Habitat Suitability Assessment for Reintroducing *Testudo kleinmanni* at Omayed Protected Area, Egypt

04/09/2024

4,942 Words

PGCert - Ecological Surveying Techniques

University of Oxford

Table of Contents

List of Figures

List of Tables

1 Abstract

This study evaluates habitat suitability within the Omayed Protected Area (PA) in Egypt for the reintroduction of the critically endangered Egyptian Tortoise (*Testudo kleinmanni*). Geographically Weighted Regression (GWR) models and field surveys assessed key habitat parameters: Species Richness (SR), Food Plant Cover (FPC), and Proportion Bare Earth (PBE). The GWR analysis identified two potential release sites based on higher habitat suitability scores. Further analysis and contextualization, considering factors such as release site size, food plant diversity, and disturbance levels, determined Site B as the most suitable location. A soft-release strategy is recommended to reduce predation risks and allow tortoises to acclimate, with additional measures proposed to manage human activities and grazing pressures within the PA. The study underscores the importance of habitat restoration and effective management practices to ensure the long-term success of the reintroduction program for *T. kleinmanni*.

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3 Introduction

As part of the environmental studies for Egypt's construction of the High-Speed Rail (HSR) network, spanning over 2000 km, a Biodiversity Action Plan was developed with a focus on the critically endangered Egyptian Tortoise (*Testudo kleinmanni*). A reintroduction program using ex-situ reared individuals is required to mitigate the ecological impacts of the HSR project. Unverified sightings of *T. kleinmanni* in the Al-Omayed Protected Area (PA) on Egypt's northern Mediterranean coast highlight the region's importance as a critical habitat for this species. However, to-date, no studies have directly evaluated the localized habitat suitability within the Omayed PA.

This study integrates existing knowledge on *T. kleinmanni*'s behavioral ecology, primary data collection, Geographically Weighted Regression (GWR) techniques, and geospatial mapping to determine the optimum release site within the PA based on food availability, floral diversity, and shelter availability.

3.1 Ecology of *Testudo kleinmanni*

Testudo kleinmanni, the smallest species in the genus *Testudo* (Figure 3-1), is critically endangered due to significant declines in its population and range. Once widespread across the Mediterranean coastal areas of Libya, Egypt, and Palestine (Israel), it is now primarily found in fragmented populations in Libya, with the species considered effectively extinct in Egypt [30, 20]. Despite some habitats remaining in relatively good condition, threats such as overgrazing, agricultural expansion, habitat destruction, and illegal collection for the pet trade are contributing to further habitat degradation and decline of the species [27, 21]. Although listed under CITES Appendix I and theoretically protected by Egyptian law, enforcement is insufficient, and there is no legal protection in Libya, highlighting the need for urgent conservation measures to prevent further habitat loss and protect the species [7, 27].

Figure 3-1: Photograph of Female Egyptian Tortoise (Photo Credit: Baha El Din, n.d)

They also face substantial natural predation pressures, especially juveniles. Predators include birds like the Brown-necked Raven (*Corvus ruficollis*) and Carrion Crow (*Corvus corone*), which find increasing nesting sites with human structures, and various birds of prey that target young tortoises [6, 2, 21]. Terrestrial predators such as the Desert Monitor (*Varanus griseus*), Desert Red Fox (*Vulpes rüppelli*), and Red Fox (*Vulpes vulpes*) also pose a significant threat, particularly to juveniles, along with other carnivores and domestic animals like dogs and rats [11, 2].

T. kleinmanni inhabits desert and semi-desert areas, including sand and gravel plains, scattered rocks, shallow sandy wadis, and coastal salt marshes. In Libya, it is typically found in coastal shrubby sand and stone deserts dominated by *Artemisia monosperma*, while in Egypt, habitats are dominated by *A. monosperma, Thymelaea hirusta*, and *Anabasis articulata* [30, 6]. Adapted to extreme desert conditions, *T. kleinmanni* can tolerate high temperatures and relies on sparse vegetation for both cover and food.

T. kleinmanni requires a diverse array of floral species to thrive in its arid environment. While some studies have provided valuable insights into their diet and refuge requirements, results have varied by location. In Northern Sinai, it primarily consumes perennial plants such as *Convolvulus lanatus, Echiochilon fruticosum, Pancratium sickenbergeri*, and *Centropodia forsskaolii*, which provide a reliable food source in arid environments [5]. In contrast, other studies have found that annual plants, including *Erodium crassifolium, Senecio glaucus coronopifolius, Ononis serrata*, and *Polycarpon succulentum*, form a larger part of their diet, particularly after autumn rains [11, 6, 28]. This variation may be due to seasonal shifts in plant availability and tortoise dietary preferences.

As ectotherms, *T. kleinmanni* require effective strategies to survive extreme temperatures and predation. They are most active when ambient temperatures range between 20-24°C, but activity decreases when temperatures rise, as they seek refuge in cooler, shaded areas [11]. To cope with these conditions, they rely heavily on both rodent burrows and desert vegetation for shelter. Rodent burrows provide a cooler microenvironment essential for thermoregulation and water conservation, particularly during the hot summer months and periods of aestivation [15, 40]. Additionally, desert vegetation, especially larger shrubs like *Artemisia monosperma*, offer vital thermal refuge by reducing surface temperatures and creating stable microclimates, crucial for survival during extreme heat [3]. This reliance on a combination of refuges underscores the importance of closely spaced shelters which are vital for preventing overheating and ensuring survival [26].

Despite extensive studies in other regions, there is a critical lack of research on the habitat suitability of Al-Omayed PA for *T. kleinmanni*. Understanding these habitat requirements is crucial for the success of the reintroduction program planned within the PA as part of the HSR project.

3.2 Study Area

The Omayed Protected Area (PA), situated 11km inland from Egypt's northern Mediterranean coast (30°40'43.8"N, 29°07'19.1"E, Figure 3-2), is part of Egypt's Western Coastal Desert and the only protected area in Egypt representing the Mediterranean coastal desert ecosystem [23]. Originally designated as a 75,800-hectare UNESCO Biosphere Reserve in 1981, the PA once encompassed five distinct habitat types but has been reduced to 69.5 km² due to inadequate protection measures and extensive human activities, including the construction of coastal resorts, irrigation canals, and agricultural expansion [14]. These activities have led to a significant decline in the area's natural flora from 253 to 145 taxa and an increase in invasive species, severely impacting the habitat's ecological integrity [14].

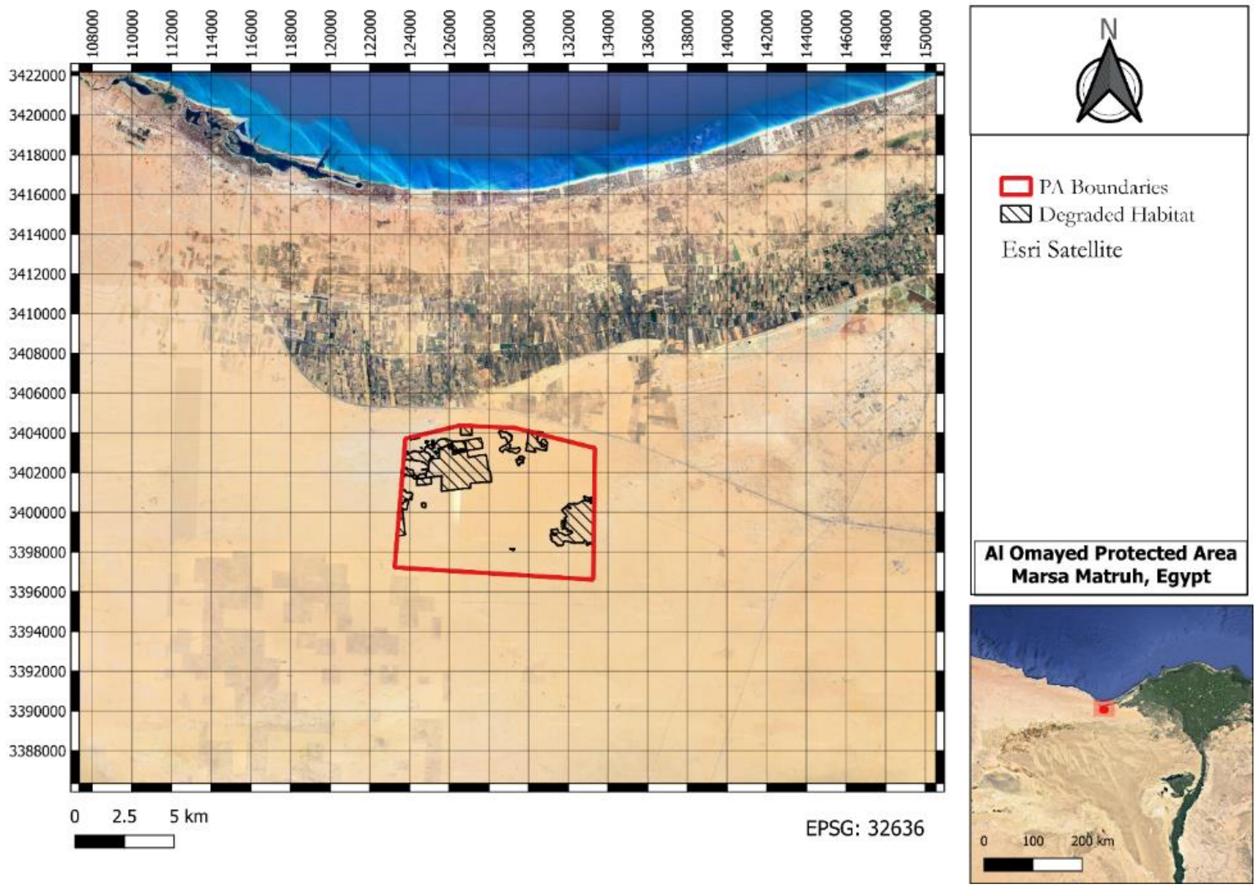

Figure 3-2: Map showing Location of Al Omayed PA

The habitat now primarily consists of an inland plateau characterized by calcareous, shallow soils at elevations ranging from 71 to 124 meters above sea level. The area experiences a subdesert climate, with temperatures ranging from 21-36°C in the summer and 10-22°C in the winter [24], with rain occurring in autumn and winter only [14]. Vegetation is sparse and unevenly distributed (Figure 3-3), dominated by *Artemisia monosperma, Thymelaea hirusta*, and *Anabasis articulata*, which are characteristic of *T. kleinmanni* habitats and provide critical food and shelter resources [6]. The PA's flora comprises about 12% of Egypt's flowering plants and 17% of its bryophytes, making it an essential biodiversity hotspot despite the pressures it faces [14]. Additionally, the area supports a diverse microbiome, including 72 fungal species and 257 bacterial species associated with the plant rhizosphere, which play vital roles in nutrient cycling and plant health [14].

Figure 3-3: Field Photographs of Omayed PA Habitat

The PA is bounded to the north by the main road and extensive agricultural lands, and to the east, south, and west by a large plot, reportedly belonging to the United Arab Emirates for the conservation of the endangered African Houbara, though the exact boundaries and size are not publicly disclosed (Figure 3-4). Within the PA, there is an extensive network of unsealed, compacted roads, and Bedouin communities that allow their camels, goats, and sheep to graze on the local vegetation.

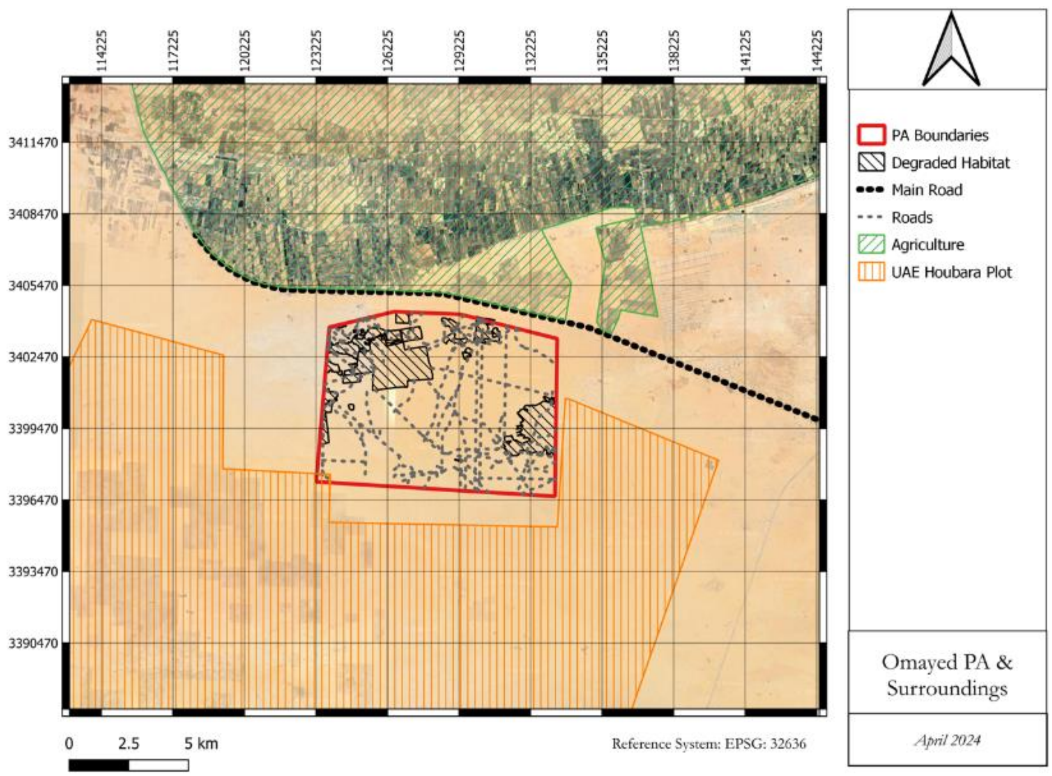

Figure 3-4: Map showing immediate surroundings of the Omayed PA

The PA lacks fencing or clear delineation of its borders. Management practices include bi-annual flora and fauna censuses and regular security patrols; however, insufficient resources hinder the team's ability to effectively manage the area. The most recent biodiversity census, conducted by PA Management, recorded a wide variety of species, including *T. kleinmanni*.

