

Supplementary Feeding and Changes in Breeding-Site Occupancy of Griffon Vultures *Gyps fulvus* within the King Salman Bin Abdulaziz Royal Natural Reserve, Saudi Arabia

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Abstract

This study assessed Griffon Vulture *Gyps fulvus* breeding-site occupancy before and after the introduction of supplementary feeding in the King Salman Bin Abdulaziz Royal Natural Reserve, northern Saudi Arabia. Fifty-seven cliff sites were surveyed in 2024 and resurveyed in 2025 after feeding stations operated during the breeding period. Occupancy increased from 56.1% to 75.4%, with colonization of inactive sites exceeding losses. Occupancy was highest in the zone where feeding-station use was greatest, although this zone also had the highest pre-feeding occupancy. Across the survey area, 82 active nests were recorded in 2025. The results suggest that carefully managed feeding using veterinary-screened carcasses may support breeding-site use, but the before-and-after design without an independent unfed control area limits causal inference, and longer-term monitoring is needed to distinguish sustained population growth from short-term redistribution.

Keywords

Griffon Vulture, *Gyps fulvus*, Supplementary Feeding, Nest Occupancy, Breeding Sites, Vulture Conservation, Hail Region, Saudi Arabia, KSRNR

1. Introduction

Supplementary feeding stations are widely used in vulture conservation to support breeding success and reduce mortality [1]. However, most evaluations of supplementary feeding have focused on survival rates, productivity, or population size,

whereas explicit quantification of nest-site occupancy responses remains comparatively limited, particularly in arid ecosystems of the Arabian Peninsula. Although Griffon Vulture *Gyps fulvus* is globally classified as Least Concern, its regional status varies considerably, and the species remains of conservation concern in parts of the Arabian Peninsula. In Saudi Arabia, the Griffon Vulture has been described as threatened by poisoning, electrocution, disturbance, and changes in access to food resources [2] [3]. Breeding has been documented across several regions of Saudi Arabia, including the south-western mountains and northern rocky landscapes [3]-[7]. Within the Hibran area in north-western Hail, part of the King Salman Bin Abdulaziz Royal Natural Reserve (KSRNR), a breeding colony with 22 suspected active nests has recently been documented [8].

In arid landscapes, food limitation for vultures may not necessarily reflect a shortage of carrion alone. Access to safe and predictable carrion may also be reduced by carcass-disposal practices, including burial, disposal in pits, removal from open areas, or exposure to poisoned or contaminated carcasses. In Saudi Arabia, poisoning and inappropriate carcass disposal have been identified as important threats to vultures [3] [9]. Therefore, feeding stations using veterinary-screened carcasses may provide a practical conservation tool for improving access to safe carrion. Despite these recent observations, published assessments of temporal changes in Griffon Vulture nest occupancy following targeted management interventions remain limited in Saudi Arabia.

This study aimed to evaluate nest occupancy responses of Griffon Vultures to a supplementary feeding programme implemented during the breeding period in northern Saudi Arabia. Using repeated surveys of fixed nesting sites conducted before and after feeding activation, temporal changes in occupancy were quantified, and spatial differences among zones with differing levels of exposure to supplementary feeding were assessed. This appears to be the first published assessment of temporal changes in Griffon Vulture nest occupancy in Saudi Arabia using a repeated-site before-and-after framework. Higher occupancy and increased use of nesting cliffs were expected following feeding activation, particularly in areas closer to feeding stations.

2. Materials and Methods

2.1. Study Area

The study was conducted in the Hail region of the King Salman Bin Abdulaziz Royal Natural Reserve (KSRNR), northern Saudi Arabia. The area is characterized by arid desert landscapes, rocky cliffs, and open plains that provide suitable nesting and foraging habitats for Griffon Vultures *Gyps fulvus* [8]. The climate is arid, with hot summers and mild winters; mean temperatures range from 10.8°C in winter to 34.1°C in summer, with annual rainfall of approximately 116.4 mm [10]. Three survey zones were selected within the Hail region: Zone 1 (Alnafs), Zone 2 (Hibran), and Zone 3 (Arnan) (Figure 1). These zones were selected because they contained extensive rocky cliffs suitable for nesting, were located near livestock areas, and had previous records of Griffon Vulture activity.

