POPULATION STRUCTURE, BREEDING SUCCESS, AND BEHAVIOR OF WHITE-RUMPED VULTURE *Gyps bengalensis* IN THE GANDAKI RIVER BASIN, NEPAL

A THESIS SUBMITTED TO THE

CENTRAL DEPARTMENT OF ZOOLOGY

INSTITUTE OF SCIENCE AND TECHNOLOGY

TRIBHUVAN UNIVERSITY

NEPAL

FOR THE AWARD OF

DOCTOR OF PHILOSOPHY

IN ZOOLOGY

BY

RAMJI GAUTAM

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EXTERNAL EXAMINERS

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Asst. Dean

DECLARATION

Thesis entitled **"Population structure, breeding success, and behavior of white-rumped vulture *Gyps bengalensis* in the Gandaki River Basin, Nepal"** which is being submitted to the Central Department of Zoology, Institute of Science and Technology (IoST), Tribhuvan University, Nepal for the award of the degree of Doctor of Philosophy (Ph.D.), is a research work carried out by me under the supervision of Associate Prof. Dr. Hari Prasad Sharma of Central Department of Zoology, Tribhuvan University and co-supervised by Research Associate Dr. Nabin Baral of School of Environmental and Forest Sciences, University of Washington, Seattle, USA.

This research is original and has not been submitted earlier in part or full in this or any other form to any university or institute, here or elsewhere, for the award of any degree.

Ramji Gautam

RECOMMENDATION

This is to recommend that **Ramji Gautam** has carried out original research entitled **"Population structure, breeding success, and behavior of white-rumped vulture *Gyps bengalensis* in the Gandaki River Basin, Nepal"** for the award of Doctor of Philosophy (Ph.D.) in **Zoology** under our supervision. To our knowledge, this work has not been submitted for any other degree elsewhere.

He has fulfilled all the requirements laid down by the Institute of Science and Technology (IoST), Tribhuvan University, Kirtipur for the submission of the thesis for the award of Ph.D. degree.

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LETTER OF APPROVAL

Date: 22/4/2024

On the recommendation of Associate Prof. Dr. **Hari Prasad Sharma**/Research Associate, Dr. **Nabin Baral**, this Ph.D. thesis submitted by Ramji Gautam entitled **"Population structure, breeding success, and behavior of white-rumped vulture *Gyps bengalensis* in the Gandaki River Basin, Nepal"** is forwarded by the Central Department Research Committee (CDRC) to the Dean, IoST, T.U.

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Ramji Gautam

शोध सार

दक्षिण एसियामा व्यापक रूपमा फैलिएका डंगर गिद्ध (*Gyps bengalensis*) को संख्या तिव्र रूपमा घट्नुमा पशु उपचारमा प्रयोग हुने डेक्लोफेनेक औषधीको असर थियो । वि.सं. २०६३ (सन् २००६) मा यस औषधीको उत्पादन र प्रयोगमा छिमेकी देशसहित नेपालले प्रतिबन्ध लगायो । यस अध्ययनले प्रतिबन्ध पछिको अति संकटपूर्ण रूपमा रहेको डंगर गिद्धको दीर्घकालीन संख्याको अनुगमन, प्रजनन सफलता र पर्यावरणीय अवलोकनका बारेमा गण्डकी जलाधारमा अनुसन्धान गर्ने लक्ष्य राखेको थियो । वि.सं. २०६३ देखि २०७९ सम्म (सन् २००६ देखि २०२२) गण्डकी जलाधार क्षेत्रमा डंगर गिद्धको दीर्घकालीन संख्याको अनुगमन, प्रजनन सफलता र पर्यावरणीय अवलोकनका साथै गिद्धको व्यवहारमा गणितीय प्रयोग पनि गरियो । डंगर गिद्धले गुँड लगाउने रुखको पहिचान गरी गुँड लगाउने रुखका विशेषताहरूको बारेमा पनि अनुसन्धान गरिएको छ । बिंगत १६ वर्षको अध्ययन अवधिभर डंगर गिद्धको संख्यामा गिरावट रहेको देखियो । डंगर गिद्धको औसत निम्नतम संख्या ५४ र अधिकतम संख्या ११४ रहेको पनि पाइयो । जसमध्ये उच्चतम ९०.२३% वयस्क र क्रमैसँग अल्प-वयस्क र किशोर रहेका छन् । डंगर गिद्धको संख्याको प्रतिगमन वृद्धिदर (औसत गणना विधि (β = ०. ०१, t = १.०४, p = ०.३२ र अधिकतम गणना विधि β = ०. ०१, t = १.०४, p = ०.३२) स्थिर रहको देखियो । प्रजनन सफल गुँडको ३.७% वृद्धिले डंगर गिद्धको संख्यामा असर पार्‍यो । डंगर गिद्धका २४% (n = २०५) गुँड बनाउँदा, १६.८४% (n = १४४) ओथारो बस्दा र ११.२३% (n = ९६) बच्चा उडाउने बेलामा प्रजनन असफल रह्यो । डंगर गिद्धको प्रजननलाई वार्षिक वर्षा र औषत न्यूनितम तापक्रमले असर पार्‍यो । प्रजननको समयमा डंगर गिद्धले धेरै समय (> ७०%) सन्तानको रेखदेखमा व्यथित गरेको पाइयो । डंगर गिद्धले जम्मा १८ प्रजातिका रुखमा गुँड बनाए पनि सिमलको रुखलाई अधिकतम प्रयोग गरेको भेटियो । यसरी गुँड बनाउँदा जमिनबाट पहिलो अग्लो हाँगा र धेरै हाँगाहरू भएको रुखहरूलाई रोजेको पाइयो । अव्यवस्थित भौतिक संरचना र रुख कटानहरूले गर्दा डंगर गिद्धले आफ्नो गुड लगाउने स्थानहरूलाई असर गरेको भेटियो । जसले गर्दा डाइक्लोफेनेक प्रतिबन्ध पछि संख्या घट्नुमा प्रजननमा अवरोध, गुँड बनाउने रुखहरूको क्षति हुनु पनि यो गिद्धको संख्या घट्नुको प्रमुख कारण हो । डंगर गिद्धले गुँड बनाउने सिमलका ठुला रुखहरुको संरक्षण र विषाधिमुक्त सिनोको प्रयोगले यस गिद्धको लामो समयसम्म बाच्ने आधार खडा गर्ने छ । यस्ता दीर्घकालीन अध्ययनले डंगर गिद्धको प्रजाति र स्थान विशेष संरक्षण रणनीतिहरुको आधार स्थापित गर्ने छ भन्ने कुरालाई सारको रूपमा प्रस्तुत गरिएको छ ।

ABSTRACT

Once abundant, the white-rumped vulture (*Gyps bengalensis*), suffered a catastrophic population decline due to the veterinary use of diclofenac. South Asian countries, including Nepal banned veterinary diclofenac production, distribution, and use in 2006. However, little is known about the population trends on critically endangered white-rumped vulture within the Gandaki River Basin of Nepal. This study investigated the population trends of white-rumped vultures in the Gandaki River Basin through direct observations in the field from 2006 to 2022. This involved total count surveys to record a population size, and the number of occupied nests and productive nests. In addition, the white-rumped vulture behavioral sequences were also assessed during the breeding season using Monte Carlo simulations. This study also explored white-rumped vulture's tree species preferrences for nest building and the factors influencing it. This study found the white-rumped vulture population continuously declining over the past 16 years, despite the veterinary diclofenac ban. The minimum and maximum number of vultures were 54 and 114, respectively. Among the recorded individuals the highest average adult population was 90.23%, and followed by sub-adults, and juveniles. The intrinsic population growth rate was declining (mean-count: $\beta = 0.01$, $t = 1.04$, $p = 0.32$; maximum-count: $\beta = 0.01$, $t = 1.04$, $p = 0.32$) during the study period. The population growth was determined by the number of productive nests, which increased 3.7% in the study area. Twenty-four percentage (n = 205) occupied nests remained eggless during the egg laying period, 16.84% (n = 144) nests failed during incubation period, and 11.23% (n = 96) in fledgling period. The breeding success i.e., fledging of chicks from the nest was influenced by precipitation, and average maximum and minimum temperature. The behavioral sequence of white-rumped vulture indicated that they spent > 70% time in breeding activities and exhibited predatory behavior. The white-rumped vultures built nests on 18 tree species in the study area. The kapok/silk cotton tree (*Bombax ceiba*) was the preferred one for nest construction ($\chi^2 = 115.38$, df = 1, $p < 0.001$) among the available tree species. The nest construction of white-rumped vultures was influenced by specific tree characteristics, such as the number of whorls, canopy spread, and tree height. Unfortunately, human activities in infrastructure development and commercial logging of the nesting trees decreased the availability of large and matured trees in nesting sites for the white-rumped vultures. This study found that the major cause of the decrease in the nesting colony was the destruction of its nesting trees. This study indicates that veterinary diclofenac is not only the major determining factors for white-rumped population decline. Other factors, such as low breeding success, potential disruptions in behavioral patterns, and critical nesting habitat loss posed additional threats to the white-rumped vulture population in the Gandaki River Basin. Based on these findings, this study recommends prioritizing the conservation of kapok trees, a preferred nesting habitat for white-rumped vultures. These baseline data can be used for developing site-specific conservation strategies to increase vulture population sizes.

Keywords: *Conservation, Critically Endangered Species, Nesting Habitat, Predatory Behavior, Population Trend, Scavengers*

LIST OF ACRONYMS AND ABBREVIATION

AFS	: Augmented Focal Sampling
BLI	: BirdLife International
CITES	: Convention on International Trade in Endangered Species of Wild Fauna and Flora
DNPWC	: Department of National Parks and Wildlife Conservation
DoFSC	: Department of Forests and Soil Conservation
GoN	: Government of Nepal
IUCN	: International Union for Conservation of Nature
MCM	: Markov Chain Model
MoEF	: Ministry of Environment and Forests
MoEFCC	: Ministry of Environment, Forest, and Climate Change
MoFSC	: Ministry of Forests and Soil Conservation

LIST OF SYMBOLS

r	: Correlation Coefficient
$<$	: Less Than
p	: Probability Value
r	: Intrinsic Rate of Increase
α	: Level of Significance
β	: Slow of Line
λ	: Finite Population Growth Rate
μ	: Population Mean
σ^2	: Population Variance
χ^2	: Chi-square

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CHAPTER 1

1 INTRODUCTION

1.1 Background

Vultures are categorized into two distinct groups: new-world vultures and old-world vultures. The former one belongs to the Cathartidae family with seven species (Johnson *et al*., 2016; Ogada *et al*., 2012), and are found in North and South America. They exhibit a facultative scavengering behavior i.e., they scavange opportunistically but also hunt for feeding on carcass (Avery & Cummings, 2004). New world vultures have a well-developed sense of smell and eyesight to locate food (Houston, 1974; Potier *et al*., 2019). The later one belongs to the family Accipitridae with 16 species, and they are mostly obligate scavengers restricted to Africa, Asia, and Europe (Hunter *et al*., 2007; Murn, 2014). They rely on keen eyesight to locate carcasses (Houston, 1974). These scavengers play an essential fuction within the ecosystem by efficiently removing carcasses (Attwell, 1963), they prevent the spread of diseases (Moleón *et al*., 2014; Grilli *et al*., 2019; Vicente & Vercauteren, 2019) that could threaten both wildlife and human populations (Frank & Sudarshan, 2023).

Vultures, despite their important ecological role, are facing multitude of threats including the veterinary use of diclofenac (Green *et al*., 2004; Oaks *et al*., 2004; Shultz *et al*., 2004; Prakash *et al*., 2007), food shortage (Shah *et al*., 2019), habitat destruction (Hla *et al*., 2011; Gautam & Baral, 2013), electrocaution (Angelov *et al*., 2012; Hamal *et al*., 2023), and poisoning (Clements *et al*., 2013). These problems have caused a significant decline in their populations. These combined threats were major causes for the global vulture population decline by 74% in recent decades (BirdLife International (BLI), 2021). The old world vultures in their range countries have declined upto 81% until 2021 (BLI, 2021). Consequently, 50% of these species are critically endangered under the IUCN Redlist of threatened category (BLI, 2021). Among the nine vulture species of Nepal, 44% are listed as critically endangered species, including white-rumped vulture (*Gyps bengalensis*) (BLI, 2021).

The white-rumped vulture is a medium-sized (0.75–0.85 m in length with a wingspan of 1.92-2.6 m) vulture species. Its sexual diamorphism is not clearly distinguished. However, they can be distinguished in age classes based on their body size, color, and body feathers. Adults are comparatively larger (~0.75–0.85 m in length) with black body, white neck-ruff, rump, and underwing-coverts. Sub-adults are medium-sized and drabber brown in color. Juveniles are smaller (< 0.75–0.85 m in length) and dark brown with prominent white shaft-streaks and white down on head and neck (Alstrom, 1997; Grimmett *et al*., 2016).

The white-rumped vulture is widely distributed across South Asia and Southeast Asia. They are found in Bangladesh, Bhutan, Brunei Darussalam (non-breeding), Cambodia, India, Myanmar, Nepal, Pakistan, and Russian Federation (non-breeding) (Ali & Ripley, 1987; Hla *et al*., 2011; BLI, 2021). The species typically inhabits tropical and subtropical regions. In Nepal, it is a resident breeder and inhabits upto 1,800 m in summer (DNPWC, 2015; Grimmett *et al*., 2016).

The white-rumped vulture was the most common and abundant species across its distribution ranges before the 1990s. Unfortunately, its population experienced a catastrophic decline in the mid-1990s (Prakash, 1999; Giltbert *et al*., 2002; Prakash *et al*., 2003; Sarrazin *et al*., 2004). Later, it was confirmed that the main reason for the population crash was the veterinary use of diclofenac, a non-steroidal anti-inflammatory drug (Green *et al*., 2004; Oaks *et al*., 2004; Shultz *et al*., 2004).