However, the PA has experienced significant habitat degradation, primarily due to quarrying activities, agricultural expansion, and overgrazing. Currently, 13 km^2 (18.7%) is occupied by quarries, some of which remain active and continue to expand. With these complex habitat disruptors, a static or homogenous spatial relationship across the whole study area is not anticipated. Instead, the researchers hypothesized that habitat suitability factors (food availability and diversity, and shelter availability) will show differential spatial distribution within the PA according to their proximity to the quarry sites and proximity to the main road. As such a Geographically Weighted Regression (GWR) approach was selected.

3.3 Geographically Weighted Regression (GWR)

[22] highlight the advantages of GWR over traditional regression models for analyzing spatial data with inherent non-stationarity. GWR allows the relationships between predictors and outcomes to vary across geographical locations, accommodating the complex nature of spatial data and enhancing model accuracy by adapting to local conditions. This method enables the identification of significant "hot spots" and localized trends that global models may overlook, making it a powerful tool for both exploratory and confirmatory spatial analysis. GWR has been effectively applied in ecological research, such as mapping distribution of fish species [9], mapping the spatial distribution of invasive plant species [38], modeling habitat suitability and black bear distribution for wildlife conservation [34], and predicting localized frozen soils [39]. These applications demonstrate GWR's ability to address spatial non-stationarity and provide insights to understand the localized distribution of suitable habitats within the PA.

3.4 Research Objectives

This study aims to assess the potential for reintroducing *T. kleinmanni* in Al Omayed PA by evaluating localized variations in habitat suitability factors, namely, food availability and diversity, and shelter/refuge availability. These factors are critical for selecting optimal reintroduction sites, ensuring that released tortoises have access to essential resources to enhance the probability of survivorship. Specifically, the study aims to answer the following research questions:

1. Are there any *T. kleinmanni* currently residing within the Omayed PA?
2. How does floral species richness and abundance differ between disturbed and undisturbed habitats?
3. What is the geospatial distribution and abundance of plant species known to be food sources for *T. kleinmanni*?
4. What is the geospatial distribution of potential refuge sites/shade plants?
5. What is the optimum release site within the PA accounting for all three habitat suitability factors?

4 Methodology

Fieldwork was conducted under the supervision of the Protected Area Management Team, after securing permits from the Egyptian Ministry of Environment and receiving ethical approval from University of Oxford (Annex VI: Permits & Approvals).

Disturbed and undisturbed strata were initially delineated using satellite imagery from ESRI and Google Earth. During fieldwork, new active quarries were discovered and subsequently mapped using a handheld GPS (Garmin eTrex 10 GPS) by walking the perimeter of the quarry area and recording the track (Figure 4-1).

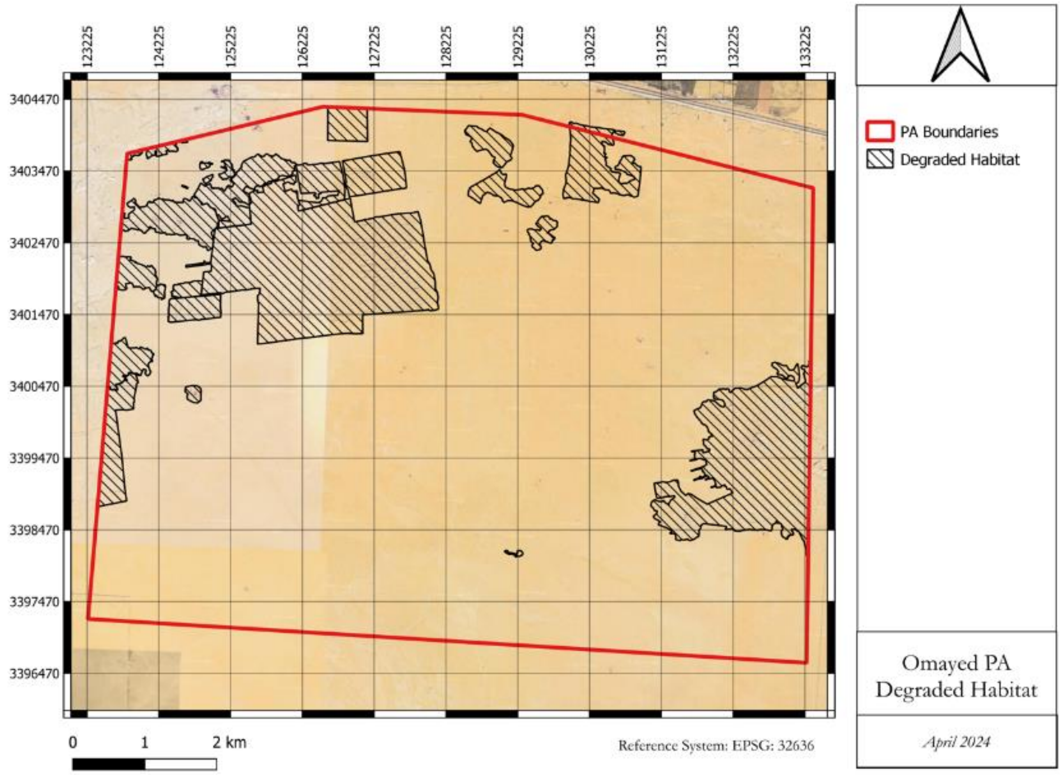

Figure 4-1: Map of PA showing all Quarry Areas

Random stratification for floral quadrats and fauna transects was conducted using QGIS 3.28 Firenze (EPSG:32636). The study area was divided into a 100m grid as habitats within each stratum are relatively homogenous, but sampling points need to be representative whilst avoiding spatial autocorrelation. A custom MS Excel spreadsheet (Annex VIII: Randomization Spreadsheet) generated random grid cell numbers and x-y offsets from the bottom left of each cell, ensuring unbiased sampling. The coordinates generated marked the southwestern corner of each quadrat. To ensure comprehensive coverage, sampling points within already sampled grid cells were skipped in undisturbed strata, and the next random point was selected. For transects, the starting point was determined using the same algorithm, and the Azimuth and Distance Plug-in in QGIS generated random bearings for the transect direction (Figure 4-2).

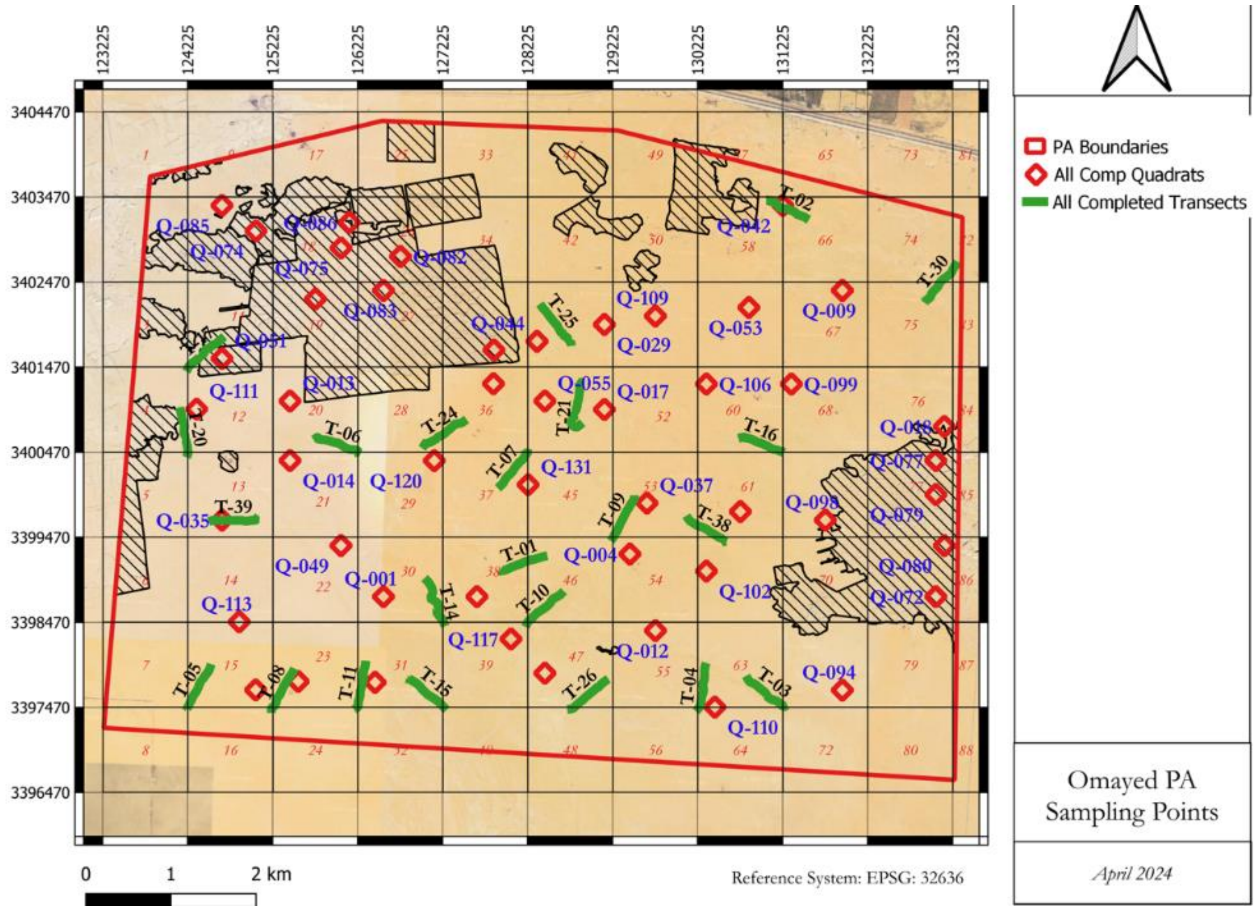

Figure 4-2: Map showing Locations of all Quadrat and Transect Samples Completed

Fieldwork was conducted from April 12-27 2024, aligning with the mating season and peak activity period for tortoises, with temperatures ranging from 12-28ºC to increase encounter probability. Transects were conducted in the morning (7am-12pm) to avoid high afternoon temperatures.

Forty-eight 5x5m floral quadrats were established using pegs and paracord, with right angles ensured using steel squares. Geotagged photographs of quadrats and plant species were taken using a Canon 6D. Plant species were identified to species level with the help of a local botanist. Data collected included individual counts, and observational estimates of Braun-Blanquet abundance, soil type, depth, compaction, and aspect. Environmental variables were measured to account for microhabitat conditions with anemometer (Amgaze GM 816), hygrometer (Tacklife HM01). Wind direction and quadrat aspect were determined using a compass (Annex II: Datasheets).

Twenty-three 100m transects were walked by two observers, recording faunal signs and direct sightings using standardized data sheets (Annex II: Datasheets).

Quadrat photographs were perspective-transformed using GIMP 2.10, imported into ImageJ for analysis, scaled using the quadrat's diagonal line set to 7.071m, converted to 8-bit, thresholded (0–100), and analyzed for percentage bare earth (Annex V: ImageJ Photo Transformations & Analysis). Plant species were classified as diet or non-diet plants for *T. kleinmanni* based on existing literature.

Species without documented evidence of consumption by *T. kleinmanni* were conservatively categorized as non-diet plants (Table 4-1).

Table 4-1: Classification Table of all Observed Floral Species and Delineation as T. kleinmanni Food Species

Species	Food	Source
Anabasis articulata	Yes	[5]
Artemisia monosperma	Yes	[11]
Astragalus annularis	No	[36]
Atractylis carduus	Yes	[5]
Bassia muricata	No	[30]
Cynodon dactylon / lolium perenne	Yes	[36]
Daucus durieua	Yes	[36]
Deverra tortuosa	No	*Not studied*
Dipcadi erythraeum	Yes	[5]
Echinops spinosissimus	Yes	[36]
Echiochilon fruticosum	Yes	[11]
Gymnocarpus decanter	No	*Not studied*
Launaea fragilis	Yes	[30]
Launaea nudicaulis	Yes	[30]
Moltkiopsis ciliata	Yes	[5]
Monsonia nivea	No	*Not studied*
Noaea mucronata	Yes	[5]
Onopordum spp.	Yes	[36]
Pancratium sickerbergeii	Yes	[5]
Panicum turgidum	No	[30]
Reichardia tingitana	Yes	[30]
Schismus barbatus	Yes	[11]
Thymelaea hirsuta	Yes	[5]
Zygophyllum album	Yes	[5]

Distances from each quadrat to the nearest quarry and main road were calculated using the NNJoin tool in QGIS to assess habitat disturbance. Proportion Bare Earth (PBE) was used as an inverse indicator of shade availability, with lower PBE suggesting more vegetation cover and, consequently, more shade. Species Richness (SR) measured the number of plant species per quadrat, and Food Plant Cover (FPC) represented the total percentage cover of identified diet plants. A square-root transformation was applied to normalize the data.

