An Ecological Study on Nesting Patterns and Behavioural Dynamics of Vultures in Kangra Valley, Himachal Pradesh

Thesis Submitted to

The Saurashtra University, Rajkot (Gujarat)

For the award of the Degree of

Doctor of Philosophy
in
Wildlife Science

By

Malyasri Bhattacharya

Under the supervision of

Dr. Gautam Talukdar

भारतीय वन्यजीव संस्थान
Wildlife Institute of India

Chandrabani Dehradun - 248001
Uttarakhand, INDIA

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DECLARATION

I hereby declare that the work conducted under the thesis titled " **An Ecological Study on Nesting Patterns and Behavioural Dynamics of Vultures in Kangra Valley, Himachal Pradesh"** is an original and independent research work done by me. Subsequently submitted for the award of the degree of **Doctor of Philosophy in Wildlife Science to the Saurashtra University, Rajkot (Gujarat)**. This research work has been carried out under the guidance and supervision of Dr. **Gautam Talukdar** of **Wildlife Institute of India, Dehradun**.

The work has not formed the basis of any other degree, diploma or any other qualification. I also declare that the thesis embodies my own work, analysis, and observation and the particulars given in it are true and the best of my knowledge.

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This is to certify that the thesis of **Ms. Malyasri Bhattacharya** entitled " **An Ecological Study On Nesting Patterns and Behavioural Dynamics Of Vultures In Kangra Valley, Himachal Pradesh"** is an original piece of work carried out under our guidance and supervision, submitted to the **Saurashtra University, Rajkot (Gujarat)**, for the award of the **Doctor of Philosophy in Wildlife Science**.

Ms. Malyasri Bhattacharya has researched this thesis for more than six terms under my supervision and guidance. The work presented in this thesis has not been submitted to any other degree. It meets all the specifications stated forth in the ordinances of the **Saurashtra University in Rajkot, Gujarat, and the Wildlife Institute of India.**

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I certify that the research work was appreciated by all who were present, and the comments made by the faculty and researchers have been appropriately included in the thesis.

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Summary

Vultures are nature's most efficient scavengers, playing a critical role in maintaining ecological balance. Their populations in India have suffered a drastic decline from 97-99% between 1993 and 2002, leading to the establishment of captive breeding programs aimed at species recovery. Threats of decline have now stabilized, but little is known about the ecology and survival of the vultures in the wild, necessitating this study for the conservation of vultures in their natural habitat. Kangra Valley, situated in the westernmost region of Himachal Pradesh state in India, is one of India's important vulture sites, supporting most of the nine vulture species recorded in the country. Among these, the White-rumped Vulture (*Gyps bengalensis*), Egyptian Vulture (*Neophron percnopterus*), Bearded Vulture (*Gypaetus barbatus*), Himalayan Griffon (*Gyps himalayensis*), and Eurasian Griffon (*Gyps fulvus*) are the most observed, while the Cinereous Vulture (*Aegypius monachus*), Red-headed Vulture (*Sarcogyps calvus*), Slender-billed Vulture (*Gyps tenuirostris*), and Indian Vulture (*Gyps indicus*) are recorded occasionally. Kangra is also one of the most densely populated districts of Himachal Pradesh, with an extensive road network, contributing to anthropogenic pressures on vulture populations. While the region has a long history of vulture census efforts, aspects of their breeding ecology remain poorly understood. Why do they select a particular tree for nesting? What are the variables that affect nest site selection? What is the nest success rate? Where do they move, and what is their home range? What are the threats? This study, conducted between 2019 to 2024, focuses on the breeding ecology of White-rumped Vultures in Kangra, examining their nesting preferences, reproductive success, threats to nesting colonies and spatial movements. Additionally, the research explores the climatic niche availability for all nine vulture species found in the region, assessing current and future climatic scenarios to predict potential habitat suitability.

The Chir Pine forests of Kangra serve as the breeding habitat for White-rumped Vultures in the region. The breeding season of the White-rumped Vulture (*Gyps bengalensis*) in the area extends from November to April, encompassing mating, incubation, hatching, and fledgling development, lasting approximately 25–28 weeks (October–April). Over three consecutive breeding seasons (2021–2024), the study recorded 17 active nesting colonies with a total of 617 active nests, primarily in Chir Pine (*Pinus roxburghii*) trees. Nest site selection was influenced by tree characteristics, with vultures preferring trees with a larger girth at breast height (GBH) (average

GBH of 254.8 cm ± 49.3 SD), lower canopy cover (5-10%), greater shrub density (77-100%), and proximity to other nesting trees and water sources. Conversely, areas with high fire activity, dense canopy cover, and limited nearby trees were found to be less suitable.

In addition to breeding ecology, the study identified 36 carcass dumping sites in the region. These sites, managed by local communities, serve as designated areas for livestock carcass disposal, primarily for cattle and buffalo. The carcasses are transported from households to the dumping sites by local cobblers, locally known as "Harijans." The decline of open carcass disposal areas has posed further challenges for vulture populations.

To understand movement patterns, five wild White-rumped Vultures were satellite-tagged in Kangra, Himachal Pradesh, in 2021. The tagged individuals exhibited extensive movements, ranging across Jammu & Kashmir, the Pakistan border near Punjab, and Uttarakhand. Three of these vultures have consistently nested in Dolba and Lapiana within Kangra between 2021 and 2024. The study recorded an average home range of 1367.6 km^2 for non-breeding individuals and 1719.8 km^2 for breeding individuals across seasons. The future distribution for the nine vulture species shows a significant decline in the modeled climatic niche for seven vultures by 2041–2060 and 2061–2080.

The study identified electrocution, forest fires and poisoning as major threats, with notable vulture fatalities recorded. Major forest fire-prone areas include Gopalpur, Pathiar Range, Lunj, and Baranj Sirmani. This study offered insights into India's largest documented aggregation of 617 White-rumped Vulture nests.

The study recommends targeted conservation interventions to ensure the long-term survival of White-rumped Vultures. These include the protection of nesting sites, preservation of old-growth forests, and support for cobbler communities engaged in carcass disposal. Additionally, designated vulture feeding stations within forested areas should be established. Given these findings, the study proposes designating the region as a Vulture Safe Zone, suitable areas for releasing captive-bred vultures with continuous monitoring. Himachal Pradesh Forest Department (HPFD) and the Ministry of Environment and Climate Change (MoEFCC) have to come up with guidelines to declare a vulture safe zone as well as a strategic conservation plan to safeguard this critically endangered species.

.The study has been distributed in **seven chapters**, outlined as follows:

Chapter 1

Chapter 1 introduces vultures in India, highlighting their ecological significance and presenting the objectives and research questions that shape this study. It offers an overview of vulture conservation efforts in India and incorporates a literature review of studies from Asia. Additionally, the chapter identifies research gaps.

Chapter 2

Chapter 2 provides a comprehensive overview of the study area, offering an in-depth description of Kangra Valley's geographical features, diverse habitat types, and ecological significance. It explores the region's topography, dominant vegetation, and key landscape elements that shape the local environment. Additionally, the chapter delves into the human communities inhabiting the valley, their livelihoods, and their relationship with the land.

Chapter 3

Chapter 3 offers a comprehensive analysis of the breeding biology of White-rumped Vultures. It details the methodologies used for nest surveys and assessments of nesting success. The chapter also explores the objectives of nest monitoring efforts and evaluates the population status of White-rumped Vultures in Kangra.

Chapter 4

This chapter examines the nest site selection of White-rumped Vultures, including their tree preferences and the factors influencing nest selection. It also highlights the threats posed by forest fires, resin tapping, and various anthropogenic activities.

Chapter 5

Chapter 5 provides a detailed analysis of movement dynamics, including home range sizes, movement patterns, and habitat preferences. The chapter identifies areas for conservation and highlights the potential of Kangra district as Vulture Safe Zone.

Chapter 6

Chapter 6 explores the present and future climatic niche of nine Old World vulture species in India. By incorporating multiple Shared Socioeconomic Pathways (SSPs), the chapter assesses the long-term viability of vulture populations and identifies regions most susceptible to changes driven by climate change.

Chapter 7

This chapter discusses the concept of Vulture Safe Zone and outlines the key threats to vultures in Kangra. It further recommends designating Kangra district as a Vulture Safe Zone in Himachal Pradesh. It tries to outline future research and management directions.

Abbreviations

Scientific & Conservation Terms:

- BV-Bearded Vulture
- CR- Critically Endangered
- CV-Cinereous Vulture
- EG- Egyptian Vulture
- EG-Eurasian Griffon Vulture
- EN-Endangered
- HG-Himalayan Griffon Vulture
- IV-Indian Vulture
- LC-least concern
- NSAID-Non-steroidal Anti-Inflammatory Drug
- NT- Near Threatened
- RHV-Red-headed Vulture
- SBV-Slender-billed Vulture
- VSZ- Vulture Safe Zone
- VU- Vulnerable
- WRV-White-rumped Vulture

Statistical/Modeling Terms:

- AIC-Akaike Information Criterion
- aKDE- Autocorrelated Kernel Density Estimation
- AUC- Area under curve
- CDSCO-Central Drugs Standards Control Organisation
- COVID19-Coronavirus Disease 2019
- ENM-Ecological Niche modeling
- GBH- Girth at Breast height
- GCM- General Circulation Model
- GLMMs- Generalized Linear Mixed Models
- KDE- Kernel Density Estimation
- Kuenm-Kernel Uncertainty ENMeval Model
- KV- Killo Volt
- Masl- meters above sea level
- MaxEnt-Maximum Entropy Modeling algorithm
- MCP- Minimum Convex Polygon
- MIROC-ES2L-Model for Interdisciplinary Research on Climate - Earth System version 2 for Long-term simulations.
- P-value- Probability Value

- ROC -Receiver Operating Characteristic
- SD- Standard deviation
- SDM-Species Distribution Modeling
- SE- Standard Error
- SSP-Shared socioeconomic pathways

Institutions:

- BNHS- Bombay Natural History society
- HPFD- Himachal Pradesh Forest Department
- MoEFCC- Ministry of Environment, Forest and Climate Change
- SAVE- Saving Asian Vultures from Extinction
- VCBC- Vulture Conservation Breeding Centre
- VCC- Vulture Conservation Centre
- WII- Wildlife Institute of India

Other terms:

- GPS-Global Positioning System
- GPS-GSM- Global Positioning System - Global System for Mobile Communications
- HP- Himachal Pradesh
- HWI (Home Range Index)
- INR- Indian Rupees
- USD- United States Dollar

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List Of Publications, Conferences, And Workshops Attended

Papers published and accepted

1. Bhattacharya. M, & Talukdar. G. (2024). Nest site selection and threats to nesting colonies of white-rumped Vulture (*Gyps bengalensis*) in Himachal Pradesh. ***Forest Ecology and Management*, *573*, 122335,** DOI:10.1016/j.foreco.2024.122335.(ISSN: 1872-7042)
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3. Bhattacharya. M and Talukdar. G. (2022). Telemetric studies on White-rumped Vulture from Himachal. **Indian Bird Monitoring Symposium. April 29-30,2022.** https://www.birdmonitoring.in/symposium-2022/schedule-2022/

Workshops

SAVE (Saving Asian Vultures from Extinction) workshop held in Royal Chitwan national Park, Nawalparsi, Nepal March 08-11,2023.

Chapter 1: Introduction

1.1. Background

"The Vultures are the most righteous of birds, they do not attack even the smallest living creature."-Plutarch-Greek Philosopher.

Almost one-fifth of the world's vertebrates are threatened with extinction (Hoffman *et al.* 2010), and approximately 40 per cent of birds throughout the world are in decline Lee *et al.*2022, (State of the World's Birds 2022). Scavenger species are generally reported to be under threat worldwide (Hoffmann *et al.* 2010). Avian scavengers are often perceived as a bad omen by humans due to misconceptions, fear, and their association with death or disease. Vulture populations are one of the fastest declining groups of birds (Green *et al.* 2004, Oaks *et al.* 2004, Ogada 2014). Despite playing a crucial role in ecosystem cleanup, vultures often go unnoticed in conservation efforts, overshadowed by more charismatic species like Tigers. Vultures are the highest extinction-prone species among all avian groups (Sekercioglu *et al.* 2004), with nearly half of the world's 23 vulture species at risk of extinction; their conservation has become a critical priority. It's time to recognize their significance and champion their survival.

1.2. General Introduction

Vultures are large, short-tailed, solitary birds belonging to the "birds of prey" group, uniquely adapted to a scavenger lifestyle by feeding on carcasses. With specialized skills for this role, they travel across vast geographical ranges, making the conservation and protection of their feeding and nesting grounds crucial for their survival. Vultures are divided into two groups: New World vultures of the family Cathartidae (7 Species) and Old-World vultures of the family Accipitridae (16 species).

Table 1.1. New and old-world vultures

SI No.	Vulture Common Name	Scientific Name	New/Old world
1	Black Vulture	*Coragyps atratus*	New
2	Turkey Vulture	*Cathartes aura*	New
3	Lesser Yellow-headed Vulture	*Cathartes burrovianus*	New
4	Greater Yellow-headed Vulture	*Cathartes melambrotus*	New
5	King Vulture	*Sarcoramphus papa*	New
6	California Condor	*Gymnogyps californianus*	New
7	Andean Condor	*Vultur gryphus*	New
8	Cinereous vulture	*Aegypius monachus*	Old
9	Griffon vulture	*Gyps fulvus*	Old
10	White-rumped vulture	*Gyps bengalensis*	Old
11	Rüppell's vulture	*Gyps rueppelli*	Old
12	Indian vulture	*Gyps indicus*	Old
13	Slender-billed vulture	*Gyps tenuirostris*	Old
14	Himalayan vulture	*Gyps himalayensis*	Old
15	White-backed vulture	*Gyps africanus*	Old
16	Cape vulture	*Gyps coprotheres*	Old
17	Hooded vulture	*Necrosyrtes monachus*	Old
18	Red-headed vulture	*Sarcogyps calvus*	Old
19	Lappet-faced vulture	*Torgos tracheliotos*	Old
20	White-headed vulture	*Trigonoceps occipitalis*	Old
21	Bearded vulture (Lammergeier)	*Gypaetus barbatus*	Old
22	Egyptian vulture	*Neophron percnopterus*	Old
23	Palm-nut vulture	*Gypohierax angolensis*	Old

They have experienced sharp population declines due to several anthropogenic factors, resulting in the loss of suitable breeding and foraging habitats and induced intoxication (Mingozzi and Estève 1997, Herremans and Herremans-Tonnoyer 2000, Green *et al*. 2004, Thiollay 2006, Ogada *et al*. 2012). In Asia, the vulture population has declined by 99.9% from the 1990s to 2000 in just 10 years due to the use of a veterinary drug called Diclofenac, used as a painkiller for livestock, that was fatal and affecting the kidneys of vultures with neck drooping syndrome. Nine species of vulture are reported from India, and most of them are under the threat of extinction, Keith *et al*, 2015, (IUCN). In the 1980s, India had as many as 80 million White-rumped Vultures (Gyps bengalensis), but now only a few thousand remain (Prakash *et al.* 2019).

Vulture provides ecosystem services as top cleaners in cities, villages, and the countryside. According to the Ministry of Agriculture (2019), 19th livestock census, dog population increased by 7.25 million between 1992-2012, along with Vulture decline and the number of deadly diseases like rabies and tuberculosis. A group of vultures can consume carcasses within 20 minutes (Houston 1972), dogs and other scavengers take days, increasing the risk of disease transmission through water, air, and soil. The dramatic crash in India's three vulture species ranks among the fastest population declines ever recorded in any bird species. (Shultz *et al*, 2004). Three species of vultures have declined drastically (Gilbert *et al*. 2004; Prakash *et al*. 2003), leading the International Union for the Conservation of Nature to list White-rumped vulture (*Gyps bengalensis*), Long-billed vulture (*Gyps indicus*) and Slender-billed vulture (*Gyps tenuirostris*) as Critically Endangered. In Southeast Asia, nearly half of the vulture population has disappeared, largely due to the decline of wild ungulates and shifts in livestock carcass management practices, which have drastically reduced their food sources (Clements *et al*. 2013). In Cambodia, vultures are threatened by extremely low population densities of wild ungulates, a decline in the number of free-ranging domestic ungulates, logging nest trees and accidental poisoning by eating dead animals that were poisoned to kill stray dogs or wild animals. (Clements *et al*. 2013).

1.3. Introduction to vultures:

White-rumped and Slender-billed Vultures were historically abundant across Southeast Asia and Yunnan Province, China, until the mid-20th century. By the late 1900s, these species had nearly disappeared from the region, with relict populations now confined to northern and northeastern Cambodia, occasionally spilling into adjacent areas of Laos and Vietnam. Elsewhere, including Malaysia, Thailand, Myanmar, and Yunnan, sporadic records likely represent transient individuals. Myanmar has reported significant vulture population declines.

India is a stronghold for vultures, hosting nine species that play an ecological role in maintaining ecosystem health by scavenging on animal carcasses. The resident species includes many, including White-rumped Vulture (*Gyps bengalensis*), Indian Vulture (*Gyps indicus*), Slender-billed Vulture (*Gyps tenuirostris*), Long-billed Vulture (*Gyps indicus*), and Red-headed Vulture (*Sarcogyps calvus*). The region is regularly visited by migratory species such as the Himalayan Griffon (*Gyps himalayensis*), Cinereous Vulture (*Aegypius monachus*), and Eurasian Griffon

(*Gyps fulvus*), while the Egyptian Vulture (*Neophron percnopterus*) occurs both as a resident and a migrant.

1.4. Threats to Vultures:

1.4.1. Toxic non-steroidal anti-inflammatory drugs (NSAIDs):

The primary driver of vulture population declines in India has been the use of non-steroidal anti-inflammatory drugs (NSAIDs), particularly the veterinary drug Diclofenac, which was commonly administered to livestock until its ban in 2006. Beyond Diclofenac, other non-steroidal anti-inflammatory drugs (NSAIDs) such as Aceclofenac, Ketoprofen, and Nimesulide have also been proven highly toxic to vultures. In a significant step, Aceclofenac and Ketoprofen were banned in 2021 (Galligan *et al.*, 2021), followed by the veterinary ban on Nimesulide in December 2024 (Davies, 2025). However, enforcement of these bans remains a major challenge. Meanwhile, two NSAIDs—Meloxicam and Tolfenamic acid—have been scientifically tested and confirmed as safe for vultures. Meloxicam, recognised as a vulture-safe alternative (Swarup et al., 2007), is now widely used, and Tolfenamic acid has also emerged as another suitable option. With ongoing research, additional safe alternatives are expected to be identified, offering renewed hope for vulture conservation.

1.4.2. Poison Baits:

Although vultures are not deliberately targeted in India, annual poisoning incidents continue to occur, particularly in Himachal Pradesh and Assam, due to baited carcasses intended to eliminate feral dogs and livestock predators. These baits inadvertently kill scavengers, including vultures. The rise in feral dog populations, driven by surplus food previously consumed by vultures, has likely increased poisoning cases. Globally, poison baits remain a leading vulture threat (Botha *et al.*, 2017).

1.4.3. Power Infrastructure:

Electrocution on pylons and collisions with wind turbines and power lines pose emerging threats to vultures. Addressing these risks requires proactive planning and risk mapping near vulture habitats.

1.4.4. Habitat Loss:

Habitat loss is a significant threat to vulture populations across Asia, driven by deforestation, urbanization, and agricultural expansion. Many vulture species rely on old-growth trees for nesting and roosting, but widespread logging, land conversion, and infrastructure development have severely reduced their available habitat (Safford 2019; Jha *et al* 2021; Harris 2013). In addition, the decline of wild ungulate populations and changes in traditional livestock management practices have limited food availability. Historically, high vulture populations thrived on cattle carcasses. As disposal practices have changed, there might be insufficient food to support the existing vultures that exist today (Ghosh-Harihar *et al,* 2024). Protected areas and community-led conservation efforts are crucial in mitigating habitat loss, ensuring vultures have safe nesting sites and sufficient foraging grounds to sustain their populations.

1.5. Vulture Decline

Once numbering in the tens of millions and recognized as the world's most abundant large raptor, the White-rumped Vulture now has an estimated global population of just 8,000 individuals, with 6,000 in India. By 2004, multiple scientific studies conclusively identified the veterinary use of the NSAID Diclofenac as the primary cause of the catastrophic vulture population declines (Oaks *et al*., 2004; Green *et al*., 2004). Since the mid-1990s, the drug has been widely used to treat pain in both cattle and humans, with millions of doses administered each year (Pain *et al*., 2008). Diclofenac remains in cattle tissues for several days post-treatment, and even minimal concentrations render the tissues highly toxic to vultures consuming carcasses of livestock that were treated within 72 hours of death (Oaks *et al*., 2004; Swan *et al*., 2006a; Green et al., 2006; Prakash *et al,* 2012). Scientific modeling demonstrated that contamination of less than 1% of cattle carcasses with Diclofenac could account for the observed vulture population declines (Green *et al*., 2004). Surveys confirmed that Diclofenac concentrations in cattle tissues available to vultures were sufficient to explain the rapid population collapse entirely. The persistent use of toxic non-steroidal anti-inflammatory drugs (NSAIDs), despite the ban, continues to severely impact vulture population recovery. Weak enforcement of these bans has impeded vulture population recovery in the wild, even after the dramatic population declines of the 1990s (Prakash *et al*., 2003; Prakash *et al*., 2024; Cook et al., 2024).

1.6. Vulture Conservation Breeding

Following the drastic decline, to create a viable population of vultures, conservation breeding centres were established in India by the Ministry of Environment Forest and Climate Change through the Bombay Natural History Society (BNHS) in Pinjore, overseeing aviary construction, bird health, and feeding across four centres since 2001 (Bowden, 2020; Ranade, 2023). The program, managed by BNHS, has expanded to house over 800 vultures in Pinjore, Haryana, Buxa, West Bengal, Bhopal, Madhya Pradesh, and Rani, Assam. Following the release of the South Asia Vulture Recovery Plan in February 2004, the existing Vulture Conservation Centre (VCC) was upgraded to the first Vulture Conservation Breeding Centre (VCBC), in accordance with the plan's recommendation to initiate a conservation breeding programme for the three critically endangered vulture species. In 2020, eight captive-bred White-rumped Vultures were released into the wild for the first time in India from the Jatayu Conservation Breeding Centre in Pinjore, Haryana. More recently, in August 2024, 20 captive-bred vultures were released in Tadoba Tiger Reserve, Maharashtra, marking a significant milestone in the species' conservation journey.

1.7. Vulture Safe Zone

In 2009, Nepal pioneered the concept of a Vulture Safe Zone (VSZ) in the Gaidatal Village Development Committee (VDC). With the first government-certified Vulture Safe Zone established in Gandaki Lumbini province in Nepal, a VSZ is an area surrounding one or more vulture nesting colonies, large enough to cover the average foraging range (>30,000 km^2) and completely free from Diclofenac use. There are eight proposed Vulture Safe Zones in India by a consortium called Saving Asian Vultures from Extinction (SAVE). India has recently begun releasing captive-bred vultures into the wild, necessitating the establishment of safe zones.

1.8. Harijan communities and Vultures:

The Harijan community has been traditionally associated with leatherwork and handling livestock carcasses. Historically, the community was involved in skinning dead livestock and processing hides, leaving the remains in open fields where vultures scavenged. This relationship ensured the efficient disposal of carcasses, benefiting both the community and the vultures. However, changes in traditional practices and the decline of vulture populations have disrupted this dynamic.

With the advent of synthetic materials and mechanized processes, the demand for traditional leatherwork has decreased, affecting the livelihoods of Chamar communities. Additionally, the catastrophic decline in vulture populations, primarily due to diclofenac poisoning, has led to an accumulation of carcasses in rural areas, creating health hazards and economic challenges for these communities. The absence of vultures has increased dependency on alternative methods of carcass disposal, such as burial or incineration, which are often less efficient and more labour-intensive.

A recent study has shown that the lifetime scavenging value of a vulture ranges from USD 4457 to USD 4047 in urban India, whereas USD 3825 to USD 3357 in rural India, based on 2014–2015 prices. Annually, a single vulture provides scavenging services valued between USD 235 and USD 187(Ishwar and Das 2024). Investing in the recovery of wild vulture populations in Protected Areas and urban landscapes could save the government millions of rupees while simultaneously promoting ecosystem health, benefiting wildlife, livestock, and local communities. Chamars through sustainable livelihoods, linked to conservation goals, can play a vital role in ensuring the long-term survival of vultures while supporting the community's economic resilience.

1.9. Study Species: White-rumped Vulture (*Gyps bengalensis*):

The White-rumped Vulture (WRV) is a medium-sized Old-World vulture that nests in colonies and is characterized by a distinctive white patch on its lower back. Once abundantly found and most common in the Indian Subcontinent, including Bangladesh, Pakistan, Nepal and parts of Indonesia, it is now rarely found. (Wilbur 1983, Prakash *et al*. 2003). The White-rumped Vulture (*Gyps bengalensis*), classified as Critically Endangered, is currently distributed across 13 states in India, including Jammu & Kashmir (Kichloo et al., 2020), Madhya Pradesh (Roy, 2007; Navaneethan *et al.*, 2015), Rajasthan (Chhangani, 2009), Gujarat (Grubh 1974, Gadhvi & Dodia, 2006; Moradiya & Goswami, 2021), Kerala (Vishnu, 2018), Andhra Pradesh (Sivakumar & Manakadan, 2005), Uttar Pradesh (Sethi & Chauhan, 2010), Uttarakhand (Sharma *et al.*, 2007; Kumar *et al.*, 2022), Tamil Nadu (Samson & Ramakrishnan, 2020; Kannan *et al.*, 2013), Maharashtra (Pande *et al.*, 2013; Majgaonkar *et al.*, 2018), Himachal Pradesh (Thakur, 2015), Assam (Chakdar, 2019), and Chhattisgarh (Dutta et al., 2021). In Nepal, its breeding ranges are in the lower elevation ranges (Baral *et al,* 2005). In Azad Jammu Kashmir, Pakistan (Ahmad *et al,* 2020) and parts of Bangladesh (Khan and Monirul, 2013). They typically nest in colonies, building their nests on trees and often nesting close to one another.

1.9.1. Phylogeny and taxonomy:

The White-rumped Vulture was first formally described in 1788 by German naturalist Johann Friedrich Gmelin in his expanded edition of Carl Linnaeus's *Systema Naturae*. (Gmelin 1788; Mayr 1979). Initially classified under the genus *Vultur*, Gmelin assigned it the binomial name *Vultur bengalensis*, based on the "Bengal vulture" described and illustrated in 1781 by English ornithologist John Latham in *A General Synopsis of Birds*. Latham had observed a live specimen at the Tower of London, reportedly originating from Bengal.

Subsequent taxonomic revisions led to its reclassification within the genus *Gyps*, introduced in 1809 by French zoologist Marie Jules César Savigny. The genus name *Gyps* is derived from the Ancient Greek gups, meaning "vulture." closely related to the African White-backed Vulture (*Gyps africanus*), with some classifications considering them conspecific. At times, both species have been placed in the separate genus *Pseudogyps*, based on the distinguishing characteristic of typically having 12 rectrices instead of 14. The species is monotypic, and it has no recognised subspecies. (Gill *et al*, 2022)

1.9.2. Geographical distribution and abundance:

The White-rumped, once widespread, was called the most common bird of prey (Cunningham *et al*., 2003). Historically, White-rumped Vultures were common in Northeastern India (Stuart Baker, 1928), though they were scarce in the Khasi Hills but greater abundance in the Brahmaputra valley (Hooker, 1854). Nesting densities of White-rumped Vultures were recorded at 2.7 nests/km² in Delhi (Galushin, 1971) and 12 nests/km² in Keoladeo National Park, India, during the 1970s-1980s (Prakash, 1999). White-rumped vultures were also common in West Bengal. In Pakistan, White-rumped Vultures were abundant along the Indus (Roberts, 1991). The species is distributed across Pakistan, India, Bangladesh, Nepal, Bhutan, Myanmar, Laos, Cambodia, and southern Vietnam, but is likely extirpated from southern China and Malaysia (BirdLife International, 2025). Currently, viable populations persist primarily in northern Myanmar and Cambodia, with estimated numbers likely in the low hundreds (Hla 2003; Anon 2003, 2008; Eames 2007a, b; Hance 2009). Unlike South Asia, where veterinary NSAIDs have driven declines, the primary factor in Southeast Asia appears to be the loss of large ungulate populations and improved animal husbandry, reducing available carcasses for vultures (Anon 2003, 2008).

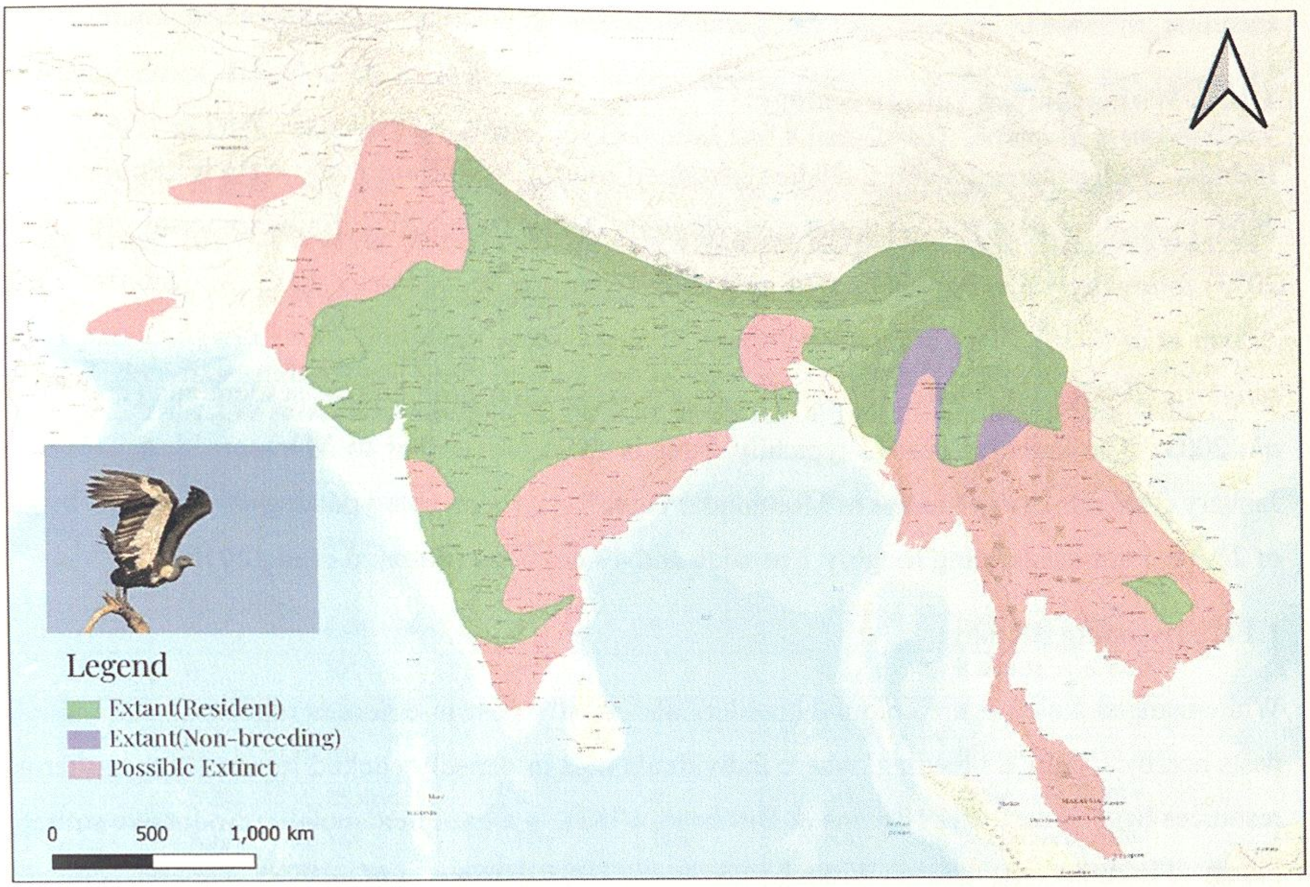


Figure 1.1. The geographical range of White-rumped vulture Gyps bengalensis (adapted from www.iucnredlist.org) with resident, non-breeding and possible extinct ranges.

1.10. Literature review

1.10.1. Methods

We performed an inclusive electronic search in Open Access Theses and Dissertations: OATD, Shodhganga, Researchgate and Google Scholar to identify all available literature related to vulture population and breeding studies up to January 2024. We used the terms 'vulture' or 'bird scavenger' or 'avian scavenger' in combination with the terms 'nest', 'population'. Additionally, we included a supplementary study identified through our electronic database search. From each scientific article, we collected information related to the publication (such as journal name, type, and year) and study details (including subject, species, sample size, field and analytical methods, and outcomes). It is important to note that a single article could be relevant to multiple categories; therefore, the total count across all categories exceeds the number of individual articles reviewed.

1.10.2. White-rumped vulture ecology:

In India, White-rumped Vulture studies pertained mostly to vulture decline study (Prakash *et al* 2003; Prakash *et al,* 2019) and tissue analysis study (Nambirajan 2021; Sathyamoorthy 2012; Roy 2013) following a few regional breeding studies (Samson 2020; Pande 2013; Majgaonkar 2018; Anoop *et al* 2020). They are known to nest in large trees, including *Ficus benghalensis*, *Ficus religiosa*, *Terminalia arjuna*, and *Azadirachta indica*, often near human settlements (Prakash *et al*., 2003). The breeding season typically extends from November to March, with eggs laid in January (Prakash 1999). Studies in Mudumalai Tiger Reserve reported nesting at an average height of 26.7 m, with nests being roughly 1 m wide and 40 cm deep (Samson *et al*., 2016).

1.10.3. Breeding Biology:

White-rumped Vultures are colonial breeders and mostly nest in colonies together with multiple nests nearby. Colonial breeding, where individuals nest in densely packed territories that offer no resources beyond nest sites (Perrins & Birkhead, 1983), is a complex social reproductive strategy observed in many vertebrates (Wittenberger *et al*., 1985; Brown *et al*., 1998). This phenomenon presents an evolutionary challenge, as breeding in high densities appears to impose fitness costs on individuals. Despite the potential costs, several hypotheses have been proposed to explain the benefits of colonial breeding, though empirical support remains limited (Wittenberger *et al*., 1985; Siegel-Causey *et al*., 1990). Early discussions focused on advantages such as improved foraging efficiency (Barta, 1995) and reduced predation risk (Wittenberger *et al*., 1985; Anderson *et al*., 1993). However, coloniality is now recognized as a complex, non-uniform phenomenon, with different colonies exhibiting adaptive significance for varying reasons. Most of the breeding ecology studies were based on nest monitoring followed by a questionnaire survey, and very few used GIS. Majgaonkar, Bowden, and Quader (2018) reported only two nest failures in their study on White-rumped Vultures (WRV) in India, highlighting that forest colonies had a significantly higher nesting success rate (52.9%) compared to plantation colonies (21.2%). Nesting stage and site characteristics played a crucial role in determining success across these habitats, with plantation colonies experiencing a higher number of nest failures (39) than forest colonies (8). The overall nesting success in plantation colonies (21.2%) was lower than reported success rates for

WRV colonies in India, Nepal, and Pakistan post-2000, which ranged from 30% to 73% (Baral et al., 2007; Baral, Gautam, & Tamang, 2005b; Gilbert *et al.*, 2004; Thakur, 2012; Mamming and Xu 2015). In contrast, Bangladesh recorded even lower success rates of 15.6% and 25.8% between 2009 and 2011 in Diclofenac-affected colonies (Monirul and Khan, 2013). However, some studies have reported higher success rates, such as 70% in WRV colonies (Venkitachalam & Bharathidasan, 2013). In Nepal, Baral, Gautam, and Tamang (2005b) recorded a breeding success rate of 0.5 young per nest across 70 occupied nests.

Table 1.2. Breeding studies from India and Nepal. (Study type: 1. Breeding biology, 2. Nesting behaviour, 3. Nest site selection, Method: A. Nest Monitoring, B. Questionnaire survey, Data absent 0, Data present 1)

SI No.	Study Type	Method	Observed nests	Nest success	Productivity	Nest site	Source
1	1	A	6 colonies	1	0	0	Baral *et al* 2005
2	2	A	NA	0	0	0	Kambale, A.A. (2011)
3	2	A,B	68 nests	0	0	3	Ramakrishnan *et al* 2014
4	1	A	66	1	0	2	Majgaonkar *et al* 2018
5	3	A,B	25 nests	0	0	NA	Ghimire *et al* 2019
6	1,3	A,B	NA	NA	NA	NA	Samson *et al* 2020
7	1	A	83	NA	NA	9	Rana *et al* 2019
8	1,3	A,B	3	NA	NA	3	Vishnu *et al* 2024
9	1,3	A	1161	NA	NA	4 districts	Gautam *et al* 2024
10	1	A	24	1	1	2	Bhushal *et al* 2023

1.10.4. Movement Ecology:

Vultures rely on specialized behavioural adaptations to locate unpredictable and widely dispersed food sources (Houston *et al.*,1974). Tracking their movement patterns across different seasons and landscapes provides crucial insights into their foraging strategies. Over the past three decades, research on vulture spatial ecology has expanded globally, with telemetry studies becoming increasingly prevalent. Alarcón and Lambertucci (Alarcón and Lambertucci 2018) documented a surge in such studies, particularly in the last decade, reflecting the growing interest in understanding vulture movement dynamics. However, movement studies on White-rumped vultures are very scarce with only three studies one from Gujarat (Ram *et al.*,2022) and the other two as captive-release vulture movement studies from Nepal (Bhusal *et al.*,2018; Mallord *et al.*,2024). Studies on resident vultures, such as the White-rumped Vulture, indicate that the breeding season significantly influences their spatial use, daily and monthly movement patterns, and seasonal activity levels.

Table 1.3. White-rumped Vulture tagging studies showing wild and captive-bred vultures tagged

Si No.	Region	Method used	Wild or captive	Number of individuals	Study
1.	Saurashtra, Gujarat	GPS/GSM	Wild	2	Ram *et al.*,2022
2.	Nawalparsi, Nepal	GPS	Captive release	50	Mallord *et al.*,2024
3.	Nawalparsi,Nepal	GPS	Captive release	6	Bhusal *et al.*,2018

1.10.5. Behavioural Ecology:

Research on the behaviour of White-rumped Vultures in India are limited with few studies on feeding habits, nesting ecology, and social interactions. Observational studies have documented their feeding behaviour, noting their competitive dominance at carcasses and immediate feeding responses compared to other vultures in captivity (Lahkar *et al.*, 2010). Courtship and breeding behaviours have been recorded, detailing the role of males in nest-building and the elaborate head-billing displays during courtship (Yadav *et al.*, 2018). White-rumped Vultures are typically monogamous, with pairs remaining together across breeding seasons (Rana *et al.*, 2019). Females lay a single egg, and both parents participate in incubation and chick-rearing (Baral *et al,* 2005).

Social interactions at carcasses reveal a dominance hierarchy, with White-rumped Vultures often displaced by larger species like Red-headed Vultures (*Sarcogyps calvus*) (Hille et al.,2016; Islam et al.,2018). The impact of anthropogenic disturbances, including competition with feral dogs and food resource limitations, has been a growing concern in recent studies on behaviour of vultures in the wild (Bajpai *et al.*,2020; Santangeli *et al.*,2022; Kushwaha *et al* 2020; Mahajan *et al.*,2024; Vishnu *et al* 2024). With very limited data on behaviour, studies are crucial for understanding their foraging strategies, nesting dynamics, and social interactions, which directly influence their survival and conservation in the wild.

1.11. Objectives

1. Study the nesting biology of White- Rumped vultures.

i. What is the productivity and nesting success of WRV?

ii. What is the breeding time of WRV?

2. Assess the population trend of White-Rumped vultures.

i. What is the population trend of nesting WRV?

3. Assess nest site selection and associated threats to nesting sites.

i. What are the factors affecting the nest site selection of WRV?

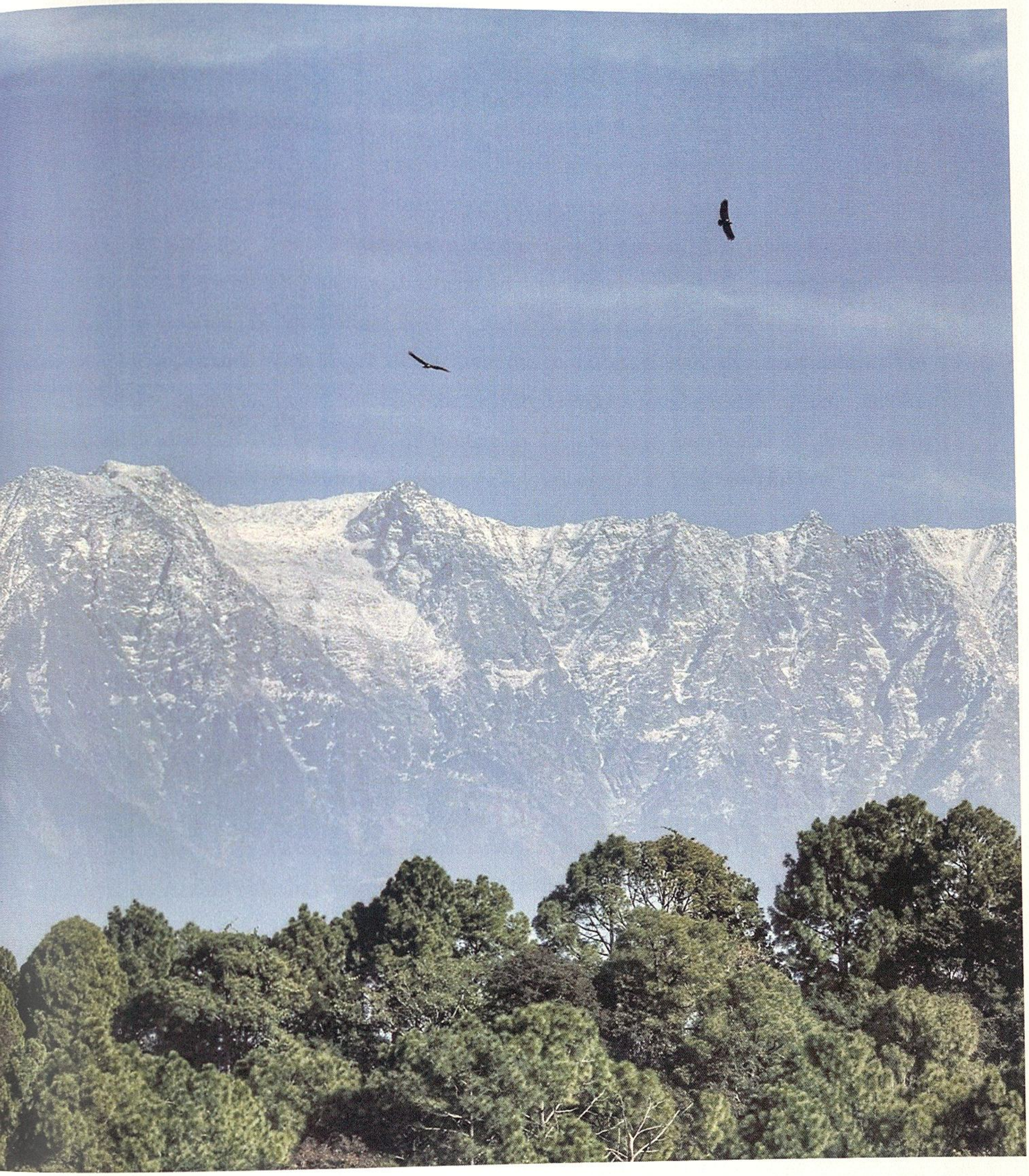
ii. What are the threats associated with nesting sites of WRV?

4. Assess movement dynamics in White-rumped vultures.

i. What is the home range of WRV?

1.12. Significance

The White-rumped Vulture has experienced a drastic population decline across its range, prompting extensive research into the underlying causes. In response, India initiated a captive breeding program to restore wild populations (Bowden 2009; Khan 2011). Despite the ban on toxic NSAIDs and the establishment of captive-bred populations, vulture numbers continued to decline (SOIB 2023). Given this alarming trend, restoring vulture populations to their natural habitats has become a critical and urgent conservation goal (Anoop et al, 2020). The present study focuses on Kangra, Himachal Pradesh, a region that supports one of the few remaining viable populations of the species. The region's vast Chir Pine (*Pinus roxburghii*) forests provide critical nesting sites for this critically endangered species. While previous studies have focused on the cause of the decline of the White-rumped vulture (Prakash et al, 2003; Ogada et al 2012; Pain et al 2003; Anderson et al 2001), understanding the influence of ecological and anthropogenic factors on its long-term survival is crucial. Movement ecology provides key insights into habitat use and survival strategies. In this context, the present study is the first of its kind to comprehensively examine the breeding and movement ecology of White-rumped Vultures in the wild, contributing to a deeper understanding of their conservation requirements.



Chapter 2: Study Area

2.1. Historical Background:

Nestled in the western Himalayas, Himachal Pradesh is a region of remarkable ecological and cultural diversity. Its varied altitudes and forest types support a rich assemblage of flora and fauna, making it a vital landscape for conservation in northern India. Kangra district, located in Himachal Pradesh, is among the state's oldest and largest administrative regions. Historically known as Trigarta, it was governed by the Katoch dynasty, recognized as one of the longest-surviving royal lineages in India (Charak 1978; Vogel 1933). Over the centuries, Kangra witnessed invasions by Mahmud of Ghazni, the Mughals, and later the British, leaving behind a legacy of forts, temples, and cultural traditions. The landscape of Kangra is breathtaking, dominated by the majestic Dhauladhar Range, which rises steeply from the valley, creating a striking contrast between snow-capped peaks and lush green valleys. The region is home to dense forests, tea gardens, and river basins, making it an ecologically rich and diverse area. Kangra is also famous for its ancient temples, including the revered Brajeshwari Devi Temple, the Baijnath Temple dedicated to Lord Shiva, and the Jawalamukhi Temple, known for its eternal flames (Sharma 2022). These sacred sites, set against the backdrop of stunning natural beauty, make Kangra a unique blend of history, spirituality, and scenic splendour. Traditionally, the inhabitants of Kangra have depended on agriculture and livestock rearing as their primary sources of livelihood.

2.2. Location:

The study area lies in the Western Himalaya at an elevation between 450m-1200 msl in the district of Kangra, Himachal Pradesh (Figure 2.1). The entire area is 5739 sq. km lying between 32.8307°, 32.2925°N and 75.9305,76.5426°E.

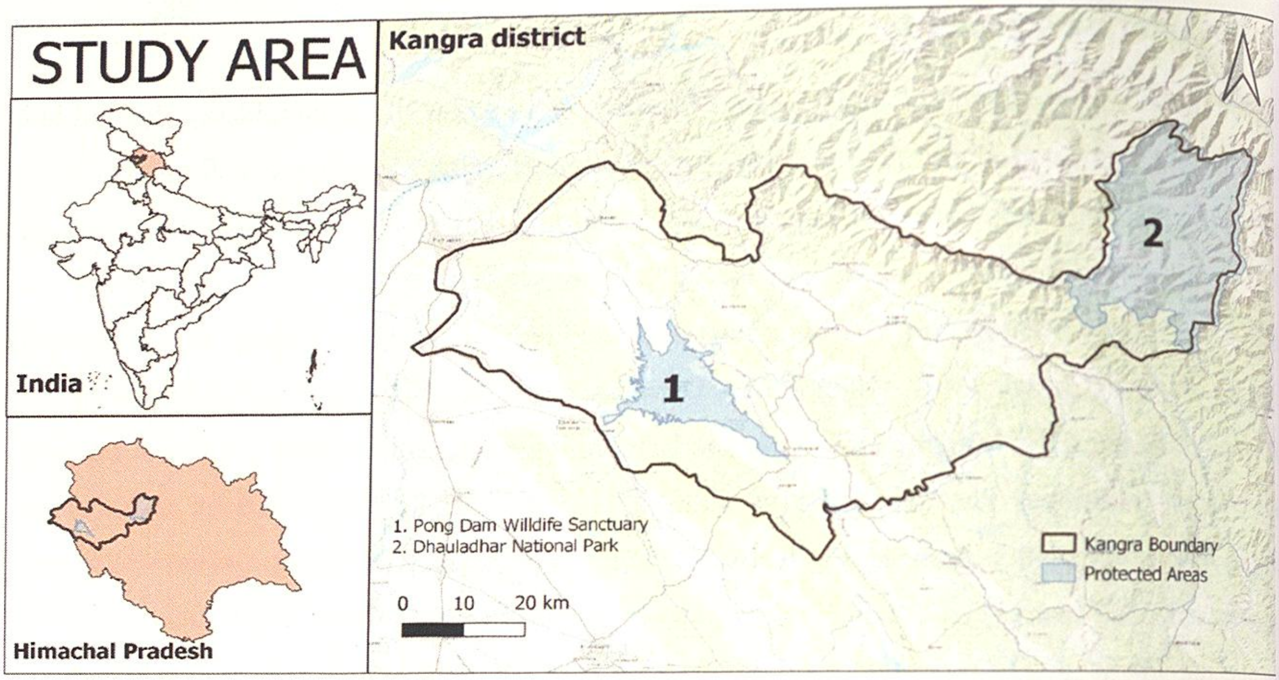


Figure 2.1. The study area Kangra district in Himachal Pradesh.

The habitat is mostly undulating terrain, having subtropical pine and subtropical broad-leaved hill forests. The dominant trees are Chir pine (*Pinus roxburghii*) trees, along with occasional ficus trees. The habitat consists largely of contiguous stretches of Chir pine forests, Curry tree (*Murraya koenigii*), along Date palm tree (*Phoenix* sp.). The area has a few mountain ranges with steep slopes. The climate varies between subtropical dry to subtropical humid, with an average annual rainfall of 1169 mm (Meteorological Centre, Shimla). The area is notable for cultivation, having 16.54% cultivated land of the total area. The human population of the district is 1,510,075, which is among the highest from HP (Sharma and Sharma 2023).

Table 2.1. 12 Forest range and 32 beats of Kangra district Himachal Pradesh.

Sl. No.	Range	Beats
1	Nagrota-Surian	Khuman, Bilaspur, Masroor
2	Jawalaji	Surani
3	Lapiana	Pandwar, Kotru, Harnera, Lanj, Boad Kualoo
4	Mallan	Aerla, Kandi, Danoa, Sarhood, Pathiar
5	Kangra	Gheena
6	Shahpur	Salol, Minjgran, Tiara, Salol
7	Kotla	Anuhi, Bhali, Dola, Ambal, Batuhi, Mastgarh
8	Nurpur	Tattal, Kherian
9	Jawali	Junat
10	Rey	Khatiar
11	Baijnath	Baijnath, Sansal
12	Palampur	Paror

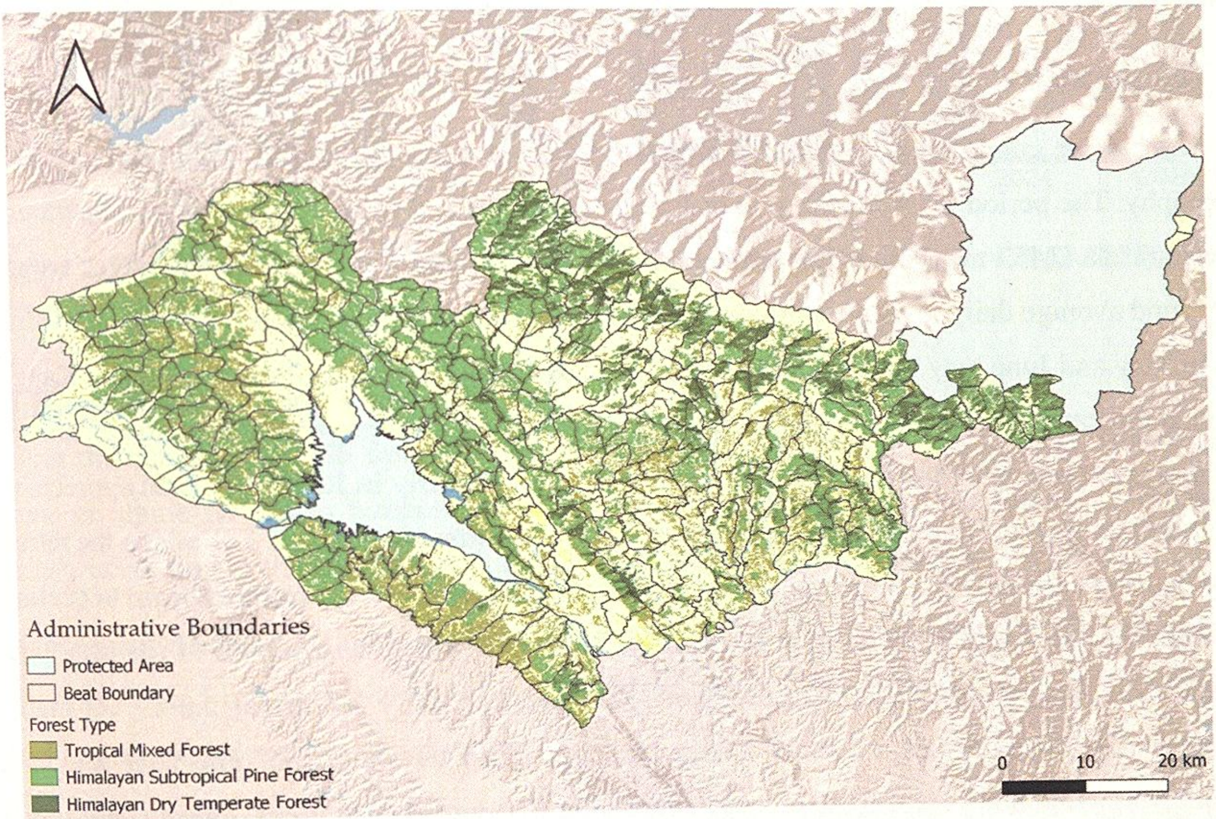


Figure 2.2: Administrative boundary and forest types of Kangra district

2.3. Geology:

The Kangra Valley has been divided into eight major geomorphic zones from Dhauladhar ranges in the north to upper Shivalik ranges in the south (Sah and Pal 1991) as detailed below: Perma Frost Zone, High mountainous zone, Piedmont Zone, Fan Zone, Bedland Molasse Topography, Fluvial Terraces, Alluvial fan Terraces, highly dissected outer Hill, Choe zone. The area surrounding consists of the upper, middle and lower Shivalik formations, which are highly susceptible to erosion.

