; (bottom) Ector soils showing taller plants with mainly closed canopy typical in much of the pasture (soil series as in USDA-NRCS 2012).

support taller shrubs and small trees, including sugar hackberry *(Celtis laevigata),* kidneywood *(Eysenhardtia texana),* redberry juniper *(Juniperus pinchotii)* and some Ashe juniper *(J. ashei),* honey mesquite *(Prosopis glandulosa),* and oaks (*Quercus* spp.). Forbs and grasses are sparse with availability dependent on rainfall.

Species composition indicated that the west Texas study site's rangeland is in good condition and, despite the thin, rocky soils, there are many plants available to the gazelles that have been ranked palatable and nutritious for native white-tailed deer on the Edwards Plateau and in south Texas (Wright et al. 2002). Plant species composition was similar throughout the site, differing mainly in plant density. The eastern portion of the site has less surface rock and, thus, greater plant density and more productive forage. Intervening alluvial west Texas valleys are dry much of the year except for occasional heavy rains. Water in ponds and troughs is available to the gazelles. No supplemental feed was available except during one winter period when temperatures dipped below freezing, at which time some of the dama gazelles found leftover hay put out for cattle.

Larger and denser areas of brush in the smaller study pasture on the Edwards Plateau reflect the more mesic conditions. However, past heavy use by domestic livestock has left plant species diversity low and much of the vegetation coarse or thorny. Shrub cover was estimated from aerial photographs to be approximately 50%. Blackbrush acacia (*Vachellia* (=*Acacia*) *rigidula*)*,* a semi-evergreen, thorny shrub abundant on rocky ridges, is the dominant woody plant species and is the most important forage plant for the dama gazelles. Historically, dama gazelles in Africa were associated with *Acacia* savanna (RZSS & IUCN Antelope Specialist Group 2014; Jebali & Mungall 2018). Prickly pear is abundant and provides energy rich, edible fruits. Dama gazelles use this in spite of its numerous spines. Other common plants on the hillsides are the shrub coyotillo (*Karwinskia humboldtiana*)*,* the leaves and berries of which are highly toxic, and the succulent leatherstem (*Jatropha dioica*)*.* Neither of these plants provides food for the gazelles. In the valleys and along drainages, there is a more diverse mix of shrubs, including spiny hackberry (*C. pallida*), Texas persimmon (*Diospyros texana*), Ashe juniper, and catclaw mimosa (*Mimosa borealis*). A few live oak trees (*Q. virginiana*) grow along the dry creek on the northeast side of the pasture at the lowest elevation. These plant species all provide some food to browsing ungulates, although they are not classified as preferred browse species as evaluated for native white-tailed deer (Wright et al. 2002). Grass and forbs are sparse. Species composition of annual plants depends on rainfall. The Edwards Plateau pasture has a water trough at each of the five feeder areas dispersed throughout the pasture (Fig. 4). The gazelles get little of the protein pellets provided because of the crowd of larger animals such as scimitar-horned oryx and longhorn cattle that rush to consume the feed as soon as it is put out.

Global Positioning System (GPS) radio collars were fitted on three adult males and two subadult males darted from the established population of at least 50 individuals on the west Texas study site. Because no information was available that dama gazelles had ever been collared before, females were deemed too valuable to risk collaring. For the subsequent Edwards Plateau trials, collars were placed on all of the dama gazelles put into the study pasture. This was seven adult females, one maturing male, and zero, one, or three adult males depending on the social situation being monitored. All animal handling was approved by Texas A&M Agricultural Animal Care and Use Committee, Animal Use Protocol # 2012-098A, and followed the ASM guidelines for research on live animals (Sikes et al. 2011).