After the devastating population crash of the vultures in South Asian countries, mainly in Nepal, India, and Pakistan, white-rumped vulture's current estimated global population ranges between 4,000 to 6,000 individuals in the wild (BLI, 2021). The population of the species was decreased >99% in India during the period 1992 to 2015 (Prakash, 1999; Prakash *et al*., 2024), 63% in Pakistan during the period 2000 to 2003 (Giltbert *et al*., 2004), and 60% in Bangladesh (Khan, 2013). In Nepal, 2,000 individuals are estimated in the wild (DNPWC, 2015). A critical intervention was initiated in 2006 by the government to ban veterinary use of diclofenac (DNPWC/MoFSC/GoN, 2009; DNPWC, 2015; MoEF, 2016; MoEFCC, 2020). However, the threats of pharmaceutical poisoning persist, with vultures potentially susceptible to other drugs like ketoprofen (Naidoo *et al*., 2010), aceclofenac (Galligan *et al*., 2016), and nimesulide (Cuthbert *et al*., 2016). To address this ongoing challenge and reverse the population decline, Nepal implemented a comprehensive Vulture Action Plan in 2009 with key strategies including the establishment of artificial breeding center to sustain the vulture populations, vulture restaurants or vulture safe feeding sites to provide safe food, diclofenac-free zones to further minimize exposure to contaminated carcasses, and public awareness about the importance of vulture conservation (DNPWC/MoFSC/GoN, 2009; DNPWC, 2015; DNPWC & DoFSC, 2023). These efforts demonstrate Nepal's commitment to safeguarding ecologically vital scavengers including white-rumped vultures.

Despite being one of the most closely monitored raptor species, the white-rumped vulture population in Nepal experienced a continuous decline over the past two decades (Baral *et al*., 2005 & 2013; Chaudhary *et al*., 2012). Interestingly, a consistent pattern is reported across the country, with population declines being slower in the western regions compared to eastern regions (Giri & Baral, 2001; Chaudhary *et al*., 2012; Prakash *et al*., 2012; Baral *et al*., 2013; Gautam & Baral, 2013; Bhusal *et al*., 2020). This spatial variation in decline rates necessitates further investigation to understand the underlying factors, such as breeding success, and behavior and habitat characteristics for more targeted conservation efforts.

The breeding success of white-rumped vultures directly impacts their population size. The quality of nesting habitats and their availability are primary determinants of breeding success (Newton, 1980). However, Nepal has experienced a gradual decline in vulture colonies due to breeding failures and nesting habitat loss (Baral *et al*., 2005; Gautam & Baral, 2013).

Changes in traditional livestock farming practices and carcass disposal in Nepal have worsened food scarcity for white-rumped vulture. It indicates the importance of ongoing conservation initiatives (Baral *et al*., 2005; Baral & Gautam, 2007; BLI, 2021). The establishment of vulture safe feeding sites is one of the critical conservation strategies in Nepal (DNPWC/MoFSC/GoN, 2009), which serves as a crucial intervention to address the food scarcity issue (DNPWC, 2015). These sites provide a controlled location, where old, unproductive, and dying cattle are collected, and consumed by vultures after their natural death. However, the effectiveness of vulture safe feeding sites need evaluation. One concern is the potential alteration of natural foraging behavior. Vulture safe feeding sites might reduce the vultures' natural carcass searching activities and even lead them to attack weak or non-aggressive cattle (Duriez *et al*., 2015). The frequent availability of carcasses at vulture safe feeding sites, concentrated near dying cattle, could be a factor influencing this behavior. Investigating such potential changes in white-rumped vulture behavior might have valuable information. Understanding these behavioral changes could not only inform the future vulture safe feeding site management practices but also provide valuable baseline data for behavioral science.

The behavioral activities of an individual vulture depend upon various internal and external factors (Boake, 1994), and they vary between individuals based on the circumstances (Bell *et al*., 2009). For example, a sudden decrease in the number of individauls in a community can cause various psychological effect on the survival one. In this situation, the gathered data on behavior are crucial information for the management and conservation of the critically endangered species.

The white-rumped vultures are obligate tree nesters and require large, tall trees for successful breeding (Ghimire *et al*., 2019). However, their specific nesting tree preferences and selection within these trees are limited. Understanding nesting behavior is important because it directly impacts the breeding success. For example, the nesting height above the ground, potentially linked to protecting chicks from predators (Baral *et al*., 2005; Grimmett *et al*., 2016; Majgaonkar *et al*., 2018). In addition, identifying the tree species and specific locations, such as branching order, whorl within the trees favored by white-rumped vultures potentially link to breeding success. However, knowledge on white-rumped vulture's nesting ecology is little known.

Despite ongoing efforts, a significant knowledge gap persists regarding the white-rumped vultures' long-term population structure, breeding success, behavior, and nesting ecology in Nepal. While population monitoring, conservation practices, and management have been focused, crucial aspects of their breeding success, behavior, and nesting ecology remain understudied. This study investigated long-term population trends for assessing the viability of breeding colonies, breeding success to assess the population dynamics, breeding behavior for identifying the current activities and its influence on reproductive outcomes, and identifying the preferred nesting habitat characteristics for informing the habitat conservation strategies. This comprehensive study provides the data which are necessary to develop site-specific conservation programs, and such programs can then be used to guide the recovery of white-rumped vulture populations in Nepal.

1.2 Rationale

The white-rumped vulture's population trend exemplifies the impact of human actions on wild populations. In the middle of 1990s, white-rumped vulture experienced a catastrophic population decline (Prakash, 1999). The use of diclofenac to treat the livestock was the main cause of the death of white-rumped vulture in south Asain countries (Green *et al*., 2004; Oaks *et al*., 2004; Shultz *et al*., 2004). Due to rapid population decline, white-rumped vultures are classified as critically endangered species since 2000 (BLI, 2021). Fortunately, recorgniszing the urgency of the situation, the Nepal Government banned the manufacture, distribution, and sale of diclofenac in 2006 (DNPWC/MoFSC/GoN, 2009). However, despite the ban, the white-rumped vulture populations continued to decline (Chaudhary *et al*., 2012; Baral *et al*., 2013; Gautam & Baral, 2013). Potential explanations for that ongoing decline are likely food shortages, habitat destruction, human persecution, and unintentional poisoning (BLI, 2021). This urges the need for a multifaceted conservation approach to address the threats and ensure the recovery of this ecologically vital scavenger. This study aimed to minimize the knowledge gap on white-rumped vultures in Gandaki River Basin, Nepal by collecting data on long-term population trends, breeding success, behavior, and nesting tree prefernces to inform the development of a site-specific and species-specific management plan for their conservation after the banning of diclofenac. Such programs can then be used to guide reintroduction efforts and ultimately to promote the recovery of white-rumped vulture populations in Nepal.

1.3 Objectives

The general objective of the study was to count the population size, breeding success, general behavior, and nesting ecology of white-rumped vulture in the Gandaki River Basin, Nepal. The specific objectives of the study were:

i) To assess the population size of different age classes of white-rumped vultures in the Gandaki River Basin, Nepal.
ii) To assess the breeding success of white-rumped vultures in the Gandaki River Basin, Nepal
iii) To evaluate the behavior of white-rumped vultures in the Gandaki River Basin, Nepal.

iv) To analyze the nesting tree preferences by white-rumped vultures in the Gandaki River Basin, Nepal.

1.4 Organization of the thesis

This study presents a comprehensive investigation of white-rumped vultures in the Gandaki River Basin of Nepal. It covers a wide range of aspects of population size, breeding behavior, nesting ecology, and overall success of white-rumped vulture population. Chapter 1 has research concept and a comprehensive background section that summarizes relevant prior studies and literature. The remaining five chapters present the research findings. Chapters 2 to 5 focused on specific results intended for publication, with two chapters already published in peer-reviewed journals. These chapters provide concise description of the method and discussion to focus on the main results.

In Chapter 2, the population of white-rumped vulture, and the factors affecting the population size were investigated. Chapter 3 estimated the breeding success of white-rumped vultures based on occupied and active nests as a primary unit. Chapter 4 focused on white-rumped vulture behaviors using a Markov chain model. Chapter 5 identified factors that influence the white-rumped vulture's nest construction. Lastly, Chapter 6 provides a concluding summary, overall conclusions, and recommendations for future. These subsequent chapters provide a wider understanding of the white-rumped vulture population, breeding habits, and nesting ecology.

CHAPTER 2

LONG-TERM POPULATION MONITORING OF WHITE RUMPED VULTURE IN THE GANDAKI RIVER BASIN, NEPAL

Abstract

Population trends are determined by birth rate, death rate, immigration, and emigration. These demographic parameters are obtained by regular monitoring of population. This study used direct observation and total count methods to assess the population size of the critically endangered white-rumped vulture (*Gyps bengalensis*) in Nepal's Gandaki River Basin between the 2006/07 and 2021/22. Nineteen colonies were monitored, and identified a decline of 20.18% in mean population and 17.65% maximum population size. The adult vulture population remained high throughout the study period. The temperature and precipitation were major influencing factors for population fluctuation. Average minimum temperature and total rainfall had positive impact on vulture numbers, while extreme temperature and excessive rainfall had a negative effect. In addition, a decrease in carcasses availability (66.67%), and colony abandonment (68.42%) were other major threats in the study area. The study suggests to minimize the human disturbance and ensuring consistent access to quality food sources to vulture population recovery.

2.1 INTRODUCTION

Changes in a species population size over space and time is population trends, which can be determined by either regular data collection in a specific area or by synthesizing data from published studies across different periods (Nichols & Williams, 2006; Wegge *et al*., 2022). Long-term monitoring of colonies is another important source of population trend data, crucial for species conservation efforts (Yoccoz *et al*., 2001; Baral et al., 2013; Paleczny *et al*., 2015). Population trend data plays a vital role in proactive species management, which allows for timely interventions to prevent extinction by guiding the implementation of conservation and management strategies (Durant *et al*., 2007; Baral *et al*., 2013; Jones *et al*., 2013). Furthermore, data from monitoring programs can raise public awareness about population shifts, motivating conservation efforts (Walsh *et al*., 2023). It also informs the public about environmental health, potential drivers of population changes (Hudson *et al*., 2017), and the effectiveness of conservation actions for threatened species (Prakash *et al*., 2024). In addition, regular monitoring is also essential for evaluating management effectiveness and policy decisions (Nichols & Williams, 2006). Therefore, well-designed and analyzed monitoring studies are essential to understand the drivers of population decline and prioritize research for implementating conservation actions (Kéry & Schmidt, 2008; Goldsmith, 2012). In addition to population size, understanding the factors influencing population dynamics is equally important for species conservation (DNPWC/MoFSC/GoN, 2009).

Food shortage and environmental factors are key drivers of population fluctuations (Kamp *et al*., 2021). Food availability and suitable habitat significantly impact reproductive success by providing essential nutrients for growth and development (Jenkins, 2000; Harrison *et al.*, 2010; Mihoub *et al*., 2012), directly influencing population growth. Mismatches between breeding cycles and food resource availability can cause bird population declines, particularly among migratory and resident species (Both *et al*., 2006; Sanderson *et al*., 2006; Moller *et al*., 2008). Climate change is likely to further exacerbate this issue for resident bird populations by affecting their behavior and reproduction (Netwon, 1998). For example, it can accelerate species' physiological changes and distribution shifts (Stenseth *et al*., 2002). Climate change can also trigger natural disasters, such as storms and floods, which become major factors in nest failure (Newton, 1998; Keyser, 2002; Baral *et al*., 2013), ultimately limiting population size. The negative effect of preciptation (snowfall and rainfall) was noticed on breeding density in griffon vulture (*Gyps fulvus*) and breeding success in Egyptain vulture (*Neophron percnopterus*) (Donazar *et al*., 1993; Zuberogoitia *et al*., 2019). In addition, the temperature can also influence foraging and flying time (Shepard *et al*., 2013; Williams *et al*., 2018) as seen in bird species (*See* Andean condor *Vultur gryphus*; Márquez-Alvis *et al*., 2023), however, the specific effects of climatic factors on white-rumped vultures (*Gyps bengalensis*) is little known.

The white-rumped vulture, a critically endangered vulture species, is of medium-sized (length: 0.75-0.85 m; wingspan: 1.92-2.6 m) and tree nester (Ali & Ripley, 1987). It is primarily distributed in the southern region of the Himalayas from Pakistan to Bangladesh at altitudes below 1800 m above sea level (Grimmett *et al*., 2016; BLI, 2021). They can fly long distances which allow to search carcasses over a large areas (Houston, 1974). Their blade head and long neck are usually adapted to feed upon the internal soft body parts of deceased ungulate carcasses. They are found to consume the organs by passing their head through anal part or hole on body made by other scavengers (Ali & Ripley, 1987). In case of food shortage, they may attack live, immovable weak cattle, targeting the eyes, tongue, and anal sphincter if the cattle are lying near partially consumed carcasses (Duriez *et al*., 2019).

Previously, the white-rumped vulture was the most prevalent and abundant species in the wild, with population more than millions of individuals across its distribution range (Ali & Ripley, 1987). Later in mid-1990s, its population was decreased catastrophically (Hla *et al*., 2011; Chaudhary *et al*., 2012; Prakash *et al*., 2012; Baral *et al*., 2013). The current estimated global population is <6,000 individuals (BLI, 2021), with <2,000 individuals in Nepal (DNPWC, 2015). The dramatic decline in white-rumped vulture population was due to the veterinary use of diclofenac, a non-steroidal anti-inflammatory drug (Oaks *et al*., 2004; Shultz *et al*., 2004; Gilbert *et al*., 2004; Hla *et al*., 2011). This drug was found lethal to vultures when they consumed carcasses of livestock treated shortly before their death (Oaks *et al*., 2004; Shultz *et al*., 2004). After recognizing the dire situation, a multi-national effort led to a ban on the production, transportation, and use of diclofenac in Bangladesh, India, Nepal, and Pakistan since 2006 (DNPWC, 2015; MoEF, 2016; MoEFCC, 2020). Further the additional conservation interventions were implemented to safeguard the white-rumped vulture from extinction, including the establishment of vulture-safe feeding sites, vulture breeding centres, and diclofenac-free zones across its distribution range, including Nepal (Mukherjee *et al*., 2014; DNPWC, 2015). These initiatives were designed to mitigate the threats faced by the white-rumped vulture. To implement these conservation strategies effectively, the Government of Nepal adopted the Vulture Action Plan in 2009, 2015, and 2023 (DNPWC, 2015; MoEF, 2016; DNPWC & DoFSC, 2023).

