BREEDING BIOLOGY AND DIET OF TAWNY EAGLES *(Aquila rapax)* IN DESERT NATIONAL PARK, RAJASTHAN, INDIA

by

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Dissertation Thesis

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For the partial fulfilment for the degree

Master of Science
in
Wildlife Science

Under the supervision of

Varun S. Kher, Scientist-C (Supervisor)

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

AcSIR

June 2026

DECLARATION

I hereby declare that the work conducted under the thesis entitled **"Breeding behaviour and Diet of Tawny Eagles (Aquila rapax), in Desert National Park, Rajasthan, India**", is a record of original and independent research work done by me and subsequently submitted for the award of the degree of **Master's in Wildlife Science** at the **Academy of Scientific and Innovative Research.** This research work has been carried out under the guidance and supervision **of Mr. Varun Kher, Scientist- C** of Wildlife Institute of India, Dehradun. The work has not formed the basis for the award of any other degree, diploma, or any other qualification. I also declare that the thesis embodies my own work, analysis, observation, understanding and the particulars given in it are true to the best of my knowledge.

Gayathri Varma.

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CERTIFICATE

This is to certify that the thesis by **Gayathri Varma** entitled **"Breeding behaviour and Diet of Tawny Eagles (*Aquila rapax)*, in Desert National Park, Rajasthan, India"** is an original and independent research work submitted to the **Academy of Scientific and Innovative Research**, for the award of the degree of **Master's in Wildlife Science**.

Gayathri Varma has put one semester of research work embodied in this thesis under my guidance and supervision. The work presented in this thesis has not been submitted to any other University or Institute for the award of any degree, diploma or distinction.

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Gayathri Varma

June, 2026

Executive Summary

The Tawny Eagle (*Aquila rapax*), is raptor species, found across the Indian subcontinent, widely spread and poorly studied. There is very limited quantitative information present on the nest-site selection, breeding behaviour and diet selection of Tawny Eagles. This study investigates the factors influencing habitat selection, breeding ecology and diet composition of the population of Tawny Eagles in the Thar desert landscape of Rajasthan, India, during the 2025-2026 breeding season. This study aimed to provide a baseline understanding of the species ecology by examining nest-site selection, spatial distribution of nests, parental behaviours, provisioning behaviours and seasonal changes in prey compositions.

Nest search was conducted across approximately, 2000 km^2, with approximately 4000 km of nest search effort with active nest tree characteristics mapped, and distance between the nest and the protected grasslands calculated. A total of ten nests were found across the study area, with all nest occurring within, or in close proximity to the protected grasslands in Desert National Park. Nine out of ten nests were either inside enclosures or located immediately adjacent to them, with an average distance of 1.56 km from enclosure boundaries. Nest trees were predominantly *Prosopis cineraria*, with nesting trees averaging over 7.5 m in height and providing large crown structures suitable for nest placement, with all nests being placed at the top of the tree. As all the nests were recorded in only a small part of the study area, a rapid population survey was conducted across the study area to determine the spatial distribution of the species across the study area. Raptor surveys covering 734.78 km across 63 grids recorded 14 Tawny Eagle sightings, confined largely to areas where nests had been located.

Breeding behaviour was studied using focal observations and CCTV monitoring across active nests, generating approximately 900 hours of behavioural data. Breeding was found to occur in the winter months, with most eggs being laid in December and January, hatching in the months of January and February, with fledging occurring by the end of March through April. Results showed differences in parental roles, with females primarily responsible for nest attendance and chick care, while males acted as the primary providers of prey. Female nest attendance decreased as chicks matured, while chick vigilance increased with age. Provisioning behaviour demonstrated seasonal variation, with Spiny-tailed Lizards (Saara hardwickii) becoming the dominant prey item during warmer months.

Diet composition was assessed using pellet analysis, CCTV observations, and drone surveys, resulting in 224 prey records from nine nests. Tawny Eagles showed dietary flexibility, with mammals (41.9%) and reptiles (40.1%) comprising the majority of prey items. Diet composition changed significantly across months and nesting stages, with a shift from mammalian prey during colder months towards increased reptilian prey as temperatures rose and Spiny-tailed Lizards became more available.

Overall, this study highlights the importance of protected grassland habitats within Desert National Park for supporting Tawny Eagle populations by providing suitable nesting structures, reduced disturbance, and productive foraging habitats. The findings provide the first detailed quantitative assessment of habitat selection, breeding behaviour, and diet composition of Tawny Eagles from the Indian population and establish a foundation for future long-term studies on population status, reproductive success, and conservation requirements of this species.

Keywords: *raptor conservation, Thar Desert, pellet analysis, occupancy survey*

Chapter 1: Introduction

Raptors or birds of prey constitute a taxonomically diverse group of species characterised by their sharp, hooked bills, curved talons, acute eyesight, and powerful flight. They occupy a high trophic level in the food-web and typically function as either tertiary consumers, apex predators or scavengers in the ecosystem. Given their higher trophic level, they are often used as indicators of ecosystem health (Natsukawa & Sergio, 2022), and their demographic trends are important warning signals for environmental degradation.

Despite their ecological importance, raptors are among the more threatened groups of birds globally. Approximately 30% of the world's raptor species are experiencing population declines, many threats, such as, habitat loss and degradation to direct persecution, poisoning through lead and rodenticides, collisions with energy infrastructure, and the illegal wildlife trade (McClure et al., 2018). Among migratory raptors of Africa and Eurasia, a disproportionately high number are listed as Vulnerable, Endangered, or Critically Endangered on the IUCN Red List, with declines particularly severe across Asian and African populations (Jones et al., 2023). These trajectories are a cause for concern since raptors have inherently slow reproductive rates and small population sizes, rendering their populations slow to recover once depleted.

Commonly referred to as true eagles, Aquila species are large, powerful raptors distributed across a broad range of habitats spanning open grasslands, arid steppes, montane forests, and semi-desert landscapes across Africa, Europe, Asia, and Australia (Newton, 1979). Ecologically, Aquila eagles function predominantly as apex predators, feeding on small to medium-sized mammals, birds, and reptiles, and play important roles in regulating prey populations. However, the genus is facing considerable conservation pressure globally. Several

species, including the Indian Spotted Eagle (Aquila hastata), the Eastern Imperial Eagle (Aquila heliaca), and the Steppe Eagle (Aquila nipalensis), are listed as Vulnerable or of conservation concern on the IUCN Red List (IUCN 2026). Key threats include habitat loss driven by agricultural expansion and land-use change, collision and electrocution on power lines, poisoning, nest disturbance, and in some regions, direct persecution (McClure et al., 2018). Population declines in Aquila eagles are of particular concern because of their K-selected life history traits, low reproductive output, delayed sexual maturity, and long lifespans, which severely limit the capacity for rapid population recovery.

1.1 Conservation Ecology of the Tawny Eagle

Tawny Eagle (*Aquila rapax*), or more specifically the Indian Tawny Eagle (*Aquila rapax vindhianus*) is a medium sized resident raptor found in dry open-natural ecosystems of India. It was historically treated conspecific to the migratory Steppe Eagle (Aquila nipalensis), but subsequent taxonomic reviews led to its reclassification as a separate species in 1991 (Clark, 1991). The Tawny Eagle is a wide-ranging species with populations in Africa, West Asia and the Indian sub-continent. Typically, three distinct subspecies are recognised, *Aquila rapax vindhiana* in Pakistan and India, *Aquila rapax belisarius* in North Africa, Arabia, and tropical Africa, and the nominate *Aquila rapax rapax* in south Kenya and southern Africa (Sibley & Monroe, 1990).

The Tawny Eagle is a predatory raptor but can also resort to scavenging occasionally (ref.). Natural history accounts suggest that the species can feed on small mammals, birds and lizard, but can also consume other food items when available. The hunting style is to dive on prey from a perch or to stoop from a high overhead soar. The breeding typically occurs in the winter, however there is much variation in the time of the year across its vast breeding range. The

Indian subspecies is known to start breeding between October and February. The nests of the species are built on top of medium to large sized trees and are made up of sticks and other compacting material.

The populations of all three subspecies of the Tawny Eagle have shown a significant decline in recent years. Studies from Africa have attributed the decline to a combination of habitat degradation and intentional poisoning attempts by farmers (Brown, 1991). In India, while no systematic studies on the population of the species have been conducted, citizen-science based reports such as the State of India's Birds suggest that the species has suffered massive declines (SOIB, 2023). The reasons for this decline are not clearly known and need to be investigated, but the potential causes include conversion of open natural ecosystems into crop fields, habitat degradation, expansion of energy infrastructure and other alterations being made to their environment.

In India, the Tawny Eagle is identified as a species of conservation concern (Schedule I) and accorded the highest form of protection under the Wild Life (Protection) Act, 1972. Other policy-oriented documents have also listed the species as one deserving conservation concern given the observed declines and range contractions in some parts, together with pressures due to shifting land-use and livestock management practices (SOIB, 2023). However, no national or regional conservation action plan is currently in place and much needs to be understood before any structured conservation action can be undertaken.

1.2 The Tawny Eagle and the Thar Desert

The Thar Desert, spanning northwestern India and eastern Pakistan, represents one of the most ecologically significant arid landscapes in South Asia for raptors. The mosaic of open scrublands, grasslands and agricultural fields supports a surprisingly rich raptor assemblage, including resident breeding species as well as a considerable diversity of migratory raptors that use the region as a wintering ground or passage stopover along the Central Asian Flyway. The Thar's expansive open terrain provides suitable foraging and nesting habitat for large soaring raptors in particular, making it a stronghold for several species of conservation concern.

The Thar Desert supports a diverse raptor community, especially in the winter season. Apart from the resident community, which includes a variety of species such as the Shikra (*Accipiter badius*), Black-winged Kite (*Elanus caeruleus*), White-eyed Buzzard (*Butastur teesa*), Long-legged Buzzard (*Buteo rufinus*), and the Laggar Falcon (*Falco jugger*), there are a large number of winter migrants as well, such as the Steppe Eagle (*Aquila nipalensis*), Montagu's Harrier (*Circus pygargus*), Pallid Harrier (*Circus macrourus*), and various buzzards (Naoroji, 2006).

The Tawny Eagle (*Aquila rapax*) has a broad but increasingly fragmented distribution across the Indian subcontinent, occurring across the arid and semi-arid zones of Rajasthan, Gujarat, Madhya Pradesh, and parts of the Deccan Plateau, as well as the terai grasslands of the Indo-Gangetic Plain (SOIB, 2023). Once widespread, the species has undergone significant range contraction and population decline across much of its Indian range, driven largely by the degradation and conversion of Open Natural Ecosystems (ONEs), including grasslands, scrublands, and arid steppes, that constitute its primary foraging and nesting habitat. Across India, ONEs have been historically undervalued in conservation policy, frequently classified as "wastelands" and subjected to large-scale afforestation, agricultural encroachment, and industrial development, resulting in the steady erosion of habitats critical to the Tawny Eagle

and other open-country raptors. Within this context, the Thar Desert stands out as holding the largest and most intact Open Natural Ecosystems in the country, and consequently supports what is believed to be the most significant remaining population of Tawny Eagles in India, underscoring the exceptional conservation value of this landscape for the species.

Within the raptor community of the Thar Desert, the Tawny Eagle occupies a central ecological role as one of the largest resident breeding raptors in the landscape. As an apex predator and opportunistic scavenger, it interacts with a broad guild of sympatric raptor species. Its presence and breeding success are reflective of the integrity of the Thar's raptor community, and its decline would likely have cascading consequences for the trophic structure of the ecosystem (Sergio et al., 2006).

Targeted surveys and project reports from the landscape level in the Thar and adjoining arid zones have recorded Tawny Eagles as breeding residents or seasonal breeders, but long-term, quantitative data on nest success, demography, and habitat associations are limited.

1.3 Knowledge Gaps and rationale for the study

Despite playing an important role in functioning of the dryland ecosystem, the Tawny Eagle has received very little scientific attention in India. The nominal information available about the status of the species in India comes from old natural history accounts (Dharmakumarsinhji., 1955, 1972; Naoroji, 2006), or some recent multispecies surveys (Kher et al., 2024). Many aspects of the species' ecology are currently unknown and this is likely to hinder effective conservation planning. For example, lack of knowledge about the distribution of the species in all the regions that it is found is critical to planning conservation, but such information is not available from any part of its Indian breeding range. Similarly, there is virtually no information on aspects of habitat selection shown by this species. Diet There is a gap in our understanding

of their breeding ecology and habitat requirements; therefore, this study aims to understand these factors quantitatively and bridge this gap.

