Wadi ElGimal Gazelle Survey Project – 2025

A project commissioned by the Italian Agency for Development Cooperation on behalf of Nature Conservation Sector, EEAA.

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Executive Summary:

The Nature Conservation on Sector – Egyptian an Environmental Affairs Agency (EEAA) is keen to establish the status of gazelle species in Wadi ElGimal National Park (WGNP). A project was formulated and sponsored by the Italian Agency for Development Cooperation. The project commenced in June 2025, aiming at surveying a total area of 4800 Km² encompassing the Gazelle's known habitat in Wadi El Gimal National Park WGNP. The study aimed to assess 4 parameters, mainly the Gazelle population size & density, Gazelle activity, and Gazelle occupancy in the area. The study started in June 2025 and ended in early Nov. 2025. The study involved Habitat classification and mapping in WGNP, and Distance sampling of indirect marks of gazelle presence (dung piles) over 140 km of line transects covering 4800 Km² of range. Also, the study involved 1,350 days of camera trapping across 15 sites distributed selectively within the Gazelle habitat of WGNP. In addition, some interviews were done with some elderly members of the local community to gather their local knowledge about the species.

Fortunately, gazelle presence was abundant in the study, with some indirect detections (dung and tracks) and more direct visual observations by the surveying teams or camera-trap images.

The study concluded that a viable population of Dorcas Gazelle (Gazella dorcas) is still roaming the study region in WGNP. It is highly likely to recover naturally if proper protection measures are in place. Conservation measures of the species and action plan is proposed. These are also in line with the conservation guidelines and measures proposed for the species under the CMS Sahelo-Saharan Mega Fauna Initiative.

ملخص تنفيذى

يحرص قطاع الحفاظ على الطبيعة – جهاز شئون البيئة المصري على التعرف على حالة أنواع الغزلان في محمية وادى الجما ل. وتمت صياغة المشروع ورعايته من قبل الوكالة الإيطالية للتعاون الإنمائي. بدأ المشروع في يونيو 2025 بهدف مسح مساحة إجمالية تبلغ 4800 كيلومتر مربع تشمل محمية وادي الجمال. هدفت الدراسة إلى تقييم عاملين أساسيين، حجم تعدا د الغزال وإشغال الغزال في المنطقة. بدأت الدراسة في يونيو 2025 وانتهت في أوائل نوفمبر 2025. وتضمنت الدراسة أخذ قياسات لعلامات تواجد الغزال على قطاعات خطية غير المباشرة لوجود الغزلان (أكوام الرو ث والاثار) وتم المسح باستخدام مسافة 140 كيلومترًا من خطوط المسح التي تغطي نطاقاً يبلغ4800 كيلومتر مربع. كما تضمنت الدراسة 1350يومًا من المسح بالكاميرا في 14 موقعًا موزعة بشكل انتقائي في منطقة موائل الغزال في المحمية. بالإضافة إلى ذلك، تم إجراء بعض المقا بلات مع بعض كبار السن من المجتمع المحلي لجمع معلوماتهم المحلية عن هذا النوع .

لحسن الحظ، كان وجود الغزال بارزا و وفيرا في منطقة الدراسة مع عدد وافرمن من الاكتشافات غير المباشرة (الروث والآثا ر) و عدد أقل من المشاهدات المباشرة من قبل فرق المسح أو التسجيلات المباشرة عن طريق الكاميرا الفخية، تمكنت الدراسة من إثبات أن حالة تعداد الغزال المصرى في محمية وادى الجمال لا زالت جيدة ويقدر أ نها مرشحة للتعافى و الحفاظ على أعداد غزال قابلة للحياة بينما من المحتمل أن يعزى الانخفاض الحالي إلى العوامل البشرية (الصيد غير المشرو ع و التهديد من نشاطات التعدين غير المشروعة) .

وخلصت الدراسة إ أن هناك أعدادا قليلة قابلة للبقاء من الغزلان (Gazella dorcas) لا تزال تتجول منطقة الدراسة WGNP، ومن المرجح جدا أن تنتعش إذا تم اتخاذ تدابير الحماية المناسبة. وقد تم اقتراح تدابير لحماية هذا النوع وخطة عمل للصون النوع. وتتوافق هذه التدابير أيضا مع المبادئ التوجيهية والتدابير المقترحة لحما ية هذا النوع ضمن مبادرة Sahelo-Saharan Mega Fauna Initiative ال طورتها.CMS

تم تطوير خطة مقترحة للحفاظ على أنواع الغزلان تتضمن سلسلة من الإجراءات التي من شأنها إن طبقت ان تساهم في استعادة أنواع الغزلان التي من المفروض ان تكون جزءا من التنوع الحيوي المصري

Contents

Introduction:

Egyptian deserts are home to two gazelle species: the Dorcas gazelle (*Gazella dorcas*) and the Slender-horned gazelle (*Gazella leptoceros*). The later is ENDANGERED (EN), and its range is restricted to a very limited area in the western desert and around a few remaining oases, while the Dorcas gazelle is in a slightly better situation, where it is classified as VULNERABLE (VU) (IUCN, 2017). Its Egyptian range spans areas in the Western Desert, Eastern Desert, Southern Egypt, and the littoral plains of Sinai (El Alqamy & Baha El Din, 2006). The Egyptian population of the Slender-horned gazelle is very significant to the species' global survival, as it is considered the only surviving population of that subspecies. On the other hand, the Egyptian population of the dorcas gazelle is also significant to the global population as it is estimated to comprise about 10% of the species' global population and is an essential subspecies. The Redlist designates both species as of declining population trends across their global range. (Husam ElAlqamy, Alaa Soultan, Adnan Abdelhameed and Abdullah Nagy, 2011) showed that the southern Sinai popula on of dorcas gazelle showed a continuous decline of about 94% during the period of 1999 to 2011. Yet, there is no conservation action plan for the species as reported by the IUCN RedList assessment.

Unfortunately, except for some surveys done during the 2000s and earlier in South Sinai, there is no systematic monitoring for gazelle species throughout its Egyptian Range. Annual surveys for the dorcas gazelle have been conducted by Saint Katherine Protectorate since 1998; however, surveys were interrupted from 2003 to 2005 due to a lack of human resources and logistical reasons. In 2006, surveys were resumed with good hope of continued progress. The survey was conducted during the summer of 2006 by the St. Katherine Protectorate (SKP) ranger team. Another anecdotal survey was conducted in the Siwa Protected Area in 2009. Due to the lack of a systematic monitoring program by the Nature Conservation Sector (NCS), few investigations of the WGNP gazelle populations were conducted over time. Attum et. Al. (2014) conducted a study in which annual precipitation was correlated with gazelle activity in WGNP and concluded that the carrying capacity in WGNP is significantly reduced during drought periods and that the gazelle population may not be able to withstand long droughts. The same study also estimated the gazelle Kilometric index in WGNP between 0.1 to 2.8 obs/Km during 2008.

The current document reports the results of the WGNP Gazelle survey commissioned by the Italian Agency for Development Cooperation on behalf of the Nature Conservation Sector, EEAA 2025. The survey was conducted in the WGNP encompassing all the terrestrial part of WGNP. The survey effort was done from June to Nov. 2025. This effort aims to provide some insight and working knowledge about the current status of the gazelle population in this vicinity. Thus, 2 main investigation protocols were applied to the study. First, Distance sampling was applied as the primary sampling protocol for population size inference, as devised by El Alqamy 2003. Second, the species' occupancy was also targeted using camera-trap sampling coupled with the Daryl & Mackenzie occupancy estimation model.

Study Region:

The study focused on the terrestrial portion of Wadi ElGimal National Park (WGNP). The total survey target area is 4800 Km². This area is usually known as a hot spot for Gazella dorcas based on both local knowledge and published literature (Attum et al. 2014, 2021 , ElAlqamy 2003, 2006 and Nagy2022). The topology of the study region was a variable mix composed of rocky massifs, high mountains, coastal plains, inland plains, and wadi channels dissecting the whole study area, with channels running east-west in general. The total annual rainfall for the area was under

50mm for the last decade, calculated from the CHIRPS (Funk, 2015) database, as shown in map (1). The vegetation of the study region is distributed amongst three layers, from the herb layer to the tree layer. The most dominant species in the area are listed in Table 1. The extent of the surveyed area is shown in Map (2). The survey targeted parts only deemed potential for gazelle presence and as suitable gazelle habitat. These included coastal plains, inland plains, wadi channels and plains with rocky outcrops.

1Table (1) Dominant flora species in the study region

La n Name	Vernacular Name
Balanites aegyptiaca	(Lehleeg)
Zilla spinosa	(Silla)
Nitraria retusa	(GHARQAD)
Phoenix dactylifera	(NAKHL)
Phragmites australis	(HAGNA)
Tamarix nilotica	(ATHL)
Acacia sp.	(TALH)