Three two-variable Geographically Weighted Regressions (GWRs) were conducted using the 'GWmodel' library in R Studio, with Species Richness (SR), Proportion Bare Earth (PBE), and Food Plant Cover (FPC) as dependent variables (Annex VII: R Script Extracts for GWR Example). The GWR coefficients were exported to CSV, imported into QGIS, and duplicated to represent the two distance factors. To determine the non-stationarity of these factors, a Monte Carlo Test (MCT) was used, providing a measure of statistical significance for each variable. Due to resource constraints, a full ecological modeling approach using MaxEnt or Bioclim was not performed. Instead, a novel multi-layered weighted scoring combined with geospatial analysis was employed.

GWR coefficient point layers were converted to raster using Inverse Distance Weighting (IDW) interpolation and reclassified into quantiles. These raster layers were then converted to vector layers with the 'Polygonize (Raster to Vector)' tool. Each quantile was assigned a class score from 1 to 5, with scores inverted for PBE. A significance multiplier of 2 was applied to factors with statistically significant ($p<0.05$) MCT results, due to higher confidence interval in the non-stationarity of that factor, while non-significant results were multiplied by 1. The Factor Score (FS) was calculated as:

$$FS = Class\ Score\ \times Significance\ Multiplier$$

Vector layers for distance factors were combined using the intersection tool, and their factor scores were summed to generate a final variable score for each habitat suitability parameter. The resulting vector layers were merged, with FPC and PBE scores given double the weight of SR scores to prioritize food and shelter availability over floral diversity for reintroduction site selection. The weighted scores of all variables were summed to produce a Resulting Score (RS):

$$RS = 2(FS_{FPC}) + 2(FS_{PBE}) + FS_{SR}$$

The final vector layer was categorized into quantiles based on the Resulting Score in QGIS, and the dissolve tool was used to merge overlapping or intersecting polygons with the same class.

5 Results

No direct sightings or signs of *T. kleinmanni*, such as tracks, scat, or uric acid solids, were observed during the study period.

A total of 24 vascular plants were recorded across the surveyed quadrats (Table 4-1, Annex III: Data Summary). The most prevalent species were *Anabasis articulata* and *Artemisia monosperma*, each present in over 30 quadrats. Other commonly observed species included *Echiochilon fruticosum, Panicum turgidum,* and *Zygophyllum album*, found in more than 20 quadrats. In contrast, species like *Daucus aureua* and *Moltkopsis ciliata* were less frequently encountered, appearing in only a few quadrats (Figure 5-1).

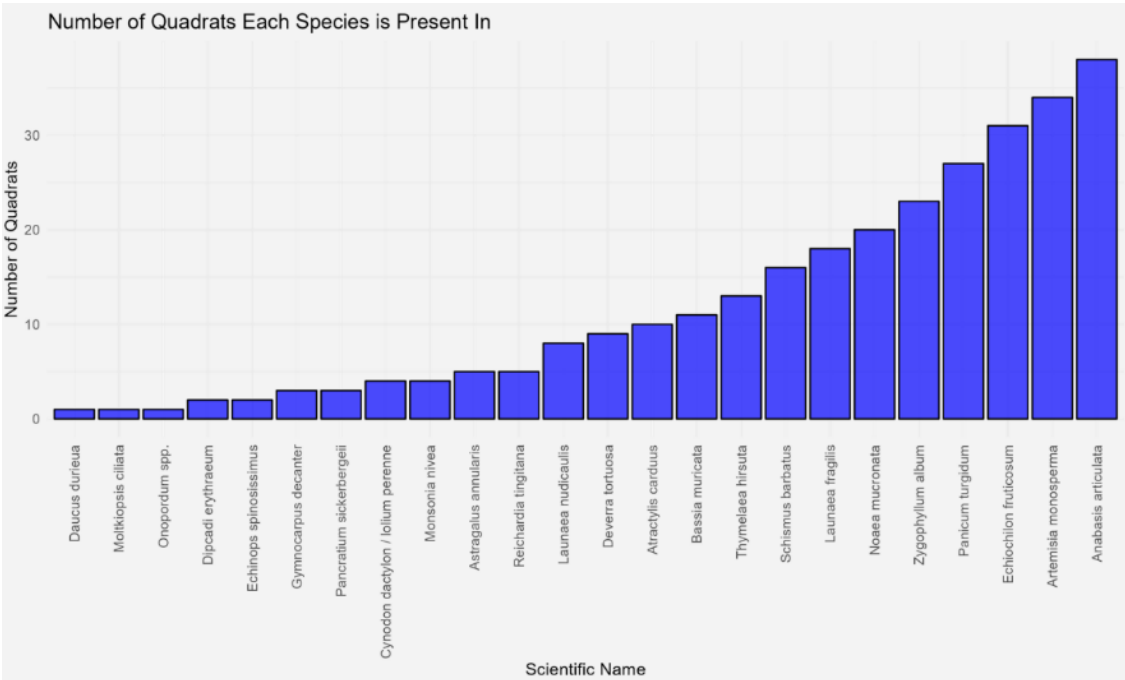

Figure 5-1: Histogram Showing Floral Species Presence Frequency within Quadrats

ANOVA tests showed no significant differences in Species Richness based on Aspect (*F(4,43)=1.58, p>0.05*), in Food Plant Cover (sqrt) and Shelter Plant Cover (sqrt) based on Soil Texture (*F(3,44)=2.79, p>0.05* and *F(3,4)=2.42, p>0.05*, respectively), or in Proportion Bare Earth (sqrt) based on Soil Depth (*F(2, 45) = 2.84, p>0.05*), suggesting that these factors do not significantly impact habitat suitability in the study area.

An independent t-test showed that both Species Richness (SR) and Food Plant Cover (FPC) were significantly higher in undisturbed habitats ($\bar{x}_{SR} = 6.86 \pm 0.32, \bar{x}_{FPC} = 18.0 \pm 1.82$) compared to disturbed ones ($\bar{x}_{SR} = 3.5 \pm 0.88, \bar{x}_{FPC} = 5.07 \pm 2.62$) with *t=-4.52* and *t=-4.99*, respectively and *df=46, p<0.05*. FPC was also significantly higher in uncompacted soils ($\bar{x}_{FPC} = 19.06 \pm 1.85$) versus compacted soils ($\bar{x}_{FPC} = 3.22 \pm 0.91$) with *t=6.23, df=46, p<0.05* (Figure 5-2). A Mann-Whitney U-test revealed that the Proportion Bare Earth (PBE) was significantly lower in undisturbed habitats ($\bar{x}_{PBE(Undisturbed)} = 82.05 \pm 1.81$ versus $\bar{x}_{PBE(Distrubed)} = 94.87 \pm 2.60$) and on uncompacted soils ($\bar{x}_{PBE(Uncompacted)} = 80.99 \pm 1.84$ versus $\bar{x}_{PBE(Compacted)} = 96.72 \pm 0.93$) with *u=383.5* and *u=433*, respectively; *p<0.05*, indicating better habitat suitability conditions in these areas (Figure 5-3).

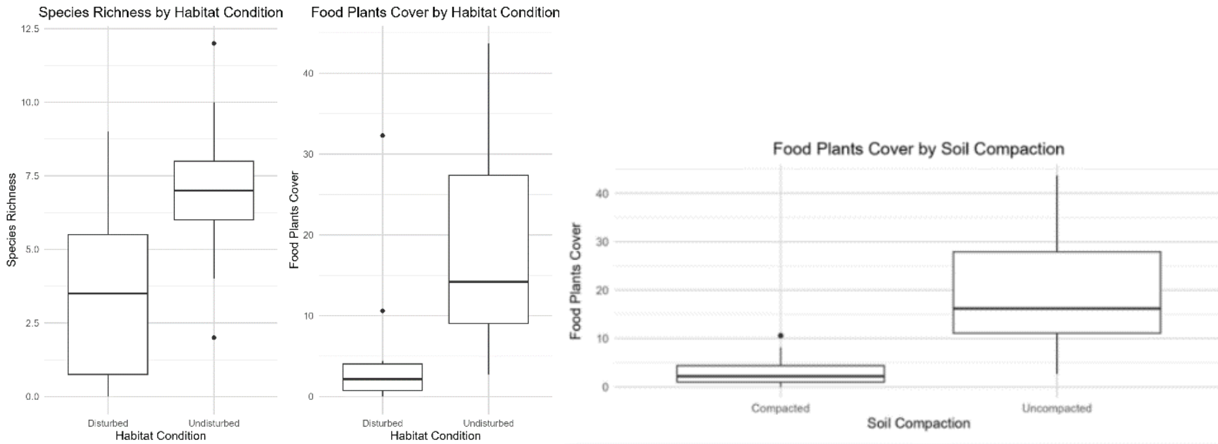

Figure 5-2: Boxplots of (a) Species Richness and (b) Food Plants Cover by Habitat Condition (c) Food Plants Cover by Soil Compaction (Untransformed Data)

Figure 5-3: Boxplots of Proportion Bare Earth (PBE) across (a) Habitat Condition, and (b) Soil Compaction (Untransformed Data)

Moran's I test for spatial autocorrelation showed no significant spatial autocorrelation for Species Richness (SR), Food Plant Cover (FPC), or Proportion Bare Earth (PBE) (*$I=-0.021$, $p>0.05$* for all variables), ensuring model validity [22]. Three Geographically Weighted Regression (GWR) models were conducted (bisquare kernel, fixed bandwidth=0.07) to assess localized spatial variation in habitat suitability parameters. These models evaluated the impact of distance to the main road and quarries on FPC, SR, and PBE, revealing significant spatial heterogeneity (Table 5-1,

Table 5-2).

Table 5-1: Global Regression Model Outcomes

Variable	Estimate *(Intercept)*	Std. Error *(Intercept)*	Estimate *(Distance to Main Rd)*	Std. Error *(Distance to Main Rd)*	Estimate *(Distance to Quarry)*	Std. Error *(Distance to Quarry)*	Adjusted R^2	AICc	MCT P-Value *(Distance to Main Rd)*	MCT P-Value *(Distance to Quarry)*
Food Plant Cover	4.20	1.18	-0.023	0.021	0.041	0.018	0.0659	184.63	0.267	**0.027****
Species Richness	3.27	1.73	0.015	0.030	0.083	0.026	0.2583	221.40	0.623	**0.003*****
Proportion Bare Earth	8.65	0.49	0.013	0.009	-0.012	0.007	0.0248	100.04	0.133	0.109
** p<0.1, ** p<0.05, *** p<0.01*										

Table 5-2: GWR Model Outcomes

Variable	Min *(Intercept)*	Max *(Intercept)*	Min *(Distance to Main Rd)*	Max *(Distance to Main Rd)*	Min *(Distance to Quarry)*	Max *(Distance to Quarry)*	Adjusted R^2	AICc	P-Value *(Distance to Main Rd)*	P-Value *(Distance to Quarry)*
Food Plant Cover	2.95	7.51	-0.110	-0.006	0.006	0.124	0.2723	174.23	**0.032****	**0.002*****
Species Richness	1.70	7.10	-0.075	0.037	0.017	0.185	0.3169	219.03	0.255	**0.006*****
Proportion Bare Earth	6.75	9.04	0.006	0.058	-0.051	0.001	0.2070	91.69	**0.008*****	**0.002*****
**** p<0.1, ** p<0.05, *** p<0.01***										

Table 5-1 presents the global regression outcomes. For FPC and SR, distance to the quarry showed a significant effect (*$p<0.05$*), but distance to the main road did not (*$p>0.05$*). For PBE, neither predictor was significant (*$p>0.05$*). These results suggest varying influences of factors but do not account for local spatial variability.

The GWR models provided a better fit than the global models by accounting for spatial variability (Figure 5-4). The FPC model showed an increase in adjusted R^2 from 0.0659 to 0.2723 and a reduction in AICc from 184.63 to 174.23, indicating improved model performance and predictive power. The Monte Carlo Test revealed significant spatial variability for distance to the quarry (*$p<0.05$*) and distance to the main road (*$p<0.05$*) (

Table 5-2).