1.4 Study Area

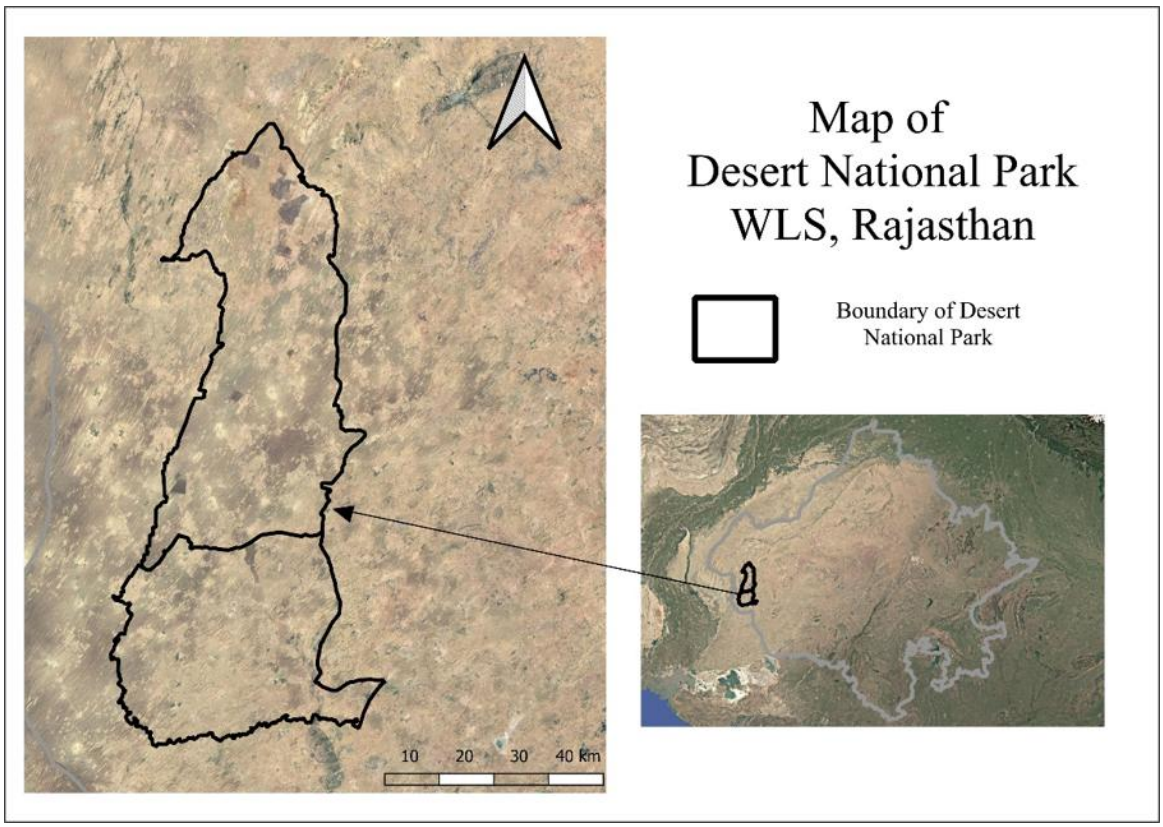

Figure 1: Map of the Study Area, Desert National Park WLS, Jaisalmer

This study was conducted in and around Desert National Park, situated in the Jaisalmer district of western Rajasthan within the Thar Desert biogeographic zone (Mani, 2012). This landscape contains some of the largest Open Natural Ecosystems in the Indian Subcontinent and is an important habitat for many species (Sen, 2025). Spanning roughly 3,162 km², DNP features a diverse landscape that includes protected grasslands, community rangelands, agricultural plots, dunes, and numerous human settlements (IUCN, 2018). Desert National Park is the largest protected area within the Thar–Cholistan Desert complex, and it has been recognised by BirdLife International as an Important Bird and Biodiversity Area (IBA). The area acts as an important breeding and stopover site along the Central Asian Flyway for many threatened and migratory species of birds (Ram et al., 2024). The arid climate, characterised by low and unpredictable rainfall (100–300 mm annually), frequent droughts, and extreme summer temperatures exceeding 50°C, shapes

the ecological dynamics of the region. The topography is dominated by stabilised dunes interspersed with flat interdunal valleys, many of which are seasonally cultivated and subjected to intensive livestock grazing. The absence of large mammalian predators further alters the trophic structure of the landscape, providing opportunities for avian predators and scavengers to occupy key ecological niches.

Given these characteristics, the landscape offers an ideal setting to study Tawny Eagles, a wide-ranging raptor that plays an important role as both a predator and a scavenger in arid ecosystems. Understanding their breeding ecology, resource use, and behavioural adaptations in this extreme and human-modified environment can provide crucial insights into how apex avian predators persist in open natural systems under increasing anthropogenic pressures.

Chapter 2: Objectives and Aims

1. To Understand the Factors Affecting Site Selection
    - *What are the factors affecting habitat selection?*
    - *What are the factors affecting nest site selection?*

2. To understand the Behavioural Ecology of Tawny Eagles
    - *What is the composition and frequency of prey items and other resources delivered by adult Tawny Eagles to their chicks across different stages of chick development?*
    - *How does the composition and frequency of prey items change across seasons?*

3. To Understand the Diet of the Tawny Eagles
    - *What is the overall diet composition of Tawny Eagles?*
    - *Is there a shift in diet across seasons?*

Chapter 3: Nest Site Selection and Distribution of Tawny Eagles

3.1 Introduction

Understanding the factors that influence the habitat selection of raptors is integral to both conservation planning and our broader understanding of the arid landscape that they thrive in. Occupancy and habitat selection of a species are a spatial expression of their ecological requirements, such as prey availability, available nesting sites, lack of human disturbance, and much more.

In India, the species still persists as fragmented populations across the arid regions of Rajasthan and Gujarat, yet we still do not know what factors drive their local distribution. The Thar Desert, with its mosaic of sandy plains, agricultural fields, scrub woodland patches and increasing human presence, is both a stronghold for the species and a zone of increasing pressure.

Site selection in raptors is governed by a large number of factors. At a fine scale, nest site selection is largely dependent on factors such as tree height, crown width and structure, and human disturbance levels. In an arid environment, additional factors such as changes in land use, the presence of livestock, roads, and human presence have been identified as some of the primary determinants of occupancy (Concepcion et al., 2018).

In the Thar Desert specifically, the landscape presents a mosaic of relatively intact arid savanna, pastoralist grassland, rain-fed agriculture, and rural settlement, set against a backdrop of expanding infrastructure and intensified land use. This mosaic creates a gradient of habitat suitability that offers an opportunity to understand the relative contributions of vegetation structure, prey availability, and human disturbance to eagle site selection.

One of the most important aspects of a raptor's breeding ecology is nest site selection. The area that a raptor chooses to nest in affects everything from their exposure to predators, the microclimate conditions of their nest, accessibility of foraging grounds, and their overall nesting success (Natsukawa & Sergio, 2022; Newton, 1979). Large eagles do not establish new nest sites each year . Instead, they maintain long-term territories that they occupy during successive breeding seasons. This means the features of a nest site have lasting effects on reproduction over time. Tawny Eagles prefer tall, emergent trees in open landscapes. These trees offer easy aerial access by flight and wide visibility across the area (Naoroji, 2006). In the Thar Desert, where trees are sparse and simple, finding a suitable nesting area may limit the distribution of breeding territories. Understanding the habitat features that predict nest site occupancy and how these characteristics relate to breeding success is essential for learning about the ecology of this population. It also helps identify the landscape elements needed to support sustainable breeding over the long term.

Based on previous observations in the study area, Tawny Eagles are known to be winter breeders that nest from October to April. They typically construct nests at the crown of solitary trees, open to the sky; they have also been recorded to construct their nest on powerline pylons. In the Thar Desert, they are usually observed to be nesting on *Prosopis cineraria* and *Acacia tortilis.* They construct their nests with sticks and twigs and tend to line the bottom with leaves. While some of this basic information is known, the distribution of the nests has not been explored systematically and drivers of nest site selection are unknown.

There are quite a few protected grasslands present within the boundaries of Desert National Park. These enclosures have been constructed by the Rajasthan Forest Department to

protect the critical breeding habitats of the critically endangered Great Indian Bustard, which is the flagship species for the park. These protected grasslands provide areas of high prey densities and high-quality nesting habitats due to reduced human disturbance and reduced grazing pressure. Tawny Eagles have been observed to be using these enclosures and their surroundings with a higher frequency, compared to areas further away from enclosures. This indicated that the presence of enclosures may have an impact on Tawny Eagle presence across the landscape.

3.2 Methods

3.2.1 Field Methods

A systematic nest search effort was conducted within and around Desert National Park, in Jaisalmer district. The nest search effort was concentrated in the breeding season from December to February. Nest search was done entirely through vehicular surveys. Main roads were avoided, and inner routes were chosen in order to maximise the coverage of the interior landscape and detection of nests. This method ensured that we did not encounter the problem of detection bias since we had surveyed all suitable habitats for nesting.

Once a potential nest was discovered, the structure was examined to determine species identity and occupancy. The nests were confirmed largely by direct observations of the adults on or in the nest. The nest locations were recorded and then mapped to understand their distribution across the study area. Next, the nest site characteristics were recorded, such as the tree species, GBH, tree height, nest height, and crown width. A total of 10 nests were found across the study area. These variables were selected to characterise the physical attributes of the trees with nests and to see how they compare across the landscape.

In addition to doing nest searches during the breeding season, we have conducted surveys to assess encounter rates of Tawny Eagles in the non-breeding season. Tawny eagle

presence and habitat use were assessed across a 36 km² study area using systematic vehicular transects. The study area was divided into 68 grid cells, within each of which 12–15 km was surveyed either as a single 12 km transect or as two 6 km transects, depending on the available roads and tracks present within the grid.

Surveys were conducted during April 2026 and were restricted to the early morning and late evening hours, when raptors were expected to be perched on trees, poles, or other elevated structures rather than in flight. This timing was adopted to maximise detection and ensure consistent behavioural states across all detections. The vehicle was driven at a speed of 20–40 km/h, allowing sufficient time for observers to scan the surrounding landscape.

Following each detection, we recorded the GPS location of the sighting. During the survey, we followed the double observer method (Nichols et al., 2000), where each survey was conducted by a group of 2. Both surveyors are actively looking for birds, and observations taken are combined.

3.2.2 Analytical Methods

All analyses were conducted in R (version 4.5.0) and QGIS. To visualise the nests found across the study, we created a map in QGIS. The locations of the nest were visualised along with the boundaries of the national park and the enclosures. In QGIS, we used the distance matrix tool to calculate the inter-nest distance. Using these values, the average distance between nests was calculated. Next, we used the shortest distance between features tool, to calculate the distance between the nests and the protected grasslands. This was done to see if the Tawny Eagles prefer to nest close to the enclosures, which are areas of higher prey densities.

We analysed the results of the nest site characteristics collected by visualising the average tree height, crown width, GBH, trunk height, and height of the nest. Standard errors were calculated and plotted as well to see the variation amongst nests.

To analyse the results of the raptor surveys conducted, we first mapped the locations of Tawny Eagle sightings using QGIS. Then, using R, we visualised the spatial distribution of Tawny Eagles sighted. We used the packages sf, ggplot2, and rnaturalearth. The Tawny Eagle sightings were extracted from the overall list of raptor sightings from the survey. The coordinates were converted to a spatial object. A two-dimensional binned surface density was generated using a bin size of approximately 6 x 6 (36^2 km) to visualise the encounter rate of Tawny Eagle sightings across the study area. Encounter rate was calculated grid-wise using the following formula:

$$Encounter\ Rate = \frac{Number\ of\ Tawny\ Eagle\ Individuals\ Sighted}{Transect\ Distance\ Surveyed\ (km)}$$

Encounter rates were calculated across the entire study area, including the grids where there were no Tawny Eagles sighted, to account for the sampling effort.

3.3 Results

A total of ten nests were found across the study area through a total of 4000 km of nest search effort. Nest search was done across an area of approximately 2000 km^2. Nest locations were mapped to give the following graph.

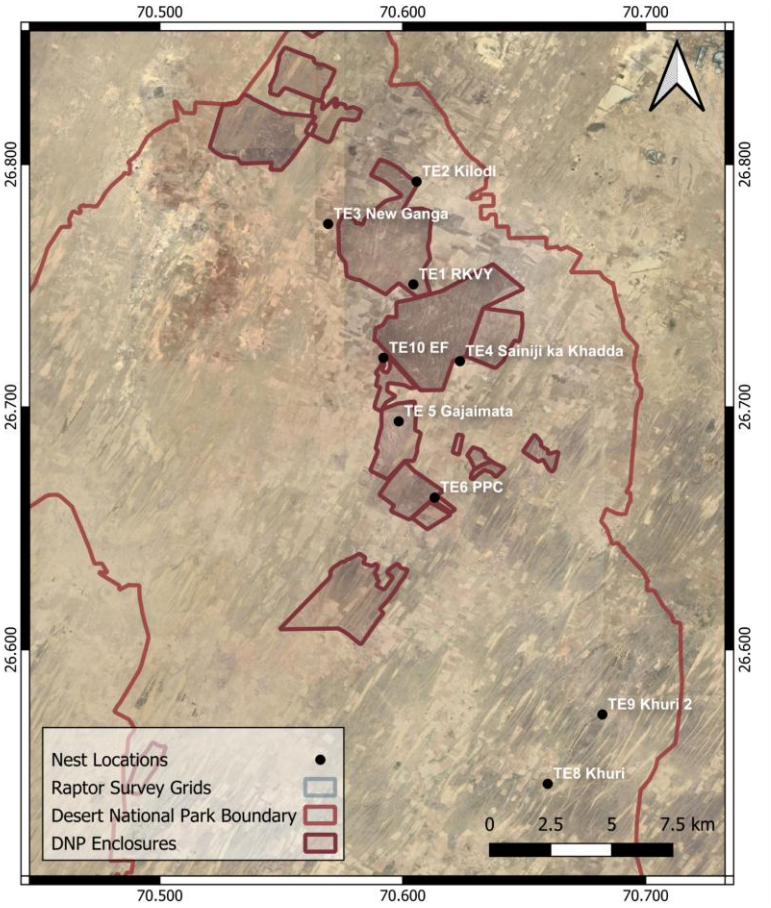

Figure: Map of Nest located across the Study Area in Desert National Park WLS, Jaisalmer

All the nests that were found to be within the national park boundaries, except for one found in the enclosures at Ramdeora. The nests we found appeared to be clustered together, and all the nests were in proximity to one another. The inter-nest distance was calculated in QGIS, and the values are given in the table below.