1Pic(1) Wadi Channels landscape

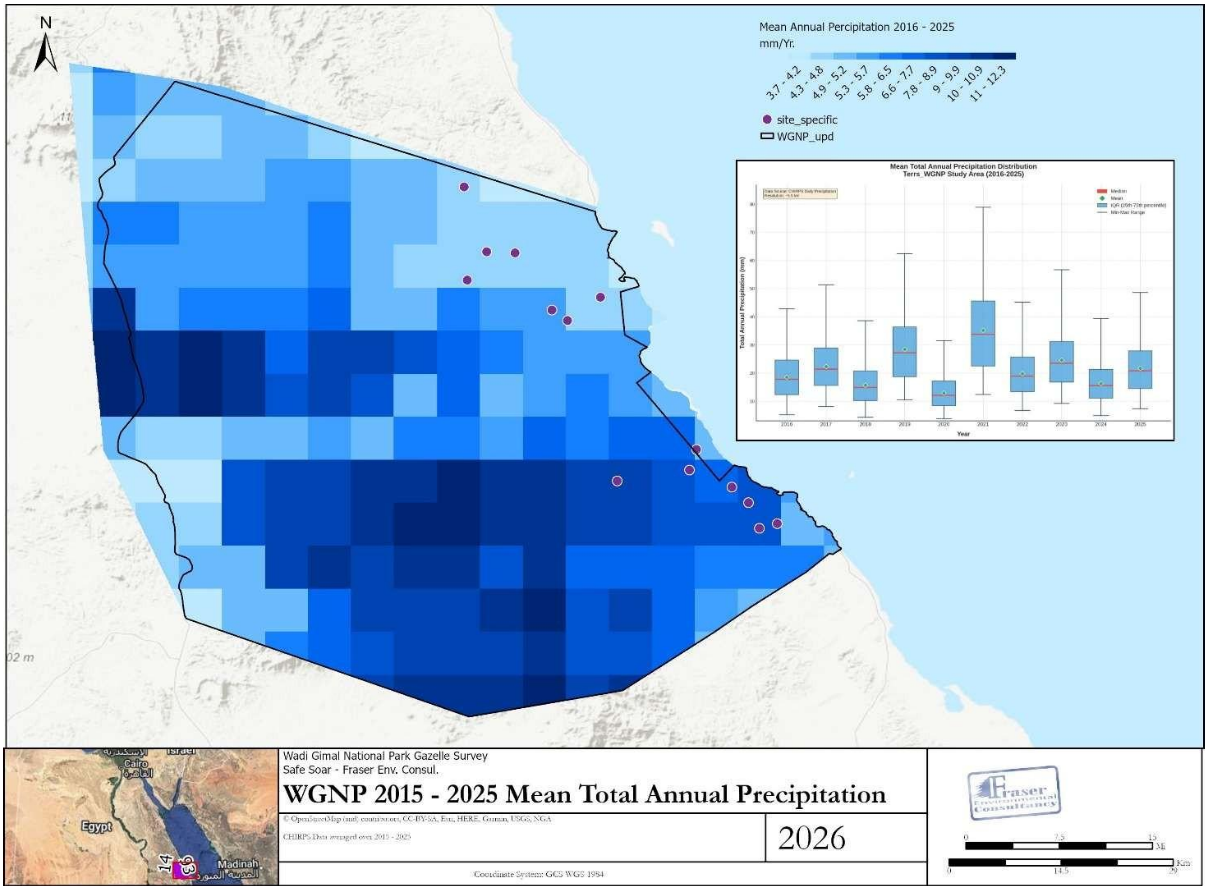

2Pic(2)Coastal plain

3Pic(3) Acacia Wadis

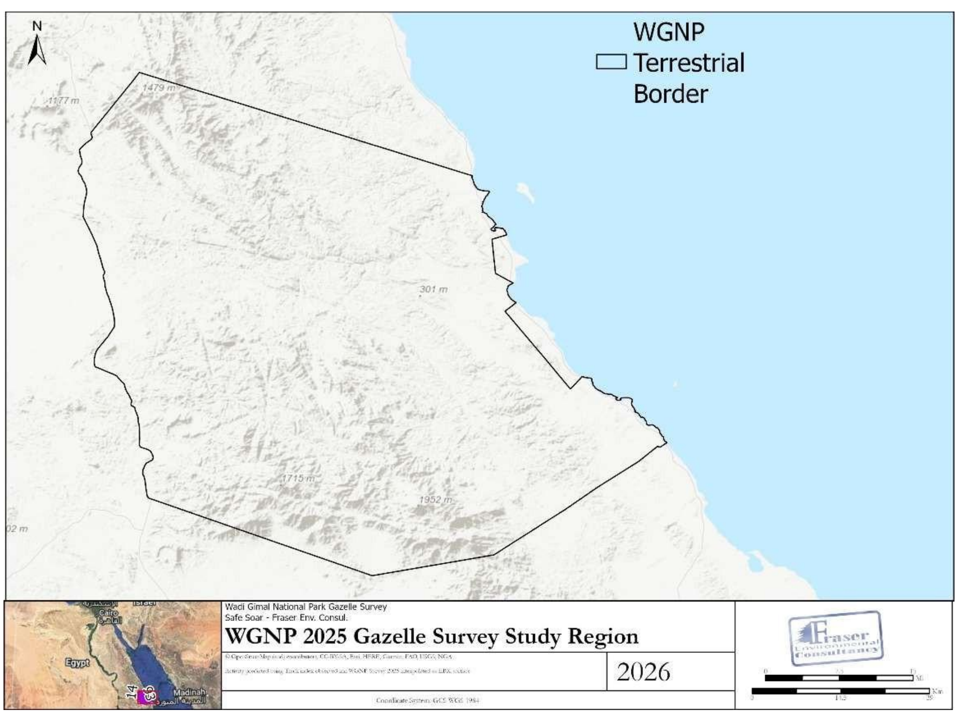
The study region was stratified according to habitat classification obtained earlier by unsupervised classification of Sentinel-2 imagery. Systematic Random line transects were laid over the area representing effort allocation according to the corresponding density in each stratum. Transects were laid out as a stop every 3 kilometers in the wadi channels and accordingly on parallel lines in the plains. The total effort was 132.78 Km of line transects distributed as shown in table 2 below.

Table (2) Survey effort par oning parameters

Habitat	No of transects	Effort (km)	Detec ons
Wadi Channels	155	89.55	11
Coastal Plains	16	22.97	3
Inland Plains	2	1.4	0
Plains with Rocky Outcrops	24	18.86	0



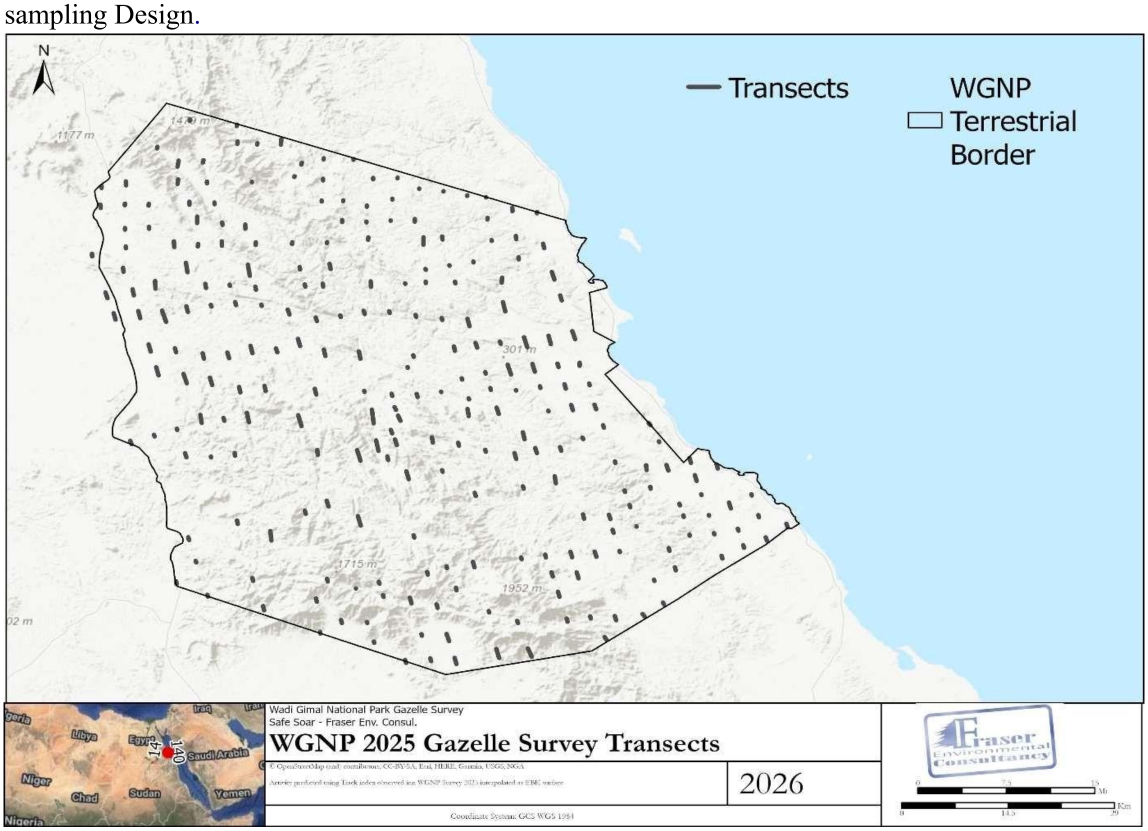
Map(1) shows the total annual precipita on in WGNP for the decade 2016 – 2025, showing extreme arid condi ons of total annual rainfall below 50mm annually.



Map (2) Study Region of WGNP Gazelle survey 2025.

3. Methods:

3-a. Distance Sampling: The study region was stratified according to types of habitats obtained by unsupervised classification of Sen nel-2 images (2025). Classification was done using GEE script where 5 categories were specified for the classification. Map(1). Systematic Random line transects were laid over the area representing effort allocation according to proportional area of each habitat class. It was reported that considerable clustering and varia on occur in the distribution of dorcas gazelle throughout the study area. Also, there was a noticeable gazelle density in the narrow-vegetated wadis of the northern eastern part of WGNP (pers. Comm., local knowledge). Thus, there was a need for representative coverage for the whole area with appropriate effort allocation to the highly populated areas relative to the low-density ones. Systematic segmented sampling was used to identify the sample transects. It involves randomly superimposing a systematic set of segmented parallel lines onto the survey region. The lines were assigned different arrangements according to the spatial configuration of sampled habitat. Accordingly, parallel lines were laid out across the study region spaced 3 km apart along wadi channels and differently in wider habitats such as in coastal plains and inland plains. Transects were placed over these parallel lines in an on-off fashion. Transects were spaced by 3Km along the parallel line and were of a length of 1Km where possible in the low-density stratum and a corresponding transect length of 2 Km where possible in the assumed high-density habitats. Also, the direction of the transects was assigned as northwest to the southeast (315° bearing) that's to coincide with the streamlines and small channels caused by the major water flow direction in the landscape. See map (3) for detailed sampling Design.



5Map (3) Transect layout and sampling effort distribu on across strata in the Study Region

A handheld GPS receiver was used to locate the start point of each transect. The exact location of the start and end points was recorded to the nearest meter. Transects were surveyed by a two-person team, an observer in the front, and a recorder behind. The observer walked ahead of the recorder, pulling a 20 m rope that acted as the reference point for the transect line to measure perpendicular distances to gazelle dung (Pic. 5). Transects were made at an angle to cross wadis from side to side and at bearing of 315° in the open plains. Bearings were chosen to cross the water made runways and ditches, which gazelles prefer to walk along to maximize encounter rate. At the beginning of each transect habitat and terrain type were ranked according to the category system summarized in Table (3). The occurrence and loca on of all recently deposited gazelle and camel dung piles within 10 m of the transect were recorded. The age of dung piles was es mated and assigned to one of six categories according to system devised on Alqamy, 2002. Only relatively recent dung piles in categories 1, 2, and 3 were recorded as perpendicular distances to the rope. Older dung ranked as 4,5 and 6 were overlooked. Distances were measured with a metal measuring tape, and all were recorded to the nearest 1.0 mm. Gazelle tracks crossing the transect line from side to side of the rope were recorded as tally marks. Camel dung was also tallied to compare spatial distribution of camels and gazelles.

Density of Gazelle dung was then analyzed using DISCTANCE 8.0 so ware. Transects were divided according to the habitat they fall in. Density es mate was stratified as per habitat. A habitat-based es mate was calculated and then all habitats' es mates pooled into one global es mate for the study region. Global density es mate is the mean of stratum es mates weighted by total effort in each stratum or habitat.

Table (3) Habitat and Terrain scoring values used on line transects.

Habitat Category	Terrain Category
1- Coastal Plain	1- Gravel
2- Inland Plain	2- Sandy
3- Wadi Channel	3- Rocky
4- Plain with Rocky outcrops	


6 Pic(5) observer and recorder traversing line transect pulling 20m rope as a reference line

3-b Activity Index & Comparing Camels and Gazelle spa al distribution.

The number of gazelle tracks per km of transect was used to measure gazelle activity, called the Activity Index, in each area. The number of gazelle and camel dung piles encountered per km along each transect was called the Encounter Rate and was used to investigate the relative Activity distribution of these two species using a Cremer von Misese-type test (Syrjala1996). Models under so ware package were used to evaluate the interaction between Dorcas gazelles and free-ranging camels as the two species are believed to use the same resources and share the same habitat for their livelihood. Script provided at Annex I.

3-c. Occupancy estimation:

In addition to population size, this survey is also concerned with es ma ng the occupancy of gazelle species across the study region and this part of its Egyptian range. The Occupancy concept was developed by McKenzie et al 2000 (DARRYL I. MACKENZIE, JAMES D. NICHOLS, JAMES E. HINES, MELINDA G. KNUTSON,, 2003). Occupancy is a good parameter to monitor the range of a species especially when it is rare and shy and cannot be easily detected. However, due to imperfect detection, the species will not always be detected when present leading to false absences which, if unaccounted for, could lead to misleading conclusions about the occurrence or distribution of the species. The Occupancy parameter is called Psi (ψ), it can be simply defined as the proportion of sites occupied by a species in relation to total sites investigated for its presence. Calculations were conducted using R package, and unmarked package (Kellin, et. Al, 2023).

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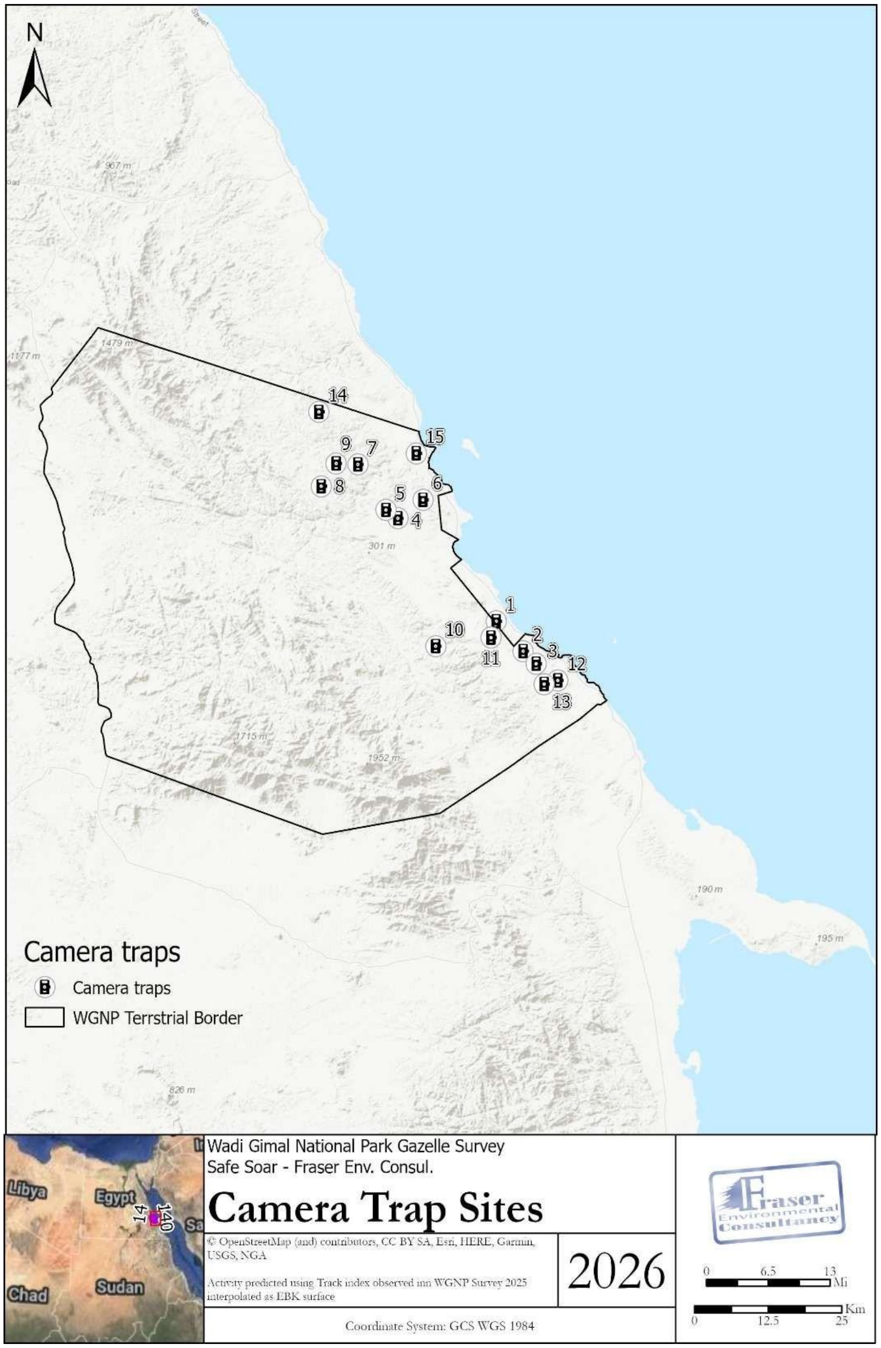
Fourteen camera traps were strategically distributed over the area reported by local community and local rangers of recent continuous gazelle habituation. These cameras lasted for around 90 days each. Targeting a total sample of 1260 days of camera trapping. Camera trap sites are shown in map (4). Ψ covering the reportedly known gazelle presence and activity area.