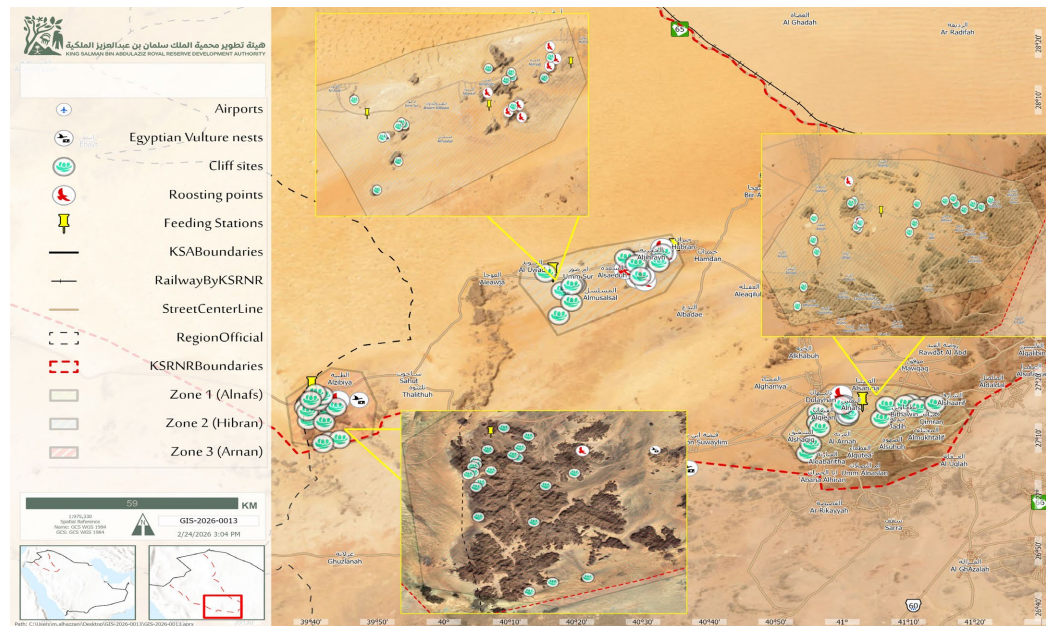


Figure 1. Study area and survey layout in the Hail region of KSRNR, showing the three survey zones, fixed cliff sites, supplementary feeding stations, previously identified roosting sites, and Egyptian Vulture nest records documented during the 2024-2025 surveys.

Vegetation across the study zones is typical of arid and semi-arid ecosystems, dominated by sparse perennial shrubs and scattered herbaceous plants adapted to low rainfall and high temperatures, including *Acacia gerrardii*, *Haloxylon salicornicum*, and *Stipagrostis plumosa* [11].

2.2. Survey Design and Nest Assessment

Field surveys were conducted during the Griffon Vulture breeding period in May 2024, before supplementary feeding began, and in May-June 2025, after feeding-station activation. The 2024 survey provided the pre-feeding baseline, whereas the 2025 survey represented the first breeding season following feeding activation.

A total of 57 fixed cliff sites within KSRNR in Hail region were surveyed in both years using the same field protocol and comparable seasonal timing (Figure 1). These sites were identified from previous reserve records, earlier field observations, and reconnaissance surveys conducted before feeding-station activation. They represented the known Griffon Vulture breeding cliffs available for repeated monitoring within the selected survey zones at the time of the baseline survey. Therefore, the before-and-after comparison was based on the same fixed set of cliff sites rather than on a random sample of cliffs across the entire reserve.

For the occupancy analysis, each cliff site was treated as a single binary sampling unit. Cliff-site occupancy was defined as the presence of at least one active Griffon Vulture nest within a cliff site. Nests were classified as active when eggs, incubating adults, chicks, or other clear evidence of current breeding activity were observed. Cliff sites with no evidence of current breeding activity were classified as unoccupied. Where multiple active nests occurred within the same cliff site, these

were recorded descriptively as nest counts but did not alter the binary occupancy score of that cliff.

