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Home range size of the goitered gazelle (*Gazella subgutturosa subgutturosa* Güldenstädt, 1780) in the steppes of the Iori-Mingachevir ecological corridor

Sevinj Sarukhanova[1*], Elmar Babayev[2], Elshad Askerov[3,4], Afag Rizayeva[5], Aynura Babaliyeva[4], Nugzar Zazanashvili[6]

[1]*Department of Bioecology, Baku State University, 23 Academician Z. Khalilov Str., AZ1148, Baku, Azerbaijan*
[2]*Precaspian Institute of Biological Resources, Dagestan Federal Research Centre of the Russian Academy of Sciences, 45 M. Gadjiyev Str., 36700, Makhachkala, Russia*
[3]*Department of Terrestrial Vertebrates, Institute of Zoology of the Ministry of Science and Education of the Republic of Azerbaijan, Block 504, Pass 1128, 115 A. Abbaszade Str., AZ1004, Baku, Azerbaijan*
[4]*WWF Azerbaijan, Badamdar, 1st Residential Area, Turn 11, House 3, Sabail, AZ1021, Baku, Azerbaijan*
[5]*SILVIS Lab., Department of Forest and Wildlife Ecology, University of WisconsinMadison, 1630 Linden Drive, Madison, WI 53706, USA*
[6]*WWF Caucasus Program Office, 11 M.Aleksidze Str., 0193, Tbilisi, Georgia*

[*]***For correspondence:*** *s.saruxanova@gmail.com*

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This study took place along the Azerbaijan-Georgia border, in the Eldar and Ajinour steppes – key parts of the Iori-Mingachevir ecological corridor, which supports a transboundary population of Goitered gazelles. We used data collected using GPS collars to track and analyze annual and seasonal home ranges for 4 male and 4 female Goitered gazelle individuals. Our results showed a clear difference in annual home range size between the sexes (Kernel Density Estimation 95%: t=4.220, p=0.005). On average, males ranged across 73.64±9.46 km², while females occupied smaller areas of 33.28±1.37 km². Although seasonal home range sizes did not differ significantly overall, notable sex-based differences appeared in the summer, when male home ranges were roughly three times larger than those of females. Goitered gazelles in the Eldar and Ajinour steppes travel extensively and exhibit a nomadic lifestyle, sometimes covering up to fifteen kilometers in a single day. Seasonal changes in forage and water availability, along with human-related pressures, especially livestock grazing and disturbances from shepherds and their dogs play an important role in shaping the size and dynamics of their home ranges. Our findings are essential as a baseline to support habitat management, inform conservation strategies, and aid future reintroduction initiatives.

Keywords: *Ajinour steppe, Eldar steppe, Gazella subgutturosa subgutturosa, Goitered gazelle, GPS telemetry, home range*

INTRODUCTION

Understanding how animals use space begins with two key concepts: the home range, the area in which an animal conducts its daily activities, and the core area, referring to the part of the home range used most intensively (Kaufmann, 1983). Studying the structure and dynamics of home ranges reveals important aspects of a species' ecological needs, behavioral patterns, and habitat preferences.

Modern home range analysis depends on collecting extensive spatial data, much of which is now generated using telemetry techniques, such as GPS-based remote tracking. The GPS-tracking provides high-resolution data on animal

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movements over extended periods, allowing researchers to track behavior with high precision. Beyond mapping range boundaries, GPS collars and satellite tags have advanced the studies on predator-prey interactions, foraging strategies, and habitat selection (Kie et al., 2010; Kays et al., 2015).

Today, the widespread human transformation of natural landscapes is leading to severe habitat fragmentation and ecological disruption, driving many species into small, isolated populations (Damm & Franco, 2014). The Goitered gazelle (*Gazella subgutturosa*) in Azerbaijan is no exception. Once common across semi-desert plains and foothill zones, the Goitered gazelle now persists in fragmented habitat patches scattered across Azerbaijan (Sarukhanova, 2016). The Goitered gazelle is included in the Red Book of Azerbaijan and listed as Vulnerable on the IUCN Red List (IUCN, 2017). Currently, most of Azerbaijan's Goitered gazelle population is confined to protected areas, some of which have been established only in recent years (Sarukhanova, 2016). The largest and most genetically isolated population is in Shirvan National Park, home to over 90% of the country's Goitered gazelle population (Mallon et al., 2012). Smaller populations are found in the Ajinour Steppe (including the Gakh State Nature Sanctuary and Ilisu State Nature Reserve), the Korchay State Nature Reserve and Sanctuary, Ag-Gol and Absheron National Parks, the Eldar Steppe (a transboundary region between Azerbaijan and Georgia), and the Gobustan Plateau. Most of these small groups are the result of an ongoing reintroduction program, initiated in 2008, which aims to restore Goitered gazelles to parts of their historical range (Sarukhanova, 2016; Weinberg et al., 2020).

As part of the reintroduction initiatives, landscapes across the Caucasus were evaluated, and the Eldar and Ajinour steppes, comprising the Iori-Mingachevir ecological corridor, were identified as the most ecologically suitable and strategically important for reintroduction (Mallon et al., 2012). Over a ten-year period, the release of Goitered gazelles into different areas within the Eldar and Ajinour steppes resulted in continuous population growth, confirming the corridor's suitability as a reintroduction zone (Askerov et al., 2021).