2.4. Rainfall:

The Kangra region experiences varying levels of precipitation, with an increase from the southwest to the northeast. However, in the Saraj region, precipitation declines sharply as one move northward and northwestward. The district's annual average precipitation ranges from 1387.0 mm at Dehra-Gopipur to 3722.5 mm at Dharamsala (Lower). On average, the district receives 1852.3 mm of rainfall annually, with approximately 78% of it occurring during the monsoon season. Rainfall during the summer season primarily occurs in the form of thundershowers.

2.5. Temperature:

The temperature conditions in the different parts of the district are influenced largely by their topography. The period from March to late June is characterized by a steady rise in temperature. In Dharamsala (1457 m), June is the hottest month, with average daily high temperatures around 31.0°C and average daily lows of approximately 21.3°C. The maximum temperature on individual days in May and June may go up to about 38°C at Dharamsala. At lower elevations in the Kangra region, temperatures are higher. At higher elevations, however, the temperatures are lower, and the weather is pleasant. With the onset of the southwest monsoon early in July, there is an appreciable drop in day temperatures; however, nights are as warm as in summer months. Following the retreat of the monsoon around mid-September, both daytime and nighttime temperatures begin to decline, with nighttime temperatures falling more rapidly. January is the coldest month of the year, with average daily high temperatures around 14.6°C and average daily lows near 5.6°C. At higher elevations, the temperatures are much lower, depending on the elevation. The cold season is extremely bracing, and severe frost occurs on many days at higher elevations. During cold waves which affect the district as they move across lower Punjab and Kashmir, the minimum temperature even at places below 1200 meters drops down to about a degree below the freezing point of water and frosts occur. Snowfall occurs in the Kangra district during the period December to April at elevations as low as about 1500 meters on quite a few occasions, at times the snow accumulations being quite appreciable. Some snowfall continues to occur at elevations as low as 1500 meters even in May. However, later during the southwest monsoon season, snowfall is rarely below 4500 meters.

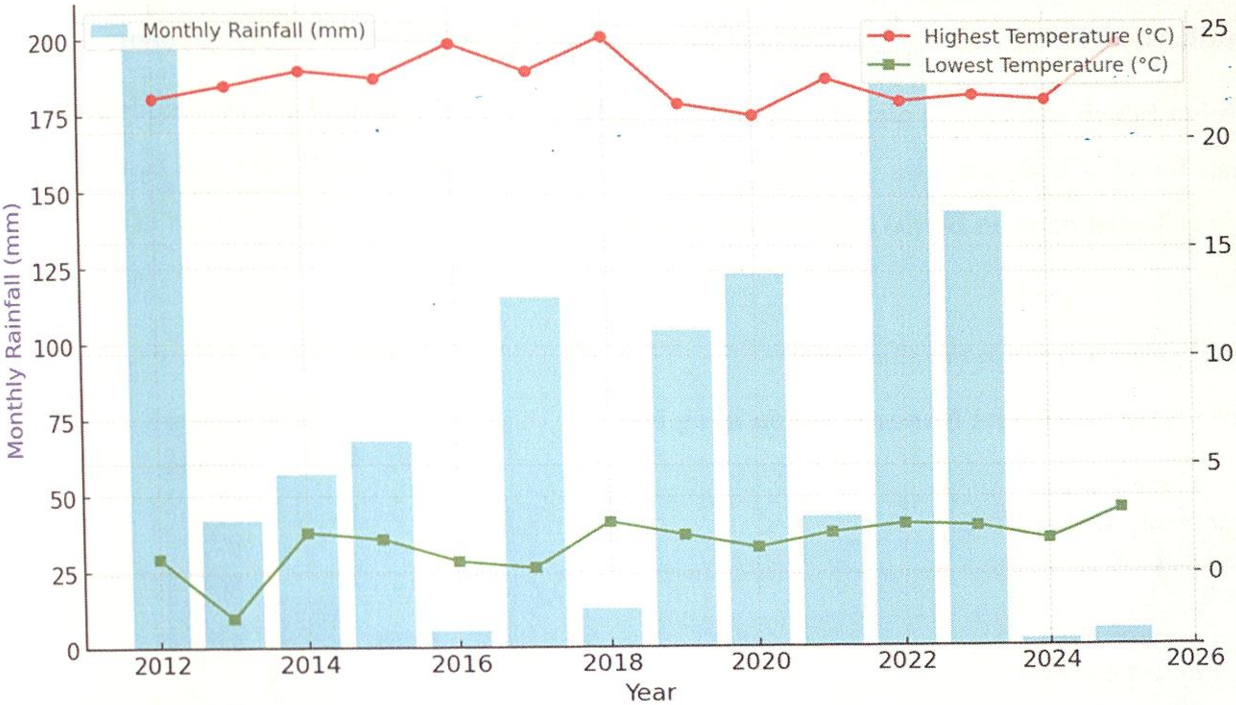


Figure 2.3. Interannual Variability in Temperature and Rainfall in Kangra (2012-2025) (Source mausam.imd.gov.in)

2.6. Biogeography and Forest Type:

Kangra district has variable forest types starting from high-altitude Sub-tropical forests, Sub-Alpine or alpine forests to temperate forests. The forest types of Kangra district in Himachal Pradesh, according to the Champion & Seth (1968) classification, include the following:

1. **Subtropical Forests:** 5B/C1: Himalayan Subtropical Pine Forest dominated by Chir Pine (*Pinus roxburghii*) found in lower elevations (~500-1800m) and 5/DS1: Himalayan Subtropical Scrub found in degraded slopes and drier regions

2. **Moist Temperate Forests: 12C1: Himalayan Moist Temperate Forest,** found in mid-elevation zones (~1500-2500m), **12C1(a): Oak Forest,** found in areas with high moisture

retention and **12/DS1: Himalayan Temperate Secondary Scrub,** degraded oak forests with shrub species.

3. Dry Temperate Forests: 13/C4: Himalayan Dry Temperate Coniferous Forest, occurs in higher altitudes (~2500m and above), dominated by Deodar (*Cedrus deodara*), Blue Pine (*Pinus wallichiana*), and Himalayan Cypress (*Cupressus torulosa*), and :**13/C5: Dry Temperate Broadleaved Forest** found in moisture-deficient zones

4. Alpine Scrub (at higher elevations in Dhauladhar Range): 15/C1: Birch-Rhododendron Forest, found at high altitudes (~3000m and above) in the Dhauladhar Range and composed of *Betula utilis* (Himalayan Birch) and *Rhododendron campanulatum* (The state flower of Himachal Pradesh).

Table 2.2 Forest types in the study area

Forest types of district Kangra	Area in sq Km
Very dense Forest	298.76
Moderately Dense Forest	1288.65
Open Forest	766.78
Scrub	15.66
Total area of District	5739
Total forest cover	2354.19

2.7.Livestock:

As of the 2011 human census, 89.96% of Himachal Pradesh's population resides in rural areas. Agriculture forms the backbone of the state's economy, with small-scale farming being predominant. According to the agricultural census, 87.95% of all landholdings are categorised as small or marginal. Livestock rearing is a vital aspect of the rural economy, contributing significantly to the livelihoods of small and marginal farmers. According to the 20th Livestock Census conducted in 2019, the area has livestock populations, including cattle, buffaloes, sheep, goats, and poultry. The official census report provides comprehensive figures for each category, reflecting the region's strong dependence on animal husbandry.

Livestock rely partially on fodder and grass from common property resources (CPRs) in addition to crop residues. Nearly every rural household keeps some form of livestock, and these animals contribute to household income. Indigenous breeds and their crossbred offspring are heavily dependent on grazing lands, pastures, and forests for sustenance. However, when livestock become unproductive, old, or sick, they are often abandoned rather than cared for.

Grasslands and pastures in the state are underutilized and yield below their potential, resulting in a gap between the demand for and supply of green fodder. In Kangra, grasslands cover 69,781.7 hectares, accounting for 27.51% of the total area (Singh et al., 2009). The challenge of maintaining livestock productivity has worsened with shrinking landholdings and the declining availability and productivity of common grazing lands over time.

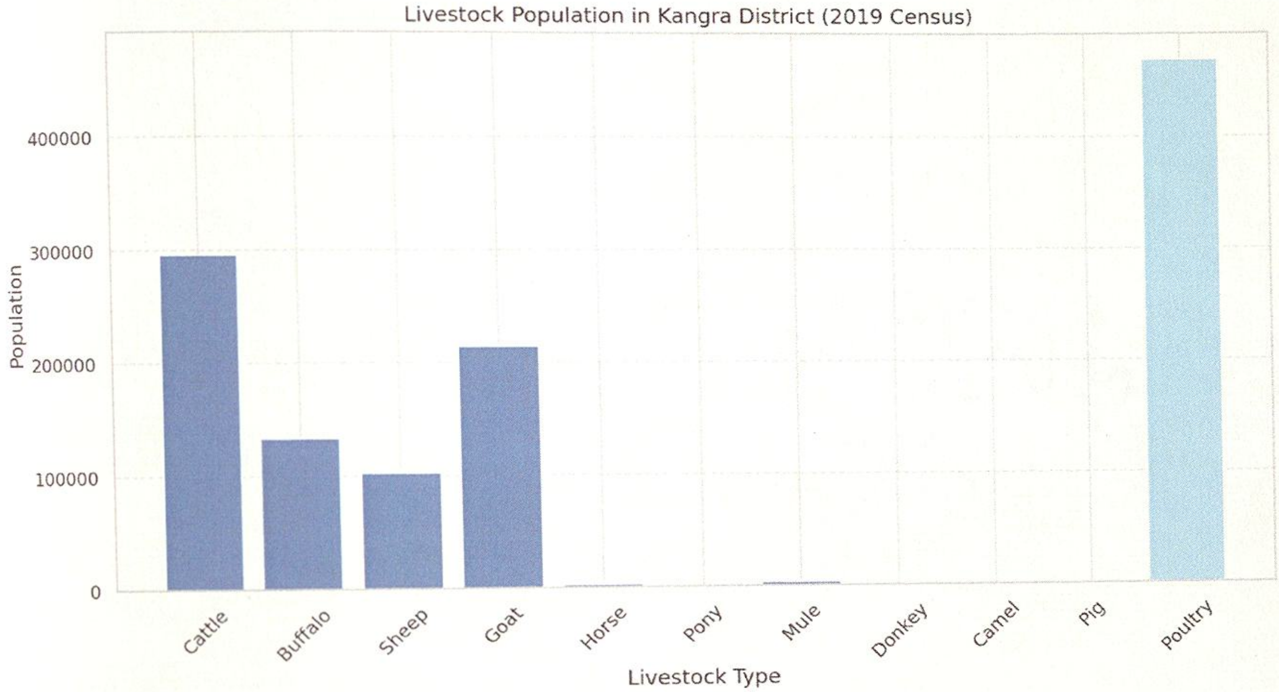


Figure 2.4 20th Livestock Census of Kangra district showing number of livestock from 2019

2.8. Agricultural importance:

The people of Kangra district primarily rely on diverse land use and agricultural practices. The district cultivates a range of crops, including Wheat, Corn, Paddy, Maize, Barley, and Millet. According to the 18th Livestock Census 2007, Kangra has 380591 Cattle, 156094 Buffaloes and 67757 Sheep, other than the Buffaloes and sheep reared by the Gujjar and Gaddi communities in the area. A key feature of their farming system is kuhl, a traditional irrigation network managed by local communities. These small canals, now predominantly constructed of cement, redirect water from larger sources to villages and fields via smaller drains. Water flow is regulated by *pucca* or *kachcha* gates, which are opened and closed on a set schedule. Despite Kangra's Green Revolution, farming here remains largely rain-fed, limiting cultivation primarily to wheat and maize.

Figure 2.5 Agricultural practices in Pong Dam area

2.9.Pong Dam Wildlife Sanctuary:

The study area encompasses a wetland of international importance, the Ramsar site called Pong Wetland. It was established in 1975 on the River Beas in Himachal Pradesh. It comprises a total geographical area of 207.59 sq km, mainly up to 429 masl, falling in Nurpur and Dehra Forest Divisions. Its total catchment area of 12562sq.Km lies in Kangra, Mandi and Kullu districts with the Himalayas in the background and Shiwalik foothills in the forefront. The Final Notifications of this wetland as a Wildlife (Birds) Sanctuary was issued vide Notification No. FEE-B-F(6)-8/99 dated Shimla, the 23.10.1999.

Pong Dam Wildlife Sanctuary was designated as a Wetland of National Importance by the Ministry of Environment and Forests, Government of India, in 1994. It later became the first wetland in Himachal Pradesh to receive international recognition as a Ramsar Site during the Ramsar Convention held in Spain in 2002.The wetland became one of the largest human-made wetlands in North India. Pong Dam's location in the trans-Himalayan flyway of migratory birds and its variety of habitats have excellent biodiversity value. Over 400 species of 100,000 migratory birds make Pong their home during the migratory season, including the largest congregations of Bar-headed geese (*Anser indicus*). This is the first significant wetland that serves as a potential stopover and wintering ground for migratory birds arriving from the trans-Himalayan region, as wetlands in Europe and North and Central Asia freeze over during winter, leading to a severe shortage of food. Some rare species, such as Red-Necked Grebe (First time recorded in 1992), Lesser White Fronted Goose, and Eurasian Oystercatcher have been noticed every year during winters. Pong Lake hosts the world's largest congregations of Bar-headed Geese, with over 45% of the global population recorded at this single wetland. The dam was commissioned in 1974, primarily for power generation, irrigation, and flood control.

Figure 2.6 Pong Wetland at Kangra serving as an unique habitat for thousands of migratory birds

2.10. Fauna:

Kangra district in Himachal Pradesh hosts a rich faunal diversity due to its varied terrain, ranging from lowland plains to the high-altitude Dhauladhar range. The region supports a mix of Himalayan and sub-Himalayan species, including mammals like Common leopards(*Panthera pardus*),Leopard cat (*Prionailurus bengalensis*), Goral (*Nemorhaedus goral*), Barking deer (*Muntiacus muntjak*), Sambar (*Cervus unicolor*), Himalayan black bear (*Ursus thibetanus laniger*), Indian Porcupine (*Hystrix indica*), Wild boar (*Sus scrofa*) , Indian black turtle (*Melanochelys trijuga*) and Indian flap shell turtle (*Lissemys punctata*). 23 species of fauna belonging to 23 different genders, 17 families and seven orders. Rodentia with four species and Primate and Lagomorpha with two species were recorded from here (Thakur and Banyal 2023).

2.11. People:

The villagers of Kangra Valley belong to diverse communities, including the semi-nomadic Gaddi pastoralists, who migrate seasonally to graze their sheep and goats, the Gujjars who migrate with their Buffaloes to the low-elevation regions, the Chamars who maintain their daily livelihood by disposal of cattle carcasses along with the Pahadi community. The Gaddi tribe encompasses various castes such as Brahmins, Thakurs, Chowdharys, and Rajputs, while other groups like Halis and Dogris also reside in the region. The valley boasts a rich linguistic heritage, with dialects shifting every few miles. However, the Pahari dialect is increasingly under threat as children are sent to Hindi- and English-medium schools. This cultural and linguistic diversity is as evident in the traditions of the people as it is in the valley's abundant flora and fauna. Over centuries, diverse communities migrated to Kangra Valley, seeking refuge from invasions and drawn by its role as a thriving center of trade and commerce. The Gaddis and other groups gradually transitioned to settled agriculture, largely influenced by British colonial land policies that promoted permanent farming for revenue generation. This shift led to the expansion of cultivated lands and the establishment of permanent settlements. Since the 1960s, the valley has also witnessed an influx of Tibetans, following the establishment of Dharamshala as the Tibetan government-in-exile's capital, along with growing tourism and seasonal migration from Delhi and Punjab. Despite these changes, the deep connection to agriculture remains strong, with farming rhythms and rituals continuing to shape the lives of those who still work on the land.

Figure 2.7 Traditional Livelihood of the Gaddi People in Kangra: Reliance on Goat and Sheep Re in the Mountainous Landscape

Chapter 3: Nesting Biology of White-rumped Vultures in Kangra

3.1. Introduction:

The breeding biology of White-rumped vultures in India remains poorly documented, with only a few region-specific studies available (Majgaonkar *et al.*, 2018; Samson *et al.*,2020; Pande *et al.*, 2013). Existing research has primarily been short-term, leaving significant gaps in our understanding of wild-breeding populations. Long-term studies are essential to assess this critically endangered species' survival strategies and adaptive responses.

One of the key questions in vulture conservation is determining the reproductive success of White-rumped Vultures. Site-specific parameters such as clutch size, nesting success, and nesting mortality provide valuable insights into their nesting biology. Understanding these factors is fundamental for developing effective conservation strategies. This chapter explores the nesting biology and population trends of White-rumped Vultures in Kangra, addressing these knowledge gaps and highlighting the ecological factors influencing their reproductive success.

3.1.1. Nesting Biology

White-rumped Vultures (WRVs) are typically found in areas near villages, towns, or cities, predominantly inhabiting lowland regions, extending up to approximately 1500 meters in the Himalayan foothills (Ghimire *et al.*, 2019; Bhusal *et al.*, 2023). The species forms monogamous pairs and exhibits strong nest site fidelity, breeding colonially (Bhusal *et al.*, 2020; Gautam *et al.*, 2024). WRVs generally nest on relatively tall trees, including Chir Pine (*Pinus roxburghii*), Coconut (*Cocos nucifera*), and occasionally *Ficus* species (Majgaonkar *et al.*, 2018).

In India, the breeding season typically commences in October and continues through March or April. Breeding pairs usually lay a single white egg, with an incubation period ranging from 45 to 52 days. Both parents share responsibilities for incubation and chick rearing, and fledglings generally attain independence after approximately three months (Thakur, 2015; Rana *et al.*, 2019; Bhusal *et al.*, 2023). The nesting cycle of WRVs is defined as the period from nest construction initiation to fledgling development.

India has its nesting population pockets found from several states of India, including Madhya Pradesh (Roy, 2007; Navaneethan *et al.*, 2015), Rajasthan(Chhangani, 2009), Gujarat(Gadhvi *et al.*, 2006; Moradiya & Goswami, 2021), Kerala(Vishnu, 2018), Andhra Pradesh(Sivakumar and Manikadan, 2005), Uttar Pradesh(Kumar 2020, Sethi and Chauhan, 2010), Uttarakhand(Sharma *et al.*, 2007; Kumar *et al.*, 2022), Tamilnadu (Samson *et al.*,2020), Maharashtra(Pande *et al.*, 2013) and Himachal Pradesh(Thakur, 2015). Its nesting range is even distributed in the coastal states of Maharashtra (Majgaonkar *et al.*, 2018) and the Sigur plateau of Tamil Nadu (Kannan *et al.*, 2013).

3.1.2. Population of WRVs from India

The population trends of White-rumped Vultures (WRV) in India have primarily been assessed through road transect surveys conducted in Rajasthan, Madhya Pradesh, Gujarat, Maharashtra, and other states, excluding the present study area. In 2022, only 106 WRVs were recorded along these transects. Over the past 30 years, population indices have shown a sharp decline, with the most significant reduction occurring between 1992 and 2007. Between 2002 and 2022, the annual population multiplication rate (λ) remained significantly below one, indicating a continued decline. Relative to 2002, population indices for 2003–2022 suggest an additional 67% decline, compounding the 98% loss recorded between 1992 and 2002 (Prakash *et al* 2017; Prakash *et al.*,2024).

Long-term trends have also been assessed using citizen science data from the *State of India's Birds* (SoIB 2023) project, which reported a 97% decline in WRV records across India since 2004. The discrepancy between road transect surveys and citizen science data may be due to the former's focus on protected areas, where vulture densities are higher and less severe decline (Prakash *et al.* 2012, 2019). In contrast, the broader geographic coverage of citizen science checklists likely reflects steeper declines in areas farther from protected zones, highlighting the continued vulnerability of WRV populations across the landscape. To understand the population of vultures several methods can be applied like mark-recapture, vehicle transect surveys, nest counts, and Lincoln-Petersen estimates.

3.1.3. Colonial nesting in WRVs:

White-rumped Vultures are colonial nesters, meaning they breed in clusters, often establishing nests in tall, mature trees within a shared habitat (Majgaonkar *et al.*, 2018). This colonial nesting behavior offers several advantages, such as increased protection from predators, social interactions that aid in breeding success, and enhanced foraging efficiency through communal roosting(Fernández *et al.*, 2016). This also makes them highly vulnerable to habitat disturbances, including deforestation, selective logging, and human encroachment (Zuberogoitia *et al.*, 2019).

Nesting colonies are often located near human settlements, where threats such as poisoning, infrastructure development, and resource extraction can significantly impact breeding success.

3.1.4. Vulture studies from Himachal:

In Kangra Valley, Himachal Pradesh Forest Department has monitored the numbers of the breeding population of WRV since 2004. In 2015, Thakur reported twenty-four colonies in Himachal Pradesh with 102 nests nesting in Chir Pine (*Pinus roxburghii*) forests with a nesting success of 56·1% in 2009–10 and 79·4% in 2010–11. (Thakur 2012). A study from 2008 in Kangra has reported 24 sites with 352 active nests. (Sehgal and Kumar 2022). The breeding population has increased steadily from 26 to 404 active fledglings between 2004 to 2021, supported by the continuous effort of the Himachal Forest Department to annually monitor the nesting sites of WRV (HPFD Report 2021).

The present study aims to identify 1) the nesting biology of WRVs in the study area 2) the population trend of WRVs in the study area.

3.2. Methods

3.2.1. Nest Survey and Nest Monitoring:

Nest surveys and monitoring of WRVs were conducted systematically across identified nesting colonies to assess breeding success and population trends. Surveys were carried out by walking along designated forest trails and using vantage points for unobtrusive observations with binoculars (8*42). Each active nest was marked and monitored at regular intervals to document key breeding parameters, including occupancy, incubation, chick development, and fledging success.

3.2.1.1. **Pre-nesting Phase**:

During the pre-nesting phase, which occurs between September and October, known nesting sites were systematically surveyed to identify early signs of nest construction. Field visits were also conducted to monitor the behavior of nesting pairs and to detect any faecal signs that might indicate active nest preparation. Opportunistic records were made of various nesting activities, including nest visits, nest building, the refurbishing of old nests with fresh pine needles, courtship displays, and mating behavior.

3.2.1.2. **Nesting Phase**

We monitored a few selected nests during 2021-2024. Nest watches vary during different periods of the day, ranging from one to five hours per day. Observations were carried out mostly from 09:00 to 14:00 hours and sometimes in the extreme winters from 11:00 to 16:00 hours (Table 3.1). Observations were made from the top canopy, hiding from nearby top viewpoints using 10*42 binoculars inside the forest, as most of the nests are situated at 20-25m height. During each visit, the time of the first egg seen and the fledgling seen were recorded, as well as the times noted for parents leaving and visiting the nest. Nest watches were conducted for a total of 45 nests for the four-year study period, sampling opportunistically from five large colonies, including Lalpur, Lunj, Nurpur, Salon and Sirmani areas. Nest tree reuse was also recorded each year (Table 3.7).

3.2.1.3. **Nest population monitoring**

Nest population monitoring was conducted annually from October to March (2021-2024), following the hatching period of most birds. A complete count of nest trees was undertaken, distinguishing between active and inactive nests. All trees were marked with paint for identification. Observations were conducted using binoculars and spotting scopes to minimize disturbance. Key parameters such as nest tree species, height, girth at breast height (GBH), nest height, and colony size were recorded (details in Chapter 4). Nest populations were monitored across all identified colonies by walking along designated forest trails, using a random sampling survey within the study area.

3.2.1.4. **Nest Success**:

45 nests were selected for focal sampling from five different colonies. Nest success was assessed through repeated monitoring of identified nest colonies during the breeding season (October-March,2021-2024). Nests were observed at regular intervals to record breeding stages, including incubation, hatching, and fledging. A nest was defined as successful if it produced at least one fledgling. Key parameters such as nest survival rates, causes of nest failure (e.g., predation, disturbance, weather events), and breeding success were documented. Data was analyzed using Mayfield's method and apparent nest success calculations to estimate overall reproductive success in the study area. Descriptive statistics were used to depict the length of the breeding cycle, incubation period and other parameters of the breeding biology.

Table3.1.: Annual Nest Monitoring Effort for White-rumped Vultures in the Study Area

Year	Total Days Observed	Total Hours Observed	Observation Intensity (Hours/Day)
2021-22	235	719	3.06
2022-23	285	1114	3.91
2023-24	270	986	3.65

3.2.2. **Nest Success Analysis**:

We used the Mayfield Nest Success (Mayfield 1975; Hensler 1981; Mayfield 1961) method to estimate daily nest survival rates while accounting for exposure time. The daily survival rate (DSR) was calculated as DSR = 1 - (Failures / Exposure Days), in Program R- Nest Success=$DSR^{\text{Mean Nesting Period}}$. This approach minimises biases compared to apparent nest success and is effective for small sample sizes.

3.3. Results:

We covered the area on foot with 840 km walk efforts and 740 hours (Figure 3.1), and detected 17 nest colonies with 617 active nests in Chir Pine trees (*Pinus roxburghii*) over three consecutive breeding seasons (2021-2024) (Table 3.2). The breeding season spanned 193 days from egg laying to fledgling development.

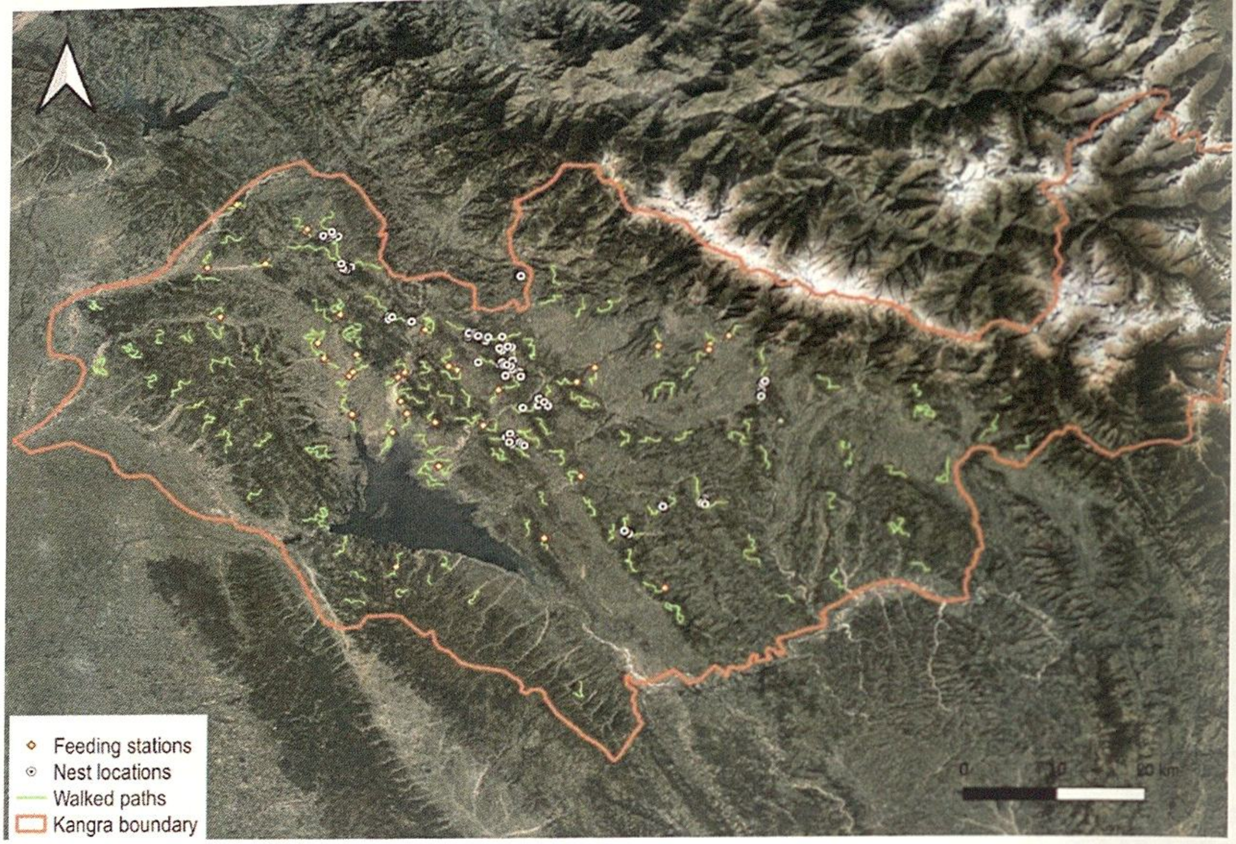


Figure 3.1.Transects Walked in Kangra district, Himachal Pradesh (2020-2024)

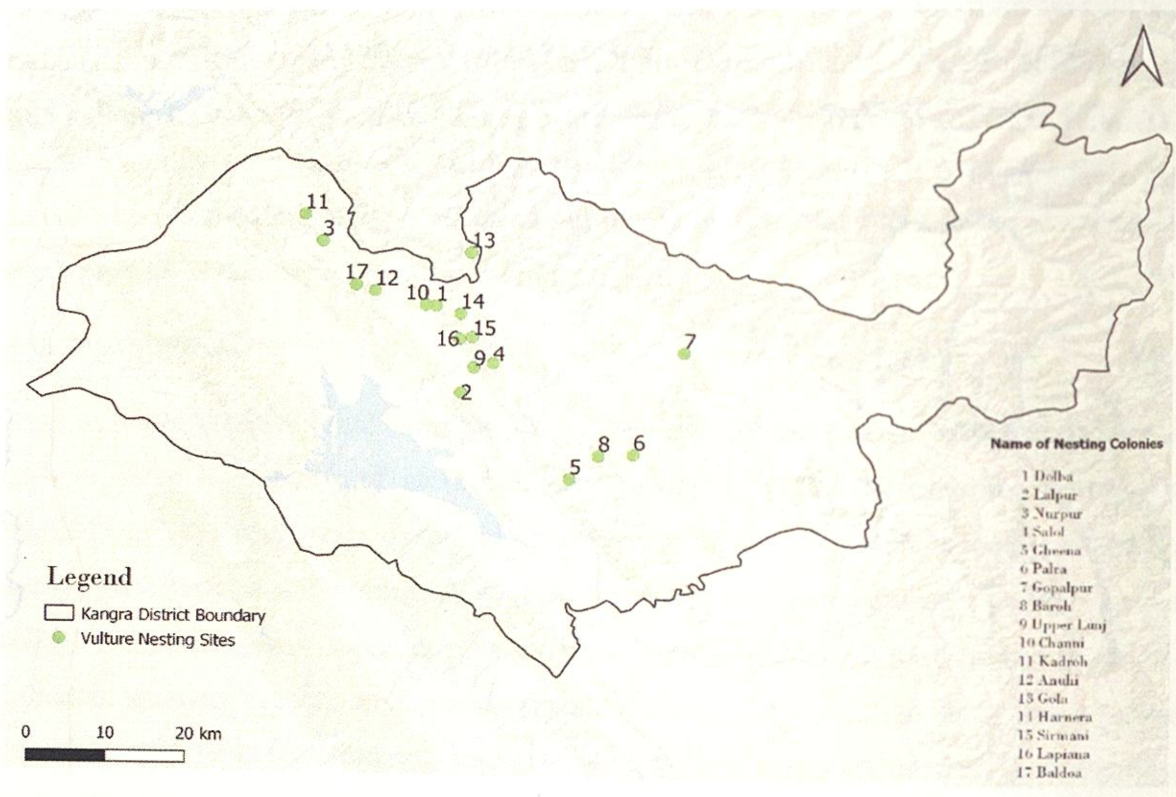


Figure 3.2.: Nesting colonies of WRV in the study area showing 17 nesting colonies found from 2019-2024.

Table 3.2.: Nesting colony with number of nests across beats from 2021-2024.

SI No.	Nesting Colony Name	Division	Beat	Nest Count
1	Dolba	Nurpur	Jol	66
2	Lalpur	Dehra	Khuman	62
3	Nurpur	Nurpur	Minjgram	54
4	Salol	Dharamshala	Kotharoo	68
5	Gheena	Dharamshala	Balagaloa	59
6	Palra	Dharamshala	Kandi	27
7	Gopalpur	Dharamshala	Pathiar	46
8	Baroh	Dharamshala	Danoa	23
9	Upper Lunj	Dharamshala	Lunj	27
10	Channi	Nurpur	Bhali	18
11	Kadroh	Nurpur	Minjgram	24
12	Anuhi	Nurpur	Anuhi	11
13	Gola	Chamba	Urli	20
14	Harnera	Dharamshala	Shahpur	10
15	Sirmani	Dharamshala	Pandhwar	53
16	Lapiana	Dharamshala	Pandhwar	32
17	Baliara	Nurpur	Batuhi	17
			Total	**617**

3.3.1. Nesting ecology:

Both sexes participated in the nest site inspection and construction. During the pre-nesting phase twigs or small branches of Chir Pine (*Pinus roxburghii*) with evidence of scratch marks were observed, indicating that vultures used their beaks to break these twigs from the branches. In several instances, copulation was observed both on tree branches and at nests. These observations continued from September through November, marking the completion of the nest-building phase. Pre-breeding behaviors, such as mating and nest preparation, were observed as early as August or September.

WRVs exhibited strong nest site fidelity, often reusing previously built nests. It was noted that the timing of nest building varied significantly, influenced by seasonal fluctuations in temperature . The nesting season starts when the vulture starts to use the nest and sit on it for several hours. Observation on activities such as nest rebuilding and fledgling vocalization were recorded in different years. Specific behavioural observations like interactions with other vultures in the same colony and interaction with Large-billed crows(*Corvus splendens*) in the nest were recorded. Predation of eggs by Bengal monitor lizard (*Varanus bengalensis*) and Indian Rock Python (*Python molurus*) was recorded only twice during the study period.

The timing of nesting varied across years and colonies. In 2021 and 2022, nesting was primarily initiated in late October, whereas in 2023, it began in early November. Additionally, nesting initiation varied between colonies due to differences in elevation and seasonal conditions. Colonies located at higher elevations, such as Gopalpur and Gheena, exhibited delayed nesting compared to lower-elevation sites like Lalpur. These variations are probably due to the influence of environmental factors on breeding phenology in White-rumped Vultures. The length of the nesting cycle, (from incubation to chick fledging) varied between different colonies. The nesting cycle of the WRV ranged from 50 to 65 days for incubation following 3-4 months for fledgling growth time.

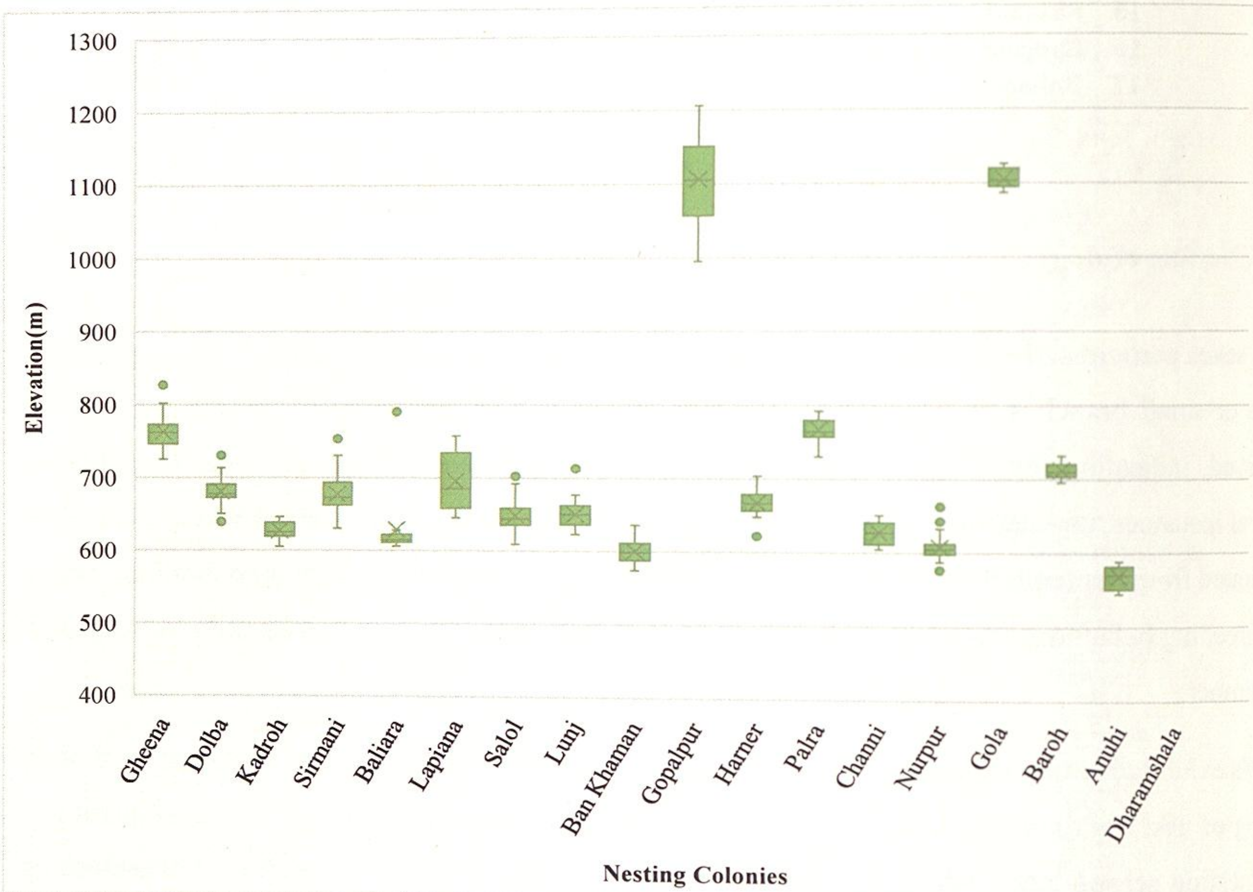


Figure 3.3.: Elevation of nesting colonies of the WRV

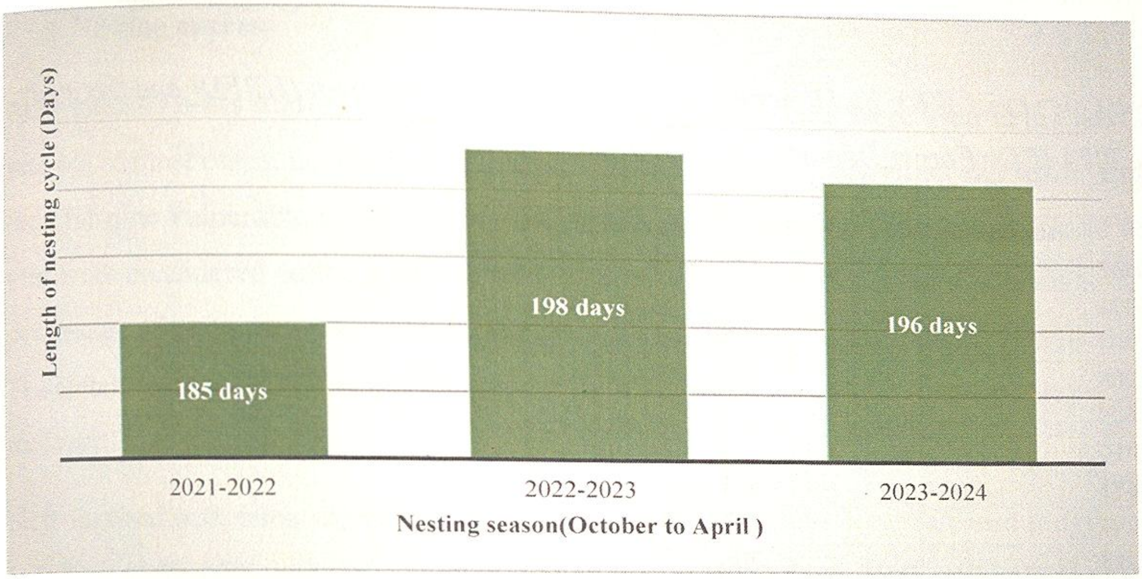


Figure 3.4.: Nesting cycle length in days for White-rumped vulture over three years.

3.3.2. Breeding Population in the study area:

The total number of WRVs counted through nest counts taking one nest as a breeding pair and having a fledgling as given in Table 3.3. The Himachal Pradesh Forest Department (HPFD) has been conducting nest surveys to monitor the nesting population of White-rumped Vultures (WRV) in the region since 2004. However, survey methods were not uniform across all years, leading to variability in data collection. Our systematic data from the last five years (2020–2024) indicate a clear increasing trend in the breeding population. The number of active nests detected by us increased from 152 in 2020 to 617 in 2023–2024, with detected breeding pairs increasing from 456 to 1851 over the same period. This might be partly due to increasing survey efforts and the expansion of survey areas over time, providing a more comprehensive understanding of WRV populations in the region.

Table 3.3.: Nest survey of WRV by Himachal Pradesh Forest Department (HPFD) and this study from 2005 to 2024 (FD=Forest Department, WII Study)

Year	Number of WRV nests	Survey By
2005	69	FD
2006	90	FD
2007	93	FD
2008	129	FD
2009	165	FD
2010	258	FD
2011	513	FD
2012	600	FD
2013	702	FD
2014	723	FD
2015	807	FD
2016	840	FD
2017	882	FD
2018	939	FD
2019	1056	FD
2020	267	FD
2021	915	WII Study
2022	1350	WII Study
2023	1536	WII Study
2024	1851	WII Study

Table 3.4. Number of nesting pairs of White-rumped vultures from 2020-2024 through nest site surveys.

SI No.	Year	Nesting trees	Active nest numbers	Number of nesting pairs
1	2020	159	152	456
2	2020-2021	261	305	915
3	2021-2022	398	450	1350
4	2022-2022	455	512	1536
5	2023-2024	553	617	1851

3.3.3. Nesting success

Among the 45 nests studies (Table 3.6), few of the unused nests were used in the next consecutive year but in most cases, nests became inactive due to forest fire activities and resin tapping making the Chir pine vulnerable to fall during the storm. Nests that were at least used and rebuilt in the year were considered active until any chick mortality recorded. Nesting success is defined as the percentage of nests that have at least one chick that successfully fledges from them. (Mishra 2020). The clutch size for WRV is one chick annually, thus chick survival is very important for population recovery.

Nest survival estimates varied across colonies, with Mayfield Nest Success ranging from 4.86% in Lalpur to 76.07% in Salol. Total exposure days varied from 1863 to 1047 days. Nest failures were most frequent in Lalpur (13 failures) because of forest fire incidents, whereas Sirmani and Salol had the lowest failures (2 each). The daily survival rate (DSR) remained high across colonies, ranging from 0.991 in Lalpur to 0.998 in Sirmani, indicating that most nests survived on a daily basis. However, the overall nest success showed considerable variation, with Salol and Sirmani exhibiting significantly higher nest success rates (>66%) compared to other colonies. These results suggest that nesting conditions or external threats vary across colonies, influencing long-term nest survival.

Table 3.5.: Nest success in five colonies was monitored for three breeding seasons.(DSR=Daily Survival Rate is the probability that an individual (e.g., a nest, chick, or adult bird) survives from one day to the next during a specified period of monitoring.)

Colony	Total exposure days	Total nest failures	DSR(Av)	Mayfield Nest Success (Av.) (%)
Lalpur	1549	13	0.991	18.827
Lunj	1047	6	0.994	32
Nurpur	1863	8	0.995	43.056
Salol	1164	2	0.997	76.072
Sirmani	1409	2	0.998	77.466

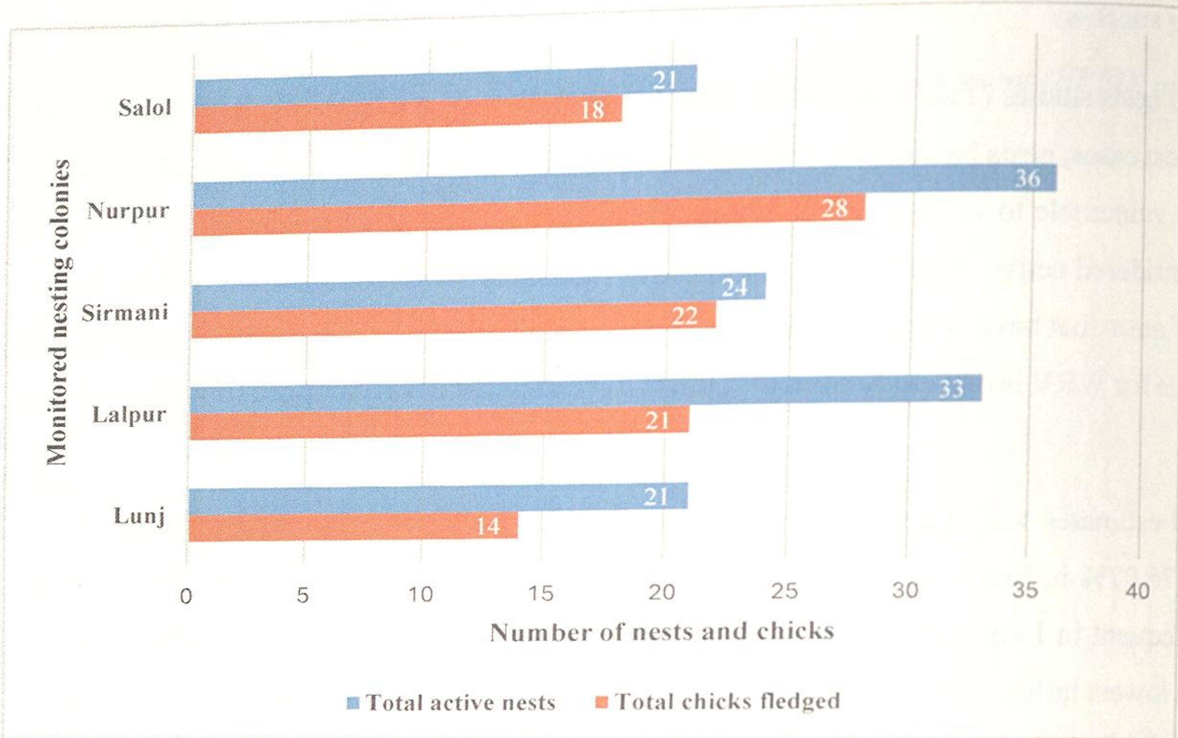


Figure 3.5: Fledgling success in five different nest colonies monitored intensively for nest success for three breeding seasons

Table 3.6.: 45 nests monitored to understand nest success of White-rumped vulture from five selected nesting colonies (1,2,3 represents three breeding seasons monitored 2021-2022,2022-2023 and 2023-2024)

SINo	NestID	Colony	Exposure days			Nest fate(0=Failed,1=Success)					
			1	2	3	1	Cause of nest failure	2	Cause of nest failure	3	Cause of nest failure
1	LU1	Lunj	55	54	60	1		1		1	
2	LU2	Lunj	52	61	65	1		1		1	
3	LU3	Lunj	48	62	22	1		1		0	Unknown
4	LU4	Lunj	25	15	63	0	Nest tree dried	0	Abandoned	1	
5	LU5	Lunj	48	53	63	1		1		1	
6	LU6	Lunj	58	32	64	1		0		1	
7	LU7	Lunj	55	25	20	0	Abandoned	0		0	Abandoned
8	LAL1	Lalpur	62	46	58	1		1		1	
9	LAL2	Lalpur	53	45	59	1		1		1	
10	LAL3	Lalpur	52	57	65	1		1		1	
11	LAL4	Lalpur	34	32	31	0	Abandoned	0	Forest fire nest tree failed	0	Forest fire nest tree failed

12	LAL5	Lalpur	35	15	22	0	Forest fire nest tree failed	0	Forest fire nest tree failed	0	Forest fire nest tree failed
13	LAL6	Lalpur	61	35	21	1		0	Forest fire nest tree failed	0	Forest fire nest tree failed
14	LAL7	Lalpur	46	62	62	1		1		1	
15	LAL8	Lalpur	59	61	61	0	Abandoned	1		1	
16	LAL9	Lalpur	51	39	62	1		0		1	
17	LAL10	Lalpur	31	46	22	0	Forest fire nest tree failed	0	Forest fire nest tree failed	0	Forest fire nest tree failed
18	LAL11	Lalpur	25	39	63	0	Unknown	0	Abandoned	1	
19	SIR1	Sirmani	46	59	63	1		1		1	
20	SIR2	Sirmani	64	58	59	1		1		1	
21	SIR3	Sirmani	52	47	63	1		1		1	
22	SIR4	Sirmani	49	21	64	1		0	Abandoned	1	
23	SIR5	Sirmani	47	53	62	1		1		1	
24	SIR6	Sirmani	58	60	64	1		1		1	
25	SIR7	Sirmani	46	56	60	1		1		1	
26	SIR8	Sirmani	51	20	64	1		0	Unknown	1	
27	NUR1	Nurpur	56	55	64	1		1		1	
28	NUR2	Nurpur	58	45	65	1		1		1	
29	NUR3	Nurpur	59	49	22	1		1		0	Unknown
30	NUR4	Nurpur	54	25	59	1		0	Unknown	1	
31	NUR5	Nurpur	50	57	62	1		1		1	
32	NUR6	Nurpur	53	52	63	1		1		1	
33	NUR7	Nurpur	64	47	22	1		1		0	Unknown
34	NUR8	Nurpur	35	55	59	0	Unknown	1		1	
35	NUR9	Nurpur	65	23	64	1		0	Abandoned	1	
36	NUR10	Nurpur	56	61	60	1		1		1	
37	NUR11	Nurpur	63	62	22	1		1		0	Abandoned
38	NUR12	Nurpur	38	21	63	0	Unknown	0	Abandoned	1	
39	SAL1	Salol	62	20	60	1		0	Unknown	1	
40	SAL2	Salol	48	60	59	1		1		1	
41	SAL3	Salol	24	56	60	0	Forest fire nest tree failed	0	Unknown	1	
42	SAL4	Salol	51	57	59	1		1		1	
43	SAL5	Salol	47	50	60	1		1		1	
44	SAL6	Salol	35	59	64	0	Abandoned	1		1	
45	SAL7	Salol	47	57	59	1		1		1	

Table 3.7. Total number of nests monitored in five colonies of White-rumped vulture in Kangra district across three years

Colony	Total number of nests monitored	Number of active nests		
		2021-2022	2022-2023	2023-2024
Lunj	7	5	4	5
Lalpur	11	6	7	8
Sirmani	8	8	6	8
Nurpur	12	10	9	9
Salol	7	5	6	7
Total	**45**	**34**	**32**	**37**

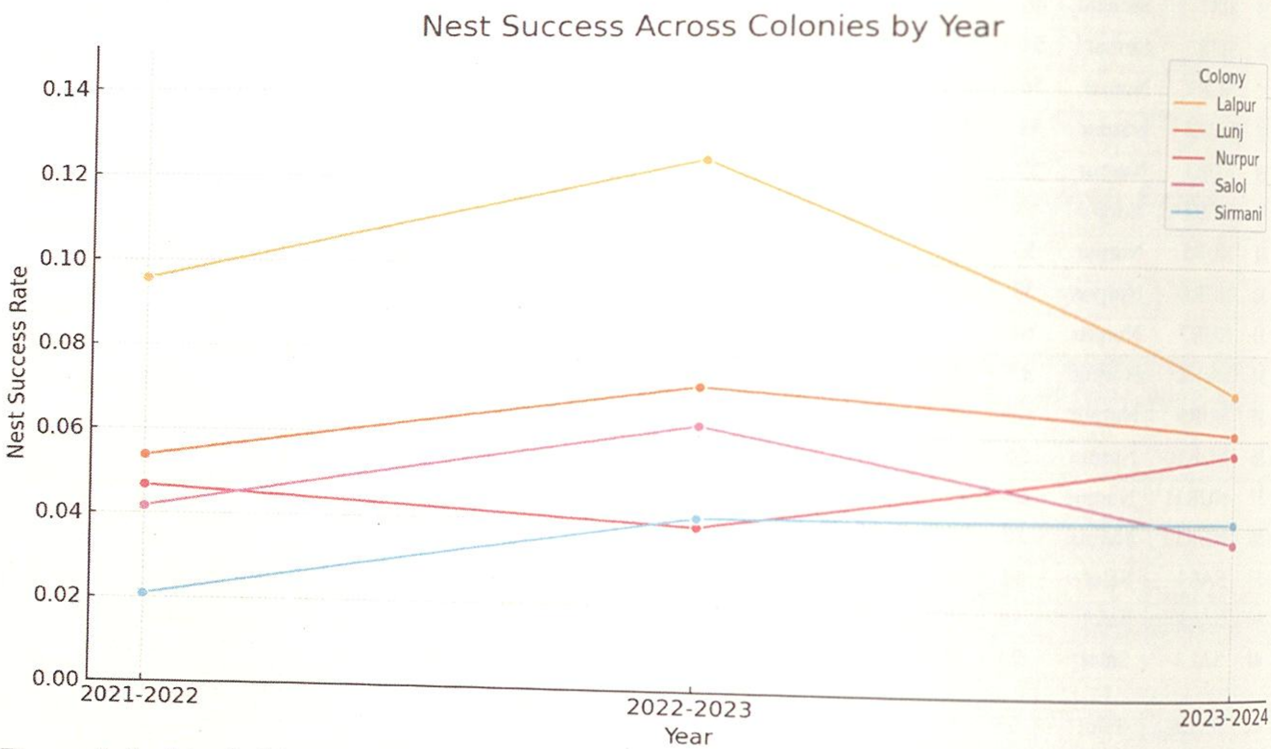


Figure 3.6.: Mayfield nest success across five different monitored colonies of WRV for three breeding seasons, 1:2021-2022,2:2022-2023 and 3:2023-2024.