Nest ID	Nearest Neighbour	Distance
TE9 Khuri 2	TE8 Khuri	3.88
TE4 Sainiji ka Khadda	TE10 EF	3.14
TE1 RKVY	TE10 EF	3.57
TE 5 Gajaimata	TE10 EF	2.97
TE3 New Ganga	TE2 Kilodi	4.11
TE6 PPC	TE 5 Gajaimata	3.78
TE2 Kilodi	TE3 New Ganga	4.11
TE8 Khuri	TE9 Khuri 2	3.88
TE10 EF	TE 5 Gajaimata	2.97

Table 1: Minimum Inter-nest distance of two Tawny Eagle Nests in Desert National Park WLS, Jaisalmer

The average distance of the nests was calculated excluding the value for TE7 RCBC, as it was skewing the mean. The average distance between the nests was 3.6 km with a standard deviation of 0.45 km.

All the nests that were found were in proximity to the protected grasslands, so we calculated the distance between the nesting locations and the boundaries of the enclosures using QGIS. The distances are given in the table below.

Nest ID	Enclosure	Distance
TE9 Khuri 2	Maneri	9.332935
TE4 Sainiji ka Khadda	Sudasari_ACD	0.119175
TE1 RKVY	Sudasari_RKVY	Inside Enclosure
TE7 RCBC	Ramdeora	Inside Enclosure
TE 5 Gajaimata	Gajaimata	Inside Enclosure
TE3 New Ganga	Sudasari_RKVY	0.418618
TE6 PPC	Chauhani_PPC	0.018586
TE2 Kilodi	Sudasari_RKVY	0.054381
TE8 Khuri	Maneri	5.452238
TE10 EF	Sudasari_EF	0.219098

Table: Minimum Distance between Tawny Eagle Nests and Enclosures in Desert National Park WLS, Jaisalmer

From these distances, we calculated the average distance to the enclosure from a Tawny Eagle nest is 1.56 km, with a standard deviation of 3.2 km. From these calculations, we can assume that the Tawny Eagles show a preference to nest close to the enclosures.

The nesting tree characteristics collected across all nests were averaged and plotted along with the standard deviation to get the following graph.

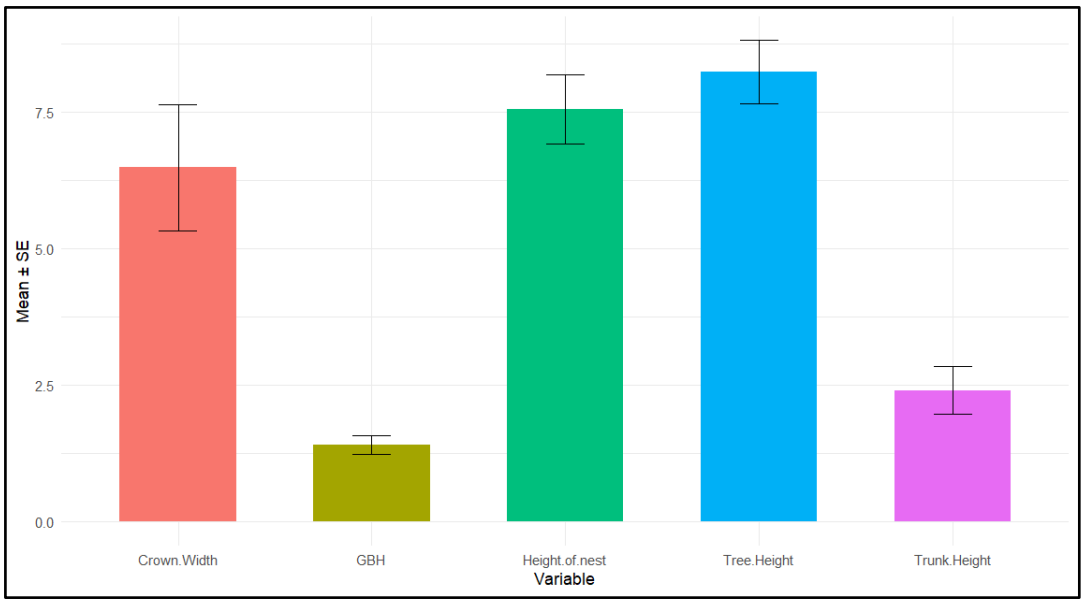

Figure: Tree Characteristics of Acacia tortelis and Prosopis cineraria trees, on which Tawny Eagle Nests were found, in Desert National Park WLS, Jaisalmer

Crown Width, GBH, Height of Nest, Tree Height, and Trunk Height were plotted to visualise the characteristics of the trees used by Tawny Eagles for nesting. From this graph, we can see that the average tree height is above 7.5 meters. The average height of nests constructed across the landscape was approximately 7.5 meters. The trees used for nesting have an approximate crown width of 6 meters, a GBH of 1.2 meters, and a trunk height of 2.5 meters. The nests were found mostly on *Prosopis cineraria,* with 8 out of ten nests constructed on trees of this species. The remaining 2 trees were found on *Acacia tortellis* trees.

Next, we moved on to analysing the data collected through the raptor surveys. The total survey effort was 734.78 km across an area of 2268 km^2, split into 63 grids. We had a total of 14 Tawny Eagle sightings throughout the survey. The sighting locations of Tawny Eagles were mapped on QGIS to create the following map.

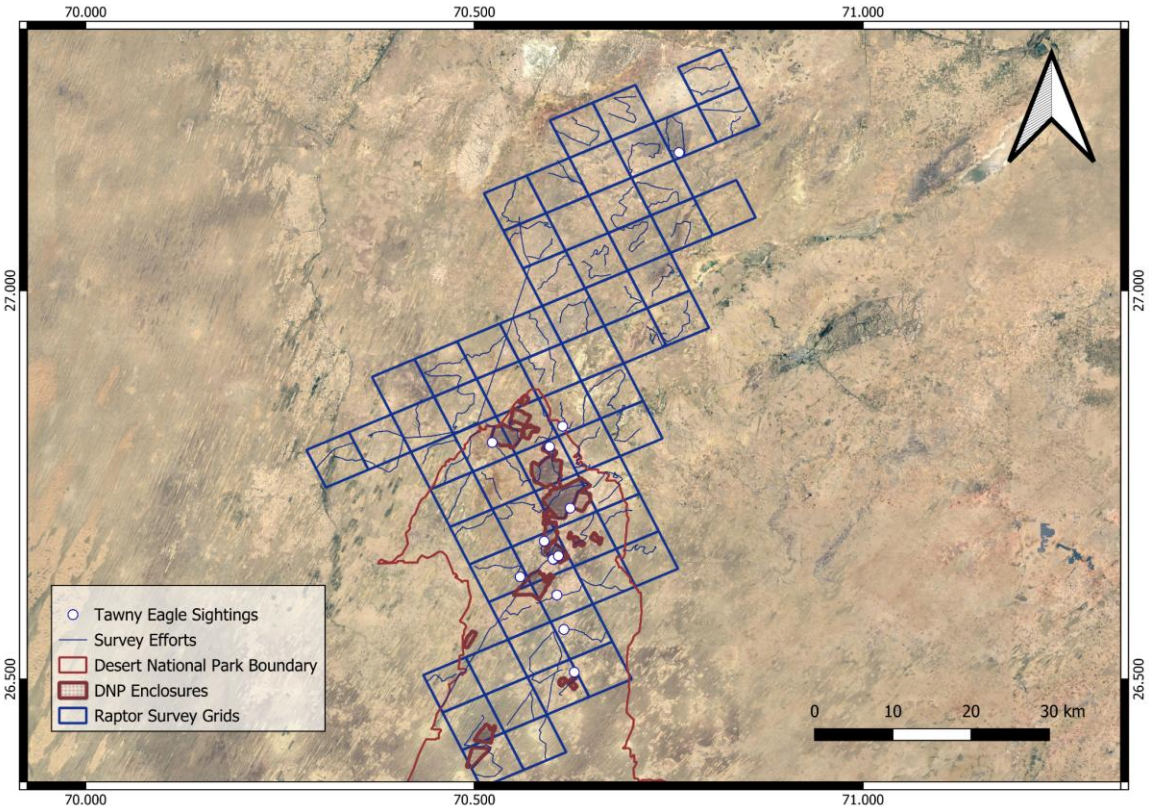

Figure: Map of Tawny Eagle Sightings and Survey Effort of raptor surveys conducted across the study area, in Desert National Park WLS, Jaisalmer

Most of the Tawny Eagle sightings were within the boundaries of Desert National Park. This suggests that the Tawny Eagles show a preference towards the protected grasslands within the Desert National Park boundaries. There were only two Tawny Eagle sightings outside Desert National Park throughout the surveys. The distribution of Tawny Eagle sightings was used to produce the following graph using R.

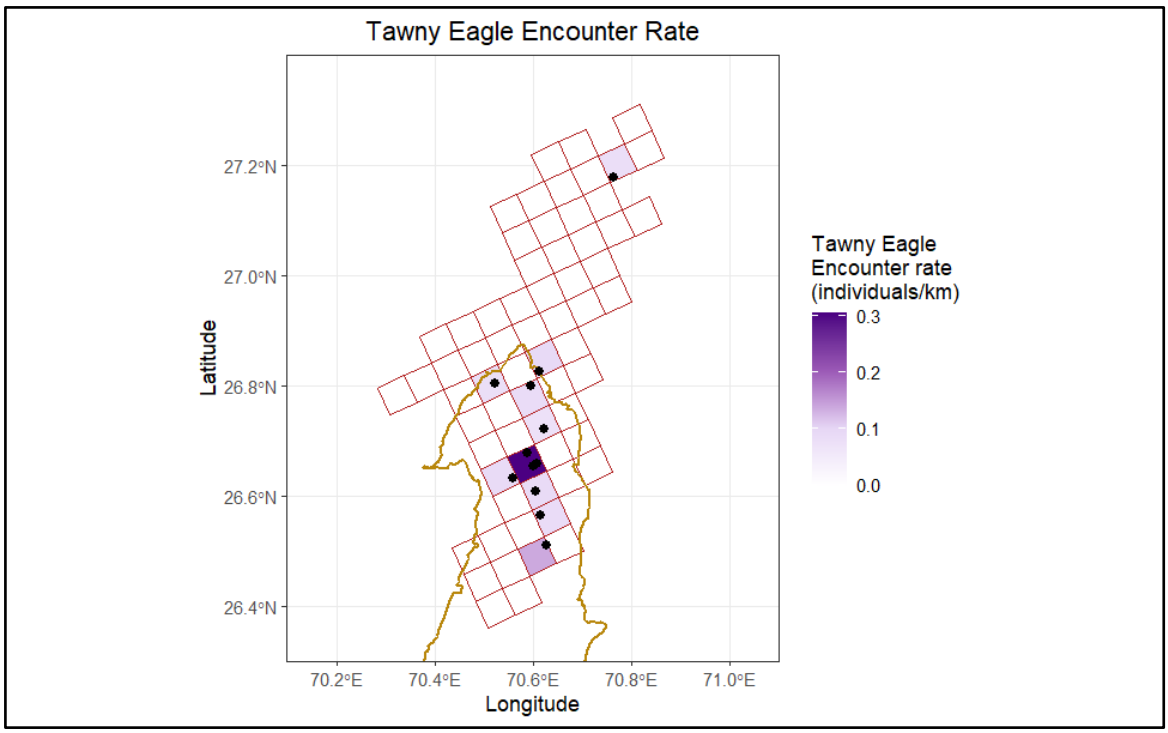

Figure: Encounter rates of Tawny Eagle Sightings during Raptor Surveys conducted in April 2026, mapped across the survey grids

This graph shows the encounter rates of Tawny Eagles across the surveyed area. Most of the sightings fall within the boundaries of Desert National Park, with the highest encounter rates and relative frequency of sightings.

A total of 63 survey grids were assessed for raptor occurrence, covering a cumulative survey effort of 734.78 km. Tawny Eagles were recorded in 14 sightings across the surveyed area, with one individual recorded per observation. The overall encounter rate of Tawny Eagles was 0.019 individuals km^{-1} (equivalent to 1.91 individuals per 100 km surveyed). Tawny Eagle detections were restricted to a subset of surveyed grids, indicating a relatively low occurrence rate across the study landscape.

3.4 Discussion

The results of the nest search effort provide very valuable insights into the nesting site preferences of the species. From the data we collected, we can see that all of the Tawny

Eagles have nested within the boundaries of Desert National Park. Upon further analysis, we can say that the Tawny Eagles in the study area show a strong association with the protected grasslands, with 8 out of ten nests found either inside enclosures or at a near-zero distance from the enclosures, with a mean distance of 1.56 km ± 3.2 km. The remaining 2 nests were still within range of the enclosures, considering the average daily distance covered by the species can be up to 88 km in the non-breeding season (Ram et al., 2024). The proximity to enclosures across all the nesting sites suggests that nest sites are actively selected to be in proximity to high-quality landscapes, with minimal human disturbance and grazing pressure. The enclosures are primarily established to protect GIB and grassland habitat; this is likely beneficial to the Tawny Eagles in the breeding seasons. The protected grasslands likely support higher densities of rodents and other small prey (Read & Cunningham, 2010), and preserve large trees that are often removed and lopped in areas of heavy grazing, reducing overall disturbance around the nest during the breeding period.