Observations were conducted from fixed vantage points using Swarovski EL Range binoculars (8 × 42) and a Swarovski ATX spotting scope (25 – 60 × 85) to minimise disturbance. A DJI Mavic 3 Cine drone was used selectively to confirm nest status where direct visual confirmation was not possible from ground vantage points. Geographic coordinates of nesting sites were recorded using a Garmin Montana 750i handheld GPS unit, and nest orientation was recorded using a handheld compass.

Because each cliff site was surveyed during a single seasonal visit in each survey year, occupancy estimates represent apparent occupancy and were not corrected for detection probability. To reduce the risk of false absences, observers used fixed vantage points, repeated scanning of nesting ledges during each visit, optical equipment, and selective drone confirmation where ground-based confirmation was insufficient. Survey effort, observer team composition, daily observation duration, and spatial coverage were kept as consistent as possible between 2024 and 2025. Surveys were conducted over three consecutive days during each breeding-season survey, from sunrise to sunset, with reduced observation effort during midday hours to avoid extreme heat and reduced detectability. However, some risk of false absence remains and is acknowledged as a limitation.

In addition to the temporal before-and-after comparison, spatial variation in occupancy was assessed among the three survey zones: Zone 1 (Alnafs), Zone 2 (Hibran), and Zone 3 (Arnan). Zone-level exposure to supplementary feeding was evaluated using the distribution of feeding stations relative to surveyed cliff sites and feeding-station use recorded during the activation period. Spatial differences in occupancy among zones were then compared to assess whether occupancy patterns varied with feeding-station exposure. Because exposure was assessed at the zone level, and because zones may differ in habitat quality, baseline breeding density, or other ecological factors, spatial patterns were interpreted as associative rather than causal.

2.3. Feeding Station Establishment and Monitoring

Five supplementary feeding stations were established between December 2024 and April 2025 within the Hail region. Feeding stations were located approximately 3 - 5 km from known nesting sites in open terrain to enhance visibility to vultures while reducing direct disturbance to nesting cliffs. Donkey carcasses were provided at feeding stations during the activation period. All carcasses underwent veterinary inspection and laboratory screening by the National Center for Wildlife (NCW) to ensure compliance with disease safety standards. To facilitate efficient feeding access, carcasses were prepared following established protocols to allow vultures access to soft tissues [12] [13].

Feeding-station activation from December 2024 to April 2025 overlapped with the main Griffon Vulture breeding period in the region, including egg-laying, in-

cubation, and early chick-rearing stages. All five feeding stations received initial provisioning of veterinary-screened donkey carcasses. Subsequent provisioning was not applied equally across stations; it was adjusted based on carcass depletion and camera-trap evidence of Griffon Vulture visitation. Re-provisioning occurred only at the Arnan feeding station during the activation period (**Table 1**). The post-activation surveys in May-June 2025 were conducted after the feeding period, when many active nests were expected to be in late chick-rearing or pre-fledging stages, to assess cliff-site occupancy and active nest records following feeding-station activation during the breeding season.

Table 1. Feeding-station provisioning schedule during the activation period from December 2024 to April 2025.

Feeding station	Zone/Study area	Provisioning date	Carcass input	Provisioning status
FS1	Alnafsa/Zone 1	11 December 2024	4 carcasses	Initial provisioning only
FS2	Hibran/Zone 2	11 December 2024	4 carcasses	Initial provisioning only
FS3	Hibran/Zone 2	11 December 2024	4 carcasses	Initial provisioning only
FS4	Hibran/Zone 2	11 December 2024	4 carcasses	Initial provisioning only
FS5	Arnan/Zone 3	11 December 2024	4 carcasses	Initial provisioning
FS5	Arnan/Zone 3	20 December 2024	14 additional carcasses	Re-provisioning
FS5	Arnan/Zone 3	16 January 2025	12 carcasses	Re-provisioning
FS5	Arnan/Zone 3	14 April 2025	8 carcasses	Final reduced provisioning

Note: All five feeding stations received initial provisioning with veterinary-screened donkey carcasses. Re-provisioning was carried out only at FS5 in Arnan because this station showed continued carcass consumption and Griffon Vulture visitation during the activation period.