Despite conservation efforts, knowledge regarding the population size and influencing factors of white-rumped vultures remains limited, particularly after diclofenac ban in 2006 (Chaudhary *et al*., 2012; Prakash *et al*., 2012; Baral *et al*., 2013; Gautam &

Baral, 2014). To address this knowledge gap, this study aimed to investigate the population size and factor affecting white-rumped vulture populations within the Gandaki River Basin of Nepal over the past 16 years. This study hypothesize that the white-rumped vulture population has increased since the diclofenac ban in Nepal.

2.2 METHODS

2.2.1 Study area

The Gandaki (Narayani) River Basin includes seven tributaries: Trisuli, Budhi Gandaki, Marsyangdi, Madi, Seti, Modi, and Kali Gandaki also referred to as Sapta Gandaki. It is a trans-boundary sub-river basin of the Ganges Mega-river Basin (82.88º to 85.81º E and 27.32º to 29.33º N) (Bajracharya & Shrestha, 2011; Dandekhya *et al*., 2017) (Figure 1). Its elevation ranges from 44 m to 8,167 m above sea level. It covers 44,770 km^2 in the Central Himalaya, China (Tibet comprises ~10%), Nepal (comprises ~72%), and India (~18%) (Dandekhya *et al*., 2017). In Nepal, the basin encompasses 19 districts at different ecological regions (Mountain, Hill, and Tarai). The study was focused on four districts within the basin: Kaski, Syangja, Tanahu, and Palpa (83°15' to 84° 46' E and 27° 26' to 28° 36' N) in hilly region of Nepal which still has active white-rumped vulture roosting and nesting colonies during the study period. The first three districts are situated in Gandaki Province, while the last one Palpa district is situated in Lumbini Province of Nepal. The area comprises 5,996 km^2. The southern regions are hilly with a tropical monsoonal climate while the north regions have an alpine tundra climate. The rainy season extends from June to September, followed by cool dry winter from October to January, and a hot dry summer from February to May. The absolute maximum and minimum temperature recorded in the study area were 42.2°C and 0.5°C in May 2007 in Chapakot and January 2013 in Syangja, respectively in 2006 and 2021. In the same period, the total amount of annual precipitation ranged from 2,984.40 mm to 5,399.58 mm and the average annual precipitation was 3,720.92 mm.

The nesting colonies of white-rumped vultures are recorded between 303 m to 1,168 m above sea level which had the mixed forest of sal tree (*Shorea robusta*), needlewood tree (*Schima wallichii*), chestnut (*Castanopsis indica*), redcedar (*Cedrela tuna*) kapok/silk cotton (*Bombax ceiba*), cutch tree (*Senegalia catechu*), and alder (*Alnus nepalensis*) trees falling in the subtropical and temperate climatic zones. The common avian fauna includes Asian koel (*Eudynamys scolopaceus*), kalij pheasant (*Lophura leucomelanos*), spangled drongo (*Dicrurus hottentottus*), spotted owlet (*Athene brama*), and black kite (*Milvus migrans*). The common mammalian fauna includes jungle cat (*Felis chaus*), Indian hare (*Lepus nigricollis*), and rhesus macaque (*Macaca mulatta*), yellow-throated marten (*Martes flavigula*).

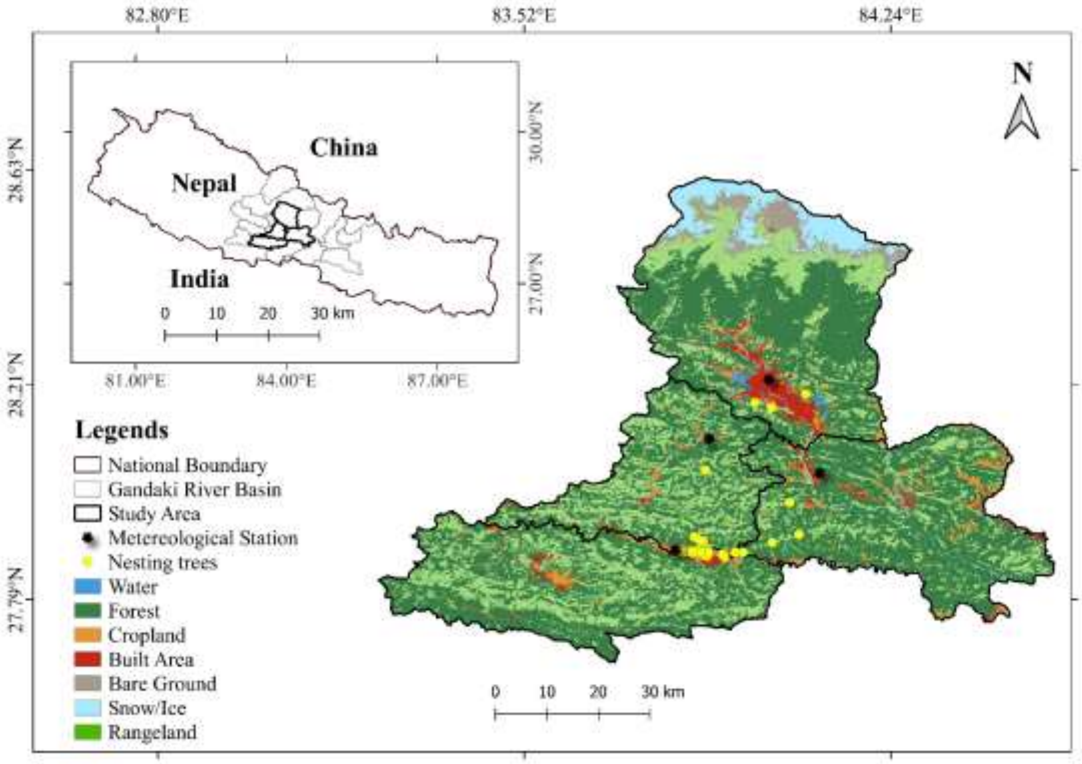

Figure 1: Study area with white-rumped vulture nesting trees in the Gandaki River Basin, Nepal

2.2.2 Data collection

2.2.2.1 Total count

A total count method was applied in the field to count the individuals of white-rumped vulture between 2006/07 and 2021/22. The population census was regularly recorded by following the same protocol applied by Baral and Gautam (2013) in which all roosting and nesting sites were visited during early in the morning (06:30-09:30 hr) and late in the evening (15:00-18:30 hr) during breeding season. As all white-rumped vulture colonies were small and a total count was done in each visit. Visits were made in each of nest building, incubation, and chick raising periods. All the white-rumped vultures seen on nests and perched at roosts including non-breeders were recorded (Dobrev *et al.*, 2020). During this study, white-rumped vultures were catagorized into four age classes based on their plumage (Alstrom, 1997): adults (> 3 years old) with black body and white under wing-coverts, neck-ruff, and rumped, sub-adults (1-3 years old) with drabber brown in color, juveniles (four month to one year old) with dark brown with prominent white shaft-streaks, and nestling (<4 months old) with dark brown color with creamy head (Alstrom, 1997; Grimmett *et al*., 2016).

The meteorological data were collected from the Department of Meteorology and Hydrology, Babar Mahal, Kathmandu. The meteorological data, especially daily maximum temperature, minimum temperature, and precipitation were collected from four stations: Pokhara Airport, Putalibazar, Khairinitar and Chapakot near by the vulture colonies of Kaski, Syangja, Tanahu and Palpa district, respectively. From these meterological data, 15 variables were prepared to evaluate the effect of the variables to the population sizes (Appendix I).

In addition, the number of dead white-rumped vultures were recorded in and around the nesting and roosting sites. The reason of death was also recorded after the consultation with local people and veterinary officials. In addition, livestock carcasses in the vicinity of nesting and roosting sites were also recorded opportunistically.

2.2.3 Data analysis

The log transformation was applied to the finite rate of population growth to calculate linear regression. The log geometric mean population growth (μ) and the variance of the change in population sizes (σ^2) was calculated. To assess the population trend, a total of 16 years data (between the breeding season 2006/07 and 2021/22) were used. The finite rate of population growth (λ) was estimated by N_{t+1}/N_t and the intrinsic rate of population growth (r) was estimated by taking log of finite rate of population growth i.e. log (λ) in both the mean population and the maximum replicate count. The population mean is the summation of individuals from all census divided by total census in a particular year and the maximum population was the higest number of individual recorded in a particular year.

Confidence intervals were estimated for each parameter by following Dennis *et al*. (1991). The following formula:

$$\mu \pm t_{\alpha\, q-1} \times SE(\mu) \qquad (1)$$

Where, $t_{\alpha\ q-1}$ is the critical value of a t-distribution with $\alpha = 0.05$ and $q = 15$ because 16 annual surveys data were collected. The confidence limits for σ^2 were estimated by using the chi-squared distribution with q–1 degree of freedom

$$(q - 1)\ \sigma^2/\chi^2_{0.025,\ q-1},\ (q-1)\ \sigma^2 / \chi^2_{0.975,\ q-1} \qquad (2)$$

The correlation coefficient r was calculated to find the relationship between the population sizes with 15 meteorological variables such as average maximum temperature, average minimum temperature, absolute maximum temperature, absolute minimum temperature, average daily mean temperature, average daily different temperature, total precipitation, longest dry day, longest wet day, dry spell, wet spell, total rainy day, extreme rain, daily rain intensity, and yearly rain intensity of entire year (Appendix II). The highly correlated $r > 0.7$ variables were excluded from the analysis. A generalized linear model was used with yearly meteorological data to identify their effects on maximum abundance of white-rumped vultures. All the analysis were performed in R Program (R Core Team, 2022).

2.3 RESULTS

2.3.1 Population size and age structure of white-rumped vulture

In the last 16 years between the breeding season 2006/07 and 2021/22, the mean and maximum replicate count of white-rumped vultures was ranged from 54 to 114 (± 16.84 SD) with confidence interval 68 to 86 and 71 to 144 (± 21.67) with confidence intervals 89 to 112, respectively (Table 1). The mean values (μ) of intrinsic rate of population growth were negative with confidence intervals. The mean and maximum replicate counts ranged from -0.13 to 0.10 and -0.13 to 0.10 and intrinsic rate of population growth of mean and maximum replicate counts ranged from -0.24 to 0.42 and -0.32 to 0.52, respectively. The overall mean and maximum-count population were declined by 20.18% and 17.65%, respectively. The annual rate of decreased in mean and maximum population count was 1.26% and 1.10% in the breeding season between 2006/07 and 2021/22, respectively.

The mean value of population growth rates was positive: the mean-count ($\beta = 0.02$, $t = 1.49$, $p = 0.16$) and the maximum-count ($\beta = 0.01$, $t = 1.04$, $p = 0.32$).

The moderate positive correlation ($r = 0.3$ to 0.5) was found between the maximum population with absolute maximum temperature, average minimum temperature, average maximum temperature, and average daily mean temperature. Likewise, the moderate negative correlation (r = -0.3 to -0.5) was found in between maximum abundance with longest wet day (r = -0.4) and total rainy day (r = -0.5) (Appendix II).

The total precipitation, average minimum temperature, absolute maximum temperature, average daily different temperature, wet spell, total rainy day, extreme rain, daily rain intensity, and yealy rain intensity were major influencing factors to the population of white-rumped vultures during the breeding season 2006/07 and 2021/22 (Table 2).

Table 1: White-rumped vultures' abundance, the finite rate of population growth, and intrinsic growth rate in the Gandaki River Basin, Nepal. Λ: the finite rate of increase; r: intrinsic rate of increase; μ: the arithmetic mean of population growth rate (r); σ^2: the variance of μ; N_t and N_{t+1}: population at time t and t+1; the values in parentheses: 95% confidence intervals

Survey year	**Mean of replicate counts**			**Maximum replicate counts**		
	Abundance	**$\lambda=N_{t+1}/N_t$**	**r=log(λ)**	**Abundance**	**$\lambda=N_{t+1}/N_t$**	**r=log(λ)**
2006/07	114	-	-	136	-	-
2007/08	98	0.86	-0.15	144	1.06	0.06
2008/09	80	0.82	-0.20	105	0.73	-0.32
2009/10	63	0.79	-0.24	92	0.88	-0.13
2010/11	76	1.21	0.19	94	1.02	0.02
2011/12	74	0.97	-0.03	106	1.13	0.12
2012/13	90	1.22	0.20	116	1.09	0.09
2013/14	72	0.80	-0.22	90	0.78	-0.25
2014/15	61	0.85	-0.17	75	0.83	-0.18
2015/16	66	1.08	0.08	71	0.95	-0.08
2016/17	54	0.82	-0.20	89	1.25	0.23
2017/18	68	1.26	0.23	87	0.98	-0.02
2018/19	62	0.91	-0.09	90	1.03	0.03
2019/20	65	1.05	0.05	75	0.83	-0.18
2020/21	99	1.52	0.42	126	1.68	0.52
2021/22	91	0.92	-0.08	112	0.89	-0.12
Mean(μ)	-0.02 (-0.13 to 0.10)			-0.01 (-0.13 to 0.10)		
Variance (σ^2)	0.04 (0.001 to 0.007)			0.04 (0.001 to 0.008)		

The population structure of adults, sub-adults, and juveniles of white-rumped vultures were ranged from 67 to 135 (± 18.99), 2 to 11 (± 2.52), and 0 to 18 (± 4.52), respectively (Figure 2). The ratio of adults, sub-adults, and juveniles of white-rumped vulture was 90.23% (n = 1,450), 5.29% (n = 85), and 4.48% (n = 72), respectively. During the study period, the average death rate of white-rumped vultures was 2 ± 4.13 (min = 0; max = 16) with adults 46.88% (n = 15) and chicks 53.13% (n = 17) in the study area. These deaths were from heavy storm (37.5%), unintentional poisoning (6.25%), electrocution (3.13%) and predation (3.13%), however, 50% of remaining vultures' death was unknown.