The Lotek 3300S collars (Lotek Wireless Inc., Newmarket, Ontario, Canada) were programmed to store one location every 3 hr for a 1-yr study period. A data collection frequency greater than 2 hr has been shown to be appropriate in studies of ungulate distribution on south Texas rangelands in order to minimize autocorrelation of locations that can be statistically problematic in home range studies (Perotto-Baldivieso et al. 2012). The timed drop-off units were programmed to open at the end of the study year in order to obviate the risks involved in recapturing the gazelles. The radio component was used to locate the animals during monthly visual welfare checks as well as to find the collars after they dropped off. This allowed the investigators to triangulate and map pasture use periodically during the study as well as to check that no problems were developing for the animals or their collars. Each collar was color coded to aid visual recognition during the monthly welfare checks and behavioral observations. Animal designations start with A for the west Texas adults and start with S for the west Texas subadults: A1 for the largest west Texas male, A2 and A3 for the other two west Texas adults, S1 and S2 for the west Texas subadults. “Adult” and “subadult” were defined as for gazelles in general by Walther et al. (1983). Similarly, on the Edwards Plateau study site GM was used for green collar adult male, GF for the green collar adult female, Rm for the red collar immature male, etc.

For the work in west Texas, collaring was done on 16 January 2013, and GPS data for the project was used for one year beginning on 23 January 2013. The week delay in start date was to avoid any effects of disorientation that might have been caused by the capture. On the Edwards Plateau, collaring started on 15 December 2014 with data used for one year beginning on 19 December 2014 when animals were initially released into their new research pasture.

After retrieval of the collars at the end of the study, the data were downloaded and processed through differential correction software (N4Win, Lotek, Ontario, Canada) to give a positional accuracy of ±2 m. The corrected collar data were imported into ArcView (ESRI, Redlands, California, USA) for spatial analysis. The HRE extension in ArcView 3 was used to calculate the annual and seasonal kernel home ranges (KHRs) of the animals, and the volume method was applied to view the home range in 10% increments. This method provides a mathematical probability of an animal using an area and provides a reliable representation of animal distribution (Seaman & Powell 1996). Locations beyond the 95% KHR are considered indicative of exploratory behavior rather than being included as part of the animal’s home range. The 50% KHR is typically used to denote the core use area of an animal. Proximity of animals to each other was calculated by the Euclidian distance between simultaneous GPS locations.

Habitat use was determined by assessing the proportion of GPS collar locations in each habitat type as defined by the NRCS soil types (USDA-NRCS 2012). Habitat selection was determined using Chi-squared test to compare the proportion of GPS locations in each habitat (observed) with the distribution of an equal number of random points on the landscape (expected).

Similar Chi-squared goodness of fit tests were performed to explore influence of both natural and man-made features on gazelle distribution. Features tested were hill slope (particularly steep inclines of > 11-27 degrees or 20-50 %), areas of dense vegetation, roads, natural drainages, water troughs, and feeders. Frequency of occurrence of gazelles within mapped areas, or within 10 m of man-made features, was compared with the distribution of 3,000 random points generated in ArcView 10. Differences were considered significant at $P \leq 0.05$. For the west Texas study site, affinity for water sources within 500 m was also investigated using a Chi-squared test. For the smaller Edwards Plateau study site, affinity for water sources within 100 m was also investigated using a Chi-squared test.

Results

In west Texas, four of the five collars succeeded in obtaining a full year of data (2,866 ± 60 of a possible 2,920 locations per collar), but the collar of the subadult S1 ceased functioning four mo early. Thus, it had fewer fixes (1,785 locations) in addition to the points triangulated during monthly visual observations. On the Edwards Plateau, two of the female collars developed problems. One stopped working six wk early and another fell off two wk early.

West Texas – Home Ranges and Core Areas.–The adult males kept extensive, partially overlapping home ranges (95% KHR) averaging 1,783 ± 364 ha, with non-overlapping 50% core areas averaging 440 ± 144 ha. The two subadult males had home ranges averaging 3,150 ha which overlapped with each other as well as with the home ranges and core areas used by the adult males. Core areas of the subadult males were nearly identical in space and averaged 381.58 ± 89.56 ha. There was no evidence of consistent seasonal variation in home range size and distribution of male dama gazelles (Table 3).

West Texas – Habitat Selection.–The dama gazelles primarily used the eastern side of the ranch with its vegetatively more productive soils (USDA-NRCS 2012 as reported for growth of grasses useful as cattle forage) and selected for the less rugged topography: $\chi^2 = 88.51$, *df* 5, $P < 0.001$.