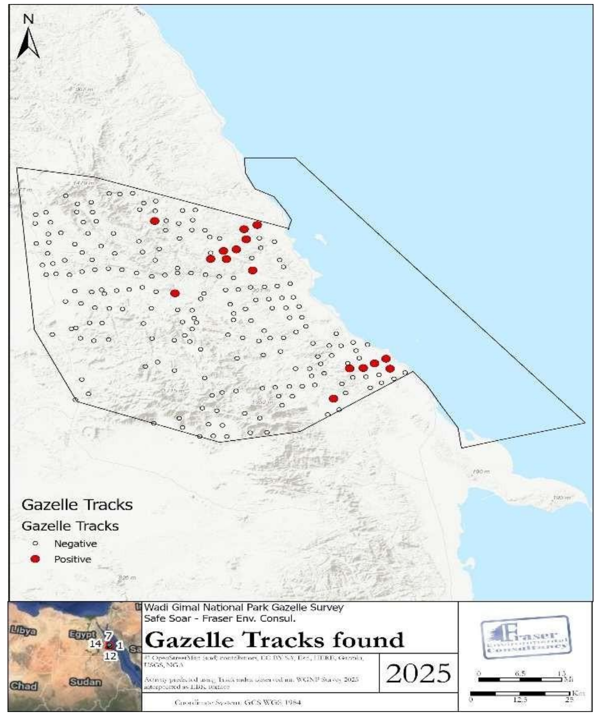
Map (4) sites for camera trapping with some emphasis on the high-density stratum

4. Results

4-a-1 Gazelle activity

Gazelle Activity in the WGNP study area was relatively abundant. Gazelle tracks were recorded along 17 transects in WGNP. Map (5) shows the locations of all surveyed transects and those where gazelle tracks were detected.

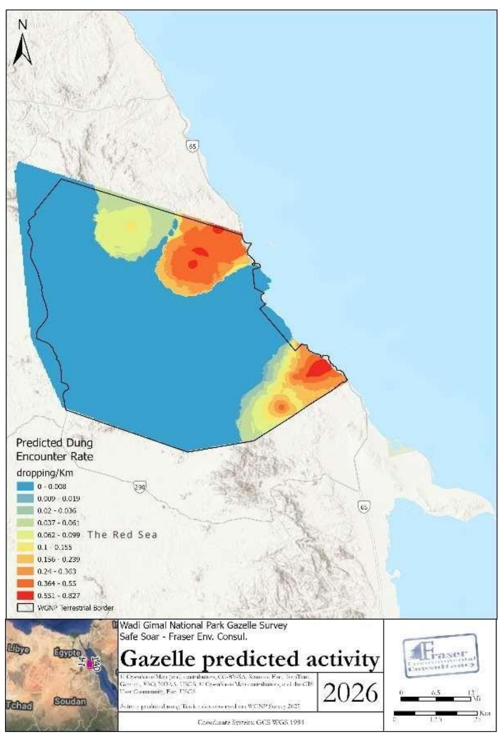
In 2025, the gazelle Activity Index in the WGNP study area was 0.405 tracks/km, based on a total surveyed distance of 138.72 km and 56 detected track occurrences. There are no previous track/km baseline values from WGNP for direct comparison. To place this value in context, we compare it with historical indices from the Qaa Plain – South Sinai, during periods when gazelles were more common in WGNP compared to South Sinai. In 2002, the kilometric index for Qaa Plain was 7.090 tracks/km, and in 2006 it was 1.620 tracks/km (Husam El Alqamy, 2006). At that time, WGNP reportedly yielded even higher rates of gazelle encounters than Qaa Plain, according to visits by Sinai staff.



Map(5) showing loca ons of observed posi ve gazelle ac vity

Given these comparisons and the kilometric activity index as a semi-quantitative indicator, it can be inferred that the WGNP gazelle population has been in decline since at least 2006.

The same value of Gazelle Kilometric activity index estimated as trk/Km was spatially modeled over the study region of WGNP using Empirical Bayesian Kriging in ArcPro to result in 2 main gazelle activity zones a bigger more intense northern zone and a less active southern activity zone as shown on map (6)



Map(6) showing the expected spread of Gazelle activity based on observed values of Activity Index Trk/Km index - Empirical Bayesian Kriging

4-a-2 Density estimate for Gazelle Dung:

There was about 138.7 Km of survey effort dispersed along 197 transects over 4 potential Gazelle habitats, namely; Wadi Channels, Coastal plains, in-Land plains and Plains with Rocky outcrops. The effort was allocated as shown in table (3)

Table (3) Survey effort partioning parameters

Habitat	No of transects	Effort (km)	Detec ons
Wadi Channels	155	89.55	11
Coastal Plains	16	22.97	3
Inland Plains	2	1.4	0
Plains with Rocky Outcrops	24	18.86	0

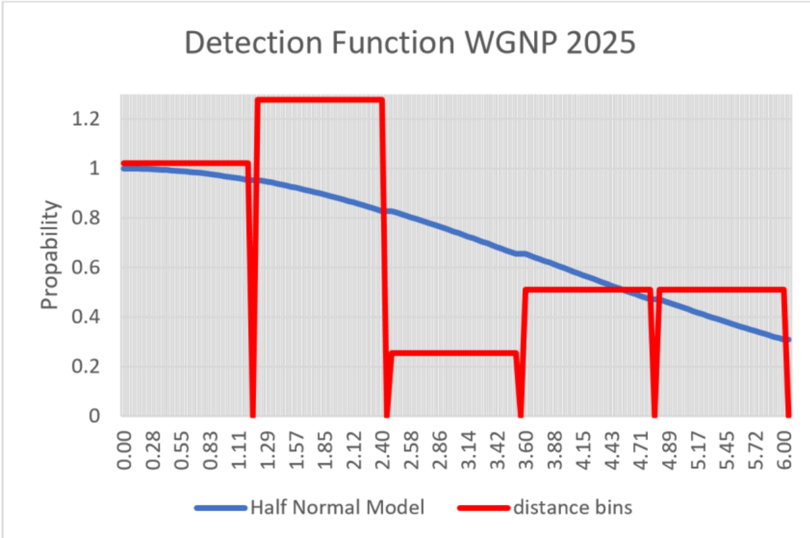
Analysis was done using the conventional distance analysis CDS. No covariates affecting detection were identified as the terrain and vegetation cover were almost uniform over the study region. The applied scenario is conventional detection modeling without the inclusion of environmental covariates and adopting the assumption that only distance from the transect line solely affects the observers' detection of gazelle dung. In this case, we would use Conventional Distance Sampling (CDS). 16 detections were recorded over 138 Km of transects. However, transects were assigned to different habitats as determined from the habitat classification done through supervised classification over GEE. Habitats used were 1)Wadi Channel, 2)Coastal plain and 3)inland plain.

CDS was run with a selection between applicable models of hazard rate and the half-normal model as they might yield different shapes of detection function and thus a different point es mate of Density (D). Selection between the two rival models is done based on the lower Akaike Informa on Criterion (AIC) . The two tested models are :

1- Half-normal model : $k(y) = e^{-\frac{y^2}{2xA(1)^2}}$ where Y is the recorded distance and k(y) is the detection function

2- Hazard Rate Model: $k(y) = 1 - e^{\left(-\frac{y}{A1}^{-A2}\right)}$

A(1) & A(2) are parameters calculated by the model as A(1)= 3.918 & A(2)=1.765 where Y is the recorded distance and k(y) is the detection. Running the AIC for selection, the half-normal Model returns a Minimum AIC = 50.741 while the Hazard Rate model computes an AIC of 51.909. Thus, model 1 (Half normal) is selected for the detection function over the Hazard Rate. Fig (1) shows the modelled 2 functions, where the half-normal detection function is selected for further analysis.



Fig(2) Half -normal detection function of the 2025 WGNP distance survey

Proceeding further with the analysis DISTANCE density and abundance of Gazelle dung in WGNP study region are calculated. reports the findings as shown in Table (4)

Table 4 Point es mates of dung density and abundance in the WGNP region 2025

	Point Es mate	%Coeff. Of Varia on	df	95% Confidence Interval	
Wadi Channel (D dung/Km²)	16.104	51.70	135.72	6.10503	42.165
Wadi Channel N (dung counted)	12883	51.70	135.72	4920	33732
Coastal Plain (dung/Km²)	26.939	81.55	17.10	5.9757	121.44
Coastal Plain N(dung counted)	10102	81.55	17.10	2241.0	45541
Inland Plain (dung/Km²)	0.0	0.0	0.0	0.0	0.0
Plain with Rocky Outcrops (dung/Km2)	0.0	0.0	0.0	0.0	0.0
Plain with Rocky Outcrops N (Dung counted)	0.0	0.0	0.0	0.0	0.0
Pooled D (dung/Km²)	14.454	45.85	127.61	6.088	34.315
Pooled N (dung counted)	1735	45.85	127.61	731.00	4118

Pic(6) example of Gazelle dung in category 4.

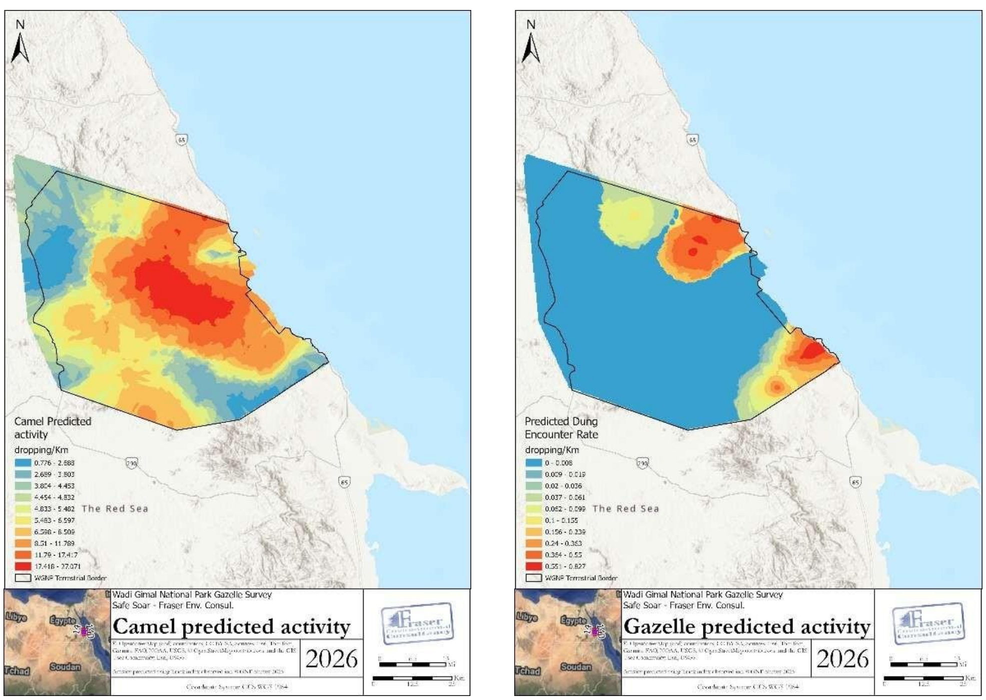
The estimates for Gazelle dung density and abundance are listed in table (5). The pooled global density es mate for WGNP is 14.45 dung/m^2, however it is higher in the wadi channels habitat where it reaches 16.104 dung/Km^2 and much higher one in the coastal plain habitat reaching a density of 26.939dung/Km^2. The inland plains and Plains with rocky outcrops were totally void of any gazelle detections on transects and theses 2 are deemed ignored by gazelles and not at all utilized.