The inter-nest distance data show evident clustering of the Tawny Eagle nests around suitable nesting locations, with an average distance between nests of 3.6 km ± 0.45. This provides further support for the idea that nests are concentrated around a limited number of suitable nesting habitats. This suggests that the underlying driver of nest-site selection is more likely to be proximity to enclosure, rather than proximity to neighbouring nests. From previous literature, we know that the inter-nest distance between nests of Tawny Eagles has been recorded to be much larger (Herholdt et al., 1996) than the distances recorded in this landscape. This provides further support for the theory that nests are clustered around suitable nesting habitats in proximity to the enclosures.

An important point of consideration is raised by the low number of nests located across the study area. Does this reflect a scarcity of breeding individuals in the population, or does it reflect a scarcity of suitable nesting habitats, regardless of the breeding individuals in the population? The data collected is insufficient to answer these questions conclusively, but it can provide partial evidence to distinguish between these two possibilities.

If the breeding population of Tawny Eagles in the study area was limited, we would expect to find a low number of nests, distributed in a relatively uniform manner across the study area, since the population would be scarcely distributed, nesting wherever suitable landscapes exist. On the contrary, the nests found in this landscape were very tightly clustered together and around the enclosures. This kind of clustering suggests that the low nest number is a result of habitat limitations rather than a low breeding population. The low nest number may be evidence for a lack of suitable nesting sites across the 2000+ km^2 study area, since most of the nests are clustered in a certain area, with only a small number of trees meeting the structural requirements to be suitable for nesting. Under this interpretation, the breeding population across the study may be higher than 10 pairs, but they are constrained by suitable nesting habitats.

The results of the raptor survey lend support to the alternative explanation. The encounter rates of Tawny Eagles across the surveyed area were 0.019 individuals per km, with only 14 Tawny Eagle sightings throughout the entire survey. This indicates that Tawny Eagles are detected very infrequently, even outside the nest search effort. If habitat were the only limiting factor, we could expect to find a larger pool of non-breeding or unsuccessfully breeding individuals through the general surveys conducted. The low encounter rate across

the survey suggests that the population in the study area may be small, rather than a larger population with a limited nesting area.

The findings from this chapter should be interpreted cautiously, since the sample size is very limited. It is difficult to conclude habitat selection and nest site selection from a sample size of ten nests and fourteen individual sightings of Tawny Eagles. Although we can see that there is a strong preference towards the enclosures for nesting, there is a skewed mean with a high standard deviation, due to two nests being further away from the enclosures compared to the other nests, which were either inside the enclosure or in their direct proximity. A larger multi-year dataset, ideally combined with information on nesting success and productivity, will help confirm whether the apparent preference for proximity to enclosures is providing a fitness benefit or reflects a limited availability of large nesting trees elsewhere.

When pooled, the nest site distribution, tree-use patterns, and Tawny Eagle sightings across the study area all suggest that there is an important role played by the protected grasslands in supporting the Tawny Eagles' breeding and nonbreeding population, as foraging and nesting grounds. The continued maintenance of these grasslands may have a direct impact on the long-term persistence of the species in the landscape and therefore should be considered along with the other conservation priorities of the landscape.

3.5 Conclusion

This chapter aimed to characterise the nesting habitat and distribution of Tawny Eagles in and around Desert National Park. Nest searches, raptor surveys, and nest site characterization were conducted across a study area of approximately 2000 km^2. The results

point towards a strong association between Tawny Eagle nesting and protected grasslands within the park, with nine out of ten nests located either within the enclosure or in direct proximity to the enclosure. The majority of the sightings of Tawny Eagles during the raptor surveys also fell within the boundaries of Desert National Park. Nesting trees were also characterised and were found to be of substantial height, girth, and crown width.

The overall scarcity of Tawny Eagle nests and sightings across the study area indicates that they are an uncommon species in the landscape. We cannot say for certain whether this scarcity in sightings is due to a small breeding population, a lack of suitable nesting habitats outside the enclosures, or a combination of both factors that cannot be completely explained by the data collected in this study.

Overall, the findings of this chapter suggest that the enclosures within Desert National Park, established primarily for the protection of GIBs and grasslands, provide benefits for the Tawny Eagles as both nesting and foraging grounds. From a conservation standpoint, this provides evidence for the continued protection of these grassland habitats and potentially for consideration to create new enclosures. Protecting suitable nesting trees from felling and lopping in areas surrounding Tawny Eagle detections is very important as it will ensure the continuation of the species in this landscape. Future work should incorporate multiple years of data, with nesting sites, nesting success, and characterization of suitable but unoccupied trees across the landscape. This would further our understanding of the relative effect of population size and availability of suitable nesting habitat on the number of nests found and strengthen the evidence for any relative conservation measures to be undertaken.

Chapter 4: Breeding Ecology of Tawny Eagles

4.1 Introduction

Breeding ecology covers all behavioural, physiological, and ecological processes that impact reproductive effort and success. Large raptors have a longer breeding period than the rest of the avian community. They produce small clutches, are slow to mature, and they invest heavily in their offspring. Compared to smaller and more productive species that can compensate for breeding failure through sheer reproductive output, large raptors cannot recover quickly from sustained reproductive failure. They usually breed only once a year, and in cases where the breeding attempt fails, it likely means that they have lost their reproductive output for that year. The breeding ecology of raptors, from nest site selection, breeding season, division of parental duties and reproductive success, is an important area of study because it allows us to understand the species and the health of the ecosystem that they are a part of.

Natural history observations from the past show that the Tawny Eagle typically has a clutch size of 1 to 2 eggs; occasionally, they have been recorded to have a clutch size of 3. They usually rear one chick to maturity. Their incubation period lasts around 42- 44 days. The bulk of the incubation is done by the females, and they are occasionally relieved by the males. The fledging period has been observed to be approximately 75 days (Naoroji, 2006). Although these broad parameters of the Tawny Eagle's breeding biology have been documented at a species level, there has been limited quantitative study done on the breeding biology of Indian populations, and the factors that drive reproductive success, individual pairs and territories remain poorly understood. We have a baseline understanding of nest placement, clutch size, and developmental periods (Dharmakumarsinhji, 1955; Naoroji, 2006), but we have limited knowledge of the

variations of breeding behaviour, such as incubation periods, provisioning periods, number of provisioning events happening in a day, etc. In the Thar Desert, breeding takes place in the winter season, a time when prey availability shifts drastically, and the climate also undergoes significant shifts. This chapter tries to build upon existing natural history knowledge by examining the breeding ecology of eight monitored Tawny Eagle nests found in the Jaisalmer district of the Thar Desert during the 2025-2026 breeding season. It documents their behaviour across the nest stages from incubation to fledging and attempts to describe their timeline, time activity budget of the birds, and provisioning rates.

4.2 Methods

4.2.1 Field Methods

Behavioural data was collected through two independent approaches complementary to each other. Direct focal observations were conducted in the field, and the nests were continuously monitored using CCTV cameras. The two methods differed in temporal coverage and the nature of the behavioural data that they produced. Together, they were able to provide a more exhaustive record of their breeding behaviour than either method could have individually.

4.2.1.1 Focal Observations.

Direct focal observations were conducted at active nest sites from December till the 15th of February. Observations were conducted from a stationary position around 100 to 200 metres away from the nest to minimise the disturbance to the adults, while also maintaining visibility of the nest and its surroundings. All observations were made using a spotting scope.

Sampling was done in two separate sampling blocks of 4 hours, getting 8 hours of observations per day, morning and evening. The morning session started at 8 am and went on till 12 pm. The evening session started from 3 pm until 7 pm. This sampling procedure was designed to capture the periods of highest activity at the nest and avoid the midday hours, during which raptor activity is mostly limited to soaring, reducing activity at the nest. During each session, all behaviours occurring at the nest were recorded, such as incubation periods and prey deliveries.

4.2.1.2 CCTV Nest Monitoring

CCTV cameras were at 4 active nest sites from the 10th of January to the 27th of January, providing continuous video footage during the day through the remainder of the breeding season. The cameras were positioned to provide a clear view of the entire nest and as much of the crown of the tree as possible. This allowed us to reliably identify the individual behaviours, prey items delivered to the nest, and by which bird.

All the CCTV footage was reviewed in its entirety, rather than sub-sampling, to understand the full daily time-activity budget. This ensured that infrequent events that hold ecological significance were not missed through subsampling, such as siblicide, prey deliveries, and nest predation.

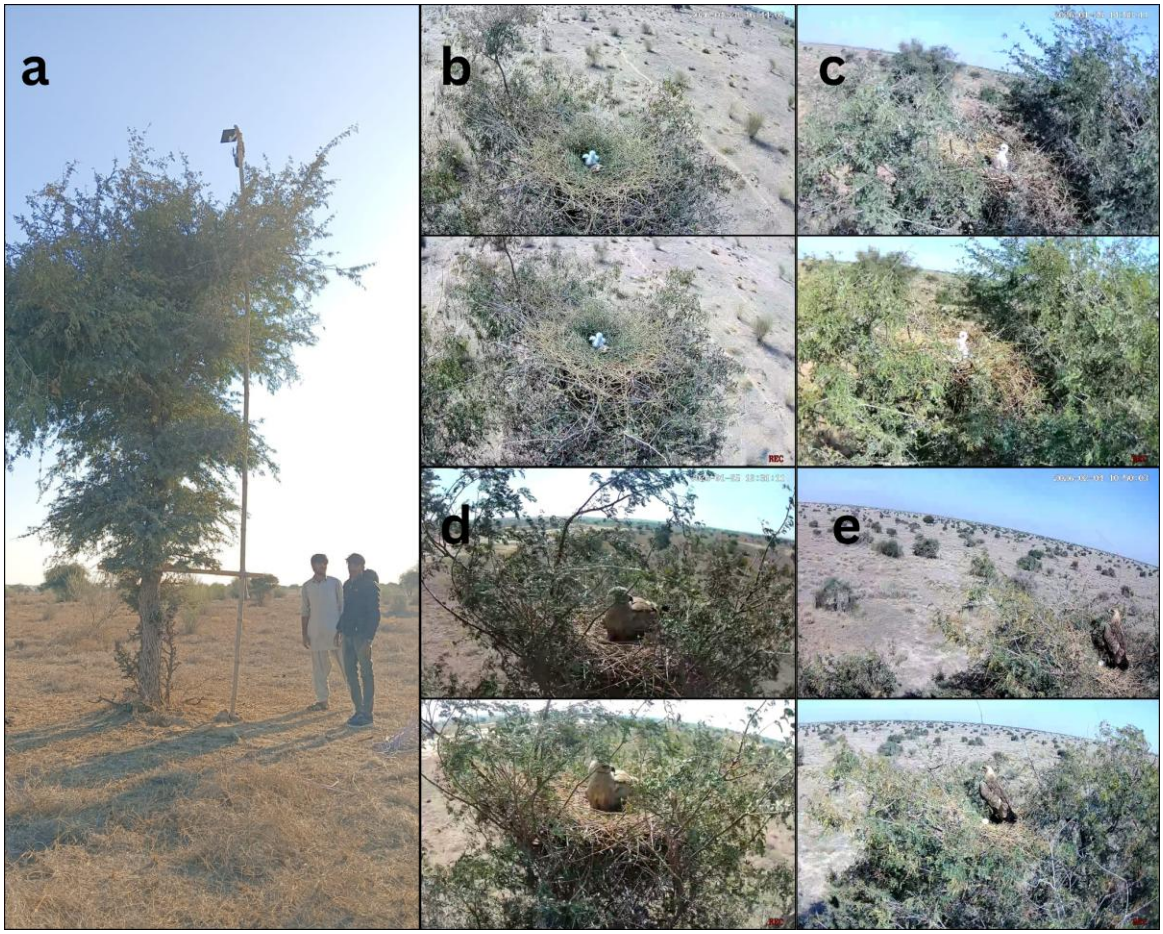

Figure 2: CCTVs set up (a) CCTV setup at the Gajaimata Nest, (b,c,d,e) view from the CCTV Cameras from the four nests recorded, in Desert National Park WLS, Jaisalmer

A significant portion of the CCTV dataset was lost due to a hardware malfunction that resulted in a loss of most of the footage from February, March, and the majority of April as well. Usable footage was recovered only from the final weeks of April, capturing only the fledging period and the period directly preceding that. The behaviour analysis should be interpreted keeping this limitation in mind and with the understanding that it does not cover the entire nesting period.

4.2.2 Analytical Methods

All analysis was done on R. Since a substantial portion of the dataset was lost, we have not attempted to draw any patterns from the data left over. We have used descriptive methods to visualise the data. We have made time activity budgets to understand what behaviours are exhibited throughout the day. To understand what behaviours were exhibited across the day, graphs were made to understand the mean proportion of time spent on each behaviour across the day. We also looked at the "Deliver" behaviour to see the number of prey items brought back by the adult birds per day. To further understand the feeding behaviours, we looked at the mean number of feeding attempts by the chick and provisioning attempts by either adult bird across the months.

All graphs have been scaled to account for the variation in daily sampling effort before visualisation and analysis. For the Time-Activity budget, the proportion of each behaviour theme, relative to total observation time, was calculated for each individual per day. The proportions were averaged across the days within a month, and zeroes were assigned to the days where a certain theme was absent. This ensured that these values were calculated as a part of the overall mean, rather than being excluded, causing the proportions to skew towards other, more frequently exhibited behaviours. When visualising provisioning, all the delivery events were scaled by the rate of deliveries per hour. This was calculated by dividing the total number of delivery events by the total observation time in minutes, to then scale it to an hourly rate. This allowed us to compare the provisioning rates across the months. We visualised the mean number of feeding attempts across months as well. This was done only from the CCTV data, since feeding behaviours were only observed in the CCTV footage.