A comparison of the percentage of GPS readings by soil type as compared to the percent occurrence of each soil type in the study area is presented in Fig. 7. Four of the five collared male dama gazelles in the large west Texas pasture maintained their home ranges and core

Table 3. Seasonal home ranges expressed by 95% kernel home range (KHR) and 50% kernel home range core areas of male dama gazelles on the Terrell County, Texas, study site. Animal abbreviations: A=adult; S=subadult. *=dual core areas; †=collar failed.

Season	Months	KHR	A1	A2	A3	S1	S2
winter	JFM	50%	413.59	328.91	424.12	351.63	515.66*
spring	AMJ	50%	281.23	270.17	615.44*	665.55*	188.75
summer	JAS	50%	434.10	609.09*	736.35*	333.87	256.98
fall	OND	50%	330.34	308.84	459.23*	†	174.54
winter	JFM	95%	1,666.30	1,281.67	1,767.23	2,960.84	2,868.77
spring	AMJ	95%	1,242.99	1,046.96	2,189.97	4,025.02	991.10
summer	JAS	95%	1,764.38	2,921.05	2,570.49	2,829.91	1,754.45
fall	OND	95%	1,222.67	1,118.93	2,258.41	†	886.71

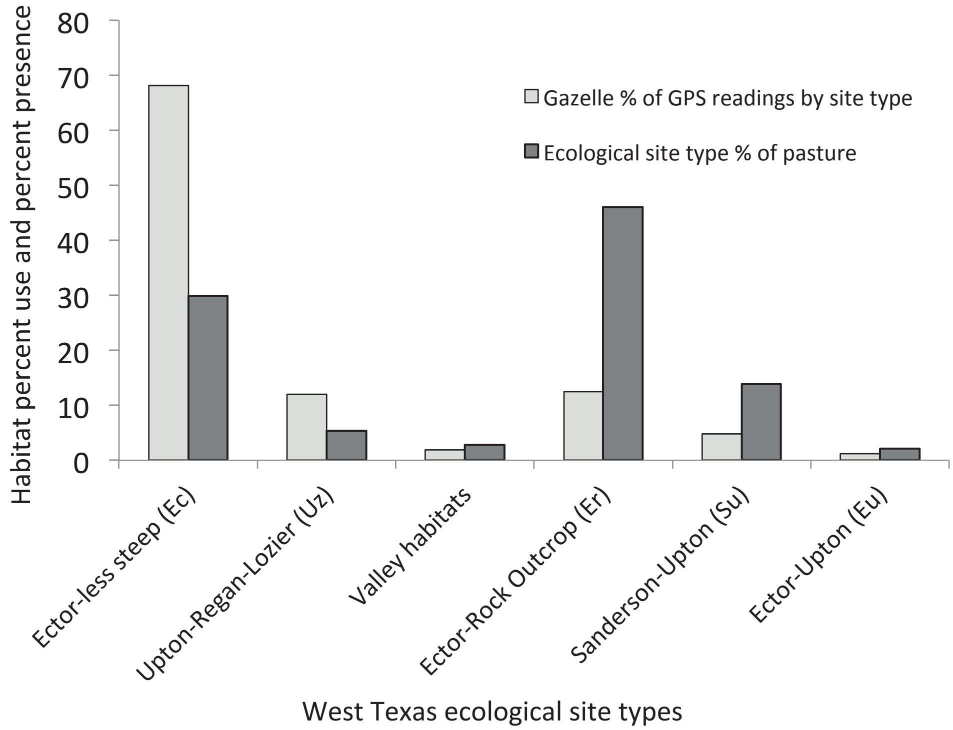

Figure 7. Comparison of dama gazelle GPS locations and occurrence of different soil types (soil series as in USDA-NRCS 2012).

areas predominantly on the Ec soil type. Adult male A2 used a larger proportion of the more rugged and less productive (less productive by NRCS agricultural standard, USDA-NRCS 2012) Er habitat in his home range (40.86% of home range and 42.03% of core area compared with 46.09% of total Er soil area in the pasture). The other two adults used only 0% and 20.13% Er soils in their home ranges, and the two subadult males used only 3.66% and 19.78% Er soils in their home ranges. The 40.86% Er usage and 36.12% Ec usage that A2 had in his home range, and the 42.03% Er usage and 41.61% Ec usage in his core area illustrate what a large percentage of Er soils habitat he was able to use. Considering all five males together, the gazelles spent roughly two thirds of their time (mean 68.12%) on Ec soil sites even though the Ec soil habitat was only about a third (29.85%) of the available habitat.