Table (5) Other results from Distance Sampling (explanation can be found in Annex I , glossary of Terms)

	Estimate	CV%	LL (95%)	UL (95%)
m	1.0			
LnL	-24.370			
f(0)	0.23293	20.96	0.14883	0.36456
p	0.71552	20.96	0.45717	1.0000
ESW	4.2931	20.96	2.7430	6.7191

4-a-3 difference between camel and Gazelle distributions:

In the study of spa al or geographic distributions of populations, questions arise about whether one population's distribution differs from another's. A similar distribution may indicate niche overlap, with the 2 populations competing over the same resources, or avoidance of the same threat, such as a predator or poaching risk. Plotting a parameter representing both populations graphically on the same geographical extent might show this, but a more definitive statistical test is more reliable. (Syrjala, 1996) developed that type of statistical test .



Map (7) plotting the predicted spatial distributions of both Camels and Gazelles over WGNP using dung encounter rate (n/l) as a representative parameter independently for each population.

Kriging was used to interpolate values of camel and gazelle dropping encounter rates between transects to obtain an es mated distribution for the entire Study Region. Kriging uses the autocorrelation between values to estimate encounter rates in unsurveyed areas, no information about environmental factors underlying the distribution is involved in the model. Kriging is a method to interpolate point data, while the es mated dropping encounter rates are associated with transect lines, thus the geometrical center of the line was used for kriging. Figure 3 shows that gazelles and camels appear to be using the study area differently.

The Cramer von Mises sta s c, $W_n{}^2$ can be used to measure the level of agreement between the distribution of gazelle droppings (Gn(x)) and camel droppings (FX(x))

$$W_{n2} = n \int_0^1 [G_n(u) - u]^2 \, d_u$$

This statistic is used to test the null hypothesis that droppings of the two species are distributed in a similar way over the Study region [Ho: Gn(x) = FX(x)]. The encounter rates with camel and gazelle droppings were used to describe these distributions. The ordered individual encounter rates of transects are used to calculate the statis c T :

$$\Gamma = \left(\frac{n_1 \times n_2}{(n_1 + n_2)^2} \right) \times \sum_{i=1}^{n} (S_{1i} - S_{2i})^2$$

where :

S_1 is the first event (gazelle dung encounter rate) & n_1 number of transects used to assess event 1

S_1 is the second event (camel dung encounter rate) & n_2 number of transects used to assess event 2

Test Results

Cramer-von Mises Permutation Test:

Γ statistic: 87422.72 , p-value: 0

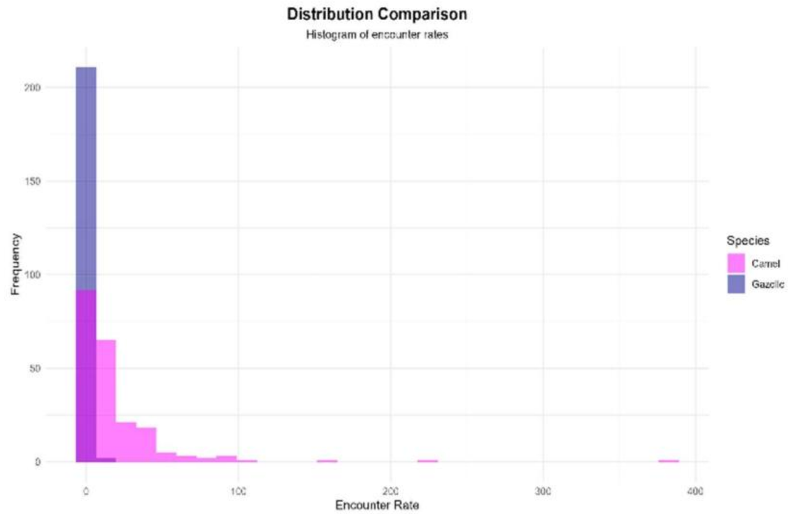
Decision: REJECT the null hypothesis

Conclusion: The distributions are SIGNIFICANTLY DIFFERENT ($p < 0.05$)

The two cumulative distribution functions are shown in Fig. 3. The null hypothesis is rejected. The calculated value of Γ for WGNP study region is 87422.72

Accordingly, it is concluded that the spa al distribution of gazelle droppings are significantly different from that of camels'. Cremer-Von Mises distribution was used to es mate distribution function densities of camel dung and gazelle dung as 2 independent proper es as shown graphically in Fig(3). This calculation suggests that camels are not posing spa ally threat as a proofed competition for gazelles over the limited resources of food. The 2 different spa al distributions of the two species might also suggest the 2 species are utilizing 2 different grazing strategies and partitioning the landscape differently among them. However, the camel numbers need to be precisely accounted for to reach a conclusive verdict.

Fig(3) graphical representation of Cumulative Density Function of Encounter Rates of Camel dung and Gazelle dung encounter rates showing different spatial distribu on.



4-b Occupancy Results

4-b-1 Gazelle species

Occupancy:

A total of 1781 camera-trap days were sampled during this study. This is 14 camera trap sites over 180 days. The number of actual operational days of every site where slightly variable where the minimum site showed an operational history of 59 days on one site and the maximum was 104 days on 4 sites with other sites opera ng for 91 to 99 days. Fortunately, enough plenty of records of Dorcas gazelle were obtained through out the survey. Table (6) shows the summary parameters of the sampling effort and findings for Dorcas gazelle occupancy survey.

Table(6) showing Camera trap sampling parameters for Dorcas gazelle in WGNP 2025

Metric	Value
Number of sites	14
Sampling occasions	104
Total detections	38
Sites with detections	11
Altitude range (m)	34-250
Duration range (days)	56-104

4.b.2 Detection Patterns

A total of 38 gazelle detections were recorded across the survey period. Detections occurred at 11 of 14 sites (78.6%), yielding a naive occupancy es mate of 0.7858. However, this es mate does not account for imperfect detection. Figure 4 shows the complete detection history, revealing sporadic detec on pa erns with most sites showing few detections. Figures 5&6 display temporal patterns and site-level varia on in detection frequency.

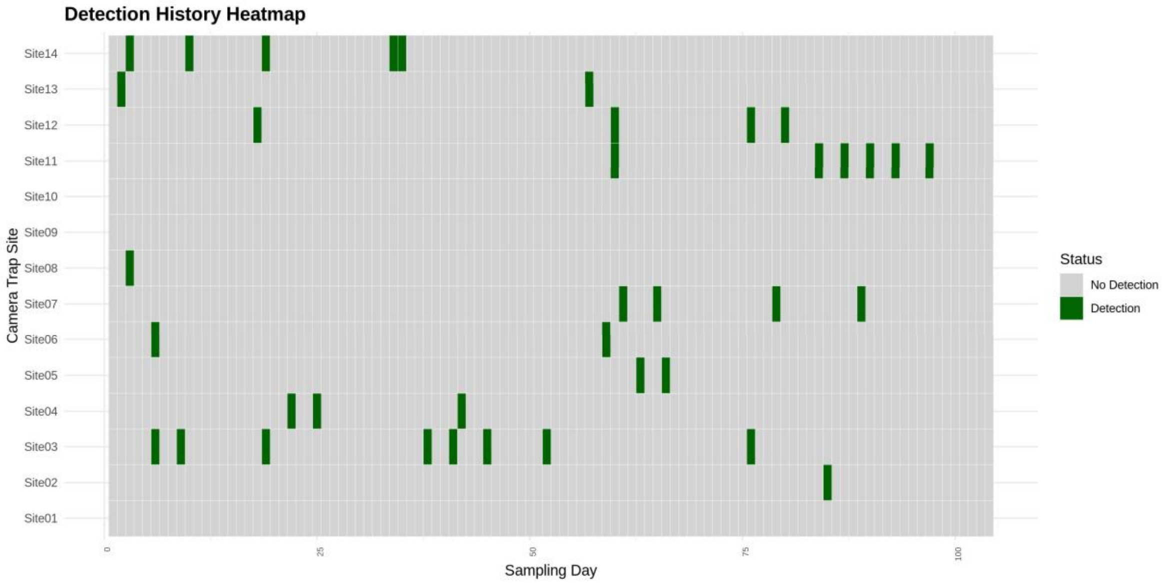
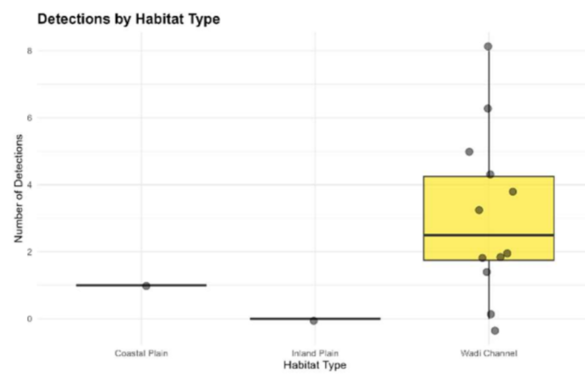


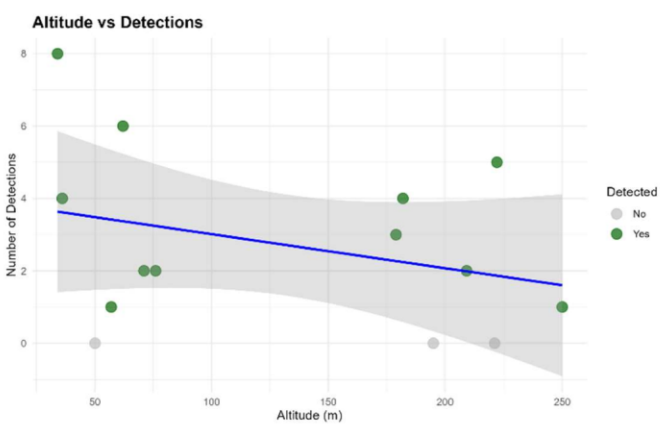
Figure 4. Detection history heatmap showing gazelle presence (green) and absence (gray) across all sites and sampling days.

Occupancy estimate	Psi SE	Naïve Occ. Es mate	Detc ons	Detec/sampling occasions
0.8130	0.11469	0.78571	38.0	36.53%

Analysis revealed that there is variation in detection patterns among habitats (Figure 5). This pattern was similar to that shown by line transects where the highest number of detections is in the Wadi Channel habitat, only few in the coastal plains and nothing in inland plains. Altitude also showed associations with detection frequency (Figure 5). Where higher detection frequency was observed at lower altitudes than higher ones. A fact that is logically coinciding with gazelle preference for lower lands.