3.4. Discussion:

Kangra district has recorded the highest number of healthy population of WRVs in India. The total number of nests was counted across three breeding seasons. In 2021, we rescued two chicks fallen from the nest tree damaged by a forest fire, which collapsed. In 2022, an early nesting WRV abandoned the nest only after 15 days of nest building, these were because of alterations in the tree's branch configuration. When a branch collapses, the entire safety of the nest is compromised, leading to abandonment. However, unlike many other countries, Nepal has shown promising numbers, with the latest survey reporting a total of 1,161 vulture nests across the country (Gautam et al.2024). Whereas In Himachal only in the Kangra district nest number found about 617 is a great matter for urgent conservation measures. Different organizations (MoEFCC 2020; SAVE 2021; Botha et al. 2017) and reports together have highlighted the fact of implementation or regulation of the banned drugs in the country. In August 2023, the Health Ministry and Central Drugs Standards Control Organisation (CDSCO) of the Government of India banned other toxic NSAIDs like Aceclofenac, Ketoprofen in August 2023 and Nimesulide in December 2024. In light of these findings, coordinated efforts for all the states are imperative to ensure the preservation and recovery of WRV populations across India, emphasizing the urgent need for comprehensive regulatory measures to address the ongoing threats posed by toxic NSAIDs.

Management Implications and Conclusion

Enhanced knowledge of White-rumped Vulture breeding performance can significantly improve conservation strategies, where reintroduction and conservation programs are underway. Research should prioritize identifying the causes of breeding failures through intensive monitoring of vulture pairs, particularly during the late incubation stage and the first two months after hatching. Addressing human-induced threats, especially during the February to April/May period when forest fires are most prevalent, is critical to reducing breeding failures. Focused nest surveillance during this period can help identify and mitigate these threats. Breeding success may depend on resource availability and breeding experience, particularly during the reproductive stage. Providing alternative food sources, such as vulture restaurants established by forest departments during the hatching and early chick-rearing period (December–March), could significantly enhance reproductive success. Colonial nesting in WRVs also provides advantages, including enhanced vigilance against predators, increased opportunities for mate selection, and collective defence of nesting sites. The vultures engage in frequent social interactions, such as allopreening and synchronized nesting activities, which help strengthen pair bonds and facilitate cooperative breeding behaviors. The presence of multiple nests in close proximity may also contribute to higher chick survival rates by creating a safer environment through communal roosting and shared parental responsibilities. Furthermore, their synchronized breeding cycles within colonies suggest that social cues may influence nesting timing and chick-rearing success. The persistence of such nesting colonies over time highlights the importance of conserving traditional breeding sites and maintaining undisturbed, old-growth nesting habitats to support their long-term population viability.

Chapter 4: Nest site selection

4.1. Introduction

Among avian species, the quantity and quality of breeding habitat are critical determinants of reproductive success and long-term population viability. A reduction in available habitat is typically accompanied by a corresponding decline in suitable nesting sites (Cody, 1985); this is particularly significant for long-lived species that exhibit site fidelity by reusing the same nesting sites over multiple consecutive years (Kruger, 2002; Kruger *et al.*, 2015). Understanding the factors affecting successful nesting is essential for designing effective wildlife management interventions (Verner *et al.*, 1986; Sutherland & Green, 2004) and ex-situ conservation measures, including species reintroduction (Donazar *et al.*, 1993).

Once widespread across South Asia, the White-rumped Vulture (WRV) is now classified as critically endangered and has become extremely rare (Wilbur and Jackson, 1983; Prakash *et al.*, 2003). As obligate scavengers, WRVs primarily fed on the carcasses of domestic ungulates and historically thrived in human-dominated landscapes associated with cattle rearing (Pain *et al.*, 2003). A sudden and dramatic population decline of WRV (up to 99% in its entire distribution range from 1993 to 2003) occurred as a result of residual Diclofenac in cow carcasses (Prakash *et al.*, 2003; Prakash *et al.*, 1999; Oaks *et al.*, 2004; Green *et al.*, 2004; Prakash *et al.*, 2012). Following the clear demonstration of Diclofenac's toxic effects on vultures, its veterinary use was officially banned in India. Despite this, White-rumped Vulture (WRV) mortality continues, largely due to the use of other non-steroidal anti-inflammatory drugs (NSAIDs) with similar effects. However, recent evidence indicates that the population decline may have slowed (Sharma *et al.*, 2012; Stokstad, 2021; Chandramohan *et al.*, 2022). A recent study from Nepal reported high adult survival rates in wild vultures and found no evidence of NSAID-related mortality from Diclofenac, suggesting signs of partial population recovery in the region (Mallord *et al.*, 2024; *Galligan et al.,2020*).

Despite the successful growth of captive breeding populations across various ex-situ programmes in India, our understanding of the wild population of White-rumped Vulture (WRV) remains limited. Only a handful of studies have explored their breeding ecology, nest selection, and nest success in the wild from Himachal Pradesh (Thakur, 2012; Sehgal and Kumar, 2022). Nest site selection plays a crucial role in the breeding success and survival of White-rumped Vultures (*Gyps bengalensis*). Factors such as tree height, girth at breast height (GBH), and proximity to food sources can influence nesting preferences. Nesting colonies face significant threats, including habitat degradation, selective logging, resin tapping, and forest fires. Anthropogenic pressures, along with climate-related changes, pose additional risks to their already fragile populations. The ecological requirements of nesting sites and the impact of threats are essential for designing effective conservation strategies. Our objectives were to understand nest site selection by WRV and identify and map nesting colonies and associated threats to the White-rumped vulture.

4.2. Methods:

4.2.1. Field methods:

Nest search surveys were carried out on foot from October to May each year between 2021 and 2023, with an average daily effort of 4.5 km across various nesting colonies (Figure 2). Surveys were not conducted in 2020 due to COVID-19 restrictions. The purpose of the surveys was to assess the status of nests, categorising them as active, inactive, or failed. Nests were classified as active or used if adult vultures exhibited signs of occupation, such as presence at the nest site (Steenhof *et al*., 2017). In contrast, a nest was deemed inactive when there were no visible signs of adult presence or recent nesting activity, such as the addition of fresh Chir Pine (*Pinus roxburghii*) leaves. In some instances, failed nests were identified following forest fire events, where the fire had impacted an active nest tree.

A total of 740 hours and 864 Km were covered during the nest survey by walking. Searches were also conducted for old nesting sites and sites based on local information and forest department survey reports. Nests were located with the help of Bushnell 8×42 Binoculars. Nest tree characteristics and GPS locations were taken at each nest tree location. Parameters such as GBH (Girth at Breast Height), tree height, nest height from the ground and total number of branches were recorded using a Nikon Forest Pro Rangefinder. Additional covariates were also recorded, like the percentage of canopy cover and shrub cover under the nest tree, which were measured visually (Table 4.1). The branching pattern of the tree was also noted during the survey. Threats were also recorded for each tree, such as the percentage of fire that affected the tree's GBH and resin tapping in the nest trees. Additionally, we established 20 m radius plots around each nesting tree, where non-nesting trees were randomly selected, to collect data on the above characteristics from non-nesting trees.

4.2.2. Analysis:

To understand factors influencing nesting tree selection, we used Generalized Linear Mixed Models (GLMMs) with the Laplace approximation (Bolker *et al.*, 2009). These account for variations specific to groups or clusters in the data, capturing random variability at different levels. A total of 18 variables were considered for analysis (Table 4.1). The response variable was nesting occupancy, defined as 1 for nesting trees and 0 for non-nesting trees, with various nesting colonies as the random effect. We have created multiple models(n=50) using different combinations of variables. We selected a subsample of the dataset for calculation with nesting tree characteristics for n=607 and non-nested tree characteristics for n=167. We ran 50 models in several combinations, including the occupancy as the response variable and other variables as predictors. The chosen model was based on the lowest AIC, considering all subsets of predictor variables. All statistical analyses were conducted using RStudio (2024.04.1). We utilized the "lmer" function from the "lme4" package (Bates *et al.*, 2015) to run the GLMMs, and all figures were created using the "ggplot2" package (Wickham, 2016). Mean values are presented with standard deviation, and statistical significance was set at $P < 0.05$.

Table 4.1. Variables Used for Nest Site Selection

Sl No.	Variable	Definition/Details
1	Tree height (m)	The height of the tree. Measured using the Nikon Forestry Pro II Laser rangefinder from the base of the tree
2	Girth at breast Height(m)	The diameter of the trunk of a tree at breast height of a standing tree.Measured using a measuring tape at the breast height of the trunk.
3	Total Number of branches	The total number of branches in the tree
4	First branch height(m)	The first branch height from ground was taken using the Nikon Forestry Pro II Laser rangefinder.
5	Percentage of fire	The fire percentage affected the tree's GBH size, as measured from observation(%). In 10% intervals.
6	Shrub cover (%)	Percentage of ground vegetation cover under the canopy covered by shrub (%). In 10% intervals.
7	Canopy cover (%)	Percentage of canopy under the tree using visual observation (%). In 10% intervals.
8	Nest height(m)	The height of the nest location. Measured using the Nikon Forestry Pro II Laser rangefinder from the base of the tree
9	Nearest tree distance(m)	The distance (m) to the nearest tree. Measured using the Nikon Forestry Pro II Laser rangefinder from the base of the tree

10	Nearest nest tree distance(m)	The distance (m) to the nearest tree having nests. Measured using the Nikon Forestry Pro II Laser rangefinder from the base of the tree
11	Elevation(m)	Height above sea level for the particular tree. Calculated from ArcMap Desktop 10.7.1
12	Aspect(Degree)	The direction in which a slope faces is typically measured in degrees from north.Calculated from ArcMap Desktop 10.7.1
13	Slope(Degree)	A surface's incline, or steepness, is measured in degrees from horizontal (0-90). Calculated from ArcMap Desktop 10.7.1
14	Distance to water(m)	Distance from nest to nearest water source, using waterbody and river data from OpenStreetMaps. Calculated from ArcMap Desktop 10.7.1
15	Distance to road(m)	Distance from nest to the nearest road, using road network data from OpenStreetMaps. Calculated from ArcMap Desktop 10.7.1
16	Distance to villages(m)	Distance from villages using village boundary locations collected from the study. Calculated from ArcMap Desktop 10.7.1
17	Distance to feeding site(m)	Calculated from ArcMap Desktop 10.7.1 Distance from the feeding sites using feeding site locations collected from this study
18	Resin tapping	If the tree is heavily used for resin tapping or not

4.3. Results:

We recorded 17 active nesting colonies with 617 active nests (Figure 3.2) between 2020-2024. In addition, the study identified 36 carcass dumping sites in the area. The disposal sites managed by local communities serve as areas where the remains of deceased livestock are deposited. Carcasses, mostly of dead Cattle and Buffaloes, are taken by local cobblers, also called "Harijans", from the household areas to the dumping sites. The Harijans historically played an important role in disposing of cattle carcasses by removing the hides for leather and leaving the remains for the scavengers. This practice supports both local economies and the ecosystem by providing food for scavengers. (Kapoor, 2023; Pal,2024) .

WRVs nest in tall Chir pine trees(25-26m) in forested areas of Himachal, locally called "Chakbans." These forested areas are fragmented and come under the reserve forest areas closer to human habitation. Out of the 553 nesting trees, the majority of the trees have only one nest(n=499), followed by trees having two nests(n=45), three nests(n=8) and one tree has four nests(n=1). The sampled nesting area was between 545-1211 masl, with most nests between 600-800 masl. The maximum number of nests(n=182) was located on low to moderate inclination with a slope of 3.7-7.5. The shortest nest tree was 12m, and the tallest was 38m. The lowest-located nest was 9m high, while the highest was 35m. The majority of nests were constructed in the northwest and northeast directions, as determined by the aspect and slope of the specific nest location.

Comparison of multiple hypotheses (candidate models) found maximum support for the model with GBH, Distance to water and canopy cover as explanatory variables. Variables that influenced nest site selection were: GBH (β=0.03 , SE=0.006 , $p<0.005$), shrub cover (β=0.02 , SE= 0.009, p=0.02), distance to nearest nest (β=0.02 , SE= 0.009, p=0.007), nearest tree distance (β= (-)0.1, SE= 0.02 , $p<0.005$), distance to feeding sites (β=0.78 , SE=0.3 , p=0.01) and distance to water (β=(-)1.4 , SE=0.38 , $p<0.005$) (Table 4.2). These results suggest that WRV's selected taller GBH, more shrub cover (75%) and proximity to nesting trees and water for nesting. Areas with higher fire activity, denser canopy cover, and fewer nearby trees are less favourable for the species.

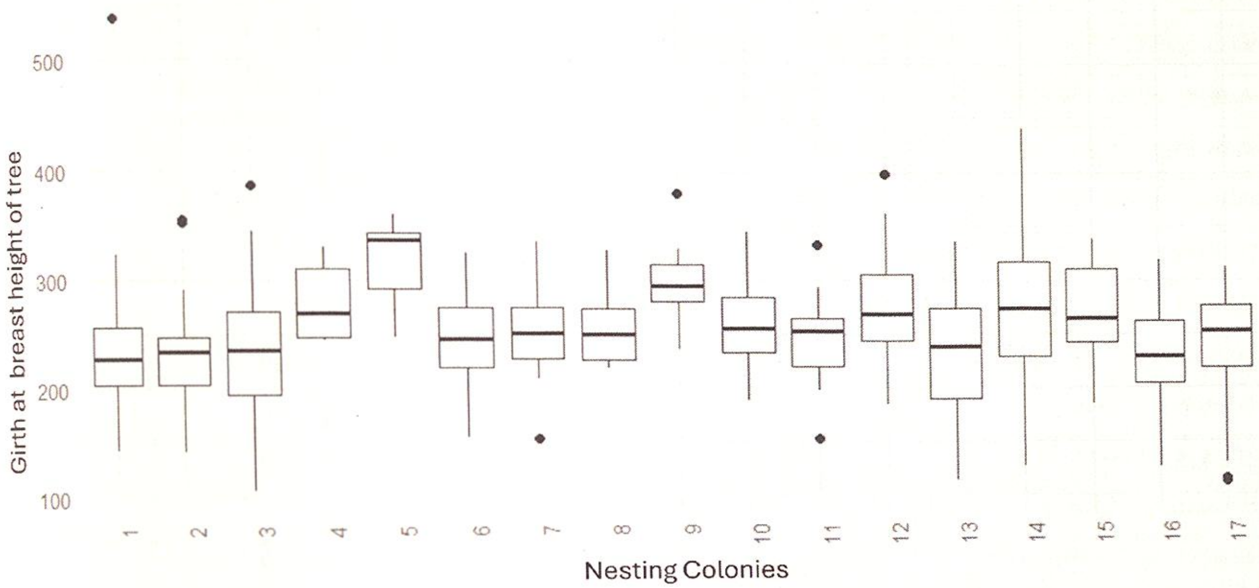


Figure 4.1: Box plot of tree girth at breast height (GBH) measurements for 17 colonies of WRV.

Generally, the nests were made with the leaves and branches of the *Pinus roxburghii* tree. Most of the nests were located at the top of the tree. The study also reveals that most vultures prefer building their nests on branches that grow near each other, often with minimal gaps between them in the upper canopy. The variables showing the negative effect on the nest site were first branch height, distance to water, and distance to villages. The variables GBH and Canopy cover gave the best model fit with the highest significance (AIC=240.5).

Table 4.2. Generalized Linear Mixed Model (GLMM) Results for Nest Site Selection of White-rumped Vultures with Higher Significance Indicated by More Stars.

Variable	Estimate	SE	Z Value	P value	Significance
Intercept	-2.44073	3.800534	-0.642	0.52074	
Tree height (m)	0.030825	0.067143	0.459	0.64616	
Girth at breast Height(m)	0.033552	0.006009	5.583	2.36E-08	***
Total Number of branches	0.007925	0.060487	0.131	0.89576	
First branch height(m)	-0.08545	0.055765	-1.532	0.12542	
Percentage of fire	-0.02127	0.010348	-2.055	0.03987	*
Shrub cover (%)	0.021662	0.009405	2.303	0.02127	*
Canopy cover (%)	-0.08723	0.016705	-5.222	1.77E-07	***
Resin tapping	1.312439	0.59301	2.213	0.02689	*
Nearest tree distance(m)	-0.10426	0.021377	-4.877	1.08E-06	***
Elevation	0.008417	0.003493	2.41	0.01596	*
Aspect	0.000704	0.002652	0.265	7.91E-01	
Slope	0.122334	0.054215	2.256	0.2404	*
Distance to water	-1.47923	0.379732	2.41	9.80E-05	***
Distance to road	0.991042	0.435165	2.277	0.2276	*
Distance to villages	-1.27773	0.424948	-3.007	0.02276	**
Distance to feeding site	0.776653	0.317355	2.447	0.01439	*
Nearest nest tree distance(m)	0.024799	0.009294	2.668	0.00763	**

4.4. Discussion

Colonial scavengers breeding in forests are very sensitive to changes in habitat and forest management practices over time (Niemi and Hanowski, 1997; Fargallo *et al.*, 1998; Donazar *et al.*, 2002). Numerous studies on habitat and nest site selection indicate that identifying selection patterns can help predict species occurrence, offering critical insights for forest managers to develop and implement effective conservation strategies (Newton *et al.*, 1981; Donazar *et al.*, 1993; Austin *et al.*, 1996; Ferrer and Harte, 1997; Suarez *et al.*, 2000; Liberatori and Penteriani, 2001; Loyn *et al.*, 2001). Kangra Valley hosts one of India's most prominent and healthiest White-rumped Vulture (WRVs) source populations. Throughout the four breeding seasons, the number of nests varied each year due to forest fires, which caused nest abandonment and re-establishment nearby. About, 10–12 nests were relocated yearly from one tree to the nearest available tree due to forest fire disturbances.

4.4.1. Nest site selection:

The study reveals that WRVs prefer mature and stable trees, and girth at breast height (GBH) along with canopy cover, were the most significant predictors of vulture occupancy (Figure 4.1In the Kangra region, forest habitats are extensively fragmented by road networks. Field surveys recorded approximately 125 nests located near roadsides across 17 nesting colonies. Additionally, observational data indicate a preference among vultures for nesting in trees surrounded by dense shrub cover at the base, with nine colonies exhibiting an average shrub cover exceeding 75%. Forested areas selected by vultures also showed lower anthropogenic disturbance, with signs of the Common leopard(*Panthera pardus*) and Wild boar(*Sus scrofa*). While earlier studies have highlighted nest height as a key factor in nest site selection (Majgaonkar *et al*., 2018; Johnson *et al*., 2022), our findings did not support this, likely due to the uniformity in tree height across the Chir Pine forests surveyed (mean height ~24 m). Beyond specific nest site variables, colonial nesting vultures exhibit strong social behavior and rely heavily on the presence of nearby nesting trees for colony formation.

Most colonies have more than ten nests, indicating a clustering preference for nesting. All nesting colonies observed were in old-growth Chir pine with minimal disturbances influencing nest site selection.

Table 4.3. : Habitat Characteristics of WRV Nesting Colonies

SI No.	Colony Name	Elevation Range aprrox(m)	Area (Km^2)	Resin tap	Plants other than *Pinus roxburghii*(Chir Pine)	Mammals found	Nearby av. number of villages	Additional comments
1	Dolba	600-700	15	No	Phanera vahlii,Justicia adhatoda L. (Kambal),*Murraya Koenigii*,Cassia sp.	Common Leopard,Yellow throated martin,Wild Boar,Barking deer	4	Mostly untouched forests.Wild boar poaching encounters several times.
2	Lalpur	500-600	8	No	*Phoenix* sp.,Murraya Koenigii	Wild Boar,Barking deer	12	Forest use widely by locals for pheanix leaves in use of Broom
3	Nurpur-Kadroh	590-650		No	Justicia adhatoda L. (Kambal), *Carissa spinarum*,*Lantana camara*,Amla *Emblica officinalis*,To	Leopard,Wild Boar,Barking deer	11	Mostly untouched forests.Leopard habitat.
4	Salol	590-690	6	Yes	*Mangifera, Terminalia, Erythrina, Bombax*, and *Ficus*	Leopard,Wild Boar	10	Forest use by gaddis during winter
5	Gheena	690-790	7	Yes	Kambal,*Justicia adhatoda L.*	Leopard,Wild Boar	6	Untouched dense forest
6	Palra	730-780		Yes	Only Chir	Leopard,Wild Boar	9	
7	Gopalpur	1030-1200	7	Yes	Only Chir	NA	11	Lot of activities including fire and timber collection
8	Baroh	700-730	2	Yes	Only Chir	NA	9	Lot of activities including fire and timber collection
9	Upper Lunj	610-650		Yes	Phanera vahlii,Justicia adhatoda L. (Kambal),Murraya Koenigii,Cassia sp.	Wild Boar	12	Use by Gaddis during winter
10	Channi	600-650		No	Phanera vahlii,Justicia adhatoda L. (Kambal),Murraya Koenigii,Cassia sp.	Leopard,Wild Boar	11	Use by Gaddis during winter
11	Nurpur	570-630		Yes	Justicia adhatoda L. (Kambal), *Carissa spinarum*,*Lantana camara*,Amla *Emblica officinalis*,To	Leopard,Wild Boar,Barking deer	12	typical plantation of chir pines as well as few leftover remaining forests
12	Anuhi	500-600		Yes	*Phoenix* sp.,Murraya Koenigii	Leopard,Wild Boar,Barking deer	12	Untouched dense forest

3	Gola	1000-1120	0.51	No	Only Chir	Leopard,Wild Boar	5	Use by Gaddis during winter
4	Harnera	620-700	4	Yes	*Phoenix* sp.,Murraya Koenigii	Leopard,Wild Boar	10	Chir forest fragmented by human habitation
5	Sirmani	610-750	7	Yes	*Phoenix* sp.,Murraya Koenigii	Leopard,Wild Boar,Barking deer	10	Untouched dense forest
6	Lapiana	620-750	7	Yes	*Phoenix* sp.,Murraya Koenigii	Wild Boar,Barking deer	10	Surrounding village,timber extraction by locals
7	Baliara	590-625	2.5	Yes	Phanera vahlii,Justicia adhatoda L. (Kambal),Murraya Koenigii,Cassia sp.	Wild Boar	11	Chir forest fragmented by human habitation

4.4.2. Nesting Colonies and Threats:

The WRV nesting colonies have distinct characteristics. Three of the 17 colonies were located in reserve forests. Dolba and Nurpur are situated in highly dense forests far from human habitation. The highest number of nests was recorded in Salol and Dolba. The 17 colonies face various threats, including forest fires, resin tapping, and logging (Table 4.4). Forest fires pose a major threat to wildlife in Himachal (Thakur *et al.*, 2024). Most forest fires and nest failures occurred in Baroh(54%), Palra(46.6%) and Harnera(32.5%). Observations revealed that continuous resin tapping reduces the circumference of trees at breast height, increasing their chances of pest attack, followed by susceptibility to forest fires and storms. In addition, trees with a larger diameter at breast height are heavily exploited for resin tapping, making old-growth Chir Pine forests vulnerable to forest fire practices.

Forest management strategies must prioritise the conservation of vulture nesting colonies by integrating targeted and innovative approaches. Small nesting colonies, often overlooked, should be secured with appropriate signage to protect them from unintentional disturbances. Such measures ensure that local communities and forest users recognise and respect the ecological importance of these areas.

To mitigate the risk of forest fires, an alternative strategy is to plant fire-resistant vegetation around nesting sites. Native species such as *Bombax* and *Ficus*, which are already integral to vulture nesting, can act as natural fire barriers while providing additional nesting and perching opportunities. Protecting old-growth Pine trees (*Pinus roxburghii*), which serve as nesting sites, must remain a priority despite existing protocols (Brown *et al.*, 2011; Dhadwal and Kumar, 2022; Walia, 2006).

Resin tapping, a traditional practice, poses direct threat to old-growth trees, which vultures depend on for nesting. Sustainable resin tapping methods should be employed so as to reduce the number and size of cuts made on trees, and rotating tapping locations to allow sufficient time for trees to heal. These practices can help balance the needs of local livelihoods with vulture conservation. Protection of old-growth Pine trees, as per the existing guidelines, must be enforced so that the nesting sites are preserved. These trees, with their robust structures and ideal nesting conditions, are irreplaceable as nesting sites (Brown *et al.*, 2011; Dhadwal *et al.*, 2022; Walia, 2006). The role of vulture social behaviour in nesting site selection and foraging underscores the need for nuanced conservation strategies. Studies have shown that vultures benefit from communal foraging (Cortes-Avizanda *et al.*, 2014; Harel *et al.*, 2017; Jackson *et al.*, 2008), relying on social cues to locate food and assess the safety of nesting sites. Social signaling is integral not only for scavenging (Kendall *et al.*, 2012) but also for choosing and maintaining suitable nesting sites (Mateo-Tomás & Olea, 2011). This indicates that the collective requirements of group living may have a stronger influence on nest-site selection than the characteristics of individual nest trees.

Table 4.4.: Colony-wise nest numbers and percentage of fire and resin tapping.

Sl No.	**Nesting Colony Name**	**Nest Count**	**Percentage Fire Affected (%) (years)**			**Resin tapped trees**
			2021	2022	2023	
1	Dolba	66	10	11	12	No
2	Lalpur	62	22	19	18	Yes
3	Nurpur	54	10	10	10	No
4	Salol	68	25	20	20	Yes
5	Gheena	59	25	20	37	Yes
6	Palra	27	15	35	46.6	Yes
7	Gopalpur	46	25	21	21	Yes
8	Baroh	23	65	56	54	Yes
9	Upper Lunj	27	25	26	26	Yes
10	Channi	18	19	25	30	Yes
11	Kadroh	24	5	6	2	No
12	Anuhi	11	7	10	6	No

13	Gola	20	15	16	16	Yes
14	Harnera	10	25	30	32.5	Yes
15	Sirmani	53	15	16	16	Yes
16	Lapiana	32	7	8	6.8	No
17	Baliara	17	2	7	9.4	yes

To address these needs, intensive surveys that focus on colony-based nest-site selection and habitat characteristics are crucial. Such studies will provide critical insights into the factors that influence colony formation, allowing for more informed forest management practices. These insights are especially important for habitats outside the boundaries of protected areas, where human activity often poses significant threats. Identifying and safeguarding these areas as "Vulture Safe Zones" in Himachal Pradesh could be a crucial step toward their long-term conservation.

Chapter 5: Movement ecology

5.1. Introduction:

Movement patterns of wild vultures between breeding and non-breeding seasons are important for their conservation. Identifying resource availability and threats along their journey has consequences on individuals' survival rates and their populations' long-term viability. Telemetry technologies such as solar GPS-GSM or Satellite tags provide data on movement behaviours, distribution, habitat use, and population survival strategies (Cooke 2008; Hoffmann *et al.* 2010). Detailed movement patterns are still unknown for most Asian Vultures, including the four critically endangered Vultures: WRV, Indian Vulture, Slender-billed Vulture and Red-headed Vulture. Only the captive-bred population has been tagged and released by BNHS, while wild White-rumped Vultures have been tagged by Bird Conservation Nepal (Bhusal *et al.*, 2018). While many telemetry studies have focused on migratory vultures like Bearded Vulture (Subedi *et al* 2020), Cinereous Vulture (Reading *et al* 2020, Efrat *et al* 2021), Egyptian Vulture (Buechley *et al* 2018), Himalayan Griffon and Eurasian Griffon Vulture (McGardy *et al* 2006, Arkumarev *et al* 2019, Ram *et al* 2022), hardly any work exist on resident endemic vultures for the Indian Subcontinent. Most information is based on scant records of observations. Evidence on Asian Vultures is especially crucial given their rapid nationwide decline (Prakash *et al.*, 2003). Many species continue to face various threats, including poisoning, rapid habitat loss, urbanization, and collisions with powerlines. Wildlife poisoning has a long global history (Ogada, 2014). As India proceeds with the captive reintroduction of vultures, it becomes increasingly important to monitor the survival of wild populations using remote-tracking technologies.

While studies have recorded the resource availability of vultures and their nesting patterns, detailed satellite tracking studies on habitat use are almost non-existent, except a few on Bearded vultures (Subedi *et al,* 2020) from Bhutan. The recent advances in remote tracking instruments and the addition of accelerometers or thermal sensors have allowed the detailed study of the physiology and energetics of free-living raptors in their natural habitat (Wilson *et al.* 2008; Guilford *et al.* 2011; Sokolov 2011). Studies that focus on species-specific information typically assess home range size, extent, activity patterns, and habitat use to understand the potential impacts of environmental changes and associated threats (Cooke 2008; Kie *et al.* 2010; Wilson *et al.* 2015). We focus on a Critically Endangered vulture, the WRV *Gyps bengalensis* and explain for the first time the movement, behavior with respect to breeding and non-breeding seasons that are mostly resident vultures in and around the district Kangra in Himachal Pradesh (India).

5.1.1. Home range:

Animal home ranges reflect the connection between their movements and resource distribution for survival and reproduction, influenced by factors like food availability, suitable habitats, and competition. (Boerger *et al.* 2008; Kie *et al.* 2010; Perez-Garcia *et al.* 2013). Mapping home ranges and analyzing resource utilization offers insights into a species' behavioural and spatial ecology, aiding conservation planning (Cooke 2008; Hebblewhite and Haydon 2010). Various methods are employed to estimate home ranges from tracking data, selected based on study goals and data resolution (Laver and Kelly 2008; Kie *et al.* 2010; Powell and Mitchell 2012). In conservation studies, simple yet easily interpretable analytical methods are commonly employed to define home ranges (Hebblewhite and Haydon 2010). The two most commonly used ones are the creation of Minimum Convex Polygons (MCPs) and the utilization of distribution contours by Kernel Density Estimation (KDE) (Laver and Kelly 2008; Kie *et al.* 2010). The Minimum Convex Polygon (MCP) method, one of the earliest approaches used in tracking studies, provides a basic representation of an animal's home range. It constructs a polygon by connecting the outermost GPS points with internal angles less than 180°, thereby delineating the estimated maximum area utilised by the animal (Mohr 1947; Harris *et al.* 1990). Yet, MCPs assume uniform space use within the polygon, criticized for their sensitivity to location data's sample size. They often include large areas never visited by the tracked animal due to the incorporation of outlying locations (Borger *et al.* 2006; Downs and Horner 2008). The KDE method is more preferable for many studies as it can identify multiple centres of activity and exclude unused areas, resulting in a more accurate depiction of space use (Hemson *et al.* 2005; Laver and Kelly 2008; Kie *et al.* 2010). KDE calculates the intensity of habitat use across the home range by placing a probability density function, or kernel, over each GPS location, overlaying a grid of a selected scale (determined by a "smoothing factor"), and averaging the densities of all the kernels that overlap at each grid intersection to produce the probability of occurrence of the tracked animal at that point (Worton 1989; Seaman and Powell 1996).

5.1.2. Objectives

1) To estimate the seasonal home ranges

2) To understand the resource utilization patterns.

5.2. Methods:

5.2.1. Capture site:

Five Vultures were captured in three different sites. The capture sites are mostly open carcass disposal areas. The habitat of capturing locations included open grassland areas with dominant Acacia trees used for perching by WRV at the open feeding grounds managed by locals. 11 kV powerlines dominated the areas. The availability of open carcass disposal areas in Kangra makes it a primary location for the wild vulture population. Besides the White-rumped vulture, the area has abundant Egyptian (*Neophron percnopeterus*) and Himalayan Griffon vulture *(Gyps himalayensis*) as it provides an important foraging and nesting habitat for the species.

5.2.2. Field procedure: Bird Capture method and GPS tagging

The White-rumped vultures were tagged with E-Obs Global Positioning System/Global System for Mobile Communication (GPS/GSM) solar tag from September to October 2021(Table 5.1: Summary table). We tagged five individuals of WRV from three different carcass disposal areas at Kangra, Himachal Pradesh. GPS tags collected latitude and longitude programmed for one location every hour, depending on the relative movement of the vultures as observed from 6.30 am to 6.00 pm. The vultures were tagged in open carcass disposal areas managed by locals for decades. Three adult vultures were tagged from the Meira area, one from Sidhpur Khad and one sub-adult from the Jawalaji area.

Table 5.1.: Vulture tagging details along with morphometric measurements

Sl No.	Vulture Ring number	Tag number	Date tagged	Body weight(Kg)	Beak(mm)	Wingspan(cm)	Metatursus(mm)
1	752	8708	09.09.21	8	38.34	not taken	78
2	F43	8705	14.09.21	7.5	40	194	80
3	NA	8703	24.09.2021	5.1	39.45	143	84
4	730	8706	24.09.2021	5.6	41.2	155	72.6
5	717	8707	08.10.2021	7.6	38.17	170.68	74

Figure 5.1. : White-rumped Vulture capture from feeding site at Kangra

The capturing technique involved the use of a walk-in ground noose carpet (Harrity et al.,2020). A noose carpet was made with multiple noose traps. The traps were placed along a carcass (dead animal disposed of in the open by locals. The eyes were covered as a safety protocol. Two people held the bird, and two worked to attach and adjust the tag to the bird. The tag was fitted following Anderson et al 2020 thoracic X-strap harness with a 12 mm wide Teflon ribbon using a leather hub precut to size and threaded with the Teflon after adjusting the size before fitting to the bird. It was scaled with a small stainless steel crimp bead and super glue. The weight of the solar tag and GPS together was 55g. Each vulture was banded for individual identification with coloured rings provided by Bombay Natural History Society (BNHS). Our capture included four adults and one sub-adult. Each bird was weighed with a weighing instrument, and the average weight was 7.08 Kg.

5.2.3. Data preparation and analysis:

The total data collected from 01.10.2021 to 31.01.2024. We settled daily fixed rates for each individual for one location every hour. Fixes received during the first two weeks of post-deployment have been excluded from the analysis with the use of outlier removal by MoveApps The analysis of the study was performed with the help of MoveApps .The analysis used in this study was performed on MoveApps (www.moveapps.org, Workflow name 'aKDE', App names 'Movebank', 'Remove Outlier', 'Filter Data by Season', 'MoveStack to Telemtry.list', 'Variogram, 'Fit a Continuous-Time Movement Model (ctmm)', 'Estimate Average Speed and Distance Moved (ctmm)' and 'Autocorrelated Kernel Density Estimate (aKDE)' accessed on [05.02.2024]) This was done for the vulture to be familiar with the tag and continue its normal movement patterns. We compared the daily movement of the vultures using their space use patterns i.e., daily home range and core area depending on their breeding, non-breeding or annual patterns. All the movement data were standardized for equal timeframes. For breeding activity patterns, we used data from October- April. The non-breeding season was defined from May -September; this included all fixes with equal duration for every consecutive year.

5.3. Results:

A total of five White-rumped Vultures comprising four adults and one sub-adult captured from the wild from September to October 2021. We collected a total of 63,110 location points from October 2021 ± January 2024 using solar-powered E-Obs GPS/GSM transmitters. A total of 63,110 location points 47,793 location points were used for analysis after removing duplicates.

Figure 5.2..:Tagged individual 8705 at nesting site Lapiana as on April 2024.

Two of the vulture tags stopped connecting after July 2023. For all five vultures total number of GPS locations was recorded between 06.30 hours to 16.30 hours. The average daily distance travelled by the vultures was 28.43 ± 12.56 km. The sub-adult vulture travelled a maximum of 124 Km in one day. The other vultures were mostly confined to the Kangra district with daily movement from nesting to feeding sites and back.

Table 5.2: Summary of home ranges all the tagged individuals

Sl.No.	**GPS points (Total)**	**Sampled points**	**ID**	**Adult / Subadult**	**Tracking period (Days)**
1	9121	7236	8708_Himayu	Adult	696
2	11736	9221	8707_Teij	Sub-adult	493
3	11545	9193	8706_Op	Adult	852
4	11706	9362	8705_Khiti	Adult	852
5	8463	6781	8703_Morut	Adult	852
Total	**63110**	**41793**	--	--	**3745**

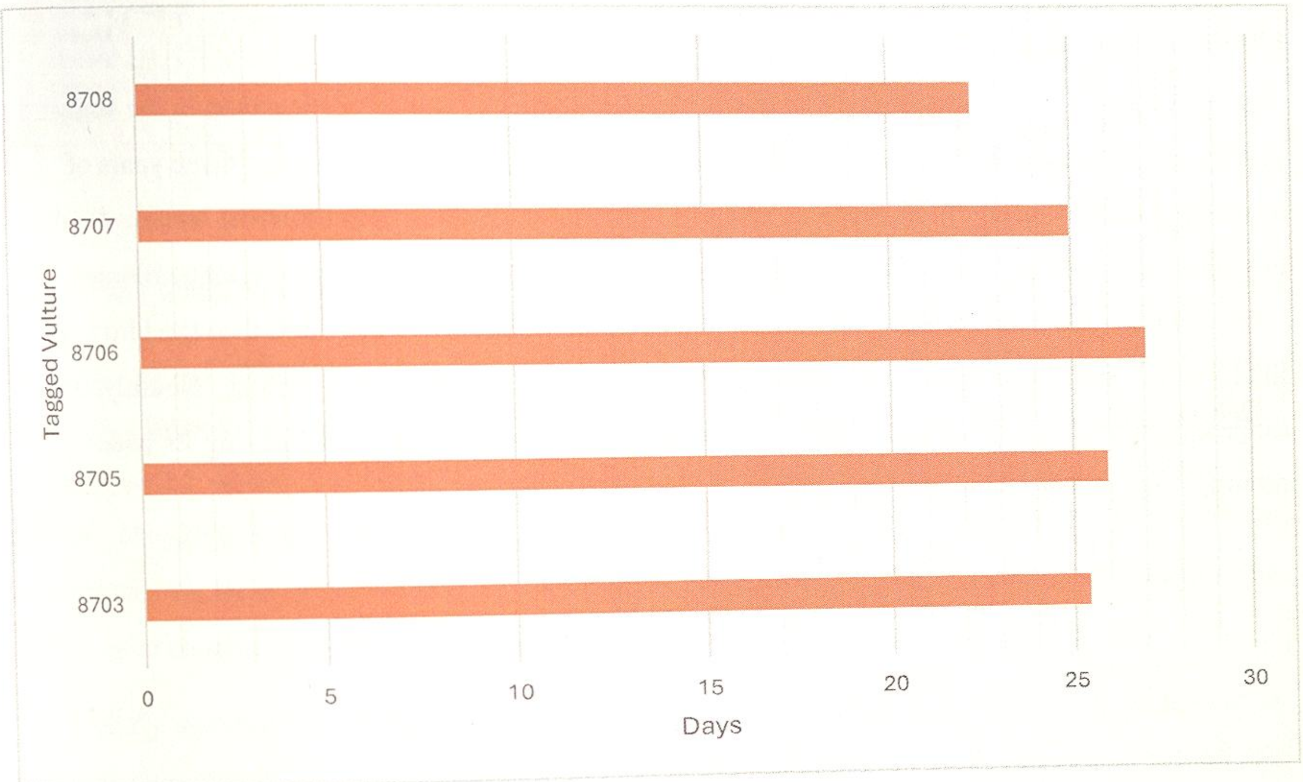


Figure 5.3. Average daily movement by WRV

5.3.1. Home Range:

The wild vultures occupied home ranges (median 95% aKDE; Table 5.3) largely concentrated in the areas surrounding the breeding colonies, especially Baranj, Dolba and a few feeding stations. The areas were located around roosting sites near feeding stations and nest sites that were used for three consecutive years. The areas overlapped with the reserve forest under the territorial Forest divisions, showing the importance of small reserve forests in the conservation of vultures. The sub-adult recorded the largest home range, 95%akDE (4677.86 km^2). Interestingly, in two cases, vultures approached the Pakistan border in the Punjab region but returned to India without crossing the border, underscoring the critical role of open carcass disposal as a key resource for vulture movement in this landscape.

5.3.2. Details on the individual tagged bird:

8707 / Teij Sub-adult

The tracked bird was identified as a sub-adult and did not engage in nesting during the study period. It's estimated home range spanned **6,281 km^2**, based on an average of three years of movement data. Among the monitored individuals, this individual exhibited the most extensive movements typical of a sub-adult. It frequently travelled between multiple nesting colonies without following a consistent movement pattern. This behaviour suggested that the bird was likely in the process of exploring and attempting to establish a suitable territory. Notably, its range extended from Jammu and Katra to the India-Pakistan border, highlighting its wide-ranging dispersal tendencies(Figure 5.4).

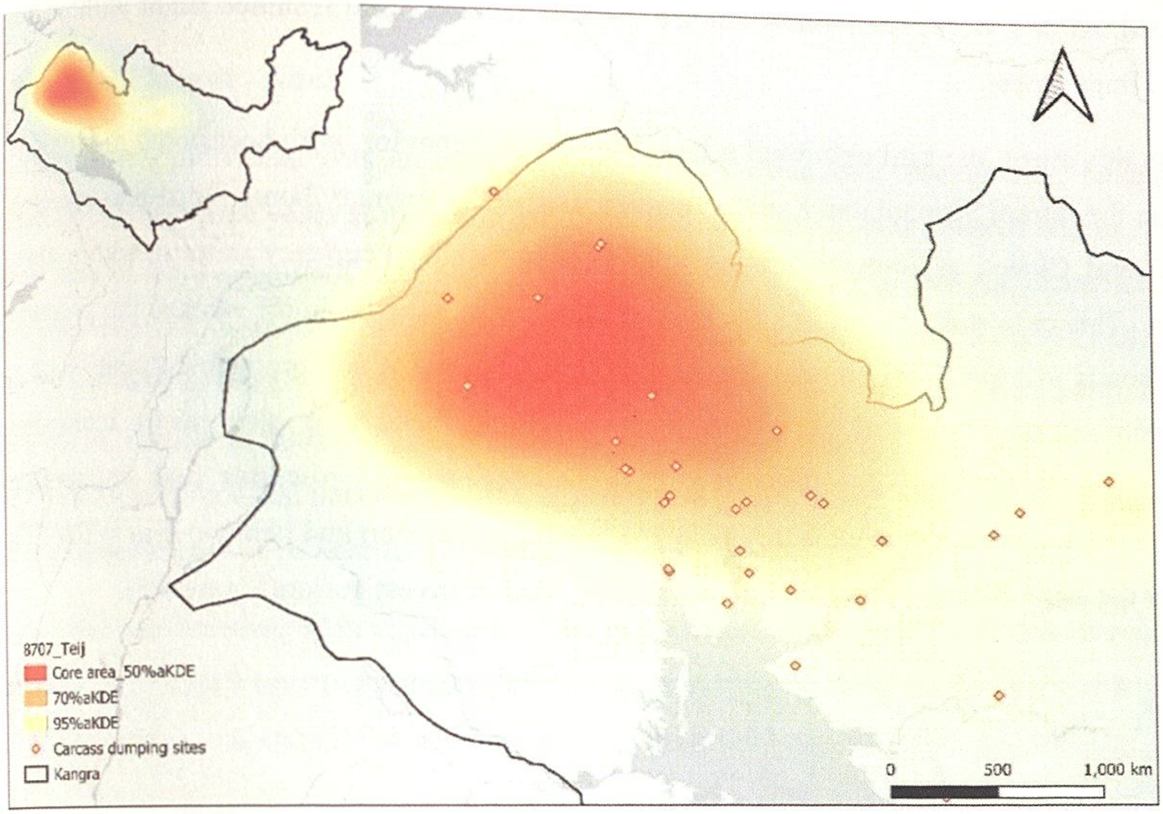


Figure 5.4.: Home range of WRV sub-adult tag 8707 for all years

1. **8708 / Himayu - Adult**

The monitored individual was an adult that did not engage in nesting activity during the tracking period. Over three years, its estimated home range was calculated to be approximately **1,186 km².** The bird resided within the Dolba Forest Range, a reserve forest area, where it was regularly observed. Throughout the study period, its movements were closely monitored, particularly in relation to known feeding sites and nesting colonies. Despite extensive tracking efforts, no nesting attempts were recorded for this individual.

A particularly noteworthy observation occurred in 2022 when the tagged vulture sustained an injury due to electrocution. Following the incident, the bird remained perched on a single tree near the Meira feeding site for over a week. During this period, we carried out intensive monitoring. A second vulture, likely its mate or a closely associated conspecific, was observed visiting the injured individual and providing food. This caregiving behavior is a rare and significant observation in White-rumped Vultures, as such instances of intraspecific assistance have been infrequently documented. After a week, the injured vulture showed recovery and resumed flight without any noticeable impairment.

Other than this event, the bird exhibited a largely resident behavior, with occasional movements recorded in the Baranj Sirmani and Lapiana nesting areas. The primary home range encompassed the Dolba and Channi regions, indicating a relatively stable occupancy pattern within these landscapes. This case study highlights the species' fidelity to specific home ranges, the potential for social bonds within vulture populations, and the implications of anthropogenic threats such as electrocution on their survival. The recorded caregiving behaviour also raises interesting ecological and behavioural questions regarding vulture social structures and cooperative interactions, such as whether there is any colony-specific interaction and behaviour in WRV? Do they prefer the same colony kin selection? warranting further investigation(Figure 5.5).

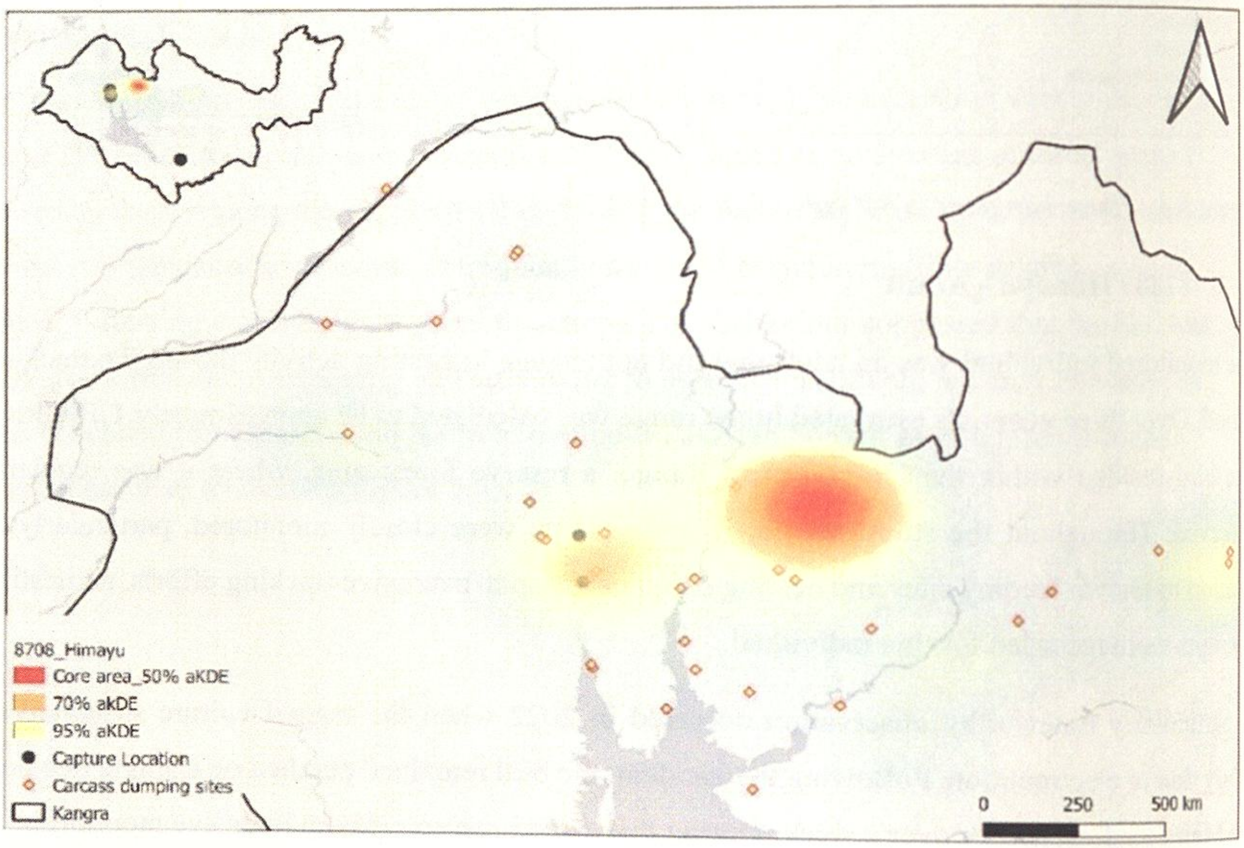


Figure 5.5.: Home range of vulture individual adult tag 8708 for all years

2. 8703 / Morut - Adult

The monitored individual was an adult that exhibited strong nest site fidelity, having nested consecutively for three years at the same location. The nesting site was situated within the reserve forest area of Baranj Sirmani, one of the densest forested regions in Kangra, characterized by a high presence of Common Leopards (*Panthera pardus*). Given the topographical challenges, the nesting tree was not easily accessible, as it was located on a steep downslope of a high mountain. As a result, regular monitoring of the nest was not feasible. However, the vulture was regularly observed at feeding sites, particularly at Chambi Pool, Meira Khad, and Kali Mitti, allowing for indirect assessments of its breeding status and behavior.