Although Goitered gazelles have been studied extensively, including assessments of their home range (Askerov et al., 2021), previous research has not examined how these patterns vary by sex or season. The primary objective of this study was to evaluate home range size in relation to sex and seasonal movement patterns among reintroduced Goitered gazelles across the Iori-Mingachevir ecological corridor in Azerbaijan and Georgia. We expected that male and female gazelles would exhibit different home range sizes and that summer ranges would be larger than winter ranges due to forage availability and the need for broader spatial exploration during warmer months.

MATERIALS AND METHODS

The study was conducted in 2013-2020 in the South Caucasus, between the Greater and Lesser Caucasus Mountain ranges, at elevations ranging between 100-1,000 meters above sea level (Askerov et al., 2021). All fieldwork, including Goitered gazelle releases and GPS-based tracking, took place within the Iori-Mingachevir ecological corridor, specifically across the Eldar and Ajinour steppes (Figure 1).

The Eldar steppe borders Georgia's protected Vashlovani mountain region to the north, the Iori River to the south, and the Mingachevir Reservoir to the southeast, offering over 350 km² of habitat suitable for Goitered gazelles. The Ajinour steppe covers a larger area, bordered by the Mingachevir Reservoir in the south and the Dashuz Ridge in the north, encompassing roughly 550 km² of potential Goitered gazelle habitat (Askerov et al., 2021).

Four protected areas are located within the study region. In Georgia, the Vashlovani Protected Area complex includes both the Vashlovani Strict Nature Reserve and the Vashlovani National Park (covering a combined 350 km²). A new protected area (13,3 km^2) named after Nugzar Zazanashvili was established in 2022 at the left bank of the Iori river, to support gazelle restoration in Georgia. In Azerbaijan, the Ajinour lowland section of the Gakh State Nature Sanctuary (250 km²) and the Akhar-Bakhar section of the Ilisu State Nature Reserve (51 km²) are key protected zones.

All Goitered gazelle individuals released into the Eldar and Ajinour steppes were captured in Shirvan National Park without the use of tranquilizers. All details on the capture and release protocol, fieldwork logistics, and transportation procedures are available in Askerov et al. (2021).

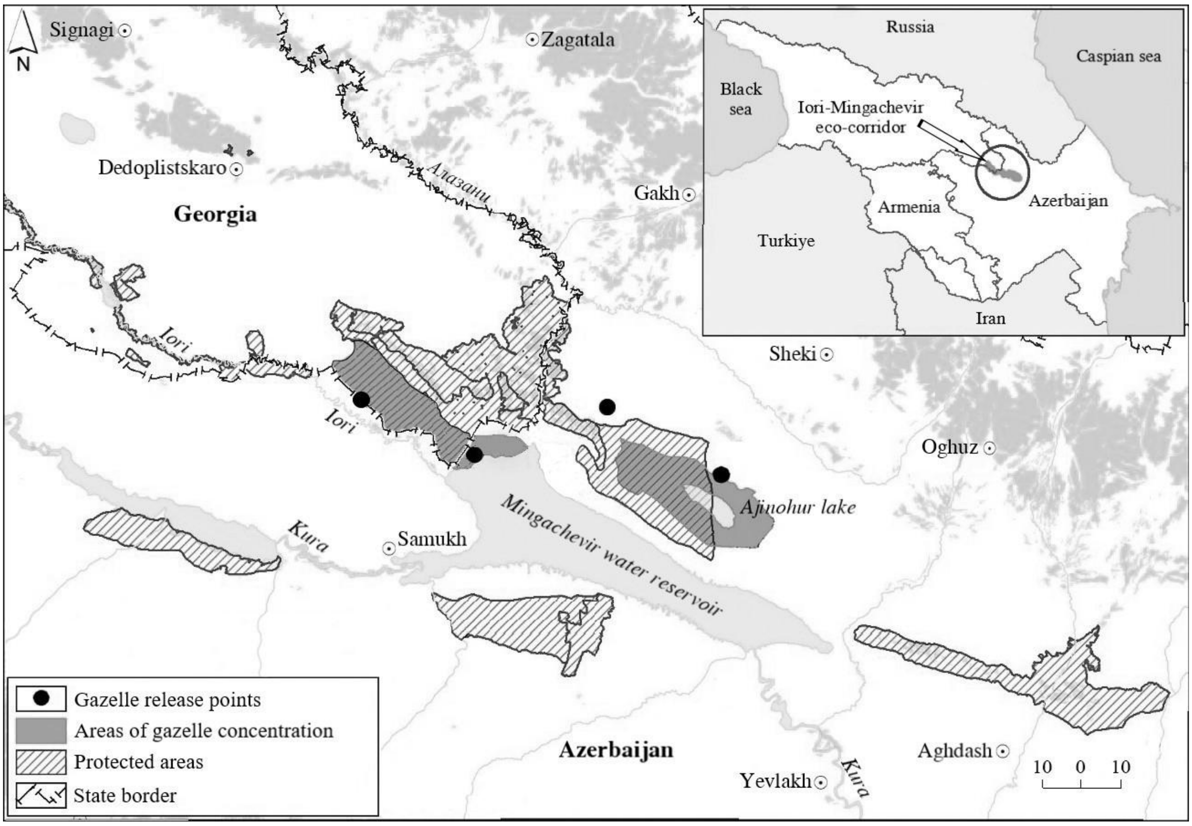

Fig. 1. Map of the study area, showing release sites and Goitered gazelle concentrations within the Eldar and Ajinour steppes.

Some animals were fitted with a GPS Plus Vertex Survey collar (Vectronic Aerospace GmbH, Berlin, Germany. Technical specifications are available at vectronic-aerospace.com). In addition to GPS coordinates, each device recorded timestamps, ambient temperature, altitude, and a GPS accuracy metric (Dilution of Precision, or DOP). Collars were programmed to collect two fixes per day, at 8:00 and 20:00 local time. If the collar transmitted identical location data across 24 hours (i.e., no movement detected), this was flagged as a potential mortality event.