Figure(5) Gazelle camera detection frequency by habitat type



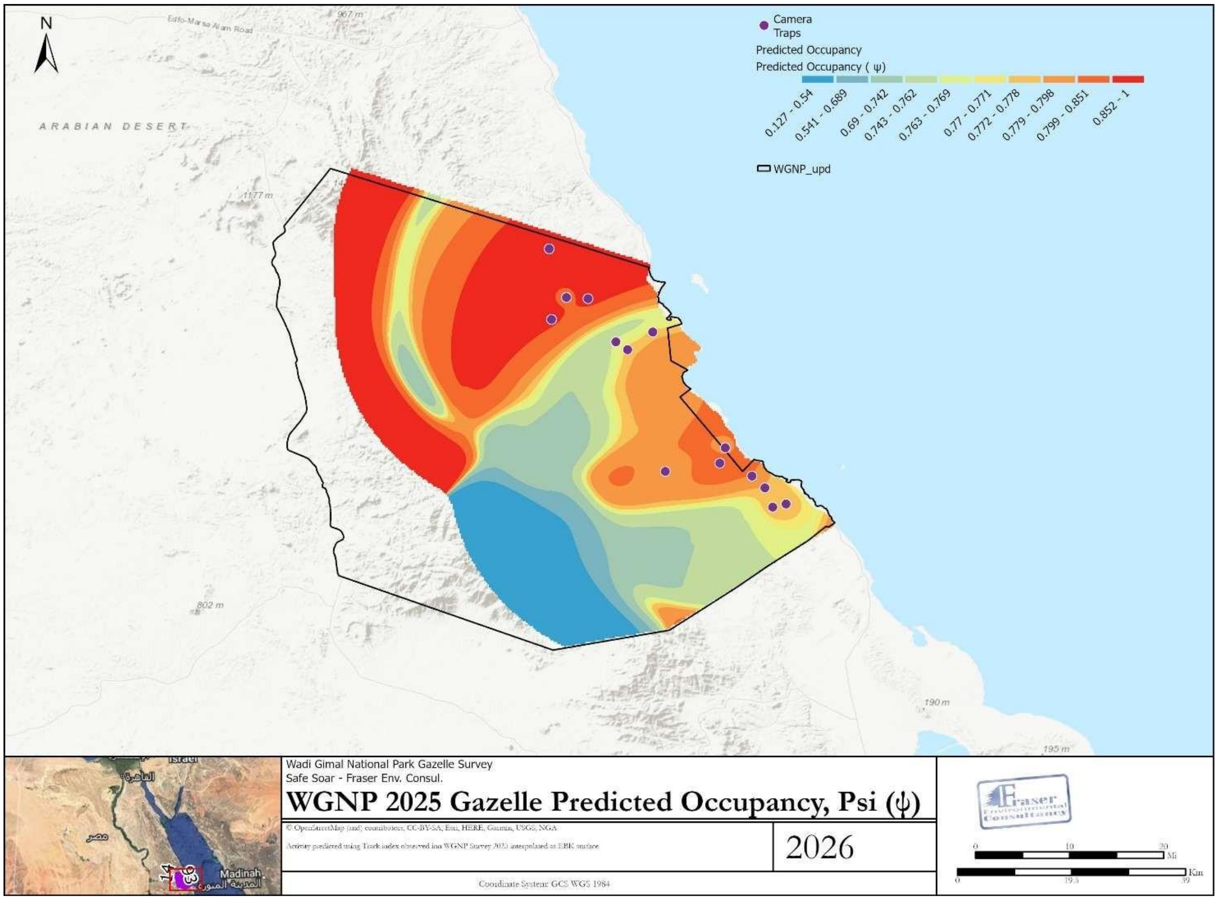
Figure(6) Gazelle camera detection frequency by Altitude

Moreover, a trial was made to model the gazelle occupancy as a continuous surface over the whole study area in an attempt to provide a spatial potential input to gazelle management approaches in WGNP if a spatial conservation planning is endeavored.

Occupancy values per site were interpolated using Empirical Bayesian Kriging and the resultant surface showed a high occupancy

$\mathbf{\Psi_{gaz}}$

zone in the north of WGNP and another high occupancy zone in the middle and south east. The southern western area was predicted as almost void of gazelle presence. Predicted Gazelle occupancy is shown on map (8).



Map(8) Predicted Gazelle Occupancy in WGNP from Camera Trap survey 2025

Relatively long-term sampling with camera traps applied here enabled some analysis of the diurnal and nocturnal activity pattern of several wild species recorded on Camera.

Alternatively, other species were recorded in this camera trap survey. About four wild species were recorded in addition to the free-roaming livestock (camels). These species included Red Fox *Vulpes vulpes,* Cape hare *Lepus capensis*, Rock Hyrax *Procavia capensis* and Rupillii's fox *Vulpes rupillii*. Occupancy is calculated for those species as shown in Table (6).

Table 6. Occupancy parameters for other wild species recorded by camera-traps in WGNP during the survey .

Species	Occupancy es mate	Psi SE	Naïve Occ. Es mate	Detec ons	Posi ve occasions/total sampling occasions
Red Fox	0.6996	0.3130	0.4285	9.0	14.42%
Ruppell's Fox	0.9991	0.0001	0.5000	9.0	14.42%
Rock Hyrax	0.0757	0.0734	0.0714	3.0	2.88%
Cape Hare	0.1515	0.0998	0.1429	6	5.77%
Camel	0.7177	0.1214	0.7143	52.0	50.00%

It is surprising that gazelle scored the highest value of occupancy among the wild species with Psi=0.8130 compared to a very generalist assumingly abundant species of Red Fox that only scored 0.6996. This could be attributed for the camera sites being selectively and strategically distributed in the gazelle high density areas and not randomly. Also it is surprisingly that the occupancy of Ruppell's fox is slightly higher than that of the Red fox. Other species like the hyrax and the capehare are showing occupancy values around the expected range.

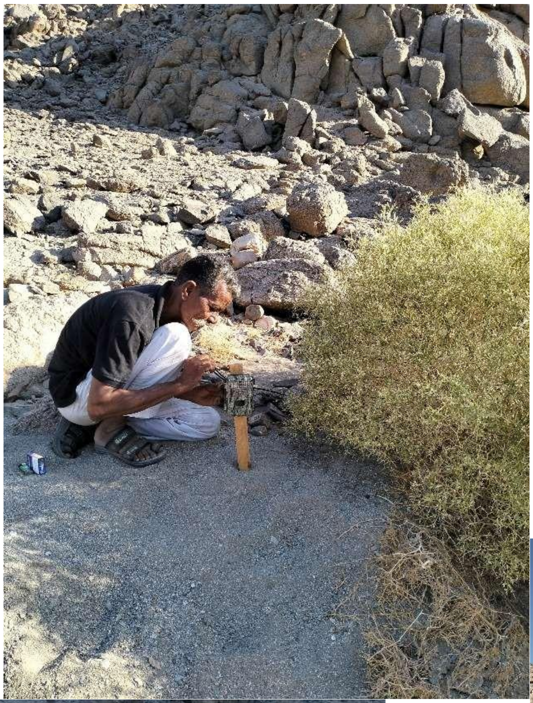
Ruppell's Fox is a desert specialist and has been known to inhabit sandy and stony deserts. There is also the expectation of a high camel density, since they are known for their well adaptation to desert life and often managed in large herds, which would result in a high intercept scenario.

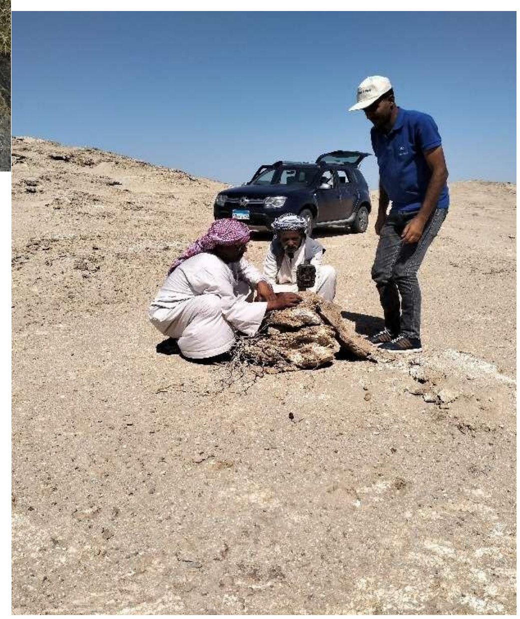
The Red Fox (Vulpes vulpes) has a slightly narrow niche with an occupancy of 0.6996 which may be facilitated by being more of a generalist species. As its range overlaps with the specialist Ruppell's Fox, (Velpes ruppelli) some amount of interspecific competition may be involved in its distribution.

The Rock Hyrax and Cape Hare, however have considerably lower es mates of occupancy (0.0757 and 0.1515, respectively). This could mean that although they are a part of the ecosystem, their microhabitat needs may be relatively narrow. For example, Rock Hyraxes are reliant on rock outcrops and mountainous environments for refuge, which may not be homogenously distributed throughout the study area. 2. Cape Hares are however relatively better suited to arid regions, although their distribution is likely more fragmented due to the abundance of vegetation used for browsing and cover.

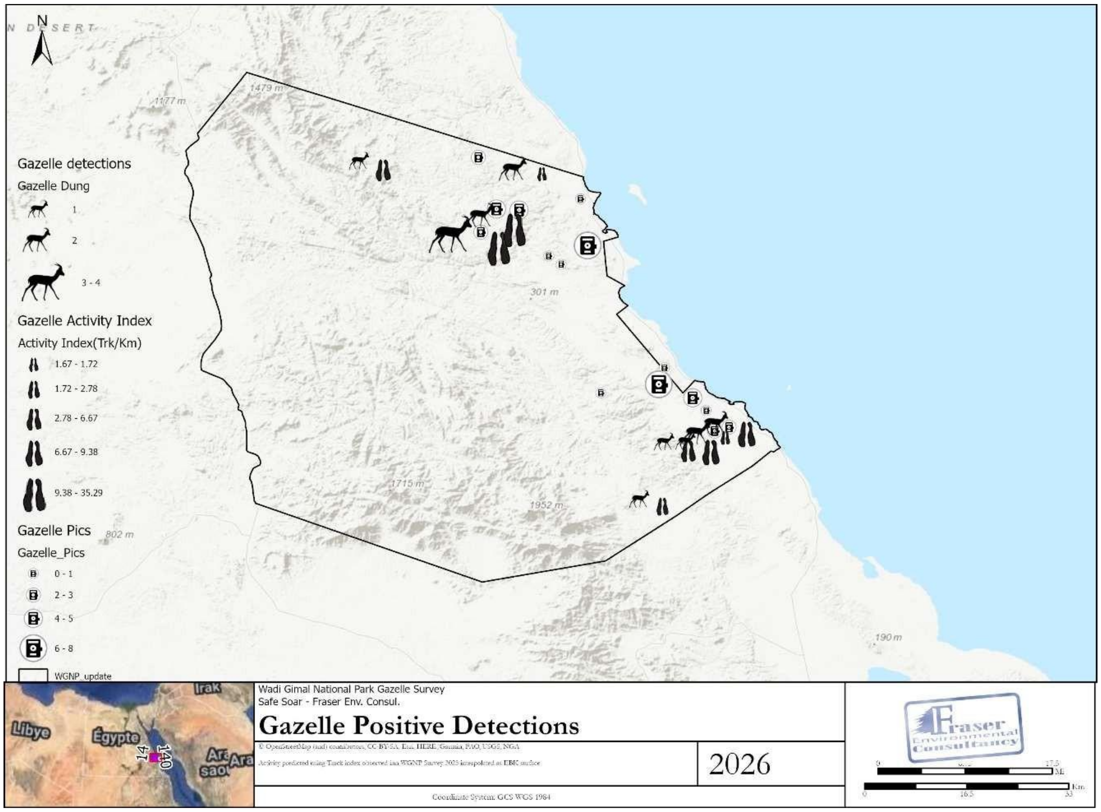
Camera-traps is an optimal method to study and assess these illusive shy and hard to record species especially in arid ecosystem context such as WGNP. Continuous camera-trapping is highly recommended as a routine monitoring program to be implemented by WGNP rangers in the future.

The team (local community) while fixing camera traps in the survey study region to collect occupancy records.

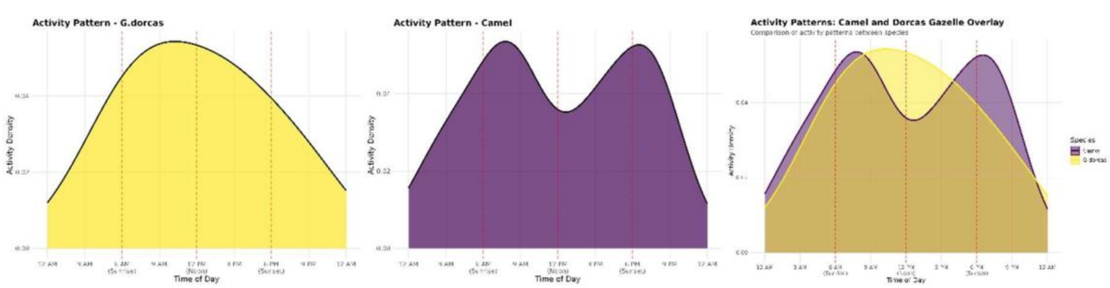




Map (9) collective Gazelles records in WGNP Survey 2025



Further analysis of activity patterns of the wild species recorded in WGNP allowed for some further insight into the interaction between species in WGNP. Plotting the Gazelle activity throughout the day shows a start of activity around midnight and a peak around noon me and activity is tapering off again to midnight. On the other hand, Camel activity shows a different pattern. The camel activity also starts at mid night but it peaks twice a day. Tow activity peaks are recorded, the first is around after sunrise, followed by a period of lower activity frequency around noon at the middle of the day and then peaking its activity again around sunset. These varying patterns shows some temporal separation of resources consumption and an attempt from gazelles to use the midday camel dormancy period to reduce the competition and maximize the benefit of the common grazing resources (fig6).