4.3 Results

4.3.1 Time-activity budget

We have behaviour data collected across a span of 74 days. Out of these days, we have 32 days of CCTV footage and 42 days of focal behaviour observations. Overall, we have data for the Tawny Eagle's behaviour at the nest for approximately 900 hours. Out of these 900 hours of data, approximately 230 hours are from direct focal observations and the remaining 700 hours have been annotated from CCTV footage. Using this data, we first constructed a time-activity budget to see how much time is being spent on different behaviours. The behaviours were classified into themes to be more interpretable in a graph.

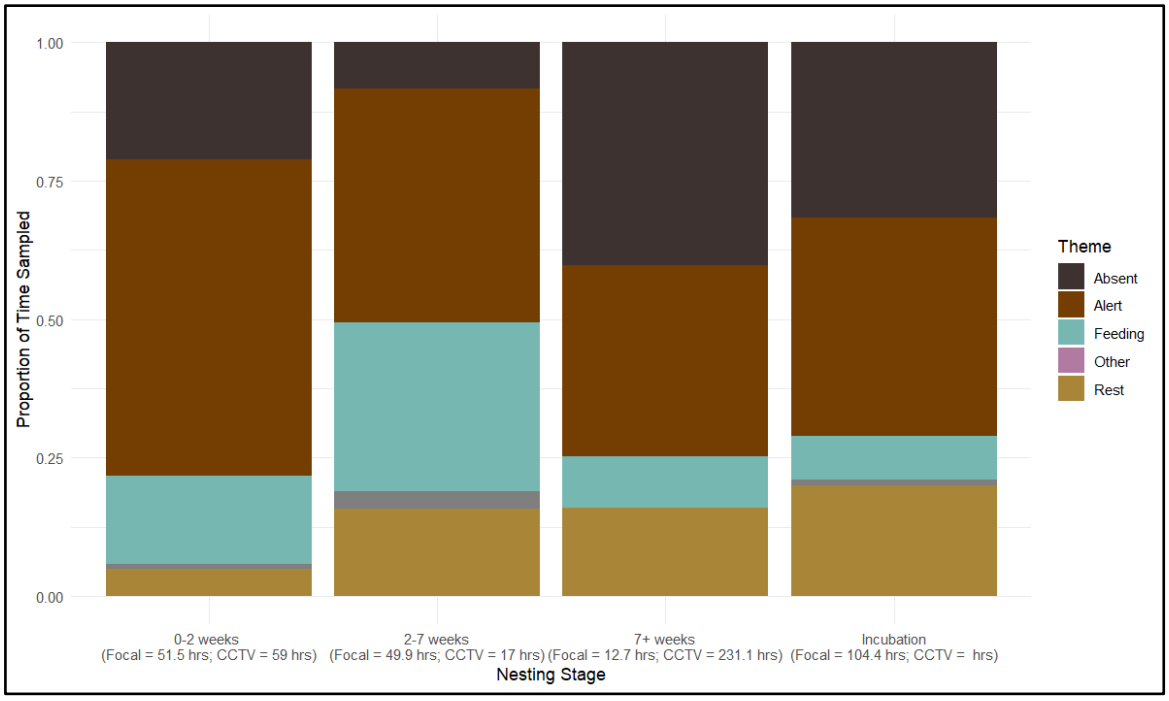

Figure: Time-activity Budget for the Female Tawny Eagles, from the sampled nests in Desert National Park WLS, Jaisalmer

The time activity budget was visualised across nesting stages rather than looking at their overall time activity budget, to see if there was any significant shift in behavioural patterns

and shifts across the nesting stages. Females were observed to spend the least amount of time away from the nests and the most amount of time feeding during the hatchling stage of the chick, aged between 2-7 weeks. An increase in time spent away from the nest can also be observed later in the season. This suggests that there is an increase in time spent away from the nest in later nesting stages, as the chicks grow older.

To understand what behaviours were exhibited across the day, the mean proportion of time spent on behaviours was visualised. Behaviour themes were used here as well.

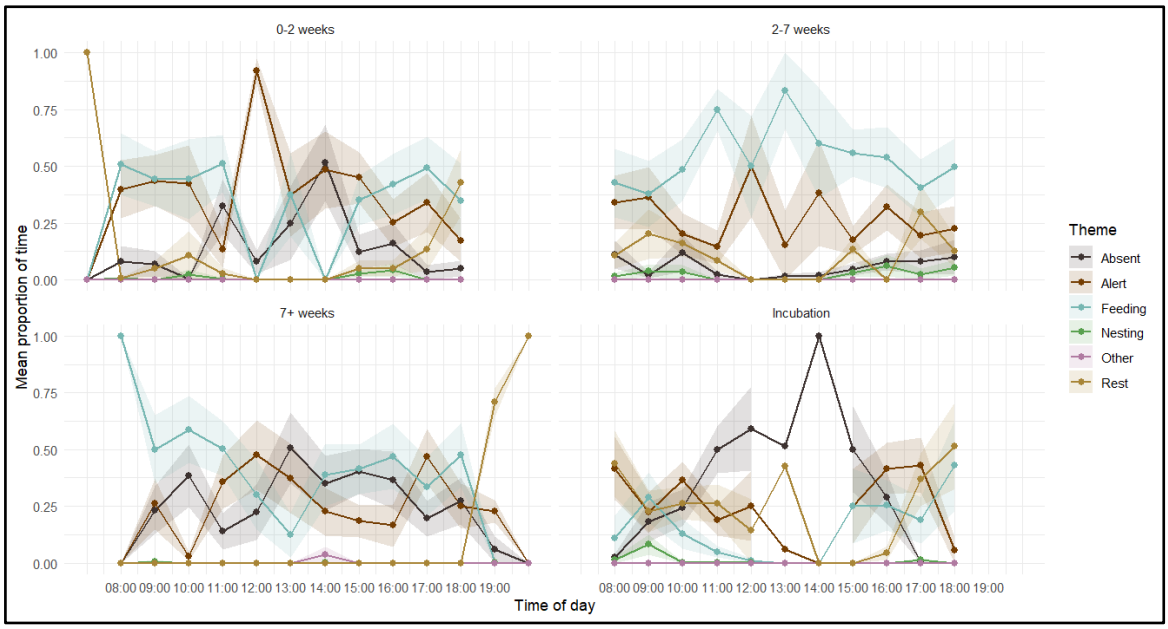

Figure: Proportions of time spent on each different behaviour themes by the Tawny Eagle females, across the, from the sampled nests in Desert National Park WLS, Jaisalmer

The female showed an evenly distributed behavioural budget, with alertness and absence from the nest being the most prominent themes. There is a shift in behavioural patterns across the nesting stages. During the Incubation phase, the females spent a distinct period between 12-3 pm absent from the nest. During the hatchling stage (0-2 weeks), alert behaviour was shown consistently throughout the day but was shown consistently at 12pm, while absence bouts were observed at around 2pm, likely corresponding to foraging bouts. Rest increased towards the end of the day. The Nestling stage (2-7 weeks) showed a much

more balanced distribution of behaviour proportions. Absence at the nest is much lower than in the previous nesting stages with feeding being the behaviour theme with the highest proportions across the day. Feeding peaks at midday. By the Fledgling stage the behaviours exhibited across the day became even more balanced, with almost equal proportions of all behaviours being exhibited throughout the day.

Feeding was consistently present throughout the day at low but stable levels across nesting stages. Compared to the chick, the female showed lower day-to-day variability in her behavioural budget, reflected in the narrower standard error bands across most themes.

Time activity budgets were made separately for the adult females and the chicks. Since the male has only been observed visiting the nest to deliver prey, and rarely spends time on the nest, time activity budgets could not be made.

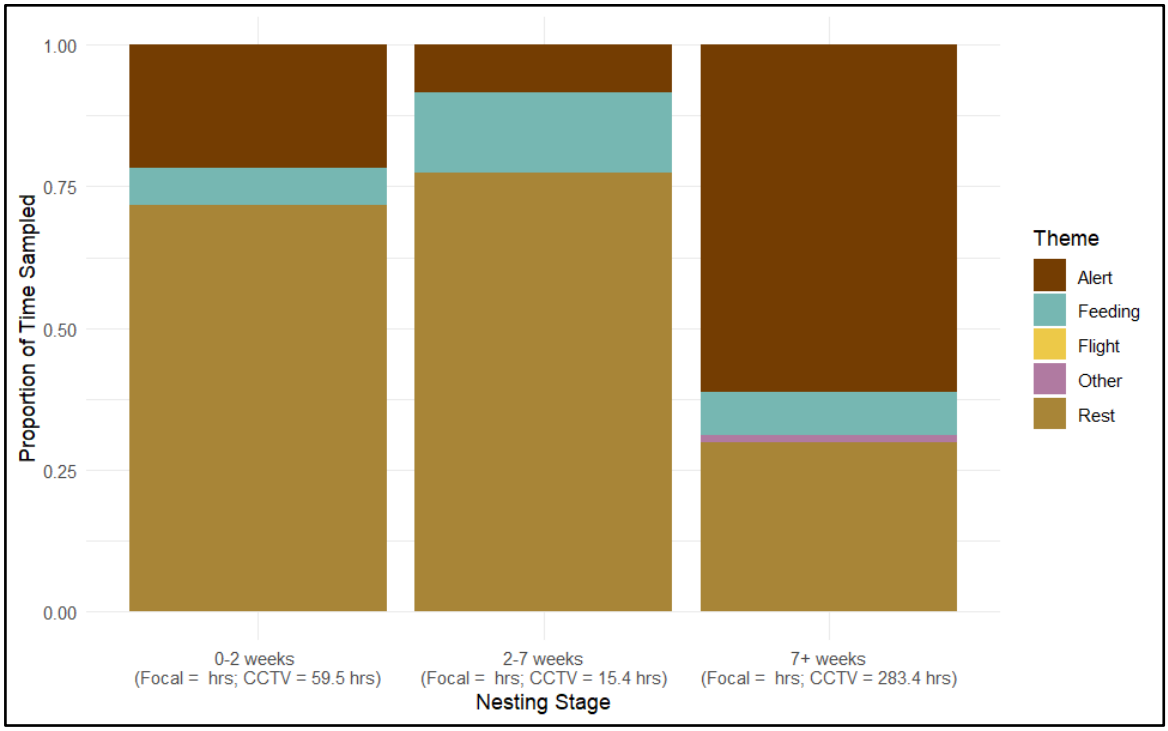

Figure: Time-activity Budget for the Tawny Eagle chicks, from the sampled nests in Desert National Park WLS, Jaisalmer

The time activity budget of the chick shows that the chick spends more time alert as it matures in age. Time spent on feeding seems to remain constant overall. Once again, behaviours exhibited across the day were visualised.

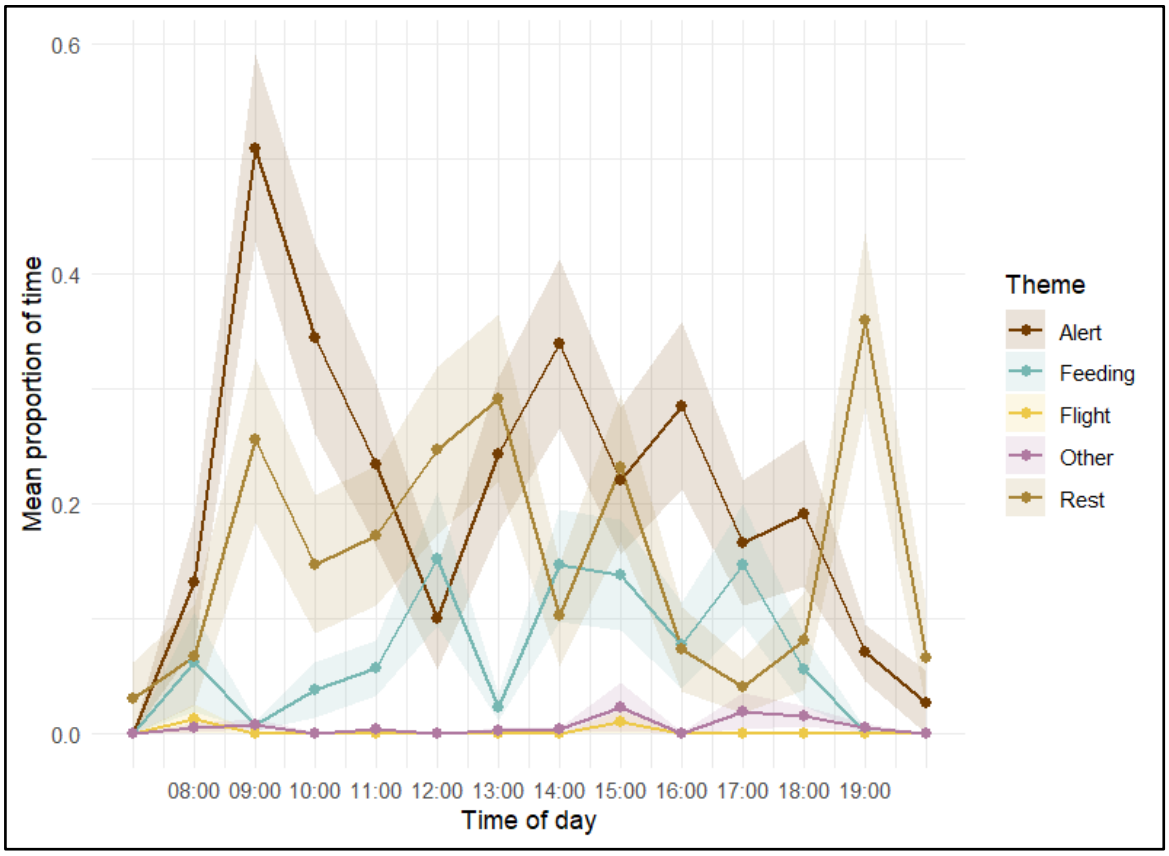

Figure: Proportions of time spent on each different behaviour themes by the Tawny Eagle chicks, across the, from the sampled nests in Desert National Park WLS, Jaisalmer

The chick spent most of its time displaying vigilance behaviour and being Alert. The Alert behaviour seemed to peak in the morning at 9:00 and then decline across the rest of the day. Rest behaviour followed a different pattern, with a high frequency in the middle of the day and then again late in the afternoon. This suggests that the chicks alternate between vigilance and rest across the day. Feeding remained consistently low, reflecting the chick's dependence on parental provisioning.