Dama gazelles were most commonly seen on the hills, giving the impression that they avoided valley habitats. However, this was an artifact of the lesser abundance of valley habitat. In fact, the gazelles used hills (81.12% of gazelle locations, 78.07% of study area) and valleys (18.18% of gazelle locations, 21.93% of study area) in proportion to their availability ($\chi^2 = 0.76$, *df* 2, *P* >0.05).

Many animals use ranch roads for ease of travel in rough or shrub-dominated terrain. The dama gazelles tended to favor flatter areas of the kind where roads are constructed. At the west Texas study site, dama gazelles were often located within 100 m of ranch roads on the flatter terrain ($\chi^2 = 42.34$, *df* 4, *P* <0.001). This makes it hard to distinguish whether roads *per se* or flat ground are the important attribute.

No special use was made of the seasonal drainage areas. These remained dry except after the infrequent heavy rains. This desert-adapted species showed no special affinity for areas within 500 m of water sources at the west Texas study site ($\chi^2 = 11.11$, *df* 4, *P* >0.05).

Feeders were not a consideration on the west Texas study site. Here, the animals live on natural forage which they find for themselves.

Edwards Plateau – Home Ranges and Core Areas.–All the dama gazelles in the smaller, more mesic Edwards Plateau pasture used the entire pasture for their home range. They had similar 50% core areas of 57 ± 10 ha for males and 55 ± 15 ha for females. No large difference was detected in soil type selection between males and females. When three grown males were added to the pasture, two established core areas with only minimal overlap. Only 3% of their GPS locations showed these males within 50 m of each other. This was strongly indicative of the adult males maintaining social separation in spite of having the entire pasture for their home range. The third added male was still using a core area extensively overlapping the core areas of the other two males by the time he was suddenly found dead after nearly 3 mo.

Edwards Plateau – Habitat Selection.–The Edwards Plateau pasture has more uniform terrain, mainly comprising Ec soils (soils and soils coverage defined as in USDA-NRCS 2012). No soil site selection was found (χ^2 = 1.42, *df* 3, *P* >0.05) other than that steep slopes > 20% were avoided (χ^2 = 69.00, *df* 10, *P* <0.001). However, three of the seven females did show an elevated use of the flatter, more open area of deeper De soils in the east, and one female (during the time she was mainly alone before becoming a consistent group member) stayed mainly in the low-lying drainage area with deeper EKc soils in the southwest (χ^2 = 27.49, *df* 10, *P* <0.01). Although parts of these areas were more heavily vegetated, the gazelles did not show selection for or against more densely vegetated areas as plotted from aerial photography of the ranch (χ^2 = 14.55, *df* 10, *P* >0.05).

In this rocky pasture, the gazelles were often seen using the smooth caliche dirt roads to move across the pasture. Nevertheless, dama gazelles on the Edward Plateau study site did not select for ranch roads but used them in proportion to their extent within the habitat. As a group, it appeared that gazelles favored these roads as travel routes (χ^2 = 40.79, *df* 10, *P* ≤0.001), but further examination indicated that much of this statistic was due to the distribution of the three females using the narrow northeast arm of the pasture. In this area, the road parallels a creek bed along the valley floor and is bounded by the fence to the north and steep hillside to the south. Thus, the distribution of these three females near the creek bed (χ^2 = 31.12, *df* 2, *P* ≤0.001) cannot be separated from their proximity to the road (χ^2 = 28.00, *df* 2, *P* ≤0.001) or vice versa. Dama gazelles using the larger western part of the pasture did use the roads but only in proportion to the extent of roads within the habitat (χ^2 = 12.79 *df* 8, *P* >0.05).

Another calculation was made to investigate whether the creek or drainage areas received special use. However, the gazelles frequenting the western part of the pasture showed no overall attraction to the creek and drainage areas (χ^2 = 3.27, *df* 8, *P* >0.05).