Figure(6) alterna ng peaks of ac vity among Camels and Dorcas gazelle repeating the same kind of activity pattern analysis for all other wild species recorded reveals some interesting facts about the inter-relation between these species and Gazelle and also among each other. Inspecting the activity of another competing herbivore, the goats, shows that there is the same temporal partitioning of grazing me between gazelles and goats. However, this one is to a less extent than between gazelle and camels. Gazelles seems to thrive during noon where goats are the least active just like with camels but goats are less active between the 2 peaks for relatively a shorter period. See Figure 7.epa

Overal most species seems to exhibit this noon resting period with minimal activity except for gazelles, who on the contrary exhibits a peak of activity. The noon resting period is the norm for all mammals living in an arid high temperature arid ecosystem. This is a behavioral adaptation to avoid the hottest periods of the day and to conserve water that may be wasted in evaporative cooling. However, it is not practiced by gazelles in WGNP and this fact is strange and needs more sampling and further investigation.

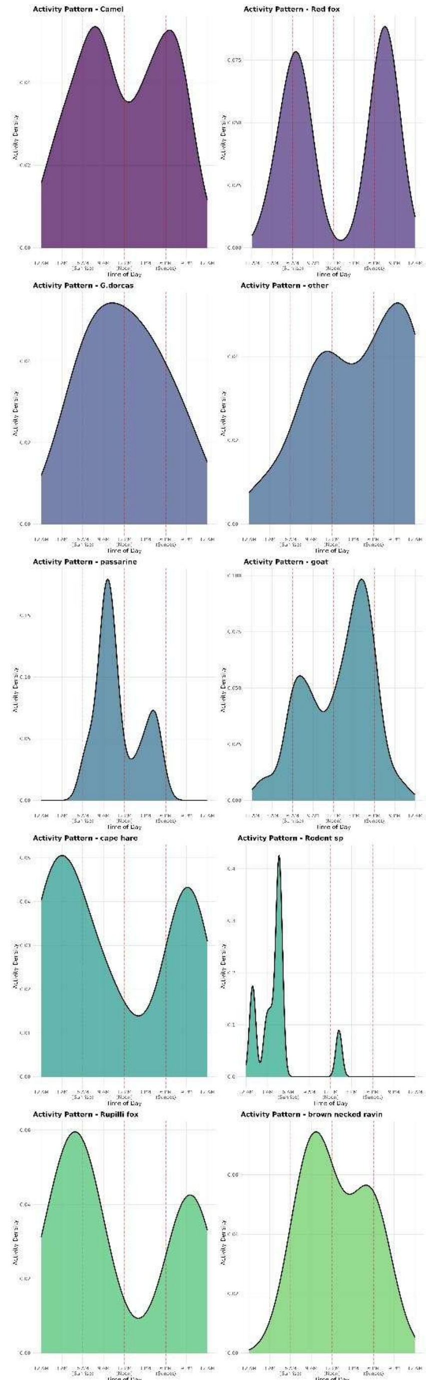
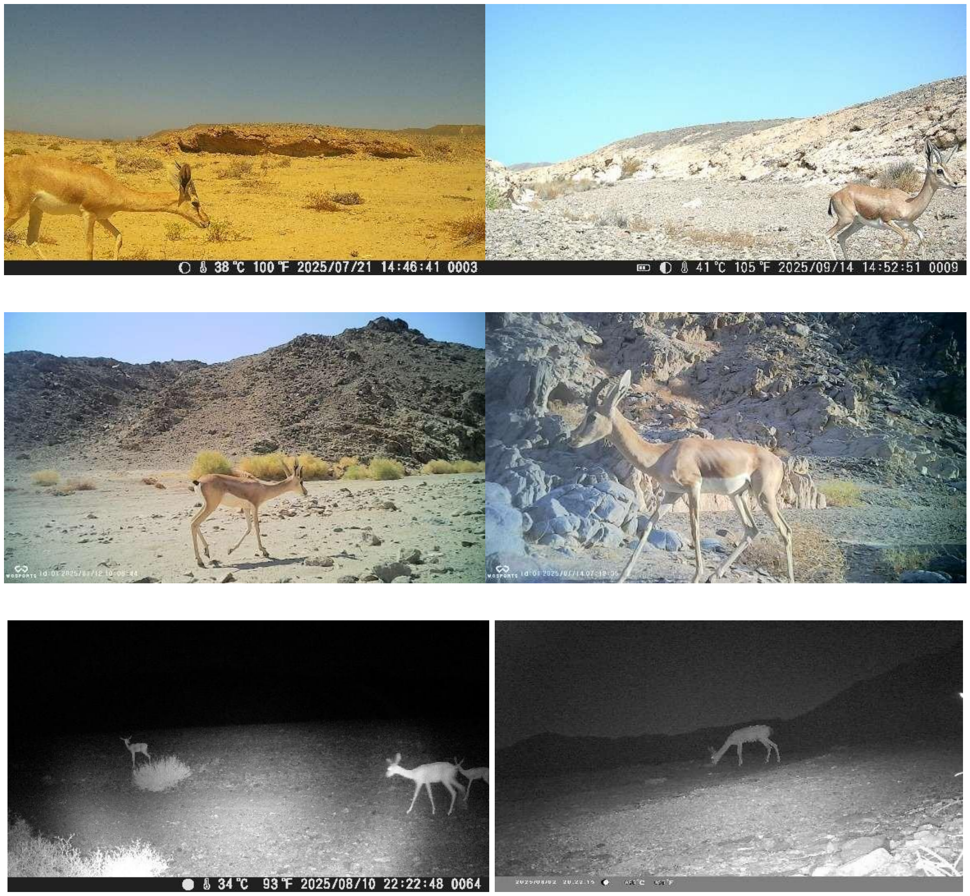


Figure (7) Diurnal Activity patterns of wild and livestock species in WGNP as recorded by Camera traps

Examples of Dorcas gazelle recorded on Camera Traps in WGNP

Dorcas Gazelle (Gazella dorcas)

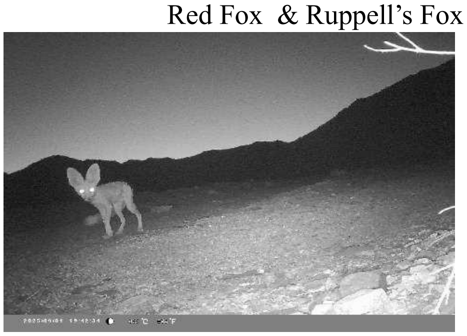


Examples of wild species recorded on Camera Traps in WGNP study

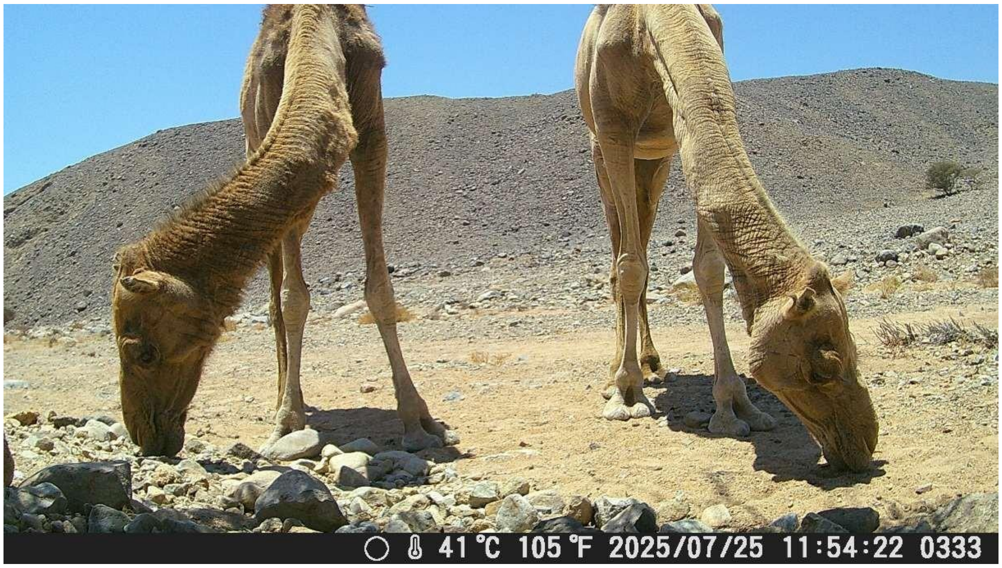
Capehare (Lepus capensis)

Rock Hyrax (Procavia capensis)   Unknown rodent

Red Fox & Ruppell’s Fox (Vulpes vulpes , Vulpes rupelli)



Free-Ranging livestock (Camels)



5. Discussion and Conclusion:

A comprehensive and representative land survey of the WGNP shows that this part of the Egyptian Gazelle Range is s ll harboring a surviving population of Dorcas gazelle (Gazella dorcas). The population size is still surviving to maintain and evolve into a viable population. Also, the occupancy survey for 1783 camera days established this fact and proved an occupancy (Ψ) of 0.8130 for the gazelle species. In addition, 138 Km of transects managed to detect 14 dung piles and 17 gazelle tracks.

The study was able to establish that the status of the habitats around WGNP Range is still in good condition and should be able to sustain a viable gazelle population. However, investigation showed that the area was subject to a long period of drought and low rainfall during the period 2016 – 2025. This fact is adding another stress on the current population. Unfortunately, there is no systematic quantitative studies for Gazelle population size or activity index in WGNP, however, (Omar Attum, 2014) conducted a line transect survey in WGNP and reported a Kilometric index of about 2.75 obs/Km. Comparing this to the value of 0.405 Trk/Km obtained in the current survey a fact that shows a drastic decline in gazelle population. These numbers show an es mated decline of about 85% of the population size since 2014. Attum et. al. concluded that precipitation is an important factor in gazelle decline and it explained 53% of the varia on in the kilometric index of gazelle detections among sites in WGNP.

There were great varia on of gazelle presence and gazelle abundance among the four potential habitats assessed in this study. Both Inland Plains and Plain with rocky outcrops showed zero presence of gazelle and the density estimate was 0 in both. On the other hand, considerable gazelle density with es mated for Coastal plains and Wadi channels. Coastal Plains was the top habitat for Dorcas Gazelle in WGNP where a density estimate of 26.939 dung pile /Km^2 was estimated for this habitat. On the other hand, Wadi Channels scored a density of 16.104 dung pile/Km^2. A strong preference is noticed for the coastal plain habitat may be interpreted as being preferred by gazelle as open land which enables their survival instinct of adopting swift escapes as a predator evasion strategy. However, the wadi channels are still utilized due to their considerable vegetation and crevices where hiding is possible.

The conservation action on this species is strongly tilted to the *in-situ* conservation while some *exsitu* conservation practices are not ruled out. Where the only the most effective action here is active protection and habitat enhancement. Given the current status of the gazelle population, strict and close protection could add more numbers to the population and render it viable. In addition, habitat enhancement by actively adding more acacia trees to the coastal plains and Wadi Channels will be the right way to go for gazelle population strengthening and enhancement. On the same track, it is recommended to endeavor population enforcement or even full reintroduction. However, this is not valid unless the threats are addressed first and a through gene c assessment is preceding this measure. Continuous assessment with a systematic repeated survey is key to this effort and also strongly recommended.

On the other hand, other wild species were recorded during the survey using camera traps and line transects. It was noticeable the high encounter of the cape hare.

Between 2013 and 2021, species conservation strategies were developed for many Sahelo-Saharan antelopes with a marked absence of any Egyptian input on the official side and the total absence of NCS from the table. Over the past 3 decades, the NCS has missed many opportunities to conserve the species, despite recommendations from its staff and studies. It is noteworthy that SMC developed a conservation action plan – as Part of the Sahelo-Saharan Mega Fauna Initiative (SSMFA)- for several Sahelo-Saharan species, including the Dorcas Gazelle and Slender-horn Gazelle. The current status of *G. leptoceros* & *G. dorcas* cannot be verified in the light of the current study. An action is advised to conduct pilot Positive-Negative surveys for the species all over its Egyptian range based on an initial stage of collecting local Knowledge, and accordingly delineate the potential areas for further surveys to establish the status.

6. Recommenda ons and Proposed Action Plan:

It is hard to draw recommendations on the National level based on a localized assessment such as the one at hand. However, as required by NCS and in light of the current findings and previous work, the following actions are recommended. Locally, a set of threats to conservation was identified in WGNP through fieldwork and literature review. These threats are identified below, along with a set of recommended conservation actions. However, following a theoretical framework and consistency with the actions proposed by the IUCN- Antelope Specialist Group ((IUCN SSC ASG and RZSS, 2020) for the species, the following ac on options can be proposed:

Dorcas Gazelle (Gazella dorcas)

Gazella dorcas, summarizing, those proposed conservation actions and adding to them it is deduced that the only viable ac on now is assessing the status of the species in its Egyptian range and build the knowledge body required for further planning. In addition to species and population status assessments, it is crucial to assess the habitat status for establishing a viable gazelle reintroduction in parallel to the proposed gazelle survey efforts.