2.3.2 Food availability

A total of 82 carcassess was recorded from the study area in the last 16 years. The annual mean carcasses availability was 5.13 ± 4.73 (min = 0; max = 18). Among 82 carcasses, majority (95%; n = 78) were from livestock (cow: 58.54%; buffaloes: 30.78%; goats: 5.13%, and unidentified livestock: 2.56%) and remaining 5% were dog's carcasses. The carcasses availability was decreased by 66.67% during the study period between 2006/07 and 2021/22.

Table 2: Generalized linear model for factors affecting the population size of white-rumped vultures in the Gandaki River Basin, Nepal. Variables maximum abundance was used as response variable, and average minimum temperature (°C), absolute maximum temperature (°C), absolute minimum temperature (°C), average daily different (°C), precipitation (mm), longest dry day (number), wet spell (number), total rainy day (number), extreme rain (mm), daily rain intensity (mm/h), and yearly rain intensity (mm/day) were random variables for the model

Variable	Estimate	SE	z	P
Intercept	3.99	1.24	3.23	0.001
Average minimum temperature	0.42	0.06	7.02	<0.001
Absolute maximum temperature	-0.08	0.03	-2.80	0.005
Absolute minimum temperature	-0.01	0.02	-0.55	0.59
Average daily different	-0.13	0.05	-2.43	0.01
Precipitation	<0.001	<0.001	9.32	<0.001
Longest dry day	<0.001	0.002	0.26	0.80
Wet spell	-0.03	0.006	-5.06	<0.001
Total rainy day	-0.02	0.002	-9.31	<0.001
Extreme rain	-0.003	<0.001	-3.81	<0.001
Daily rain intensity	0.10	0.01	6.94	<0.001
Yearly rain intensity	-0.05	0.01	-6.26	<0.001

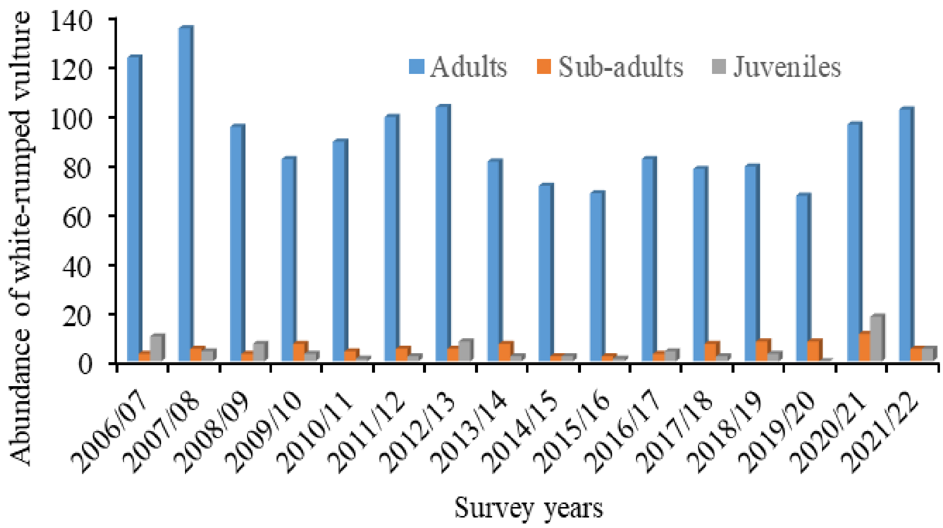

Figure 2: Adults, sub-adults, and juveniles of white-rumped vultures in the Gandaki River Basin, Nepal

2.4 DISCUSSION

Over the past 16 years the overall population size of white-rumped vultures decreased slightly in the Gandaki River Basin of Nepal. Despite the negative trend, the mean and maximum growth rates did not significantly change. The population decline might be due to habitat destruction and human disturbances (*see* Chapter 5) with a high number of colony desertions. Interestingly, the productive nest was increased by 3.70% in the past 16 years in the study area (see Chapter 3), however, the population of white-rumped vultures was decreased in the same period. It might be due to the local emigration of individuals or their death (see death from unintentional poison and electrocaution between 2011 and 2023; Bhusal *et al.*, 2023; Hamal *et al.*, 2023). In addition, the white-rumped vulture population decline was due to the chick collection from the study areas ex-situ conservation by Vulture Conservation and Breeding Centre, Chitwan National Park (DNPWC/MoFSC/GoN, 2009) as well as logging of roosting and nesting trees (Baral *et al.*, 2005; Gautam & Baral, 2013). However, a partial recovery of the white-rumped vultures' population was recorded in western Nepal between 2002 and 2018 (Galligan *et al.*, 2019) and a stable number of nests was observed in the monitoring colony in Arghakanchi district of Nepal during the period between 2010 and 2021 (Bhusal *et al.*, 2023). It might be due to establishment of vulture safe feeding sites, diclofenac-free zone, and captive breeding and released programs of the species. However, the results of previous studies showed the rapid decline of the population and the nests in tarai region of Nepal between 2002 and 2011 (Chaudhary *et al*., 2012; Prakash *et al*., 2012) where majority of vulture safe feeding sites are located (DNPWC, 2015).

The rate of population decline was site specific (Gautam & Baral, 2012 & 13; Baral *et al*., 2013). The overall result of write-rumped vulture population decline was lower than the population decline in the south Asian and south east Asian countries (Gilbert *et al*., 2004; Prakash *et al*., 2007; Hla *et al*., 2011; Khan, 2013). It might be due to the ban of veterinary use of diclofenac in Asian countries (*see* banned in Nepal, India and Pakistan in 2006; Bangladesh in 2010; Oaks *et al*., 2004; Shultz *et al*., 2004) and establishment of vulture safe feeding sites (DNPWC/MoFSC/GoN, 2009). In addition, breeding failure, habitat destruction and anthropogenic disturbances were the reasons of local population decline in Nepal (Baral *et al*., 2005; Gautam & Baral, 2012; Baral *et al*., 2013; BLI, 2017). The white-rumped vulture population in the study area exhibited a continuously decline of 42.28% (decreased from 123 to 71 individuals) before 2015/16. Fortunately, there has been a positive trend since then. It might be due to the carcasses availability, low human disturbance, and low nesting habitat destruction in the study area. Over the past decade, the total number of carcasses availability was decreased. It was probably change in the traditional practice of livestock farming and carcasses disposal system due to modernization and sanitary policy (Donazar *et al*., 2010) where the dead bodies of livestock buried immediately after the death. However, after the establishment of vulture safe feeding sites and diclofenac-free zone, people voluntarily provide the old and unproductive cow to the site (DNPWC/MoFSC/GoN, 2009; DNPWC, 2015), which ensures a safe food source for the vultures.

The average minimum temperature, total precipitation, and daily rain intensity had significant effects on the population size whereas absolute maximum temperature, average daily different temperature, wet spell, total rainy day, extreme rain, and yearly rain intensity had negative effects. The strength of relationship between population trend and climate suitability varied in relation to food or carcasses availability and nests (Paital *et al*., 2015). It is suggested that negative responses to climate change may be less pronounced than for positive population responses (e.g.

Parmesan, 1996; Parmesan & Yohe, 2003; Gregory *et al*., 2009; Rockwell *et al*., 2012). White-rumped vultures may prefer warm climate, i.e., the white-rumped vulture population size increased with the average minimum temperature. In Nepal, all of the white-rumped vulture colonies were in the lower elevation (Baral *et al*., 2005; Chaudary *et al*., 2012; Grimmett *et al*., 2016; Bhusal *et al*., 2023). Daily activities are influenced by the rainfall, cloud cover, and temperature. In addition to this during extreme cold days, there might be more chances of casualty of diseased and old wild and domestic ungulates which might be beneficial to scavengers because the probability of getting carcasses might be high. All the vulture colonies of the study areas are either in or around the human habitat (Baral *et al*., 2005) so the chances of getting wild ungulates in the study areas might be low which lead them to forage upon the carcasses of livestock even though the vulture foraging territory is high (Margalida *et al*., 2014; Ram *et al*., 2022).

The proportion of adult white-rumped vulture population (90.23%) was comparatively higher than the sub-adults (5.29%) and juveniles (4.48%). Comparatively high adults (80%) were also recorded in the Deccan Plateau of India (Ravikanth & Baskaran, 2024). It was probably due the conservation efforts of government after diclofenac ban in 2006. The presence of larger population of adults suggests the potentiality of increasing population, however unintentional poisioning becomes major threats to the adults (Bhusal *et al*., 2023). In Nepal, 22 poisonous incident become death for 224 individuals of seven vulture species including 93 white-rumped vultures during the period between 2011 and 2023 (Bhusal *et al*., 2023). Comparatively lower number of juveniles and sub-adults suggests a high mortality of juveniles which may lead overall decline in population in future (Ginsberg & Milner- Gulland, 1994).

This study recorded a high vulture chick mortality between 2006 and 2022 due to springtime storms that dislodged nests during the chick raising phase. These storms coincided with the chicks' initial flight attempts, making them especially vulnerable. Additionally, defenseless chicks faced predation by other birds, and unintentional poisoning and electrocution posed ongoing threats to vulture populations.

2.5 CONCLUSIONS

The study reveals the dynamic changes in the white-rumped vulture population over the 16-year period. Initially, there had been a notable decrease in population size in the first four years followed by slightly constant during the middle seven years, and ultimately an increased in the last five years. Despite of these fluctuation, the overall population experienced decrease in mean and maximum population size. The environmental factors particularly average minimum temperature and precipitation had positive effect on population size. The decline in carcass availability contributes to fluctuation and an overall decrease in population size. The findings of the study have important implications for the pattern and change of local white-rumped vulture population and factors influencing abundance and distribution.

CHAPTER 3

LONG-TERM MONITORING OF BREEDING SUCCESS OF WHITE-RUMPED VULTURE IN THE GANDAKI RIVER BASIN, NEPAL

Abstract

The white-rumped vulture (*Gyps bengalensis*) is a critically endangered species, with its breeding success being crucial for conservation efforts. The success is determined by the number of occupied and productive nests. The status of nests is obtained through regular monitoring. This study used direct observation and potential area search methods to assess breeding success of the critically endangered white-rumped vulture (*Gyps bengalensis*) in the Gandaki River Basin, Nepal between the breeding season 2006/07 and 2021/22. The study recorded an increase of productive nests by 3.70% in the last 16 years. Most of the nests failed during the nest building phase was due to weak support of nesting branch. The average minimum temperature, longest wet day and daily rain intensity, absolute minimum temperature, precipitation, dry spell, extreme rain, and yearly rain intensity had influenced on the breeding success of white-rumped vulture. Two additional factors contributing to nest loss were nesting habitat destruction and chick collection by breeding centers. Conservation efforts to improve vulture breeding success should prioritize protecting nesting trees and enhancing food availability in vulture habitats.

3.1 INTRODUCTION

Breeding success and survival of offsprings are the important parameters to determine the population size of the species (Hunt *et al*., 1986). In addition, birth, migration, immigration, and mortality regulate the population size (Klaassen *et al*., 2013). Out of these, the breeding success has positive effect on population size while breeding failure have negative effect (Siriwardena *et al*., 2000; Briskie & Mackintosh, 2004). Despite species-specific variations in population regulation, a common pattern seems across mammals, birds, fishes, and insects in which a high rates of population growth can be found at low population densities due to readily available resources (Carr *et* *al*., 2002; Sibly *et al*., 2005; Peacock & Garshelis, 2006). However, this growth isn't limitless. The size of a breeding population ultimately hinges on resource availability within a specific ecological context, including factors like quality of breeding habitat and food abundance (Newton, 1980; Rodenhouse *et al*., 1997; González *et al*., 2006). Food supply acts as a limiting factor that profoundly affects all the aspects of breeding and annual cycle (Pollock *et al*., 2017; Wegge *et al*., 2022). Adverse environmental conditions decrease the food accessibility and timely arrival at the breeding ground, resulting in reduced breeding success (Newton, 1980; Stephens *et al*., 2007). Long term familiarity with neighboring nesting sites and nests are also beneficial to breeding success (Beletskey & Orians, 1989). For the resident bird species, nesting and roosting in a particular location for many years (Ali & Ripley, 1987; Gautam & Baral, 2013) is also advantageous for them to locate undetected food by following the already detected the food (Cortés-Avizanda *et al*., 2014; Rouviere & Ruxton, 2022). Easy food finding or access might also be beneficial for breeding success for the species (Yom-Tov, 1974). Furthermore, the quality of nesting trees and other environmental variables also exert an influence on vulture breeding success (Garcia- Heras *et al*., 2017; Aresu *et al*., 2022). Multiple factors such as diet (Margalida *et al*., 2012), high wind speed, low precipitation, low human disturbance (Aresu *et al*., 2022), and mature nesting tree (Moreno-Opo *et al*., 2013) influence the breeding success in vultures. Precipitaion directly and indirectly influence the food availability in vulture (Ogutu *et al*., 2008). Population of ungulates might be regulated by primary productivity. Rainfall in turn impacts on the food base for the vulture. In the dry and cold winter with below average rainfall likely triggers additional ungulate mortality due to low food availability (Cruz- McDonnell & Wolf, 2015). Increase in ungulate carcasses likely leads to increase food availability for vultures caused improving breeding success in those years (Santangeli *et al*., 2018). In addition, human activities not only influence breeding success during the breeding season but also lead to change in distribution patterns and individual behavior (Sutherland, 2007).