We used the data from a total of eight GPS collars collected between August 2013 and March 2020, yielding 7,353 location records (Table 1). In a few cases, a single collar was reused after the initial animal died; in these instances, we only included in the analyses the dataset with the longer tracking duration. Collar runtimes varied, and for individuals tracked over multiple years, we used only one full calendar year of data to estimate annual home ranges. For collars without a full year of data, the available location points contributed to seasonal home-range estimates instead. To ensure consistency, we excluded the acclimatization period from all data, which is the time from release until the animal joined free-ranging Goitered gazelle groups. This acclimatization period typically lasted between one and one-and-a-half months, though in some cases it was longer (Tables 1 and 2; see Durmuş, 2010). We only made an exception for male AG2 and female AG6: both were originally released animals that had already integrated into the local population and were later recaptured for collaring. For these individuals, we included all location data without excluding an acclimatization window.

We excluded from the analysis records with high GPS inaccuracy (Dilution of Precision, or DOP). Since DOP values below 4 are considered to provide high spatial accuracy (Moen et al., 1997; Durmuş, 2010), we filtered out the records with DOP values above 4, which accounted for only a small portion of the dataset.

Table 1. Basic information on tagged Goitered gazelles.

Individual	Collar number	Sex	Collar working period	Cause of drop	Number of locations	Location
AG1	13377	Male	26.08.2013-15.03.2015	Self-unfastening	1,004	Ajinour steppe
AG2	13379*	Male	03.10.2014-05.07.2015	Death	565	Ajinour steppe
AG3	13380	Male	26.08.2013-25.02.2015	Self-unfastening	835	Eldar steppe
AG4	19395	Male	28.09.2015-11.01.2019	Self-unfastening	1,574	Eldar steppe
AG5	19394	Female	28.09.2015- 26.12.2017	Self-unfastening	1,417	Eldar steppe
AG6	34097*	Female	15.01.2019-02.11.2019	Death	424	Ajinour steppe
AG7	34164	Female	21.09.2018-07.03.2020	Self-unfastening	869	Ajinour steppe
AG8	34165	Female	21.09.2018-22.10.2019	Self-unfastening	665	Eldar steppe

Note: Asterisks indicate collars that were used on two individuals. Data is presented only for the individual with the longer dataset.

Table 2. The number of location records and time periods used to calculate seasonal home range sizes.

Individual	Spring	Summer	Autumn	Winter	Rutting period	Period of Birth of lambs	Time frames used to distinguish seasons
AG1	177	173	92	173	116	–	01.12.2013-20.12.2014
AG2	172	–	114	175	121	–	03.10.2014-29.05.2015
AG3	153	143	74	121	109	–	19.12.2013-20.12.2014
AG4	163	166	161	163	110	–	01.03.2017-28.02.2018
AG5	161	165	153	157	104	107	01.03.2016-28.02.2017
AG6	152	106	–	69	–	97	15.01.2019-04.08.2019
AG7	155	157	154	109	107	104	01.03.2019-29.09.2020
AG8	214	132	99	156	109	110	07.10.2018-14.08.2019

Note: Dashes indicate missing data.

We excluded from the analysis records with high GPS inaccuracy (Dilution of Precision, or DOP). Since DOP values below 4 are considered to provide high spatial accuracy (Moen et al., 1997; Durmuş, 2010), we filtered out the records with DOP values above 4, which accounted for only a small portion of the dataset. Additionally, we excluded all records with a “mortality” label, especially for collars that operated for less than one year, because the label occurred in cases when the final data point transmitted by a collar remained in a specific location due to accidental release or predation. Removing such repetitive, static signals helped prevent bias in home range estimates, particularly when using Kernel Density Estimation (KDE).

We conducted home range calculations for both full-year and seasonal periods. We defined six biologically relevant seasons based on the Goitered gazelle’s life cycle: spring (March-May), summer (June-August), autumn (September-November), winter (December-February), breeding (rut) period (October 20 - December 20), and fawning season (May 1 - June 30).

There is currently no universally accepted standard for measuring home ranges, and estimates can vary considerably depending on the analytical method used (Halbrook & Petach, 2018). Hence, we applied three widely used methods, each with well-documented strengths and limitations (Getz et al., 2007; Halbrook & Petach, 2018; Wilson et al., 2020). Minimum Convex Polygon (MCP) included 100% of location points. Fixed Kernel Density Estimation (KDE) used a biweight kernel with a reference bandwidth (href) to define the area encompassing 95% of location points; we calculated the core areas (KDE 50%) using the 50% contour. The third method, Local Convex

Hull (LoCoH-a) is non-parametric, where the smoothing parameter "a" was set to the maximum distance between any two points. We created the polygons using the HoRAE (Home-Range Analysis and Estimation) plugin for the open-source GIS platform OpenJUMP v. 1.7.1 (Steiniger & Hunter, 2012), and conducted all spatial measurements in QGIS v. 3.3 (QGIS Development Team, 2014). While not our primary objective, we also compared the three home range estimation methods, which allowed for a better understanding of how methodological choices can influence spatial ecological metrics.