The ranch provided water and supplemental feed at five locations within the pasture (Fig. 4). There was no evidence that the gazelles made appreciable use of these locations: water $\chi^2 = 0.07$, *df* 10, $P > 0.05$ (within 100 m of water), feeders $\chi^2 = 12.44$, *df* 10, $P > 0.05$. Only one animal, the most dominant adult male, showed any attraction to a feeder site with its flat, open area. He was sometimes seen there alone instead of with the nearby female group.

The main results for the two study sites are summarized in Table 4.

Discussion

Dama gazelles are a critically endangered species and as a result only occur in low numbers. Data from even the few animals followed in this study is critical to improving our understanding of the habitat requirements of this species. Larger sample sizes of these gazelles are not currently possible. At the west Texas study site, five males were collared out of a population of at least 50 males and females in the pasture. Females were deemed too valuable to risk capture. At the Edwards Plateau study site there were 8 to 11 individuals (number depending on the phase of the study) with all individuals collared. The two remaining wild populations of eastern dama gazelles were estimated to have at least 8 individuals and 50 to 60 individuals (Mungall 2018a). Similarly, the three remaining dama gazelle populations known for the wild (Central dama gazelles*, N. dama dama)* were estimated to have at least 2 individuals, at least 3 individuals, and as many as 50 to 60 individuals (RZSS & IUCN Antelope Specialist Group 2014, Stéphane 2020). Thus, the Texas information should be particularly relevant in planning strategies for assisting this critically endangered species in the wild.

Small sample size in the Texas study limits what can be compared with the situation for dama gazelles in the wild before the large decrease in wild dama gazelle numbers in Africa in the 1970s (Mungall 2018a). Herds of 100 or more no longer gather for occasional treks into the desert. Even in the few cases where there are as many as 100 dama gazelles on a Texas pasture, fences would keep the population from travelling far as a single herd. However, the

Table 4. Summary of main results for the two study sites.

Characteristic	West Texas study site	Edwards Plateau study site
Size of study site	8,996 ha	202 ha
Main soil type selected for home range	Ector soils for 4 males Ector soils & Ector-Rock Outcrop Complex soils for 1 male	Ector soils (main soil type on study site for all gazelles)
Home range size	1,783 ha ave. for adult males 3,150 ha ave. for subadult males All home range used in all seasons	202 ha (whole pasture for both males and females)
Core area size	440 ha ave. for adult males 382 ha for subadult males	57 ha ave. for adult males 55 ha ave. for adult females
Hill vs.valley and slopes usage	Use hills and valleys in proportion to availability	Avoid slopes of > 20%
Topography and vegetation density	Less rugged sites used most	No selection for or against more heavily vegetated areas
Road use or use flat areas	Favored flat areas of kind where roads are made	Favored flatter areas irrespective of whether were using roads
Natural drainage and creek	No special use of drainage areas	No special attraction to creek or natural drainage areas
Water sources	No affinity on test for within 10 m or 500 m	No affinity on test for 10 m or 100 m
Supplemental feed	No supplemental feed for the gazelles	No use of feeders found during project. Large species monopolized feed

present situation in Africa makes it unlikely that such treks can occur anytime soon.

Although the gazelles on the Edwards Plateau study site are in a pasture where the entire space (202 ha) is smaller than even the 440 ha average core area of the adult males on the particularly large west Texas site (8,996 ha), information on site selection under the more restricted conditions is still important. The majority of the approximately 1,500 dama gazelles in Texas are in medium size pastures such as this on the Edwards Plateau, so the continuation of dama gazelles in Texas depends on appropriate management for the species under such conditions. The present study shows that dama gazelles have the flexibility to adapt their behavior to these areas which are more limited in space but which support more forage. Distribution patterns on the Edwards Plateau study site emphasize the effect of such features as cliffs and fences to delimit areas used by the animals. Data from the Edwards Plateau study site also show the concentration of use on parts of the selected habitat. Dama gazelles are social animals, and so they congregate with each other. This makes these varying patterns of behavior – in very large pasture and in medium size pasture – different rather than unnatural.