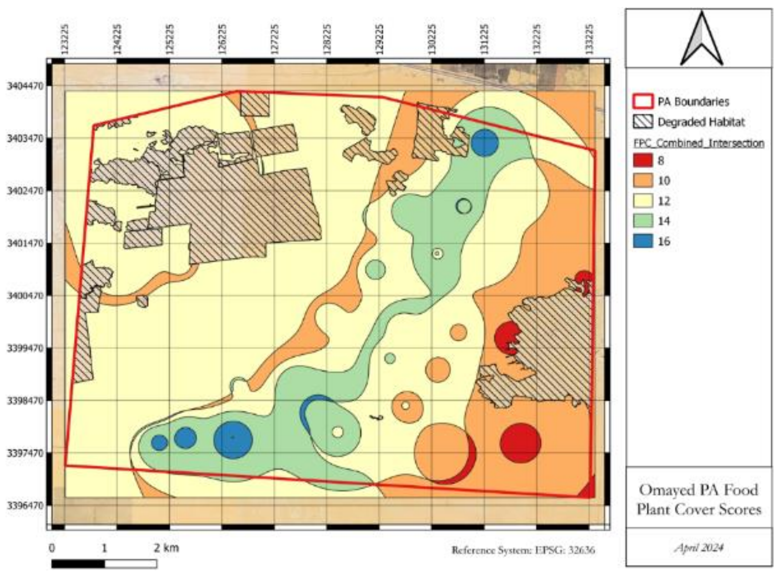

Figure 5-4: Map of Food Plant Coverage (FPC) Combined Factor Scores Distribution of across PA showing the highest FPC in the central and southern sections of the PA between the two large quarry areas.

For PBE, the GWR model's adjusted R^2 increased from 0.0248 to 0.2070, with an AICc improvement from 100.04 to 91.69. Both distance to the main road and quarry showed significant spatial variability (*$p<0.05$*). For SR, the adjusted R^2 increased from 0.2583 to 0.3169, and the AICc decreased from 221.40 to 219.03, further demonstrating the importance of spatial variability (Figure 5-5). The Monte Carlo Test indicated significant spatial variability for distance to the quarry (*$p<0.05$*).

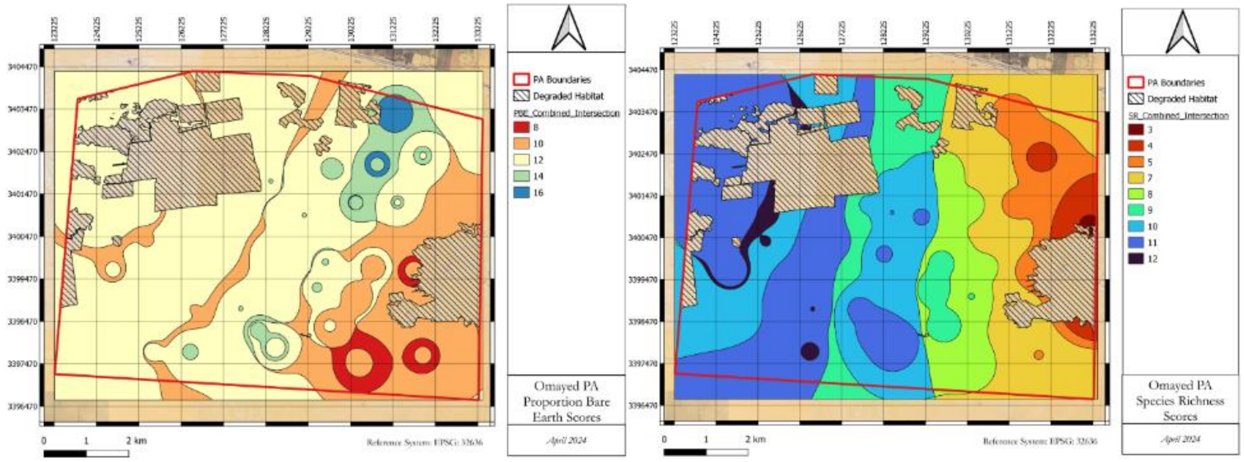

Figure 5-5: Map Showing: (a) Distribution of Proportion Bare Earth (PBE) Combined Factor Scores, and (b) Distribution of Species Richness (SR) Combined Factor Scores across PA

Overall, the GWR models provided a better fit and offered geospatial-specific insights compared to global models. The analysis identified 6.11 km² of the PA with the highest habitat suitability scores (44-52) and an additional 11.67 km² with medium-high scores (40-44). Two potential release sites for *T. kleinmanni* were located in the south-central and south-western sections of the PA, near the southern border at centroids 30°39'11.028"N, 29°6'3.398"E, and 30°39'26.141"N, 29°7'10.178"E (Figure 5-6).

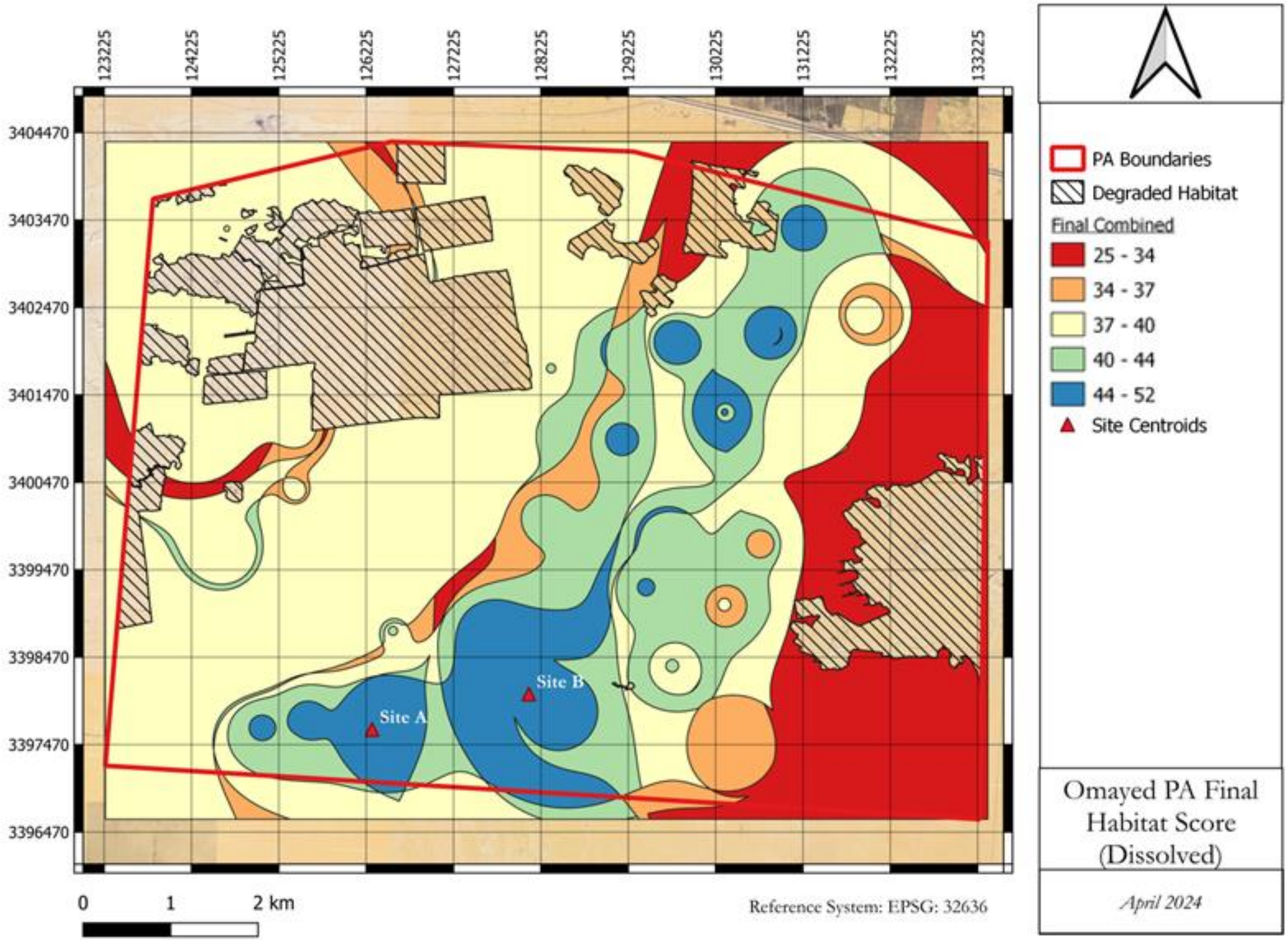

Figure 5-6: Map Showing Distribution of Resultant Class Scores across PA with Diffused Polygons

6 Discussion

The lack of direct sightings or indirect signs (tracks, scat, uric acid solids) during the 15-day fieldwork at the peak of *T. kleinmanni*'s activity and mating season suggests that the species is currently absent from the Omayed Protected Area, highlighting the urgent need for conservation efforts and habitat restoration.

As expected, habitat suitability parameters—Species Richness (SR), Food Plant Cover (FPC), and inverse Proportion Bare Earth (PBE)—were significantly lower in areas impacted by quarrying activities. This confirms that quarrying severely degrades potentially suitable habitats by removing topsoil, destroying native vegetation, and altering substrates. Studies have shown that such disturbances result in poor soil structure and slow vegetation recovery, even after decades [8, 33]. Furthermore, quarry restoration often fails to fully restore native biodiversity, as dense grass stands from commercial seed mixtures can impede the growth of native species [16]. These findings clearly indicate that ongoing and expanding quarry activities will continue to destroy viable habitat for *T. kleinmanni*, and even with habitat restoration efforts, the recovery of these areas may take a very long time, jeopardizing the potential for successful reintroduction.

The Geographically Weighted Regression (GWR) models revealed significant localized variations in habitat quality parameters within the study area, supporting the validity of the geospatial mapping and the selection of potential release sites. The results demonstrate that Species Richness (SR), Food Plant Cover (FPC), and Proportion Bare Earth (PBE) are heavily influenced by proximity to quarries. This localized analysis identified two optimal reintroduction sites for T. *kleinmanni*, each providing a sizable area of suitable habitat (1.32 km^2 and 2.67km^2 for Site A and Site B, respectively). These sites are close to each other and connected by a 'medium-high' habitat zone, forming a moderately sized continuous area ideal for reintroduction efforts (Figure 6-1, Annex IV: Field Photographs).

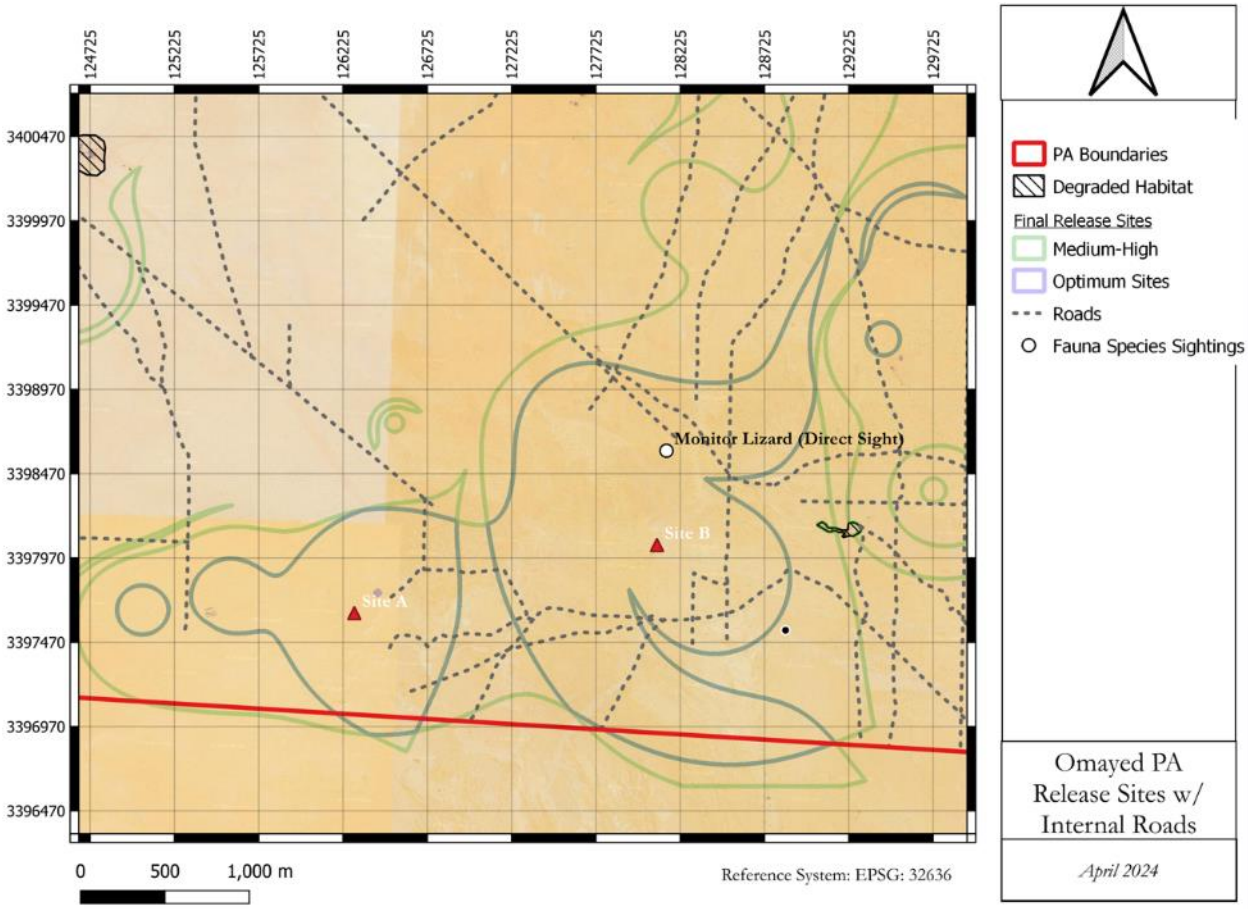

Figure 6-1: Map showing Optimum and Medium-High Habitat Areas and Internal Roads

Site B has been selected as the optimal site due to several key factors. Site B is larger in size, providing more space for the tortoises to establish territories, and is more favorably positioned relative to the boundaries of the Protected Area (Figure 6-1). Mean Food Plant Cover (FPC) at Site B is 13.63%, and Species Richness (SR) is 9.71, both higher than those at Site A with FPC=8.9% and an SR=7. Similarly, mean Proportion Bare Earth (PBE) is lower at Site B than Site A with PBE=86.67% and 89.5% respectively indicating higher shelter and shade availability at Site B.