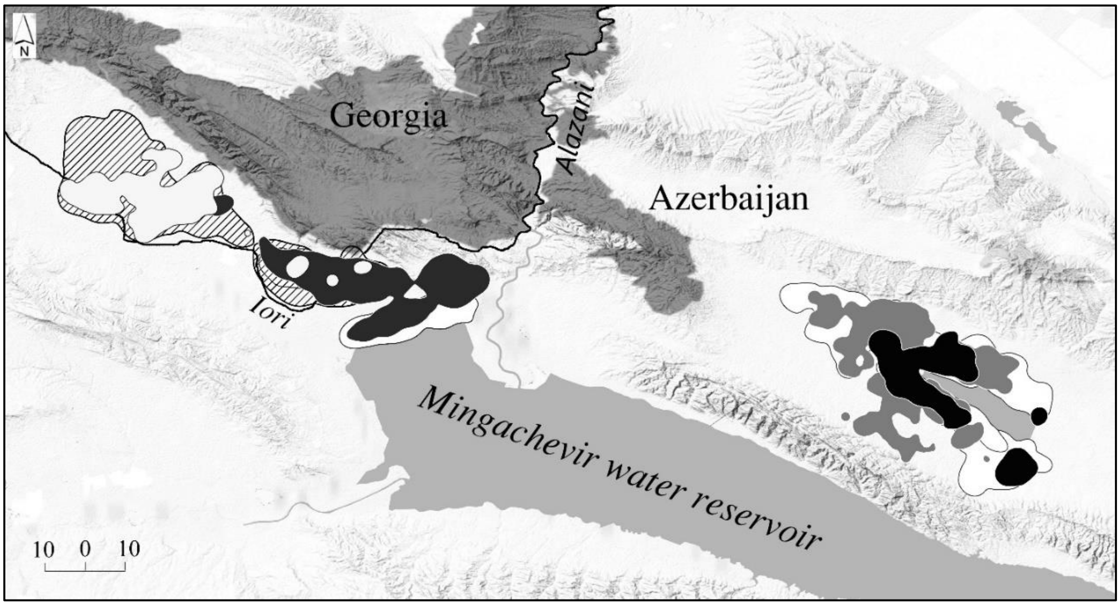

Fig. 2. Annual home ranges of all tracked Goitered gazelles based on Kernel Density Estimation 95%. The contours and shaded areas represent the home ranges of individual Goitered gazelles.

For each Goitered gazelle individual, we calculated four separate home ranges for one polygon for each period (annual and seasonal) using the three methods. In total, we generated 32 annual and 164 seasonal home range polygons across eight individuals (e.g., Figure 2).

To test for differences across individual, seasonal, and annual home range sizes we used a one-way analysis of variance (ANOVA) and the exact permutation test, which is well-suited for small sample sizes. We report the average values using the arithmetic mean ($\bar{X}$) and the standard error of the mean (S*x*). We conducted all statistical analyses using Statistica 13 and PAST v. 4.13.

RESULTS AND DISCUSSION

Using the 100% Minimum Convex Polygon (MCP) method, we estimated the average annual home range size across all eight Goitered gazelle individuals to be 90.03±9.05 km² (Table 3). The 95% Kernel Density Estimation yielded 53.46±8.81 km², and the Local Convex Hull (LoCoH-a) method yielded 48.55±7.58 km². We observed statistically significant sex-based differences in annual home range sizes across all three methods (MCP 100%: t=4.128, p=0.028; KDE 95%: t=4.220, p=0.028; LoCoH-a: t=3.293, p=0.056; KDE 50%: t=2.449, p=0.042). On average, male Goitered gazelles had home ranges, including the core areas nearly twice as large as those of females (Table 3, Figure 3).

Table 3. Annual home range sizes of Goitered gazelles calculated using different methods.

Individual	Sex	Home range, km^2			
		MCP	KDE 95%	KDE 50%	LoCoH-a
AG1	Male	113.14	69.88	12.51	78.61
AG2	Male	105.51	76.13	15.34	65.09
AG3	Male	103.48	51.31	8.5	42.2
AG4	Male	120.42	97.22	25.6	72.69
AG5	Female	96.46	37.22	6.58	47.58
AG6	Female	61.69	32.52	5.88	22.59
AG7	Female	64.23	32.52	6.7	34.47
AG8	Female	55.35	30.84	6.95	25.2

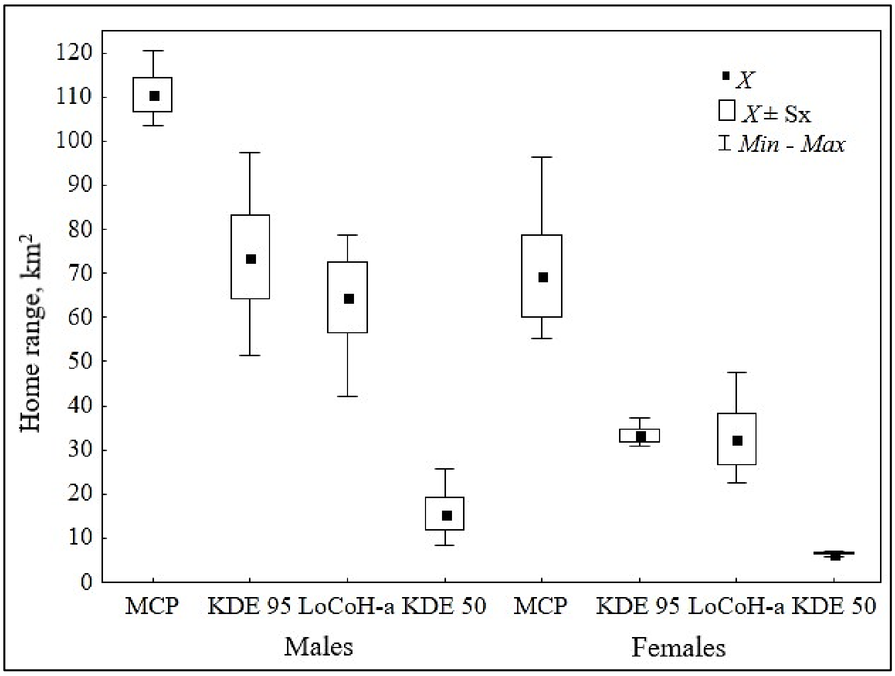

Fig. 3. Annual home range sizes of Goitered gazelles.