During the non-breeding season, the estimated home range of the individual was calculated to be approximately **1,018 km²** (averaged over three years). The vulture exhibited resident behavior, remaining within and around the nesting site with minimal long-distance movements.

As of the 2024–2025 breeding season, the bird has shifted its nesting location, to a more open area near a roadside habitat almost 12 km away from the previous site. This change in nesting preference warrants further investigation. The vulture remains active within its established range, reaffirming its strong site fidelity and residency pattern within the Kangra landscape (Figure 5.6).

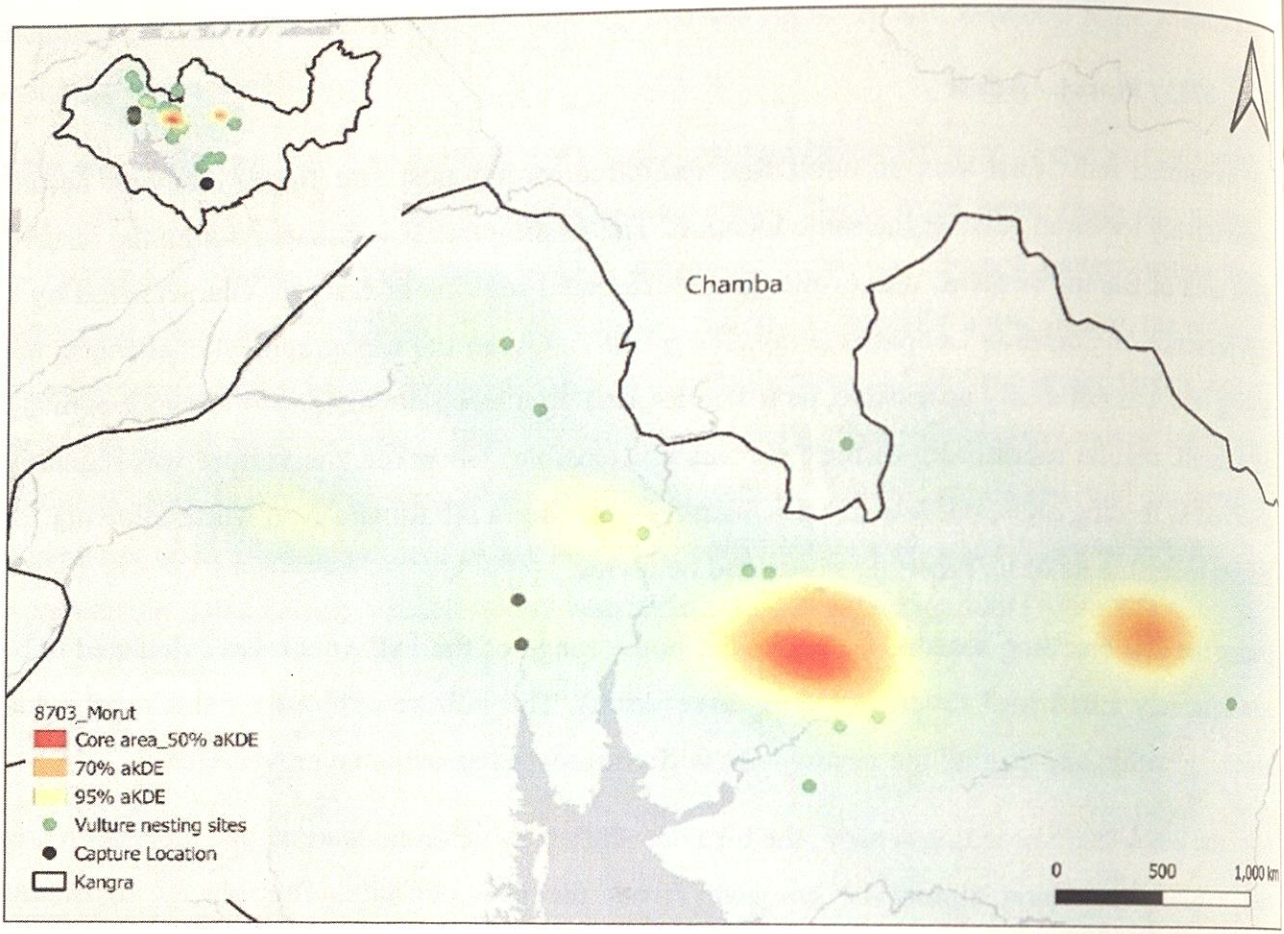


Figure 5.6: Home range of individual vulture named 8703 for all years

3. 8705 / Khiti - Adult

The monitored individual was an adult that demonstrated strong nest site fidelity, having nested consecutively for three years at the same location in Lapiana. The estimated home range during the non-breeding season was approximately **892 km², ** averaged over three years. Lapiana is a reserve forest area situated near human settlements, with the nest site located within 200 meters of habitation. Unlike other, more remote nesting locations, this nest tree was easily accessible, allowing for continuous monitoring throughout the breeding seasons to document nest activity.

During the first year of monitoring, the vulture pair initiated nesting; however, breeding was unsuccessful as nesting activity ceased after 53 days. In the second year, nesting resulted in successful fledging. In 2024, the nest tree suffered significant damage due to an extensive forest fire that affected the surrounding habitat. The vulture has continued nesting on the same tree and has already initiated nest construction for the current breeding season(2024-2025).

The bird exhibited strong residency patterns, primarily moving between its nesting site in Lapiana and known feeding locations, including Gangath, Meira, Kali Mitti, and Chinmaya Tapovan in Dharamshala. The estimated daily movement distance averaged approximately 37 km, with increased movement during the non-breeding season, reaching up to 59 km (Figure 5.7).

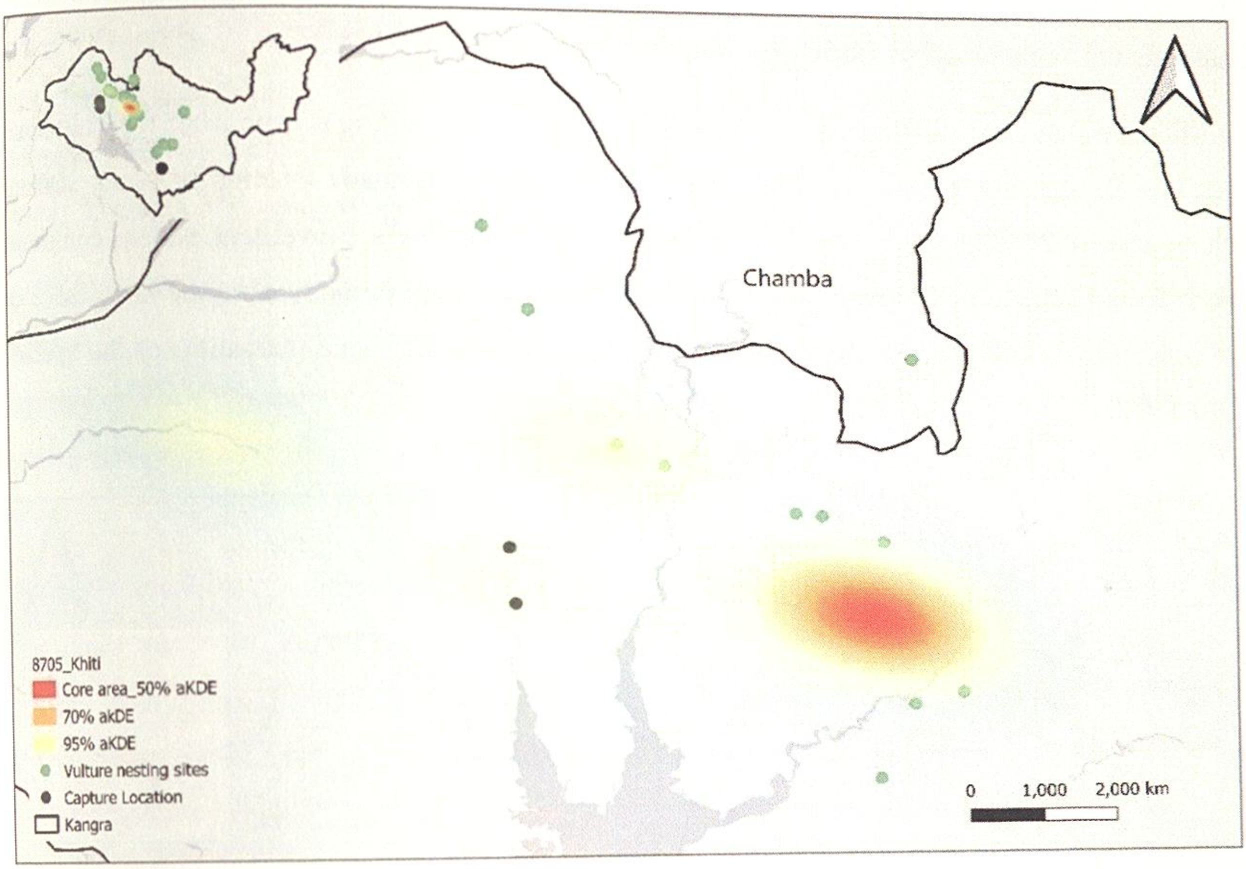


Figure 5.7: Home range of WRV tag 8705 for all years

4. 8706 / Op -Adult

The monitored individual was an adult that exhibited strong nest site fidelity, having nested in the same location near the Baranj Sirmani area for three consecutive breeding seasons. The estimated home range during the non-breeding season was calculated to be approximately **1,408 km²,** averaged over three years. This vulture demonstrated a largely resident movement pattern, frequently commuting between known feeding sites in Dharamshala and its nesting area.

One of the most notable observations of this individual was its long-distance movement. The bird traveled as far as Paonta Sahib, a region near the Himachal Pradesh-Uttarakhand border, marking a significant excursion beyond its usual range. Additionally, it was recorded near the Pinjore Vulture Breeding Centre, where it remained for a day before returning to the study site. Another instance of long-distance movement was observed when the bird travelled to the Mandi region near Kullu. Such behaviors indicate the need for further investigation into the social structure of White-rumped Vultures, particularly regarding information exchange, site selection, and possible interactions with other vulture populations.

A significant behavioral shift was recorded in the 2024–2025 breeding season when this individual changed its nesting site, relocating to a more open area near a roadside location in Baranj Sirmani which is almost 25 Km away from the previous site. The bird's movement pattern continues between feeding areas in Dharamshala and its new nesting site, underscoring the importance of preserving both breeding and foraging habitats for the long-term conservation of the species (Figure 5.8).

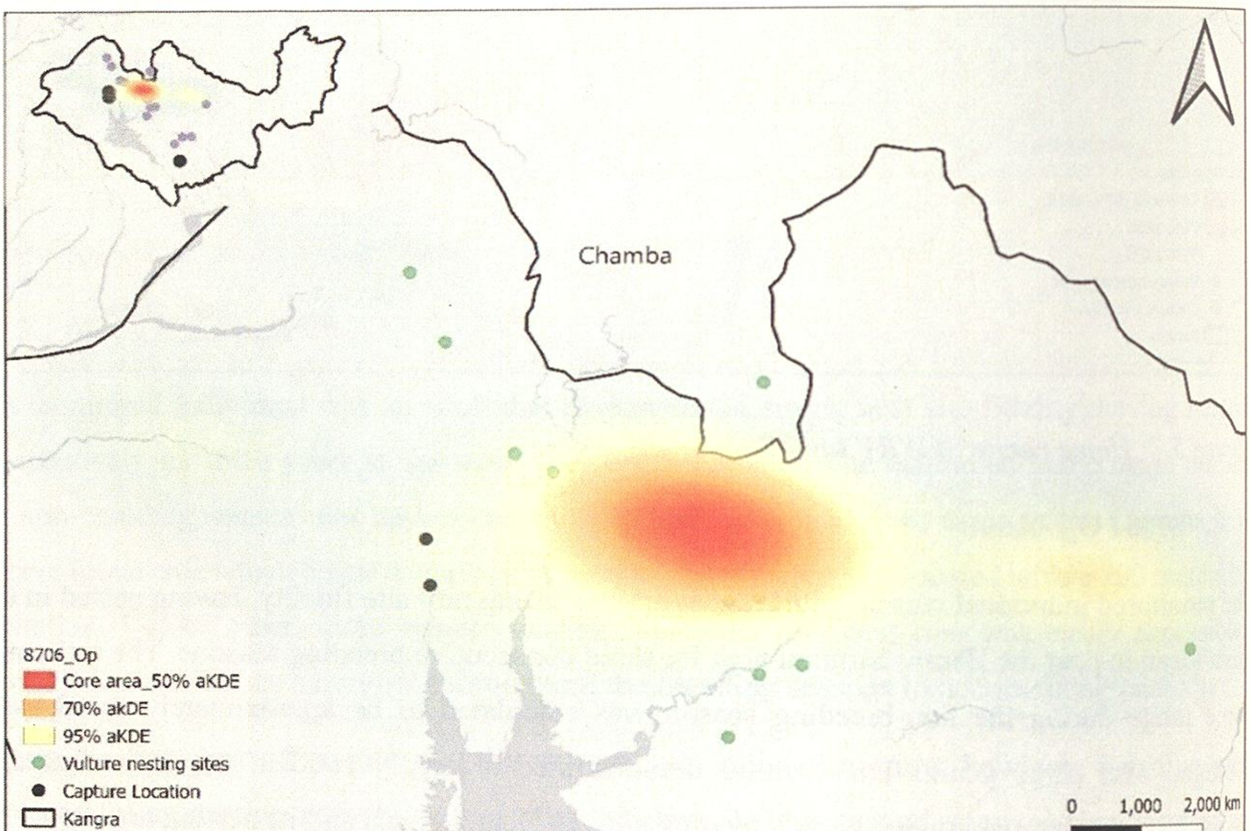


Figure 5.8: Home range of WRV 8706 for all years

5.3.3. Seasonal Home ranges:

The analysis of home range patterns across breeding and non-breeding seasons for five tagged vultures revealed significant variations in movement ecology. These variations were largely influenced by breeding constraints, food availability, and environmental factors.

Khiti (8705) exhibited a distinct difference between breeding and non-breeding home ranges. Its home range reduced from 1181 km² in the non-breeding season to 781 km² in the breeding season. This suggests that once breeding constraints were lifted, the vulture explored a much larger area, possibly in search of food resources or social interactions.

Op (8706) displayed a drastic reduction in breeding home range, decreasing from 3781.33 km² in the first year to 960.79 km² in the second year. The large home range in the first breeding season suggests exploratory behavior before the bird settled into a stable nesting site. In contrast, the non-breeding home range remained relatively stable, with a slight increase from 742.69 km² to 1086.26 km².

Teij (8707), a sub-adult individual, exhibited substantial inter-annual variation in its non-breeding home range size, with an expansive range of 7,249.65 km² recorded in the first year, which markedly declined to 2,106.07 km² in the second year—a reduction of approximately 70%. This pronounced contraction may reflect a shift towards more localized movement patterns, potentially driven by increased stability in food resources or modifications in roosting behavior.

Morut(8703) maintained a relatively stable breeding home range, with only a slight decrease from 1007.55 km² in the first year to 894.87 km² in the second year. However, its non-breeding home range exhibited a striking contrast, declining from 1525.01 km² in the first year to just 448.42 km² in the second year, representing a 70% reduction. This suggests that, unlike other individuals that expanded their home ranges post-breeding, this vulture remained restricted to a smaller area during the non-breeding season, potentially due to stable food sources in proximity and time of breeding.

Himayu (8708) has not nested during the entire season; its non-breeding home range expanded significantly from 649.63 km² in the first year to 1028.67 km² in the second year, representing a 58% increase. This trend indicates that, similar to Vulture 8705, the bird required larger foraging areas during the non-breeding season.

Overall, the results demonstrate that vultures exhibit smaller and more localised home ranges during the breeding season, reflecting their dependence on a nesting site. In contrast, non-breeding home ranges varied considerably, with some individuals expanding their range significantly, while others reduced their movements, possibly due to localised food availability.

Table 5.3: *Seasonal 95%akDE home range for breeding and non-breeding home ranges of WRV for two breeding seasons*

SI No.	Tag ID	Nest/Non-nest	Breeding aKDE (Sq.Km (October-April)		Non-Breeding aKDE(Sq.Km) (May-Sept)	
			First	Second	First	Second
1	**8708**	Not nesting	NA	NA	649.6334	1028.668
2	**8705**	Nesting	940.3447	620.7637	648.9653	1713.025
3	**8703**	Nesting	1007.554	894.871	1525.011	448.4248
4	**8706**	Nesting	3781.327	960.7901	742.687	1086.263
5	**8707**	Not nesting	NA	NA	7249.655	2106.07

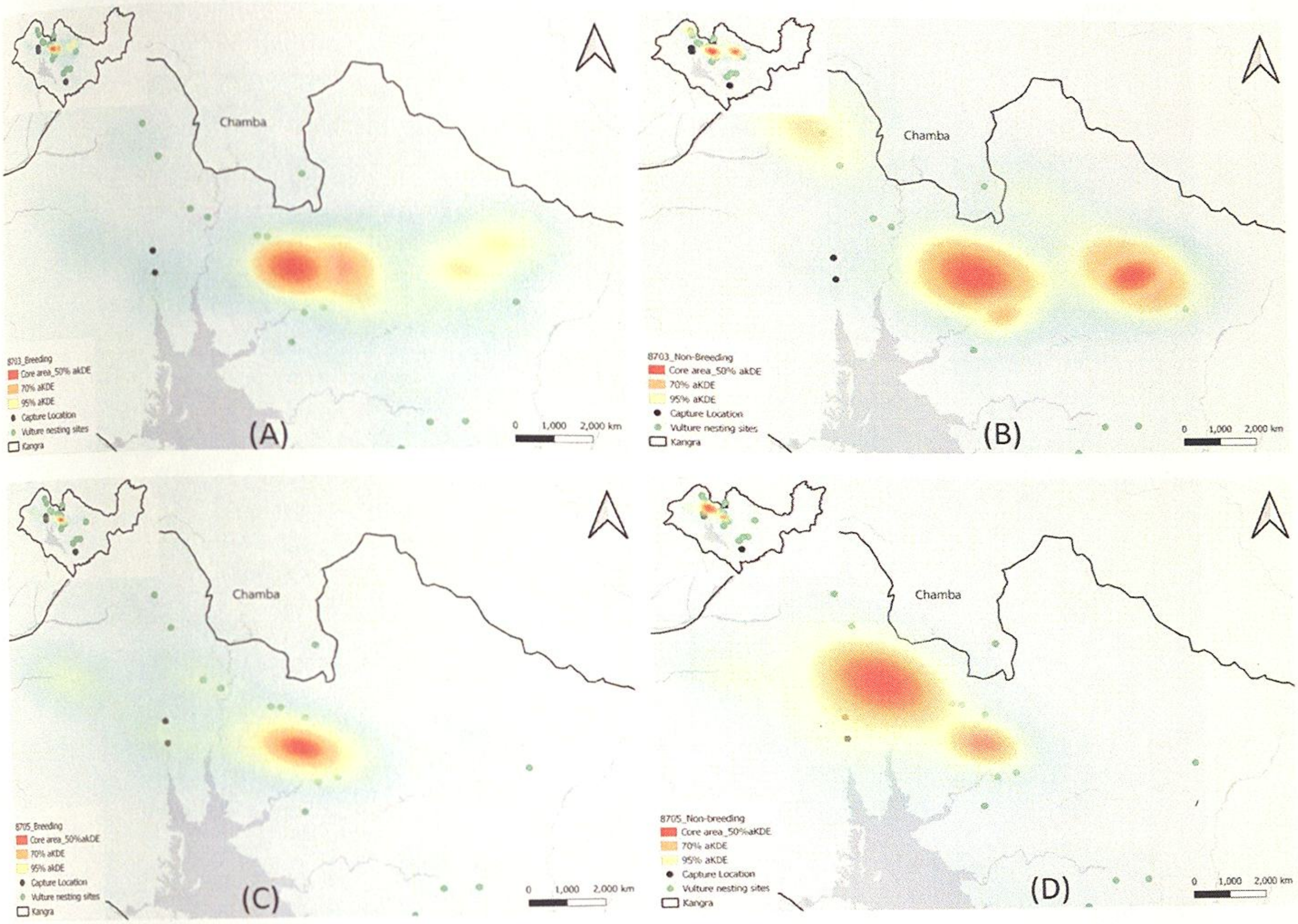


Figure 5.9: (A) and (B) Breeding and Non-breeding home range of 8703 and (C) and (D) Breeding and non-breeding home range of 8705

Figure 5.10.:Nesting tagged White-rumped Vulture with fledgling

5.3.4. Carcass dumping sites in Kangra

Carcass dumping sites in the study area are primarily designated by locals for disposing of deceased cattle or buffaloes. The cobbler community, known as Chamars, collects deceased livestock from households and transports them to these sites in exchange for monetary benefits. The carcasses are skinned, and after the vultures feed on them, the remaining bones and horns are gathered for sale. Historically, Kangra had a large number of carcass dumping sites, but with increasing infrastructure development, open lands far from human habitation have become scarce. Additionally, the tanning and bone industries across India have declined, leading to a shift in disposal practices. In Himachal Pradesh, ground burial of carcasses has largely replaced open disposal, which previously provided a vital food source for vultures. However, ground burial poses environmental risks, such as soil and water pollution, affecting the region's ecosystem health. Tracking tagged vultures in the area has identified 36 feeding stations(Figure 5.12) managed by locals, which help sustain the large vulture congregations in Kangra. Carcass disposal sites in Kangra represent a unique cultural and ecological characteristic of the Kangra district, persisting despite a shift towards carcass burial practices in other regions of Himachal Pradesh. Discussions with local landowners and patwaris revealed that in earlier times, nearly every village had designated open dumping sites for livestock carcass disposal. However, changing livestock management practices, urbanisation, and reduced cattle and buffalo holdings have led to a significant decline in these sites. Many traditional disposal areas are gradually disappearing due to increasing land use pressure and changing societal norms (Figure 5.13).

The conservation of these sites is crucial for the survival of vulture populations, as their primary food source consists of livestock carcasses. The decline in open carcass disposal poses a significant challenge to vulture conservation efforts, directly impacting their foraging opportunities. Given the critical role vultures play in maintaining ecological balance by efficiently disposing of animal remains, there is an urgent need to protect and manage these habitats. Raising awareness among local communities about the ecological services vultures provide—such as disease control and waste removal—will be essential for ensuring the long-term viability of both these disposal sites and vulture populations in Kangra.

Figure 5.11. .Carcass dumping site at Jawali

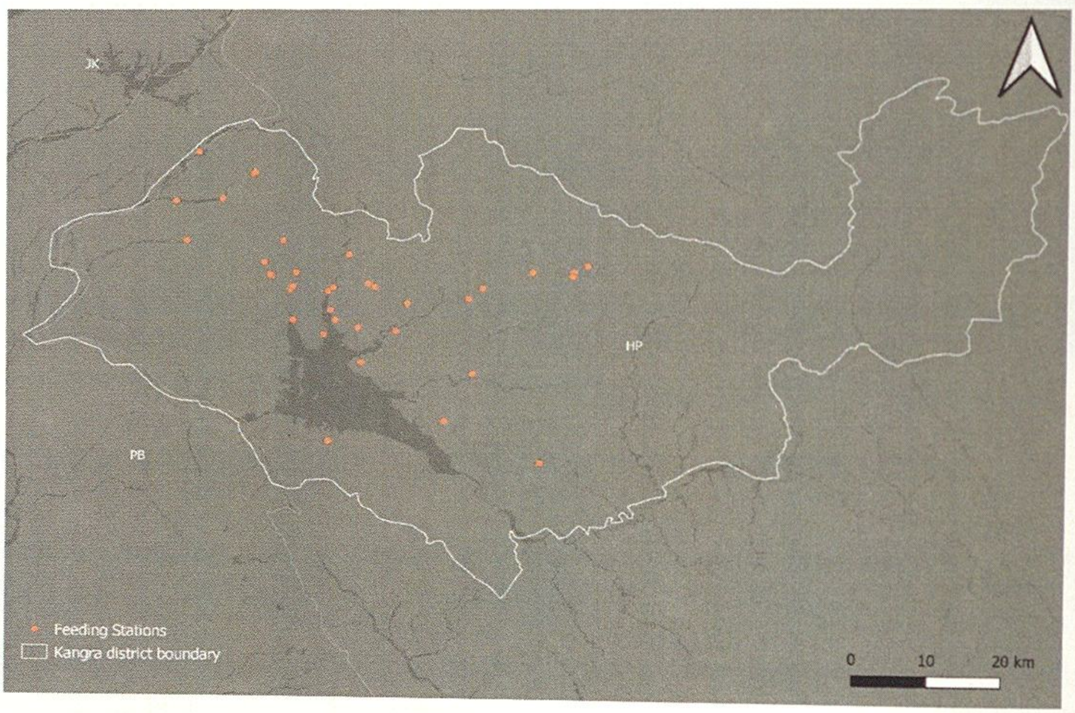


Figure 5.12.: Carcass dumping sites in the study area from 2021-2024 showing 36 local based feeding stations for the vultures

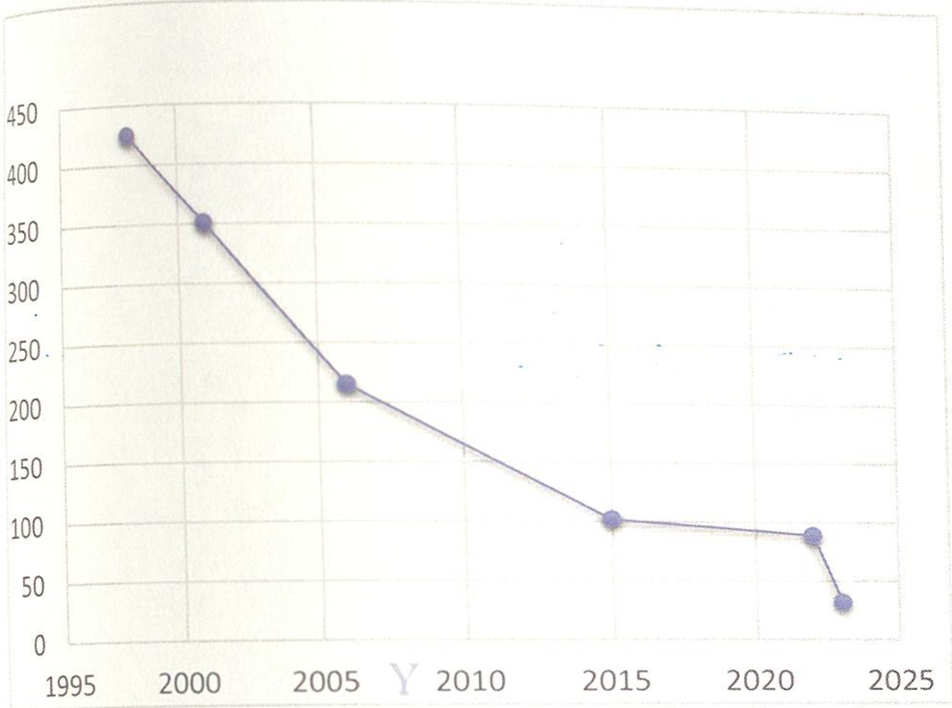


Figure 5.13.: Decline of carcass dumping sites in the study area between 1996 to 2024

5.3.5. Carcass availability and reduced home range

In September 2022, the home range of White-rumped Vultures ranged from 271 to 460 square kilometers, reflecting how strongly their spatial movements are shaped by the availability of food resources. Seasonal changes in carcass availability significantly influenced their movements, especially during the outbreak of lumpy skin disease in Kangra in September 2021. Although most domesticated cattle which were infected were buried as a precautionary measure, the region's large stray livestock population played a key role in shaping the vultures' response. The sudden surge in stray cattle carcasses served as a different resource for the vultures during the season.

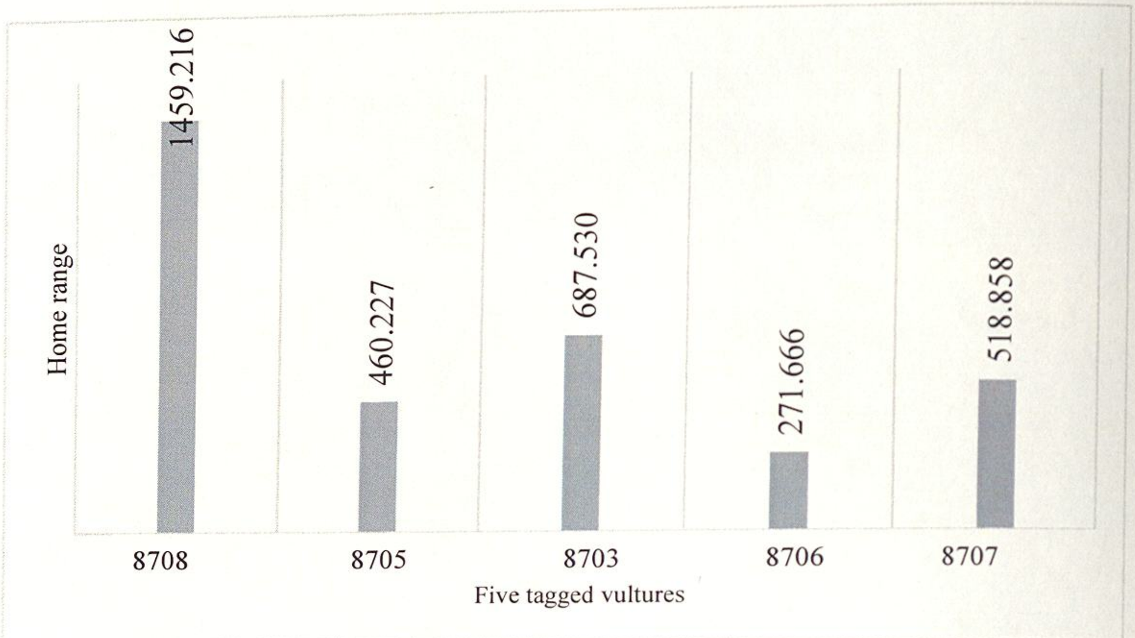


Figure 5.14: Home range of vultures during the September, 2021 outbreak of lumpy skin disease in cattle leading to resource abundance and reduced home range of WRV

5.3.6. Electrocution and overlapping feeding sites:

The home range of White-rumped Vultures overlaps with power distribution lines, posing a significant risk to their population. This threat is particularly pronounced during the breeding season when adult vultures spend more time near nesting sites and are at greater risk of collisions or electrocution. Increased fatalities during this critical period not only affect adult survival rates but also have cascading effects on reproductive success, emphasising the need for mitigation measures such as insulating power lines or rerouting them away from nesting and feeding grounds. The deaths of three White-rumped Vultures due to electrocution were recorded between 2020-2023.

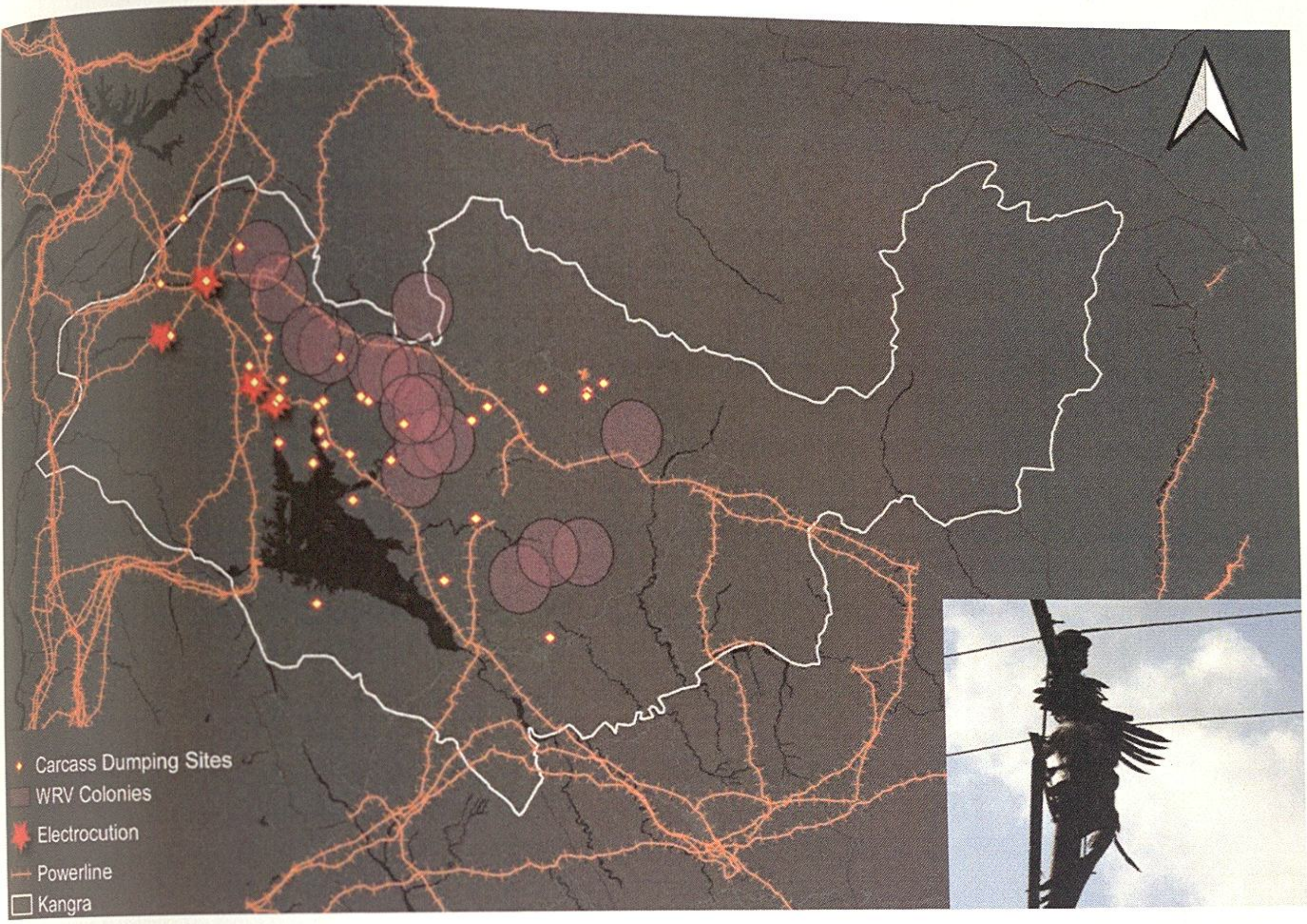


Figure 5.15: Electrocution zones at the study area overlapping with carcass disposal sites and vulture nesting sites in the area. Four main electrification zones identified, namely Meira, Jassur, Kali Mitti and Gangath area.

5.4. Discussion

The movement routes and behavior of WRV in India are virtually unknown except few unpublished records on captive-released vultures (Bhushal 2018; Bowden 2009; Bowden et al 2012).The present research identifies priority areas for the population of White-rumped vultures in Himachal Pradesh through a detailed analysis of telemetry data. The monitored vultures spent more than 95% of the study period within these key zones or travelling between them, highlighting a strong preference for areas like Lapiana, Baranj Sirmani, and Dolba.

These areas offer benefits to the vultures, including suitable breeding and roosting sites within Chir Pine forests and actively managed carcass dumping sites.The data show that social scavengers like the White-rumped Vulture can be concentrated in specific areas, allowing for targetted and effective management strategies.The telemetry-based data support the concept of Vulture Safe

Zones (VSZ) and underscore the urgent need to monitor, control, and mitigate risk factors such as electrocution, forest fires, and habitat loss.

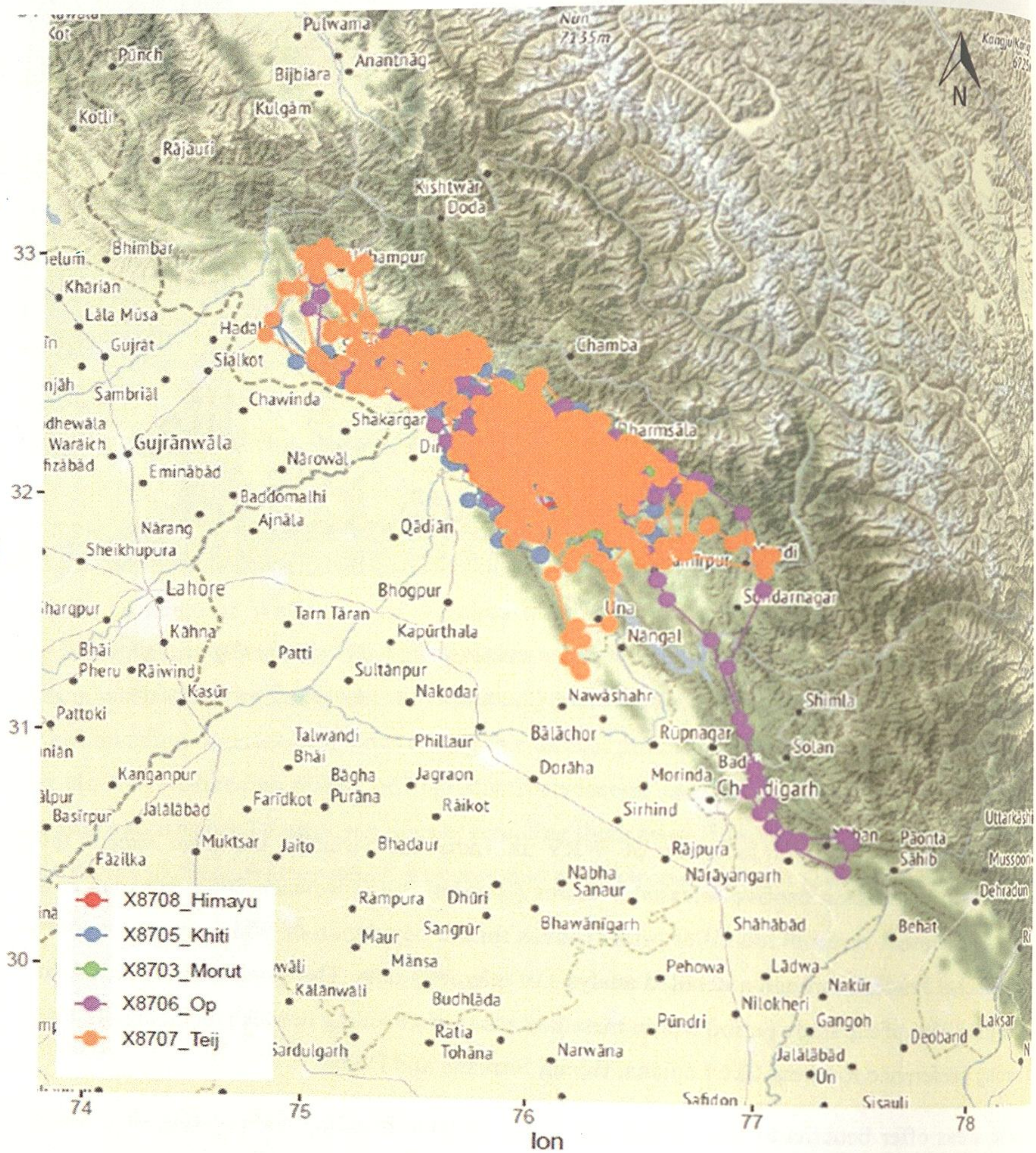


Figure 5.16: Combined movement of the five White-rumped Vultures between 2021-2024

Ethics statement:

Capturing and handling of wild vultures were followed strict safety protocols and guidelines as advisory by Ministry of Environment Forest and Climate change with permission from Chief Wildlife Warden Himachal Pradesh Forest Department (HPFD). The banding was done using rings provided by Bombay natural History Society (BNHS) and was approved by (HPFD). No harm caused to the animal during the capturing and fitting process. Maximum time taken for tag fitting and releasing the bird was 25 minutes. (Permit Number:1-16/2021 WL, 02.07.2021).

Chapter 6: Climatic Niche Modeling to Assess the Impact of Climate Change on Nine Vulture Species in Asia

6.1. Introduction

Vultures deliver a range of environmental, economic, and cultural services. Despite unique characteristics, most vulture species (61%) worldwide are threatened with extinction (Ogada *et al.* 2011). In Asia, *Gyps* vultures declined (>95%) rapidly after the 1990s (Prakash *et al.* 2017), primarily due to the extensive use of diclofenac, a non-steroidal anti-inflammatory drug (NSAID) used to treat cattle (Oaks *et al.* 2004). Other threats to vulture populations include risk of collisions with powerlines (Boshoff *et al.* 2011), habitat degradation, climate change effects (Bridgeford and Bridgeford, 2003), and changes in carcass disposal practices (Mundy *et al.* 1992, Ogada *et al.* 2015b).

India has nine vulture species: Egyptian Vulture *(Neophron percnopterus)*, Griffon Vulture *(Gyps fulvus)*, Himalayan Vulture (*Gyps himalayensis*), Bearded Vulture *(Gypaetus barbatus)*, Cinereous Vulture (*Aegypius monachus*), White-rumped Vulture (*Gyps bengalensis)*, Indian Vulture *(Gyps indicus)*, Slender-billed Vulture (*Gyps tenuirostris)* and Red-headed Vulture (*Sarcogyps calvus;* Table 1). Four are endemic to the Indian subcontinent, i.e., the White-rumped Vulture, Indian Vulture, Slender-billed Vulture, and Red-headed Vulture. The populations of White-rumped Vulture, Indian Vulture, and Slender-billed Vulture have declined by 99.9% since the 1990s. The Red-headed Vulture population also decreased by 91%, and the Egyptian Vulture by 80%. The Griffon Vulture and Bearded Vulture have experienced less decline due to their migratory behavior (Ogada *et al.* 2012, Gil *et al.* 2014). The White-rumped Vulture was once widespread enough to be considered the most common bird of prey by some authors (Cunningham *et al.* 2003). Historically, White-rumped Vultures and Slender-billed Vultures were common in northeastern India (Baker 1928), moderately abundant in the Brahmaputra Valley (Hooker 1854), and scarce in the Khasi Hills. White-rumped Vultures nested densely at 2.7 nests/km² in Delhi (Galushin 1971) and 12 nests/km² in Keoladeo National Park, India, during the 1970s–1980s (Prakash 1999). White-rumped Vultures were also common in West Bengal and abundant along the Indus River in Pakistan (Roberts 1991). The White-rumped Vulture has nearly disappeared from Southeast Asia, particularly Laos and Vietnam (Thewlis *et al.* 1998).

Following the drastic decline of *Gyps* vulture populations (Green *et al.* 2004) and the ban on veterinary diclofenac (Mahapatro and Arunkumar 2014), Bombay Natural History Society (BNHS)launched captive breeding programs for White-rumped, Indian, and Slender-billed

Vultures across India (Bowden *et al*. 2012). In 2021, aceclofenac and ketoprofen were also banned (Galligan *et al*. 2021). To mitigate NSAID poisoning, the consortium Saving Asian Vultures from Extinction (SAVE) introduced the Vulture Safe Zone concept, establishing 100-km-radius zones around an area with nesting colonies of critically endangered *Gyps* vultures (Bhusal *et al*. 2018). India currently has proposed eight potential Vulture Safe Zones (Mukherjee *et al*. 2014).

The decline of Asian vultures has a long-term impact on the essential ecosystem services they provide (Markandya *et al*. 2008). According to the citizen science data, one source shows vulture numbers were still decreasing (2000-2022) (State of India's Birds 2023). Following the decline of vultures, diseases such as rabies, anthrax, and botulism spread as the number of feral dogs increased. The rise in feral dogs is a serious issue as they partially consume carcasses, then move into nearby villages and homes, spreading deadly diseases like rabies and sometimes attacking people. Ministry of Agriculture 2003, Swan *et al*. 2006). The decline occurred concomitantly with a reduction in large-mammal carcass availability due to changing carcass disposal practices (Prakash *et al*. 2007, Harris 2013). In addition, vultures are sensitive to climatic conditions, such that the predicted area of suitable habitat declines under extreme climatic scenarios for White-rumped Vultures in southern India (Anoop *et al*. 2020). Breeding success and population size of Cape Vulture vary with increasing temperature and rainfall patterns (Bridgeford and Bridgeford 2003, Virani *et al*. 2012). A study on seven vultures from central India shows that temperature and precipitation variables are essential for future habitat suitability (Jha *et al*. 2021).

Understanding the climatic niche of a species is important for identifying climatically favourable areas for a species (Bonetti *et al*. 2014), assessing the species' responses to climate change, and developing effective conservation strategies. Ecological niche modeling (ENM) predicts the species' potential niche in a geographic area based on a set of environmental variables and presence points. ENM has been used to investigate the effect of climate change on species' distribution and management (Elith *et al*. 2009, Porfirio *et al*. 2014). For example, climatic niche has been modelled for the Cape Vulture (*Gyps coprotheres*) in South Africa (Phipps *et al*. 2017), endemic herpetofauna from southern Western Ghats (Srinivasulu et al. 2021), American White Pelicans (*Pelecanus erythrorhynchos;* Illán *et al*. 2022), and Buff-bellied Hummingbirds (*Amazilia yucatanensis;* Vásquez-Aguilaret *et al*. 2021). ENMs can also help researchers quantify the environmental variables that are important for understanding species' habitat preferences, ecological requirements guiding reintroduction efforts, particularly for poorly studied or rare species (Loiselle *et al.* 2003, Guisan and Thuiller 2005, Elith and Leathwick 2009, Morán-Ordóñez *et al.* 2017, Flessner *et al.* 2017, Ramesh *et al.* 2017). Among the distribution modeling studies investigating the causes of vulture decline in Asia, few have explored the potential impact of climate change on their niche (Phipps *et al.* 2017, Jha and Jha 2021, Anoop *et al.* 2020, Sheykhi Ilanloo *et al.* 2020).

To fill this knowledge gap, we aimed to identify the distributional shifts of climatic niches for nine vulture species across current and future periods. By examining these shifts, this study offers insights into how climate change could impact vulture distribution. This knowledge is crucial for anticipating conservation challenges and developing effective strategies for identifying key areas to release captive-bred vultures into the wild.

6.2. Methods

The study was conducted for nine vultures from the Old World (Fig. 1) that occur in India. We used eBird data to determine species occurrence (eBird 2020; Sullivan et al. 2009). The eBird dataset was used along with a set of bioclimatic variables from WorldClim-Global Climate Data 2.0 (Fick and Hijman, 2017) to model the likely climatic niche, which we then projected to four future shared socioeconomic pathways (SSP)-based climate scenarios (Fick and Hijmans 2017) of two periods, 2040–2060 and 2060–2080.

6.2.1. Species Occurrence Data:

Species presence points were collected from the citizen science platform eBird (eBird 2020). eBird data gathered from millions of citizen birdwatchers have different automated filters and are reviewed by a systematic assessment process; the global team of bird experts and eBird reviewers ensure that reliable and accurate data can be used for global bird studies (Sullivan et al. 2009). On 20 October 2020, we obtained occurrence records for nine vulture species from the eBird basic dataset for dates between 2000 and 2020, ensuring broad geographic coverage across the Old World We downloaded a total of 430,168 occurrence points for all nine vulture species. However, citizen science data are often biased and noisy (Johnston et al. 2023). The occurrence data were filtered in sequential steps to create robust models. We used SDMtoolbox v2.4 in ArcGIS 10.8 to remove duplicate records and rarefied the data (keeping one single record in 5 km^2) to avoid spatial clustering. Furthermore, we visually checked and removed uncertain points. Finally, 25,060 spatially filtered occurrence data points (Fig. 1) and eight selected bioclimatic variables were used to train the models for nine vultures. For each species, we split the data into two equal portions, one for calibrating the models (50% data) and the other (50%) for independently evaluating the models. Furthermore, the calibration portion was split randomly into training (70%) and test (30%) datasets.

6.2.2. Bioclimatic Variables:

We used eight bioclimatic variables (Fick and Hijman, 2017) from WorldClim-Global Climate Data 2.0 (www.worldclim.org/bioclim) with a spatial resolution of 2.5' (arc minute; approx. 21 km^2). Bioclimatic variables are derived from monthly temperature and precipitation values and are intended to approximate climate dimensions meaningful to biological species (Fick and Hijmans 2017). We performed the Pearson correlation coefficient test and removed correlated variables through SDMtoolbox V2.4 (Brown et al. 2017) in ArcMap 10.8.

6.2.3. Future Climatic Data:

To assess the potential future climatic niche of the target nine species of vultures we used future SSP-based climate layers (https://worldclim.org/data/cmip6/cmip6climate.html) of four future warming scenarios (SSP126, SSP245, SSP370 and SSP585) from the MIROC-ES2L(Model for Interdisciplinary Research on Climate – Earth System version 2 for Long-term simulations) and General Climate Model (GCM) for two time periods: 2040–2060 and 2060–2080, following previous studies (Srinivasalu et al. 2021, HamadAmin and Khwarahm 2023, Moya-Moraga and Pérez-Ruíz 2022). We used MIROC-ES2L (Watanabe et al. 2011) due to its strong performance in simulating South Asian climate patterns, but we acknowledge that incorporating multiple GCMs in future studies would enhance projection reliability. The scenario names consist of SSP (SSP126 – SSP585) combined with the expected amount of radioactive forcing involved (1.9 to 8.5 W/m^2).

6.2.4. Species Distribution Modelling (SDM) for Vultures:

We used the *kuenm* (Cobos *et al*., 2019) package in R 4.0.3 to model the vulture's present and future distribution. *Kuenm* is an R package designed to develop ecological niche modeling in MaxEnt. *Kuenm* is a widely used R package (Cobos et al. 2019) that facilitates ecological niche modeling (ENM) through MaxEnt. It provides tools to build, evaluate, and interpret niche models systematically and efficiently, especially in studies examining species' responses to climate change (Zheng et al. 2023, Li et al. 2024). The package is particularly advantageous due to its automation capacity and rigorous statistical model performance evaluation. The package uses three important steps of environmental niche modeling: calibration, final model creation, and evaluation.

6.2.5. Model Calibration:

We calibrated our models for the nine Old World vultures using the training data and the set of eight bioclimatic variables. We used a combination of different feature types (i.e., linear, quadratic, product, threshold, and hinge) and 6 regularization multiplier values (0.1, 1, 2, 3, 4, 5) as recommended (Cobos et al. 2019). The combination determines the complexity or generality of the modelled response, creating different models for model calibration. For each species, we generated 186 candidate models (Supplemental Material Table S1). We tested the candidate models with test data using the "kuenm_ceval" function. The best suitable models for each species were selected using the criteria of statistically significant candidate models with the lowest pROC and AIC_c values (Table S2).

6.2.6. Final Model Building:

The final model for each species was created with ten replicates (replication type: bootstrap), 10000 randomly generated background points, and 500 iterations. The output format was set to "cloglog" and we used the average of the ten replicates for further analysis (Table S3). Furthermore, using the presence points, we created a buffered MCP from which presence points falling outside the predicted areas were excluded.where the species were unlikely to occur. The buffer size was determined based on the published records of daily distance travelled and home range of the vultures, as well as ranges of similar species in areas where data was unavailable (Table S4); it helps prevent overprediction by excluding fragmented or unsuitable areas while maintaining biologically meaningful connectivity.

6.2.7. Future Projection:

The final models for each species in the present-day scenario were projected to future climate change scenarios for 2040–2060 and 2060–2080. Results for each SSP scenario were used to separately interpret future potential climatic niches of vultures under different SSP scenarios. For future projections, we considered a complete future dispersal scenario to identify the potential climatic niche. Although our analysis was conducted across the entire Old World, we created maps specifically for India to provide a more detailed representation of changes in the nine species' climatic niche within its current range. This regional focus allows for a more precise evaluation of ecological patterns and conservation needs within India. The net niche reduction was calculated by subtracting the future niche contraction from the future niche expansion, representing the overall change in suitable habitat for the species. Additionally, the future suitable climatic niche was identified for eight potential Vulture Safe Zones in India. VSZs are focused areas with a radius of about 100 km, where concentrated efforts are made to eliminate vulture-toxic NSAIDs and create a safe environment for releasing captive-bred vultures. VSZ approach has been adopted across South Asia to enable in-situ vulture conservation. In the study, all potential vulture habitats were combined and divided into eight VSZs, applying a 100-km-radius buffer around each location to assess future climatic suitability.

6.2.8. Independent Model Evaluation:

We used the "kuenm_feval" function for independent model evaluation to evaluate final Maxent models in terms of statistical significance (partial ROC) and omission rate.