To conclude a conservation action plan for the Gazelle species in Egypt is proposed with the following ac vi es in the following order:

6.2.1 Determining current status (Gazella dorcas) in the wild

1. Build the required knowledge body to enable any planning as the status of Gazelle species in Egyp an Range is totally lacking, by:
    a. Field survey in known Gazelle areas on four ac ons: 1) local knowledge gathering; 2) pilot positive negative surveys; 3) distance sampling surveys and 4) genetic assessment.
    b. Assess the habitat status for gazelle species requirements systematically with high priority inside potential current Protected Areas.
2. Using the collected Data and body of Knowledge and involving species experts conduct a series of brainstorming sessions, workshops, etc.. to develop the National Conservation Acion Plan as a framework for reviving the species in its Egyptian Range.

3. As part of this proposed National Action plan, local population management plans should be cascaded to provide a road map for managing individual sites into the general national vision of reviving the gazelle species. Thes local sites should monitor and report periodically on the status of the species and the status of implementations of the national ac on plan.

6.3.1 Identifying threats:

1. Habitat loss:

Acacia trees are significant element of the Dorcas gazelle habitat in WGNP (A um, 2012). Threats to the tree species is a direct hazard to the Dorcas gazelle. Charcoal production from Acacia trees may also nega vely impact Dorcas gazelle populations. The local pastoralists historically produced charcoal from burning dead Acacia trees (Andersen and Krzywinski, 2007). However, it is believed that some people may resort to burning live trees to produce charcoal during economic distress (Andersen and Krzywinski, 2007). The loss large Acacia trees negatively impact gazelle populations by reducing food and refuge availability. Trees may indirectly affect social the behavior of Dorcas gazelles because animals are losing conspicuous landmarks that could be used for midden sites.

1. *Competition with livestock:*

   Livestock and feral wildlife populations o en have negative consequences on native wildlife. For example, feral animals compete with na ve ungulates (Madhusudan, 2004). In WGNP this is proven to be the case since field investigation and comparing the spatial distribution of free ranging camels and Dorcas gazelles showed that the 2 species are using different resources configuration and thus competition is not imminent.

2. *Gold prospecting:*

   Camera traps photos and discussion with local and WGNP rangers proved that there is a significant number of active individuals working in packs of 2 or 3 in the business of gold prospecting allover WGNP with no control. This ac vity and these individuals pos a noticeable risk to the gazelle population, either by forcing the species into hide and reduce their grazing/browsing me during day me, or directly by poaching the species. An incident of a young gazelle fresh carcass was spotted near a camp site with a camp fire during the survey.

Gold prospectors caught on camera trap in WGNP.

3. *Climate Change:*

   Evidence from comparable arid and mountain systems suggests that Egypt’s vulnerable ungulates-specially Dorcas gazelle- will likely face substantial climate-driven reshuffling of suitable habitat and connectivity, challenging the long-term effectiveness of the existing protected-area network and underscoring the urgency of corridor planning and adaptive PA design.

Omar, et. Al., (2026) identified Climate change as a serious threat for ungulate species in Egypt. The results showed that protected areas in Egypt play a vital role in preserving these species, as indicated by the high coverage rate. For the Dorcas gazelle, coverage is currently 34 % in protected areas, but is projected to decline to 31 % by 2050 and 30 % by 2070. Based on these findings, effective management of protected areas, including continuous monitoring, evalua on, and adap ve boundary adjustments, is crucial for conservation. This is especially important in WGNP since it is one of the few remaining strongholds of the gazelle species in the protected areas of Egypt.

7. Proposed Conservation Actions:

7.1 Strengthening protection of known sites

1. Enhance the protection efforts in current Protected areas spanning the known gazelle range and enable active coordination with military and border guards for real rangers' presence in Protected Areas.
2. In the light of survey findings and other literature findings, Acacia trees are integral to the survivorship and the well-being of the gazelle population in WGNP. It is highly recommended to start a program of Acacia trees rehabilitation and plantation in selected wadis in WGNP. This program can be conducted by funding and enabling the local communities in a conservation related activity that enhances both the economic status of the community and boosts the ecological values and status of WGNP and its Gazelle population.
3. Active anti-poaching patrolling should be immediately started in WGNP to combat that imminent proofed threat that is undergoing and directly hi ng the gazelle population in WGNP. This is a priority in the conservation action plan if the species is to thrive in WGNP.

7.2 Enhancing ex-situ populations.

4. Investigate and work towards the objec ve of building an ex Situ conservation plan aiming at captive breeding followed by reintroduction of Gazelle species into identified areas resul ng from Ac vi es 1 & 2.
5. Initiate communication with captive breeding ins tu ons and captive population holders to start building an Egyptian nucleus for the gazelle founder population intended for breeding and reintroduction.
6. Implement the Ac on plan through a na onal strategy to implement ac ons, monitor, and report back to a governing body.

7.3. Reintroduction and reinforcement of populations

The potential for these options is limited at the present me because the captive population is small and has low gene c diversity. Since Egypt has no cap ve population, it is necessary to build rela ons with the two exis ng breeding centers in North Africa and the metapopulation in North America and help increase the numbers in captivity. The species usually gives birth to twins so under experienced management in adequately sized facilities, it should be possible in future to produce stock for return to the wild. Any future release site must contain an adequate area of suitable habitat and be under strict protection before any opera on takes place.Habitat modeling studies should be conducted to identify candidate sites for reintroduction.

On a parallel front, PAs should manage the habitat in a way that ensures the availability of a suitable range adequate to support the reintroduced population.

7. The NCS should be the custodian of the previously mentioned activities and engage in a self-assessment process to achieve maximum performance on the objective of building the populations of gazelle species into its Egyptian Range.

8. Acknowledgement.

The authors would like all the staff who worked on this project and whose efforts are indispensable and without which this work wouldn't be possible. We would like to thank them for their sincere field efforts where they traversed the desert fasting on days of Ramadan and accomplished all assigned tasks. Namely, they are:

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* Abdelnour Saad Abdullah (Ranger)
* Mohamed Ali (Guard)
* Hassan Ahmadani (Guard)
* Hassan Moustafa Saad (Assitant)
Fraser Environmental Staff
*Mahmoud El Gould
*Abdallah Eid
*Ahmed Ahmed Shabana.
*Omar Abdo.
*Abou El TAher.
*Omar Ghaiesh

Annex I

Distance Sampling Glossary of terms

Data items: n - number of observed objects (single or clusters of animals) L - total length of transect line(s) k - number of samples

K - point transect effort, typically K=k

T - length of me searched in cue coun ng ER - encounter rate (n/L or n/K or n/T)

W - width of line transect or radius of point transect x(i) - distance to i-th observa on r-p - probability for regression test chi-p- probability for chi-square goodness-of-fit test

Parameters or func ons of parameters: m - number of parameters in the model

A(I) - i-th parameter in the es mated probability density func on(pdf) f(0) - 1/u = value of pdf at zero for line transects u - W*p = ESW, effec ve detec on area for line transects p - probability of observing an object in defined area