A comparative analysis of annual home range estimates using MCP, KDE 95%, and LoCoH-a methods regardless of sex revealed statistically significant differences between methods (F=7.095, df=2, p<0.01). We found similar patterns when analyzing males and females separately (males: F=10.597, df=2, p<0.01; females: F=11.561, df=2, p<0.01). We excluded KDE 50% from these comparisons, as it is not methodologically equivalent; it uses only 50% of the location points for polygon estimates, unlike the other approaches. Of the methods used, MCP consistently produced the largest estimates for home ranges. We found no significant differences between KDE 95% and LoCoH-a estimates, neither when compared directly (t=0.421, p=0.675) nor when analyzing males (t=0.726, p=0.451) or females (t=0.140, p=0.957) independently. We attribute the lack of statistical difference to the small sample size for each sex.

Analysis of male home range sizes (Table 4) showed no significant variation across seasons (MCP 100%: F=0.647, df=4, p=0.637; KDE 95%: F=0.418, df=4, p=0.792; KDE 50%: F=0.297, df=4, p=0.874; LoCoH-a: F=1.271, df=4, p=0.327). Likewise, seasonal ranges for females did not show significant differences (MCP 100%: F=0.899, df=5, p=0.504; KDE 95%: F=0.914, df=5, p=0.496; KDE 50%: F=0.594, df=5, p=0.704; LoCoH-a: F=1.148, df=5, p=0.977). The absence of seasonal differences is likely due to the limited number of individuals in the sample and the high degree of intra-seasonal variation in individual range sizes.

This variability may reflect behavioral differences among Goitered gazelle individuals.

Pairwise comparisons of seasonal home ranges between males and females revealed statistically significant differences during the summer season across all methods (Table 5). We observed significant differences in home ranges of males and females in spring (MCP method), in winter (LoCoH-a), and during the rutting period (MCP). During the summer, male home ranges were 2-3 times larger than those of females. We observed this male-biased range expansion also in other seasons (Table 6). Core area sizes were consistently larger for males across all seasons. For visualization, we used KDE-based polygons when comparing seasonal home range sizes, as kernel density estimation is among the most widely adopted methods for calculating home ranges for Goitered gazelles. Notably, similar seasonal trends for home range sizes were observed across all methods.

Male Goitered gazelles tended to occupy the largest home ranges during summer, with a slight decrease in winter. Spring marked the smallest range of sizes. Autumn and the rutting period showed similar range sizes, with a slight increase during the rut. In contrast, females had the largest ranges in winter, slightly smaller ranges in summer, and considerably smaller territories in spring, autumn, and during the rut – these three seasons showed nearly equivalent range sizes. During the fawning season, female home ranges were comparable to summer values and occupied an intermediate position between autumn and winter (Figure 4).

Table 4. Seasonal home range sizes (km²) of tagged Goitered gazelles calculated using different methods.

Individual	Method	Season, period						*X*	*Sx*
		Spring	Summer	Autumn	Winter	Rutting	Birth		
AG1	MCP	40.68	85.79	26.64	42.58	41.72	–	47.48	10.01
	KDE 95%	19.08	59.92	16.41	28.76	26.51	–	30.14	7.79
	KDE 50%	3.56	11.45	4.77	5.99	4.81	–	6.12	1.39
	LoCoH-a	16.74	52.47	22.51	39.51	41.12	–	34.47	6.52
AG2	MCP	51.51	–	25.29	103.48	40.86	–	55.29	16.94
	KDE 95%	34.96	–	7.43	82.11	10.61	–	33.78	17.24
	KDE 50%	7.57	–	1.18	17.18	2.54	–	7.12	3.62
	LoCoH-a	27.96	–	18.26	83.17	21.63	–	37.76	15.27
AG3	MCP	30.57	42.3	39.72	32.12	53.76	–	39.69	4.15
	KDE 95%	4.11	25.16	36.51	11.52	39.19	–	23.30	6.85
	KDE 50%	0.79	4.18	7.11	2.69	7.26	–	4.41	1.26
	LoCoH-a	12.94	20.83	20.42	25.31	19.44	–	19.79	1.99
AG4	MCP	70.31	82.21	94.15	87.37	69.18	–	80.64	4.84
	KDE 95%	50.26	68.52	86.69	73.22	76.08	–	70.95	5.97
	KDE 50%	10.28	17.55	22.5	16.29	23.29	–	17.98	2.36
	LoCoH-a	35.81	30.74	51.25	45.47	45.1	–	41.67	3.69
AG5	MCP	23.91	33.72	15.04	85.02	24.41	17.1	33.20	10.71
	KDE 95%	16.01	17.79	7.85	40.55	12.91	18.52	18.94	4.61
	KDE 50%	3.06	2.84	2.05	6.14	3.14	5.41	3.77	0.66
	LoCoH-a	20.9	20.49	15.01	30.75	23.36	17.1	21.27	2.25
AG6	MCP	20.03	20.03	–	18.48	–	26.55	21.27	1.80
	KDE 95%	8.19	8.19	–	14.03	–	10.07	10.12	1.38
	KDE 50%	0.91	0.91	–	2.63	–	2.05	1.63	0.43
	LoCoH-a	19.95	19.95	–	9.15	–	21.03	17.52	2.80
AG7	MCP	21.62	19.09	45.39	45.39	26.06	18.96	29.42	5.16
	KDE 95%	7.01	11.52	13.59	13.59	12.77	12.93	11.90	1.03
	KDE 50%	0.83	1.73	2.38	2.38	1.85	2.81	2.00	0.28
	LoCoH-a	19.9	17.03	21.21	21.21	14.78	14.89	18.17	1.23
AG8	MCP	41.86	13.04	18.01	34.95	16.43	14.5	23.13	4.96
	KDE 95%	12.8	7.42	9.04	13.85	6.34	13.83	10.55	1.37
	KDE 50%	3.1	1.73	1.62	1.51	1.56	3.27	2.13	0.34
	LoCoH-a	9.97	10.62	5.28	17.18	8.31	11.52	10.48	1.61