6.3. Results

6.3.1. Calibration results:

We evaluated candidate model performance based on significance (partial ROC, with 500 iterations and 50% of data for bootstrapping), omission rates (E = 5%), and model complexity (AICc). A total of 186 candidate models were tested for each species by combining six regularization values (0.5, 1, 2, 3, 4, 5) with 29 feature class combinations (linear = l, quadratic = q, product = p, threshold = t, and hinge = h) to select final models that balanced fit and predictive performanceTable S1. The suitable models were selected according to the following criteria: significant models with omission rates ≤5%. Models with ΔAICc values of ≤2 were chosen as final models from the model set.

6.3.2. Final model creation and projection:

The selected parameters from the model with the lowest AIC value were used to create the final model for nine species for the present-day scenario. Furthermore, the present climatic conditions and model were projected for the nine Old World vulture species for current and future SSP scenarios. Our final model's AUC value ranged from 0.85 to 0.97 (Table S5), indicating a good prediction

6.3.3. Jackknife test results and variable importance:

The jackknife test identified variable contribution and the importance of Maxent modeling for the potential distribution of vultures (Fig. S1). The result suggests that different bioclimatic variables play a significant role for each vulture species. For the Cinereous Vulture and Egyptian Vulture, precipitation in the coldest quarter (bio19) contributes 35.3% and 29.2%, respectively. Annual precipitation (bio12) was the dominant factor in the Bearded Vulture and Slender-billed Vulture models, with 33.9% and 56.4%, respectively. For Griffon Vultures and Himalayan Vultures, the annual temperature range (bio7) contributed 30.3% and 28.3%. For the Indian Vulture, White-rumped Vulture, and Red-headed Vulture, precipitation seasonality (bio15) had the highest contribution among eight bioclimatic variables with 61.3%, 30.8% and 23.5%, respectively (Fig. 2; Table S5).

6.3.4. Present climatic niche

Maximum training sensitivity plus specificity refers to the optimal threshold in a classification model in which the sum of sensitivity (true positive rate) and specificity (true negative rate) is maximized, ensuring balanced performance. We used the "maximum training sensitivity plus specificity" threshold (Table S3) to convert outputs (range: 0–1) into binary maps. Among all vulture species, the Himalayan Vulture has the widest suitable climatic niche under present-day conditions, covering an area of 6,764,265,000 km^2 across the Old World, followed by Cinereous Vulture (5,649,470,000 km^2) and Bearded Vulture (5,053,459,000 km^2; Table S7, Fig. S2).

6.3.5. Future climatic niche

We projected the climatic niche of the nine vulture species for four future climatic scenarios (i.e., SSP126 [~1.7–1.8°C projected warming], SSP245 [~2.0-2.7°C, projected warming], SSP370 [~2.1–3.6°C projected warming], and SSP585 [~4.7-5.1°Cprojected warming]) and two temporal time scales (i.e., 2040–2060 and 2060–2080). The output was expressed as a probability range between 0–1 and was converted to binary maps for area calculation (Fig. 3, 4, S3, S4). We found significant differences between the nine vultures' present and future suitable climatic niches (Table S8). The future climatic niche for all four critically endangered species (i.e., the White-rumped Vulture, the Red-headed Vulture, the Slender-billed Vulture, and the Indian Vulture) varied individually for different scenarios.

I. **White-rumped Vulture (Critically Endangered).** Across all future scenarios, models predict a significant decline in the White-rumped Vulture's climatic niche, driven largely by precipitation seasonality (30.8% contribution). The greatest climatic niche loss (49.6%) is expected under SSP585 (2060–2080). Additional projections show a 37.8% decline under SSP370 and reductions of 38.4% (2040–2060) and 49.6% (2060–2080) under SSP585 (Table S8).

II. **Slender-billed Vulture (Critically Endangered).** Models predict a 78.7% increase in the Slender-billed Vulture's suitable climatic niche under SSP585 (2060–2080), with annual precipitation (Bio 12) as the key driver. Niche expansion is also projected under SSP126 (27.5–29.1%), SSP245 (30.3–37.1%), and SSP370. The largest gains are expected under SSP585, with a 48.4% increase (2040–2060) and 78.7% by 2080 (Table S8).

III. **Red-headed Vulture (Critically Endangered).** All future projections indicate a significant decline in the Red-headed Vulture's suitable climatic niche, with precipitation seasonality (Bio15, 23.5%) as the primary factor. The largest contraction (~22.6%) is expected under SSP370 (2060–2080). Net niche loss is estimated at 8.4% (2040–2060) and 12.1% (2060–2080). Across SSP126, SSP245, SSP370, and SSP585, the proportion of current climatic niche change is minimal (Table S8).

IV. **Indian Vulture (Critically Endangered).** Precipitation seasonality (Bio15) was the most influential factor (61.3% contribution). Under SSP126, the species' predicted climatic niche shrank by 23.4% (2040–2060) and 28.1% (2060–2080). For SSP370, contractions averaged 29.7% and 40.5%, respectively. The most severe decline (~44.5%) was projected under SSP585 (2060–2080; Table S8).

V. **Cinereous Vulture (Near Threatened).** Precipitation of the coldest quarter (Bio 19) was the most important factor for the Cinereous Vulture (35.3%). For future scenarios, models showed niche expansion of 22.36 × 10^5 km^2 in 2040–2060, and a niche contraction of ~84.9×10^2 km^2 in 2060–2080 with negligible percentage change. For SSP245, the suitable climatic niche expanded by 1.9 % in 2040–2060 but decreased by 0.3% in 2060–2080. For SSP370, range expansion is predicted for the Cinereous Vulture in both 200–2060 and 2060–2080. (Table S8).

VI. **Himalayan Vulture (Near Threatened).** Temperature annual range (Bio7) was a key factor for the Himalayan Vulture. Under SSP126, the species' climatic niche shrank by 9.5% (2040–

2060) and 8.2% (2060–2080). For SSP245, reductions were 9.0% and 9.5%, respectively. Among SSP126, SSP245, SSP370, and SSP585, the Himalayan vulture's climatic niche remains largely unchanged, showing a negligible rate of contraction. This may be because they are migratory and therefore less impacted by localized climate changes.(Table S8).

VII. **Bearded Vulture (Near Threatened).** Annual precipitation (Bio-12) acted as the most significant variable for the species. For SSP126, a net climatic niche contraction of 35.2×10^5 km^2 (19.9%) in 2040-2060 and 32.41×10^5 km^2 (18.3%) in 2060–2080 was projected in the models. For SSP370, a net climatic niche contraction of 34.49×10^5 km^2(19.5%) in 2040–2060 and 45.34×10^5 km^2 (25.7%) in 2060–2080. In all future climatic scenarios, this species will have a significant niche contraction (Table S8).

VIII. **Egyptian Vulture (Endangered).** Precipitation of coldest quarter (Bio 19) contributed the highest for the Egyptian Vulture. For the SSP126 scenario, a net climatic niche contraction of 11.05×10^5 km^2 (4.5%) in 2040–2060 and 9.7×10^5 km^2 (3.9%) in 2060–2080. For SSP370, a net climatic niche contraction of 14.01×10^5 km^2 (5.7%), and 14.1×10^5 km^2 (5.7%) was projected in 2040–2060, and 2060–2080. Overall, in all future scenarios, there is a significant niche contraction for the Egyptian Vulture (Table S8).

IX. **Griffon Vulture (Least Concern).** Temperature annual range (Bio 7) was the most important contributing variable for Griffon Vulture. For the SSP126 scenario, a net climatic niche contraction of 12.78×10^5 km^2 (13.4%), and 10.14×10^5 km^2 (10.6%) was projected in 2040–2060, and 2060–2080, respectively. For the SSP370 scenario, a net climatic niche contraction of 9.9×10^5 km^2 (10.4%) and 10.14×10^5 km^2 (10.6%) was projected in 2040–2060, and 2060–2080 respectively (Table S8).

X. **All species**. Considering SSP126, SSP245, SSP370, and SSP585 scenarios of 2040–2060 and 2060–2080, the ratio of the proportion of the climatic niche that has remained the same as the current niche, with no observed expansion or reduction over time.is greatest for the Himalayan Vulture and smallest for the Red-headed Vulture (Table S8). For the Cinereous Vulture, Bearded Vulture, White-rumped Vulture, Griffon Vulture, Himalayan Vulture, Indian Vulture, Egyptian Vulture, and Red-headed Vulture, projected climatic niche area gradually decreases with increased warming scenarios.

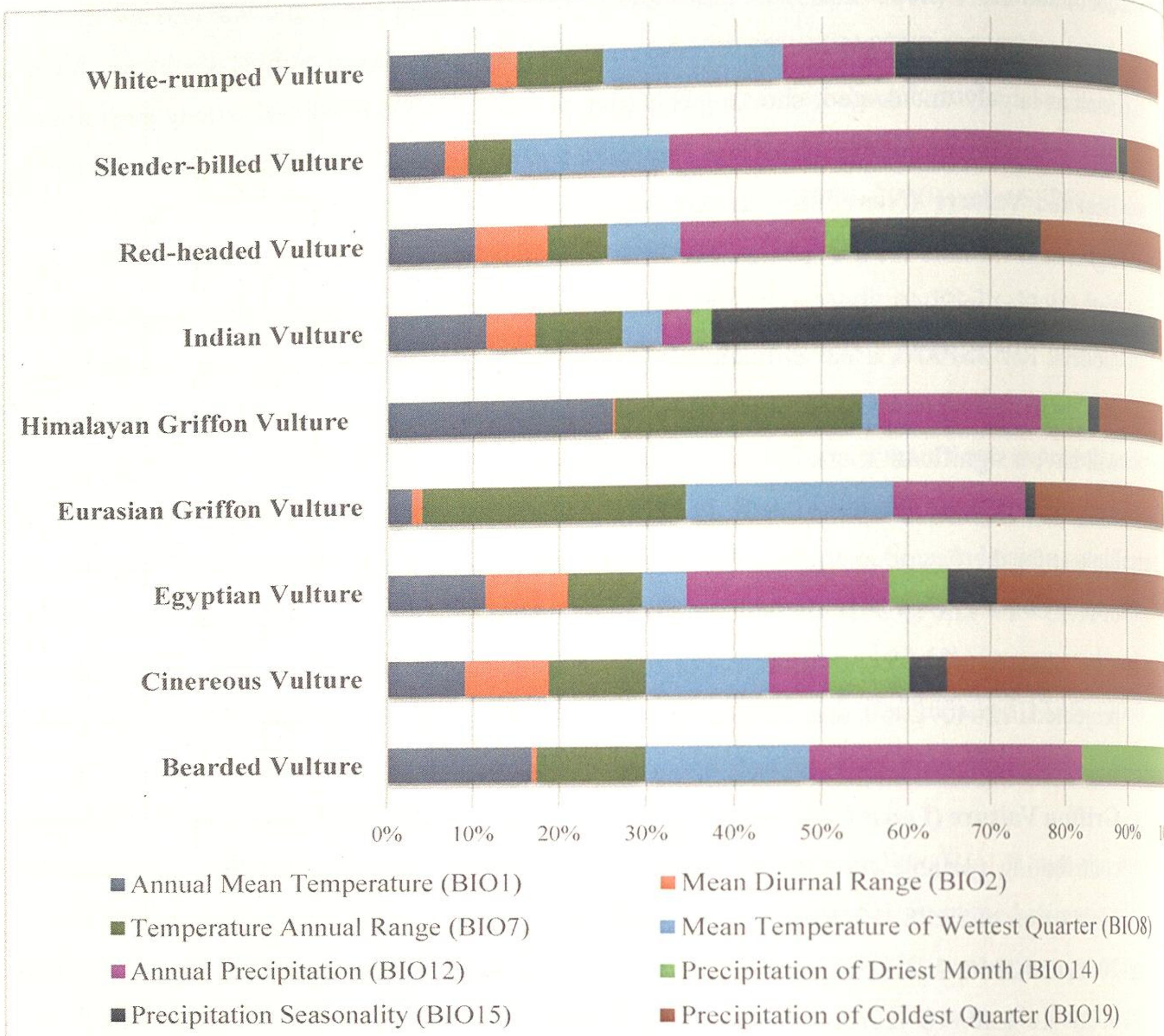


Figure 6.1..Contribution of each bioclimatic variable used for modeling the climatic niches of nine vulture species in Asia.

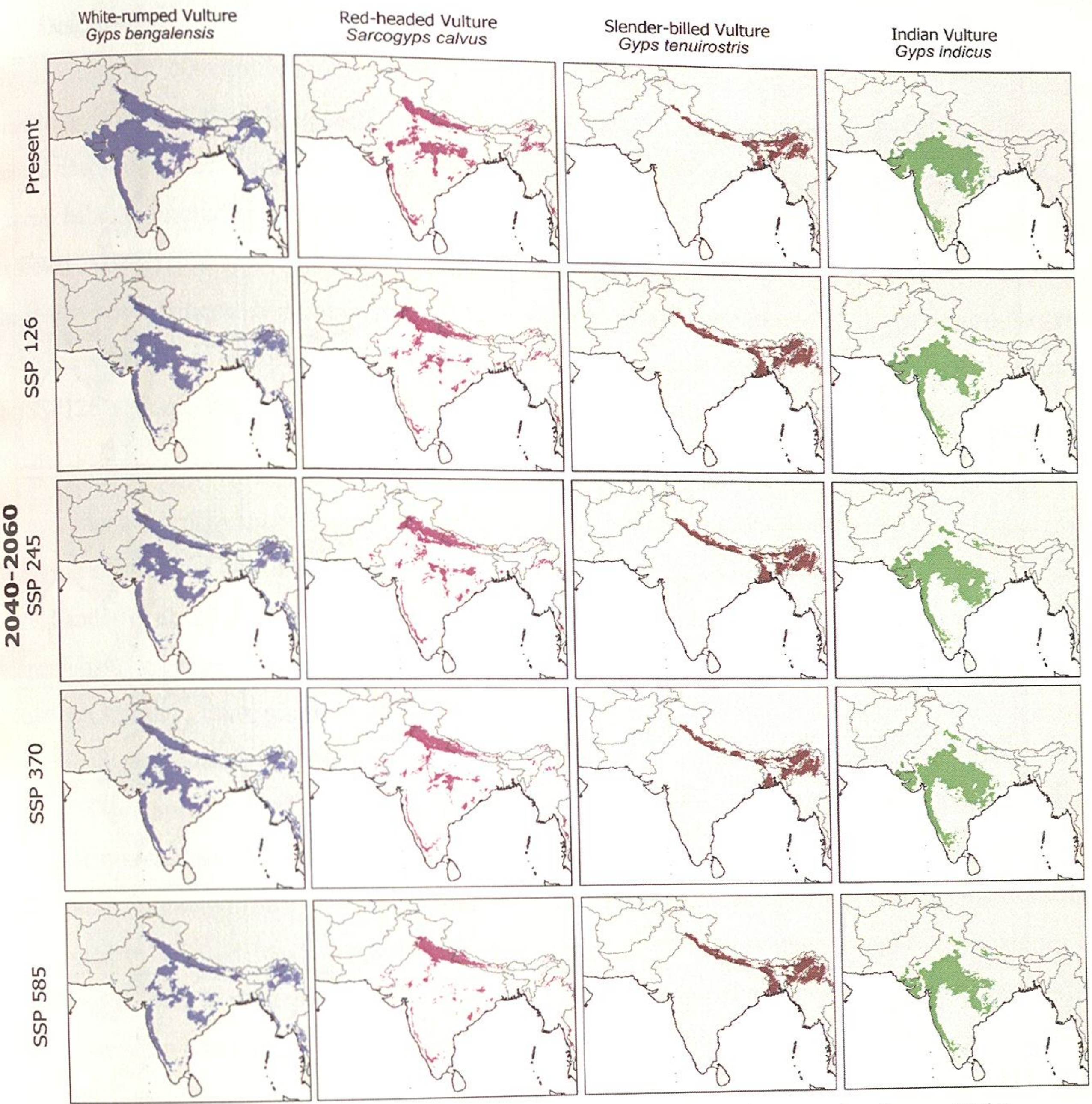


Figure 6.2. Current and future climatic niche of four critically endangered vultures (White-rumped Vulture, Red-headed Vulture, Slender-billed Vulture and Indian Vulture) for the year 2040-2060 for four future Socio-economic pathway scenarios (SSP126, SSP370, , SSP245, SSP585

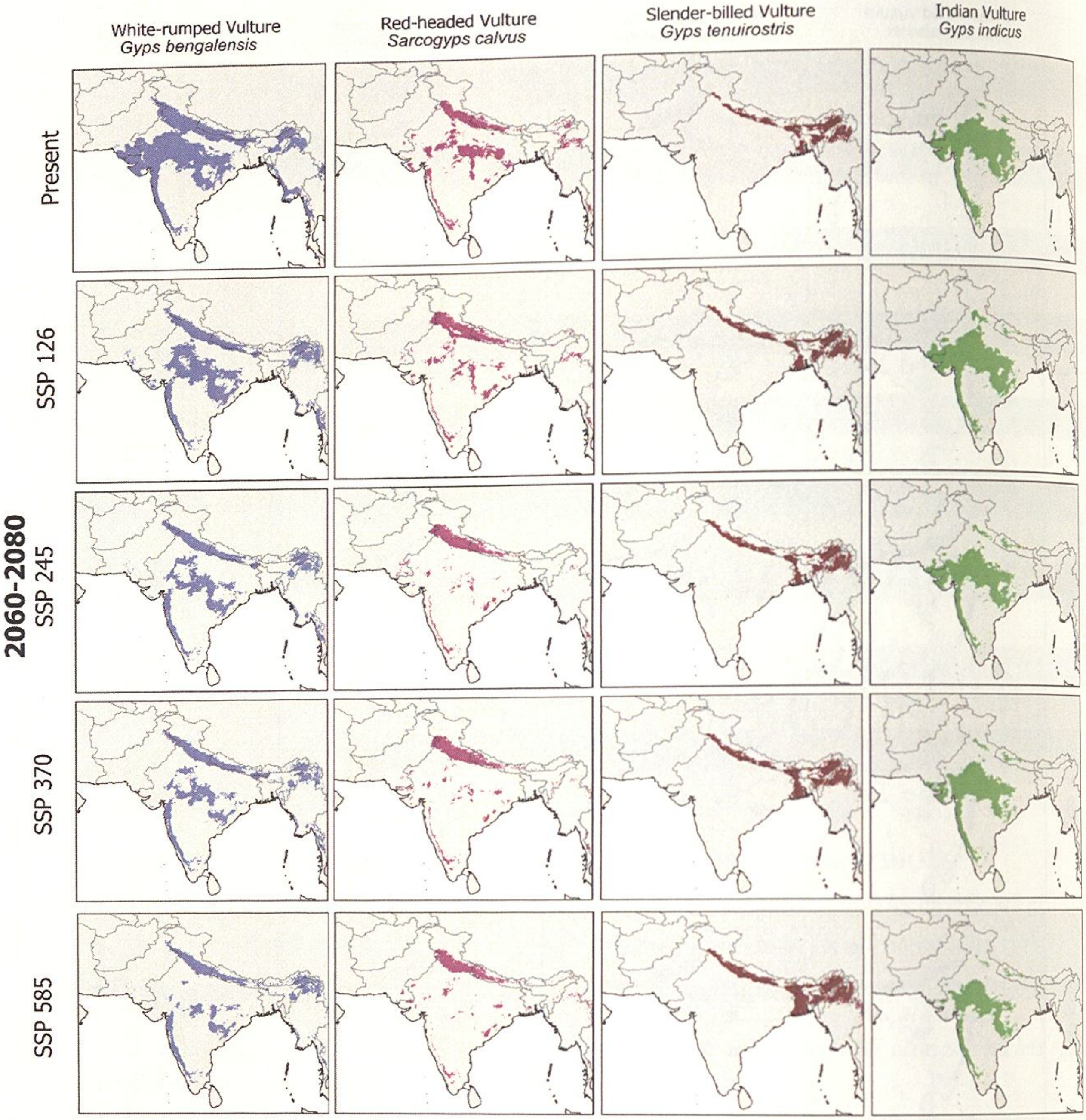


Figure 6.3.. Current and future climatic niche of four critically endangered vultures (White-rumped Vulture, Red-headed Vulture, Slender-billed Vulture and Indian Vulture) for the year 2060-2080 for four future Socio-economic pathway scenarios (SSP126, SSP370, SSP245, SSP585).

6.4. Discussion

Our findings indicate significant niche expansions and contractions for vulture species under future climate scenarios. The White-rumped Vulture is projected to experience the greatest niche contraction, with a 50% reduction by 2060–2080(SSP585), raising critical conservation concerns. Crucial habitats, including regions in Gujarat, Rajasthan, and parts of the lower Himalayas, are expected to be unsuitable in future. The Red-headed Vulture, with its already restricted range on the Indian subcontinent, is projected to lose a suitable climatic niche from the southern Eastern Ghats to central India. In contrast, the Slender-billed Vulture may see a 29% niche expansion under the SSP126 scenario by 2060–2080, potentially including Indochina and the western Bangladesh region.

Climate change significantly impacts bird distribution, particularly for Griffon Vulture, Himalayan Vulture, and Bearded Vulture in the high-elevation Himalayas (Gómez et al. 2016, Winger et al. 2019, Fandos et al. 2020). These species have restricted elevation ranges due to their evolutionary adaptations to specific climatic conditions, notably temperature and rainfall (Subedi et al. 2020). Long-term climatic changes may affect these vultures' breeding behavior, food availability, and demography (Seddon 2012, Phipps et al. 2017, Torney et al. 2018, Fandos et al. 2020). We found that annual precipitation strongly affects the Slender-billed Vulture, whereas precipitation during the driest month has minimal impact on the Griffon Vulture. Seasonal precipitation patterns differentially impact vulture breeding conditions. Bearded Vultures, adapted to cold temperatures, are affected by limited food availability(Vignali et al.,2021). Therefore, monitoring changes in climatic conditions is necessary to determine if these species will shift their ranges in response to global warming. Although climate influences bird distributions, factors like land cover, topography, and prey-predator dynamics also play a crucial role. Habitat loss, elevation constraints, and fluctuations in food availability may limit vultures' ability to occupy otherwise suitable areas. Future research should integrate these variables for a more comprehensive assessment. Successful reintroduction of captive-bred vulture species into the wild depends on understanding their climatic and habitat requirements, which is critical for conservation planning for critically endangered vultures. The next step involves releasing the captive-bred vultures into climatically resilient, diclofenac-free environments or designated Vulture-safe Zones (VSZ). Thus, understanding appropriate climatic niches is essential for successfully releasing vultures into the wild (Osborne and Seddon 2012).

Among the potential vulture-safe zones in India, the Pinjore area in Haryana emerges as the most important one (Fig. 5) in terms of future suitable climate (222,30.29 km²), followed by Dudhwa (154,64 km²) and Katarniaghat (133,20 km²). Successful reintroduction of captive-bred vultures depends on identifying and prioritizing stable habitats where the climatic niche remains unchanged over time.These stable areas can be prioritized for future captive vulture release programs in India (Supplementary Table S10). To strengthen conservation planning for VSZs, future research should incorporate multiple Global Climate Models (GCMs) to address inter-model variability and improve the accuracy and reliability of climate projections.

Among the potential VSZ in India, the Pinjore area in Haryana emerges as the most important VSZ (Figure 6.4) in terms of future suitable climate (222,30.29 km²), followed by Dudhwa (154,64 km²) and Katarniaghat (133,20 km²). These areas can be prioritized for future captive vulture release programs in India.

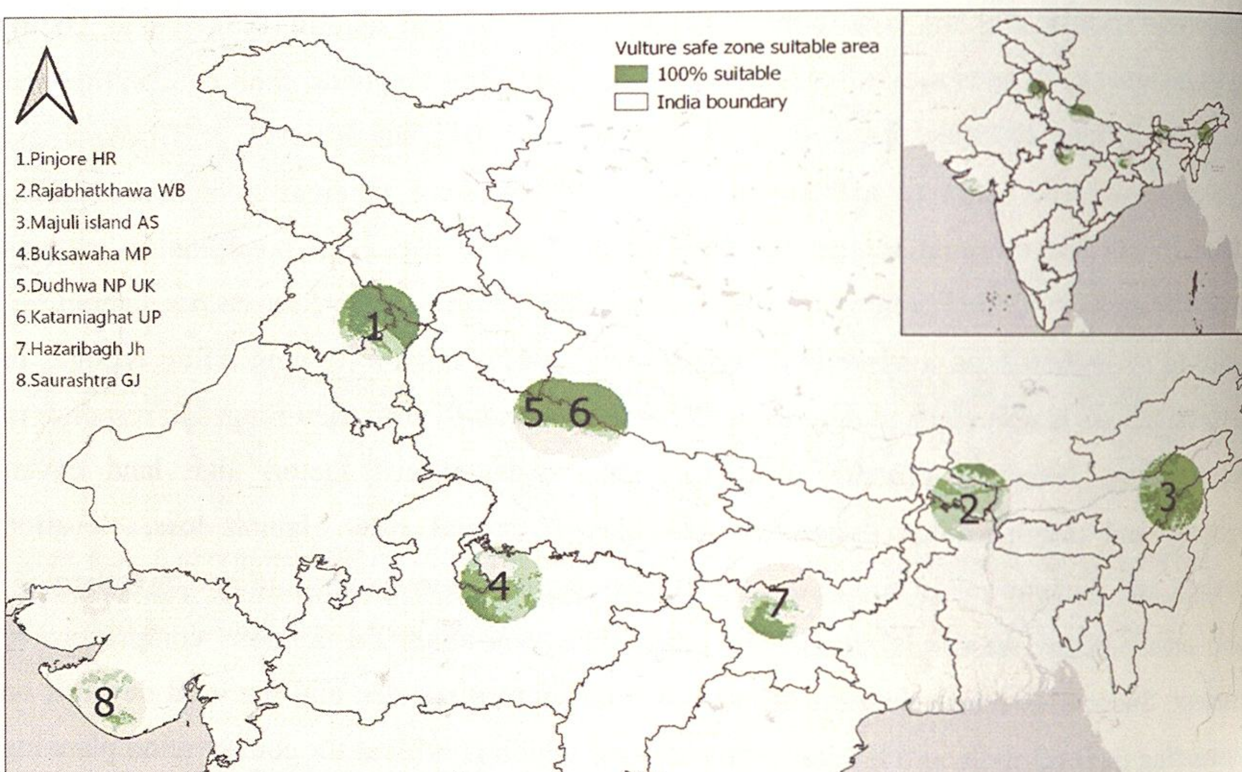


Figure 6.4..Potential Vulture Safe Zones based on the climatic niche of the year 2060-2080 from SSP 246 and 585 scenarios.

Chapter 7: Vulture Safe Zones and Way Forward

7.1. Vulture Safe Zone

Vultures are susceptible to toxic non-steroidal anti-inflammatory drugs (NSAIDs), including Diclofenac, Aceclofenac, Ketoprofen, and Nimesulide, which cause kidney failure. They are usually exposed to it when they feed on dead livestock treated with this drug. At least 12 different NSAIDs are known to be used in India for veterinary purposes, including Diclofenac (Cuthbert *et al.* 2011). Currently, the safest alternative is Meloxicam along with Tolfenamic acid. In 2006, Diclofenac was banned for veterinary use throughout India under Section 26A of the Drugs and Cosmetics Act, Aceclofenac & Ketoprofen in 2023, and Nimesulide in 2024.Refer the table in text.

Table 7.1.: NSAID list with details (10th SAVE Report)

Meloxicam	SAFE	Tested and shown vulture safe. (Swarup *et al* 2007)
Tolfenamic acid	SAFE	Tested and shown vulture safe. (Chandramohan *et al* 2022).
Carprofen	TOXIC	Shown toxic at high levels (Fourie *et al.* 2015,Naidoo *et al* 2018)
Flunixin	TOXIC	Shown toxic to wild Gyps vultures in Spain and Italy. No full experimental tests.
Nimesulide	TOXIC	Popular drug in India. The experimental test showed toxic (Galligan *et al* 2021, Nambirajan *et al* 2021).
Aceclofenac	TOXIC	Shown equivalent toxic as Diclofenac (Galligan *et al* 2016, Sharma 2012). Banned from India 2023
Ketoprofen	TOXIC	Toxicity confirmed by experiment (Naidoo *et al* 2009). Banned in India 2023.
Diclofenac	TOXIC	Highly toxic confirmed by experiments. (Oaks *et al* 2004). Banned in India 2006.

The concept of a "**Vulture Safe Zone (VSZ)**" was proposed by partners of SAVE (Saving Asia's Vultures from Extinction, a consortium of like-minded government and non-government organisations actively conserving vultures across South Asia). A **Vulture Safe Zone (VSZ)** is an area specifically designated and managed to protect and support vulture breeding populations and their habitats, and where there is a very low risk of poisoning due to the toxic NSAIDs used to treat cattle. The world's first government-nominated VSZ has been established in Nepal in association with Bird Conservation Nepal and VSZ.

7.2. VSZ criteria (SAVE)

The criteria to establish a VSZ should include:

i) The area should surround one or more surviving wild vulture nesting colonies of at least one of India's four Critically Endangered *Gyps* Vultures (Mukherjee *et al,* 2014).

ii) Based on White-rumped Vulture range, the area should be in a radius of at least 100 Km from the breeding colony.

iii) Vulture population within the area should be stable or increasing.

iv) There should be continuous annual monitoring of vulture population.

v) The area will have no usage of veterinary Diclofenac surrounding the breeding colony (100 km radius) and ensure use of vulture-safe drug Meloxicam.

vi) The area may comprise some management units in the form of territorial forest divisions, protected areas and in some cases, vulture habitats under the ownership of other governmental agencies, autonomous councils, companies, communities or private individuals.

vii) The area should ensure continuous food supply and incorporate designated areas for open carcass disposal as a "Jatayu Restaurant/Vulture Restaurant".

viii) Extensive education and awareness programmes on the value of vultures for the local community regarding their ability to clean up carcasses and, therefore, help reduce the risk of disease due to the increasing numbers of feral dogs.

ix) Workshops with vets, pharmacists and farmers about the importance and use of Vulture safe drug Meloxicam.

x) Working with State Government should be of fundamental importance for a VSZ, with regular meetings with Forest department, food and drugs administration, Animal husbandry, District administration, Education department and public relations department. The meetings will ensure good livestock veterinary practices

xi) Other indicators, such as the amount of veterinary Diclofenac still being used, should be measured regularly by carcass sampling to determine the progress towards the conservation objective.

These VSZ criteria are mostly related to toxic NSAIDs and resource use. Other significant threats, such as electrocution, forest fire, and poisoning, are not discussed here.

7.3. Threats to Vultures in Kangra District

Apart from the threat posed by toxic NSAIDs, vultures in the Kangra district face several other conservation challenges which include electrocution, reduction in open carcass disposal sites, accidental poisoning from baited carcasses, collisions with structures, forest fires, and by resin-tapping activities.

7.3.1. Toxic NSAIDs

Between 2021 and 2023, a covert pharmacy survey was conducted across all panchayat divisions within the study area, comprising 123 visits. In 80 cases, veterinary drugs were either purchased or identified, while in 43 cases, pharmacists declined to sell drugs or were advised to visit government veterinary centres. Among the NSAIDs obtained, Meloxicam—primarily in bolus form and often combined with Paracetamol—accounted for 99% of purchases. Nimesulide and Aceclofenac were encountered only twice. The survey preceded the formal ban on Aceclofenac and Nimesulide.

7.3.2. Power infrastructure:

Vultures are dying as a result of electrocution on pylons and collisions confirmed by opportunistic records. Nevertheless, the severity of the threat to vultures and their recovery is currently far lower than that of toxic NSAIDs. From December 2021 to March 2024, we recorded the deaths of twelve HGV (*Gyps himalayensis*), five EV (*Neophron percnopterus*) and two WRV (*Gyps bengalensis*) along a few of the lower voltage powerline infrastructures at feeding stations Kangra. Reducing the risk of electrocution in different areas of Kangra is of utmost importance. Especially the Meira Khad area and Jassur Khad, as more than 300 White-rumped Vultures and more than 200 Himalayan Griffon Vultures are reported in this area. The location of the poles are close to the feeding stations amplify electrocution risk. The poles need to be relocated or insulated to reduce electrocution risk. APLIC (2006) suggested 152 cm of horizontal and 102 cm of vertical parting between different phases and between phases and grounded equipment. However, the recommended categories may not work for vultures as they are more prominent, with large wingspans (2.56 m-3.1m). Even minor faults can impact large electrocution to vultures (Dwyer and Mannan 2007).

Fig 7.1.: Electrocution of a Himalayan Griffon near a 55 kV Powerline in the study area

7.3.3. Vulture feeding stations:

Historically, vulture populations in India were sustained by the vast availability of domestic cattle carcasses. Traditional carcass disposal practices, rooted in Hindu beliefs, prohibit the consumption of dead cattle. Hence, the carcasses left for natural scavengers, a process often managed by Dalit communities. These communities historically earned income by collecting carcasses, selling the hides and, after vultures had fed, gathering the remaining bones for medicinal purposes. The rise of synthetic alternatives and restrictions on animal-derived products has led to a sharp decline in the hide and bone trade.

Our field study in Kangra identified 36 active vulture feeding stations managed by Dalits. Interviews with residents revealed that the number of such sites has decreased by approximately 85% since 1991, highlighting the need to preserve and manage remaining 36 traditional feeding grounds.

7.3.4. Poison baits:

Although there is no direct evidence of vultures being deliberately targeted for poisoning in India, several incidents are reported each year where vultures die after feeding on baited carcasses. Such cases have previously been documented in Assam and, more recently, in Himachal Pradesh. The purpose of these poison baits is to eliminate feral dogs or carnivores that prey on livestock. However, these baits inadvertently kill non-target scavengers, including vultures. Outside South Asia, poisoning remains the leading cause of vulture mortality (Botha et al., 2017).

In a recent incident in Himachal Pradesh on 11th May 2025, nine vultures died following a suspected mass poisoning event. Among the casualties were two Himalayan Griffon Vultures and seven Critically Endangered White-rumped Vultures. The situation was alarming given the uncertainty around the cause and scale of the poisoning. However, 22 vultures were successfully rehabilitated and released back into the wild. This involved inducing regurgitation by gently pressing the abdomen to expel ingested toxins and administering 0.5 ml of Atropine as an antidote. The treated vultures showed rapid improvement, and additional support was provided through saline administration. Some individuals required a second dose of Atropine as well.

Figure 7.2.: WRV and HGV poisoning in Study area and administration of Atropine to the affected vulture

Figure 7.3.: Release of treated WRV in Wild

7.3.5. Forest fire and resin tapping:

In Himachal Pradesh, the peak forest fire season typically commences in mid-February, extending over approximately nine weeks. The following sites in Kangra district are mostly affected by forest fire, and a loss of 77% of nesting trees occurred. Forest fire activities are also elevated by resin tapping of Chir pine trees in the area, which is mostly done to collect resin and serve as a forest resource.

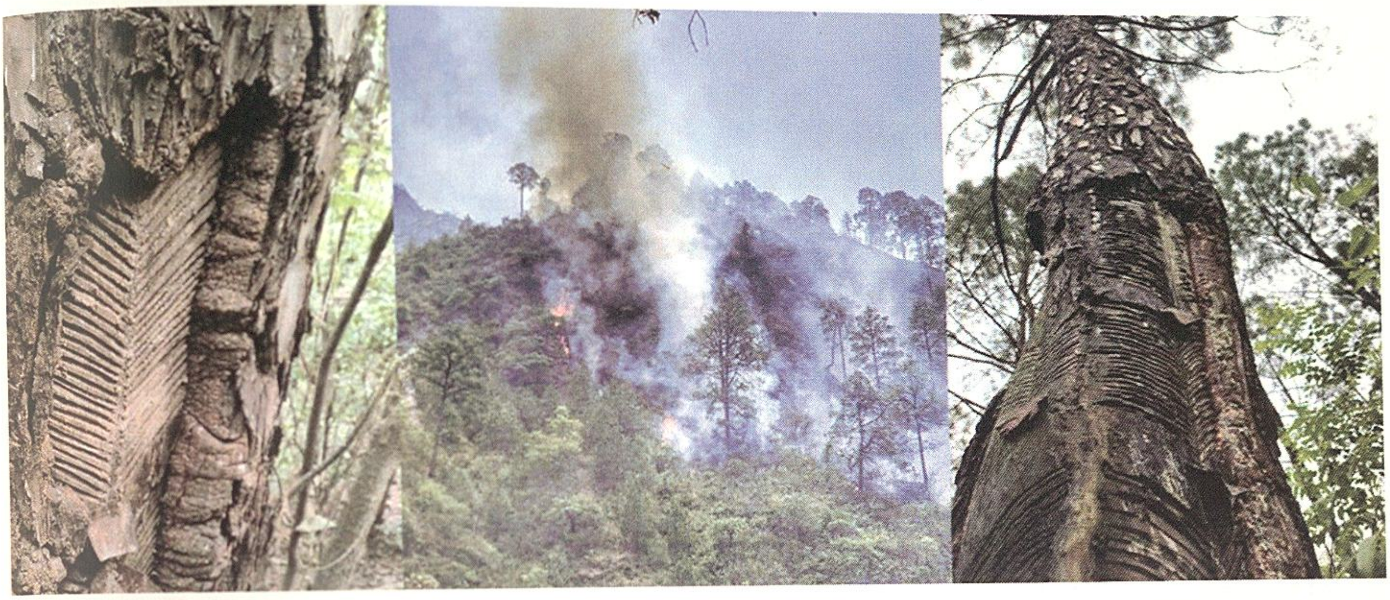


Figure 7.4: Forest fire and resin tapping in Kangra

7.4. Potential for Kangra district to be declared as a Vulture Safe Zone

7.4.1. Strengths

i) We located 617 White-rumped Vulture (*Gyps bengalensis*) nests spread across 17 nesting colonies in Kangra. This is the highest reported nesting aggregation in India to date for this species.

ii) The undercover pharmacy research reveals that the area is free from any toxic NSAIDs, and only vulture-safe Meloxicam is being used in the area.

iii) The area has a continuous food supply in terms of three vulture restaurants created by HPFD, along with 36 locally available carcass dumping sites.

iv) Climatic niche modelling using MaxEnt indicated that Kangra and adjoining districts present highly suitable habitats for vultures under current and future climate projections.

7.4.2. Actionable points to mitigate the threats to vulture:

Immediate actions include strong enforcement of banned NSAIDs, establishing community-veterinary awareness programs, and implementing forest protection guidelines to conserve nest trees.

1. **Toxic NSAIDs**

- Conduct **region-specific awareness drives** for veterinarians, paravets, and livestock owners about the lethal impact of toxic NSAIDs (e.g., Diclofenac, Aceclofenac, Ketoprofen) on vultures.
- **Promote the use of vulture-safe alternatives** such as Meloxicam and Tolfenamic Acid.
- Organize workshops and sensitization sessions for veterinary professionals to encourage responsible prescription practices.
- **Strengthen enforcement of the ban on toxic NSAIDs** through regular inspections of veterinary clinics and pharmacies.
- **Establish monitoring systems** to track the availability and sale of toxic vs. safe NSAIDs at local pharmacies.
- **Involve Panchayats, forest departments**, and local NGOs in monitoring veterinary drug use in vulture zones.
- **Develop and distribute posters**, pocket guides, and leaflets in local languages to raise public awareness about vulture conservation.

2. **Powerline infrastructure**

   - **Relocate carcass dumping sites close to distribution of powerlines or transformers:** Relocate carcass dumping sites from areas near dangerous transmission or distribution lines, especially near the Jawali area.
   - **Install Diverters**: Use bird flight diverters like Firefly to make power lines more visible to vultures.

- **Insulate Power Lines**: Install insulation on high-risk sections of power lines to prevent electrocution.
- **Underground cables** of < 40 kV powerlines wherever feasible, especially in the breeding area
- **Reconfiguration:** Changing jumper wires that pass under the cross-arm rather than over it and switch from upright pin insulators to suspended chain insulators.

3. **Vulture feeding stations**

- **Equip** established carcass dumping sites with clear signage and markers, indicating them as official feeding stations.
- **Relocation and Establishment of New Sites:** Identify and designate suitable areas within forest lands for relocating existing sites and creating new carcass dumping areas. These locations should be away from human habitation to minimize conflict and ensure safety for vultures.
- **Provide Revenue to Butchers and Carcass Dumpers:** Implement a scheme to pay butchers and carcass dumpers a monthly allowance.
- **Panchayat and Local Awareness Campaigns:** Conduct awareness campaigns with local panchayats to educate butchers and community members about the importance of carcass dumping sites for vulture conservation.

4. **Poisoning**

Community sensitization: Local communities, especially those involved in traditional carcass disposal practices, play a key role in supporting vulture conservation. Raising awareness about the ecological role of vultures as efficient scavengers that help prevent the spread of disease is essential to garner local support. Through education, outreach, and participatory conservation approaches, communities can be empowered to report threats and adopt vulture-friendly practices.

5. **Forest fire and resin tapping**

- **Controlled Burns and Firebreaks**: Conduct controlled burns to reduce flammable vegetation, maintain clear firebreaks around nesting sites, and establish fire watchtowers.
- **Early Detection and Monitoring**: Using satellite-based remote sensing and drones for early fire detection.
- **Establish rapid response** firefighting teams.
- **Community Awareness and Training**: Train locals and forest guards in emergency response.
- **Plant fire-resistant vegetation** around nesting sites. Plants such as *Bombax* sp, and *Ficus* sp. are important for vulture nesting sites.
- **Legislation and Enforcement**: Enforce regulations against activities causing fires.
- Transfer jurisdiction of areas with vulture breeding or feeding sites from territorial forest divisions to wildlife divisions, wherever applicable.

7.5. Scope for future research

Future research on White-rumped Vultures in Himachal Pradesh should focus on long-term monitoring of nesting colonies. Expanding movement studies with advanced GPS telemetry (activity sensors). Additionally, research on food availability, including carcass composition and contamination risks, can help assess the sustainability of existing carcass disposal sites. Socio-ecological studies exploring local community perceptions and engagement of multiple local stakeholders in vulture conservation can further enhance conservation efforts.

The study region represents one of the last breeding refuges of the White-rumped Vulture in the western Himalayas and must be prioritized for long-term conservation support.

Bibliography

Ahmad, S, Rehman. E.U., Kabir, M, and Bari, F. (2020). Population Status and Nesting Activity of White-Rumped Vulture *Gyps bengalensis* in Kotli District, Azad Jammu and Kashmir, Pakistan," *Ornithological Science* 19(1), 55-61

Alarcón, P. A., & Lambertucci, S. A. (2018). A three-decade review of telemetry studies on vultures and condors. *Movement Ecology*, *6*(1), 13.

Anderson, D. J., & Hodum, P. J. (1993). Predator behavior favors clumped nesting in an oceanic seabird. *Ecology*, *74*(8), 2462-2464.

Anderson, M. D., & Mundy, P. J. (2001). The demise of vultures in southern Asia: mortality factors and a risk to African vultures? news & views. South African journal of science, 97(9), 342-344.

Anon. (2003). Vulture death mystery explained. *The Babbler: BirdLife in Indochina* 2(2): 7.

Anon. (2008). Local increase in vultures thanks to diclofenac campaign in Nepal. *Buceros* 13(2): 5.

Anoop, N. R., Babu, S., Nagarajan, R., & Sen, S. (2020). Identifying suitable reintroduction sites for the White-rumped Vulture (Gyps bengalensis) in India's Western Ghats using niche models and habitat requirements. *Ecological Engineering*, *158*, 106034.

Arkumarev, V., Dobrev, D. and Stamenov, A. (2019). First record of Eurasian Griffon Vulture Gyps fulvus from the Balkans migrating to South Sudan revealed by GPS tracking. *Scopus: Journal of East African Ornithology*, *39*(2), pp.27-35.

Austin, G. E., Thomas, C. J., Houston, D. C., & Thompson, D. B. (1996). Predicting the spatial distribution of buzzard Buteo buteo nesting areas using a Geographical Information System and remote sensing. *Journal of Applied Ecology*, 1541-1550.

Avian Power Line Interaction Committee .(APLIC). Suggested practices for avian protection on power lines: the state of the art in 2006.(2006). Washington, DC and Sacramento, CA U.S.A Edison Electric Institute, APLIC and the California Energy Commission.

Bajpai, H., & Samson, A. (2020). White-rumped Vulture nestling predation by stray dog in Madhya Pradesh, India. *ZOO'S PRINT*, *35*(10), 41-43.

Baral, N., Gautam, R., Timilsina, N., & Bhat, M. G. (2007). Conservation implications of contingent valuation of critically endangered White-rumped Vulture *Gyps bengalensis* in South Asia. *The International Journal of Biodiversity Science and Management*, *3*(3), 145-156.

Baral, Nabin, Ramji Gautam, and Bijay Tamang. (2005). Population Status and Breeding Ecology of White-Rumped Vulture Gyps Bengalensis in Rampur Valley , Nepal. Forktail 21(January): 87–91.

Barta, Z., & Szép, T. (1995). Frequency-dependent selection on information-transfer strategies at breeding colonies: a simulation study. *Behavioral Ecology*, *6*(3), 308-310.

Bates, D., Kliegl, R., Vasishth, S., & Baayen, H. (2015). Parsimonious mixed models. *arXiv preprint arXiv:1506.04967*.

Bhusal, K. P., Chapagain, D., Joshi, A. B., Chaudhary, I. P., & Chaudhary, K. (2018). First Release of Captive White-Rumped Vulture (Gyps Bengalensis) into the Wild in Nepal. *Vulture Bull*, *8*, 3-8.

Bhusal, K. P., Chaudhary, I. P., Dangaura, H. L., Joshi, A. B., Rana, D. B., & Ghimire, S. (2020). Habitat mapping of White-rumped Vulture *Gyps bengalensis*. *Terai arc .landscape of Nepal. Minivet*, *3*, 10-6.

Bhusal, K. P., Joshi, A. B., Rana, D. B., Thakuri, D. C., & McClure, C. J. (2023). Population and productivity of the critically endangered White-rumped Vulture (*Gyps bengalensis*) in the Argha important bird and biodiversity area, Nepal. *Journal of Raptor Research*, *57*(3), 352-358.

BirdLife International (2025) IUCN Red List for birds. Downloaded from https://datazone.birdlife.org on 13/06/2025

Boerger, L., Dalziel, B.D., Fryxell, J.M.(2008). Are there general mechanisms of animal home range behaviour? A review and prospects for future research. Ecology Letters 11, 637-650.

Bolker, B. M., Brooks, M. E., Clark, C. J., Geange, S. W., Poulsen, J. R., Stevens, M. H. H., & White, J. S. S. (2009). Generalized linear mixed models: a practical guide for ecology and evolution. *Trends in ecology & evolution*, *24*(3), 127-135.

Bonetti, M. F., and Wiens. J.J. (2014). Evolution of climatic niche specialization: a phylogenetic analysis in amphibians. Proceedings. Biological sciences, 281(1795), 20133229. DOI: 10.1098/rspb.2013.3229.

Borger, L., Franconi, N., De Michele, G., Gantz, A., Meschi, F., Manica, A., Lovari, S., Coulson, T. (2006). Effects of sampling regime on the mean and variance of home range size estimates. Journal of Animal Ecology 75, 1393-1405.

Botha A.J., Andevski J., Bowden C.G.R., Gudka M., Safford R.J., Tavares J. (2017). Multi-species Action Plan to Conserve African-Eurasian Vultures. CMS Raptors MOU Technical Publication No. 5. CMS Technical Series No. 35. Abu Dhabi, United Arab Emirates: Coordinating Unit of the CMS Raptors MOU.

Bowden, C. (2009). The Asian Gyps vulture crisis: the role of captive breeding in India to prevent total extinction. *Birding ASIA*, *12*(2009), 121-123.

Bowden, C., & Botha, A. (2020). Vulture updates No 12-March 2020-Around the World of Vultures & VSG activities. *Vulture News*, *78*.

Bowden, C.G., Prakash, V., Ranade, S., Routh, A., Jakati, R.D., Cuthbert, R.J., Rahmani, A.R., Green, R.E., Prakash, N. and Parry-Jones, J. (2012). Conservation breeding for the future release of the Critically Endangered Asian Gyps vultures–progress of the programme in South Asia and why it is so important. *Journal of the Bombay Natural History Society*, *109*(1), pp.43-45.

Bridgeford, P. and Bridgeford.M. (2003). Ten years of monitoring breeding Lappet-faced Vultures Torgos tracheliotos in the Namib-Naukluft Park, Namibia. VultureNews, 48(3).

Brown CR, Brown MB. (1998). Intense natural selection on body size and wing and tail asymmetry in cliff swallows during severe weather. Evolution 52:1461–1475

Brown, P. M., Bhattacharyya, A., & Shah, S. K. (2011). Potential for developing fire histories in Chir Pine (*Pinus roxburghii*) Forests in the Himalayan Foothills. *Tree-ring research*, *67*(1), 57-62.

Brown,J. L., Joseph, R.B. and Connor. M.F. (2017). SDMtoolbox 2.0: the next generation Python-based GIS toolkit for landscape genetic, biogeographic and species distribution model analyses. PeerJ 5: e4095. DOI:/10.7717/peerj.4095

Buechley, E.R., McGrady, M.J., Çoban, E. and Şekercioğlu, Ç.H. (2018). Satellite tracking a wide-ranging endangered vulture species to target conservation actions in the Middle East and East Africa. *Biodiversity and Conservation*, *27*, pp.2293-2310.

Chakdar, B., Singha, H., & Choudhury, M. R. (2019). Bird community of Rajiv Gandhi Orang National Park, Assam. *Journal of Asia-Pacific Biodiversity*, *12*(4), 498-507.

Champion, H. G., & Seth, S. K. (1968). *A revised survey of the forest types of India*. Manager of publications.

Chandramohan, S., Mallord, J. W., Mathesh, K., Sharma, A. K., Mahendran, K., Kesavan, M. and Prakash, V. M. (2022). Experimental safety testing shows that the NSAID tolfenamic acid is not toxic to Gyps vultures in India at concentrations likely to be encountered in cattle carcasses. *Science of the Total Environment*, *809*, 152088.

Chandramohan, S., Mathesh, K., Mallord, J. W., Naidoo, V., Mahendran, K., Kesavan, M., and Prakash, V. M. (2022). Metabolism of aceclofenac to diclofenac in the domestic water buffalo Bubalus bubalis confirms it as a threat to Critically Endangered Gyps vultures in South Asia. *Environmental toxicology and pharmacology*, *96*, 103984.

Charak, Sukh Dev Singh (1978). *Indian Conquest of the Himalayan Territories* (1978 ed.). Ajaya Prakashan. p. 19.

Chhangani, A.K. (2009). Present Status of Vultures in the Great Indian Thar Desert. In: Sivaperuman, C., Baqri, Q.H., Ramaswamy, G., Naseema, M. (eds) Faunal Ecology and Conservation of the Great Indian Desert. Springer, Berlin, Heidelberg. HYPERLINK "https://doi.org/10.1007/978-3-540-87409-6_7"https://doi.org/10.1007/978-3-540-87409-6_7

Clements, T., Gilbert, M., Rainey, H.J., Cuthbert, R., Eames, J.C., Bunnat, P., Teak, S., Chansocheat, S. and Setha, T. (2013). Vultures in Cambodia: population, threats and conservation. *Bird Conservation International*, *23*(1), pp.7-24.

Cobos, M. E., Peterson.A.T, Barve.N and Osorio-Olvera.L. (2019). kuenm: an R package for detailed development of ecological niche models using Maxent. PeerJ, 7, e6281.DOI:10.7717/peerj.6281

Cody, M. L. (Ed.). (1985). *Habitat selection in birds*. Academic press. coloniality. *Current ornithology*, *7*, 285-330.

Cook, S. E., Green, R. E., Lieberherr, E., Bowden, C. G., Chaudhry, M. J. I., Alam, A. S., ... & Thapa, I. (2024). Current policies in Europe and South Asia do not prevent veterinary use of drugs toxic to vultures. *Ecological Solutions and Evidence*, *5*(2), e12357.

Cooke, S.J.(2008). Biotelemetry and biologging in endangered species research and animal conservation: relevance to regional, national, and IUCN Red List threat assessments. Endangered Species Research 4, 165-185.

Cortés-Avizanda, A., Jovani, R., Donázar, J. A., & Grimm, V. (2014). Bird sky networks: how do avian scavengers use social information to find carrion?. *Ecology*, *95*(7), 1799-1808.