Both sites are dominated by *Anabasis articulata*, a diet plant for tortoises. However, Site B has more *Zygophyllum album* compared to Site A, and *Thymelaea hirusta*, a food plant for the tortoises, which was not observed in Site A quadrats. Additionally, Site B has less *Panicum turgidum*, which is preferred by grazers [17] but not eaten by tortoises, potentially reducing competition for resources. Site B also features significantly more *Artemisia monosperma*, which provides both food and shelter (Figure 6-2). The larger size of the vegetation at Site B, likely due to reduced grazing, offers additional shade for the tortoises (Figure 6-4). These factors suggest that Site B provides a superior habitat with greater food availability and better shelter conditions.

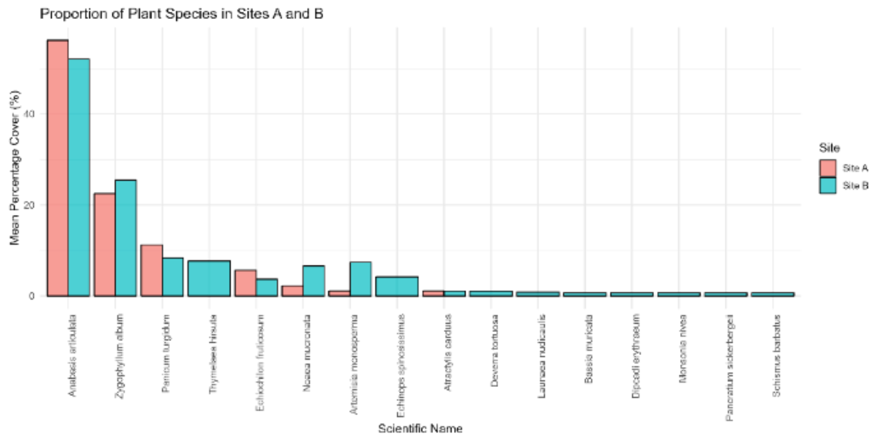

Figure 6-2: Histogram of Relative Proportion of Plant Species Cover in Site A and Site B

Figure 6-3: Field Photographs of Habitat at Transect-11 in Release Site A

Figure 6-4: Field Photograph of Habitat at Release Site B

The identified release sites are strategically advantageous due to their distance from the main road and areas of high human activity, reducing the risk of disturbance and habitat degradation. They are also located near the UAE Houbara Conservation Area, which appears to be actively managed based on sightings of several ringed houbara birds and numerous tracks throughout the Protected Area (Figure 6-5). Additionally, the prompt arrival of security patrols from the UAE conservation plot whenever the field team approached the eastern or southern borders of the Omayed PA suggests that this neighboring area is well-protected. Proximity to this well-managed conservation area could provide further benefits for the reintroduction program by minimizing human interference and supporting habitat stability, thereby enhancing the long-term success of *T. kleinmanni* reintroduction efforts.

Figure 6-5: Field Photograph of Ringed Houbara within Omayed PA

Fauna transect observations further corroborate the GWR findings, providing additional evidence of the habitat's suitability within the PA. The abundance of rodent burrows, likely belonging to jerboas (Figure 6-6), and a high presence of *Acanthodactylus scutellatus* (Figure 6-7) throughout the PA suggest that potential refuge sites are available across the study area except within the quarry zones which are barren and desolate (Figure 6-8).

Figure 6-6: Field Photographs of Burrows

Figure 6-7: Field Photographs of Acanthodactylus scutellatus

Figure 6-8: Field Photographs of Quarry Areas

A field encounter with a desert monitor (*Varanus griseus*) at Release Site B (Figure 6-9) highlights a potential predation risk for the reintroduced tortoises. Desert monitors are known to have a broad diet, including small vertebrates and reptiles like tortoises [31], and can roam over significant home ranges, from 0.075 to 2.11 km² depending on sex and environmental conditions [18, 32]. This suggests that monitors at Site B could pose a threat to both juvenile and adult tortoises. Additionally, birds of prey, observed during the spring migration season (Figure 6-10), could also contribute to predation pressure.

Figure 6-9: Monitor Lizard Sighting within the Omayed PA during Fieldwork Visit

Figure 6-10: Montague's Harrier Sightings within Omayed PA

However, the abundant presence of other prey species, such as jerboas, *Acanthodactylus spp.*, and several bird species throughout the PA (Annex IV: Field Photographs), may help mitigate this risk. Studies have shown that desert monitors adapt their diet based on prey availability, often preferring arthropods and small vertebrates when these are abundant [19]. In areas like the Southern Coastal Plain of Palestine (Israel), *Acanthodactylus* species are frequently preyed upon by desert monitors, suggesting that their presence could divert predation away from tortoises [31]. Given the high abundance of these prey species in the PA, the likelihood of monitors targeting the tortoises may be reduced, at least initially.

To further manage these risks, establishing a soft-release enclosure at Site B would provide initial protection for *T. kleinmanni*, allowing them to acclimatize while monitoring *V. griseus*'s prey preferences. This strategy could help minimize immediate predation threats and support the successful establishment of the tortoises in their new habitat.

Grazing livestock, as observed directly (Figure 6-11) and via tracks and signs (Annex IV: Field Photographs) in various transects, indicate significant grazing pressure, which could further degrade shelter availability by inhibiting larger vegetation from growth and resulting in reduced shade as well as added interspecies food competition. However, some studies suggest that in arid desert environments, livestock preferentially graze on *P. turgidum* [17] which is not a preferred food source for tortoises [30] yet, effective grazing management is critical in and around the release site.

Figure 6-11: Field Photographs of Grazing Camel Family

Soft-release reintroduction programs, which allow animals to gradually acclimate to a new environment before full release, have yielded mixed results in conservation efforts. While more resource-intensive than hard-release strategies, soft-release can be beneficial under certain conditions. Studies on gopher tortoises and Texas horned lizards have shown that soft-release can reduce initial dispersal and improve site fidelity, potentially increasing survival rates in environments where predation and habitat suitability are critical concerns [29, 25]. Conversely, research on desert bighorn sheep and eastern barred bandicoots indicates that soft-release does not always improve survival rates and may lead to higher mortality due to stress and poor acclimatization [10, 12]. These findings highlight the importance of tailoring soft-release strategies to the specific behaviors and environmental needs of the species.

For *T. kleinmanni*, a soft-release strategy is particularly relevant given the species' behavioral responses to reintroduction and the challenges of its arid habitat. Previous observations in the Omayed PA show that hard-released *T. kleinmanni* exhibited significant initial dispersal, with distances of up to 1,455 meters, likely reflecting attempts to acclimate to new surroundings [1]. Such behavior can increase exposure to predators and environmental stressors, reducing reintroduction success and explaining why no tortoise signs were found in this study. However, the identified release site, Site B, accounts for these dispersal distances by ensuring a suitable habitat within 1,500 meters (Figure 6-12).

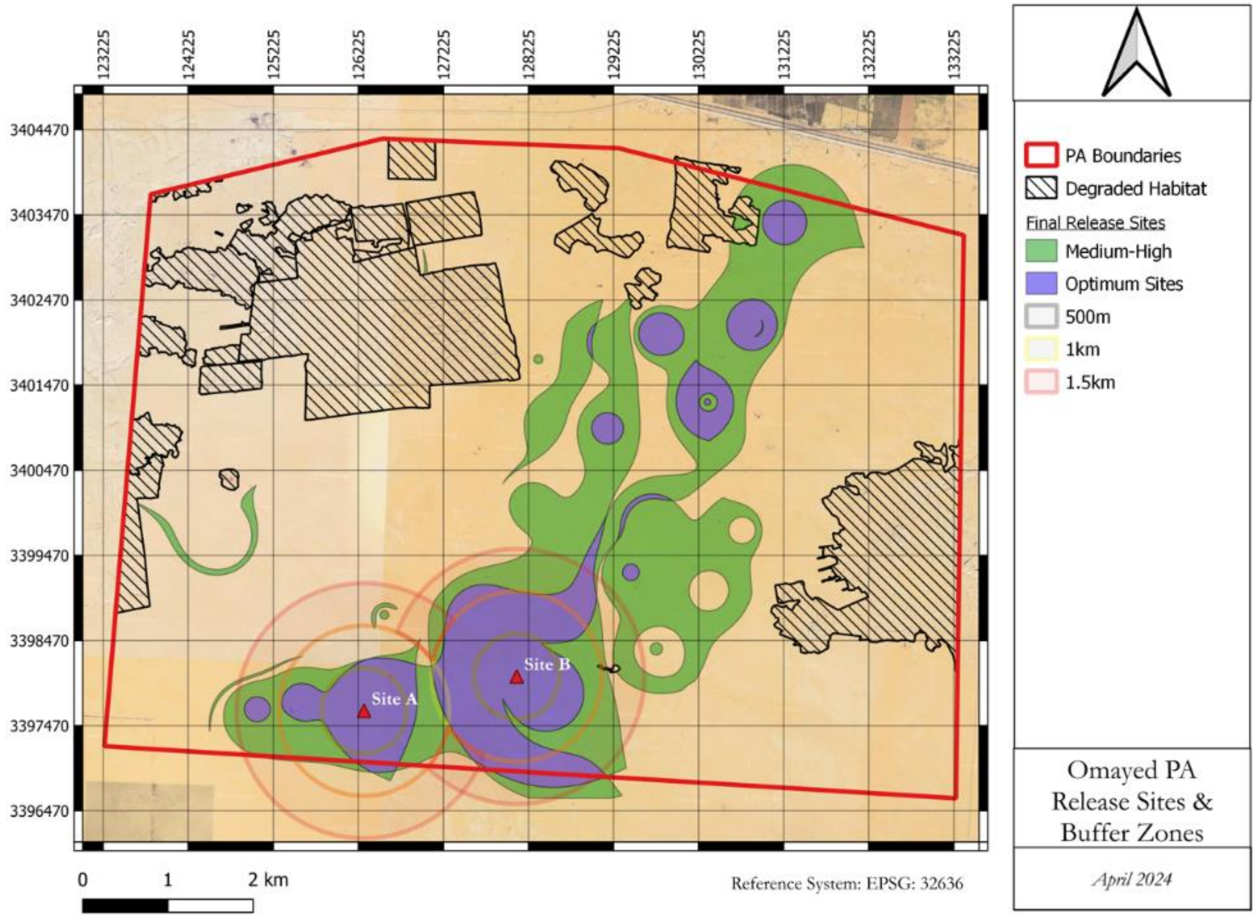

Figure 6-12: Map showing Release Site and Potential Dispersal Ranges

In contrast, a study on soft-released *T. kleinmanni* in Sinai found a 71% retention rate when released just before the aestivation season, with both resident and introduced groups displaying similar dispersal behaviors during the active season [4]. This suggests that soft-release, especially when timed before aestivation, can effectively reduce excessive dispersal and minimize exposure risks in a new environment. Similarly, initial penning of translocated gopher tortoises has been shown to significantly enhance site fidelity [35].

Therefore, employing a soft-release strategy with penning could enhance reintroduction success by minimizing dispersal and reducing risks associated with overheating and predation. A carefully designed, species-specific soft-release program that considers these factors could significantly improve the chances of successfully reintroducing *T. kleinmanni* into the wild.

7 Conclusion

This study utilized Geographically Weighted Regression (GWR) and field surveys to evaluate habitat suitability within the Omayed Protected Area (PA) for the potential reintroduction of *T. kleinmanni*. By focusing on three key habitat parameters—Species Richness (SR), Food Plant Cover (FPC), and Proportion Bare Earth (PBE)—significant spatial variations were identified, with Site B emerging as the optimal reintroduction location due to its larger size and quality habitat within the tortoises' dispersal range.

For the success of the reintroduction program, a soft-release enclosure at Site B is recommended to minimize predation risks and allow tortoises to acclimate. Regular monitoring should be conducted to observe tortoise behavior, food selection, and refuge use. To further protect the tortoises, closing internal roads at Sites A and B will help reduce human disturbances and direct mortality risks. Implementing a community-involved initiative to manage grazing intensity will aid in vegetation recovery around the release site. Additionally, the release should occur in late-spring, with final release timed just before the summer aestivation period to reduce dispersal distances and improve retention rates.

To support these conservation efforts, it is crucial that authorities prohibit new quarry permits within the PA and rehabilitate decommissioned quarries. This will enhance habitat quality through natural vegetation regeneration, contributing to the long-term survival of *T. kleinmanni*.