For the continuation of both exotic and native populations, the availability of preferred habitat in relation to the numbers of gazelles, particularly the number of male dama gazelles, vying for space is an important aspect to consider. Where suitable space is limited, dangerous fighting among male dama gazelles leads to injuries and fatalities (Mungall 2014, 2018c).

The habitat selection documented in this study should be informative for species management both in exotic locations and in native habitat. Most importantly, the dama gazelles favor flat-to-gently rolling topography. This can put the gazelles into more vegetatively productive areas (using USDA-NRCS (2012) agricultural production potential estimates), but at least parts of the less productive and rougher Er soil sites in west Texas were also acceptable for home range and core area use without requiring increased space in order to compensate for the lower forage production. This was demonstrated by the west Texas male A2 who used a larger proportion of the less productive Er soils in his home range than did the other adults even though that home range (1,794.37 ha) was intermediate in size between the home ranges of the other two adults (1,413.73 ha and 2,142.27 ha). Thus, the less productive Er soil sites in Texas could be used for home ranges even though the more rugged aspect was a negative feature for the gazelles.

The temporary expansion of home range of male A2 to the west in summer, associated with greater time spent in the valleys, may have been triggered by greater availability of shade and water in the valleys than on hilltops and plateaus. We do not consider this a displacement because this individual also spent time in the eastern part of his home range during summer.

Dama gazelles in this study did not show any consistent seasonal variation in distribution. In their native habitat, dama gazelles, in at least some regions, make seasonal movements associated with the need for water and shelter from the summer sun (Jebali 2008, Newby 2015). A similar behavior was not seen in Texas probably due to the less intense heat and the strategic distribution of numerous water points throughout the properties. The Texas dama gazelles showed no special affinity for water points, probably getting by largely on the moisture in plants. Even so, when water troughs are available exotic dama gazelles do drink regularly during hot Texas summers (Mungall, pers. observ.). At West African breeding centers, drinking water is provided either year-round or in the hot season for western dama gazelles (Abáigar 2018). Die-offs have been suspected among wild dama gazelles when increasing competition from pastoralists and their livestock have kept dama gazelles and other wildlife from sheltering in the more densely vegetated wadis during the hot, dry season, denying the gazelles water-rich plants as well as shade (Newby 2015).

The presence of supplemental feed is only expected to affect habitat selection for the gazelles if the gazelles have access to the supplemental feed. The west Texas dama gazelles in this study, where no supplemental feed was provided for the exotics, were able to maintain themselves on natural forage. In the Edwards Plateau pasture, the dama gazelles had to maintain themselves on the natural forage because of crowds of larger animals such as scimitar-horned oryx and cattle at the feeders. Blackbrush acacia was the staple food for the gazelles in the Edwards Plateau pasture. In the 720 ha West African Guembeul Fauna Reserve, repatriated western dama gazelles have only irregular access to supplemental feed because of competition from the numerous scimitar-horned oryx (Abáigar 2018). Consequently, dama gazelles need to be provided a way to get to supplemental feed when kept in areas where they require more than the natural forage. One Texas safari park, Natural Bridge Wildlife Ranch, uses simple pipe frames around some of the feeders to keep out larger animals while letting the dama gazelles in. Another option is not to put dama gazelles in the same pastures with large animals such as scimitar-horned oryx or cattle.

Analysis of possible affinity for travel on roads in the smaller Edwards Plateau pasture indicated that flat ground rather than roads was the important factor when dama gazelles were seen on roads. Therefore, this same distinction is assumed to be the case in the west Texas pasture.

Based on results from the adult males in the very large west Texas pasture with its near free-ranging conditions, the 95% home range and 50% core area kernel home ranges percentages fit well with what our data showed for these dama gazelles. Location density fell off markedly outside the 95% contour, and 50% turned out to be the level up to which space used by the adult males did not overlap. This suggested territorial behavior, as observed elsewhere in Texas dama gazelle investigations (Mungall 2018c), although territoriality could not be verified in the west Texas case because there were no visual observations demonstrating border behavior.