ESW - for line transects, effec ve strip width = W*p

D - es mate of density of animals

N - es mate of number of animals in specified area

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Annex II R- SCRIPT FOR CALCULATING THE SPATIAL DIFFERENCE BETWEEN GAZELLE AND CAMEL POPULATIONS' SPATIAL DISTRIBUTIONS.

```
################################################################################
# Cramer-von Mises Statistic Calculator with Hypothesis Testing
#
# This script calculates the Cramer-von Mises statistic (Γ) for comparing
# two distributions (gazelle and camel dung encounter rates), performs
# hypothesis testing, and generates a cumulative frequency distribution graph.
#
# Formula: Γ = (n₁ × n₂) / (n₁ + n₂)² × Σ(S₁ᵢ - S₂ᵢ)²
# # Where:
#   S₁ = Gazelle dung encounter rate per transect
#   S₂ = Camel dung encounter rate per transect
#   n₁ = Number of transects used to assess gazelle (event 1)
#   n₂ = Number of transects used to assess camel (event 2)
#
# Hypothesis Testing:
#   H₀: The two distributions are identical (no significant difference)
#   H₁: The two distributions are different (significant difference)
################################################################################

# Load required libraries if
(!require("ggplot2")) {
install.packages("ggplot2")
library(ggplot2)
}

# For permutation test
set.seed(123)  # For reproducibility

################################################################################
# SECTION 1: DATA INPUT
################################################################################

# Option 1: Read data from CSV file
# Uncomment the following lines and specify your CSV file path
# data <- read.csv("C:/WGNP/Data/example_data.csv")
# gazelle_rates <- data$Gazelle
# camel_rates <- data$Camel

# Option 2: Manual data entry (example data) # Replace these with
your actual encounter rates gazelle_rates <- c(
  # Enter your gazelle dung encounter rates here   # Example: 0.5, 1.2, 0.8,
2.1, 1.5, ...
)
camel_rates <- c(
  # Enter your camel dung encounter rates here   # Example: 0.3, 0.9,
1.1, 1.8, 2.3, ...
)

# Option 3: Read from Excel file (requires readxl package) # Uncomment the
following lines to read from Excel  if (!require("readxl")) {
install.packages("readxl")    library(readxl)
 }
 data <- read_excel("C:/WGNP/Data/example_data.xlsx", sheet = "example_data")  gazelle_rates <- data$Gazelle
camel_rates <- data$Camel

################################################################################
# SECTION 2: CONFIGURATION
################################################################################
```

```
# Set significance level (alpha)
alpha <- 0.05  # Common choices: 0.05, 0.01, 0.001

# Number of permutations for permutation test
n_permutations <- 10000  # Increase for more accurate p-value

################################################################################
# SECTION 3: DATA VALIDATION AND PREPARATION
################################################################################
# Remove NA values
gazelle_rates <- gazelle_rates[!is.na(gazelle_rates)] camel_rates <-
camel_rates[!is.na(camel_rates)]

# Get sample sizes n1 <-
length(gazelle_rates) n2 <-
length(camel_rates)
 cat("========================================\n")
cat("Cramer-von Mises Statistic Calculator\n") cat("with Hypothesis
Testing\n")
cat("========================================\n\n")
cat("Data Summary:\n") cat("  n₁ (Gazelle transects):", n1, "\n") cat("  n₂
(Camel transects):", n2, "\n") cat("  Significance level (α):", alpha, "\n\n")

# Check if we have data if (n1 == 0 ||
n2 == 0) {
  stop("Error: One or both datasets are empty. Please provide valid data.")
}

################################################################################
# SECTION 4: CRAMER-VON MISES STATISTIC CALCULATION
################################################################################
# Function to calculate Cramer-von Mises statistic
calculate_cramer_von_mises <- function(s1, s2) {   n1 <- length(s1)   n2
<- length(s2)

  # Ensure same length for paired comparison   min_length <-
min(n1, n2)   s1 <- s1[1:min_length]   s2 <- s2[1:min_length]

  # Calculate differences   differences <- s1 - s2

  # Calculate squared differences   squared_differences <- differences^2

  # Calculate sum of squared differences   sum_squared_diff <-
sum(squared_differences)

  # Calculate Cramer-von Mises statistic
  gamma_statistic <- (min_length * min_length) / ((min_length + min_length)^2) * sum_squared_diff
    return(list(     gamma = gamma_statistic,
sum_squared_diff = sum_squared_diff,     n = min_length
  ))
}

# Calculate observed statistic
result <- calculate_cramer_von_mises(gazelle_rates, camel_rates) observed_gamma <-
result$gamma sum_squared_diff <- result$sum_squared_diff n_used <- result$n

# Display results cat("Calculation Results:\n") cat("
Observations used:", n_used, "\n")
cat("  Σ(S₁ᵢ - S₂ᵢ)²:", round(sum_squared_diff, 4), "\n") cat("  Γ (Cramer-von Mises Statistic):",
round(observed_gamma, 4), "\n\n")
################################################################################
```

```
# SECTION 5: HYPOTHESIS TESTING - PERMUTATION TEST
################################################################################

cat("Performing Permutation Test...\n")
cat("  Number of permutations:", n_permutations, "\n")

# Prepare data for permutation test min_length <- min(n1, n2)
gazelle_subset <- gazelle_rates[1:min_length] camel_subset <-
camel_rates[1:min_length]

# Combine all observations
all_observations <- c(gazelle_subset, camel_subset) n_total <- length(all_observations)

# Perform permutation test
permuted_statistics <- numeric(n_permutations)

for (i in 1:n_permutations) {   # Randomly permute the
combined data   permuted_data <- sample(all_observations)

  # Split into two groups
  perm_group1 <- permuted_data[1:min_length]
  perm_group2 <- permuted_data[(min_length + 1):n_total]
  # Calculate statistic for this permutation
  perm_result <- calculate_cramer_von_mises(perm_group1, perm_group2)
  permuted_statistics[i] <- perm_result$gamma
}

# Calculate p-value
p_value <- sum(permuted_statistics >= observed_gamma) / n_permutations

cat("  Permutation test completed.\n\n")

################################################################################
# SECTION 6: ALTERNATIVE TESTS
################################################################################
# Kolmogorov-Smirnov Test
ks_test <- ks.test(gazelle_subset, camel_subset)

# Wilcoxon Rank-Sum Test (Mann-Whitney U Test) wilcox_test <-
wilcox.test(gazelle_subset, camel_subset)

# Two-sample t-test (parametric)
t_test <- t.test(gazelle_subset, camel_subset)
################################################################################
# SECTION 7: STATISTICAL CONCLUSIONS
################################################################################

cat("========================================\n") cat("HYPOTHESIS TESTING
RESULTS\n")
cat("========================================\n\n")

cat("Null Hypothesis (H₀):\n")
cat("  The two distributions are identical.\n")
cat("  (No significant difference between gazelle and camel encounter rates)\n\n")

cat("Alternative Hypothesis (H₁):\n") cat("  The two distributions are
different.\n")
cat("  (Significant difference exists between the distributions)\n\n")
 cat("----------------------------------------\n") cat("Test Results:\n")
cat("----------------------------------------\n\n")
```

```
# Cramer-von Mises Permutation Test cat("1. Cramer-von Mises Permutation
Test:\n") cat("   Γ statistic:", round(observed_gamma, 4), "\n") cat("   p-value:",
round(p_value, 4), "\n")
if (p_value < alpha) {
  cat("   Decision: REJECT the null hypothesis\n")
  cat("   Conclusion: The distributions are SIGNIFICANTLY DIFFERENT (p < ", alpha,
          ")\n\n", sep="")
} else {
  cat("   Decision: FAIL TO REJECT the null hypothesis\n")
  cat("   Conclusion: No significant difference detected (p >= ", alpha, ")\n\n", sep="")
}

# Kolmogorov-Smirnov Test cat("2. Kolmogorov-
Smirnov Test:\n")
cat("   D statistic:", round(ks_test$statistic, 4), "\n") cat("   p-value:",
round(ks_test$p.value, 4), "\n") if (ks_test$p.value < alpha) {
  cat("   Decision: REJECT the null hypothesis\n")
  cat("   Conclusion: The distributions are SIGNIFICANTLY DIFFERENT (p < ", alpha,
          ")\n\n", sep="")
} else {
  cat("   Decision: FAIL TO REJECT the null hypothesis\n")
  cat("   Conclusion: No significant difference detected (p >= ", alpha, ")\n\n", sep="")
}

# Wilcoxon Rank-Sum Test
cat("3. Wilcoxon Rank-Sum Test (Mann-Whitney U):\n") cat("   W statistic:",
wilcox_test$statistic, "\n") cat("   p-value:", round(wilcox_test$p.value, 4), "\n")
if (wilcox_test$p.value < alpha) {
  cat("   Decision: REJECT the null hypothesis\n")
  cat("   Conclusion: The distributions are SIGNIFICANTLY DIFFERENT (p < ", alpha,
          ")\n\n", sep="")
} else {
  cat("   Decision: FAIL TO REJECT the null hypothesis\n")
  cat("   Conclusion: No significant difference detected (p >= ", alpha, ")\n\n", sep="")
}

# Two-sample t-test cat("4. Two-Sample t-
test:\n")
cat("   t statistic:", round(t_test$statistic, 4), "\n") cat("   p-value:",
round(t_test$p.value, 4), "\n") if (t_test$p.value < alpha) {
  cat("   Decision: REJECT the null hypothesis\n")
  cat("   Conclusion: The means are SIGNIFICANTLY DIFFERENT (p < ", alpha, ")\n\n", sep="") } else {
  cat("   Decision: FAIL TO REJECT the null hypothesis\n")
  cat("   Conclusion: No significant difference in means detected (p >= ", alpha,
          ")\n\n", sep="")
}

# Overall conclusion
cat("========================================\n") cat("OVERALL
CONCLUSION\n")
cat("========================================\n\n")

# Count how many tests reject the null hypothesis tests_rejecting <-
sum(c(   p_value < alpha,   ks_test$p.value < alpha,   wilcox_test$p.value
< alpha,   t_test$p.value < alpha
))
if (tests_rejecting >= 3) {
  cat("STRONG EVIDENCE: The majority of tests (", tests_rejecting, "/4) reject the null hypothesis.\n", sep="")
  cat("CONCLUSION: The gazelle and camel encounter rate distributions are\n")   cat("SIGNIFICANTLY DIFFERENT at
the α = ", alpha, " significance level.\n\n", sep="")
} else if (tests_rejecting >= 2) {
  cat("MODERATE EVIDENCE: Half or more tests (", tests_rejecting, "/4) reject the null hypothesis.\n", sep="")
  cat("CONCLUSION: There is evidence suggesting the distributions may be different,\n")
```

```
  cat("but results are not entirely consistent across all tests.\n\n")
} else {
  cat("WEAK EVIDENCE: Most tests (", 4 - tests_rejecting, "/4) fail to reject the null hypothesis.\n", sep="")
  cat("CONCLUSION: There is insufficient evidence to conclude that the\n")    cat("gazelle and camel encounter rate
distributions are significantly different\n")   cat("at the α = ", alpha, " significance level.\n\n", sep="")
}

################################################################################
# SECTION 8: CUMULATIVE DISTRIBUTION FUNCTION CALCULATION
################################################################################
# Sort the data for CDF calculation gazelle_sorted <-
sort(gazelle_subset) camel_sorted <- sort(camel_subset)

# Calculate empirical CDF values gazelle_cdf <- seq(1, min_length)
/ min_length camel_cdf <- seq(1, min_length) / min_length

# Create data frames for plotting df_gazelle <-
data.frame(   observation = 1:min_length,   value
= gazelle_sorted,   cdf = gazelle_cdf,   species =
"Gazelle n/l"
)
df_camel <- data.frame(   observation =
1:min_length,   value = camel_sorted,   cdf
= camel_cdf,   species = "Camel n/l"
)

# Combine data frames
df_combined <- rbind(df_gazelle, df_camel)

################################################################################
# SECTION 9: VISUALIZATION - CUMULATIVE FREQUENCY DISTRIBUTION
################################################################################
# Create subtitle with test result if (p_value < alpha) {
  subtitle_text <- sprintf("Γ = %.4f, p = %.4f (Significantly Different)", observed_gamma, p_value)
} else {
  subtitle_text <- sprintf("Γ = %.4f, p = %.4f (Not Significantly Different)", observed_gamma, p_value)
}

# Create the cumulative frequency distribution plot
cfd_plot <- ggplot(df_combined, aes(x = observation, y = cdf, color = species)) +   geom_line(size = 1.2) +
  scale_color_manual(values = c("Gazelle n/l" = "#00008B", "Camel n/l" = "#FF00FF"))
          +   labs(
    title = "Cumulative Frequency Distribution",     subtitle =
subtitle_text,     x = "Ordered observations",     y = "CDF",     color = ""
) +   theme_minimal() +   theme(
    plot.title = element_text(size = 14, face = "bold", hjust = 0.5),     plot.subtitle = element_text(size =
10, hjust = 0.5),     axis.title = element_text(size = 12),     axis.text = element_text(size = 10),
legend.position = "right",     legend.text = element_text(size = 12),     legend.key.size = unit(1.5, "cm"),
    panel.grid.major = element_line(color = "gray90"),     panel.grid.minor = element_line(color =
"gray95")
  ) +
  scale_y_continuous(breaks = seq(0, 1, 0.05), limits = c(0, 1)) +
  scale_x_continuous(breaks = seq(0, min_length, by = max(1, floor(min_length/10))))
# Display the plot print(cfd_plot)

# Save the plot to file
ggsave("cumulative_frequency_distribution_with_test.png",        plot = cfd_plot,
width = 10,        height = 6,        dpi = 300)

cat("Plot saved as: cumulative_frequency_distribution_with_test.png\n\n")

################################################################################
```

```
# SECTION 10: PERMUTATION DISTRIBUTION VISUALIZATION
################################################################################
# Create histogram of permutation distribution perm_df <- data.frame(gamma =
permuted_statistics)

perm_plot <- ggplot(perm_df, aes(x = gamma)) +
  geom_histogram(bins = 50, fill = "lightblue", color = "black", alpha = 0.7) +   geom_vline(xintercept = observed_gamma,
color = "red", size = 1.5, linetype =
              "dashed") +   annotate("text", x = observed_gamma, y = Inf,
          label = sprintf("Observed Γ = %.4f", observed_gamma),            vjust = 2, hjust = -0.1, color =
"red", size = 4) +   labs(
    title = "Permutation Test Distribution",
    subtitle = sprintf("p-value = %.4f (based on %d permutations)", p_value, n_permutations),
    x = "Γ Statistic",     y =
"Frequency"
  ) +   theme_minimal() +
theme(
    plot.title = element_text(size = 14, face = "bold", hjust = 0.5),     plot.subtitle = element_text(size = 10, hjust = 0.5)
  )
print(perm_plot)

ggsave("permutation_distribution.png",         plot =
perm_plot,         width = 10,         height = 6,         dpi =
300)
 cat("Permutation distribution plot saved as: permutation_distribution.png\n\n")
################################################################################
# SECTION 11: EXPORT RESULTS TO CSV
################################################################################
# Create comprehensive results summary results_summary <- data.frame(
  Metric = c(
    "n₁ (Gazelle)",
    "n₂ (Camel)",
    "Observations Used",
    "Σ(S₁ᵢ - S₂ᵢ)²",
    "Γ Statistic",
    "Permutation p-value",
    "KS p-value",
    "Wilcoxon p-value",
    "t-test p-value",
    "Significance Level (α)",
    "Permutation Test Decision",
    "Overall Conclusion"
  ),   Value = c(
n1,      n2,
n_used,
    round(sum_squared_diff, 4),
round(observed_gamma, 4),     round(p_value, 4),
round(ks_test$p.value, 4),
round(wilcox_test$p.value, 4),
round(t_test$p.value, 4),     alpha,
    ifelse(p_value < alpha, "REJECT H₀", "FAIL TO REJECT H₀"),
    ifelse(p_value < alpha, "SIGNIFICANTLY DIFFERENT", "NOT SIGNIFICANTLY DIFFERENT")   )
)

# Create detailed calculations data frame detailed_calculations
<- data.frame(   Transect = 1:n_used,
  Gazelle_Rate = gazelle_subset,
  Camel_Rate = camel_subset,
  Difference = gazelle_subset - camel_subset,
  Squared_Difference = (gazelle_subset - camel_subset)^2,
  CDF_Gazelle = gazelle_cdf,
  CDF_Camel = camel_cdf
)
```

```
# Save results to CSV
write.csv(results_summary, "cramer_von_mises_summary_with_test.csv", row.names =
        FALSE) write.csv(detailed_calculations, "cramer_von_mises_detailed_with_test.csv", row.names = FALSE)

cat("Results exported to:\n")
cat("  - cramer_von_mises_summary_with_test.csv\n") cat("  -
cramer_von_mises_detailed_with_test.csv\n\n")

################################################################################
# SECTION 12: ADDITIONAL STATISTICS
################################################################################
 cat("Additional Descriptive Statistics:\n") cat("-------------------------------
---------\n") cat("Gazelle:\n")
cat("  Mean:", round(mean(gazelle_subset), 4), "\n") cat("  Median:",
round(median(gazelle_subset), 4), "\n") cat("  SD:", round(sd(gazelle_subset), 4),
"\n") cat("  Min:", round(min(gazelle_subset), 4), "\n") cat("  Max:",
round(max(gazelle_subset), 4), "\n\n")
 cat("Camel:\n")
cat("  Mean:", round(mean(camel_subset), 4), "\n") cat("  Median:",
round(median(camel_subset), 4), "\n") cat("  SD:", round(sd(camel_subset), 4),
"\n") cat("  Min:", round(min(camel_subset), 4), "\n") cat("  Max:",
round(max(camel_subset), 4), "\n\n")

cat("Difference in Means:", round(mean(gazelle_subset) - mean(camel_subset), 4),
        "\n") cat("Difference in Medians:", round(median(gazelle_subset) - median(camel_subset),
        4), "\n\n")
 cat("==========================================\n")
 cat("Analysis Complete!\n")
cat("==========================================\n")
```