7.1 Limitations & Future Research

This study faced several limitations that influence the interpretation of its findings. Conducting the floral assessment outside the prime season may have resulted in an incomplete representation of the floral community, particularly missing ephemeral and annual species that emerge after winter rains. Additionally, the manual perspective transformation of quadrat photographs to achieve a top-down view may have introduced inaccuracies in percent cover estimates, potentially affecting the accuracy of the floral data analysis. The observed abundance of avian predators during fieldwork might have been overestimated due to overlapping with the spring migration season, when transient bird populations are temporarily elevated.

To address these limitations and enhance future studies, several recommendations are proposed. Conducting floral studies across seasons would provide a more comprehensive understanding of the floral communities, especially the presence of ephemeral and annual species. Capturing photographs from a consistent bird's-eye view could improve the accuracy of vegetation cover assessments and reduce distortions. Given the near-total bareness of the quarry areas, a systematic sampling technique rather than a stratified random sampling technique could provide more spatially balanced data, which would be invaluable for enhancing habitat suitability models.

Furthermore, incorporating GWR coefficients into well-established ecological modeling techniques such as MaxEnt or Bioclim could provide more detailed habitat suitability assessments. Taking precise measurements of variables like soil texture, soil depth, and canopy cover, instead of relying on visual observations, could directly feed into the model, potentially enhancing its predictive power. These enhancements would better represent the ecological dynamics within the study area, supporting more effective conservation strategies for the Egyptian Tortoise.

8 Annexes

8.1 Annex I: References

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8.2 Annex II: Datasheets

Omayed Vegetation Survey

Page: 1 *of*

Quadrat Data Collection

Section I - General Information

Surveyor Name	Karim ElBakary			**Date** *(dd/mm/yy)*:	
Grid Cell Code:		**Quadrat Code:**		**Grid Coordinates:**	
Start Time:		**Landscape:**		**Dry Bulb Temp** *(°C)*:	
Altitude *(masl)*:		**Wet Bulb Temp** *(°C)*:		**RH** *(%)*:	
Soil Composition:		**Soil Compaction:**		**Soil Depth:**	
Aspect *(bearing)*:		**Wind**			
		Direction *(bearing)*		**Speed** *(m/s)*	
Cloud Cover:		**Precipitation**		**Visibility Score:**	

Other Weather Condition Notes:

End Time:

#	Common Name	Species / Family	# of Individuals	BB Class	Phenology Score
1					
2					

3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					

Section I - General Information

Surveyor Name		Date *(dd/mm)*		Start Time:	
Plot Code:		Transcect Code:		Grid Coordinates:	
		End Time:			
Altitude (masl):		Ambient Temp *(°C)*:		RH *(%)*	

Wind			
Direction *(bearing)*		Speed *(m/s)*	

Cloud Cover:		Precipitation		Visibility Score:	
				Other Weather Condition Notes:	
Habitat Description:				Soil Description:	

Section II - Transect Data Collection

Find #	Time (24hrs)	Direct / Indirect	Bearing	X-Distance *(m)*	Species	No.	Capture *(Y / N)*	Capture Code	Description
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									

Precipitation		
Score	**Description**	
1	*None*	No precipitation.
2	*Light*	Light rain. Does not significantly affect visibility or activities.
3	*Moderate*	Moderate rain. May start to affect visibility and activities slightly.
4	*Heavy*	Heavy rain. Significantly affects visibility and activities
5	*Violent*	Very heavy rain. Severe impact on visibility and activities

Cloud Cover		
Score	**Description**	
1	*0%*	No clouds present in the sky
2	*1 - 25%*	Very few clouds in the sky, mostly clear.
3	*26 - 50%*	Clouds covering about a quarter to half of the sky.
4	*51 - 75%*	More clouds than clear sky, covering more than half but not all of the sky.
5	*76 - 100%*	Very few to no clear spots, nearly or completely covered in clouds.

Visibility		
Score	**Description**	
1	*Very Poor*	Less than 0.5 km visibility, difficult to see immediate surroundings clearly.
2	*Poor*	0.5 - 2 km visibility, can see immediate surroundings with difficulty in identifying distant objects.
3	*Moderate*	2 - 5 km visibility, can see nearby objects clearly; distant objects might not be very clear.
4	*Good*	5 - 10 km visibility, can see most objects clearly at a distance.
5	*Excellent*	More than 10 km visibility, very clear visibility of distant objects.

8.3 Annex III: Data Summary

Table 8-1: Quadrat Data Summary

Quadrat ID	Habitat Condition	Latitude	Longitude	Altitude (masl)	Aspect	Wet Bulb Temp (C)	RH	Wind Direction	Wind Speed (m s-1)	Soil Texture	Soil Compaction	Soil Depth	Distance to Quarry (m)	Distance to Main Rd (m)	Species Richness	Dominant Species	Total Vegetation Cover (%)	Proportion Bare Earth (%)	Food Plants Cover (%)	PBE / Sqrt	FPC / Sqrt
Q-001	Undisturbed	30.663294	29.103008	98	Flat	19	46	N	5.6	Rock	Uncompacted	Shallow	2283.4	6394.56	8	*Anabasis articulata*	17	83.07	17	9.14166	4.1833
Q-002	Disturbed	30.689808	29.1155	80	Flat	16.82	55.9	E	4.2	Rock	Compacted	Shallow	0	3465.11	7	*Zygophyllum album*	4.2	96	3.9	9.82344	2.09762
Q-004	Undisturbed	30.668699	29.13303	110	Flat	17.04	52	N	2.7	Sand	Uncompacted	Deep	1105.5	5489.7	8	*Anabasis articulata*	7.4	92.6	7.4	9.64883	2.81069
Q-007	Undisturbed	30.663638	29.114463	106	S	17.34	51	N	3.5	Sand-Rock	Uncompacted	Moderate	1532.2	6371.18	12	*Anabasis articulata*	15.2	85	15.2	9.24662	3.96232
Q-009	Undisturbed	30.697383	29.157962	83	S	19.39	46.66	N	2.8	Sand	Uncompacted	Deep	1273.6	1908.97	7	*Artemisia monosperma*	29.9	70.1	29.6	8.40238	5.48635
Q-012	Undisturbed	30.660689	29.136478	100	Flat	17.33	50	N	3.1	Sand	Uncompacted	Moderate	488.6	6299.77	2	*Anabasis articulata*	32	68	32	8.27647	5.70088
Q-013	Undisturbed	30.683655	29.090717	88	S	17.24	56.6	N	5.5	Sand	Uncompacted	Deep	171.5	4118.25	5	*Anabasis articulata*	11.4	89	11.2	9.46044	3.42053
Q-014	Undisturbed	30.677353	29.090971	79	Flat	17.6	52	N	4.7	Sand	Compacted	Moderate	615.8	4818.09	5	*Anabasis articulata*	5.1	95	5.1	9.77241	2.36643
Q-017	Undisturbed	30.683911	29.129294	88	Flat	17.71	59.94	N	4.9	Sand-Rock	Uncompacted	Moderate	1159.4	3899.92	8	*Thymelaea hirsuta*	29.1	71	29.1	8.45577	5.44059
Q-018	Undisturbed	30.683347	29.171034	85	Flat	18.22	49.61	N	4.2	Rock	Uncompacted	Shallow	4.3	3198.36	9	*Anabasis articulata*	25.4	75	25.3	8.68907	5.07937
Q-029	Undisturbed	30.692914	29.128934	79	Flat	16.89	60.23	N	4.3	Sand	Uncompacted	Deep	526.5	2925.26	6	*Artemisia monosperma*	12.2	88	12.2	9.40744	3.56371
Q-035	Undisturbed	30.6708	29.082894	77	Flat	17.65	48.04	N	4.1	Sand	Compacted	Moderate	577.7	5535.7	5	*Anabasis articulata*	8.2	92	8.2	9.61769	2.94958
Q-036	Undisturbed	30.655784	29.123119	123	Flat	18.28	49	N	3.2	Sand-Rock	Uncompacted	Shallow	675.2	7077.94	8	*Anabasis articulata*	11.9	88	11.9	9.40744	3.52136
Q-037	Undisturbed	30.674163	29.134898	103	Flat	16.95	60	N	1.2	Sand	Uncompacted	Moderate	1675	4860.17	6	*Artemisia monosperma*	9.3	91	9.1	9.56556	3.09839
Q-042	Undisturbed	30.706169	29.150311	87	Flat	18.02	56.74	N	4.5	Rock	Uncompacted	Shallow	297.5	1090.93	8	*Anabasis articulata*	13.3	87	13.2	9.35414	3.70135
Q-044	Undisturbed	30.690887	29.120747	78	N	17.21	58.6	N	3.2	Sand	Uncompacted	Deep	227.5	3295.38	6	*Anabasis articulata*	36.6	64	36.6	8.03119	6.09098
Q-049	Undisturbed	30.668539	29.097583	88	W	17.89	49.6	N	4.2	Sand	Uncompacted	Deep	1517.1	5805.12	8	*Anabasis articulata*	4.2	96	3.9	9.82344	2.09762
Q-051	Disturbed	30.687905	29.082202	90	W	16.65	54	S	3.6	Sand	Compacted	Shallow	0	3636.18	4	*Artemisia monosperma*	2.6	97	2.1	9.87421	1.61245
Q-053	Undisturbed	30.695242	29.146573	83	Flat	17.05	65.5	N	5.2	Sand	Uncompacted	Deep	935.9	2349.99	4	*Anabasis articulata*	28.2	72	28.2	8.51469	5.35724
Q-055	Undisturbed	30.684593	29.121967	85	Flat	18.45	52.8	N	5.2	Sand	Uncompacted	Deep	565.5	3959.06	6	*Anabasis articulata*	23.2	77	23	8.80341	4.84768
Q-072	Disturbed	30.665309	29.170703	111	S	19.2	37.8	N	2.8	Rock	Compacted	Shallow	0	5168.37	4	*Zygophyllum album*	3.3	97	3.3	9.87421	1.94936
Q-074	Disturbed	30.701535	29.085823	88	N	18.22	46.85	N	4.2	Rock	Compacted	Shallow	0	2127.64	0	*NA*	0	100	0	10.025	0.70711
Q-075	Disturbed	30.700048	29.096314	94	N	18.48	46.02	N	4.4	Rock	Compacted	Shallow	0	2305.86	2	*Anabasis articulata*	1.1	99	1	9.97497	1.22474
Q-076	Disturbed	30.694553	29.093406	84	S	17.98	49.74	N	5.5	Rock	Compacted	Shallow	0	2912	1	*Atractylis carduus*	1	99	1	9.97497	1.22474
Q-077	Disturbed	30.679715	29.170134	119	Flat	18.32	41.65	N	5.8	Rock	Uncompacted	Shallow	0	3610.65	9	*Anabasis articulata*	32.4	68	32.3	8.27647	5.72713