The wide standard error bands around alert behaviour indicate considerable day-to-day variability in chick vigilance, particularly during the morning peak. Flight attempts and other behaviours contributed minimally throughout the day.

4.3.2 Provisioning Behaviour

Prey deliveries were visualised across the months sampled. This was further split by Sex, making the columns for male and female deliveries separate. First, we visualised the number of prey deliveries per prey species by either the male or the female.

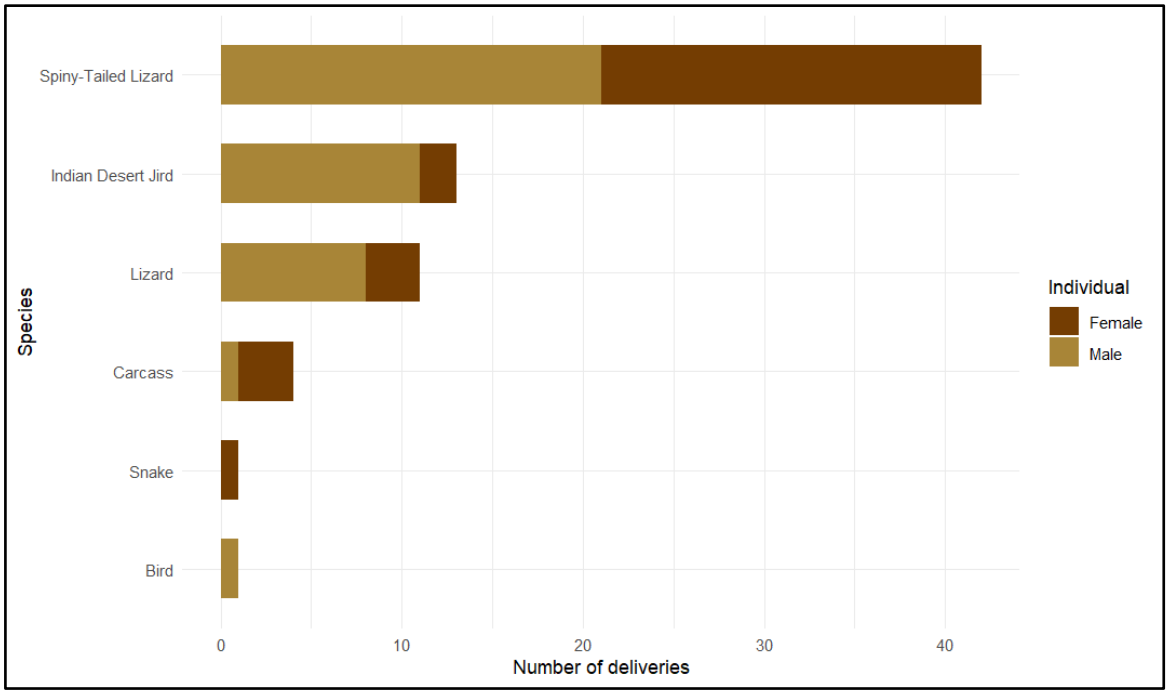

Figure: Prey deliveries by Male and Female Tawny Eagles, across four Tawny Eagle Nests in Desert National Park WLS, Jaisalmer

Spiny-Tailed Lizards were the dominant prey item delivered by both males and females overall. They account for over 40 out of the 78 deliveries made by either sex. The Indian Desert Jird and unidentified lizards were the second and third most common prey brought back to the nest. Although Carcasses, birds, and Snakes were brought back to the nest, they were brought back infrequently. The male seems to be the primary provisioner, with

males being responsible for bringing back 43 of all provisioned items across the sampling period.

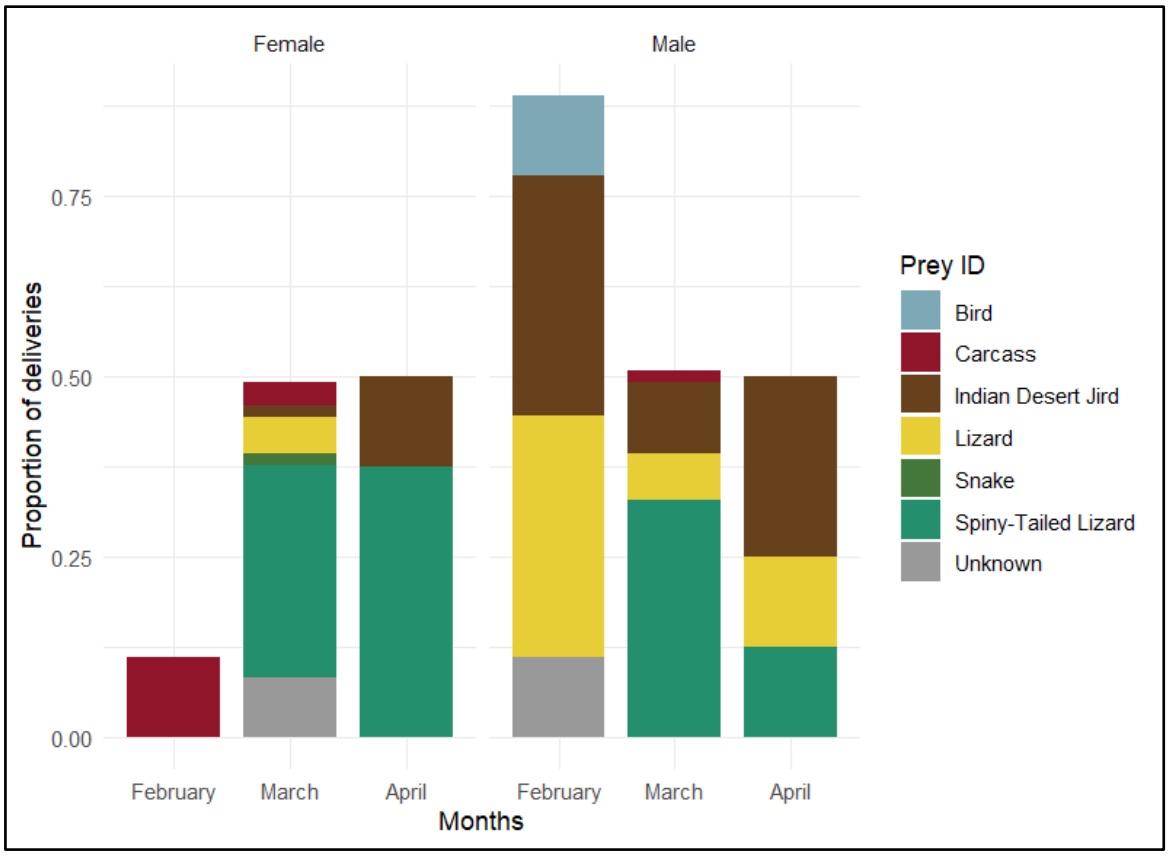

Figure: Prey deliveries by Male and Female Tawny Eagles, across months of four Tawny Eagle Nests in Desert National Park WLS, Jaisalmer

The prey preference across months changed considerably. There is a notable shift in prey composition across months for both sexes. In February, the deliveries brought back to the nest by the male were highly varied, with high proportions of Indian Desert Jirds and unidentified lizard species. Spiny-tailed lizards were the dominant prey species in March and April. The female showed limited prey diversity in February, only delivering carcasses to the nest. The prey items brought back by the female diversified by March and April, with Spiny-Tailed Lizards becoming the dominant prey species. The Eagles likely

show a preference towards the Spiny-Tailed lizards due to their increased activity and availability post winter.

4.4 Discussion

The behavioural data we collected gives us insights into how the female and chick spent their time at the nest. From the data we collected, we can also begin to see patterns forming across the breeding season. The female was observed to spend the most time feeding and the least time away from the nest in February. There is an observable increase in the time spent away from the nest in the later stages of chick development. This aligns with a shift in parental requirements: chicks require less brooding as they mature, giving the female more time to spend foraging away from the nest. This shift has been documented in other Aquila species, where females spent more time away from the nest with increased chick age (Ellis, 1979).

Female behaviour was seen to change with the age of the chicks in the nest. The proportion of behaviours across the day became much more balanced as the chick got older. At the nestling stage, feeding behaviour was the most common, with feeding happening throughout the day and peaking at midday. Absence periods were largely observed in the late mornings and late evenings, likely corresponding to foraging bouts. During the incubation period, there was a sharp peak in time spent away from the nest during the period of 12-3 pm. The proportion of rest increases towards the end of the day, with activity reducing after 18:00. Feeding behaviours seem to be exhibited consistently across the day at all other chick stages, suggesting that feeding happens opportunistically rather than at dedicated sessions.

The chick's activity shows that it spends more time alert as it matures. The increased vigilance across the breeding season is consistent with the development with the accounts of chick behaviour seen in other nestling raptor species of the Aquila genus. It seems that their vigilance increases with age, with increased standing and sitting bouts (Ellis, 1979). The high variation in alertness is largely due to the fact that the graphs were made with the data across the nesting periods and differing levels of daily disturbance. Time spent feeding largely remains constant throughout the season. This is expected since the chick is dependent on the parental provisioning frequencies.

Spiny-Tailed Lizards (*Saara hardwickii*) were the dominant prey species delivered to the nest by both male and female birds across the breeding period. Males seem to be the primary provisioners, with females bringing back prey at a lower frequency. This was similar to the patterns observed in other large-bodied raptors at the time of nesting (López-López et al., 2022). The notable shift towards Spiny-Tailed Lizards from March onwards likely reflects the increased activity of Spiny-Tailed Lizards after the temperatures warm up. The high prey diversity in the earlier months of the breeding period suggests a degree of dietary flexibility that lines up with the Tawny Eagle's classification as a dietary generalist.

4.5 Conclusion

This chapter provides an in-depth account of the behavioural patterns and provisioning strategies across nine nests of Tawny Eagles breeding in Rajasthan. The data collected gives a clearer understanding of this species' time activity budgets, changes in behaviour with seasonality, and division of parental labour.

From the data collected, we can see that there is a clear difference in parental care by the males and females at the nest. The male acts as the primary provisioner, spending very little time at the nest but bringing back prey periodically. The female largely takes up the responsibility for brooding and nest attendance. There is a shift in the amount of time spent by the female on the nest as the chick matures in age, as well as a shift in the amount of time spent being vigilant by the chick.

The dominance of Spiny-Tailed Lizards as the seasons shift indicates that the eagles show a strong preference towards them as prey. Together, these findings provide a baseline understanding of nest attendance, division of parental behaviour, and time activity budgets in the Indian population of Tawny Eagles. The findings of a shift towards Spiny-Tailed Lizards in the later, warmer months lay the groundwork for the next chapter, which will delve deeper into the diet and nutritional ecology of the Tawny Eagles.

Chapter 5: Diet Composition

4.1 Introduction

Diet is one of the most important parts of a predator's ecology. Prey availability is one of the biggest constraining factors for a large raptor, determining not just where they can settle and breed but how well they are able to provide for their chick during the nesting season (Newton, 1979). Understanding the diet of large raptors and how it is affected by seasonality and stages of chick development is an important aspect of foraging ecology, habitat use, and breeding success, making dietary studies central to understanding species ecology.

The Tawny Eagle has been characterised as a dietary generalist and an opportunistic scavenger (Naroji, 2006). They hunt live prey, poach prey from other raptors, and readily feed on carcasses as well (Hustler & Howells, 1986). This may be an adaptive response to unpredictable and often sparse distribution of prey in the desert landscapes, since having a large dietary breadth, especially during the breeding season, may protect them from prey failure. Although we have a baseline understanding of the Tawny Eagles' diet, systematic quantification or study of their diet, especially from the Indian population, is poorly understood. The effects of seasonality on prey and the effects of the different energetic requirements across nesting stages are understudied.

The Thar Desert provides an interesting backdrop to study the breeding and foraging ecology of the Tawny Eagle. It is one of the few winter breeders of the landscape, breeding during a period of reduced reptile activity and substantial temperature shifts. Due to these factors, it makes it an ideal study specimen to examine how seasonality affects a generalist raptor's diet.

The Tawny Eagle has a wide dietary breadth that ranges from small insects such as locusts to small mammals. Their diet largely consists of prey such as small rodents and reptiles, showing a preference for Spiny-Tailed Lizards (*Saara hardwickii*) in the Thar Desert. They have been recorded to pirate the kills of other raptors (Naoroji, 2006). They hunt smaller birds and snakes on occasion as well. They have also been observed to hunt larger prey, such as bigger birds like the Common Crane (*Grus grus*) and the Lesser florican (*Sypheotides indicus*) (Dharmakumarsinhji, 1955).