Note: A dash indicates missing data. *X*=arithmetic mean; *Sx*=standard error of the mean.

Table 5. Results of pairwise comparisons between male and female home range sizes by season using the exact permutation test.

Method	Season, period				
	Spring	Summer	Autumn	Winter	Ratting
MCP	0.084*	0.055*	0.444	0.239	0.055*
KDE 95%	0.197	0.055*	0.277	0.225	0.194
KDE 50%	0.183	0.083*	0.305	0.112	0.222
LoCoH-a	0.394	0.027**	0.25	0.056*	0.166

Note: p-values are provided in each cell. Significance is indicated as follows: *=*p<0.1*, **=*p<0.05*.

Table 6. Average seasonal home range sizes of Goitered gazelles.

Sex	Season, period	Home range, km^2			
		MCP	KDE 95%	KDE 50%	LoCoH-a
Males	Spring	48.26±8.5	27.1±9.96	5.55±2.1	23.36±5.23
	Summer	70.1±13.93	51.2±13.25	11.06±3.86	34.68±9.34
	Autumn	46.45±16.22	36.76±17.71	8.89±4.69	28±7.76
	Winter	66.38±17.21	48.9±17.07	10.53±3.36	48.36±12.34
	Rutting	51.38±6.36	38.09±13.94	9.47±4.7	31.82±6.58
Females	Spring	26.85±5.06	11±2.08	1.98±0.64	17.68±2.58
	Summer	24.94±5.27	14.74±3.28	2.78±0.73	14.76±2.42
	Autumn	26.15±9.66	10.16±1.75	2.02±0.22	13.83±4.64
	Winter	41.22±14.98	19.71±6.99	2.96±1.09	16.76±5
	Rutting	22.3±2.97	10.67±2.17	2.18±0.49	15.48±4.36
	Birth	19.28±2.59	13.84±1.75	3.39±0.22	16.14±1.99

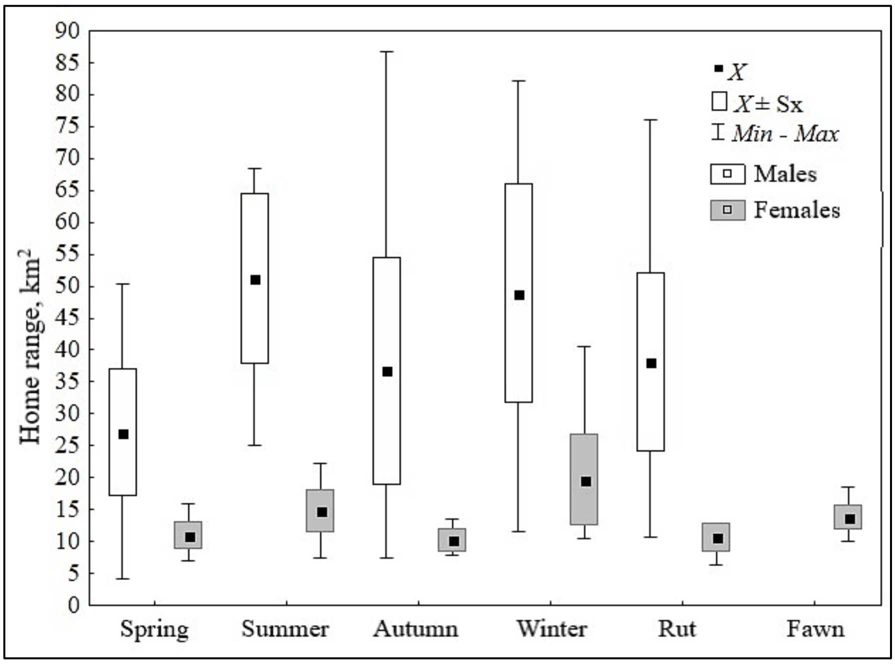

Fig. 4. Seasonal home range sizes of Goitered gazelles (KDE 95%).

Males exhibited similar seasonal trends in both home range and core area sizes (Figures 4, 5), with the largest core areas recorded in summer and the smallest in spring. Core areas were slightly smaller in winter, autumn, and the rutting period, with the rut season falling between autumn and winter values (Figure 5). In contrast, females showed some divergence between trends in total home range and core area sizes (Figures 4, 5). We observed the largest female core areas during the fawning season, followed closely by summer and winter. Spring, autumn, and rutting seasons all produced smaller, similarly sized core areas, notably smaller than those seen in summer, winter, and the fawning season (Figure 5).