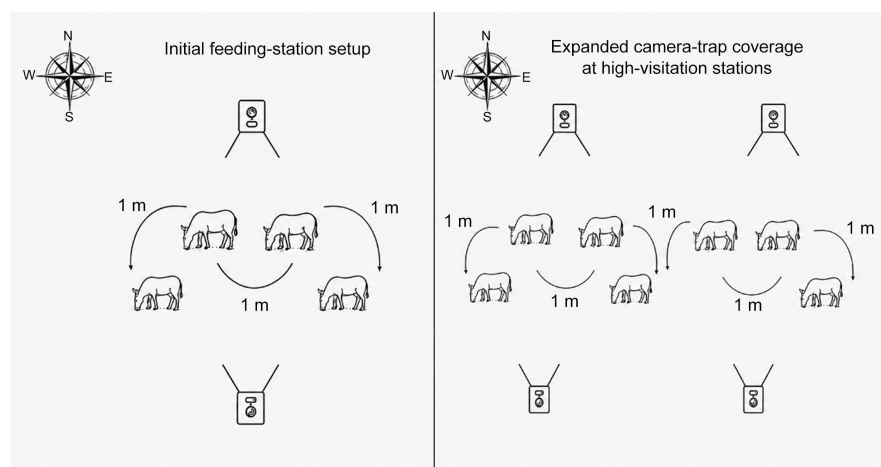


Figure 2. Camera-trap configuration, showing the initial two-camera setup and the expanded asymmetrical four-camera arrangement used to improve coverage at high-visitation stations.

Feeding stations were monitored using Reconyx HyperFire 2 Covert IR camera traps to document visitation and species presence [14] [15]. Initially, two cameras were installed per station to provide coverage from opposite orientations. Stations showing high visitation rates were further monitored using up to four camera traps arranged asymmetrically to improve coverage of the feeding area and reduce blind spots (Figure 2). Camera traps were checked weekly to minimize disturbance.

2.4. Statistical Analysis

Statistical analyses were conducted using IBM SPSS Statistics version 28 (IBM Corp., Armonk, NY, USA). Changes in cliff-site occupancy between 2024 and 2025 were assessed using McNemar's test for paired binary data, because the same 57 cliff sites were surveyed in both years. Spatial differences in occupancy among zones were evaluated using Fisher's exact test. Odds ratios (ORs) and 95% confidence intervals (CIs) were calculated to quantify the magnitude of occupancy differences between Zone 3 and Zones 1 - 2 combined. This zone-level contrast was used to evaluate spatial variation in occupancy and was not interpreted as a pre-defined experimental treatment effect. All statistical tests were two-tailed, with statistical significance set at $\alpha = 0.05$.

3. Results

All occupancy analyses were based on the 57 fixed cliff sites surveyed in both 2024 and 2025. Within these fixed cliff sites, 32 active Griffon Vulture nests were recorded in 2024, and 43 active nests were recorded in 2025. In addition, 39 active nests were documented at additional cliffs outside the fixed-site occupancy analysis in 2025, bringing the total number of active nests recorded across the wider survey area to 82. These additional nest records are reported descriptively and were not included in the statistical occupancy analyses.

In 2024, before feeding-station activation, 32 of the 57 fixed cliff sites were occupied, corresponding to an occupancy rate of 56.1%. Occupancy varied among zones: five of 15 sites were occupied in Zone 1 (Alnafs), ten of 19 in Zone 2 (Hibran), and 17 of 23 in Zone 3 (Arnan). Thus, Zone 3 had the highest baseline occupancy before supplementary feeding began. Cliff sites in Zone 3 were more likely to be occupied than those in Zones 1 and 2 combined (OR = 3.59, 95% CI: 1.14 - 11.31; Fisher's exact test, $p = 0.032$).

In 2025, after feeding-station activation, 43 of the same 57 fixed cliff sites were occupied, corresponding to an occupancy rate of 75.4%. Between 2024 and 2025, 14 previously unoccupied sites became occupied, whereas three previously occupied sites became inactive. This represented a significant increase in cliff-site occupancy between years (McNemar's test, $\chi^2 = 7.12$, $p = 0.008$). In 2025, occupancy remained highest in Zone 3, where cliff sites were more likely to be occupied than those in Zones 1 and 2 combined (OR = 13.62, 95% CI: 3.33 - 55.90; Fisher's exact test, $p = 0.002$).