From previous literature, we have a broad understanding of the diet composition of the Tawny Eagle. We know that the species has been characterised as a dietary generalist that can also be an opportunistic scavenger (Naoroji, 2006). However, no quantitative study has been done on their diet composition at a species level. We know that they are predators capable of consuming anything from insects to large mammals such as foxes as well (Naoroji, 2006), but we do not know how their diet composition shifts seasonally, or how it changes with nesting stage. These questions are especially relevant in a landscape like the Thar Desert, where breeding occurs during a period of ecological change. The Tawny Eagles breed during the winter months (Dharmakumarsinhji, 1955; Naoroji, 2006), when prey activity, especially the activity of reptiles such as Spiny-Tailed Lizards, lessens significantly (Ramesh & Sankaran, 2013). The breeding period spans through to the warmer months of March and April, after reptile activity significantly increases. The Tawny Eagle is one of the few winter breeders in this landscape, making it a good study species to understand how seasonality influences the diet of a generalist predator in a single breeding season.

This chapter focuses on a dietary dataset collected across nine active nest sites in the Jaisalmer district during the 2025-2026 breeding season to examine the diet composition

in detail. It attempts to characterises the overall diet composition of the Tawny Eagle at a taxa level and tries to examine how the composition changes across the month and across the different nesting stages. We try to evaluate the degree of individual diet variation amongst the different nests as well. Together, these analyses try to provide a detailed quantitative account of the Tawny Eagles' diet from the Indian population.

5.2 Methods

5.2.1 Field Methods

5.2.1.1 Data Collection Overview

Diet data was collected across nine Tawny Eagle nests from December 2025 to April 2026. Data was collected through three complementary methods: the regurgitated pellet collection, CCTV nest monitoring, and drone surveys. All methods were not used at every nest. All the prey records from the three methods were compiled into a single dataset. The prey items were broadly classified at the taxa level, giving us the categories Reptile, Mammal, Bird, Carcass, and Unknown.

5.2.1.2 Pellet Analysis

Regurgitated pellets were collected opportunistically during nest visits. Pellets were collected from six different nesting sites: TE1 RKVY, TE2 Kilodi, TE3 New Ganga, TE5 Gajaimata, TE6 PPC, and TE8 Khuri. Pellets were either collected from the ground directly underneath the nest or found within a 10m radius around the nest. Each pellet was coarsely examined macroscopically, and the remains present within each pellet indicated what prey was being consumed by the Eagle. The presence of feathers indicated avian prey, hair indicated mammalian prey, and the presence of skin fragments indicated reptilian prey. When a single pellet contained records of more than one prey taxon, each one was entered

as a separate record. Since the pellets were not analysed in the lab, all classifications were kept to the taxa level, and species-level identification was not attempted from the pellets.

Figure: Average size and appearance of pellets collected

5.2.1.3 CCTV Nest Monitoring

CCTV cameras were installed at four nests, TE1 RKVY, TE3 New Ganga, TE5 Gajaimata, and TE6 PPC, from approximately mid-January onwards. Cameras were placed to get a clear view of the nest and its surroundings. Prey was identified when it was brought back to the nest and logged into the behaviour dataset as a distinct behaviour, entitled “Deliver”. These “Deliver” behaviours were extracted, and the corresponding prey ID was added to the dataset. The prey was usually identified while being brought back to the nest by its general morphological features. When the prey was unidentifiable, it was marked as unknown. Items that could not be ID’d at the species level were identified to the class level.

As mentioned before, a substantial portion of the CCTV data footage was lost due to a hardware malfunction, resulting in most of the data being unrecoverable. The salvaged

footage is mostly from late March and early April, and some from early January. Therefore, the diet records from the CCTV footage are concentrated on this time period and should be interpreted accordingly.

5.2.1.4 Drone Surveys

The drone was flown opportunistically during nest visits across all nine nests to photograph the nest and its contents from above. Drone data is available in two discrete bouts, from December 2025 to mid-January 2026 and then again from the 27th of February onwards, due to the same hardware malfunction that affected the CCTV data.

During each survey, the images of the nest were reviewed, and all identifiable prey material visible in the nest was recorded. Due to the high resolution of the drone footage, most prey material was identifiable to the species level, except carcasses, fur, and bones. Each item seen in a survey was recorded as a separate record. The drone yielded high-resolution data, with species-level identification of prey such as Spiny-tailed Lizard (*Saara hardwickii*), Indian Desert Jird (*Meriones hurrianae*), Indian Desert Fox (*Vulpes vulpes pusilla*), Mongoose (*Herpestes* sp.), and Common Quail (*Coturnix coturnix*).

Figure: Prey items recorded by the drone. (a) chick surrounded by Spiny-Tailed Lizards (Saara hardwickii) tails and Indian Desert Jird (Meriones hurrianae), (b) female in the nest with a Common Quail (Coturnix coturnix), (c) female in nest with eggs and a large carcass piece, (d) fledging in nest with two whole Spiny-Tailed Lizards (Saara hardwickii)

5.2.2 Analytical Methods

All analyses were conducted in R (version 4.5.0). Data from all three methods of data collection were combined and entered into a single dataset. Overall prey composition and shift in diet composition across months were summarised descriptively. Proportions of each prey taxa was calculated by dividing the total number of observations of each taxa and dividing it by the total number of observations. The same process was used to calculate prey proportions by month and nesting stage. This was then visualised to understand the shift in diet composition across seasons and chick development stages. These values were then scaled for sampling effort by averaging them across nests to account for differences

in sample size. Standard errors were calculated to reflect the variation of the percentages across different nests. The results were visualised as a pie chart and as line graphs to show the shift in prey composition with month and nesting stage.

To test whether the diet composition of the Tawny Eagles differed significantly across the sampled months and the nesting stages, a Chi-Square Test of Independence was conducted. Separate tests were conducted for months and nesting stages. Chi-square test was chosen due to the categorical nature of the variables.

5.3 Results

5.3.1 Overall Dietary Composition

A total of 224 prey records were collected, across nine nests and four months. The time period was classified in three nesting stages, hatchling, nestling and fledgling. Mammals were the most frequently recorded prey taxon overall, making up 41.9% of all prey items, followed closely by reptiles at 40.1%. Birds accounted for 13.7% of all prey while carcass material accounted for 4.4% overall. The diet composition was dominated by reptile and mammal prey. Together, reptiles and mammals make up 82% of all recorded prey items. Birds and carrion seem to be hunted and gathered opportunistically, rather than preferred.

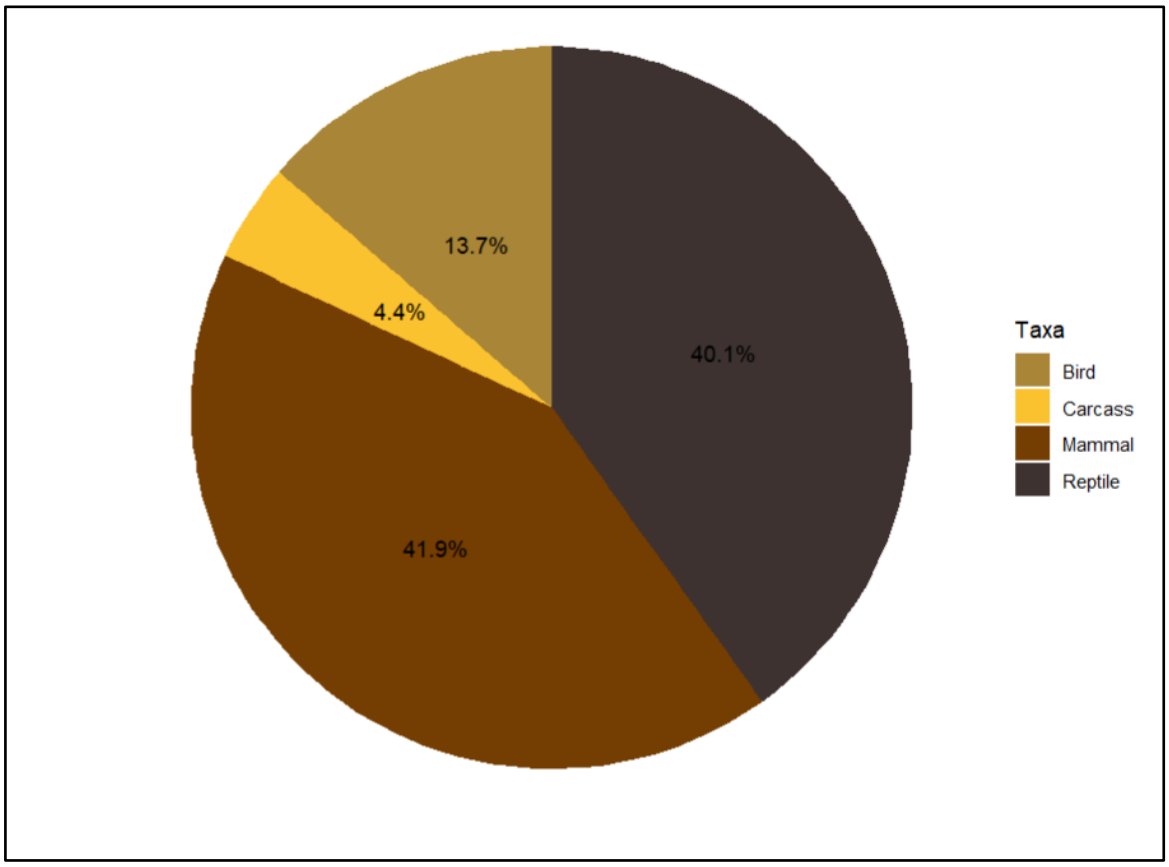

Figure: Overall Dietary Composition

There was a definite shift in the proportion of prey taxa in the diet across the four months sampled, In January, mammals made up approximately 80% of all prey items, followed by birds and carcass at 18% cumulatively. Reptiles are at the lowest for January at approximately 2% overall. In February the proportion of mammalian prey reduced to around 40% with reptilian prey increasing to around 39%. Bird and carcasses proportions stayed stable without much change. In March there is a sharp incline in Reptilian prey, with proportions rising to around 75% percent and mammalian prey falling below 25%. Birds and carcasses brought back to the nest also dip in March with their proportions falling below 10% cumulatively. In April the proportion of all prey items brought back to the nest stayed relatively similar to March, with birds and carcass falling to 0% and the reptiles and mammals at approximately 81% and 19% respectively.

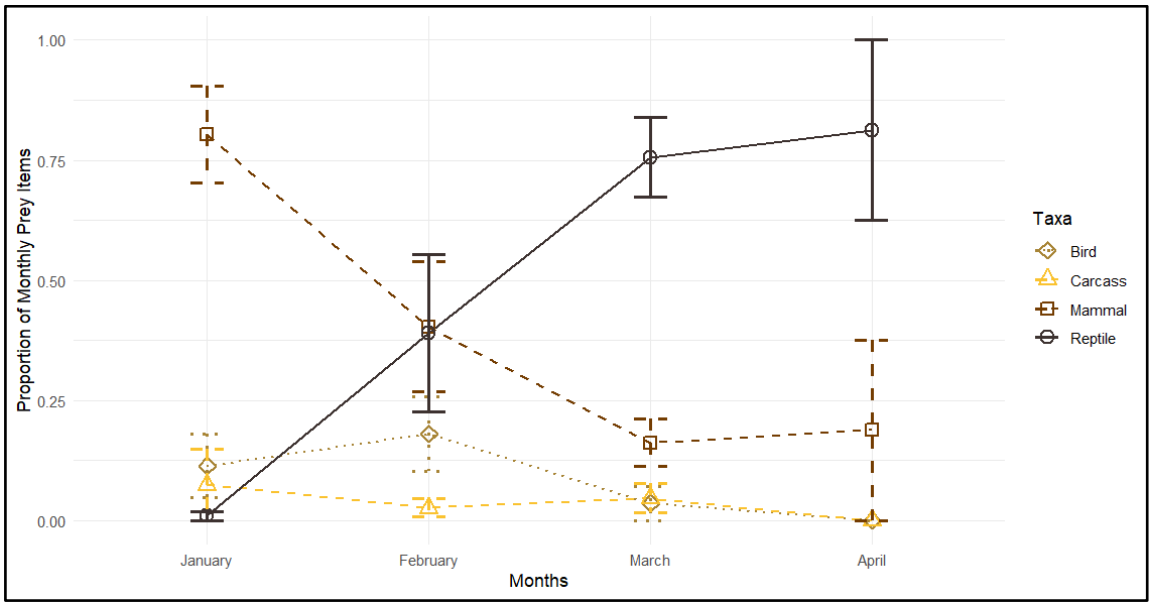

Figure: Seasonal Shift in Prey taxa

A similar but distinct pattern of dietary shift was apparent across the nesting stages (Figure 4.3). During the hatchling stage, mammals dominated at approximately 59% of prey records, with reptiles contributing around 25% and birds accounting for approximately 12%. Through the nestling stage the diet became more skewed towards reptiles, rising to

approximately 75% and mammals declining to a similar proportion, while birds reduced to around 13%. By the fledgling stage reptiles had become the clear majority taxon at approximately 54%, mammals had dropped to 30%, and birds remained stable at approximately 13%. Carcass stayed low at around 5% across nesting stages.