The white-rumped vulture is a resident and slow breeder vulture species. It lays a single egg (Sharma, 1970; Ali & Ripley, 1987). They need large and mature tree for nest construction (Ali & Ripley, 1987; Gautam & Baral, 2013; Majgaonkar *et al*., 2018; Ghimire *et al*., 2019; Ahmad *et al*., 2020; Bhusal *et al*., 2023) which mostly relates to safty. With a long breeding season which typically starts in September and remains upto the end of May (Ali & Ripley, 1987; Baral *et al*., 2005), is related to multiple factors such as food shortage, predation, contribute to their breeding success. Sudden death of disappearance of adults was the reason of poor breeding success in white-rumped vultures (Khan, 2013). The breeding success was also influenced by the size of colony in white-rumped vulture. The breeding success was higher in the smaller colony size (Majgaonkar *et al*., 2018). As a scavenger, white-rumped vulture depends mostly upon carcasses of domestic cattle and buffaloes. Carcass disposal system and traditional livestock farming system in recent years have been changed in Nepal (Baral *et al*., 2005). It leads to food shortage which ultimately effects the breeding success.

Government of Nepal prohibited the use of diclofenac, and established the vulture safe feeding sites and diclofenac-free zone to provide a safe food to the vultures. Therefore, this study hypothesized that the breeding success of white-rumped vultures was increased after diclofenac ban and establishment of vulture safe feeding site in 2006.

3.2 METHODS

3.2.1 Study area (*see* Chapter 2)

3.2.2 Data collection

The white-rumped vultures nest data were collected between 2006 and 2022 during breeding season i.e. from September to May each year. The study area was extensively searched to find the nests of white-rumped vulture following the procedure applied by Baral *et al*. (2005, 2013) and Gautam and Baral (2013). The nesting trees were tagged and monitored throughout the breeding season. In addition, nest location, status of nest, and nesting tree species were recorded. The nests were categorized into occupied (nest building activities should be done), active (incubation should be done), and productive nests (chicks should be raised successfully) (Postupalsky, 1974). Observations were made from the ground without disturbance. The breeding season was divided into nest building phase, incubation phase, and chick raising phase based on the status of the nest. Visits were made routinely throughout the breeding season covering all the phases at least once to assess breeding success.

3.2.3 Data analysis

The breeding success was calculated on the basis of occupied and active nest as primary unit (Postupalsky, 1974).

$$Bo = Nf/No*100\% \qquad (1)$$

In equation (1), *Bo* is the breeding success based on occupied nest as primary unit, *Nf* is the total number of fledgling, and *No* is the occupied nest in a particular breeding season.

$$Ba = Nf/Na*100\% \qquad (2)$$

Here, *Ba* is breeding success based on the active nest as primary unit, *Nf* is the total number of fledgling, *Na* is total number of active nest in a particular breeding season. The coefficient of correlation r was calculated to find out the relation between the breeding success and the meteorological variables such as average maximum temperature, average minimum temperature, absolute maximum temperature, absolute minimum temperature, average daily mean temperature, average daily different temperature, total precipitation, longest dry day, longest wet day, dry spell, wet spell, total rainy day, extreme rain, daily rain intensity, and yearly rain intensity. Generalized linear model was used to identify the effect of meteorological variables on the breeding success of white-rumped vulture. All the analysis were performed in R Program (R Core Team, 2022).

3.3 RESULTS

A total of 855 occupied nests of white-rumped vultures were recorded in 16 years between the breeding seasons 2006/07 and 2022, of which 76.03% (n = 650) laid eggs and 47.72% (n = 408) raised chicks successfully. The annual mean occupied, active, and productive nests was 53.44 ± 18.23 (min = 27; max = 94), 40.63 ± 14.52 (min = 25; max = 82), and 25.50 ± 7.45 (min = 14; max = 45), respectively from 2006/07 to 2021/22 (Figure 3). The number of occupied nests and active were decreased by 28.57% and 7.27%, respectively in last 16 years. However, the number of productive nests was increased by 3.70% in the study area in the same period.

The highest number of occupied nests (n = 94), active nests (n = 82), and productive nests (n = 45) were recorded in 2007/08. Whereas, the least number of occupied nests (n = 27) and active nests (n = 25) were recorded in 2015/16. The least number of productive nest (n = 14) was recorded during the breeding season 2009/10 (Figure 3).

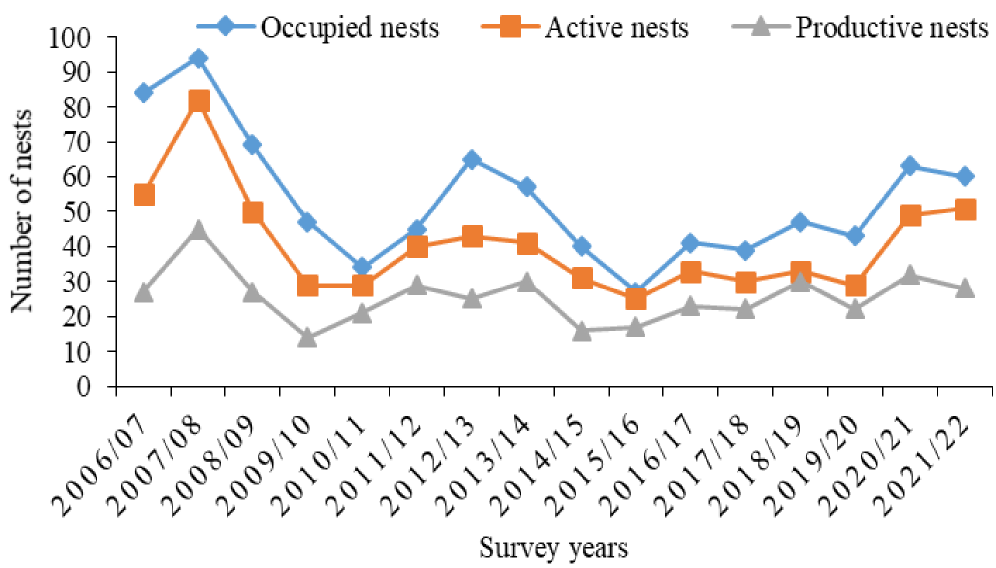

Figure 3: Occupied, active, and productive nests of white-rumped vultures in the Gandaki River Basin, Nepal from 2006 to 2022

The mean breeding success (%) of white-rumped vultures was 49.63 ± 11.21 (min = 29.79; max = 64.44) and 64.51 ± 11.97 (min = 48.28; max = 90.91) based on occupied and active nests as primary units, respectively, between 2006/07 and 2021/22 (Figure 4).

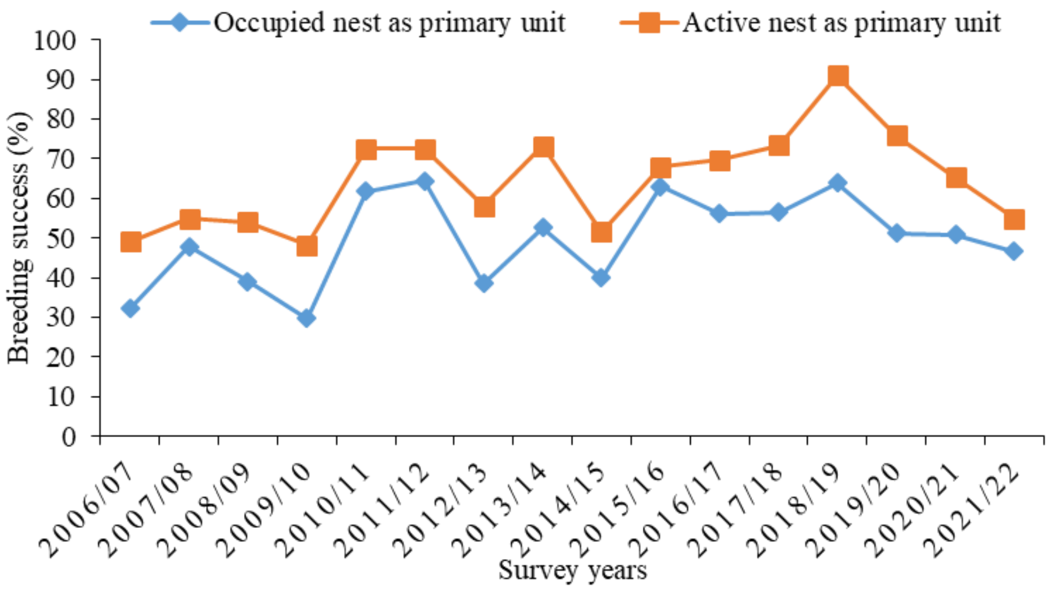

Figure 4: Breeding success of white-rumped vultures based on occupied and active nests as primary unit in the Gandaki River Basin, Nepal from 2006 to 2022

A total of 445 nest were recorded as unproductive nest, and among these 46.06% (n = 205) nests were failed during nest building phase, 32.35% (n = 144) at incubation phase, and 21.57% (n = 96) nests were failed during fledgling phase (Appendix III).

Breeding success of white-rumped vulture had weak positive correlation (r = 0.2 to 0.39) with average maximum, average minimum, absolute maximum, and average daily mean temperature. However, breeding success had moderate negative correlation with the extreme rain and yearly rain intensity (r = -0.59 to -0.40) (Appendix II).

The average minimum temperature, longest wet day, and daily rain intensity incluenced the breeding success of white-rumped vulture (Table 3).

Table 3: Generalized linear model for factors affecting the breeding success of white-rumped vultures in the Gandaki River Basin, Nepal. Variable breeding success (Bo%) was used as response variable average minimum temperature (°C), absolute maximum temperature (°C), absolute minimum temperature (°C), average daily different (°C), precipitation (mm), longest dry day (number), longest wet day (number) dry spell (number), extreme rain (mm), daily rain intensity (mm/h), and yearly rain intensity were random variables for the model.

Variable	Estimate	SE	z value	P
Intercept	0.25	0.94	0.26	0.79
Average minimum temperature	0.49	0.05	9.28	<0.001
Absolute maximum temperature	-0.03	0.02	- 1.10	0.27
Absolute minimum temperature	-0.06	0.02	-3.51	<0.001
Average daily different	-0.11	0.04	-2.46	0.01
Precipitation	-0.001	0.00	-7.0	<0.001
Longest dry day	0.002	0.00	1.24	0.22
Longest wet day	0.02	0.00	4.24	<0.001
Dry spell	-0.02	0.01	-3.29	0.001
Extreme rain	-0.01	0.00	-8.57	<0.001
Daily rain intensity	0.07	0.01	6.42	<0.001
Yearly rain intensity	-0.03	0.01	-3.53	<0.001

3.4 DISCUSSION

This 16-year study documented an increased breeding success by 3.7% of productive nest in white-rumped vulture at Gandaki River Basin of Nepal. It was probably due to the safer food available to the chicks and parental care after diclofenac ban and establishment of vulture safe feeding site and diclofenac-free zone in the study area. In this study, the adult death after 2006 was decreased (*see* Chapter 2), which might support the breeding success with more parental care. This breeding success was lower than before the diclofenac era (*see* breeding success 96%) in Jodhpur, India (Sharma, 1970). It indicates that there might be other factors can be acted on the breeding success of white-rumped vultures, so that this study also recorded the fluctuation of the occupied, active, and productive nests in the last 16 years. It might be due to destruction of nesting trees, low carcasses availability, and human disturbance (*see* Chapter 5). The lowest number of nest in the study area in 2015/16 was due to chick collection by Breeding Centre, Chitwan National Park for ex-situ conservation in 2007/08 to 2009/10 and logging of nesting trees (Gautam & Baral, 2008 & 2009; Gautam & Baral, 2013). The adults did not construct nest after the chick collection in these localities. Therefore, the number of nests was decreased since 2007/2008. It was probably due to the avoidance of white-rumped vultures in these areas. Not only was the nest, adult population also decreased in this period (*see* Chapter 2). The main reason for the gradual decrease in the number of nests was management intervention, human and natural activities including dismantling the nesting trees due to heavy storms (*see* Chapter 5). At site specific study at Tarai region of Nepal also mentioned a rapid decline of white-rumped population and their occupied nests until 2011 (Chaudhary *et al*., 2012; Prakash *et al*., 2012). However, partial recovery of the population of the species was recorded in western Nepal between 2013 and 2018 (Galligan *et al*., 2020).

The number of nests gradually increased after 2015/16 in the study area. Increase in nest numbers was recorded not only in this study but aslo in Arghakanchi district of Nepal between 2010 and 2021 (Bhusal *et al*., 2023). This was probably due to the improvement of carcass availability with the establishment of vulture safe feeding site and diclofenac-free zone, government’s role in the conservation efforts and people's awareness towards the conservation of vulture species (DNPWC/MoFSC/GoN, 2009; DNPWC, 2015; Dhakal *et al*., 2022).

In this study most of nests failed between nest-building phase and chick raising phase. The nests failure might be due to weak support of nest to the tree branch, consequently the nest was dismantled before laying. In addition, it was due to the long wet spells day and heavy rainfall in the study area during the breeding season. The long wet spell and heavy rainfall reduce food-searching efficiency of parents to provide food for the young (Newton, 1980; Paviour, 2013). Similar result of long wet spells day and torrential rainfall’s effect to nest failures was also recorded during the incubation period of Peregrine falcon (*Falco peregrinus*) in CapeTown South Africa (Sumasgutner *et al*., 2020). Egg needs a constant temperature for successful hatching, however, during breeding season from September to May the atmospheric temperature will be varied. If the parents are not able to do the parental care, the eggs or chicks will be lost. The reasons of rapid colony deserted were human disturbances such as logging of nesting trees and chick collection and natural calamities, such as heavy storm and natural death of the nesting trees (Baral *et al.*, 2005; Gautam & Baral, 2013).

3.5 CONCLUSIONS

Over a 16-year study period, the breeding success of white-rumped vulture was increased at Gandaki River Basin of Nepal. The initial five years witnessed notable drops in all nest types, followed by a relatively stable period over the subsequent nine years. In the final two years, there was a slight increase in the occupied, active, and productive nests. The breeding success was influenced by temperature and precipitation. The major reasons of all types of nests lost were the nesting habitat destruction and chicks' collection by Breeding Centre, Chitwan National Park. The breeding success can be improved by improving the food availability and protection of nesting trees.