A comparison of seasonal home range sizes in males, as calculated by different methods (MCP, KDE 95%, and LoCoH-a), revealed no significant differences between estimation approaches. We detected statistically significant differences only for females in the spring ($F=5.184$, $df=2$, $p<0.05$). While we did not observe any significant differences in other seasons, MCP consistently produced the largest home range estimates across all seasons and for both sexes (Table 6). Overall, we attribute the absence of significant differences in male home range size across the three methods, and in most seasons for females, to the small sample size.

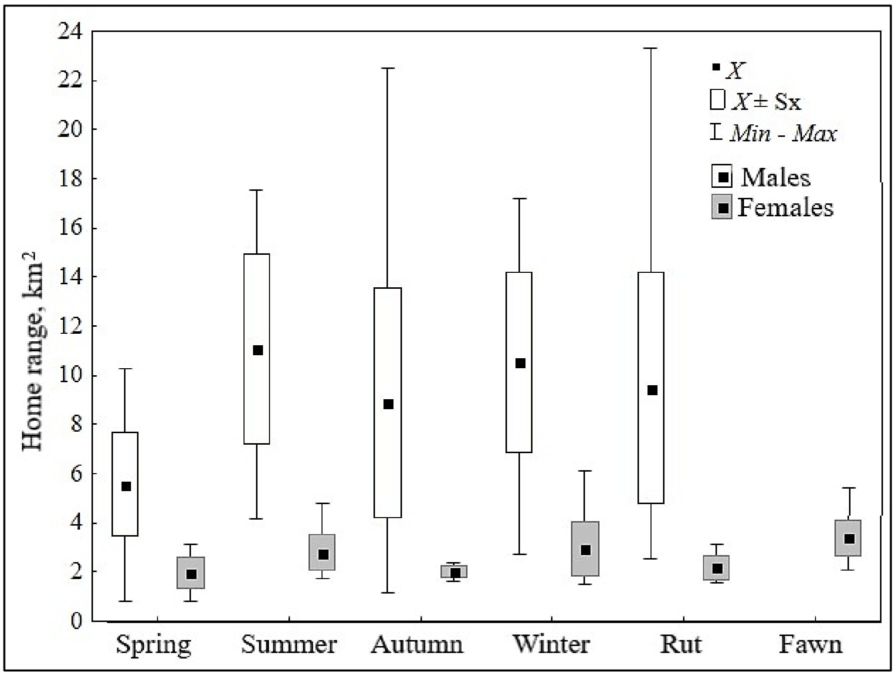

Fig. 5. Seasonal core area sizes (KDE 50%) of home ranges for male and female Goitered gazelles.

There is a notable lack of published research specifically addressing the spatial ecology of the Goitered gazelle (Martin, 2000; Durmuş, 2010). Despite the limited dataset used in our study, we present here the first GPS collar-based analysis of home range patterns for Goitered gazelle in the northwesternmost portion of its broad geographic range, namely the Iori-Mingachevir ecological corridor. Previous studies on other gazelle species have reported larger home ranges for males compared to females (Wronski, 2010, 2013; Geffen et al., 1999). Our findings are consistent with this pattern, showing that male Goitered gazelles had significantly larger home ranges than females.

Gazelles are known to exhibit both sedentary and nomadic behaviors, and some species undertake seasonal migrations (Sludskiy, 1977; Martin, 2000). In relatively small, enclosed, or habitat-limited areas, sedentary gazelles tend to maintain compact home ranges. For example, the average home range for female mountain gazelles (*Gazella gazella gazella*) in Israel is just 0.165 km², and for reintroduced populations in Saudi Arabia, around 1 km² (Dunham, 1998; Geffen et al., 1999). In the southern Negev Desert (Israel), dorcas gazelles (*Gazella dorcas*) may occupy home ranges of 1-2 km² in some areas, while in others their ranges expand up to 25 km², largely in response to food availability and human impacts (Martin, 2000). This highlights the species' behavioral flexibility, with movement patterns shaped by local conditions. In Turkey, Goitered gazelles released into a relatively large, protected area (285 km²) tended to exhibit sedentary behavior, with average annual home ranges of 2.93±1.92 km², comparable to other non-migratory gazelle populations (Durmuş, 2010).

The average annual home range (KDE 95%) for all individuals in our study area within the Iori-Mingachevir ecological corridor was 53.45±8.81 km² (KDE 95%), with male and female ranges measuring 73.64±9.46 km² and 33.28±1.37 km² (KDE 95%), respectively. These findings suggest a nomadic movement pattern in this region. Similar large-scale movements and migrations, sometimes spanning hundreds of kilometers have been documented in Central Asian Goitered gazelle populations, where they migrate seasonally between northern steppes with deep snow cover and southern deserts (Sludskiy, 1977; Zhevnerov, 1984). Goitered gazelles usually remain within 10-15 km of water sources, but during arid summer periods, they may travel substantial distances in search of reliable water access (Sludskiy, 1977).

For many ungulate species, home range size varies seasonally, influenced by climatic conditions (such as temperature and snow depth), food availability, and individual behavioral traits (Van Beest et al., 2011; Tomaszewski et al., 2022). Similar seasonal patterns have been observed for the Goitered gazelle. In Turkey, for instance, significant differences in home range size were recorded between several seasonal periods, namely, between summer and autumn, summer and the fawning period, rut and winter, rut and autumn, and spring and the fawning period (Durmuş, 2010). While our study did not reveal statistically significant seasonal differences in home range size among Goitered gazelles, we found local differences. For example, we observed the largest home ranges during summer and winter. In the hot summer months, natural water sources in the Eldar and Ajinour steppes gradually dry up, forcing Goitered gazelles to move in search of water. While typical daily movement ranges from 2 to 5 km, in summer these distances can increase to 10-15 km. Another factor contributing to this broader spatial use is the absence of transhumant sheep flocks and associated disturbances, particularly shepherd dogs, in the winter pastures during the summer. Additionally, Goitered gazelles may range more widely in summer due to declining forage quality. The most nutritious plant species, particularly legumes and grasses tend to desiccate during this time, prompting Goitered gazelles to seek out areas with more favorable vegetation conditions.