Quadrat ID	Habitat Condition	Latitude	Longitude	Altitude (masl)	Aspect	Wet Bulb Temp (C)	RH	Wind Direction	Wind Speed (m s-1)	Soil Texture	Soil Compaction	Soil Depth	Distance to Quarry (m)	Distance to Main Rd (m)	Species Richness	Dominant Species	Total Vegetation Cover (%)	Proportion Bare Earth (%)	Food Plants Cover (%)	PBE / Sqrt	FPC / Sqrt
Q-079	Disturbed	30.676113	29.170278	121	W	18.65	36.94	N	4.7	Rock	Compacted	Shallow	0	3999.82	3	*Zygophyllum album*	2.2	98.4	2.2	9.94485	1.64317
Q-080	Disturbed	30.670742	29.171532	119	E	19.32	33.5	S	4.9	Rock	Compacted	Shallow	0	4561.17	5	*Zygophyllum album*	10.6	89	10.6	9.46044	3.33167
Q-082	Disturbed	30.699367	29.103643	95	S	19.32	48.71	N	4.8	Rock	Compacted	Shallow	0	2391.28	0	*NA*	0	100	0	10.025	0.70711
Q-083	Disturbed	30.695704	29.101704	92	E	17.75	53.52	W	4.4	Rock-Sand	Compacted	Deep	0	2795.35	0	*NA*	0	100	0	10.025	0.70711
Q-085	Undisturbed	30.704109	29.081546	85	N	19.2	36.65	N	3.5	Sand	Uncompacted	Deep	121.4	1836.62	9	*Anabasis articulata*	43.9	56	43.7	7.51665	6.64831
Q-086	Disturbed	30.70278	29.097247	85	W	17.83	45.96	S	3.5	Rock	Compacted	Shallow	0	2003.87	7	*Artemisia monosperma*	4.5	95	4.4	9.77241	2.21359
Q-094	Undisturbed	30.655067	29.159639	101	Flat	18.6	25.6	E	2.4	Sand-Rock	Uncompacted	Moderate	711.3	6489.82	6	*Anabasis articulata*	17.2	83	17.2	9.13783	4.20714
Q-095	Undisturbed	30.673603	29.146391	109	E	19.61	33.1	E	3	Sand	Uncompacted	Deep	764.7	4711.53	8	*Anabasis articulata*	16.2	84	16.2	9.19239	4.08656
Q-098	Undisturbed	30.673012	29.156843	117	N	17.94	32.21	E	4	Sand	Uncompacted	Deep	81.8	4585.26	5	*Zygophyllum album*	34.2	65.7	34.2	8.13634	5.89067
Q-099	Undisturbed	30.687294	29.152104	97	N	17.85	32	E	4.8	Sand	Uncompacted	Deep	1086.4	3115.32	5	*Artemisia monosperma*	20	80	20	8.97218	4.52769
Q-102	Undisturbed	30.667177	29.142475	124	S	19.39	33.23	SE	1.8	Sand	Uncompacted	Deep	790.9	5483.28	5	*Anabasis articulata*	26.2	74	26.2	8.63134	5.1672
Q-106	Undisturbed	30.686984	29.141687	89	N	18.05	23.41	E	3.9	Sand	Uncompacted	Deep	1352.3	3339.05	6	*Thymelaea hirsuta*	11	89	11	9.46044	3.39116
Q-109	Undisturbed	30.694001	29.135149	71	W	19.34	22.95	E	2.2	Sand	Uncompacted	Deep	363.1	2693.56	6	*Thymelaea hirsuta*	37	63	37	7.96869	6.12372
Q-110	Undisturbed	30.652803	29.14409	112	Flat	16.8	44.08	SE	2.9	Sand	Uncompacted	Deep	1307.7	7020.35	10	*Thymelaea hirsuta*	27.8	72.5	27.7	8.544	5.31037
Q-111	Undisturbed	30.68245	29.079312	80	S	22.8	67.16	N	5.5	Sand	Uncompacted	Deep	185.1	4238.18	6	*Anabasis articulata*	7.7	92	7.6	9.61769	2.84605
Q-112	Undisturbed	30.652945	29.08775	106	Flat	26	63.1	N	6.5	Rock-Sand	Uncompacted	Shallow	1732.5	7523.58	7	*Anabasis articulata*	12.5	88	12	9.40744	3.53553
Q-113	Undisturbed	30.660097	29.085438	89	Flat	24	66.95	N	6	Sand	Uncompacted	Deep	1129.6	6726.93	7	*Echiochilon fruticosum*	6.8	93.4	6.7	9.6902	2.68328
Q-117	Undisturbed	30.659275	29.118812	121	W	26.4	56.04	N	4.8	Sand-Rock	Uncompacted	Shallow	1013	6775.96	8	*Anabasis articulata*	13	87	13	9.35414	3.67423
Q-119	Undisturbed	30.654185	29.102348	118	W	25.8	55.19	N	5.7	Sand	Uncompacted	Deep	2636.9	7404.76	10	*Anabasis articulata*	12.1	88	12.1	9.40744	3.54965
Q-120	Undisturbed	30.677873	29.108655	80	Flat	16.62	54.81	N	4.1	Sand	Uncompacted	Deep	835.8	4783.77	8	*Echiochilon fruticosum*	3.1	97.3	2.7	9.88939	1.78885
Q-122	Undisturbed	30.686238	29.115585	79	S	17.72	50.21	N	3.3	Rock-Sand	Uncompacted	Shallow	243.9	3861.27	7	*Anabasis articulata*	27.3	73	27.3	8.57321	5.27257
Q-126	Undisturbed	30.654	29.09292	109	Flat	25.1	65.21	N	4.7	Rock-Sand	Uncompacted	Shallow	2067.4	7412.72	7	*Anabasis articulata*	8.9	91	8.9	9.56556	3.06594
Q-131	Undisturbed	30.675675	29.120255	92	S	16.68	58.1	N	3.8	Sand	Uncompacted	Deep	1449.9	4962.24	6	*Anabasis articulata*	6.4	93	6.3	9.66954	2.60768

Quadrat ID	Anabasis articulata	Atractylis carduus	Bassia muricata	Echiochilon fruticosum	Gymnocarpus decanter	Panicum turgidum	Schismus barbatus	Zygophyllum album	Artemisia monosperma	Astragalus annularis	Launaea fragilis	Launaea nudicaulis	Reichardia tingitana	Moltkiopsis ciliata	Deverra tortuosa	Dipcadi erythraeum	Monsonia nivea	Noaea mucronata	Pancratium sickenbergeli	Thymelaea hirsuta	Cynodon dactylon / lolium perenne	Echinops spinosissimus	Onopordum spp.	Daucus durieua
Q-001	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Q-002	0	0	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
Q-004	1	0	1	1	0	1	1	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
Q-007	1	1	1	1	0	0	1	1	1	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0
Q-009	1	0	1	0	0	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Q-012	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Q-013	1	0	0	1	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
Q-014	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0
Q-017	1	0	0	1	0	1	0	1	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0
Q-018	1	0	1	0	0	1	0	1	1	0	1	0	0	0	1	0	0	1	0	1	0	0	0	0
Q-029	1	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
Q-035	1	0	0	1	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Q-036	1	1	0	0	0	1	0	1	1	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0
Q-037	1	0	0	0	0	1	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Q-042	1	1	0	1	0	0	0	0	1	0	1	1	0	0	0	0	0	1	0	1	0	0	0	0
Q-044	1	1	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Q-049	1	0	0	1	0	1	1	1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0
Q-051	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0
Q-053	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Q-055	1	0	0	1	0	1	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0
Q-072	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
Q-075	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Q-076	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Q-077	1	0	1	1	0	0	0	1	0	0	1	1	0	0	1	0	0	1	0	1	0	0	0	0
Q-079	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Q-080	1	0	1	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Q-085	1	0	0	1	0	1	1	0	1	0	1	0	0	0	0	0	1	1	0	0	0	0	1	0
Q-086	1	0	0	0	0	0	1	0	1	0	1	0	1	0	0	0	1	0	0	1	0	0	0	0
Q-094	1	0	1	1	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Q-095	1	1	0	1	0	1	0	0	1	0	0	0	0	0	1	0	0	1	0	1	0	0	0	0
Q-098	1	0	0	1	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
Q-099	1	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Q-102	1	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
Q-106	1	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
Q-109	1	0	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
Q-110	1	0	1	1	0	1	1	0	1	0	1	0	0	0	1	0	0	1	0	1	0	0	0	0
Q-111	1	0	0	1	0	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0
Q-112	1	0	0	1	0	1	0	1	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0
Q-113	0	0	0	1	1	1	0	1	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0
Q-117	1	1	0	1	0	0	0	1	1	0	0	1	0	0	1	0	0	0	0	1	0	0	0	0
Q-119	1	1	0	1	0	1	0	1	1	0	0	1	0	0	1	0	0	1	0	0	0	1	0	0
Q-120	0	0	0	1	1	1	1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1
Q-122	1	0	0	1	0	1	0	1	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
Q-126	1	1	0	1	0	1	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Q-131	1	0	0	1	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0

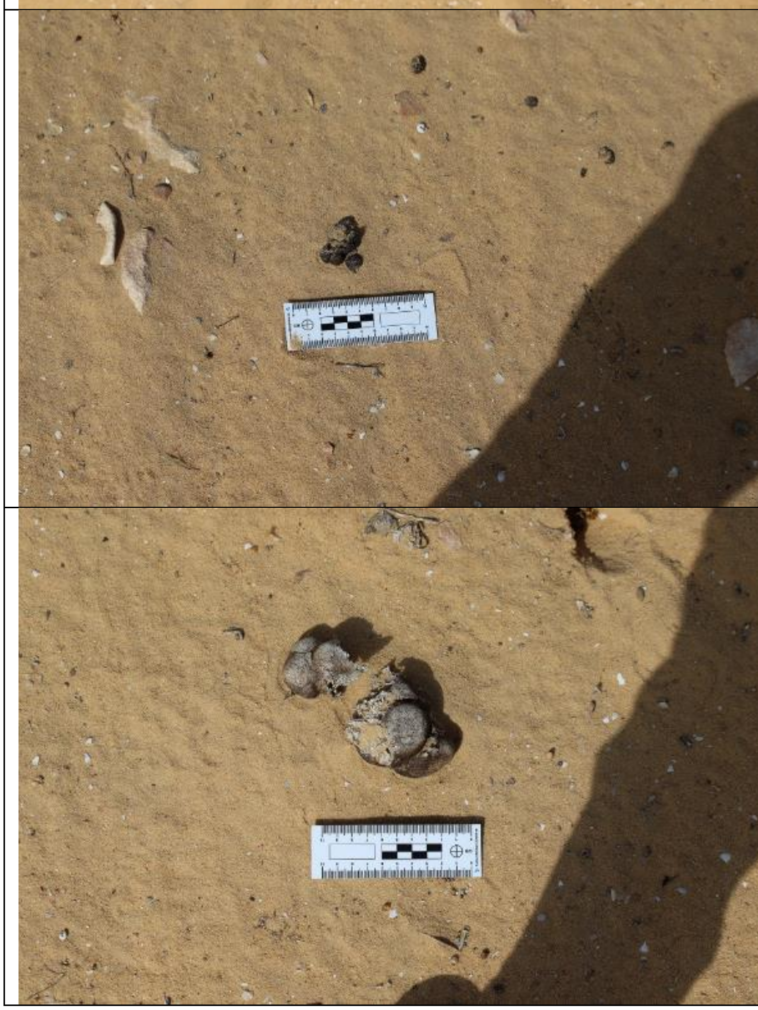
Figure 8-1: Plant-Quadrat Presence Matrix

8.4 Annex IV: Field Photographs

8.4.1 Field Photographs of Site A and Site B

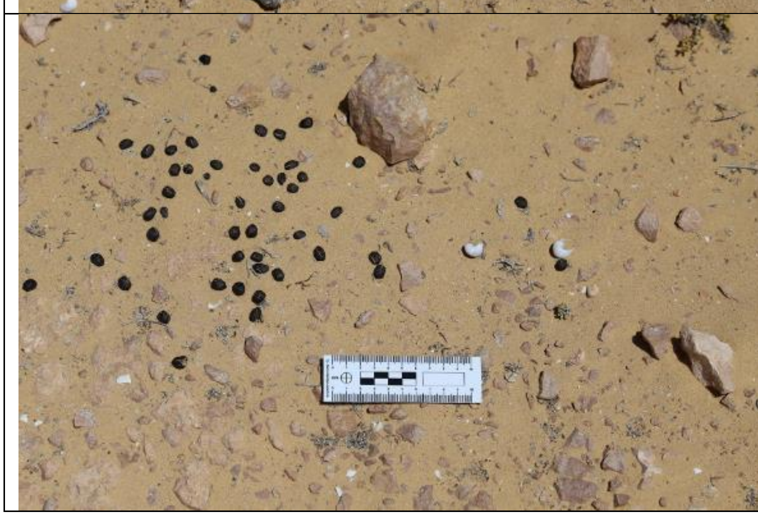
Photograph	Description
	Field Photograph of Quadrat 119 in Site A
	Field Photograph of Quadrat 126 in Site A
	Field Photograph of Transect 11 in Site A

	Field Photograph of Quadrat 007 in Site B
	Field Photograph of Quadrat 036 in Site B
	Field Photograph of Quadrat 117 in Site B

	Field photograph within Site B
	Field Photographs of Livestock Scat at T-10 within Site B

8.4.2 Field Photographs of Habitat in Close Proximity to Release Sites A and B

Photograph	Description
 	Field Photograph of Habitat at T-15 in the Medium-High Habitat Score Area in between Sites A and B
	Field Photograph of Habitat at T-26 in the Medium-High Habitat Area South-East of Site B



Field Photographs of Livestock Scat at T-26 in Medium-High Habitat South-East of Site B

8.4.3 Field Photographs of Fauna Across PA

Photograph	Description
	Photograph of unidentified Beetle
	Photograph of Ant Colony
	Photograph of Unidentified Fly

<table>
<tr><td></td><td rowspan="2">Field Photographs of Eremina desertorum, abundantly found throughout the PA</td></tr>
<tr><td></td></tr>
<tr><td></td><td></td></tr>
<tr><td></td><td rowspan="2">Field Photographs of Acanthodactylus scutellatus, abundantly found throughout the PA</td></tr>
<tr><td></td></tr>
</table>

	Field Photograph of an unidentified lizard species found within the Western Quarry
	
	Field Photograph of Sand Racer Snake found in the ecotone of the Western Quarry

	Field Photograph of Snake Tracks, thought to be a Cobra species.
  	Field Photographs of unidentified bird species

	Field Photographs of Crested Lark
 	Field Photographs of unidentified bird species