CHAPTER 4

BEHAVIOR OF WHITE-RUMPED VULTURE *Gyps bengalensis* IN THE GANDAKI RIVER BASIN, NEPAL

Abstract

The ethological study requires ability to accurately identify, process, and interpret behaviors or signals of a species. In this study, the breeding behaviors of the endangered white-rumped vulture (*Gyps bengalensis*) were classified into sequential pattern from courtship to fledgling. Twenty behaviors of eight pairs of white-rumped vulture were studied with 4,160 visual observations from September 2021 to April 2022. Three composite behaviors (i.e., breeding, foraging, and roosting) were modeled using the Markov chain model (MCMs). The Markov chain model explained the composite behavior. The vultures from four nests spent more than 70% of their time engaging in breeding activities, indicating a potential correlation between behaviors and reproductive success. Understanding the behaviors of white-rumped vulture has practical applications in the developing management plans for species conservation, including the timing of critical reproductive events, and can be extended to other species as well.

4.1 INTRODUCTION

Behavior of an individual is guided by change in external and internal environments (Boake, 1994). Behavioral activities of the individual may be inherited or learned. These activities vary among individuals over time and in response of environmental condition (Bell *et al*., 2009; Dingemanse *et al*., 2010). Ethologists need to have keen observation and basic prior behavior knowledge on the particular species. Behavioral knowledge could be helpful to identify, process, and interpret of the activities correctly (Kappeler, 2021). The results of such study are crucial for the management and conservation of the endangered species.

White-rumped vulture is listed as critically endangered species after a rapid population decline during the mid-1990s (Prakash, 1999). Veterinary use of diclofenac was the main cause of the population decline throughout the distribution range (Oaks *et al*., 2004; Shultz *et al*., 2004). In addition, the species is suffering from nesting habitat destruction and human persecution (Baral *et al*., 2005). While, understanding the behavior of critically endangered white-rumped vultures can improve the management and conservation strategies of this species. The behavioral activities of white-rumped vulture can be grouped into breeding and non-breeding (Ali & Ripley, 1987; Baral *et al*., 2005). The breeding activities are sequential events, which begin with courtship to nest construction, continue to egg laying, incubation, and rearing of chick and end with successfully fledged chick (Postupalsky, 1974; Ravikanth & Baskran, 2023). These activities are guided by surrounding environmental factors, social and community interactions (Pimm *et al*., 2015). All of these activities can be grouped into feeding, roosting, and breeding with many intermediate other behavioral activities. Observation of individual behavior helps to figure out the condition of the individual. Such observational data can be used in mathematical model to predict the future livelihood of the individual (Atherton & Kerbyson, 1999; Taha *et al*., 2014; Crall *et al*., 2015; Baltrusaitis *et al*., 2016). Such techniques are very important to conserve the threatened species (Noldus *et al*., 2002; Gautam *et al*., 2020). The data of behavioral study should be used cautiously in the mathematical modelling (Knopff *et al*., 2009). Sometimes such model can be validated by field observation to make the model robust. In this study, the collected data from field observation are used to construct Markov chain model (MCM) to estimate the behavior states of white-rumped vulture in Nepal. Here, the Markov chain analysis predicts the breeding future together with different dynamism of individual. As the population is regulated by reproductive success (Anthony & Blumstein, 2000) and the reproductive behavior helps to conserve the critically endangered white-rumped vulture.

This study offers a new insight in behavior of species. The use of Markov chain model is to estimate the transitional probability between the different white-rumped vulture behavior states. The model also predicts particular future bevavior based on previous states in a given time. The application of the mathematical model in behavior of white-rumped vulture is new. Therefore, the aim of the study was to identify behavior patterns and their relationship to each other to accurately identify vulture breeding behavior and to provide a standard observational framework for vulture studies in the future.

4.2 METHODS

4.2.1 Study area

The study was carried out in Gaukha (N 28° 2' 3.1'', E 83° 52' 31.8''), Syangja District, Nepal (Figure 5). The area falls under sub-tropical climatic zone. It has mixed forest of sal, chestnut, coromandel ebony persimmon, needle wood, and kapok. White-rumped vulture used the coromandel ebony and kapok trees of a private land and a small sacred grove for nesting and roosting.

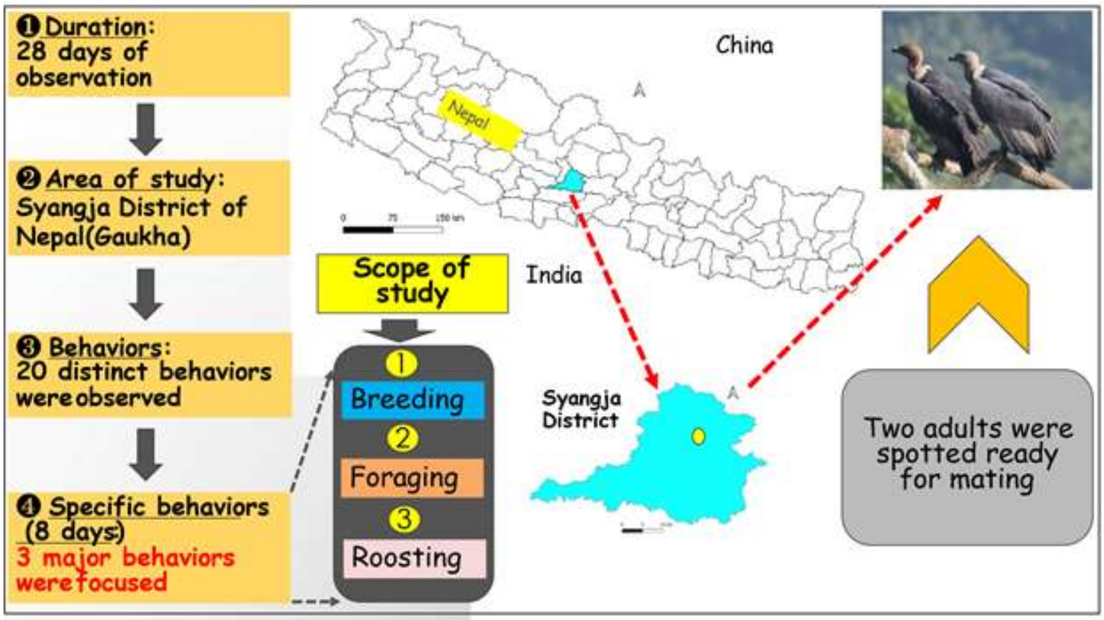

Figure 5: Study area, duration, and scope of study of white-rumped vulture behavior analysis

4.2.2 Data collection

Direct observation was conducted from ground during September 2021 to April 2022. The observations were conducted from a distance of 100 m away from the nesting and roosting trees to avoid the disturbance between 9:00 to 17:30 hr. In this area, five nests were built on a coromandel ebony persimmon, two nests on a single kapok tree and one nest on a single adjustment coromandel ebony persimmon. At least, two people were engaged in recording 20 different behaviors by using binocular and videos (Table 4). The breeding season was divided into nest building, incubation, chick raising, and fledgling periods. Visits were made in each period, spanning two days. Eight white-rumped vulture breeding pairs were monitored using an augmented focal sampling (AFS), a modification of the focal sample method (Altmann, 1974). Instead of observing a single individual a pair of white-rumped vultures was observed. This method was appropriate for the study as two adults shared a nest and the sex could not be identified during non-mating time too.

Table 4: Ethograms and their description under major and minor behaviors of white-rumped vultures

Foraging (F) **(Sub-classifications)**	**Roosting (R)** **(Sub-classifications)**	**Breeding (B)** **(Sub-classifications)**
Eating (E) = All activities from tearing to swallowing food	Aggression (A) = Action of attacking other	Basking on nest (BN) = Expose to sun by wings open
Jumping (J) = Lifting body on air and landing on	Basking (B) = Exposure to sun by wings open	Incubation (I) = Adult sitting low for warming egg on nest
Landing (L) = Bringing body on ground or on tree branch from air	Preening (P) = Cleaning feather with beak	Mating (M) = Male on the back of female for sexual reproduction
Soaring(S) = Flying on air	Pooping/ defecation (PP) = Removal of urine or undigested food materials	Nourishing (N) = Feeding to offspring by adult
Take off (T) = Leaving surface for flying	Resting (RS) = Perching on tree	Nest building (NB) = Activities of construction of nest
Walking (W) = Moving on ground with moderate speed		Nest defense (ND) = Chasing of other which approaching to nest
		Pairing (PR) = A pair of bird roosting adjacent and flying together during breeding season
		Preening on nest (PN) = Cleaning feather on nest
		Standing on nest (SN)

Before data collection, rules for recording data were established to apply AFS (Altmann, 1974). Data were recorded continuously in discrete-time intervals, and the appropriate time intervals were defined. These rules make easy to normalize minor behaviors with low frequency, which can be combined and made into broader categories of behavior.

While visiting the vulture safe feeding site at Ghachok on October 25-27, 2021, an unusual feeding behaviors of white-rumped vultures was observed. The vulture showed unusual behavior like attacking live cow and calf and showed behavior of obligate scavenger.

4.2.3 Markovian approach, model setup, and data analysis

Markov chain model is a discrete-time probabilistic model that can predict present livelihood state from the past state. The breeding behavior of white-rumped vulture was investigated by using the MCMs to establish statistical model.

The MCMs is a discrete-time probabilistic model that can predict the current state's probability depending on the previous states. MCMs were used to build statistical models to investigate the breeding behaviors of white-rumped vultures (Figure 6). The MCMs are stochastic and operate within a specific set of states that satisfy the Markov property and consider the prior probabilities of the specific state, and predict the future probabilities of that state (Geyer, 1992; Grewal *et al*., 2019; La Torre-Torres *et al*., 2020). At first, three major behaviors of white-rumped vulture (foraging, roosting, and breeding) were identified for MCMs analysis. After this, probability of occurrence was operated by recording of the transition operators. At last, the probability distribution of current behavior state was identified.

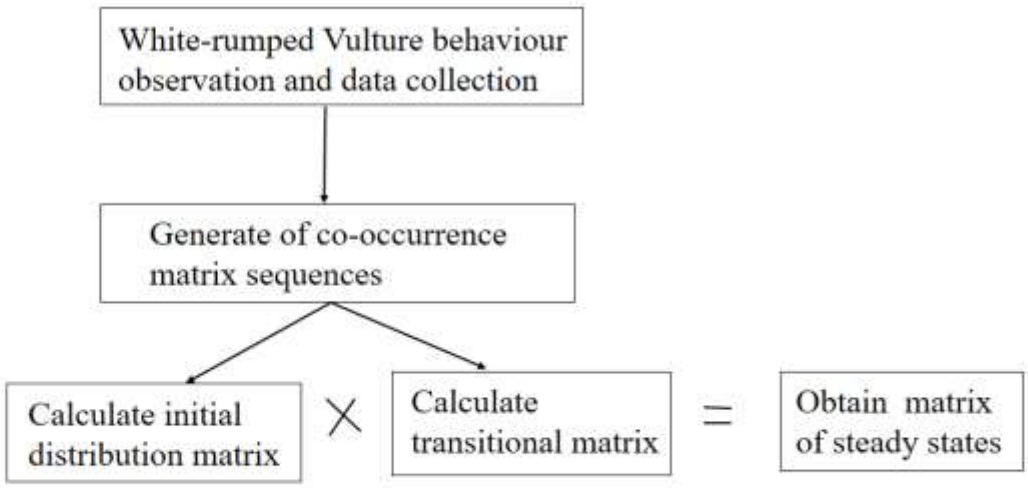

Figure 6: The conceptual model of white-rumped vulture behavior model development

The three major behaviors of white-rumped vulture were foraging, roosting, and breeding which entered in the MCMs from state F and transitioned to state R at a rate of λ_F or to state B with rate μ_F (Figure 7). In case of self-feedback mechanism the

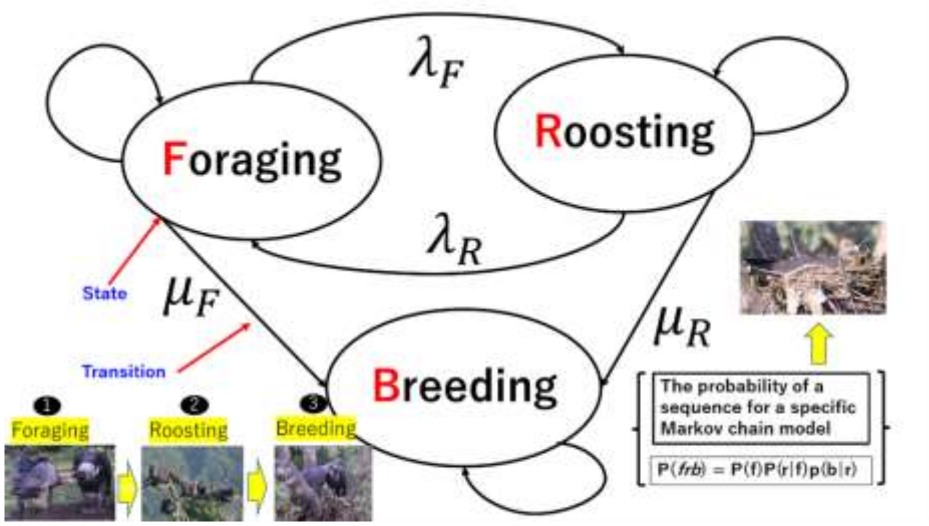

Figure 7: Probability sequence of Markov chain model in behavior analysis of white-rumped vulture

activities of white-rumped vulture were held in its current state without transition.