Cunningham, A. A., Prakash, V., Pain, D., Ghalsasi, G. R., Wells, G. A. H., Kolte, G. N., ... & Rahmani, A. (2003). Indian vultures: victims of an infectious disease epidemic?. *Animal Conservation*, *6*(3), 189-197.

Cuthbert, R. J., Prakash, V., Saini, M., Upreti, S., Swarup, D., Das, A., and Taggart, M. (2011). Are conservation actions reducing the threat to India's vulture populations?. *Current Science*, 1480-1484.

Davies.M(2025). India Issues Gazette Notification of Veterinary Nimesulide Ban SAVE website. https://save-vultures.org/2025/01/india-issues-gazette-notification-of-veterinary-nimesulide-ban/

Dhadwal, A., & Kumar, A. (2022). Planning Strategies to Improve Deteriorating Living Environment of Hill Towns: A Case of Dharamshala. In Environmental Concerns and Remediation: Proceedings of F-EIR Conference 2021 (pp. 211-220). Cham: Springer International Publishing.

Donazar, J. A., F. Hiraldo, and J. Bustamante. (1993). Factors Influencing Nest Site Selection, Breeding Density and Breeding Success in the Bearded Vulture (Gypaetus Barbatus). The Journal of Applied Ecology 30(3): 504.

Donázar.J.A, Palacios.C.J, Gangoso.L, Ceballos.O, González.M.J, Hiraldo.F (2002). Conservation status and limiting factors in the endangered population of Egyptian vulture (*Neophron percnopterus*) in the Canary Islands, Biological Conservation, 107(1),89-97. ISSN 0006-3207,https://doi.org/10.1016/S0006-3207(02)00049-6.

Downs, J.A., Horner, M.W. (2008). Effects of Point Pattern Shape on Home-Range Estimates. Journal of Wildlife Management 72, 1813-1818.

Dutta, S. K., Khan, M., Nagi, P. R. S., Durgam, S., & Dutta, S. (2021). Recovery of vulture population in roosting and scavenging areas of Bastar and Bijapur, Chhattisgarh, India. *Journal of Threatened Taxa*, *13*(13), 19956-19963.

Dwyer, J. F., & Mannan, R. W. (2007). Preventing raptor electrocutions in an urban environment. *Journal of Raptor Research*, *41*(4), 259-267.

Eames, J. C. (2007). *The Babbler: BirdLife in Indochina. Cambodian national vulture census 2007: 33-34.*

Eames, J. C. (2007). Mega transect counts vultures across Myanmar. *The Babbler: BirdLife in Indochina*: 30.

eBird. (2020). eBird Basic Dataset. Version: Ebird Release [May,2020]. EBird, Cornell

eBird: An online database of bird distribution and abundance [web application]. eBird, Cornell Lab of Ornithology, Ithaca, New York. Available: http://www.ebird.org.

Efrat, R. and Hatzofe, O. (2021). First evidence of a migration route from Eurasia to East Africa of the Cinereous Vulture (Aegypius monachus). *Journal of Raptor Research*, *55*(3), pp.451-454.

Elith, J. and Leathwick.J.R. (2009). Species distribution models: Ecological explanation and prediction across space and time. Annu. Rev. Ecol. Evol. Syst., 40 (1), 677. DOI:10.1146/annurev.ecolsys.110308.120159

Fandos, G., Rotics.S, Sapir.N,Fiedler.W,Kaatz.M, Wikelski.M, and Zurell.D. (2020). Seasonal niche tracking of climate emerges at the population level in a migratory bird. Proceedings of the Royal Society B, 287(1935), 20201799.DOI:10.1098/rspb.2020.1799

Fargallo.J, Blanco.G and Eduardo.S. (1998). Forest management effects on nesting habitat selected by Eurasian black vultures (*Aegypius monachus*) in central Spain. J. Raptor Res.. 32.

Fernández-Bellon, D., Cortés-Avizanda, A., Arenas, R., & Donázar, J. A. (2016). Density-dependent productivity in a colonial vulture at two spatial scales. *Ecology*, *97*(2), 406-416.

Ferrer, M. and Harte, M. (1997). Habitat selection by immature imperial eagle during the dispersal period. Journal of Applied Ecology, 34, 1359–1364.

Fick, S. E., and Hijmans.R.J. (2017). WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. International journal of climatology, 37(12), 4302-4315. DOI:10.1002/joc.5086

Flessner, B and Mary, H and Jerry, G (2017). Species Distribution Modeling of American Beech (Fagus Grandifolia) Distribution in Southwest Ohio. International Journal of Applied Geospatial Research, 8, 16-36. DOI: 10.4018/ijagr.2017070102.

Fourie, T., Cromarty, D., Duncan, N., Wolter, K., & Naidoo, V. (2015). The safety and pharmacokinetics of carprofen, flunixin and phenylbutazone in the Cape Vulture (Gyps coprotheres) following oral exposure. *PLoS One*, *10*(10), e0141419.

Gadhvi, I. R., & Dodia, P. P. (2006). Indian white-backed vultures *Gyps bengalensis* nesting in Mahuva, Bhavnagar district, Gujarat, India. *Indian Birds*, *2*(2), 36.

Galligan, T. H., Taggart, M. A., Cuthbert, R. J., Svobodova, D., Chipangura, J., Alderson, D., ... & Naidoo, V. (2016). Metabolism of aceclofenac in cattle to vulture-killing diclofenac. *Conservation Biology*, *30*(5), 1122-1127.

Galligan, T.H., Bhusal, K.P., Paudel, K., Chapagain, D., Joshi, A.B., Chaudhary, I.P., Chaudhary, A., Baral, H.S., Cuthbert, R.J. and Green, R.E. (2020). Partial recovery of Critically Endangered Gyps vulture populations in Nepal. *Bird Conservation International*, *30*(1), pp.87-102.

Galligan, T.H., Mallord, J.W., Prakash, V.M., Bhusal, K.P., Alam, A.S., Anthony, F.M., Dave, R., Dube, A., Shastri, K., Kumar, Y. and Prakash, N. (2021). Trends in the availability of the vulture-toxic drug, diclofenac, and other NSAIDs in South Asia, as revealed by covert pharmacy surveys. *Bird Conservation International*, *31*(3), pp.337-353.

Galushin, V. M. (1971). A huge urban population of birds of prey in Delhi India. Ibis, 113(4), 522-522.

Gautam, R., Baral, N., & Sharma, H. P. (2024). Preference of trees for nest building by critically endangered white-rumped vultures (*Gyps bengalensis*) in Nepal. *Ecology and Evolution*, *14*(3), e11175.

Ghimire, B., Acharya, R., Sivakumar, K., Biswas, S., & Dorji, C. (2019). Nesting characteristics and habitat preferences of critically endangered White-Rumped Vulture *Gyps bengalensis* in Rampur IBA, Palpa. *Vulture Bul*, *8*, 20-24.

Ghosh-Harihar, M., Yadav, N., Gurung, N., Darshan, C. S., Shashikumar, B., Vishnudas, C. K., Vibhu Prakash, Rhys E. Green & Ramakrishnan, U. (2024). Spatial patterns in the diet of Gyps vultures in India and their implications for conservation. *Biological Conservation*, *292*, 110551.

Gil, J. Antonio, Báguena. G , Sánchez-Castilla. E, Antor. R.J, Alcántara.M, and López-López.P. (2014). Home ranges and movements of non-breeding bearded vultures tracked by satellite telemetry in the Pyrenees. *Ardeola* 61(2):379-387. DOI:10.13157/arla.61.2.2014.379

Gilbert, M (2004). The Status and Decline of Vultures in the Provinces of Punjab and Sind, Pakistan: A 2003 Update." Raptors Worldwide: Proceedings of the 6th World Conference on Birds of Prey and Owls (Lumeij 1994): 221–34.

Gill, Frank; Donsker, David; Rasmussen, Pamela, eds. (2022). Hoatzin, New World vultures, Secretarybird, raptors. IOC World Bird List Version 12.2. International Ornithologists' Union. Retrieved 2 December 2022.

Gmelin, Johann Friedrich (1788). Systema naturae per regna tria naturae : secundum classes, ordines, genera, species, cum characteribus, differentiis, synonymis, locis (in Latin). Vol. 1.

Gómez, Camila, Tenorio. E.A., Montoa.P and Cadena.C.D. (2016). Niche-tracking migrants and niche-switching residents: evolution of climatic niches in New World warblers (Parulidae). Proceedings of the Royal Society B: Biological Sciences 283.1824 (2016): 20152458.DOI:10.1098/rspb.2015.2458

Green, R. E., Newton, I. A. N., Shultz, S., Cunningham, A. A., Gilbert, M., Pain, D. J., & Prakash, V. (2004). Diclofenac poisoning as a cause of vulture population declines across the Indian subcontinent. *Journal of Applied ecology*, *41*(5), 793-800.

Grubh.B.R.(1974). The birds of Gir Forest: The ecology and behaviour of vultures in Gir Forest, PhD thesis BNHS.

Guilford, T., Akesson, S., Gagliardo, A., Holland, R.A., Mouritsen, H., Muheim, R., Wiltschko, R., Wiltschko, W., Bingman, V.P. (2011). Migratory navigation in birds: new opportunities in an era of fastdeveloping tracking technology. Journal of Experimental Biology 214, 3705-3712.

Guisan, A., and Thuiller.W (2005). Predicting species distribution: Offering more than simple habitat models. Ecology Letters, 8(9), 993–1009. DOI:10.1111/j.1461-0248.2005.00792.x.

HamadAmin, B. A. and Khwarahm.N.R. (2023). Mapping impacts of climate change on the distributions of two endemic tree species under socioeconomic pathway scenarios (SSP). Sustainability, 15(6), 5469.DOI:10.3390/su15065469

Hance, I. (2009). Seven White-rumped Vultures found dead in Cambodia. *The Babbler: BirdLife in Indochina*: 14.

Harel, R., Spiegel, O., Getz, W. M., & Nathan, R. (2017). Social foraging and individual consistency in following behaviour: testing the information centre hypothesis in free-ranging vultures. *Proceedings of the Royal Society B: Biological Sciences*, *284*(1852), 20162654.

Harris S, Cresswell WJ, Forde PG, Trewhella WJ, Woollard T, et al. (1990) Home-range analysis using radio-tracking data - a review of problems and techniques particularly as applied to the study of mammals. Mammal Review 20: 97–123.

Harris, R.J.(2013). The conservation of Accipitridae vultures of Nepal: a review. *Journal of Threatened Taxa*, *5*(2), pp.3603-3619.

Hebblewhite, M., Haydon, D.T. (2010). Distinguishing technology from biology: a critical review of the use of GPS telemetry data in ecology. Philosophical Transactions of the Royal Society B-Biological Sciences 365, 2303-2312

Hemson, G., Johnson, P., South, A., Kenward, R., Ripley, R., Macdonald, D. (2005). Are kernels the mustard? Data from global positioning system (GPS) collars suggests problems for kernel homerange analyses with least-squares cross-validation. Journal of Animal Ecology 74, 455-463.

Hensler, G. L., & Nichols, J. D. (1981). The Mayfield method of estimating nesting success: a model, estimators and simulation results. *The Wilson Bulletin*, 42-53.

Herremans, Marc, and Diane Herremans-Tonnoeyr. (2000). Land Use and the Conservation Status of Raptors in Botswana. Biological Conservation 94(1): 31–41.

Hille, S. M., Korner-Nievergelt, F. I., Bleeker, M., & Collar, N. J. (2016). Foraging behaviour at carcasses in an Asian vulture assemblage: Towards a good restaurant guide. *Bird Conservation International*, *26*(3), 263-272.

Himachal Pradesh Forest Department (2021).Vulture Survey Report-1-121pp

Hla, H.T. (2003). Preliminary investigation of White-rumped Vultures (*Gyps bengalensis*) in Southern Shan states Myanmar.

Hoffmann, Michael et al. (2010). The Impact of Conservation on the Status of the World's Vertebrates. Science 330(6010): 1503–9.

Hooker JD (1854) Notes of a naturalist in Bangal, the Sikkim and Nepal Himalayas, The Kasia Mountains. Himalayan J 2:406.

Houston, D. (1972). *The ecology of Serengeti vultures* (Doctoral dissertation, University of Oxford).

Houston, D. C. (1974). Mortality of the Cape vulture. *Ostrich*, *45*(2), 57-62.

Illán, J. G., Wang. G King. D.T. and Cunningham. F.L. (2022). Seasonal variation and tracking of the climate niche of a migratory bird. Global Ecology and Conservation, 37, e02155. DOI: 10.1016/j.gecco.2022.e02155

Ishwar, N. M., & Das, S. (2024). Economics of conserving endangered birds: the case for Gyps vultures in India. *Environment, Development and Sustainability*, 1-23.

Islam, M. A., Ahammed, R., & Aktar, M. (2018). Diurnal activity pattern of white-rumped vulture, Gyps bengalensis (Gmelin, 1788) in captivity during breeding season at Bangladesh National Zoo, Dhaka. *Jahangirnagar University Journal of Biological Sciences*, *7*(1), 81-85.

J.L., Gilbert, M., Virani, M.Z., Watson, R.T., Meteyer, C.U., Rideout, B.A., Shivaprasad, H.L., Ahmed, S., Chaudhry, M.J.I., Arshad, M., Mahmood, S., Ali, A. & Khan, A.A. (2004) Diclofenac residues as the cause of vulture population decline in Pakistan. Nature, 427, 630–633.

Jackson, A. L., Ruxton, G. D., & Houston, D. C. (2008). The effect of social facilitation on foraging success in vultures: a modelling study. *Biology Letters*, *4*(3), 311-313.

Jha, K. K., & Jha, R. (2021). Study of vulture habitat suitability and impact of climate change in Central India using MaxEnt. *Journal of Resources and Ecology*, *12*(1), 30-42.

Johnson, V. M., Harper, C. A., Applegate, R. D., Gerhold, R. W., & Buehler, D. A. (2022). Nest site selection and survival of wild turkeys in Tennessee. *Journal of the Southeastern Association of Fish and Wildlife Agencies*, *9*, 134-143.

Johnston, A., Matechou, E and Dennis, E.B. (2023). Outstanding challenges and future directions for biodiversity monitoring using citizen science data. Methods in Ecology and Evolution, 14(1), 103-116. DOI: 10.1111/2041-210X.13834

Kannan, G, Balasundaram, R and Samson, A.(2013). Study on population and distribution of vultures in selected sites of Sigur plateau, Nilgiri north forest division, Tamilnadu. 10.13140/RG.2.1.3986.5204.

Kapoor, S. (2023). Death of the sacred: Cow, caste and dalit politics in India. In *Routledge Handbook of Contemporary India* (pp. 401-411). Routledge.

Keith, D.A., Rodríguez, J.P., Brooks, T.M., Burgman, M.A., Barrow, E.G., Bland, L., Comer, P.J., Franklin, J., Link, J., McCarthy, M.A. and Miller, R.M. (2015). The IUCN red list of ecosystems: Motivations, challenges, and applications. Conservation Letters, 8(3), pp.214-226.

Kendall, C., Virani, M. Z., Kirui, P., Thomsett, S., & Githiru, M. (2012). Mechanisms of coexistence in vultures: understanding the patterns of vulture abundance at carcasses in Masai Mara National Reserve, Kenya. *The Condor*, *114*(3), 523-531.

Khan, U., & Murn, C. (2011). Gyps vulture restoration project-Role of captive breeding in endangered species management. *Journal of Animal and Plant Sciences*, *21*(2), 405-409.

Khan.H and Monirul.M. (2013). Population, Breeding and Threats to the White-Rumped Vulture Gyps Bengalensis in Bangladesh. Forktail 29(29): 52–56.

Kichloo, M. A., Kumar, S. and Sharma, N. (2020). Breeding site records of three sympatric vultures in a mountainous cliff in Kahara-Thathri, Jammu & Kashmir, India. *Journal of Threatened Taxa*, *12*(9), 16166-16169.

Kie, J.G., Matthiopoulos, J., Fieberg, J., Powell, R.A., Cagnacci, F., Mitchell, M.S., Gaillard, J.-M., Moorcroft, P.R.(2010). The home-range concept: are traditional estimators still relevant with modern telemetry technology? Philosophical Transactions of the Royal Society Biological Sciences 365, 2221-2231.

Krüger, O. (2002). Analysis of nest occupancy and nest reproduction in two sympatric raptors: common buzzard Buteo buteo and goshawk Accipiter gentilis. *Ecography*, *25*(5), 523-532.

Krüger, S. C., Simmons, R. E., & Amar, A. (2015). Anthropogenic activities influence the abandonment of Bearded Vulture (Gypaetus barbatus) territories in southern Africa. *The Condor*, *117*(1), 94-107.

Kumar,V.P, Kumar.S, Rajpoot.A, Kumar.A and Rasaily.S.S (2022). Threat assessment of vultures in Uttarakhand: A review note. International Journal of Science and Research Archive, 2022, 07(02), 036–040.

Kumar. A and Kushwaha .S. (2020). Ecology of White-rumped Vultures (Gyps bengalensis) in Northern and Central India. 21. 261-269.

Kushwaha, S., Kumar, A., & Singh, A. (2020). Conflict between two best acquaintances of man: vultures and dogs. *Journal of Wildlife Research*, *8*(02), 39-44.

Lab of Ornithology, Ithaca. Available: https://ebird.org/data/download

Lahkar, D., Prakash, V., Sahu, H. K., Raut, S. D., Datta, S. K., & Prakash, N. (2010). Feeding ecology of Gyps species of vultures in captivity. *Newsletter for Birdwatchers*, *50*(5), 65-69.

Laver, P.N., Kelly, M.J. (2008). A critical review of home range studies. Journal of Wildlife Management 72, 290-298.

Lees, A. C., Haskell, L., Allinson, T., Bezeng, S. B., Burfield, I. J., Renjifo, L. M. and Butchart, S. H. (2022). State of the world's birds. *Annual Review of Environment and Resources*, *47*(1), 231-260.

Li, Y, Sun., Yang, X, Yang. M, Kleisner. K.M, Mills. K. E, Tang, Y. (2024). Social–ecological vulnerability and risk of China's marine capture fisheries to climate change. Proceedings of the National Academy of Sciences 121, no. 1: e2313773120. DOI:10.1073/pnas.2313773120

Liberatori, F. and Penteriani, V. (2001). A long-term analysis of the declining population of the Egyptian vulture in the Italian peninsula: distribution, habitat preference, productivity and conservation implications. Biological Conservation, 101, 381–389.

Loiselle, B. A., Howell. C.A., Graham. C.H. Goerck, J.M. Brooks. T Smith, K.G. and Williams, P.H. (2003). Avoiding pitfalls of using species distribution models in conservation planning. Conservation biology, 17(6), 1591-1600.
DOI:10.1111/j.1523-1739.2003.00233.x

Loyn, R.H., McNabb, E.G., Volodina, L. and Willig, R. (2001). Modelling landscape distributions of large forest owls as lied to managing forests in north–east Victoria, Australia. Biological Conservation, 97, 361–376.

Mahajan, P., Khandal, D., Dhakad, M., & Rasal, V. (2024). A dog-eat-dog world: predation and resource acquisition by free-ranging dogs around Ranthambhore Tiger Reserve, Rajasthan, India. *Ethology Ecology & Evolution*, *36*(5), 572-582.

Mahapatro, G. K., & Arunkumar, K. (2014). The case for banning diclofenac and the vanishing vultures. *Biodiversity*, *15*(4), 265-268.

Majgaonkar, I, Bowden. C.G. R., and Quader.S.(2018). Nesting Success and Nest-Site Selection of White-Rumped Vultures (Gyps Bengalensis) In Western Maharashtra, India. Journal of Raptor Research 52(4): 431.

Mallord, J.W., Bhusal, K.P., Joshi, A.B., Karki, B., Chaudhary, I.P., Chapagain, D., Thakuri, D.C., Rana, D.B., Galligan, T.H., Requena, S., Bowden, C.G.R. and Green, R.E. (2024), Survival rates of wild and released White-rumped Vultures (*Gyps bengalensis*), and their implications for conservation of vultures in Nepal. Ibis. HYPERLINK "https://doi.org/10.1111/ibi.13303"https://doi.org/10.1111/ibi.13303

MaMing, R., & Xu, G. (2015). Status and threats to vultures in China. *Vulture News*, *68*(1), 3-24.

Mateo-tomás.,Patricia and Olea, P. P. (2011). The importance of social information in breeding site selection increases with population size in the Eurasian Griffon Vulture Gyps fulvus. *Ibis*, *153*(4), 832-845.

Mayfield, H. F. (1975). Suggestions for calculating nest success. *The Wilson Bulletin*, 456-466.

Mayfield, H. (1961). Nesting success calculated from exposure. *The Wilson Bulletin*, pp.255-261.

Mayr, Ernst; Cottrell, G. William, eds. (1979). Check-List of Birds of the World. Vol. 1 (2nd ed.). Cambridge, Massachusetts: Museum of Comparative Zoology. p. 305.

McGrady, M. and Gavashelishvili, A. (2006). Tracking vultures from the Caucasus into Iran. *Podoces*, *1*(1/2), pp.21-26.

Mingozzi, Toni, and Roger Estève. (1997). "Analysis of a Historical Extirpation of the Bearded Vulture *Gypaetus Barbatus* (L.) in the Western Alps (France-Italy): Former Distribution and Causes of Extirpation." Biological Conservation 79(2–3): 155–71.

Mishra H, Kumar V, Kumar A. Factors influencing nesting success of the river lapwing, *Vanellus duvaucelii* (Lesson, 1826). (2020). Avian Biology Research. 13(3):35-43. doi:10.1177/1758155920921072

MoEFCC (2020). Action Plan for Vulture Conservation in India, 2020–2025. New Delhi: Ministry of Environment, Forest and Climate Change, Government of India.

Mohr, C.O.(1947). Table of equivalent populations of North American small mammals. American Midland Naturalist 37, 223-249.

Moradiya.M and Goswami.A.P.(2021). To study nesting of white-backed vultures (Gyps bengalensis) in Surendrangar and Bhavnagar districts of Gujarat, India. Journal of Entomology and Zoology Studies 2021; 9(1): 1834-1837.

Morán-Ordóñez, A, Lahoz-Monfort. J.J., Elith, J, and Wintle, B.A. (2017). Evaluating 318 continental-scale species distribution models over a 60-year prediction horizon: What factors influence the reliability of predictions?. Global Ecology and Biogeography 26, no. 3 (2017): 371-384.DOI:10.1111/geb.12545

Moya-Moraga, M. R. and Pérez-Ruíz.C. (2022). Application of MaxEnt Modeling and HRM Analysis to Support the Conservation and Domestication of Gevuina avellana Mol. in Central Chile. Plants, 11(20), 2803.DOI:10.3390/plants11202803

Mukherjee, A., Galligan, T.H., Prakash, V., Paudel, K., Khan, U., Prakash, S., Ranade, S., Shastri, K., Dave, R., Donald, P. and Bowden, C. (2014). Vulture safe zones to save Gyps vultures in South Asia. *Mistnet*, *15*(3), pp.4-21.

Naidoo, V., Taggart, M. A., Duncan, N., Wolter, K., Chipangura, J., Green, R. E. and Galligan, T. H. (2018) The use of toxicokinetics and exposure studies to show that carprofen in cattle tissue could lead to secondary toxicity and death in wild vultures. Chemosphere 190: 80–89

Naidoo, V., Wolter, K., Cuthbert, R., & Duncan, N. (2009). Veterinary diclofenac threatens Africa's endangered vulture species. *Regulatory toxicology and pharmacology*, *53*(3), 205-208.

Nambirajan, K., Muralidharan, S., Ashimkumar, A. R., & Jadhav, S. (2021). Nimesulide poisoning in white-rumped vulture Gyps bengalensis in Gujarat, India. *Environmental Science and Pollution Research*, *28*(41), 57818-57824.

Navaneethan, B., Sankar, K., Qureshi, Q. and Manjrekar, M. (2015). The status of vultures in Bandhavgarh tiger reserve, Madhya Pradesh, central India. *Journal of Threatened Taxa*, *7*(14), pp.8134-8138.

Newton, I., Davis, P.E. and Moss, D. (1981). Distribution and breeding of Red kites in relation to land-use in Wales. Journal of Applied Ecology, 18, 173–186.

Niemi.G.J. and Hanowski.J.M (1997). Concluding remarks on raptor responses to forest management, a Holarctic perspective. J. RaptorRes.31:191-196.

Oaks, J. Lindsay et al. (2004). Diclofenac Residues as the Cause of Vulture Population Decline in Pakistan. Nature 427(6975): 630–33.

Ogada, D.L. and Buij, R. (2011). Large declines of the Hooded Vulture *Necrosyrtes monachus* across its African range. *Ostrich*, *82*(2), pp.101-113.

Ogada, D.L., Keesing, F. and Virani, M.Z. (2012). Dropping dead: causes and consequences of vulture population declines worldwide. *Annals of the New York Academy of Sciences*, *1249*(1), pp.57-71.

Ogada, D. L. (2014). The power of poison: pesticide poisoning of Africa's wildlife. *Annals of the New York Academy of Sciences*, *1322*(1), 1-20.

Ogadalay, J.M.,(2006). The decline of raptors in West Africa: long-term assessment and the role of protected areas. *Ibis*, *148*(2), pp.240-254.

Osborne, P. E. and Seddon.P.J (2012). Selecting suitable habitats for reintroductions: variation, change and the role of species distribution modeling. Reintroduction biology: integrating science and management, 73-104.DOI:10.1002/9781444355833

Pain. D, Cunningham. A, Donald. P.F, Duckworth. J.W, Houston. D.C, Katzner .T ,Parry-Jones. J, Poole. C, Prakash. Vibhu, Round. P and Timmins. R., (2003). Causes and Effects of Temporospatial Declines of Gyps Vultures in Asia. Conservation Biology. 17. 10.1046 / j. 1523-1739.2003.01740. x.

Pal, S. (2024). *Hidden in Hides: The World of Calcutta Tannery Workers, 1905-1996* (Doctoral dissertation, Open Access Te Herenga Waka-Victoria University of Wellington).

Pande, S., Mestri, P., Deshpande, P., Warange, A. and Mahabal, A. (2013). Promising trend of in situ breeding of Oriental White-rumped Vulture Gyps bengalensis in Raigad District, Maharashtra, India: conservation implications for re-introduction of ex situ populations. *Journal of Threatened Taxa*, pp.4106-4109.

Perrins C.M, Birkhead T.R. Blackie; Glasgow, UK: 1983. Avian ecology.

Phipp, W.L., Diekmann, M, MacTavish. L.M., Mendelsohn. J.M. , Naidoo.V, Wolter.K and Yarnell. R.W. (2017). Due South: A first assessment of the potential impacts of climate change on Cape vulture occurrence. Biological Conservation, 210 (2017), 16–25. DOI: 10.1016/j.biocon.2017.03.028.

Porfirio L.L, Harris R.M.B, Lefroy E.C., Hugh. S , Gould. S.F. , Lee.G. (2014) Improving the Use of Species Distribution Models in Conservation Planning and Management under Climate Change. PLoS ONE, 9(11): e113749. DOI: 10.1371/journal.pone.0113749.

Powell, R.A., Mitchell, M.S.(2012). What is a home range? Journal of Mammalogy 93, 948-958.

Prakash, V. (1999). Status of vultures in Keoladeo National Park, Bharatpur, Rajasthan, with special reference to population crash in Gyps species. Journal of the Bom-bay Natural History Society 96:365–378.

Prakash, V., Pain, D.J., Cunningham, A.A., Donald, P.F., Prakash, N., Verma, A., Gargi, R., Sivakumar, S. and Rahmani, A.R., (2003). Catastrophic collapse of Indian white-backed Gyps bengalensis and long-billed Gyps indicus vulture populations. *Biological conservation*, *109*(3), pp.381-390.

Prakash V, Bishwakarma MC, Chaudhary A, Cuthbert R, Dave R, Kulkarni M, et al. (2012) The Population Decline of *Gyps* Vultures in India and Nepal Has Slowed since Veterinary Use of Diclofenac was Banned. PLoS ONE 7(11): e49118. HYPERLINK "https://doi.org/10.1371/journal.pone.0049118"https://doi.org/10.1371/journal.pone.0049118

Prakash, V., Galligan, T. H., Chakraborty, S. S., Dave, R., Kulkarni, M. D., Prakash, N., Shringarpure, R. N., Ranade, S. P. and Green, R. E. (2017) Recent changes in populations of Critically Endangered Gyps vultures in India. Bird Conserv. Internatn. 29: 55–70

Prakash, Vibhu, Toby H. Galligan, Soumya S. Chakraborty, Ruchi Dave, Mandar D. Kulkarni, Nikita Prakash, Rohan N. Shringarpure, Sachin P. Ranade, and Rhys E. Green (2019). Recent changes in populations of Critically Endangered Gyps vultures in India." *Bird Conservation International* 29, no. 1: 55-70.

Prakash, V., Bajpai, H., Chakraborty, S.S., Mahadev, M.S., Mallord, J.W., Prakash, N., Ranade, S.P., Shringarpure, R.N., Bowden, C.G. and Green, R.E., (2024). Recent trends in populations of Critically Endangered Gyps vultures in India. *Bird Conservation International*, *34*, p.e1.

Ram, M., Sahu, A., Tikadar, S., Gadhavi, D., Rather, T. A., Jhala, L., & Zala, Y. (2022). Home range, movement and activity patterns of six vulture species using satellite telemetry in Saurashtra landscape, Gujarat, India. *Ecologies*, *3*(4), 492-507.

Ramesh, V., Gopalakrishna, T,Barve.S, and Melnick.D. (2017). IUCN greatly underestimates threat levels of endemic birds in the Western Ghats. Biological Conservation. 210, 205-221. DOI:10.1016/j.biocon.2017.03.019.

Rana, D. B., Chaudhary, I. P., Dangaura, H. L., Joshi, A. B., & Bhusal, K. P. (2019). Monitoring of nest and breeding status of white-rumped vulture Gyps bengalensis in Nepal. *Vulture Bulletin*, *8*, 28-31.

Ranade, S., Gore, J., & Kumar, A. (2023). Breeding of Himalayan Vulture Gyps himalayensis Hume, 1869 (Aves: Accipitriformes: Accipitridae) in the Assam State Zoo, Guwahati, Assam, India. *Journal of Threatened Taxa*, *15*(7), 23601-23605.

Reading, R.P., Azua, J., Garrett, T., Kenny, D., Lee, H., Paek, W.K., Reece, N., Tsolmonjav, P., Willis, M.J. and Wingard, G. (2020). Differential movement of adult and juvenile cinereous vultures (Aegypius monachus)(Accipitriformes: Accipitridae) in Northeast Asia. *Journal of Asia-Pacific Biodiversity*, *13*(2), pp.156-161.

Roberts, TJ (1991). The Birds of Pakistan. Oxford University Press, Karachi. Ruegg, Kristen, et al. Linking climate niches across seasons to assess population vulnerability in a migratory bird. Global Change Biology 27.15 (2021): 3519-3531.

Roy, A. (2007). Nesting of the White-rumped Vulture *Gyps bengalensis* in Orchha wildlife sanctuary, Madhya Pradesh, India. J. Bombay Nat. Hist. Soc., 110(1), Jan-Apr 2013

Roy, A., & Shastri, K. (2013). Impact of kite string injuries and temporal variation in types of injuries and illnesses of White-rumped Vultures of central Gujarat, India. *Journal of Threatened Taxa*, *5*(14), 4887-4892.

Safford, R., Andevski, J., Botha, A., Bowden, C. G., Crockford, N., Garbett, R. and Williams, N. P. (2019). Vulture conservation: the case for urgent action. *Bird Conservation International*, *29*(1), 1-9.

Sah, M. P., & Pal, D. (1991). Landform and Neotectonic studies around the Kangra basin, Himachal Pradesh. using Landsat TM Data. *Mountain Resource Management and Remote Sensing. Sutya Publication, Dehra Dun*, 59-7.

Samson, A. and B. Ramakrishnan (2020). The Critically Endangered White-rumped Vulture *Gyps bengalensis* in Sigur Plateau, Western Ghats, India: Population, breeding ecology, and threats. Journal of Threatened Taxa 12(13): 16752–16763. HYPERLINK "https://doi.org/10.11609/jott.3034.12.13.16752-16763"https://doi.org/10.11609/jott.3034.12.13.16752-16763

Samson, A., & Ramakrishnan, B. (2020). The critically endangered White-rumped Vulture Gyps bengalensis in Sigur Plateau, Western Ghats, India: Population, breeding ecology, and threats. *Journal of Threatened Taxa*, *12*(13), 16752-16763.

Samson, A., Ramakrishnan, B., Veeramani, A. and Ravi, P., (2016). Population status and habitat preference of vultures in Mudumalai Tiger reserve, Tamil Nadu, Southern India. *Journal homepage: www. wesca. net*, *11*(1).

Santangeli, A., Virani, M. Z., & Margalida, A. (2022). The hidden damage of dogs to biodiversity–Dog poisoning hampers vulture conservation. *Biological Conservation*.

Sathyamoorthy, O. R., Thirumurugan, R., & Rajan, M. P. (2012). Gross anatomical studies on the sternum and ribs of white-rumped vultures (Gyps bengalensis). *Indian Journal of Veterinary Anatomy*, *24*(2), 106-108.

SAVE (2021). A Blueprint for the Recovery of Asia's Globally Threatened Vultures. Link:"https://save-vultures.org/wp-content/uploads/2021/04/SAVEBlueprint- 2021.pdf.

Seaman, D.E., Powell, R.A.(1996). An evaluation of the accuracy of kernel density estimators for home range analysis. Ecology 77, 2075-2085.

Seddon, P.J, Strauss.W.M and Innes.J.(2012). Animal translocations: what are they and why do we do them?. Reintroduction Biology: integrating science and management 1-32.

Sehgal. A and Kumar. K.(2022). Nest Records, Nesting Colony Selection of Oriental White Backed Vulture (*Gyps bengalensis*) and Role of Feeding Station in Kangra, Himachal Pradesh. Acta Scientific Veterinary Sciences 4.1: 86-91.

Şekercioğlu, Ç. H., Daily, G. C., & Ehrlich, P. R. 2004. Ecosystem consequences of bird declines. *Proceedings of the National Academy of Sciences*, *101*(52), 18042-18047.

Sethi, J, and Chauhan, N.P.S. (2010). Nesting of rare vultures in Katerniaghat Wildlife Sanctuary, Uttar Pradesh, India. Oct 2019, Indian Forester,1372-1375

Sharma, R. K., Bhatt, D., Sethi, V. K., & Joshi, V. D. (2007). Status and behaviour of white-backed and long-billed vultures in Rajaji National Park, Uttarakhand, India. *Том 16 Випуск*, 75.

Sharma, P. (2012). Aceclofenac as a potential threat to critically endangered vultures in India: a review. *Journal of Raptor Research*, *46*(3), 314-318.

Sharma, M. (2022). Social History of the Western-Himalayan Temple: Rituals and Priests. In *The Routledge Handbook of Hindu Temples* (pp. 145-164). Routledge India.

Sharma, A., Sepehya, S., Sharma, R. and Kumar, A., (2023). Impact of Various Cropping Systems on the Status and Distribution of Selected Micronutrients in Subtropical Region of Himachal Pradesh, India. *International Journal of Plant & Soil Science*, *35*(19), pp.454-463.

Sharma, R., & Sharma, V. (2023). Land use management in the context of traditional vernacular settlements for hill areas of Himachal Pradesh. *GeoJournal*, 1-11.

Sharma, S. (2023). Effect of chemical stimulants on oleoresin production and wood quality of *Pinus roxburghii* Sargent (Doctoral dissertation, Dr. Yashwant Singh Parmar University Of Horticulture And Forestry).

Sheykhi Ilanloo, S., Khani, A, Kafash, A, Valizadegan, N, Ashrafi, S, Loercher, F and Yousefi, M. (2021). Applying opportunistic observations to model current and future suitability of the Kopet Dagh Mountains for a Near Threatened avian scavenger. Avian Biology Research, 14(1), 18-26.DOI:10.1177/1758155920962750

Shultz, S., Baral, H. S., Charman, S., Cunningham, A. A., Das, D., Ghalsasi, G. R., Goudar, M. S., Green, R. E., Jones, A., Nighot, P., Pain, D. J. and Prakash, V. (2004) Diclofenac poisoning is widespread in declining vulture populations across the Indian subcontinent. Proc. Roy. Soc. Lond. B (Supplement) 271: S458–S460.

Siegel-Causey, D, & Kharitonov, S. P. (1990). The evolution of

Singh J P, Radotra S and Roy M M. (2009). Grasslands of Himachal Pradesh. Indian Grassland and Fodder Research Institute, Jhansi, Uttar Pradesh, India. p. 25–47

Singh, A. (2022). Livestock production statistics of India–2021.

Sivakumar.S and Manakadan.R(2005). Decline of vultures in Sriharikota, Nellore District, Andhra Pradesh, India. Indian Birds Vol. 1 No. 1,14 (January-February 2005)

SoIB (2023). State of India's Birds, 2023: Range, trends, and conservation status. Pp. 119. The SoIB Partnership. doi:10.5281/zenodo.11124590.

Sokolov, L.V. (2011). Modern telemetry: New possibilities in ornithology. Biology Bulletin 38, 885-904.

Srinivasulu, A., Srinivasulu.B and Srinivasulu. C.(2021). Ecological niche modeling for the conservation of endemic threatened squamates (lizards and snakes) in the Western Ghats. Global Ecology and Conservation, 28, e01700. DOI:10.1016/j.gecco.2021.e01700.

Steenhof, K., Kochert, M. N., McIntyre, C. L., & Brown, J. L. (2017). Coming to terms about describing Golden Eagle reproduction. *Journal of Raptor Research*, *51*(3), 378-390.

Stokstad, E. (2021). Vultures face new toxic threat. *Science*, *373*(6560), 1187-1187.

Stuart Baker, E. C., (1928). The fauna of British India, including Ceylon and Burma. Birds. 2nd ed. London: Taylor and Francis. Vol. V of 8 vols. Pp. i–xviii, 1–469.

Suarez, S., Balbontin, J. and sua, M. (2000). Nesting habitat selection by booted eagles *Hieraaetus pennatus* and implications for management. Journal of Applied Ecology, 37, 215–223.

Subedi, T.R., Pérez-García, J.M., Sah, S.A., Gurung, S., Baral, H.S., Poudyal, L.P., Lee, H., Thomsett, S., Virani, M.Z. and Anadón, J.D.(2020). Spatial and temporal movement of the Bearded Vulture using GPS telemetry in the Himalayas of Nepal. *Ibis*, *162*(2), pp.563-571.

Sullivan, B. L., Wood. C. L Iliff. M.J., Bonney R. E, Fink D. and Kelling S. (2009). eBird: A citizen-based bird observation network in biological sciences. Biological conservation 142, no. 10: 2282-2292. DOI: 10.1016/j.biocon.2009.05.006.

Sutherland, W. J., & Green, R. E. (2004). Habitat assessment. *Bird ecology and conservation. Oxford University Press, Oxford*, 251-268.

Swarup, D. P. R. C., Patra, R. C., Prakash, V., Cuthbert, R., Das, D., Avari, P., and Taggart, M. (2007). Safety of meloxicam to critically endangered Gyps vultures and other scavenging birds in India. *Animal conservation*, *10*(2), 192-198.

Thakur, M. L., & Narang, S. K. (2012). Population status and habitat-use pattern of Indian White-backed Vulture (*Gyps bengalensis*) in Himachal Pradesh, India. *Journal of Ecology and the Natural Environment*, *4*(7), 173-180.

Thakur, M. L. (2015). Breeding ecology and distribution of White-rumped Vultures (Gyps bengalensis) in Himachal Pradesh, India. *Journal of Raptor Research*, *49*(2), 183-191.

Thakur, S., & Banyal, H. S. (2023). Mammalian Fauna of Dharamshala and its Suburbs of District Kangra, Himachal Pradesh, India. *Asian Journal of Biological and Life Sciences*, *12*(1), 125.

Thakur, P. K., Samant, S. S., Verma, R. K., Saini, A., & Chauhan, M. (2024). Monitoring forest cover changes and its impact on land surface temperature using geospatial technique in Talra Wildlife Sanctuary, Shimla, India. *Environment, Development and Sustainability*, 1-30.

Torney, C. J., Hopcraft. J.G.C., Morrison, T.A., Couzin, I.D. and Levin, S.A. (2018). From single steps to mass migration: the problem of scale in the movement ecology of the Serengeti wildebeest. Philosophical Transactions of the Royal Society B: Biological Sciences, 373(1746), 20170012.DOI:10.1098/rstb.2017.0012

United Nations. 2018. *Aichi biodiversity targets*.

Vásquez-Aguilar, A. A., Ornelas J.F. Rodríguez-Gómez. F and Cristina MacSwiney. G.M. (2021). Modeling future potential distribution of Buff-bellied Hummingbird (Amazilia yucatanensis) under climate change: species vs. subspecies. Tropical Conservation Science, 14 (2021): 19400829211030834.DOI:10.1177/19400829211030834

Venkitachalam, R., N. Senthil, and S. Bharathidasan. (2013). Some Aspects of Breeding Biology of the White-Backed Vulture Gyps Bengalensis Nilagiri North Forest Division in Western Ghats, Tamil Nadu. International Journal of Science and Nature 4(3): 411–14.

Verner, J., Morrison, M. L., & Ralph, C. J. (Eds.). (1986). *Wildlife 2000. Modeling habitat relationships of terrestrial vertebrates*.

Vignali, Sergio, Lörcher. F, Hegglin.D, Arlettaz.R, and Braunisch.V. (2021). Modelling the habitat selection of the bearded vulture to predict areas of potential conflict with wind energy development in the Swiss Alps. Global Ecology and Conservation 25 (2021): e01405.DOI:10.1016/j.gecco.2020.e01405

Virani, M, Monadjem. A, Thomsett.A , and Kendall.C. (2012). Seasonal variation in breeding Rüppell's Vultures Gyps rueppellii at Kwenia, southern Kenya and implications for conservation. Bird Conservation International. 22. DOI:10.1017/S0959270911000505.

Vishnu, M. (2018). *Status and habitat preferences of white-rumped vulture (gyps bengalensis) population of Wayand wildlife sanctuary, Kerala* (Doctoral dissertation, Department of Wildlife Sciences, College of Forestry, Vellanikkara).

Vishnu, O., Pandiyan, J., Balan, A., Jose, C. P., & Roshnath, R. (2024). Domestic dogs and vultures feed on the same carcasses in Wayanad Wildlife Sanctuary, Kerala, India. *Biotropica*, *56*(6), e13377.

Vogel, J. Ph (1933). History Of The Panjab Hill States Vol. 1. p. 216.

Vulture Conservation Breeding Centre, Pinjore, Haryana Annual Report(2021).Central Zoo Authority.

Vulture Survey Report (2021).Himachal Pradesh Forest Department

Walia, J. S. (2006). Sustainable forest management in Himachal Pradesh. World Forestry Center, World Forest Institute.

Watanabe, S., Hajima. T Sudo. K, Nagashima. T, Takemura.T, Okajima. H and Kawamiya.M. (2011). MIROC-ESM: model description and basic results of CMIP5-20c3m experiments. Geoscientific Model Development Discussions, 4(2). DOI:0.5194/gmd-4-845-2011

Wickham, H., & Wickham, H. (2016). Getting Started with ggplot2. *ggplot2: Elegant graphics for data analysis*, 11-31.

Wilbur, S. R. (1983). The status of vultures in the western hemisphere. Pages 113-123 in S. R. Wilbur and J. A. Jackson, eds. Vulture biology and management. Univ. California Press, Los Angeles. 550pp

Wilbur.s.R and Jackson.J.A(1984). Vulture Biology and Management., Eds. University of California Press, Berkeley. xxii, 550 pp.

Wilson, A.D.M., Wikelski, M., Wilson, R.P., Cooke, S.J. (2015). Utility of biological sensor tags in animal conservation. Conservation Biology.

Wilson, R.P., Shepard, E.L.C., Liebsch, N. (2008). Prying into the intimate details of animal lives: use of a daily diary on animals. Endangered Species Research 4, 123-137.

Winger, B. M., Auteri. G.G. Pegan, T.M and Weeks. B.C. (2019). A long winter for the Red Queen: rethinking the evolution of seasonal migration. Biological Reviews, 94(3), 737-752.DOI:10.1111/brv.12476

Wittenberger, F. and Hunt, G. L. (1985). The adaptive significance of coloniality in birds. in: Avian Biology, Vol. 8 (D).

Worton, B.J., (1989). Kernel methods for estimating the utilization distribution in home-range studies. Ecology 70, 164-168.

Yadav Ruby, A. K., & Kanaujia, A. (2018). A review on aerial display, nest site selection, nest defense, courtship display, copulation, parental care: Key events of vultures during breeding, threats and management. *Int. J. Life Sci*, *6*, 586-604.

Zheng, H, Yu. G, Wang. Q, Chen. Z, Zhu. X, Bao. H, Sun. Y, Niu. P, Li. Y, Shi. P, Hao. Y, Zhang, F and Niu. Z. (2023). Divergent environmental responses of long-term variations in evapotranspiration over four grassland ecosystems in China based on eddy-covariance measurements. Journal of Hydrology 625 : 130030. DOI:10.1016/j.jhydrol.2023.130030.

Zuberogoitia, I., Martínez, J. E., González-Oreja, J. A., Pérez de Ana, J. M., & Zabala, J. (2019). Factors affecting population regulation of a colonial vulture. *Ibis*, *161*(4), 878-889.

Annexure:

1.Supplementary material Chapter 6

Figure S1. Map showing study area (i.e. Old World) considered for the climatic niche modelling. For this study, nine vultures of the Old World were used.