3.1. Feeding Station Use during the Activation Period

During the feeding-station activation period from December 2024 to April 2025, two of the five supplementary feeding stations attracted Griffon Vultures. The feeding station in Zone 3 showed the highest and most consistent visitation, with peak aggregations of c.90 - 100 individuals (**Figure 3**). The remaining stations showed either no recorded visitation or only sporadic single-day use during the activation period. Camera-trap monitoring also recorded marked individuals bearing leg rings and wing tags, indicating that some birds using the feeding station originated from outside the immediate study area (**Figure 4**).



Figure 3. Griffon Vulture aggregation at Arnan feeding station during the activation period (December 2024).



Figure 4. (A-D) Marked Griffon Vultures recorded by camera traps at Arnan feeding station (Zone 3), showing leg rings and wing tags.

3.2. Additional Nest Records

Within the study area, 82 active Griffon Vulture nests were recorded in 2025. This total included nests recorded within the fixed 57 cliff sites and 39 active nests documented at additional cliffs that were not included in the fixed-site occupancy analysis. Nine of these additional nests occurred within five sites that had been

classified as roosting-only in 2024. Of the ten roosting-only sites recorded in 2024, five supported at least one active nest in 2025. These additional nest records are reported descriptively and were not included in the statistical occupancy analyses.

3.3. Additional Scavenger and Raptor Records

In addition to Griffon Vultures, camera traps at the Arnan feeding station recorded three additional vulture species of conservation concern: Cinereous Vulture *Aegypius monachus*, Lappet-faced Vulture *Torgos tracheliotos* and Egyptian Vulture *Neophron percnopterus* (Figure 5). Egyptian Vulture breeding evidence was also recorded within the study area, with two active nests documented in 2024 and four in 2025 (Figure 1 and Figure 6). Other raptors were recorded opportunistically at feeding stations, including Eastern Imperial Eagle *Aquila heliaca*, Steppe Eagle *Aquila nipalensis*, Greater Spotted Eagle *Clanga clanga*, Common Kestrel *Falco tinnunculus*, and Pharaoh Eagle-Owl *Bubo ascalaphus*. These observations are presented as incidental records and were not included in the Griffon Vulture occupancy analyses.



Figure 5. Additional vulture species recorded at Arnan feeding station (Zone 3): (A) Cinereous Vulture, (B) Lappet-faced Vulture, (C) adult Egyptian Vulture and (D) juvenile Egyptian Vulture.



Figure 6. Egyptian Vulture breeding evidence recorded during surveys: (A) active nest near Alnafs (Zone 1) and (B) juvenile in Arnan (Zone 3).

4. Discussion

The present study documented an increase in cliff-site occupancy of Griffon Vultures following the activation of supplementary feeding stations within KSRNR. Occupancy at fixed cliff sites increased from 56.1% in 2024 to 75.4% in 2025, with colonization of previously unoccupied sites exceeding losses. The increase was also spatially uneven, with the highest occupancy recorded in Zone 3, where feeding-station use was greatest. This zone-level contrast was used to quantify the magnitude of spatial variation in occupancy between Zone 3 and Zones 1 - 2 combined. It should not be interpreted as a pre-defined experimental treatment effect. However, Zone 3 also had the highest baseline occupancy before supplementary feeding began, indicating that spatial differences may reflect feeding-station exposure as well as underlying differences in habitat suitability, historical breeding density or other local factors. The repeated-site before-and-after framework provides evidence of temporal change at the same cliff sites, but the absence of an independent unfed control area means that the observed increase cannot be attributed solely to supplementary feeding. These results represent apparent cliff-site occupancy rather than detection-corrected occupancy, because each cliff site was surveyed during a single seasonal visit each year. Although comparable timing, fixed vantage points, repeated scanning, and selective drone confirmation were used to reduce false absences, some risk of imperfect detection remains. Similar associations between supplementary feeding and improved breeding parameters have been reported in several European populations of Gyps vultures [16]-[19]. However, quantitative assessments of nest-site occupancy remain limited, particularly in arid ecosystems [15] [20].