The equation (1) of the modes of transition and process for the MCMs was:

$$Pr(X_{t+1}/X_{t-1},\ldots\ldots.., X_1) = P_r(X_{t+1}/X_t) \quad (1)$$

There was slight modification in the use of standard notation. The series of events (E_t) from time t = 1 to time point t = T. Where, the possible events (O_t) values in a countable set are O_t E1, 2,…,q. The events of white-rumped vulture behavioral activities (Table 5) serve as model inputs which represents the range of potential outcomes for MCMs. To include an event in a MCV, sequences of events are needed for all t = 0, 1, 2…., for some finite state of m within state space (S) such as S_0, S_1, S_2……S_t. In this case, the state space was a set of (breeding, foraging, and breeding). In equation (1), Pr (Xt = j) is the probability of Pr(X) at time t. The chain rule of probability is formed from left side and future state can be summarized on the basis of the equation, which depends only on the current state. Therefore, the state at time 't' depends only on the state at time t-1. It was noted that the transitional probabilities change over time. However, the objective of the study was to estimate the probability of breeding only. Therefore, the probability theorem of steady states was used assuming that the probability of white-rumped vultures spending time in each state would not be changed and it would become the long-term behavior. The behavior of white-rumped vultures was considered transient (or short-term) before the steady state.

Let P be the transition matrix for a s-state MCMs. The vector is:

$$\pi = (\pi_1, \pi_2, \pi_3, \ldots\ldots\ldots, \pi_s) \tag{2}$$

It is a steady-state distribution (equation 2). Each vector element is the steady state which reached after a series of steps of white-rumped vultures. By following the steady state theorem, the steady state equation can be derived (equation 3):

$$\lim_{n\to\infty} p^n = \begin{pmatrix} \pi_1 & \pi_2\ldots\ldots\ldots & \pi_s \\ \pi_1 & \pi_2\ldots\ldots\ldots & \pi_s \\ \pi_1 & \pi_2\ldots\ldots\ldots & \pi_s \end{pmatrix} \tag{1}$$

And $\lim_{n\to\infty} p_{ij}(n) = \pi_j$ (2)

In this situation, the steady state distribution is:

$$\pi_1 + \pi_2 + \ldots\ldots\ldots\ldots\pi_3 = 1 \ and$$
$$\pi(n+1) = \pi(n).P \leftrightarrow \pi = \pi P \tag{5}$$

Where, P is the one-step transition matrix. The transitional matrix of each nest was measured from eight nests. The activities of each nest were observed for 10 minute intervals (Figure 8). From this, the time spent was assessed by each pair of white-rumped vultures for breeding activities. The initial state matrix was: $(S_0^{n1}, S_0^{n2}, S_0^{n3}, S_0^{n4}, S_0^{n5}, S_0^{n6}, S_0^{n7}, S_0^{n8})$ (6)

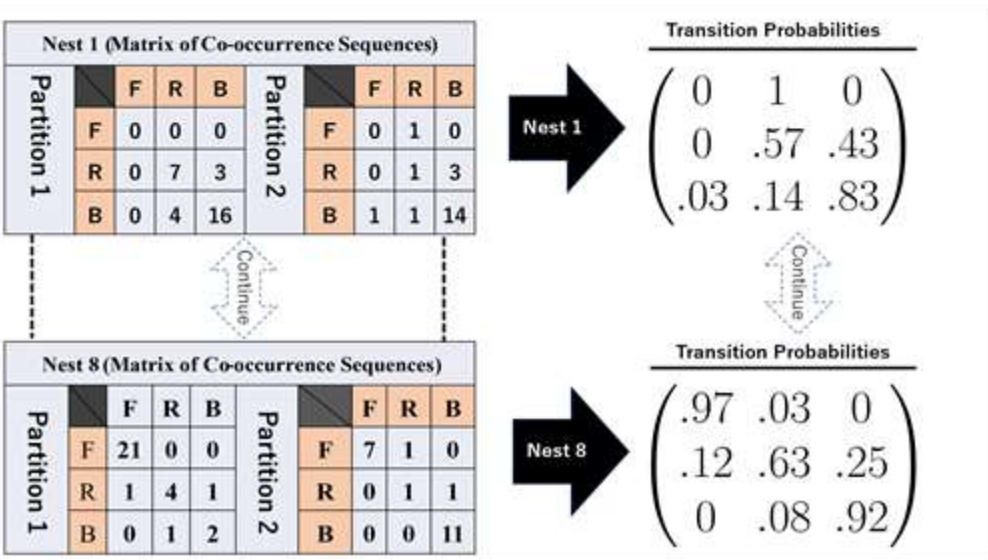

Figure 8: Matrices for transitional probabilities of white-rumped vultures

The initial ratio for each state of foraging, roosting, and breeding of white-rumped vulture for nest 1 was as follow (*see* equation 7)

$$S_0^{n1} = \begin{bmatrix} 0.019231 & 0.269231 & 0.711538 \end{bmatrix} \quad (7)$$

The initial distribution matrices for all eight nests were assessed from direct observations.

The transitional matrices were derived from the initital distribution matrices by using the following formula (equation 8).

$$S_i = S_0^{nj}.P^n \quad (8)$$

Where, S_0 is the initial distribution matrix, 'i' is the step from initial to the steady states and j is limited to 1 to 8 as there were eight nests, and P represented to the transitional probability matrix for each nest.

The state sequences were used to generate transition matrices for MCMs. At first, 20 minor behaviors were used to establish the number of transition probabilities between two states based on direct observation. All of these 20 minor behaviors combined to form three composite behaviors to simply calculations during model development:

$$X = (x(S_i, S_j)) = \begin{pmatrix} x(S_1, S_1) & x(S_1, S_2) & x(S_1, S_3) \\ x(S_2, S_1) & x(S_2, S_2) & x(S_2, S_3) \\ x(S_3, S_1) & x(S_3, S_2) & x(S_3, S_3) \end{pmatrix} \quad (9)$$

If i, j = 1, 2, 3 and S_1 = F, S_2 = R, S_3 = B, then X (S_i, S_j) be the number of pairs of states S_i, S_j. The transition matrix of X was as below.

$$S_{ij} = (X_{11}\ldots\ldots\ldots..X_{ij}) \quad (10)$$

$$X = (x_{ij}) \quad (11)$$

Next, one-step transition probabilities (p_{ij}) was also calculated, where p_{ij} is defined by:

$$i, j \in S = \{1, 2, 3\} \quad (12)$$

In this equation, one step transition probabilities from i to j given that each previous state is independent. Each white-rumped vulture must advance to one of the three states in which sum of the row probabilities equal to one. The diagonal is the likelihood of remaining in the row probabilities equal to one. For a MCM, k state is considered absorbing if p_{kk} = 1, or all p_{kj} = 0 for j is not equal to k. The absorbing state is the breeding state leading to offspring generation.

$$p_{ij} = x_{ij} / \sum_{j=1}^{3} x_{ij} \tag{13}$$

R programming language was performed to graph the MCMs visually and cohort simulations in excel. The MCMs simulations were evaluated by using post hoc analysis.

4.3 RESULTS

White-rumped vultures spent on an average of 2.71 ± 3.04 hrs (31.20%), 1.68 ± 1.76 hrs (19.68%), and 4.25 ± hrs (49.13%) daily for foraging, roosting, and breeding activities, respectively during the breeding season. They were engaged most often in nest building activities (31.00 hrs; 22.60%), which were followed by roosting activities (n = 31.00 hrs; 22.60%), and foraging (n = 8.87 hrs; 6.31 %) during the nest construction phase. Likewise, they spent comparatively more time in breeding activities (n = 116.00 hrs; 83.67%) than roosting (n = 15.5 hrs; 11.16%) and foraging (n = 7.17 hrs; 5.17%) activities during the incubation phase. In contrast, they engaged more time for foraging activities (200.50 hrs; 48.20) than breeding (n = 127.17 hrs; 30.57%), and roosting (n = 88.33 hrs; 21.23%) during the chick rearing phase. In the field, 4,160 observations were made during the breeding season. White-rumped vultures of the nests 1, 2, 6, and 7 dedicated more time to breeding activities, whereas the nests of 3, 4, 5, and 8 primarily engaged in foraging during the breeding season (Figure 9). Nests 2, 6, and 7 contained eggs but chicks were raised only from nests 2 and 6.

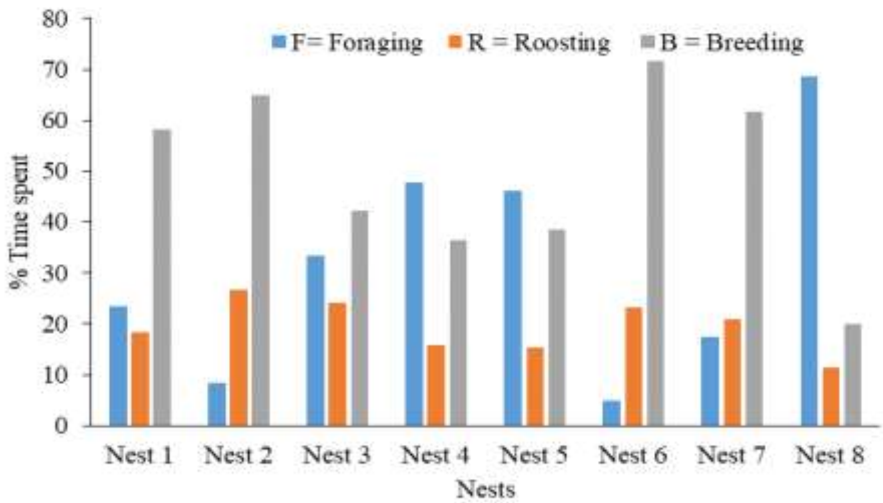

Figure 9: Time spent by white-rumped vulture in different behavioral activities during the breeding season

4.3.1 Transitional matrix via direct observation

The state sequences of state transitions of eight nests were used to prepare final transitional probability matrices from the MCMs (Figure 10). From these transition probabilities, the steady state transitions were assessed by using matrix multiplication for any n-step transitions. The initial state distribution was derived from the recorded activities of white-rumped vultures at each nest which was multiplied to all transitional matrices (Table 6). The steady state of each nest was calculated by using matrix multiplication until getting the steady state vector (Table 7).

The results suggested that nests 1, 2, 3, and 6 had greatest potentiality for nest success during the nest building phase. Direct observation was made again to determine the initial distribution (Table 8) of white-rumped vultures during the fledgling phase in turn to calculate transitional probabilities (Figure 10).

a) Nest Building Phase

$$N1 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & .7 & .27 \\ 0 & .08 & .92 \end{bmatrix} \quad N2 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & .78 & .22 \\ 0 & .07 & .93 \end{bmatrix}$$

$$N3 = \begin{bmatrix} .5 & 0 & .5 \\ 0 & .43 & .57 \\ .02 & .03 & .95 \end{bmatrix} \quad N4 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & .75 & .25 \\ 0 & .08 & .92 \end{bmatrix}$$

$$N5 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & .8 & .2 \\ 0 & .05 & .95 \end{bmatrix} \quad N6 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & .33 & .66 \\ 0 & .04 & .96 \end{bmatrix}$$

$$N7 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & .75 & .25 \\ 0 & .07 & .93 \end{bmatrix} \quad N8 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & .14 & .86 \\ 0 & .14 & .86 \end{bmatrix}$$

b) Incubation Phase

$$N1 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & .89 & .11 \\ 0 & .09 & .91 \end{bmatrix} \quad N2 = \begin{bmatrix} 0 & 0 & 1 \\ 0 & 0 & 0 \\ .02 & 0 & .98 \end{bmatrix}$$

$$N3 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & .67 & .33 \\ 0 & .09 & .91 \end{bmatrix} \quad N4 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & .5 & .5 \\ 0 & .04 & .96 \end{bmatrix}$$

$$N5 = \begin{bmatrix} .5 & 0 & .5 \\ 0 & .25 & .75 \\ 0 & .09 & .91 \end{bmatrix} \quad N6 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & .02 & .98 \end{bmatrix}$$

$$N7 = \begin{bmatrix} 0 & .5 & .5 \\ 0 & 0 & .51 \\ .02 & .02 & .96 \end{bmatrix} \quad N8 = \begin{bmatrix} .93 & .07 & 0 \\ 0 & .83 & .17 \\ .05 & .06 & .89 \end{bmatrix}$$

c) Nestling Phase

$$N1 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad N2 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$N3 = \begin{bmatrix} .82 & 0 & .18 \\ 0 & 0 & 0 \\ .26 & 0 & .74 \end{bmatrix} \quad N4 = \begin{bmatrix} .98 & 0 & .02 \\ 0 & 0 & 0 \\ .25 & 0 & .75 \end{bmatrix}$$

$$N5 = \begin{bmatrix} .88 & 0 & .12 \\ 0 & 0 & 0 \\ .07 & 0 & .93 \end{bmatrix} \quad N6 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & .04 & .96 \end{bmatrix}$$

$$N7 = \begin{bmatrix} 0 & 0 & 1 \\ 0 & 0 & 0 \\ 0 & .02 & .98 \end{bmatrix} \quad N8 = \begin{bmatrix} .95 & 0 & .05 \\ 0 & 0 & 0 \\ .25 & 0 & .75 \end{bmatrix}$$

d) Fledgling Phase

$$N1 = \begin{bmatrix} .96 & 0 & .04 \\ .07 & .93 & 0 \\ 0 & .10 & .90 \end{bmatrix} \quad N2 = \begin{bmatrix} .94 & .06 & 0 \\ 0 & .79 & .21 \\ .05 & .16 & .79 \end{bmatrix}$$

$$N3 = \begin{bmatrix} .91 & .03 & .06 \\ .23 & .77 & 0 \\ .25 & .25 & .50 \end{bmatrix} \quad N4 = \begin{bmatrix} .96 & .02 & .02 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \end{bmatrix}$$

$$N5 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \quad N6 = \begin{bmatrix} .43 & .14 & .43 \\ .25 & .38 & .37 \\ .06 & .11 & .83 \end{bmatrix}$$

$$N7 = \begin{bmatrix} .88 & .06 & .06 \\ .17 & .66 & .17 \\ .25 & .12 & .63 \end{bmatrix} \quad N8 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

Figure 10: White-rumped vulture transitional probability matrices during different phases of breeding season