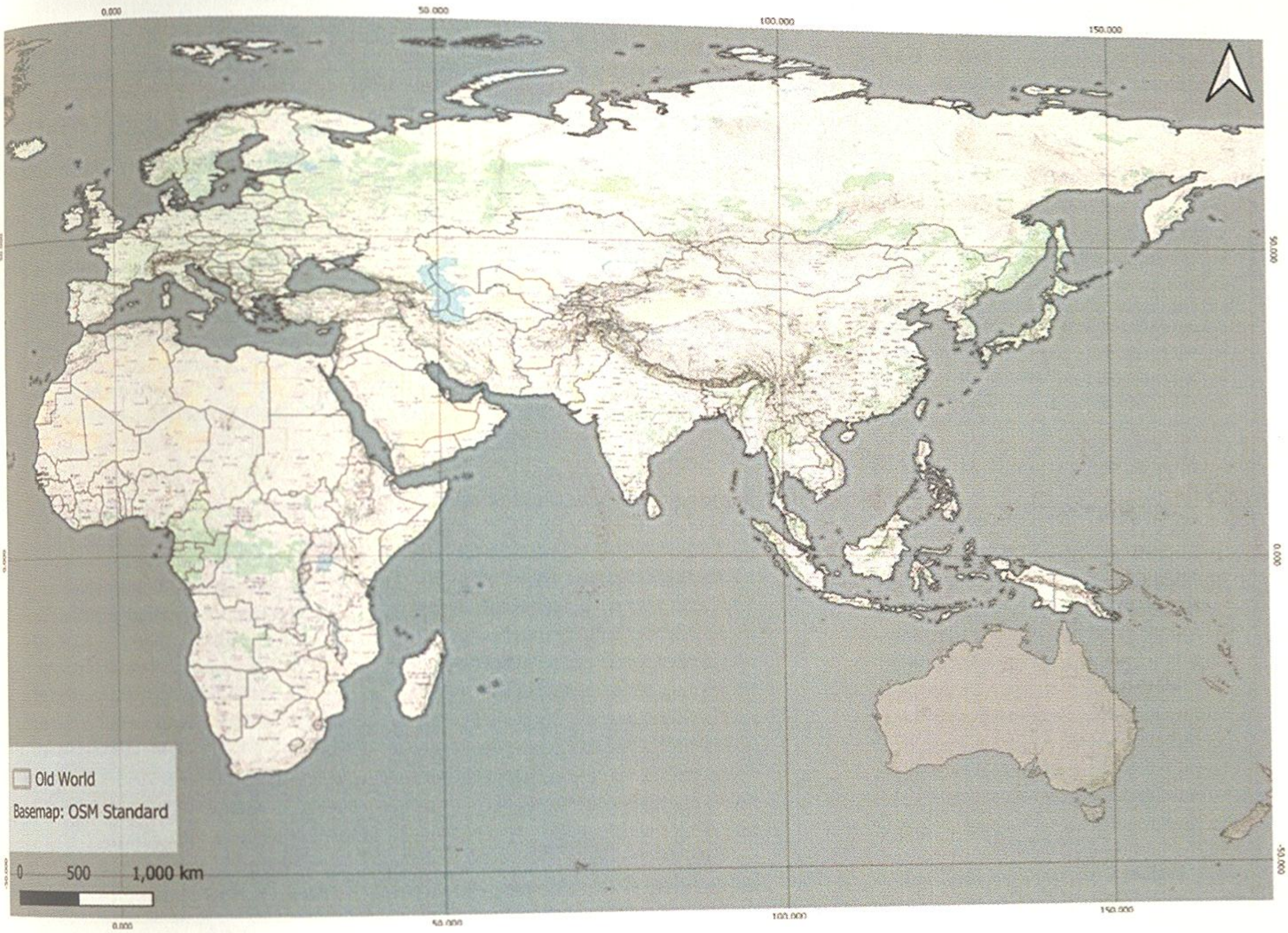
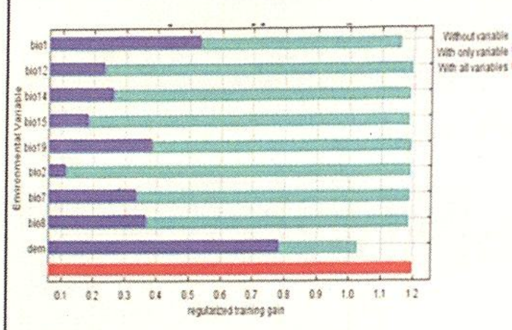
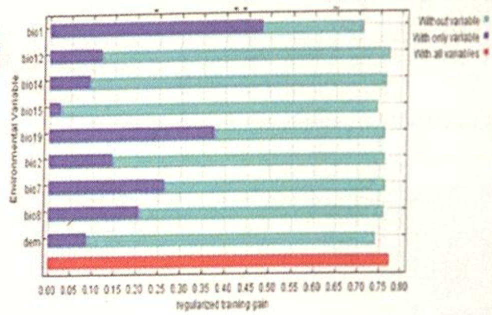


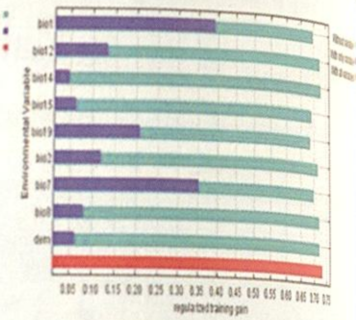
Figure S2. Jackknife test results



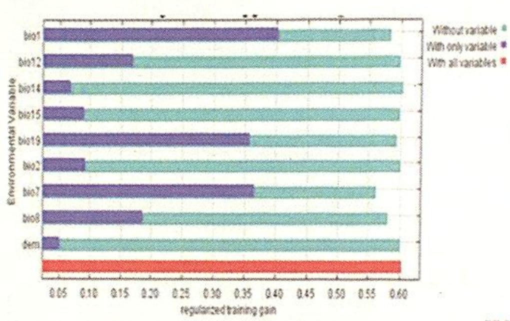
Bearded Vulture(*Gypaetus barbatus*)



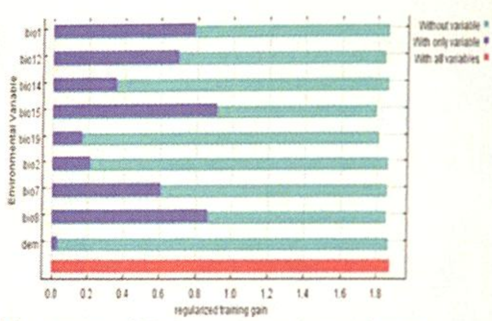
Cinereous Vulture(*Aegypius monachus*)



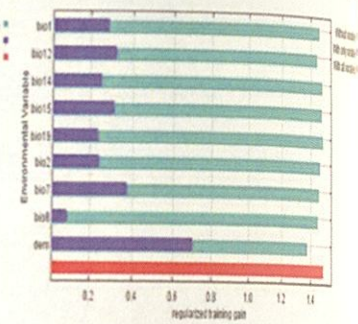
Egyptian Vulture(*Neophron percnopterus*)



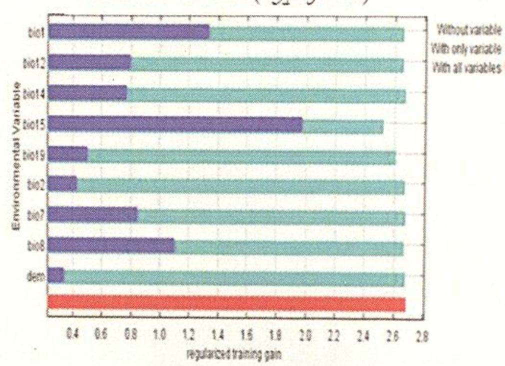
Griffon Vulture (*Gyps fulvus*)



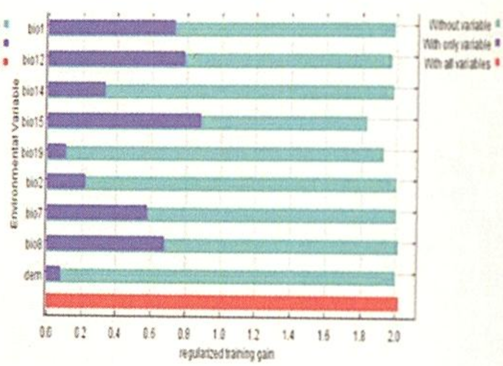
White-rumped Vulture(*Gyps bengalensis*)



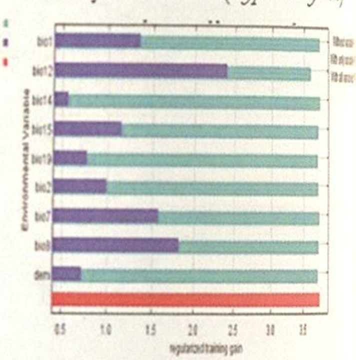
Himalayan Vulture (*Gyps himalyensis*)



Indian Vulture(*Gyps indicus*)



Red-headed Vulture(*Sarcogyps calvus*)



Slender-billed vulture(Gyps tenuirostris)

Figure S3. Current distribution maps of modelled vulture in India

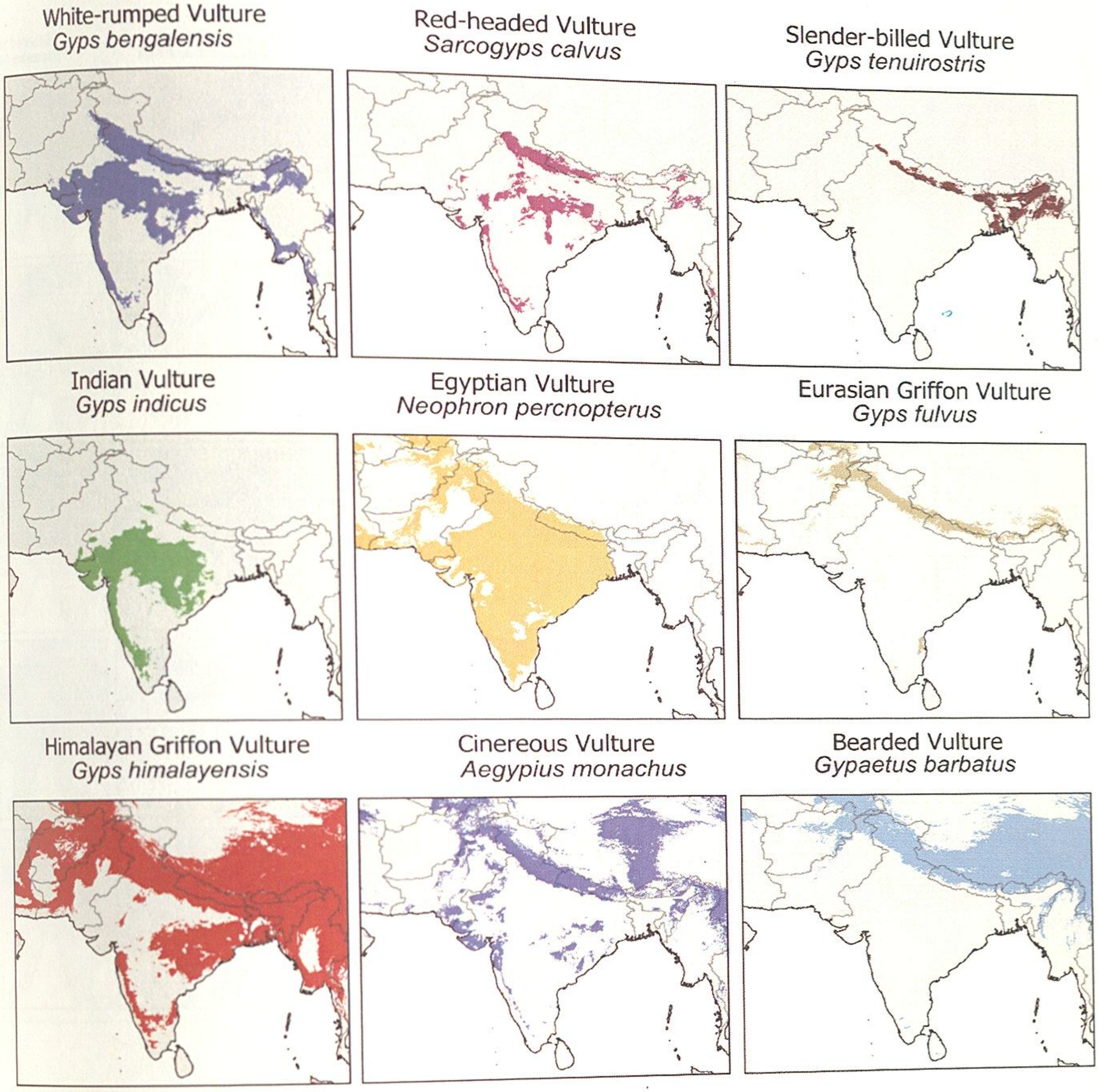


Figure S4. Future predicted climatic niche for other five vultures from India for the year 2040-2060

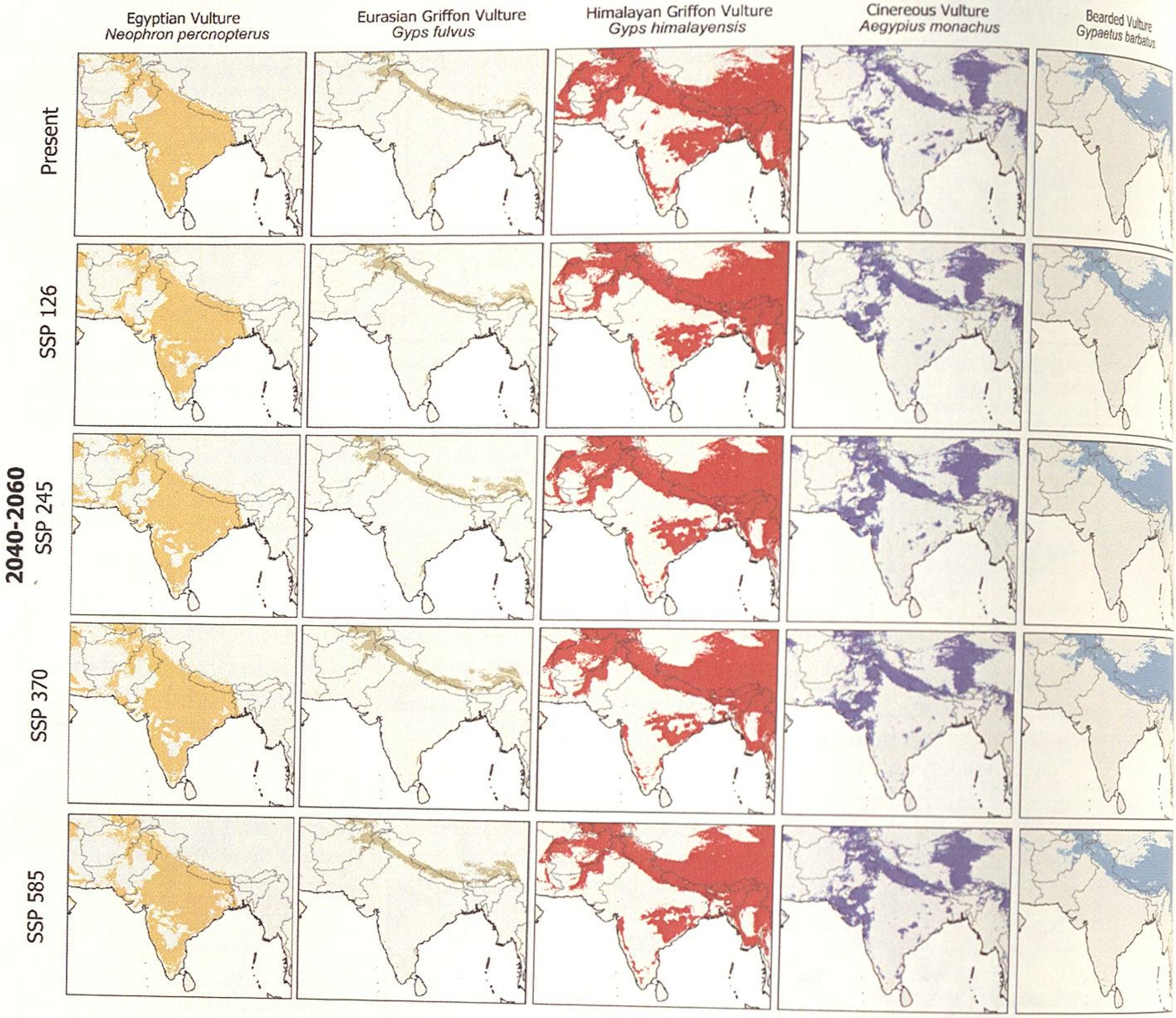


Figure S5. Future predicted climatic niche for other five vultures from India for the year 2060-2080

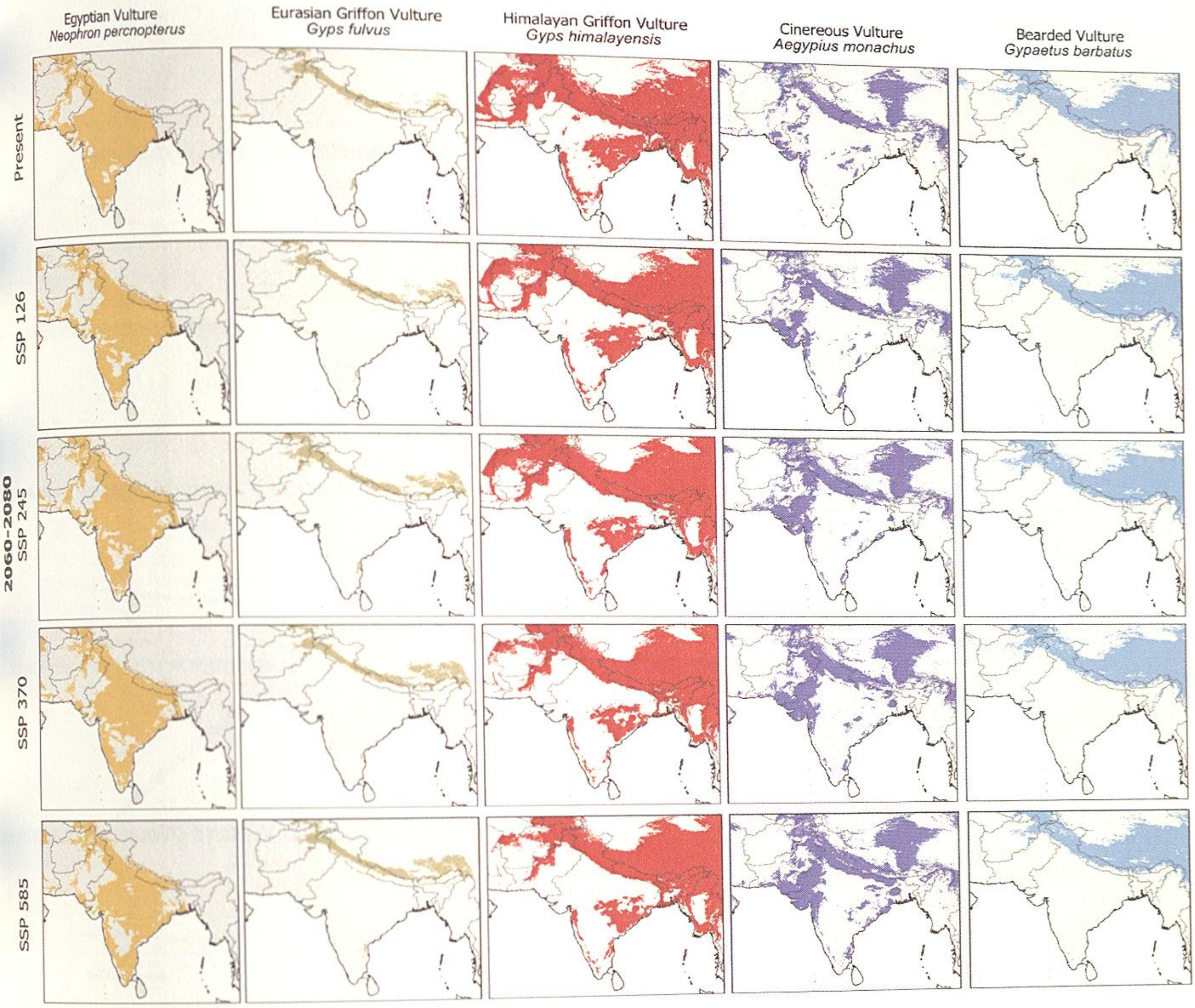
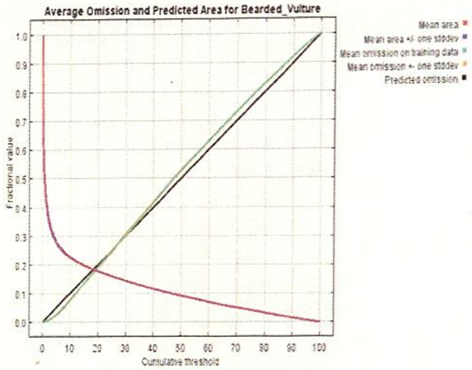
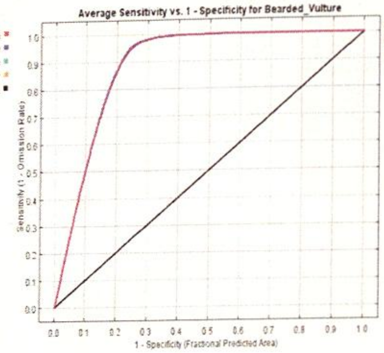
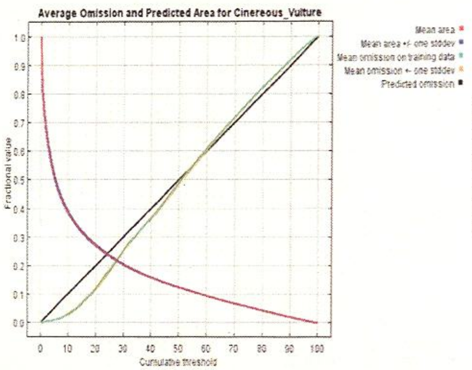


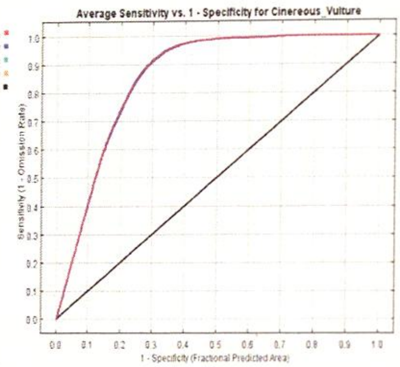
Figure S6. Omission curves



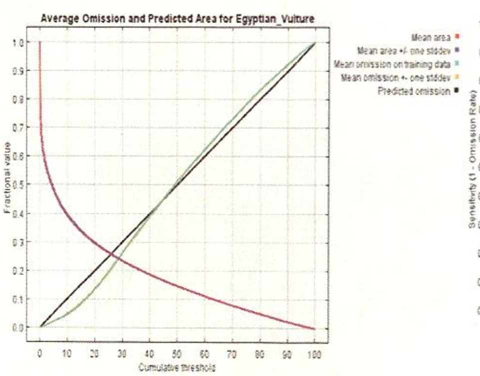


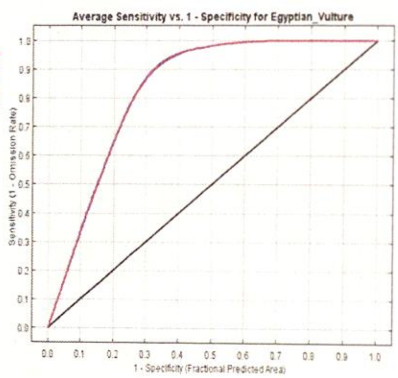
Bearded Vulture(*Gypaeutus barbatus*)



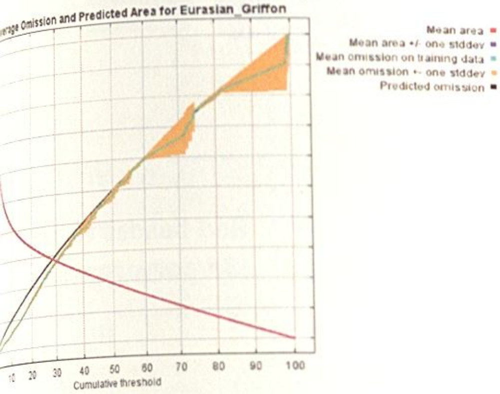


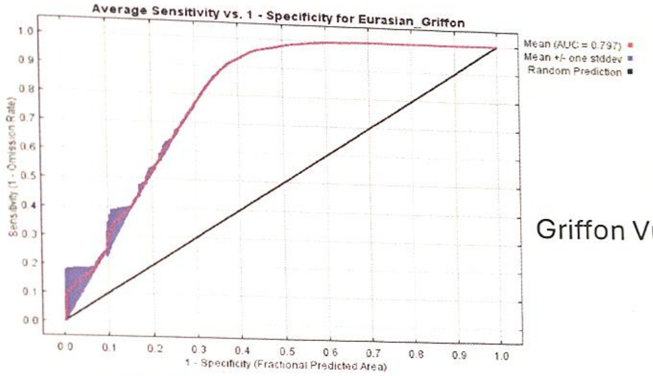
Cinereous Vulture (*Aegypius monachus*)



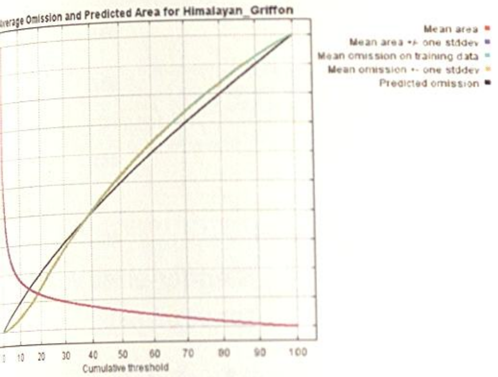


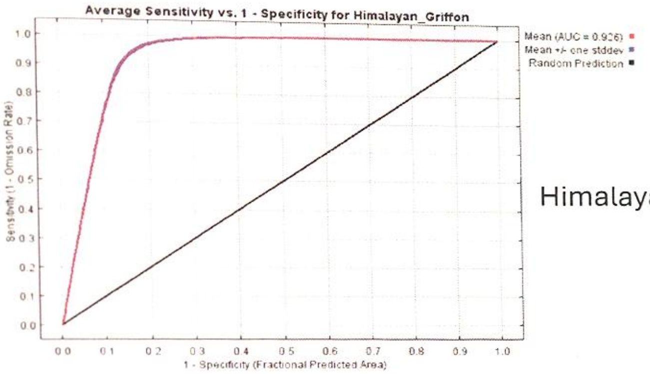
Egyptian Vulture (*Neophron percnopterus*)



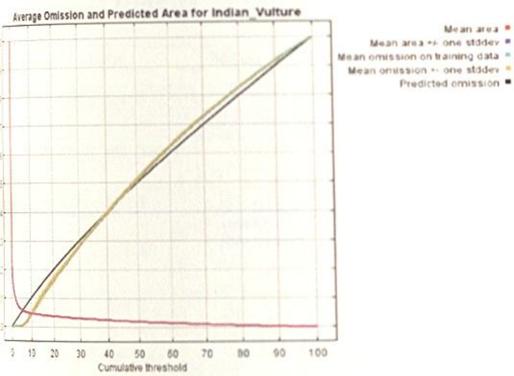


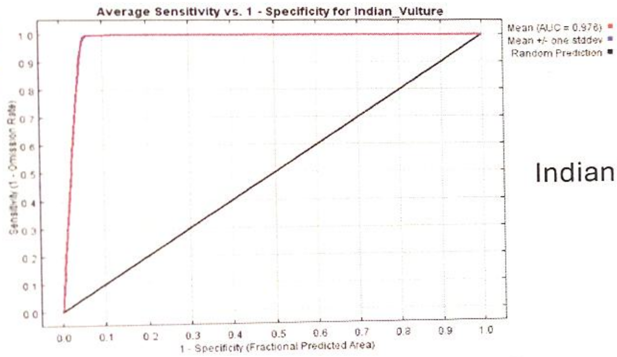
Griffon Vulture(*Gyps*



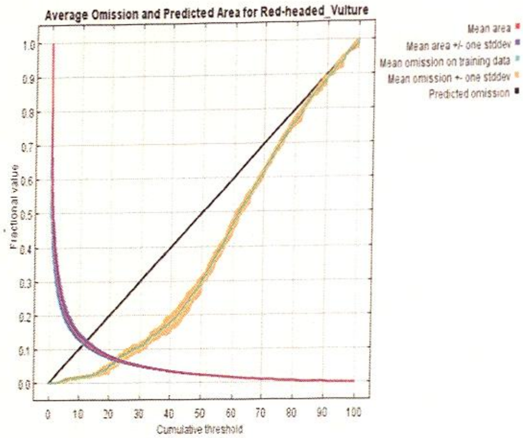


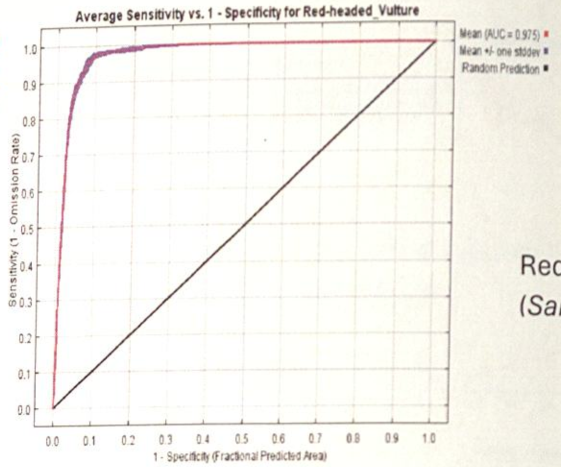
Himalayan Vulture (*Gyps*



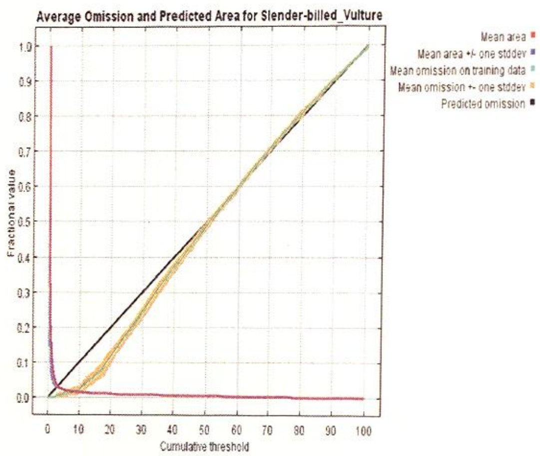


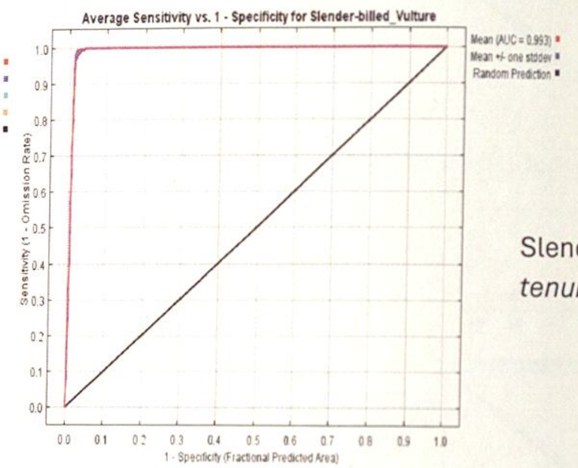
Indian Vulture(*Gyps*



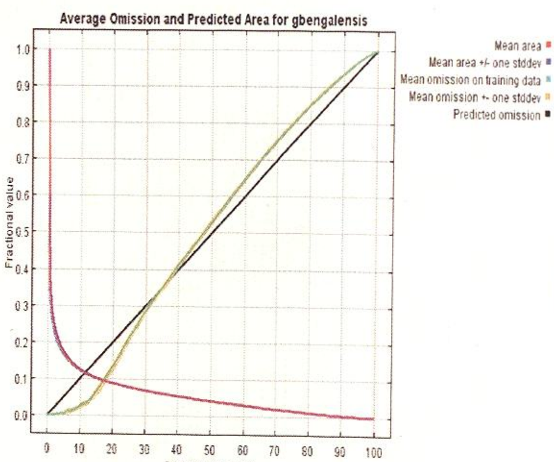


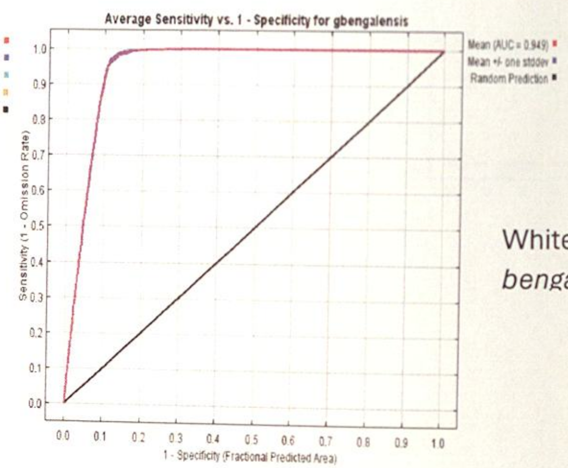
Red-headed Vulture (*Sarcogyps calvus*)





Slender-billed Vulture(G *tenuirostris*)





White-rumped Vulture(G *bengalensis*)

Table S1: Candidate models

Species	All candidate models	Statistically significant models	Models meeting omission rate criteria	Models meeting AICc criteria	Statistically significant models meeting omission rate criteria	Statistically significant models meeting AICc criteria	Statistically significant models meeting omission rate and AICc criteria
Bearded Vulture	186	186	7	2	7	2	1
Cinereous Vulture	186	186	0	2	0	2	0
Egyptian Vulture	186	186	2	2	2	2	1
Griffon Vulture	186	186	0	2	0	2	0
Himalayan Vulture	186	186	2	2	2	2	1
Indian Vulture	186	186	6	1	6	1	1
Red-headed Vulture	186	186	0	3	0	3	0
Slender-billed Vulture	186	186	0	1	0	1	0
White-rumped Vulture	186	186	1	1	1	1	1

Table S2: Details of feature chosen for final model

pecies	Model	Mean_AUC_ratio	pval_pROC	Omission_rate_at_5%	AICc	delta_AICc	W_AICc	num_parameters
rded ture	M_4_F_t_Set_1	1.221	0	0.048	67853.49	0	1	56
nereous lture	M_0.5_F_pth_Set_1	1.234	0	0.051	88590.03	0	1	223
yptian lture	M_4_F_t_Set_1	1.299	0	0.049	125690.45	0	1	84
iffon lture	M_4_F_t_Set_1	1.192	0	0.051	239516.74	0	1	68
nalayan lture	M_3_F_t_Set_1	1.129	0	0.047	38422.42	0	1	68
dian lture	M_0.5_F_lp_Set_1	1.227	0	0.048	7760.75	0	1	18
d- aded lture	M_1_F_lt_Set_1	1.317	0	0.053	8236.28	0	1	92
nder- lled lture	M_2_F_qt_Set_1	1.377	0	0.068	2004.87	0	1	23
hite- mped lture	M_3_F_t_Set_1	1.312	0	0.041	11578.92	0	1	38

Table S3: Training threshold

Species	Model	10 percentile training presence threshold		Maximum training Sensitivity plus specificity Threshold		Minimum training presence threshold	
		Cumulative	Cloglog	Cumulative	Cloglog	Cumulative	Cloglog
Bearded Vulture	M_4_F_t_Set_1_EC	15.114	0.374	29.432	0.506	0.067	0.037
Cinereous Vulture	M_0.5_F_pth_Set_1_EC	16.043	0.312	22.121	0.408	0.016	0.008
Egyptian Vulture	M_4_F_t_Set_1_EC	15.478	0.428	34.368	0.602	0.009	0.018
Griffon Vulture	M_4_F_t_Set_1_EC	12.481	0.438	26.407	0.609	0.008	0.061
Himalayan Vulture	M_3_F_t_Set_1_EC	13.744	0.263	34.09	0.557	0.204	0.052
Indian Vulture	M_0.5_F_lp_Set_1_EC	14.243	0.281	23.958	0.412	0.059	0.012
Red-headed Vulture	M_1_F_lt_Set_1_EC	25.165	0.341	31.943	0.429	0.661	0.019
Slender-billed Vulture	M_2_F_qt_Set_1_EC	22.669	0.321	25.506	0.363	0.953	0.0183
White-rumped Vulture	M_3_F_t_Set_1_EC	30.279	0.511	44.482	0.608	0.577	0.055

Table S4: MCP buffer size of vultures selected based on average daily distance travelled and home range of the vultures

Sl.No.	Name	Home range(Km^2)	Buffer size created based on daily distance travelled	References
1	Bearded vulture	286.6	259.8	Kruger et al 2017
2	Griffon Vulture	7419	1198	Ripolles et al 2011
6	Himalayan Vulture	6348	1864	Ram et al 2022
3	White-rumped vulture	384	997.16	Khatri 2016
4	Slender-billed vulture	NA	1191	NA
5	Indian vulture	5400	2445	Ram et al 2022
7	Red-headed vulture	2779	1191	Ram et al 2022
8	Egyptian vulture	4328-7323	1084	Mcgrady et al 2019,Buechley et al 2018
9	Cinereous vulture	135,430 ± 61,191 ha	535	Carrete et al 2005, Efrat 2021

Table S5: **Contribution of each variable**

Variables	Species								
	Bearded Vulture	Cinereous Vulture	Egyptian Vulture	Griffon Vulture	Himalayan Vulture	Indian Vulture	Red-headed Vulture	Slender-billed Vulture	White-rumped Vulture
bio1	16.9	9.1	11.5	2.9	26.1	11.5	10.2	6.6	11.9
bio2	0.5	9.7	9.5	1.2	0.2	5.7	8.4	2.7	3.1
bio7	12.5	11.1	8.5	30.3	28.3	9.9	6.8	5.1	9.8
bio8	18.7	14	5	23.9	1.9	4.5	8.3	18	20.6
bio12	33.9	6.9	23.4	16.2	20.2	3.3	16.7	56.4	12.9
bio14	17.1	9.3	6.9	0	6.8	2.4	2.9	0.4	0.1
bio15	0.2	4.5	6.1	1.4	1.8	61.3	23.5	1.7	30.8
bio19	0.2	35.3	29.2	24.1	14.6	1.3	23.3	9.1	10.7

Table S6: **Final Model AUC value for nine vulture species**

Species	AUC Values
Cinereous Vulture	0.856
Bearded Vulture	0.89
White-rumped Vulture	0.949
Griffon Vulture	0.797
Himalayan Vulture	0.926
Indian Vulture	0.976
Slender-billed Vulture	0.993
Egyptian Vulture	0.831
Red-headed Vulture	0.975

Table S7: Suitable areas for the present climatic niche

Species	Unsuitable area (Billion km^2) 0	Suitable Area(Billion km^2) 1	Total area(Billion km^2)	% of suitable area	% of unsuitable area
Cinereous Vulture	13.15	5.65	18.18	31.067	72.289
Bearded Vulture	13.11	5.05	18.18	27.790	72.106
White-rumped Vulture	17.51	6.57	18.18	3.611	96.285
Griffon Vulture	15.79	2.37	18.18	13.038	86.857
Himalayan Vulture	11.41	6.76	18.18	37.198	62.697
Indian Vulture	17.03	1.13	18.18	6.231	93.665
Slender-billed Vulture	17.74	4.20	18.18	2.308	97.587
Egyptian Vulture	1455	3.61	18.18	19.841	80.054
Red-headed Vulture	17.65	5.14	18.18	2.824	97.071

Table S8: The reduction/expansion in suitable areas (million km^2) for nine species of vultures under four shared socioeconomic pathways (SSP1-2.6, SSP2-4.5, SSP3-7.0, SSP5-8.5) in two future periods 2041-2060 and 2061-2080

	2040-2060				2060-2080			
Cinereous Vulture	SSP40_126	SSP40_245	SSP40_370	SSP40_585	SSP60_126	SSP60_245	SSP60_370	SSP60_585
Range Expansion	5.988	6.456	6.491	7.534	5.858	7.143	8.136	9.541
No occupancy (absence in both)	55.821	55.354	55.319	54.276	55.952	54.667	53.674	52.269
No change (presence in both)	17.232	16.969	16.683	16.179	17.054	15.786	14.749	13.688
Range contraction	5.765	6.028	6.314	6.818	5.943	7.211	8.248	9.309
Net Expansion	0.224	0.428	0.178	0.716	-0.085	-0.068	-0.113	0.232
Percentage change	0.972	1.861	0.772	3.115	-0.369	-0.294	-0.489	1.011
Bearded Vulture								
Range Expansion	0.731	0.945	0.991	0.900	0.926	0.964	1.150	1.157
No occupancy (absence in both)	66.420	66.205	66.160	66.251	66.225	66.187	66.001	65.994
No change (presence in both)	13.403	13.166	13.215	12.220	13.489	12.619	11.972	10.682
Range contraction	4.253	4.490	4.441	5.435	4.167	5.037	5.684	6.973
Net Expansion	-3.522	-3.544	-3.450	-4.535	-3.241	-4.073	-4.534	-5.816
Percentage change	-19.947	-20.075	-19.541	-25.687	-18.355	-23.067	-25.681	-32.942
White-rumped Vulture								
Range Expansion	1.166	1.086	1.113	1.238	0.986	1.260	1.260	1.378
No occupancy (absence in both)	77.678	77.758	77.731	77.606	77.858	77.584	77.584	77.466
No change (presence in both)	3.194	3.000	2.598	2.437	3.209	2.604	1.937	1.626
Range contraction	2.769	2.963	3.364	3.525	2.754	3.359	4.025	4.337
Net Expansion	-1.603	-1.876	-2.252	-2.288	-1.768	-2.099	-2.765	-2.958

Percentage change	-26.881	-31.465	-37.768	-38.366	-29.651	-35.198	-46.369	-49.618
Griffon Vulture								
Range Expansion	0.784	1.348	1.051	1.296	0.996	1.229	1.491	1.771
No occupancy (absence in both)	74.482	73.919	74.216	73.971	74.270	74.037	73.776	73.495
No change (presence in both)	7.477	7.610	7.494	7.264	7.529	7.145	7.232	6.684
Range contraction	2.063	1.930	2.046	2.276	2.011	2.395	2.308	2.856
Net Expansion	-1.279	-0.582	-0.996	-0.980	-1.014	-1.165	-0.817	-1.085
Percentage change	-13.402	-6.101	-10.436	-10.274	-10.633	-12.215	-8.564	-11.368
Himalayan Vulture								
Range Expansion	1.783	2.372	2.874	2.673	1.938	2.956	3.155	3.748
No occupancy (absence in both)	44.773	44.185	43.682	43.883	44.618	43.601	43.402	42.808
No change (presence in both)	32.844	32.433	31.931	31.103	33.160	31.662	30.093	28.678
Range contraction	5.406	5.817	6.319	7.148	5.090	6.588	8.157	9.572
Net Expansion	-3.623	-3.446	-3.445	-4.475	-3.152	-3.632	-5.002	-5.824
Percentage change	-9.471	-9.008	-9.006	-11.698	-8.241	-9.496	-13.077	-15.224
Indian Vulture								
Range Expansion	0.417	0.593	0.714	0.847	0.510	0.639	0.404	0.642
No occupancy (absence in both)	74.572	74.396	74.276	74.143	74.480	74.350	74.585	74.347
No change (presence in both)	7.100	7.060	6.185	6.159	7.339	6.297	5.441	4.804
Range contraction	2.717	2.757	3.632	3.658	2.478	3.520	4.376	5.012
Net Expansion	-2.299	-2.164	-2.918	-2.811	-1.969	-2.881	-3.971	-4.370
Percentage change	-23.421	-22.041	-29.727	-28.633	-20.053	-29.344	-40.455	-44.517
Slender-billed Vulture								
Range Expansion	1.353	1.485	1.535	2.157	1.455	1.736	2.425	3.290
No occupancy (absence in both)	79.475	79.343	79.293	78.671	79.372	79.092	78.403	77.537
No change (presence in both)	3.720	3.698	3.659	3.749	3.680	3.720	3.740	3.822
Range contraction	0.259	0.280	0.319	0.230	0.299	0.259	0.239	0.156
Net Expansion	1.094	1.205	1.216	1.927	1.157	1.477	2.187	3.134
Percentage change	-27.491	30.278	30.551	48.425	29.071	37.126	54.957	78.762
Egyptian Vulture								
Range Expansion	2.508	3.461	3.067	3.569	2.709	3.436	3.923	4.630
No occupancy (absence in both)	57.693	56.741	57.134	56.632	57.493	56.766	56.278	55.572
No change (presence in both)	20.997	21.024	20.137	19.928	20.925	20.159	19.273	18.589
Range contraction	3.609	3.581	4.469	4.677	3.680	4.446	5.333	6.016
Net Expansion	-1.101	-0.120	-1.401	-1.108	-0.972	-1.010	-1.409	-1.386
Percentage change	-4.472	-0.488	-5.695	-4.502	-3.949	-4.105	-5.726	-5.634

Red-headed Vulture								
Range Expansion	1.390	1.514	1.417	1.794	1.212	1.789	1.596	2.087
No occupancy (absence in both)	78.595	78.471	78.567	78.190	78.772	78.196	78.388	77.898
No change (presence in both)	3.027	2.914	2.712	2.433	3.025	2.521	2.133	1.951
Range contraction	1.795	1.907	2.110	2.389	1.797	2.301	2.688	2.871
Net Expansion	-0.405	-0.393	-0.693	-0.595	-0.584	-0.512	-1.092	-0.784
Percentage change	-8.389	-8.161	-14.346	-12.334	-12.121	-10.622	-22.645	-16.267

Table S9: Selected parameterization for final model

Species	maxent feature	RM	Mean AUC Ratio	Omission_rate_at_5%
Cinereous Vulture	pth	0.5	1.234	0.051
Bearded Vulture	t	4	1.221	0.047
White-rumped Vulture	t	3	1.312	0.041
Griffon Vulture	t	4	1.192	0.051
Himalayan Vulture	t	3	1.129	0.047
Indian Vulture	lp	0.5	1.227	0.048
Slender-billed Vulture	qt	2	1.377	0.068
Egyptian Vulture	t	4	1.299	0.049
Red-headed Vulture	lt	1	1.317	0.053

linear = l, quadratic = q, product = p, threshold = t, and hinge = h

Table S10: Vulture Safe Zone areas suitable for vulture reintroduction depending on climatic niche modelling

Sl No.	Potential VSZ	Future climatic niche within 100Km radius(in Km^2)
1	Pinjore, Haryana	22230.29
2	Rajabhatkhawa, West Bengal	2080.83
3	Majuli island,Assam	9225.05
4	Buksawaha, Madhya Pradesh	4751.24
5	Dudhwa National Park,Uttarakhand	15464
6	Katarniaghat, Uttar Pradesh	13320
7	Hazaribagh, Jharkhand	4854.68
8	Saurashtra, Gujarat	242.76

2. Papers published

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Nest site selection and threats to nesting colonies of white-rumped Vulture (*Gyps bengalensis*) in Himachal Pradesh

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ABSTRACT

White-rumped Vulture (*Gyps bengalensis*) suffered the most significant population decline among the three species of *Gyps* vultures impacted by the South Asia-wide diclofenac toxicity of the 1990s. Although the population lost about 99 % of its individuals, nesting populations still remain in a few pockets in India. One such population is known from the Himalayan foothills in the Kangra region, representing the northernmost nesting population of the species in India. From 2020–2024, we carried out an extensive study on the nesting ecology of the species, identifying 17 colonies with 617 active nests in 553 trees in an area of 5739 SqKm, constituting the highest nesting population reported in India. The smallest colony had ten nests, while the largest had 68. Except for a single nest on a *Ficus religiosa* tree, all others were on old-growth Chir Pine, *Pinus roxburghii*, having an average GBH of 254.8 cm (± 49.3 SD). By analyzing 18 variables, we determined vulture preferences for nest tree characteristics. Results indicate that nesting site selection primarily depends on GBH, canopy cover and nearest nest distance. About 80 % of nests were found between 600 and 800 m elevation. The primary threats include forest fire, resin tapping, and tree felling. We recommend protecting larger-sized old-growth forests through awareness campaigns with forest managers and local communities to safeguard the nest sites of the critically endangered bird.

1. Introduction

Worldwide, conditions of habitat degradation (Dolman and Sutherland, 1995) suggest urgent actions for better understanding and protecting habitats (Beresford et al., 2011; United Nations, 2018). Across bird species, the quantity and quality of available breeding habitats are crucial for reproduction and thriving populations. As available habitat declines, so does the availability of nesting sites (Cody, 1985); this can be especially important for long-lived organisms that use the same nests for multiple consecutive years (Krüger, 2002; Krüger et al., 2015). Thus, understanding the factors affecting successful nesting is essential for designing effective wildlife management interventions (Verner et al., 1986; Sutherland and Green, 2004) and ex-situ conservation measures, including species reintroduction (Donázar et al., 1993).

1.1. Background and history

Understanding the nesting habitat needs of the White Rumped Vulture (*Gyps bengalensis*) (WRV) is our core concern in this paper. The WRV is a medium-sized old-world colonial nesting vulture distinguished by a white tuft in its lower back. Once abundant across South Asia, the species is currently critically endangered and extremely rare (Wilbur and Jackson, 1984; Prakash et al., 2003). As consumers of carrions, derived primarily from domestic ungulate carcasses, WRVs previously thrived among human-dominated landscapes having cow husbandry (Pain et al., 2003). A sudden and dramatic population decline of WRV (up to 99 % in its entire distribution range from 1993 to 2003) occurred as a result of residual Diclofenac in cow carcasses (Prakash et al., 2003; Prakash, 1999; Oaks et al., 2004; Green et al., 2004; Prakash et al., 2012). Diclofenac, a non-steroidal anti-inflammatory drug (NSAID) commonly used for livestock as painkillers, has had devastating effects on vulture populations. When livestock treated with Diclofenac die and vultures consume their carcasses, the drug leads to kidney failure and visceral gout in the birds, causing rapid mortality (Oaks et al., 2004).

After clearly demonstrating the adverse effects of Diclofenac in vultures, the drug was banned for veterinary use in India. Although WRV

Abbreviations: WRV, White-rumped Vulture; GBH, Girth at breast height; GPS, Global Positioning System; NSAIDS, Non-steroidal anti-inflammatory drug; VCBC, Vulture Conservation Breeding Center.

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is still in decline today due to the presence of drugs similar to Diclofenac, recent data (Prakash et al., 2012) suggest that the decline may have waned (Sharma, 2012; Stokstad,2021; Chandramohan et al., 2022a, 2022b). A recent study from Nepal showed high survival rates of adult wild vultures and the absence of evidence for NSAID-based mortality from Diclofenac (Mallord et al., 2024) with partial recovery of the species population in Nepal (Galligan et al., 2020).

1.2. Nesting ecology

WRVs are found in sites close to villages, towns or cities. They are usually found in lowlands, with an ascending altitude of up to 1500 m in the Himalayan foothills (Ghimire et al., 2019; Bhusal et al., 2023). WRV forms monogamous pairs and nest in colonies with nest site fidelity (Bhusal et al., 2020; Gautam et al., 2024; Baral et al., 2005).They are generally tree nesters in colonies, nesting in groups in relatively tall trees of Chir Pine, Coconut, and sometimes *Ficus* (Majgaonkar et al., 2018). The WRV breeding season in India begins in October and extends through March or April. Nesting pairs usually lay a single white egg and incubate for 45–52 days. Both parents typically undertake parental care, and fledglings take about three months to reach independence (Thakur, 2015; Rana et al., 2019; Bhusal et al., 2023)

India has its nesting population pockets found from several states of India, including Jammu Kashmir (Kichloo et al., 2020), Madhya Pradesh (Roy, 2007; Navaneethan et al., 2015), Rajasthan (Chhangani, 2009), Gujarat (Gadhvi and Dodia, 2006; Moradiya and Goswami, 2021), Kerala (Vishnu, 2018), Andhra Pradesh (Sivakumar and Manakadan, 2005), Uttar Pradesh (Sethi and Chuahan, 2010), Uttarakhand (Sharma et al., 2007; Kumar et al., 2022), Tamilnadu (Samson and Ramakrishnan, 2020), Maharashtra (Pande et al., 2013) and Himachal Pradesh (Thakur, 2015). Its nesting range is even distributed in the coastal states of Maharashtra (Majgaonkar et al., 2018), the Sigur plateau of Tamil Nadu (Kannan et al., 2013).

1.3. Vulture monitoring programmes in India

Monitoring programmes in India, including population surveys (Prakash et al., 2012; Prakash et al., 2019), satellite telemetry to track movement (Ram et al., 2022) and breeding site monitoring surveys (Pande et al., 2013; Majgaonkar et al., 2018; Samson and Ramakrishnan, 2020) are ongoing. Additionally, vulture conservation efforts include toxicity surveillance (Taggart et al., 2009; Galligan et al., 2021) and diet analysis (Ghosh-Harihar et al., 2024). In Tamil Nadu and Madhya Pradesh, White-rumped Vulture (WRV) nest populations are being closely monitored (Navaneethan et al., 2015), accompanied by awareness programmes (Manigandan et al., 2021) aimed at establishing Vulture Safe Zones. These zones ensure low toxicity risk for vultures due to harmful NSAIDs used on livestock.

Captive breeding programmes were also initiated in 2006 in India following the ban on veterinary Diclofenac (Mahapatro and Arunkumar, 2014) to assist population recovery. In 2021, Aceclofenac and Ketoprofen were also banned (Galligan et al., 2021). The concept of Vulture Safe Zones, pioneered by SAVE (Saving Asian Vultures from Extinction), involves creating areas with a 100 km radius around nesting colonies of critically endangered Gyps vultures. These zones aim to reduce the risk of vulture poisoning due to toxic NSAIDs (Mukherjee et al., 2014). While eight potential Vulture Safe Zones exist in India, Nepal established the world's first government-certified Vulture Safe Zone (Bhusal et al., 2018).

2. Objectives

Despite the successful growth of captive breeding populations across various enclosures in India, our understanding of the wild population of White-rumped Vulture (WRV) remains limited. Only a handful of studies have explored their breeding ecology, nest selection, and nest success in wild from Himachal Pradesh (Thakur and Narang, 2012; Sehgal and Kumar, 2022). Our objectives were

1) To understand nest site selection by WRV
2) To Identify and map potential present nesting colonies and threats to WRV.

3. Study area

The study was conducted in the Indian Himalayan region in the Western Himalayas at a 450m-1200m asl in the Kangra district, Himachal Pradesh (Fig. 1). The entire area is 5739 sq. km, between 32.8307°, 32.2925°N and 75.9305,76.5426°E with 41.08 % forest cover (Kumar, 2024). The habitat is primarily undulating terrain, having subtropical pine and subtropical broad-leaved hill forests. The dominant trees are Chir pine (*Pinus roxburghii*) and occasional *Ficus* sp. trees. The habitat consists mainly of contiguous stretches of Chir pine forests, Curry tree (*Murraya koenigii*), and Date palm tree (*Phoenix* sp.). The area has the Dhauladhar mountain range, which merges with Manali's high-elevation Pir Panjal range. The Dhauladhars have a unique and rugged topography. While the range is mostly granite, the slopes reveal slate, limestone, and sandstone patches. The climate varies between subtropical dry and humid, with an average annual rainfall of 1169 mm (Meteorological Centre, Shimla). The area also has the Beas River's streams, tributaries, and one of the largest manmade Ramsar sites, the Pong Dam. The district has two main protected areas: Dhauladhar National Park and Pong Dam Lake Wildlife Sanctuary. Kangra district is also the region with the highest road connectivity. The human population of the district is 1510,075, which is one of the highest in Himachal Pradesh (Sharma and Sharma, 2023).

4. Methods

4.1. Field methods

Nest search surveys on foot were conducted at an average distance of 4.5 km per day around different nesting colonies from October to May each year (2020,2021,2022 and 2023), covering a total time period between February 2020 to March 2024(Fig. 2) with an exception in 2020 due to COVID-19 restrictions. Searches were conducted yearly to identify used, non-used or failed nests. Nests were identified as active or used if adults showed signs of nest occupation (Steenhof et al., 2017). A nest was classified as inactive when there were no observable signs of occupancy by adult vultures or evidence of new nesting material, such as new leaves of the Chir pine tree(*Pinus roxburghii*). In some instances, failed nests were identified following forest fire events, where the fire had impacted an active nest tree.

A total of 740 hours and 864 Km were covered during the nest survey by walking. Searches were also conducted for old nesting sites and sites based on local information and forest department survey reports. Nests were located with the help of Bushnell 8*42 Binoculars. Nest tree characteristics and GPS locations were taken at each nest tree location. Parameters such as GBH (Girth at breast height), Tree height, Nest Height from the ground, Total number of branches, etc., were recorded using a Nikon Forest Pro Rangefinder. Some additional parameters were also recorded, like the percentage of canopy cover and shrub cover under the nest tree, which were measured visually (Table 1). The branching pattern of the tree was also noted during the survey. Threats were also recorded for each tree, such as the percentage of fire that affected the tree GBH and resin tapping in the nest trees. Additionally, we established 20 m radius plots around each nesting tree, randomly selecting non-nesting trees to collect identical tree characteristic data as gathered for the nesting trees.

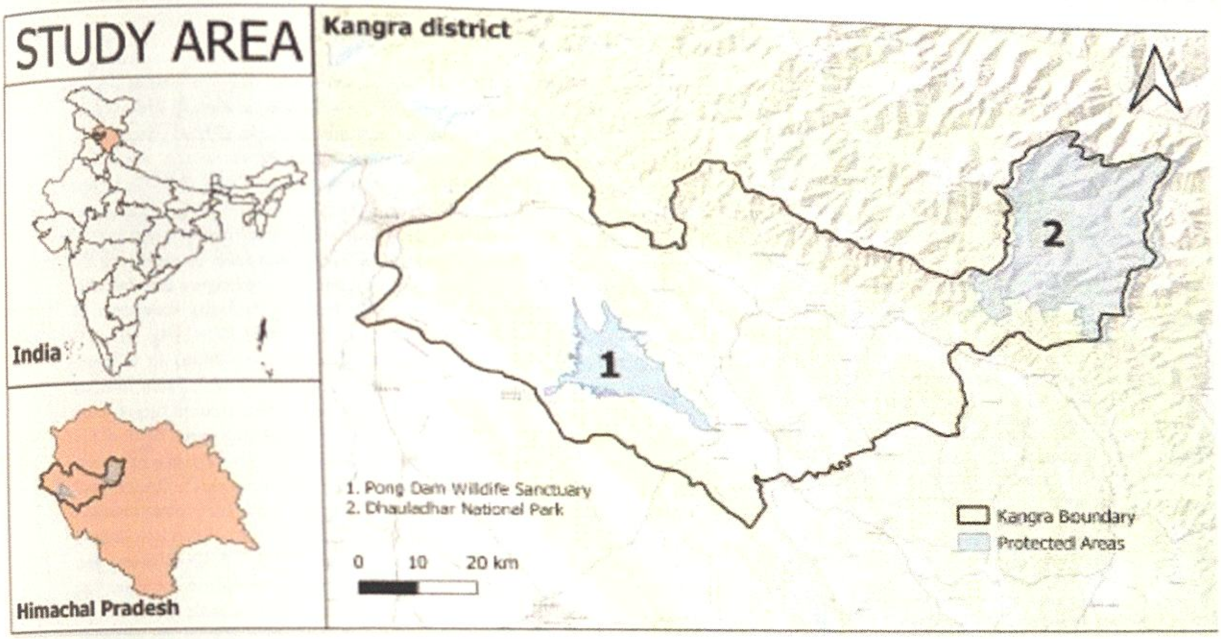

Fig. 1. Study area.