8.5 Annex V: ImageJ Photo Transformations & Analysis

Figure 8-2: Perspective Transformed Photograph

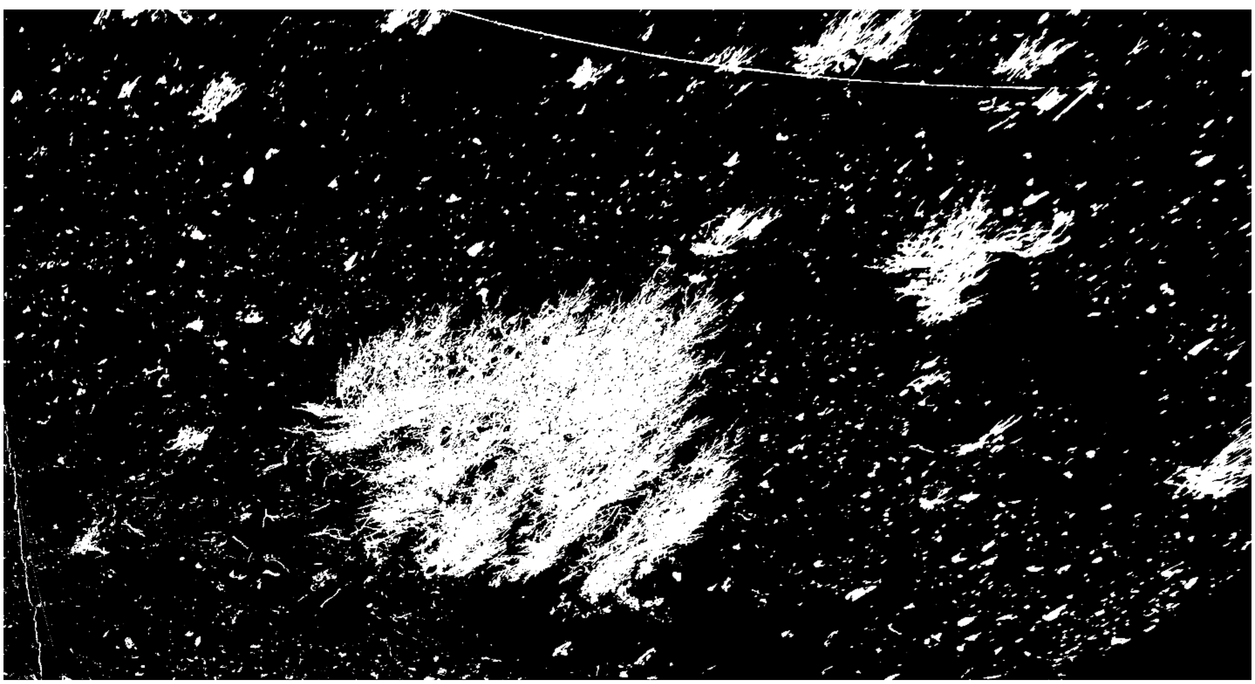


Figure 8-3: ImageJ Analysis Transformation

8.6 Annex VI: Permits & Approvals

الأرشيف الإلكترونى:
رقم الصادر :
التاريخ :

جهاز شئون البيئة
قطاع حماية الطبيعة
رقم القيد: ٥٠٠٠ /

قطاع حماية الطبيعة
صادر رقم :
تاريخ : ١٣/٣/٢٠٢٤
مرفقات :

التاريخ: / ٣ / ٢٠٢٤

السيد الأستاذ / كريم عمر البقري

تحية طيبة وبعد،،،

بالإشارة إلي خطاب سيادتكم الوارد لنا بتاريخ ٢٠٢٤/٢/٢٧ بشأن عمل دراسة ميدانية على السلحفاة المصرية بمحمية العميد الطبيعية بمحافظة مرسى مطروح كمتطلب أساسي للحصول على درجة الماجستير في تقنيات المسح البيئي من جامعة أكسفورد.

في هذا الصدد، برجاء التكرم بالإحاطه أنه ليس لدينا مانع من قيامكم بعملية المسح الميداني لأعداد وصحة مجموعات السلاحف في منطقة محمية العميد، واجراء مسوحات نباتية وتقييم للموائل بأستخدام الأسس العلمية المتبعة في هذا المجال، وذلك بهدف تقييم مدى ملائمة الموائل لاستعادة هذا النوع وفقًا لخطة عمل التنوع البيولوجي بمنطقة العميد، مع اللالتزام بالتنسيق مع السيد المهندس/ مدير عام محميات المنطقة الشمالية قبل وأثناء عملية المسح الميداني والتحديد المسبق لمنطقة العمل داخل المحمية وطريقة المسح الميداني والجدول الزمنى المقترح، بالإضافة إلى ضرورة مشاركتنا بكافة النتائج الخاصة بالدراسة والتوصيات اللازمة للحفاظ على هذا النوع.

وتفضلوا بقبول فائق الإحترام والتقدير،،،

رئيس قطاع حماية الطبيعة

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DEPARTMENT OF BIOLOGY

Local AWERB

Ref. No. APA/1/5/ZOO/NASPA/ContEd/Testudo2024

<table>
<tr><td>Project title</td><td colspan="3">Comparative Analysis of Testudo kleinmanni Populations in Quarry-Affected and Pristine Habitats of Al Omayed PA</td></tr>
<tr><td>Principle Investigator</td><td colspan="3">Karim ElBakary, Dr. Thomas Hesselberg</td></tr>
<tr><td>Date of ethical review</td><td colspan="3">07/03/24</td></tr>
<tr><td>AWERB comments</td><td colspan="3">The above project was reviewed by the Biology Animal Welfare and Ethical Review Board in accordance with University policy on the use of protected animals for scientific research.

The work investigates the ecology of a wild population of tortoises Testudo kleinmanni, in northern Egypt as part of an environmental impact assessment of a High-Speed Rail project. Following a round of revision, the AWERB was satisfied that the plan for pilot study is achievable, with appropriate description of protocols, justified number of animals used, cost to benefit analysis, and discussion of adverse effects and precautions, and is happy to approve this project.</td></tr>
<tr><td>Date of approval</td><td colspan="3">28/03/24</td></tr>
<tr><td>Name of Chair of AWERB</td><td>Professor Tom Pizzari</td><td>Signature</td><td></td></tr>
</table>

8.7 Annex VII: R Script Extracts for GWR Example

```
# -------------------Create SpatialPointsDataFrame---------------------------
# Convert the final transformed data to a SpatialPointsDataFrame
coordinates(final_transformed_data) <- ~Longitude + Latitude
proj4string(final_transformed_data) <- CRS("+proj=longlat +datum=WGS84")
# Convert to an sf object
final_sf <- sf::st_as_sf(final_transformed_data)
# -----------------Geographically Weighted Regression (GWR) for Food Cover w/Monte Carlo------#
# Set up output directory for GWR
gwr_outputs_dir <- file.path(outputs_dir, "GWR_Outputs_Without_Internal_Roads")
if (!dir.exists(gwr_outputs_dir)) {
  dir.create(gwr_outputs_dir)
}
# Ensure that all necessary variables are available and check for missing values
required_vars <- c("Food_Plants_Cover_Sqrt", "Distance_to_Main_Rd__m__Sqrt", "Distance_to_Quarry__m__Sqrt")
missing_vars <- setdiff(required_vars, names(final_sf))
if (length(missing_vars) > 0) {
  stop("The following variables are missing in the data: ", paste(missing_vars, collapse = ", "))
}
for (var in required_vars) {
  if (any(is.na(final_sf[[var]]))) {
    stop(paste("Missing values found in variable:", var))
  }
}
# Convert sf object back to SpatialPointsDataFrame for use with GWmodel
final_spdf <- as(final_sf, "Spatial")
# Use a fixed bandwidth approach for stability
fixed_bandwidth <- 0.07
# Run the GWR model
gwr_model <- GWmodel::gwr.basic(Food_Plants_Cover_Sqrt ~ Distance_to_Main_Rd__m__Sqrt +
                                  Distance_to_Quarry__m__Sqrt,
                                data = final_spdf,
                                bw = fixed_bandwidth,
                                adaptive = FALSE)
# Check if the model was created successfully
if (is.null(gwr_model)) {
  stop("The GWR model could not be created. Please check your data and parameters.")
}
# Print the summary of the GWR model
print(gwr_model)
# Perform the Monte Carlo test for the GWR model
monte_carlo_results <- GWmodel::gwr.montecarlo(Food_Plants_Cover_Sqrt ~ Distance_to_Main_Rd__m__Sqrt +
                                                 Distance_to_Quarry__m__Sqrt,
                                               data = final_spdf,
                                               bw = fixed_bandwidth,
                                               adaptive = FALSE,
                                               nsim = 999)
# Adjust the variable names list
variable_names <- c("(Intercept)", "Distance_to_Main_Rd__m__Sqrt", "Distance_to_Quarry__m__Sqrt")
# Verify that the number of p-values matches the number of variables (including the intercept)
if (num_p_values != length(variable_names)) {
  stop("Mismatch between the number of p-values and the number of variables. Please check the GWR model output.")
}
# Create a data frame to store the variable names and their corresponding p-values
monte_carlo_df <- data.frame(
  Variable = variable_names,
  P_Value = monte_carlo_results
)
```

```
# Output Monte Carlo test results to CSV
monte_carlo_csv_path <- file.path(gwr_outputs_dir, "Monte_Carlo_Results_Food_Plant_Cover_Without_Internal_Roads.csv")
write.csv(monte_carlo_df, monte_carlo_csv_path, row.names = FALSE)
# Extract the GWR coefficients
gwr_coefficients <- as.data.frame(gwr_model$SDF)
# Ensure all field names are unique and no longer than 10 characters
valid_column_names <- c("Intercept", "MainRd", "Quarry",
                        "Observed", "Fitted", "Residual", "CV_Score",
                        "StudResid", "Int_SE", "MainRd_SE", "Quarry_SE",
                        "Int_TV", "MainRd_TV", "Quarry_TV",
                        "Local_R2", "Longitude", "Latitude")
# Ensure names match and are assigned correctly
if (length(names(gwr_coefficients)) != length(valid_column_names)) {
  stop("Mismatch between column names and valid names.")
} else {
  names(gwr_coefficients) <- valid_column_names
}
# Convert the GWR coefficients to an sf object, using Longitude and Latitude from the GWR coefficients
gwr_sf <- sf::st_as_sf(gwr_coefficients, coords = c("Longitude", "Latitude"), crs = 4326)
# Define the output CSV file path
csv_file_path <- file.path(gwr_outputs_dir, "GWR_Coefficients_Food_Plant_Cover_Without_Internal_Roads.csv")
# Write the CSV file
write.csv(gwr_coefficients, csv_file_path, row.names = FALSE)
```

8.8 Annex VIII: Randomization Spreadsheet

Undisturbed	Disturbed
11	10
12	19
13	18
14	26
15	27
20	35
21	69
22	70
23	78
28	77
29	41
30	42
31	49
34	50
36	
37	
38	
39	
43	
44	

Undisturbed Habitat							
		Coordinate of SW Corner of Site Cell		Subcell Randomization		Corrected subcell coordinates (SW Corner)	
#	Cell Selection	X	Y	X-Axis	Y-Axis	X-Axis	Y-Axis
1	15	124230	3397471	G	0	124830	3397471
2	30	126230	3398471	J	1	127130	3398571
3	66	131230	3402471	B	9	131330	3403371
4	43	128230	3401471	H	5	128930	3401971
5	11	124230	3401471	F	2	124730	3401671
6	67	131230	3401471	I	4	132030	3401871
7	68	131230	3400471	G	1	131830	3400571
8	55	129230	3397471	H	1	129930	3397571
9	63	130230	3397471	G	3	130830	3397771
10	60	130230	3400471	C	5	130430	3400971
11	34	127230	3402471	C	1	127430	3402571
12	60	130230	3400471	H	1	130930	3400571
13	46	128230	3398471	J	0	129130	3398471
14	46	128230	3398471	B	4	128330	3398871
15	61	130230	3399471	H	8	130930	3400271
16	47	128230	3397471	J	8	129130	3398271
17	75	132230	3401471	D	7	132530	3402171
18	55	129230	3397471	J	7	130130	3398171
19	45	128230	3399471	E	2	128630	3399671
20	37	127230	3399471	G	0	127830	3399471

45
46
47
51
52
53
54
55
58
59
60
61
62
63
66
67
68
71
75
76
79

21	54	129230	3398471
22	60	130230	3400471
23	63	130230	3397471
24	30	126230	3398471
25	13	124230	3399471
26	68	131230	3400471
27	53	129230	3399471
28	14	124230	3398471
29	55	129230	3397471
30	23	125230	3397471
31	61	130230	3399471
32	30	126230	3398471
33	28	126230	3400471
34	51	129230	3401471
35	28	126230	3400471
36	31	126230	3397471
37	14	124230	3398471
38	51	129230	3401471
39	71	131230	3397471
40	22	125230	3398471
41	38	127230	3398471
42	63	130230	3397471
43	59	130230	3401471
44	54	129230	3398471
45	38	127230	3398471
46	59	130230	3401471
47	76	132230	3400471
48	47	128230	3397471
49	30	126230	3398471

J	3
E	8
C	2
F	9
H	2
G	4
J	1
B	8
F	4
I	9
F	5
A	8
H	1
G	6
J	8
H	9
D	7
I	6
G	5
J	0
C	5
I	8
H	0
J	2
E	5
C	3
D	3
I	7
J	2

130130	3398771
130630	3401271
130430	3397671
126730	3399371
124930	3399671
131830	3400871
130130	3399571
124330	3399271
129730	3397871
126030	3398371
130730	3399971
126230	3399271
126930	3400571
129830	3402071
127130	3401271
126930	3398371
124530	3399171
130030	3402071
131830	3397971
126130	3398471
127430	3398971
131030	3398271
130930	3401471
130130	3398671
127630	3398971
130430	3401771
132530	3400771
129030	3398171
127130	3398671