Knowledge of habitat selection and spatial requirements of dama gazelles can be used to predict the number of adult breeding males that a ranch or reserve can accommodate. This is important for conservation of the species if dangerous conflict between males is to be minimized. Given that the average size of the exclusive use core areas of adult male dama gazelles at our west Texas study site, where no fighting deaths have been documented, was 440 ha, we estimate that there should be room for 20 adult males to coexist within the 8,996 ha pasture. However, animals do not pack into a space exactly, and not all habitat is of equal value. The dama gazelles showed consistent preference for the somewhat less rugged and more vegetatively productive terrain of Ec and associated Uz valley soils (3,166.60 ha). Assuming an average core use area of 440 ha per individual, only seven adult males could establish non-overlapping core areas entirely within this preferred habitat. However, the home range and core area of the male A2 included a considerable amount of the more rugged western regions of Er soils, indicating that gazelles can use at least portions of this less than optimal habitat. As a consequence, the likely number of adult male gazelles that the ranch can accommodate lies somewhere between 7 and 20, the exact number dependent on the extent and interspersion of resources and habitat types. At the west Texas study site, an intermediate number of about 14 would allow all adult males to have some access to the favored Ec habitat within their core area. The dama gazelle population is not yet at this stage, but future monitoring of the growing population there should be able to determine at what density aggression between males becomes a limiting factor.

Interestingly, comparison with the smaller, more mesic, Edwards Plateau pasture shows considerable flexibility among dama gazelles for the way they can partition space under different conditions. With three adult males in the 202 ha pasture, the males used the entire pasture for their home range and had 50% core areas, both for males and for females, approximately eight times smaller than for adult males on the extensive west Texas study site. But a warning needs to be added. Fighting deaths were unknown in the west Texas pasture where the dama gazelles had space to spread out. By contrast, territories of 2.5 ha to 21.6 ha (this largest being an entire pasture that is flat and mainly open) have been watched in Texas, but there have been periodic fighting injuries and fatalities (Mungall 2018c). Thus, the flexibility in size for a dama gazelle male to hold a successful territory in a limited pasture may require topographic separations like the steep hills and cliffs in the Edwards Plateau pasture in order for the dama gazelle males to keep from killing each other if living with females. And, while adequate space reduces fighting between adult males, there will always be some aggression as younger males attempt to enter the breeding population. This was seen by the horn-raking injuries to the male S1 toward the end of the west Texas study when he was coming to adulthood. Working with smaller pastures, these maturing males may need to be withdrawn.

Texas owners who have dedicated land and resources to maintain dama gazelles are to be congratulated. This is especially true considering that dama gazelles are not a principal hunting species and so contribute more to eye appeal on a property than to the revenue needed to pay taxes and other upkeep costs. Build-up of "reservoir" populations of this critically endangered species increases the chances of long-term species survival. West Texas landscapes match natural habitat most closely, but Edwards Plateau pastures are more available and have become a mainstay of dama gazelle numbers in the United States.

In the future, further data explorations using the thousands of collar locations generated during this study can be completed. This will allow additional aspects of dama gazelle activity to be demonstrated. In the meantime, insights into habitat selection as shown here are available to managers involved with the welfare of these animals in both exotic and native situations.

Conclusions

Information on habitat preferences is important for selecting the best sites and the best stock for breeding or restoring dama gazelle populations. Dama gazelles raised on Texas rangelands are used to foraging in thorn scrub habitats and coping with predators and variable weather. Therefore, they should provide better adapted stock for reintroduction efforts in Africa than animals raised in zoological parks. Where possible, savanna rangelands rather than marginal rocky areas would be the preferable kinds of habitat in which to nurture populations. However, dama gazelles in both Africa and Texas have shown their adaptability in living under more marginal conditions.

International projects are being initiated to restore critically endangered dama gazelles to parts of their native distributional areas in the African Sahel (Mallon et al. 2019). Information on habitat selection will help in identifying the best sites for restoring dama gazelle populations to the wild and for breeding the species as exotics. Obtaining information on use of the landscape in the wild is extremely difficult to gather due to the scarcity of dama gazelles and to the unsettled situation in northern Africa. Meanwhile, portions of Texas offer an environment with similarities to the African Sahel and as close to natural conditions as can be found in the US. The exotic dama gazelle populations in Texas have become not only a safeguard against total extinction of the species but also a source for animals to reintroduce.

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