Fig. 2. Nest survey trails.

Table 1
List of variables measured.

Sl No.	Variable	Definition/Details
1	Tree height (m)	The height of the tree. Measured using the Nikon Forestry Pro II Laser rangefinder from the base of the tree
2	Girth at breast Height(m)	The diameter of the trunk of a tree at breast height of a standing tree.Measured using a measuring tape at the breast height of the trunk.
3	Total Number of branches	The total number of branches in the tree
4	First branch height (m)	The first branch height from ground taken using the Nikon Forestry Pro II Laser rangefinder
5	Percentage of fire	The fire percentage affected the tree's GBH size, as measured from observation(%). In 10 % intervals.
6	Shrub cover (%)	Percentage of ground vegetation cover under the canopy covered by shrub (%). In 10 % intervals.
7	Canopy cover (%)	Percentage of canopy under the tree using visual observation (%). In 10 % intervals.
8	Nest height(m)	The height of the nest location. Measured using the Nikon Forestry Pro II Laser rangefinder from the base of the tree
9	Nearest tree distance(m)	The distance (m) to the nearest tree. Measured using the Nikon Forestry Pro II Laser rangefinder from the base of the tree
10	Nearest nest tree distance(m)	The distance (m) to the nearest tree having nests. Measured using the Nikon Forestry Pro II Laser rangefinder from the base of the tree
11	Elevation(m)	Height above sea level for the particular tree. Calculated from ArcMap Desktop 10.7.1
12	Aspect(Degree)	The direction in which a slope faces is typically measured in degrees from north.Calculated from ArcMap Desktop 10.7.1
13	Slope(Degree)	A surface's incline, or steepness, is measured in degrees from horizontal (0–90). Calculated from ArcMap Desktop 10.7.1
14	Distance to water (m)	Distance from nest to nearest water source, using waterbody and river data from OpenStreetMaps. Calculated from ArcMap Desktop 10.7.1
15	Distance to road(m)	Distance from nest to the nearest road, using road network data from OpenStreetMaps. Calculated from ArcMap Desktop 10.7.1
16	Distance to villages (m)	Distance from villages using village boundary locations collected from the study. Calculated from ArcMap Desktop 10.7.1
17	Distance to feeding site(m)	Calculated from ArcMap Desktop 10.7.1 Distance from the feeding sites using feeding site locations collected from this study
18	Resin tapping	If the tree is heavily used for resin tapping or not (0,1 value)

4.2. Analysis

To evaluate the impact of nest site characteristics on nesting sites, we used Generalized Linear Mixed Models (GLMMs) with the Laplace approximation (Bolker et al., 2009). These account for variations specific to groups or clusters in the data, capturing random variability at different levels. A total of 18 variables were taken for analysis (Table 1). The response variable was occupancy, defined as 1 for nesting trees and 0 for non-nesting trees, with different nesting colonies as the random variable. We have created multiple models(n=50) using different combinations of variables. We selected a subsample of the dataset for calculation with nesting tree characteristics for n=607 and non-nest tree characteristics for n=167. The best model was based on the lowest AIC, considering all subsets of predictor variables. The best model, referred to as the GLMM_model, was identified through this selection procedure. All statistical analyses were conducted using RStudio (2024.04.1). We utilized the "lmer" function from the "lme4" package (Bates et al., 2015) to run the GLMMs, and all figures were created using the "ggplot2" package (Wickham and Wickham, 2016). Mean values are presented with standard deviation, and statistical significance was set at $P < 0.05$.

5. Results

We recorded 17 active nesting colonies with 617 active nests (Fig. 3) between 2020 and 2024 (Table 3). In addition, our study identifies 36 carcass dumping sites in the area. Carcass disposal sites managed by local communities serve as designated areas where the remains of deceased livestock are deposited. Carcasses, mostly of dead Cattle and Buffaloes, are being taken by local cobblers, also called "Chamars", from the household areas to the dumping sites. The Chamars historically played a crucial role in disposing of cattle carcasses by removing the hides for leather and leaving the remains for scavengers like vultures. This practice supports both local economies and the ecosystem by providing food for scavengers. (Kapoor, 2023; Pal,2024) (Fig. 4).

WRVs mostly nest in tall Chir pine trees(25–26 m) in different forested areas of Himachal, locally called "Chakbans." These forested areas are fragmented and mainly fall under the reserve forest areas closer to human habitation. Out of the 553 nesting trees, most of the trees have only one nest(n=499), followed by trees having two nests (n=45), three nests(n=8) and one having four nests(n=1). The sampled nesting area was between 545 and 1211masl, with most nests between 600 and 800masl. The maximum number of nests(n=182) was located on low to moderate inclination with a slope of 3.7–7.5. The shortest nest tree was 12 m, and the tallest was 38 m. The lowest-located nest was 9 m high, while the highest was 35 m. Most nests were built facing Northwest and Northeast directions. A significant effect of nest site selection was seen using the selected variables: GBH($p<0.005$) has the highest impact on nesting success. Other than that, the variables shrub cover ($p=0.02$), nearest nest($p=0.007$) and tree distance($p<0.005$), distance to feeding sites($p=0.01$) and distance to water($p<0.005$) have high significance values to nest site selection (Table 4). These results suggest that WRV's preferred nest trees with a higher GBH, less canopy cover, more shrub cover with proximity to nesting trees and water. Areas with higher fire activity, denser canopy cover, and fewer nearby trees are less favourable for the species, highlighting the critical need for effective forest fire management practices.

Generally, the nests are made with the leaves and branches of the *Pinus roxburghii* tree. Most of the nests were located at the top of the tree. The study also reveals that most vultures prefer building their nests on closely spaced branches in the upper canopy. The variables showing the negative effect on the nest site were first branch height, distance to water, and distance to villages. The variables GBH and Canopy cover gave the best model fit with the highest significance (AIC=240.5).

6. Discussion

Colonial scavengers breeding in forests are very sensitive to changes in habitat and forest management practices over time (Niemi and Hanowski, 1997; Fargallo et al., 1998; Donázar et al., 2002). Various studies on habitat and nest site selection suggest that understanding the selection patterns can predict species occurrence, providing valuable insights for forest managers to implement effective conservation measures. (Newton et al., 1981; Donázar et al., 1993; Austin et al., 1996; Ferrer and Harte, 1997; Suarez et al., 2000; Liberatori and Penteriani, 2001; Loyn et al., 2001). This study highlights that the Kangra Valley hosts one of India's most prominent and healthiest White-rumped Vultures (WRVs) source population. Throughout the four breeding seasons, the number of nests varied each year due to forest fires, which caused nest abandonment and re-establishment in new areas. Every year, 10–12 nests were relocated from one tree to the nearest available tree due to forest fire disturbances.

6.1. Nest site selection

The study reveals that WRV's prefer mature and stable trees, and girth at breast height (GBH) along with canopy cover were the most significant predictors of vulture occupancy (Fig. 5). In the Kangra area,

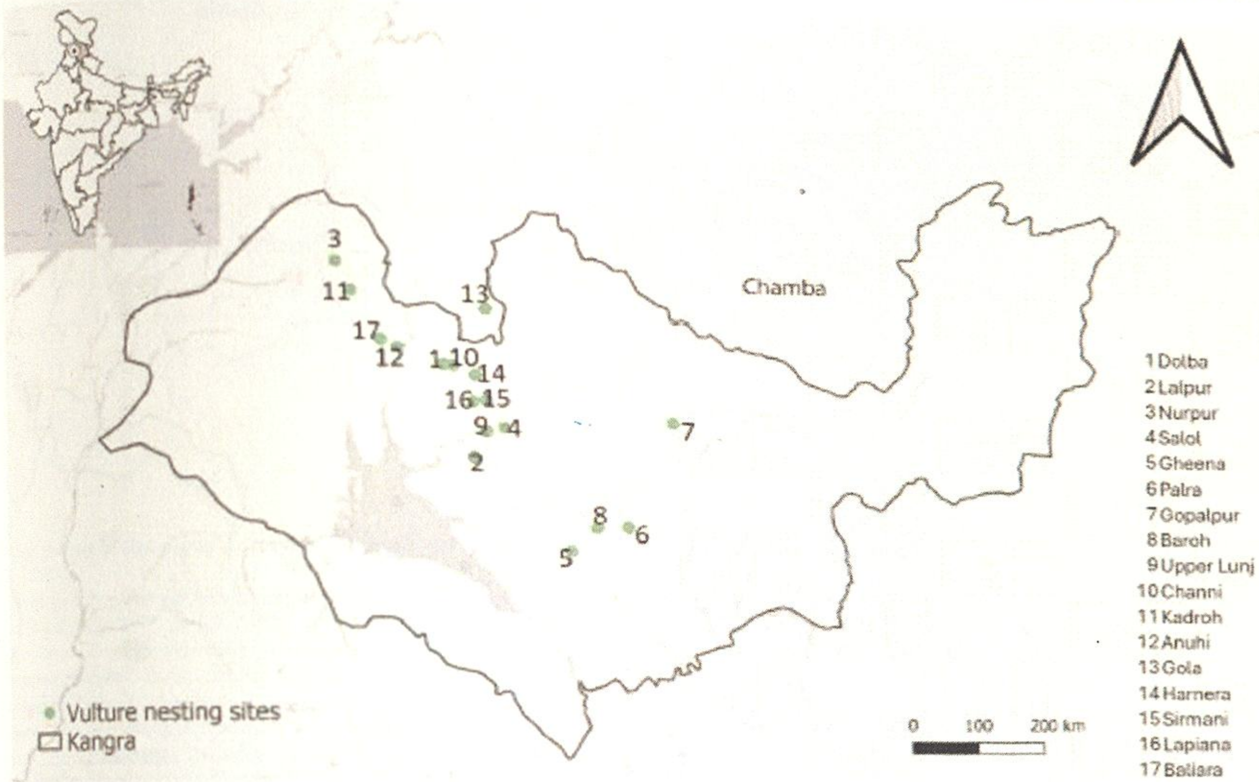

Fig. 3. Vulture nest colonies.

Table 2
Nesting colonies and nest numbers.

Sl No.	Colony Name	Division	Beat	Nest Count	Percentage Fire Affected(%)			Resin tapped trees
					2021	2022	2023	
1	Dolba	Nurpur	Jol	66	10	11	12	No
2	Lalpur	Dehra	Khuman	62	22	19	18	Yes
3	Nurpur	Nurpur	Minjgram	54	10	10	10	No
4	Salol	Dharamshala	Kotharoo	68	25	20	20	Yes
5	Gheena	Dharamshala	Balagaloa	59	25	20	37	Yes
6	Palra	Dharamshala	Kandi	27	15	35	46.6	Yes
7	Gopalpur	Dharamshala	Puthiar	46	25	21	21	Yes
8	Baroh	Dharamshala	Danoa	23	65	56	54	Yes
9	Upper Lunj	Dharamshala	Lunj	27	25	26	26	Yes
10	Channi	Nurpur	Bhali	18	19	25	30	Yes
11	Kadroh	Nurpur	Minjgram	24	5	6	2	No
12	Anuhi	Nurpur	Anuhi	11	7	10	6	No
13	Gola	Chamba	Urli	20	15	16	16	Yes
14	Harnera	Dharamshala	Shahpur	10	25	30	32.5	Yes
15	Sirmani	Dharamshala	Pandhwar	53	15	16	16	Yes
16	Lapiana	Dharamshala	Pandhwar	32	7	8	6.8	No
17	Ballara	Nurpur	Batuhi	17	2	7	9.4	yes
	Total			617				

Table 3
Vulture nest site records from Kangra district as per survey.

Sl No.	Year to	Year	No. of nesting trees	No. of active nest
1	2020	2020	159	152
2	2020	2021	261	305
3	2021	2022	398	450
4	2022	2023	455	512
5	2023	2024	553	617

most forests are fragmented by road networks. We have found almost 125 nests near the roadside in 17 colonies. Additionally, field observations reveal that vultures prefer nesting in trees with the densest shrub cover around the trunk (Nine colonies had an average shrub cover of over 75 %), which provides better protection from disturbances. Forested areas selected by vultures also showed lower disturbance from human activities, with a high abundance of Common leopard(*Panthera pardus*) and Wild boar(*Sus scrofa*) observed in the vicinity (from our study). Although previous studies have identified nest height as an essential variable in nest site selection (Majgaonkar et al., 2018; Johnson et al., 2022), this study did not reflect the same as most of the Chir

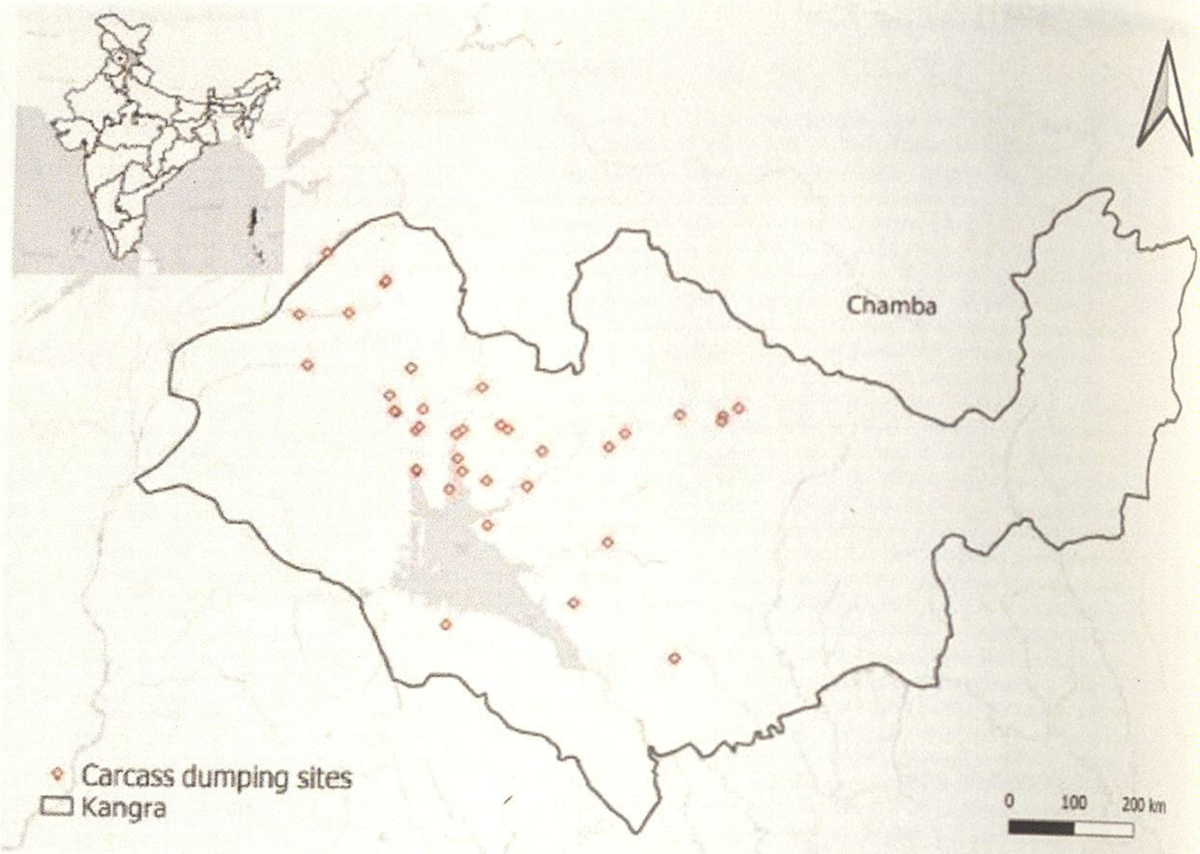

Fig. 4. Carcass dumping sites at Kangra district.

Table 4
Generalized Linear Mixed Model (GLMM) results for nest site selection of White-rumped Vultures.

Variable	Estimate	SE	Z Value	P value	
Intercept	−2.44073	3.800534	−0.642	0.52074	
Tree height (m)	0.030825	0.067143	0.459	0.64616	
Girth at breast Height (m)	0.033552	0.006009	5.583	2.36E−08	***
Total Number of branches	0.007925	0.060487	0.131	0.89576	
First branch height(m)	−0.06545	0.055765	−1.532	0.12542	
Percentage of fire	−0.02127	0.010348	−2.055	0.03987	*
Shrub cover (%)	0.021662	0.009405	2.303	0.02127	*
Canopy cover (%)	−0.08723	0.016705	−5.222	1.77E−07	***
Resin tapping	1.312439	0.59301	2.213	0.02689	*
Nearest tree distance (m)	−0.10426	0.021377	−4.877	1.08E−06	***
Elevation	0.008417	0.003493	2.41	0.01596	*
Aspect	0.000704	0.002652	0.265	7.91E−01	
Slope	0.122334	0.054215	2.256	0.2404	*
Distance to water	−1.47923	0.379732	2.41	9.80E−05	***
Distance to road	0.991042	0.435165	2.277	0.2276	*
Distance to villages	−1.27773	0.424948	−3.007	0.02276	**
Distance to feeding site	0.776653	0.317355	2.447	0.01439	*
Nearest nest tree distance(m)	0.024799	0.009294	2.668	0.00763	**

forests had similar height (24 m, average tree height). In addition to selected nest sites based on variables, colonial nesting vultures are social and heavily depend on nearby nesting trees. Most colonies have more than ten nests, indicating a clustering preference for nesting. All nesting colonies observed were located in old-growth Chir pine with mini disturbances influencing nest site selection.

6.2. Nesting colonies and threats to WRV

Each colony has distinct characteristics. Three of the 17 colon were located in reserve forests. Dolba and Nurpur are situated in high dense forests far from human habitation. The highest number of ne was recorded in Salol and Dolba. The 17 colonies face various thre including forest fires, resin tapping, and logging (Table 2). Forest fi pose a major threat to wildlife in Himachal (Thakur et al., 2024). Mo forest fires and nest failures occurred in Baroh(54 %), Palra(46.6 %) a Harnera(32.5 %). Observations revealed that continuous resin tappi reduces the circumference of trees at breast height, increasing the chances of pest attack, followed by susceptibility to forest fires a storms. In addition, trees with a larger diameter at breast height a having more cuts by resin tapping (Sharma and Lekha, 2013), affectin old-growth Chir Pine forests vulnerable to forest fire practices.

7. Conclusion

Forest management strategies should prioritize securing small col onies with appropriate signage. Alternative strategies to forest fir include planting fire-resistant vegetation around nesting sites, such a *Bombax* sp. and *Ficus* sp., which are crucial for vulture nesting. Resi tapping may be reduced by implementing sustainable tapping practices, limiting the number and size of cuts and rotating tapping locations to allow trees time to heal and recover. Furthermore, efforts should focu on protecting old-growth Pine trees that serve as nesting sites despite

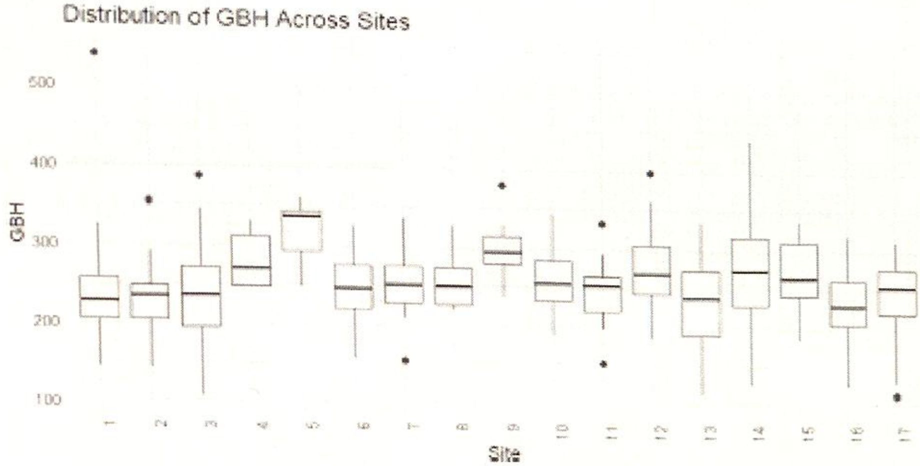

Fig. 5. Difference of GBH in each site.

existing protocols (Brown et al., 2011; Dhadwal and Kumar, 2022; Walia, 2006).

Given the advantages of communal foraging (Cortés-Avizanda et al., 2014; Harel et al., 2017; Jackson et al., 2008) and the reliance on social signals for nesting site selection (Mateo-tomás and Olea, 2011) and scavenging (Kendall et al., 2012), it is plausible that the social requirements of group living have a more pronounced impact on vulture nest-site selection than the individual attributes of the nest trees. Further, intensive surveys focusing on colony-based nest site selection and habitat characteristics will provide crucial insights for forest management beyond protected area boundaries. These sites are pivotal to vulture conservation and could be beneficial for designating as "Vulture Safe Zones" in Himachal Pradesh.

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CRediT authorship contribution statement

Gautam Talukdar: Writing – review & editing, Supervision, Project administration, Conceptualization. **Malyasri Bhattacharya:** Writing – original draft, Validation, Methodology, Formal analysis, Data curation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

References

Austin, G.E., Thomas, C.J., Houston, D.C., Thompson, D.B., 1996. Predicting the spatial distribution of buzzard Buteo buteo nesting areas using a Geographical Information System and remote sensing. J. Appl. Ecol. 1541–1550.

Baral, N., Gautam, R, Tamang, B., 2005. Population status and breeding ecology of White-rumped Vulture *Gyps bengalensis* in Rampur Valley. Nepal. Forktail 21, 87.

Bates, D., Kliegl, R., Vasishth, S., & Baayen, H. (2015). Parsimonious mixed models. *arXiv preprint arXiv:1506.04967*.

Beresford, A.E., Buchanan, G.M., Donald, P.F., Butchart, S.H.M., Fishpool, L.D.C., Rondinini, C., 2011. Poor overlap between the distribution of protected areas and globally threatened birds in Africa. Anim. Conserv. 14 (2), 99–107.

Bhusal, K.P., Chapagain, D., Joshi, A.B., Chaudhary, I.P., Chaudhary, K., 2018. First release of captive white-rumped vulture (Gyps bengalensis) into the wild in Nepal. Vulture Bull. 8, 3–8.

Bhusal, K.P., Chaudhary, I.P., Dangaura, H.L., Joshi, A.B., Rana, D.B., Ghimire, S., 2020. Habitat mapping of white-rumped vulture Gyps bengalensis. Terai arc landscape of Nepal. Minivet 3, 10–16.

Bhusal, K.P., Joshi, A.B., Rana, D.B., Thakuri, D.C., McClure, C.J., 2023. Population and productivity of the critically endangered White-rumped Vulture (Gyps bengalensis) in the Argha important bird and biodiversity area, Nepal. J. Raptor Res. 57 (3), 352–358.

Bolker, B.M., Brooks, M.E., Clark, C.J., Geange, S.W., Poulsen, J.R., Stevens, M.H.H., White, J.S.S., 2009. Generalized linear mixed models: a practical guide for ecology and evolution. Trends Ecol. Evol. 24 (3), 127–135.

Brown, P.M., Bhattacharyya, A., Shah, S.K., 2011. Potential for developing fire histories in Chir Pine (*Pinus roxburghii*) Forests in the Himalayan Foothills. Tree-ring Res. 67 (1), 57–62.

Chandramohan, S., Mallord, J.W., Mathesh, K., Sharma, A.K., Mahendran, K., Kesavan, M., Prakash, V.M., 2022a. Experimental safety testing shows that the NSAID tolfenamic acid is not toxic to Gyps vultures in India at concentrations likely to be encountered in cattle carcasses. Sci. Total Environ. 809, 152088.

Chandramohan, S., Mathesh, K., Mallord, J.W., Naidoo, V., Mahendran, K., Kesavan, M., Prakash, V.M., 2022b. Metabolism of aceclofenac to diclofenac in the domestic water buffalo Bubalus bubalis confirms it as a threat to Critically Endangered Gyps vultures in South Asia. Environ. Toxicol. Pharmacol. 96, 103984.

Chhangani, A.K., 2009. Present Status of Vultures in the Great Indian Thar Desert. In: Sivaperuman, C., Baqri, Q.H., Ramaswamy, G., Naseema, M. (Eds.), Faunal Ecology and Conservation of the Great Indian Desert. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-87409-6_7.

Cody, M.L. (Ed.), 1985. Habitat selection in birds. Academic press.

Cortés-Avizanda, A., Jovani, R., Donázar, J.A., Grimm, V., 2014. Bird sky networks: how do avian scavengers use social information to find carrion? Ecology 95 (7), 1799–1808.

Dhadwal, A., & Kumar, A. (2022). Planning Strategies to Improve Deteriorating Living Environment of Hill Towns: A Case of Dharamshala. In Environmental Concerns and Remediation: Proceedings of F-EIR Conference 2021 (pp. 211-220). Cham: Springer International Publishing.

Dolman, P.M., Sutherland, W.J., 1995. The response of bird populations to habitat loss. Ibis 137, S38–S46.

Donázar, J.A., Hiraldo, F., Bustamante, J., 1993. Factors influencing nest site selection, breeding density and breeding success in the bearded vulture (Gypaetus barbatus). J. Appl. Ecol. 504–514.

Donázar, J.A., Palacios, C.J., Gangoso, L., Ceballos, O., González, M.J., Hiraldo, F., 2002. Conservation status and limiting factors in the endangered population of Egyptian vulture (*Neophron percnopterus*) in the Canary Islands. ISSN 0006-3207 Biol. Conserv. 107 (1), 89–97. https://doi.org/10.1016/S0006-3207(02)00049-6.

Fargallo, J., Blanco, G., Edhardo, S., 1998. Forest management effects on nesting habitat selected by Eurasian black vultures (Aegypius monachus) in central Spain. J. Raptor Res 32.

Ferrer, M., Harte, M., 1997. Habitat selection by immature imperial eagle during the dispersal period. J. Appl. Ecol. 34, 1359–1364.

Gadhvi, I.R., Dodia, P.P., 2006. Indian white-backed vultures *Gyps bengalensis* nesting in Mahuva, Bhavnagar district, Gujarat, India. Indian Birds 2 (2), 36.

Galligan, T.H., Bhusal, K.P., Paudel, K., Chapagain, D., Joshi, A.B., Chaudhary, I.P., Chaudhary, A., Baral, H.S., Cuthbert, R.J., Green, R.E., 2020. Partial recovery of Critically Endangered Gyps vulture populations in Nepal. Bird. Conserv. Int. *30* (1), 87–102.

Galligan, T.H., Mallord, J.W., Prakash, V.M., Bhusal, K.P., Alam, A.S., Anthony, F.M., Dave, R., Dube, A., Shastri, K., Kumar, Y., Prakash, N., 2021. Trends in the availability of the vulture-toxic drug, diclofenac, and other NSAIDs in South Asia, as revealed by covert pharmacy surveys. Bird. Conserv. Int. *31* (3), 337–353.

Gautam, R., Baral, N., Sharma, H.P., 2024. Preference of trees for nest building by critically endangered white-rumped vultures (*Gyps bengalensis*) in Nepal. Ecol. Evol. *14* (3), e11175.

Ghimire, B., Acharya, R., Sivakumar, K., Biswas, S., Dorji, C., 2019. Nesting characteristics and habitat preferences of critically endangered White-Rumped Vulture *Gyps bengalensis* in Rampur IBA, Palpa. Vulture Bul. *8*, 20–24.

Ghosh-Harihar, M., Yadav, N., Gurung, N., Darshan, C.S., Shashikumar, B., Vishnudas, C. K., Prakash, Vibhu, Green, Rhys E., Ramakrishnan, U., 2024. Spatial patterns in the diet of Gyps vultures in India and their implications for conservation. Biol. Conserv. 292, 110551.

Green, R.E., Newton, I.A.N., Shultz, S., Cunningham, A.A., Gilbert, M., Pain, D.J., Prakash, V., 2004. Diclofenac poisoning as a cause of vulture population declines across the Indian subcontinent. J. Appl. Ecol. *41* (5), 793–800.

Harel, R., Spiegel, O., Getz, W.M., Nathan, R., 2017. Social foraging and individual consistency in following behaviour: testing the information centre hypothesis in free-ranging vultures. Proc. R. Soc. B: Biol. Sci. *284* (1852), 20162654.

Jackson, A.L., Ruxton, G.D., Houston, D.C., 2008. The effect of social facilitation on foraging success in vultures: a modelling study. Biol. *Lett.* *4* (3), 311–313.

Johnson, V.M., Harper, C.A., Applegate, R.D., Gerhold, R.W., Buehler, D.A., 2022. Nest site selection and survival of wild turkeys in Tennessee. J. Southeast. Assoc. Fish. Wildl. Agencies 9, 134–143.

Kannan, G., Balasundaram, R., Samson, A., 2013. Study on population and distribution of vultures in selected sites of Sigur plateau, Nilgiri north forest division. Tamilnadu. https://doi.org/10.13140/RG.2.1.3986.5204.

Kapoor, S., 2023. Death of the sacred: Cow, caste and dalit politics in India. Routledge Handbook of Contemporary India. Routledge, pp. 401–411.

Kendall, C., Virani, M.Z., Kirui, P., Thomsett, S., Githiru, M., 2012. Mechanisms of coexistence in vultures: understanding the patterns of vulture abundance at carcasses in Masai Mara National Reserve, Kenya. Condor *114* (3), 523–531.

Kichloo, M.A., Kumar, S., Sharma, N., 2020. Breeding site records of three sympatric vultures in a mountainous cliff in Kahara-Thathri, Jammu & Kashmir, India. J. Threat. Taxa 12 (9), 16166–16169.

Krüger, O., 2002. Analysis of nest occupancy and nest reproduction in two sympatric raptors: common buzzard Buteo buteo and goshawk Accipiter gentilis. Ecography *25* (5), 523–532.

Krüger, S.C., Simmons, R.E., Amar, A., 2015. Anthropogenic activities influence the abandonment of Bearded Vulture (Gypaetus barbatus) territories in southern Africa. Condor *117* (1), 94–107.

Sivakumar.S. and Manakadan.R.(2005). Decline of vultures in Sriharikota, Nellore District, Andhra Pradesh, India. Indian Birds Vol. 1 No. 1,14 (January-February 2005).

Kumar, S., 2024. Status of India's Forests. Forest Policies, Laws, and Governance in India: Conservation Challenges in the Face of Climate Change. Springer Nature Singapore, Singapore, pp. 207–232.

Kumar, V.P., Kumar, S., Rajpoot, A., Kumar, A., Rasaily, S.S., 2022. Threats assessment of vultures in Uttarakhand: a review note. Int. J. Sci. Res. Arch. 07 (02), 036–040, 2022.

Liberatori, F., Penteriani, V., 2001. A long-term analysis of the declining population of the Egyptian vulture in the Italian peninsula: distribution, habitat preference, productivity and conservation implications. Biol. Conserv. 101, 381–389.

Loyn, R.H., McNabb, E.G., Volodina, L., Willig, R., 2001. Modelling landscape distributions of large forest owls as lied to managing forests in north-east Victoria, Australia. Biol. Conserv. 97, 361–376.

Mahapatro, G.K., Arunkumar, K., 2014. The case for banning diclofenac and the vanishing vultures. Biodiversity *15* (4), 265–268.

Majgaonkar, I., Bowden, C.G.R., Quader, S., 2018. Nesting success and nest-site selection of white-rumped vultures (*Gyps bengalensis*) in western Maharashtra, India. J. Raptor Res. 52 (4), 431.

Mallord, J.W., Bhusal, K.P., Joshi, A.B., Karki, B., Chaudhary, I.P., Chapagain, D., Thakuri, D.C., Rana, D.B., Galligan, T.H., Requena, S., Bowden, C.G.R., Green, R.E., 2024. Survival rates of wild and released White-rumped Vultures (*Gyps bengalensis*) and their implications for conservation of vultures in Nepal. Ibis. https://doi.org/10.1111/ibi.13303.

Manigandan, S., Ramakrishnan, B., Kannan, P., Bharathidasan, S., Byju, H., 2021. Vultures: heroes of the ecosystem-International Vulture Awareness Day Celebration at Mudumalai Tiger Reserve, Tamil Nadu, India. ZOO'S PRINT 36 (4), 22–23.

Mateo-tomás, Patricia, Olea, P.P., 2011. The importance of social information in breeding site selection increases with population size in the Eurasian Griffon Vulture Gyps fulvus. Ibis 153 (4), 832–845.

Wilbur, sR., Jackson, J.A. (Eds.), 1984. Vulture Biology and Management.. University of California Press, Berkeley xxii, 550 pp.

Moradiya, M., Goswami, A.P., 2021. To study nesting of white-backed vultures (*Gyps bengalensis*) in Surendranagar and Bhavnagar districts of Gujarat, India. J. Entomol. Zool. Stud. 2021 9 (1), 1834–1837.

Mukherjee, A., Galligan, T.H., Prakash, V., Paudel, K., Khan, U., Prakash, S., Ranade, S., Shastri, K., Dave, R., Donald, P., Bowden, C., 2014. Vulture safe zones to save Gyps vultures in South Asia. Mistnet 15 (3), 4–21.

Navaneethan, B., Sankar, K., Qureshi, Q., Manjrekar, M., 2015. The status of vultures in Bandhavgarh tiger reserve, Madhya Pradesh, central India. J. Threat. Taxa 7 (14), 8134–8138.

Newton, I., Davis, P.E., Moss, D., 1981. Distribution and breeding of Red kites in relation to land-use in Wales. J. Appl. Ecol. 18, 173–186.

Niemi, G.J., Hanowski, J.M., 1997. Concluding remarks on raptor responses to forest management, a Holarctic perspective. J. Raptor 31, 191–196.

Sethi.J. and Chuahan.N.P.S.(2010).Nesting of rare vultures in Kateniaghat Wildlife Sanctuary,Uttar Pradesh,India. Oct 2019,Indian Forester,1372-1375.

Oaks, J.Lindsay, et al., 2004. Diclofenac residues as the cause of vulture population decline in Pakistan. Nature 427 (6975), 630–633.

Pain, D., Cunningham, A., Donald, P.F., Duckworth, J.W., Houston, D.C., Katzner, T., Parry-Jones, J., Poole, C., Prakash, Vibhu, Round, P., Timmins, R., 2003. Causes and effects of temporospatial declines of gyps vultures in Asia. Conserv. Biol. 17, 10.1046/j. 1523-1739.2003.01740. x.

Pal, S. (2024). *Hidden in Hides: The World of Calcutta Tannery Workers, 1905-1996* (Doctoral dissertation, Open Access Te Herenga Waka-Victoria University of Wellington).

Pande, S., Mistri, P., Deshpande, P., Warange, A., Mahabal, A., 2013. Promising trend of in situ breeding of oriental white-rumped vulture *Gyps bengalensis* in Raigad District, Maharashtra, India: conservation implications for reintroduction of ex situ populations. J. Threat. Taxa 4106–4109.

Prakash, V., 1999. Status of vultures in Keoladeo National Park, Bharatpur, Rajasthan, with special reference to population crash in Gyps species. J. Bom-bay Nat. Hist. Soc. 96, 365–378.

Prakash, V., Bishwakarma, M.C., Chaudhary, A., Cuthbert, R., Dave, R., Kulkarni, M., Kumar, S., Paudel, K., Ranade, S., Shringarpure, R., Green, R.E., 2012. The population decline of Gyps vultures in India and Nepal has slowed since veterinary use of diclofenac was banned. PloS One 7 (11), e49118.

Prakash, Vibhu, Galligan, Toby H., Chakraborty, Soumya S., Dave, Ruchi, Kulkarni, Mandar D., Prakash, Nikita, Shringarpure, Rohan N., Ranade, Sachin P., Green, Rhys E., 2019. Recent changes in populations of critically endangered Gyps vultures in India. *Bird. Conserv. Int.* 29 no. 1, 55–70.

Prakash, V., Pain, D.J., Cunningham, A.A., Donald, P.F., Prakash, N., Verma, A., Gargi, R., Sivakumar, S., Rahmani, A.R., 2003. Catastrophic collapse of Indian white-backed *Gyps bengalensis* and long-billed *Gyps indicus* vulture populations. Biol. Conserv. 109 (3), 381–390.

Ram, M., Sahu, A., Tikadar, S., Gadhavi, D., Rather, T.A., Jhala, L., Zala, Y., 2022. Home range, movement and activity patterns of six vulture species using satellite telemetry in Saurashtra landscape, Gujarat, India. Ecologies 3 (4), 492–507.

Rana, D.B., Chaudhary, I.P., Dangaura, H.L., Joshi, A.B., Bhusal, K.P., 2019. Monitoring of nest and breeding status of White-rumped Vulture *Gyps bengalensis* in Nepal. Vulture Bull. 8, 28–31.

Roy, A., 2007. Nesting of the White-rumped Vulture *Gyps bengalensis* in Orchha wildlife sanctuary, Madhya Pradesh, India. J. Bombay Nat. Hist. Soc. 110 (1). Jan-Apr 2013.

Samson, A., Ramakrishnan, B., 2020. The critically endangered white-rumped Vulture *Gyps bengalensis* in Sigur Plateau, Western Ghats, India: population, breeding ecology, and threats. J. Threat. Taxa 12 (13), 16752–16763. https://doi.org/10.11609/jott.3034.12.13.16752-16763.

Sehgal, A., Kumar, K., 2022. Nest records, nesting colony selection of oriental white backed vulture (*Gyps bengalensis*) and role of feeding station in Kangra, Himachal Pradesh. Acta Sci. Vet. Sci. 4 (1), 86–91.

Sharma, P., 2012. Aceclofenac as a potential threat to critically endangered vultures in India: a review. J. Raptor Res. 46 (3), 314–318.

Sharma, R.K., Bhatt, D., Sethi, V.K., & Joshi, V.D. (2007). Status and behaviour of white-backed and long-billed vultures in Rajaji National Park, Uttarakhand, India. *Tali 16 Rittpex*, 75.

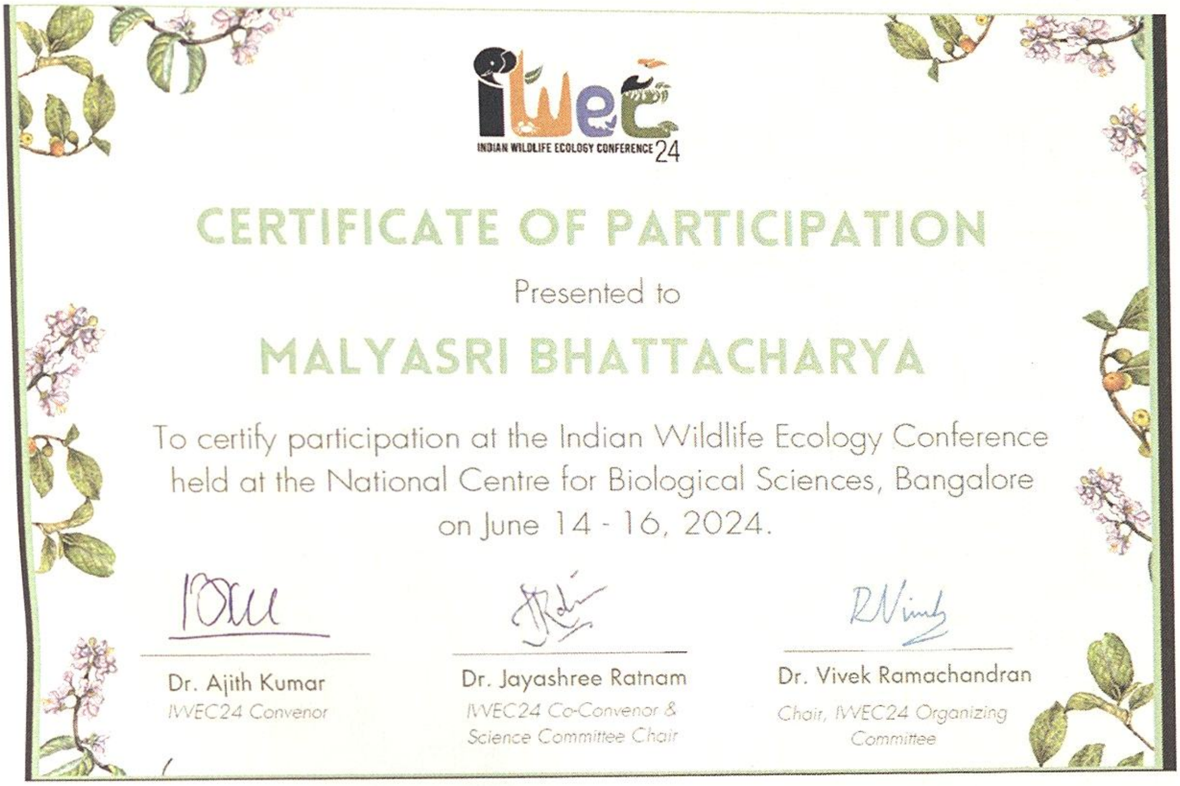
Sharma, K.R., Lekha, C., 2013. Tapping of *Pinus roxburghii* (chir pine) for oleoresin in Himachal Pradesh, India. Adv. For. Lett. (AFL) 2 (3), 53–57.

Sharma, R., Sharma, V., 2023. Land use management in the context of traditional vernacular settlements for hill areas of Himachal Pradesh. GeoJournal 1–11.
Steenhof, K., Kochert, M.N., McIntyre, C.L., Brown, J.L., 2017. Coming to terms about describing Golden Eagle reproduction. J. Raptor Res. *51* (3), 378–390.
Stokstad, E., 2021. Vultures face new toxic threat. Science 373 (6560), 1187-1187.
Suarez, S., Balbontin, J., Sua, M., 2000. Nesting habitat selection by booted eagles *Hieraaetus pennatus* and implications for management. J. Appl. Ecol. 37, 215–223.
Sutherland, W.J., Green, R.E., 2004. Habitat assessment. *Bird ecology and conservation.* Oxford University Press, Oxford, pp. 251–268.
Taggart, M.A., Senacha, K.R., Green, R.E., Cuthbert, R., Jhala, Y.V., Meharg, A.A., Mateo, R., Pain, D.J., 2009. Analysis of nine NSAIDs in ungulate tissues available to critically endangered vultures in India. Environ. Sci. Technol. 43 (12), 4561–4566.
Thakur, M.L., 2015. Breeding ecology and distribution of White-rumped Vultures (Gyps bengalensis) in Himachal Pradesh, India. J. Raptor Res. 49 (2), 183–191.
Thakur, M.L., Narang, S.K., 2012. Population status and habitat-use pattern of Indian White-backed Vulture (*Gyps bengalensis*) in Himachal Pradesh, India. J. Ecol. Nat. Environ. 4 (7), 173–180.
Thakur, P.K., Samant, S.S., Verma, R.K., Saini, A., Chauhan, M., 2024. Monitoring forest cover changes and its impact on land surface temperature using geospatial technique in Tatra Wildlife Sanctuary, Shimla, India. Environ., Dev. Sustain. 1–30.
United Nations. 2018. *Aichi biodiversity targets.*
Verner, J., Morrison, M.L., & Ralph, C.J. (Eds.). (1986). *Wildlife 2000. Modeling habitat relationships of terrestrial vertebrates.*
Vishnu, M., (2018). Status and habitat preferences of White-rumped Vulture (*Gyps bengalensis*) population of Wayand wildlife sanctuary, *Kerala* (Doctoral dissertation, Department of Wildlife Sciences, College of Forestry, Vellanikkara).
Walia, J.S. (2006). Sustainable forest management in Himachal Pradesh. World Forestry Center, World Forest Institute.
Wickham, H., Wickham, H., 2016. Get. Start. ggplot2. ggplot2: *Elegant Graph. data Anal.* 11–31.

3. Conferences attended

National: Bhattacharya, M and Talukdar (2024). Powerlines a major threat to vultures in Kangra. Indian Wildlife Ecology Conference, National Centre for Biological Sciences Bengaluru, June 14-16 2024.

Indian Wildlife Ecology Conference, National Centre for Biological Sciences Bengaluru, June.


IWEC

INDIAN WILDLIFE ECOLOGY CONFERENCE 24

CERTIFICATE OF PARTICIPATION

Presented to

MALYASRI BHATTACHARYA

To certify participation at the Indian Wildlife Ecology Conference held at the National Centre for Biological Sciences, Bangalore on June 14 - 16, 2024.

Dr. Ajith Kumar
IWEC24 Convenor

Dr. Jayashree Ratnam
IWEC24 Co-Convenor & Science Committee Chair

Dr. Vivek Ramachandran
Chair, IWEC24 Organizing Committee

Conferences attended(Abstract)

5. Powerlines a major threat to vultures in Kangra district, Himachal Pradesh

Presenting author: Malyasri Bhattacharya, Wildlife Institute of India, Dehradun; email: me.malyasri@gmail.com

Other authors: Gautam Talukdar, Wildlife Institute of India, Dehradun.

Powerlines pose a significant threat to global raptor populations. The Avian Power Line Interaction Committee (APLIC) underscores the peril of bird electrocution when contacting multiple energized wires. Recent surveys in Kangra, Himachal Pradesh, reveal a worrying increase in vulture electrocution. Fieldwork conducted near feeding stations on 110 kV transmission lines and 11kV/33kV distribution lines from December 2021 to March 2023 documented 19 fatalities among four globally threatened raptor species: Egyptian vulture, Eurasian griffon, Himalayan griffon, and White-rumped vulture. The mortality rates escalate during the vulture breeding season. Key risk factors include the proximity of power poles to feeding sites and uninsulated lines, necessitating urgent mitigation strategies. Existing avian safety measures implemented by electric companies, are inadequate to prevent avian mortality. Proposed measures include relocating or using bird diverters, insulating power poles and revising safety standards to accommodate vulture behavior. Heightened awareness and collaborative efforts are imperative to mitigate electrocution risks and safeguard vulnerable avian species.

Conferences attended

International:

Bhattacharya, M and Talukdar (2024). Conserving a globally threatened scavenger: habitat requirements and threats to nesting colonies of White-rumped Vultures from Himachal Pradesh, India.

Raptor Research Conference, Charlotte, North Carolina, USA. October 24-26,2024.

21 December 2024

Wildlife Institute of India
Dehradun, Uttarakhand
India

To whom it may concern,

Ms. Malyasri Bhattacharya presented her research work titled *"Conserving a Globally Threatened Scavenger: Habitat Requirements and Threats to Nesting Colonies of White-rumped Vultures from Himachal Pradesh, India"* at the Raptor Research Conference held in Charlotte, North Carolina, USA, from October 22–26, 2022, as a Wings to Fly awardee.

Sincerely,

Rob Bierregaard, President
Raptor Research Foundation
PO Box 4444
Topeka, KS 66604 USA
rbierreg@gmail.com
704-516-4615

Conference attended(abstract)

G09

Conserving a globally threatened scavenger: habitat requirements and threats to nesting colonies of White-rumped Vultures from Himachal Pradesh, India

Malyasri Bhattacharya, R Suresh Kumar, Gautam Talukdar
Wildlife Institute of India, Dehradun, Uttarakhand, India

Abstract

The critically endangered White-rumped Vulture (*Gyps bengalensis*), a tree-nesting species once abundant, is one of the most affected populations of endangered raptors from Asia after a rapid population decline from the 1990s. The population is now limited to only a few scattered pockets across India. These are the last surviving breeding populations of the species in the wild, and efforts are currently underway to secure them. One such population of White-rumped Vultures is known from the Himalayan foothills, representing India's northernmost breeding population. However, knowledge of successful breeding colonies and awareness of safeguarding the nesting sites still need to be improved. An extensive nest survey between 2020-2023 revealed 18 vulture nest colonies with 607 nests. Results showed vultures prefer taller, old-growth Chir Pine (*Pinus roxburghii*) trees having an average GBH of 254.8 cm (± 49.3 SD) and higher canopy cover. The distribution of the nesting colonies was primarily located in an elevation ranging between 500-800 m. Nest site selection mainly depended on the nest tree characteristics and associated threats to the breeding colony. Nesting sites are located in areas with forestry operations, such as selective logging, large-scale ground fire and extensive resin tapping. Nest failure was high during the fire season and declined afterwards. Overall, to protect the critically endangered bird, we recommend saving larger-sized old-growth forests with the help of awareness campaigns among forest managers and local people.

SESSION DETAILS

Breeding Biology I

Suite D
10:30-12:00

IN THIS SESSION

10:30-10:45
Nest-site selection of the Hooded Vulture in the Sudano-Sahelian area (Garango, Mogtédo, Burkina Faso)

Workshop attended

SAVE (Saving Asian Vultures from Extinction) workshop held in Royal Chitwan national Park, Nawalparsi, Nepal March 08-11,2023.

SAVE

SAVING ASIA'S VULTURES FROM EXTINCTION

Certificate of Participation

Malyasri Bhattacharya

To certify participation at the Saving asia's vulture from extinction(SAVE) meeting ,Nawalpur,Nepal from 9-10th March 2023

Chris Bowden
SAVE Advisor

4. Research Permit

H.P. FOREST DEPARTMENT, ARANAYA BHAWAN, TALLAND, SHIMLA-171001

No. WLM/Research Study/Vol-XIII/ 6426 Dated/ 8-12-2020

To:

Director,
Wildlife Institute of India,
Post Box No. 18, Chandrabani,
Dehradun-248001

Subject: **Request to carry out study for the project on "Ecology and Recovery of Critically Endangered Culture species in Pong Dam Protected Area (PA) and its adjoining areas in Himachal Pradesh-regarding.......**

Sir,

Kindly refer to your office letter No. WII/Vulture/12/GT/2019 dated 23rd November, 2020 on the subject cited above.

2. In this regard, as requested, the permission is hereby accorded in favour of WII Scientists and researchers of the project under Section 28(1) (c) of the Wildlife (Protection) Act, 1972 w.e.f. 15th December, 2020 to 31st December, 2023 in respect of following two points:-

I) **Logistic support for field work, base camp setup, etc. for the research team.**

II) **Ecological study including breeding, population and behavioral survey in Pong Dam Bird Sanctuary Kangra District and its surrounding areas.**

So far the permission regarding point No. 3 is concerned, you have to seek the prior approval from Civil Aviation Department to proceed further into the matter (Photocopy enclosed for ready reference).

So far the matter regarding waiving off of entry fee is concerned, the matter is being taken up with GoHP in this regard and will be intimated to you later on.

The said permission is however subject to the following conditions and all codal formalities:

a. No disturbance/ harm should be caused to the wildlife.
b. Destruction of natural habitat or roosting areas, nests or dens etc. of wild animal species is strictly prohibited.

c. The scholars/researcher should respect the local traditions and culture.

d. No waste material like polythene bags, other biological waste etc. is thrown in the area of work and cleanliness has to be maintained.

e. No fire, smoke etc. endangering the environment will be allowed in the forest area.

f. No digging/lopping/cutting and damage to plants, trees, soil surface/vegetation will be allowed. No plants/animals be removed from the area.

g. The natural water and other natural resources are not to be disturbed but kept clean.

h. No fuel wood/timber/medicinal plants shall be collected from the forests.

i. No construction of path, temporary road by breaking forest land will be allowed.

j. The research/findings shall be furnished to the CWLW, HP at the end of the research.

k. Charges of other activities inside the protected area e.g. pitching of tents etc. will charged by the concerned Divisional Forest Officers as per actual tents.

l. The Himachal Pradesh Forest Department Wildlife Wing shall not be responsible for the loss of life and/or property of the study/research Team members during the research period.

m. Any other condition, as would be imposed by as per ground situation, shall have to be fulfilled.

n. Any other condition, as would be imposed by the Divisional Forest Officers-cum-Wildlife Warden as per ground situation, shall have to be fulfilled.

o. It may be ensured that the instructions issued by GoI as well as State Government regarding COVID-19 be adhered to strictly.

Encl: As above.

Yours Sincerely,

Principal Chief Conservator of Forest (Wildlife)
and Chief Wildlife Warden, HP Shimla-171001