With the onset of autumn, home range size generally decreases, coinciding with improved availability of green forage and recharged natural water sources, reducing the need for long-distance movement. However, starting in mid-October, transhumant sheep flocks begin arriving in the Eldar and Ajinour steppes, which are traditionally used as winter pastures. By winter, the Eldar steppe supports approximately 42,000 sheep (a density of 120 animals/km²), while the Ajinour steppe hosts up to 58,000 sheep (104 animals/km²) (Askerov et al., 2021). To support their flocks during winter, herders construct artificial watering points across the pastures, which are also used by Goitered gazelles. While forage and water availability remains high during this season, the increased human and livestock presence introduces considerable disturbance, particularly from herding dogs. This, in turn, prompts more frequent movement and contributes to the expansion of gazelle home ranges in winter compared to the autumn period, which we observed.

The smallest home ranges were recorded in spring. During this season, transhumant sheep herds gradually moved from the lowlands to alpine pastures. By mid-May, domestic sheep are largely absent from the Eldar and Ajinour steppes. The resulting reduction in disturbance, especially from herding dogs combined with a high diversity and abundance of forage plants, specifically, legumes and grasses, contributes to lower mobility in gazelles. This decreased movement likely explains the smaller spring home ranges compared to other seasons.

The rut period of Goitered gazelles within the study area occurs predominantly in autumn and typically concludes by late December. This may be the reason for the similarity in home range size between the rut and autumn seasons, though range size during the rut was notably smaller than in winter. Female gazelles often tend to aggregate in large groups during the rutting season, while males establish and defend individual territories that serve to attract and maintain harems (Dunham, 1998; Blank et al., 2012). Males actively exclude rivals and control the movement of females within their range. This reproductive behavior likely contributes to the relatively limited spatial use during the rut compared to the broader winter ranges.

The home range of female gazelles reintroduced in a protected area in Turkiye were smaller during the fawning period than in both spring and summer, which was attributed to maternal behavior; females remain closely tied to the areas where their young are concealed (Durmuş, 2010). In contrast, the considerably larger summer home ranges were associated with reduced availability of food and water, prompting more extensive movement during the arid season (Durmuş, 2010). Other ungulates, such as moose and roe deer exhibit a similar decrease in mobility during fawning (Cederlund & Sand, 1994; Danilkin, 2014). In our study, female gazelle home ranges during the fawning period were larger than in spring and similar to their summer ranges (Table 6, Figures 4 and 5). While fawning can temporarily limit the mobility of females (Blank, 1985), the duration of this period is relatively short (Sokolov, 1959; Baharav, 1983). It is also important to consider that fawning in our study area occurs in May and June, with peak births around late May to early June, a time when green vegetation begins to dry out, leading to a decline in the availability of high-quality forage. The emergence of offspring may increase female mobility as they seek out remaining patches of nutritious vegetation and water, both essential for lactating females. This likely explains the larger home ranges observed during the fawning period compared to spring. The similarity in range size between the fawning and summer periods may also be due to the precocial nature of gazelle calves, including Goitered gazelles, which can follow their mothers shortly after birth. As a result, the presence of young does not significantly constrain female movement during this season.

Here, we present the first study of Goitered gazelle home ranges in the South Caucasus using GPS telemetry. Our results showed that within the Iori-Mingachevir Ecological Corridor, specifically across the Eldar and Ajinour steppe landscapes the size of annual home ranges and core areas is influenced by sex-based differences. On average, male home ranges and core areas were twice as large as those of females. While we did not find overall seasonal variation in home range size for either sex, there were statistically significant sex-based differences for specific seasons: spring, summer, winter, and the rutting period. Our study suggests that gazelles in this region follow wide-ranging movement patterns characteristic of a nomadic lifestyle. The largest home ranges for both sexes occurred during summer and winter. In summer, gazelles cover greater distances in search of water and energetically rich forage as natural sources become scarce. In winter, the presence of transhumant sheep herds and associated disturbance (e.g., from herding dogs) appear to increase gazelle movement. During the fawning period, female home ranges were similar in size to those observed in spring and summer, suggesting that, under the conditions of the Eldar and Ajinour steppes, the presence of calves does not substantially restrict female movement across the landscape in pursuit of food and water.

Overall, the key factors influencing home range size for Goitered gazelles appear to be seasonal fluctuations in forage and water availability, along with human disturbance, primarily due to livestock grazing. Our findings provide critical baseline data that can guide habitat management, conservation planning, and future reintroduction efforts.

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ORCIDS:

Sevinj Sarukhanova: https://orcid.org/0000-0002-4791-6812
Elmar Babaev: https://orcid.org/0000-0002-2250-5267
Elshad Askerov: https://orcid.org/0009-0003-6024-3223
Afag Rizayeva: https://orcid.org/0000-0002-2187-5370
Aynura Babaliyeva: https://orcid.org/0009-0002-2383-3091
Nugzar Zazanashvili: https://orcid.org/0000-0002-4607-0982

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