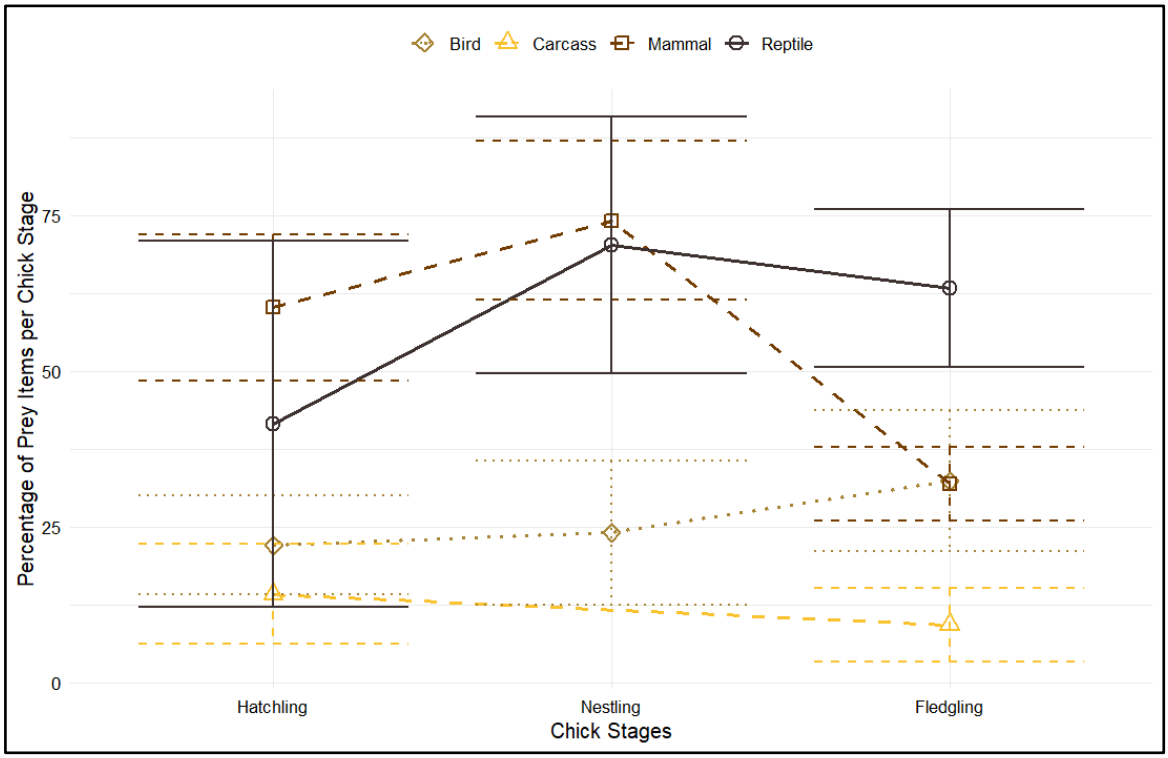

Figure: Shift in prey taxa across different nesting stages

Chi-square tests were run to check if the frequencies of the prey taxa differed significantly across the sampled months and the nesting stages. The test returned a significant result for both, $\chi^2 = 92.84$, df = 9, $p < 0.001$ across months and $\chi^2 = 24.42$, df = 6, $p < 0.001$ across nesting stages. This indicates that the diet composition does differ significantly across months. The larger χ^2 value for the shift in diet composition across months, tells us that the shift in diet composition has a stronger association with months rather than nesting stages.

5.4 Discussion

The overall dietary composition of Tawny Eagles breeding in the Thar Desert aligns with the species characterization as a dietary generalist (Naoroji, 2006). Reptiles and mammals make up the largest proportion, accounting for 81% of all recorded prey items across seasons and nesting stages. Although the overall dietary composition shows a near equal contribution of both prey classes, we can see a clear temporal shift in the proportions, which is an ecologically significant finding of this chapter. There is a sharp transition from mammals to reptiles, provisioned across seasons, with reptiles dominating in the months of March and April. This can be explained by the seasonal emergence and increased activity of Spiny-Tailed Lizards (*Saara harwickii*) as the temperatures increase with the change in season from winter to summer (Ramesh & Sankaran, 2013). The Spiny-Tailed Lizard is a commonly occurring reptile species found in the Thar Desert. It excavates burrows and hibernates throughout the winter season, emerging in late February (Chauhan et al., 2024), aligning with the sharp increase in reptilian prey seen in the Tawny Eagles' diet. Even though reptiles are almost completely absent from their diet in the colder months, Spiny-Tailed Lizards are the most frequently recorded prey in total. This suggests that the Tawny eagles show a preference towards the Spiny-Tailed Lizard, more than any other mammalian or reptilian prey. These lizards are especially conspicuous and are often seen basking on the open sandy plains as the temperatures warm up (Ramesh & Sankaran, 2013). This, combined with their large body size and diurnal activity, likely makes them a highly accessible and nutritious prey, easier to hunt in comparison to smaller lizards and small fossorial rodents.

The mammalian prey caught by the Tawny Eagles was dominated by rodents, especially by the Indian Desert Jird (*Meriones hurrianae*), recorded all three methods of data

collection and across most months and nesting stages. Rodents were observed in the nest even in the months of March and April, suggesting that the mammalian prey is hunted opportunistically, even during times of high reptile activity. Once again this stays consistent with the understanding of the species as a dietary generalist, and aligns with the patterns documented in other large generalist raptors in arid systems (Krebs & Stephens, 1986). There is an increase in mammalian prey in April after a steep decline in March, which may reflect an increase in rodent activity and detectability. April has a smaller sample size therefore, it is difficult to draw conclusions reliably.

Avian prey was recorded most frequently in the colder months of the breeding season, showing a decline after January and February. These records further prove that Tawny Eagles are dietary generalists that show flexibility in the prey that they hunt.

Although the overall occurrence of carcass material in this dataset is quite low, approximately 4.5% of total records, it is in alignment with the documented tendency of Tawny Eagles towards opportunistic scavenging. Carcass Records are mostly concentrated in the early parts of the breeding season, especially in January and February. This can serve as evidence for the theory that Tawny Eagles may be supplementing their diet with carrion during periods of very low prey availability. We cannot say with certainty whether the Tawny Eagles are actively seeking out carcasses during the periods of low prey activity or opportunistically scavenging from this dataset.

5.5 Conclusion

This chapter provides the most detailed quantitative account of the Tawny Eagle diet from the Indian Population. The dataset consists of 224 prey records collected from nine nests, over four months, and across three nesting stages. The results align with the description of the Tawny Eagle as a dietary generalist, with its diet dominated by reptilian and mammalian prey, and 81% collectively.

When assessing the prey composition across months and seasons, an interesting pattern emerges, with mammalian prey dominating the earlier and colder months of the breeding season. As temperatures increase, post the emergence of Spiny-Tailed Lizards in mid-February, there is a sharp increase in the recorded reptilian prey. This shows the flexibility of Tawny Eagles as dietary generalists. This is further evidenced by the higher presence of birds and carcasses in the months of January and February.

The shift in diet across nesting stages, although significant, is better explained by the shift in seasonality. Reptile provisioning increases as the chicks mature from hatchlings to fledglings. This could also be due to the increased energy requirements of chicks as they grow.

The integration of three distinct methods of data collection, drone, pellets, and CCTV footage, across the breeding periods, provides a more complete picture than any one method could have achieved alone. Although the loss of the CCTV footage caused significant temporal gaps, we were able to cover those gaps with data from the other two methods. Future studies should continue with this multi-method approach, with continuous data collection across the breeding period. Species level of all the prey would also provide a

much more detailed account of the prey base of the Tawny Eagles. Together, these improvements would improve the landscape-level understanding of the Tawny Eagles' prey in the Thar and improve our assessment of how diet composition varies across the breeding season.

Chapter 6: Conclusion

Overall, this study attempted to provide a baseline natural history understanding of the species. Through this study, we tried to understand the factors that influence their habitat selection, diet, and behaviour. We started by searching the area and locating active nest sites across the Thar Desert. We searched for nests across a 2000 sq km area, with 4000 km of nest search effort. We found a total of 10 nests across the study area. All the nests were found within the national park boundaries, despite nest searches also being conducted outside. All nests found were in very close proximity to the enclosures of protected grasslands inside the national park boundaries, with nine out ten nests at either near zero distances from the enclosures, or within the enclosure. Nest searches were conducted from December to February. In April, we conducted raptor surveys to obtain encounter rates of Tawny Eagles across the sampled area. We sampled an area of 2400 sq km, with 735 km of survey effort. The survey yielded a total of 14 Tawny Eagle sightings, out of which 12 fell within the boundaries of Desert National Park

For behaviour, we conducted focal behaviour sampling and set up CCTV cameras on the nests. Four CCTV cameras were set up, and combined with focal behaviour sampling, we obtained behaviour data across 9 nests, totalling 900 hours of behaviour data. We found that females spend more time on the nest when the chicks are younger and are absent for longer periods as the chicks mature. The chicks also spend more time alert as they mature. Males spend very little time on the nest, coming only to deliver prey material to the female and chicks. Males are the primary provisioners throughout the breeding period, although females also bring prey material back to the nest. As the season progressed, Spiny-Tailed Lizards came to dominate the proportion of prey brought back to the nest. This observation was further reinforced by the diet analysis.

We collected diet data through three distinct methods: pellet analysis, CCTV footage, and drone surveys. Results of the dietary analysis showed that the Tawny Eagle is a dietary generalist, consistent with previous classifications of the species. Overall, diet composition consisted of mammals and reptiles, which cumulatively accounted for 80% of their diet, with the remainder spread across carcasses and birds. There is a clear shift in diet composition across the months, with the eagles consuming a wide variety of prey, including Indian Desert Jird, Indian Desert Fox, and Common Quail. Their diet in the early months was mammal-dominated, and as the breeding season progressed there was a clear shift towards reptiles. Spiny-Tailed Lizards were the most commonly occurring prey across the breeding season, despite only being recorded after February. This indicates that the eagles shift their diet to other prey during the winter, when Spiny-Tailed Lizards are hibernating. Even during periods of high Spiny-Tailed Lizard activity, the eagles still opportunistically hunted and brought back other prey material to the nest, further reinforcing the Tawny Eagle's characterisation as a dietary generalist.

Further studies can build on this work to better understand the behaviour of Tawny Eagles. With more intensive study and a larger sample size, more behaviours could be categorised, and further inferences could be drawn about shifts in behaviour across the nesting period. The three methods of dietary data collection together provided a clearer picture of the Tawny Eagle's diet than any single method could have. Future studies should follow this multi-method approach, with a larger sample size and species-level identification of all prey items, to provide an even clearer picture of the Tawny Eagle's diet.

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Appendices

Appendix A — Prey Species List

Prey ID	Drone	Drone	CCTV	Pellet
Common Quail	1	0	0	0
Bird	0	0	5	25
Carcass	3	0	7	0
Desert Monitor lizard	0	0	1	0
Indian Desert Fox	3	0	0	0
Indian Desert Jird	2	3	14	0
Lizard	0	0	1	0
Mammal	0	0	1	55
Mongoose	1	0	0	0
Reptile	0	0	11	2
Rodent	0	0	16	0
Snake	0	0	1	0
Spiny Tailed Lizard	2	30	43	0

Appendix B — CCTV Ethogram

Sno.	Name of Behaviour	Definition	State/ Event
1	Sit	Both legs tucked under the body, head up and wings folded	State
2	Stand	The weight of the eagle is supported by its legs and it is in an upright position	State
3	Walk	The eagle is using its legs to walk	State
4	Lay	Both legs tucked under the body, the sternum is flat against the nest, head is tucked down, done when sitting in nest to incubate egg	State
5	Vigilance	Bird is standing and continuously moving its head from side to side	State
6	Alert	The bird is either laying or sitting with the head upright and continuously moving its head from side to side	State
7	Head swing	The eagle moves its head from side to side	Event
8	Head Cock	The eagle turns its head to the side to look at something with one eye	Event

9	Head bob	The eagle move its head up and down	Event
10	Head Tuck	The eagle tucks its head back between the wings in the back, when resting/ laying	State/Event
11	Allo-Grooming	The Eagle preens a conspecific	State/ Event
12	Auto Grooming	The eagle preens itself using its beak	State
13	Feather Fluff	The eagle shakes out and fluffs its feathers	Event
14	Head Scratch	The eagle scratches it head with its talons	Event
15	Flapping Flight	The eagle flies low to the ground and flaps multiple times	State
16	Gliding Flight	The eagle is descending from a height and glides downwards without flapping its wings	State
17	Soaring Flight	The eagle flies high up in the sky, usually in circular patterns, with minimal flapping	State
18	Diving Flight	The eagle tucks its wings close to its body while in flight and descends head first, rapidly towards the ground	State

19	Mating Flight	A pair of eagle circle each other while diving with their wings tucked in close together	State
20	Copulation	The eagles perch on the nest and mate, usually accompanied by a mating call	State
21	Chuffing Call	The eagle makes a chuffing call	State/ Event
22	Rest	The eagle turns its head and tucks it back between its wings, or tucks its head down and tucks it between the shoulders, while in a sitting position	State
23	Readjust	The eagle readjusts its position while sitting on nest	Event
24	Squeaking call	The Eagle makes a small squeaking call	Event
25	Construction	The Eagle is constructing the nest by fixing twigs in the nest	State
26	Material Collection	Bringing back Nesting material, such as twigs, for the construction of the nest	Event
27	Chittering	The bird opens and closes its mouth multiple times in succession, with no audible sound coming out of its mouth	State/ Event

28	Hide	The bird responds to external stimuli and tucks itself into the nest and stays still	Event
29	Feeding	The eagle is consuming something	State
30	Nestle	The bird shakes from side to side in the nest and settles into the nest	Event
31	Wing Stretch	The eagle stretches its wings out and shakes either while sitting or standing	Event
32	Provisioning	The eagle is feeding its chick with prey items	State
33	Deliver	The adult returns to the nest with prey material	Event
34	Away from the nest	The adult Eagle is absent from the nest	State
35	Wing Flap	The Chick is attempting to fly by flapping its wings repeatedly	Event
36	Wing Bob	The Eagle bobs its wings in anticipation of the arrival of a conspecific	Event
37	Aggression	The Eagle is showing aggression to either conspecifics or individuals of other species.	Event