The recording of 82 active Griffon Vulture nests within the study area in 2025 highlights the importance of KSRNR as a breeding area for the species in northern Saudi Arabia. This total included 39 active nests documented at additional cliffs that were not included in the fixed-site occupancy analysis. Although these additional nest records may reflect improved knowledge of the study area, interannual variation, or redistribution of birds within the local population, they also indicate substantial breeding activity beyond the original fixed-site sample. Comparable changes in breeding distribution have been documented in regions where food availability increased through management interventions or changes in livestock practices [21] [22]. Continued multi-year monitoring will be required to determine whether the pattern recorded in 2025 reflects sustained demographic growth or short-term redistribution. Nevertheless, the 2025 nest total indicates that the KSRNR colony has national conservation relevance.

The findings should be interpreted in the context of access to safe carrion rather than food availability alone. In arid landscapes, vultures may occur in areas where livestock and potential carrion resources are present, but carcass-disposal practices, burial, removal from open areas, or exposure to poisoned or contaminated carcasses may reduce the availability of safe and predictable food [3] [9]. The use of veterinary-screened carcasses at feeding stations may therefore have provided

a safer and more predictable resource during the study period, consistent with the role of feeding stations in reducing exposure to unsafe carcasses [12] [23]. This interpretation is consistent with the potential value of supplementary feeding as a targeted management tool, provided that feeding stations are carefully regulated, monitored, and integrated with wider measures to reduce poisoning and inappropriate carcass disposal [9] [24].

Camera-trap records of marked Griffon Vultures bearing leg rings and wing tags indicate that some individuals using the feeding station originated from outside the immediate study area. This suggests possible connectivity among breeding or foraging areas in the region, although movement was not directly quantified. Supplementary feeding can influence spatial aggregation and movement patterns in wide-ranging scavengers [14] [25].

The incidental records of Cinereous Vulture, Lappet-faced Vulture, and Egyptian Vulture at the Arnan feeding station show that supplementary feeding stations can attract additional scavenger species of conservation concern in KSRNR. These observations are consistent with the broader role of feeding stations in supporting scavenger assemblages when they are carefully managed and monitored [24]. However, because these records were incidental and species-specific responses were not quantified, they should not be interpreted as evidence of population-level benefits for other scavenger species. Based on available published literature, the Egyptian Vulture breeding records also appear to represent the first documented nesting evidence for the Hail region, highlighting the value of targeted follow-up surveys for this species in northern Saudi Arabia [4] [7] [9].

The main limitation of this study is that it covered one pre-feeding and one post-feeding breeding season. Although the repeated-site before-and-after framework allowed temporal changes in cliff-site occupancy to be assessed at the same sites, reproductive success, survival, and individual movements were not directly measured. Future monitoring should therefore include breeding success, chick survival, adult survival, and movements of marked or GPS-tagged individuals. Such monitoring will be necessary to determine whether the observed increase in occupancy reflects sustained demographic growth, improved settlement within KSRNR or short-term redistribution within the regional population.

From a management perspective, the findings support the careful and adaptive use of regulated supplementary feeding in KSRNR, provided that provisioning remains linked to veterinary screening, carcass safety, and long-term monitoring.

5. Conclusions

This study documented an increase in apparent cliff-site occupancy of Griffon Vultures within KSRNR following the activation of supplementary feeding stations during the breeding period. Occupancy at the same 57 fixed cliff sites increased from 56.1% to 75.4%, with colonization of previously unoccupied sites exceeding local losses. The highest post-activation occupancy was recorded in Zone 3, where feeding-station use was greatest, although this zone also had the

highest baseline occupancy before feeding began.

Across the wider survey area, 82 active nests were recorded in 2025, highlighting the importance of KSRNR as a breeding area for Griffon Vultures in northern Saudi Arabia. Records of additional vulture species at feeding stations and Egyptian Vulture breeding evidence also indicate the wider ecological relevance of the reserve for scavenger conservation. Because the study used a before-and-after design without an independent unfed control area, the observed patterns should be interpreted cautiously. Continued multi-year monitoring will be needed to determine whether the observed increase reflects sustained population growth, improved settlement within KSRNR, or short-term redistribution.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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