Table 5: Initial distribution of white-rumped vultures estimated from direct observation during the nest building phase

Nest ID	Foraging	Roosting	Breeding
Nest 1	0.000	0.212	0.789
Nest 2	0.000	0.192	0.808
Nest 3	0.038	0.135	0.827
Nest 4	0.000	0.231	0.769
Nest 5	0.000	0.192	0.808
Nest 6	0.000	0.058	0.942
Nest 7	0.000	0.173	0.827
Nest 8	0.003	0.016	0.019

Table 6: Initial distribution of white-rumped vulture behaviors that were estimated from direct observation during the incubation phase

Nest ID	Foraging	Roosting	Breeding	Steady state
Nest 1	0.000	0.229	0.771	24
Nest 2	0.000	0.240	0.760	9
Nest 3	0.047	0.041	0.912	24
Nest 4	0.000	0.240	0.760	24
Nest 5	0.000	0.196	0.804	28
Nest 6	0.000	0.059	0.941	10
Nest 7	0.000	0.218	0.782	32
Nest 8	0.000	0.005	0.030	4

Table 7: Initial distribution of white-rumped vulture behaviors that were estimated from direct observation during fledgling phase

Nest ID	Foraging	Roosting	Breeding	Steady state
Nest 1	0.000	0.361	0.428	85
Nest 2	0.015	0.000	0.773	4
Nest 3	0.000	0.159	0.571	25
Nest 4	0.000	0.060	0.729	20
Nest 5	0.000	0.085	0.684	9
Nest 6	0.000	0.015	0.773	5
Nest 7	0.031	0.015	0.742	14
Nest 8	0.257	0.220	0.312	90

4.3.2 Model evaluation

The behaviors of white-rumped vultures were arranged sequentially from nest 1 to nest 8 to create a matrix of co-occurrence sequence (Nests 1 and 8; Figure 11), from which the transitional probabilities were calculated. The initial and transitional probabilities of each nest were plotted and calculated (Figure 12). The steady states are not similar in different nests of white-rumped vultures. Nests 1, 2, 3, 6, and 7 spent more in breeding activities (> 70% of the time) than the vultures of remaining nests. It suggested that the nest constructions were completed earlier in nests 1, 2, 3, 6, and 7 (Table 8). The post hoc analysis of these results found that nests 1, 2, 3, 6, and 7 produced offsprings validated the results of MCM. The behaviors of each phase of white-rumped vultures were plotted in heatmap (Figure 13).

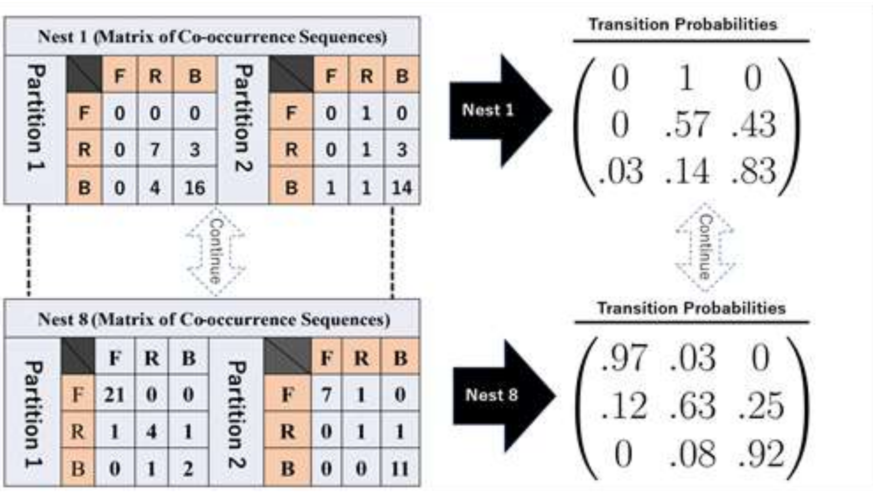

Figure 11: State transitions matrices of white-rumped vulture behaviors

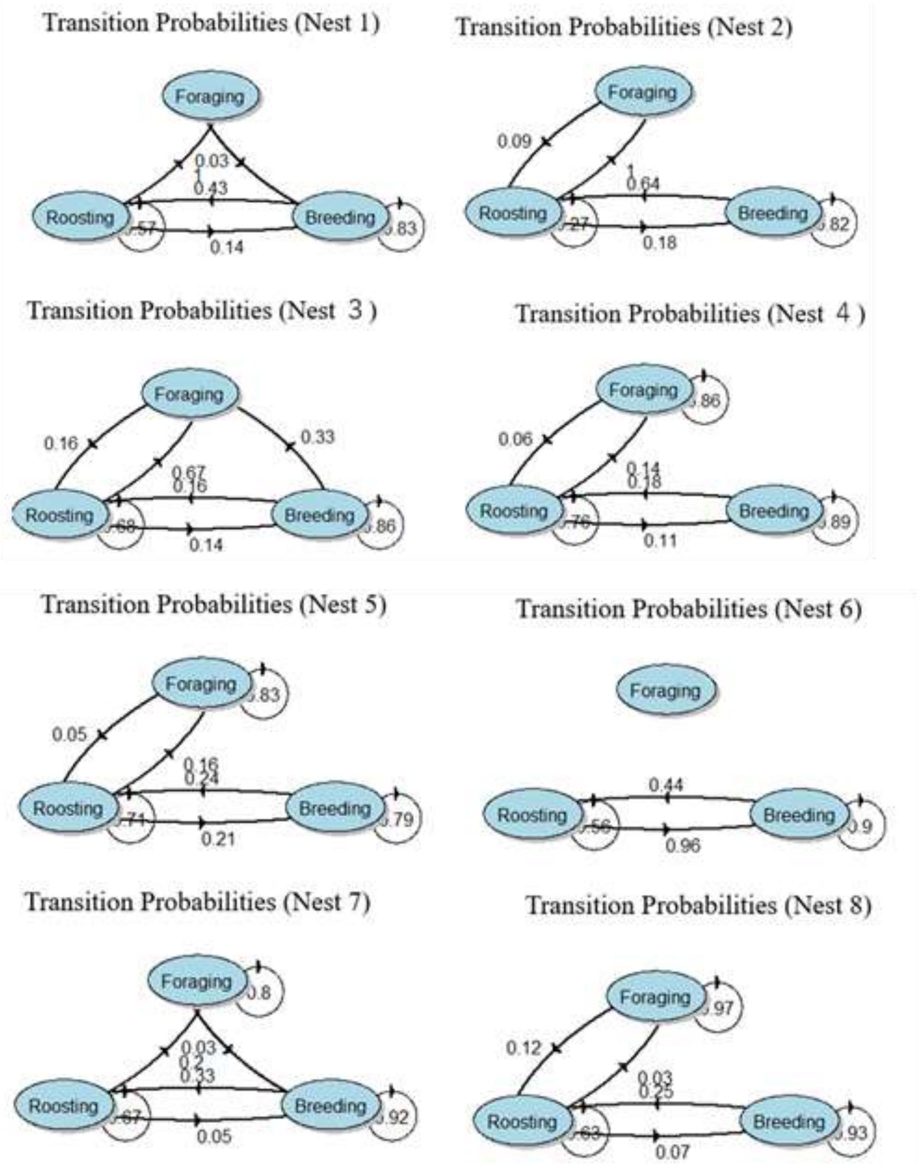

Figure 12: Transitional probabilities of white-rumped vulture behaviors during the breeding season

Table 8: Initial distribution of white-rumped vulture behaviors estimated during the breeding season from direct observations

Nest ID	F (Foraging)	R (Roosting)	B (Breeding)	Steady state
Nest 1	0.021	0.277	0.702	12
Nest 2	0.020	0.216	0.765	9
Nest 3	0.059	0.373	0.569	21
Nest 4	0.137	0.333	0.529	54
Nest 5	0.118	0.412	0.471	48
Nest 6	0.000	0.176	0.824	15
Nest 7	0.098	0.176	0.726	33
Nest 8	0.446	0.123	0.431	211

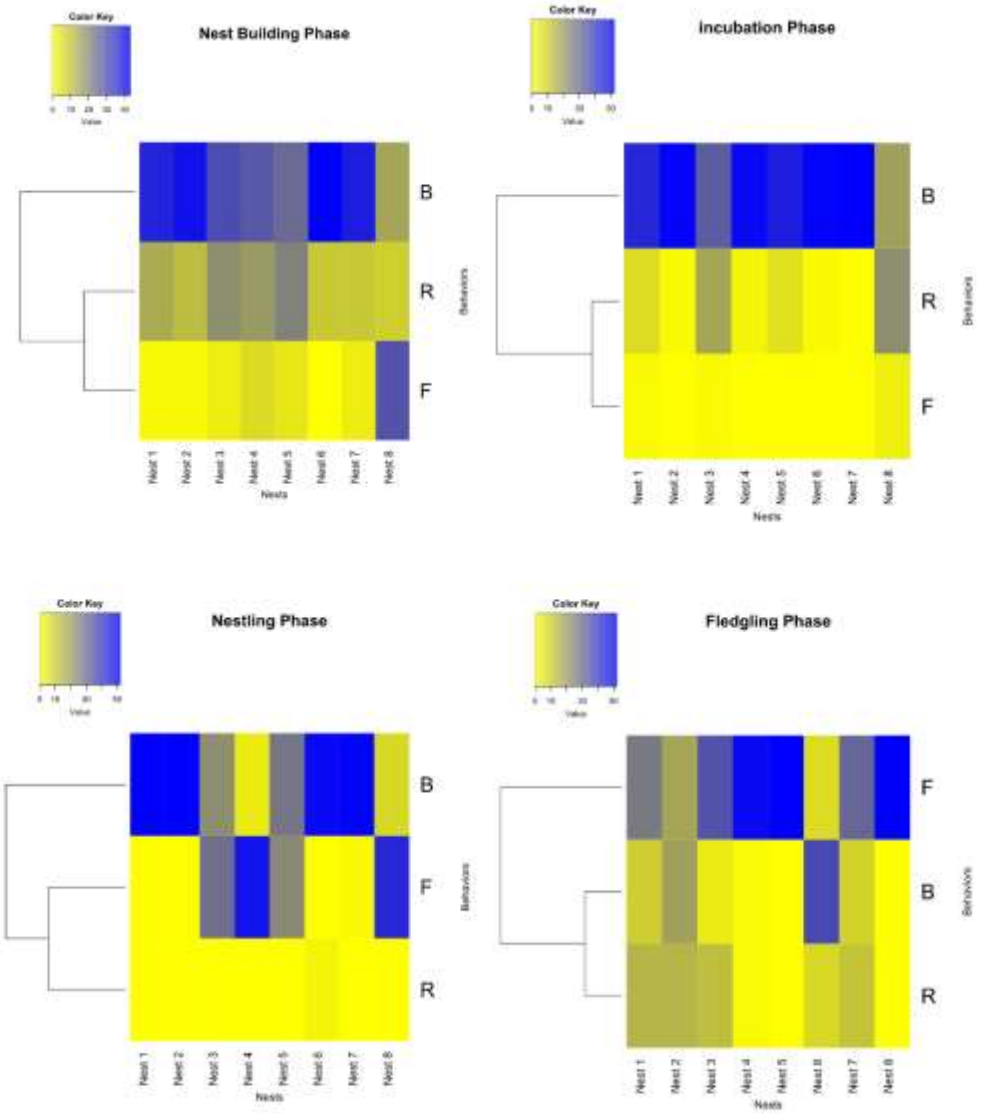

Figure 13: Different behavior activities of white-rumped vultures during the breeding season

4.3.3 Predatory behavior of white-rumped vulture

This study documented two incidents of white-rumped vultures attacking live animals in the safe feeding site Ghachok, Kaski, Nepal. In the first incident, a juvenile started to tug at the upper jaw of an adult cow while the cow was squatting in the cow shed of safe feeding site. In the same time, other vultures were consuming carcass nearby. The cow moved away from the place. The observation suspected that the sub-adult of white-rumped vulture was attacking a live cow. In the second incident, an adult white-rumped vulture landed on the ground of the safe feeding site where other vultures were consuming carcass. Instead of moving towards the carcass remains, the adult white-rumped vulture approached a frail calf that was lying on the ground nearby. The white-rumped vulture started to peck the calf's body surface from head to tail, and finally white-rumped vultures consumed the whole body of calf. Among five species of vultures recorded at the site, only white-rumped vulture was found being involved in the attack of live animals.

4.4 DISCUSSION

Understanding the behavioral activities of threatened or endangered species helps to develop, apply, and monitor of management plans for the conservation. However, only the quantitative population size and breeding data of critically endangered white-rumped vultures have been frequently reported from field observations. Not any quantitative analysis applying Markov chain models has been conducted. The present study found that the white-rumped vultures spent more time in breeding activities than in foraging and roosting. The informed and validated model which utilized the direct observation data, underscoped the importance of breeding activities. These activities of the parents were directly associated with the rate of nest construction, nest defense, incubation, and chick raising.

The limited number of nests and individual vultures could reduce the strength of the study. However, the model prediction was consistent with the results of direct observation and similar to other studies (Gautam *et al*., 2020; Jiang *et al*., 2020). This suggests the method could be used in behavior analysis of other species. Sex could not be identified during the observation in field, this method allowed observation of both mate simultaneously. Sometimes, it is cautious to consider states from the model fitted to field data are as important as the MCMs. Therefore, the most important model patterns may not be biologically relevant. Here, the behaviors state that the model predicted to the vulture breeding was supported by data of direct observations.

The behaviors of white-rumped vultures differ among the nesting pairs and breeding phases. The variation of behavior among the breeding pairs could differ due to in microclimate, food availability, predators, or age of the vultures (Islam *et al*., 2018). Thus, further research is recommended to support this hypothesis. In addition, quality of nest and environmental factors may influence behaviors and breeding success.

MCMs helped to draw inferences regarding behaviors of white-rumped vulture. The results of this study could be compared with those of other studies. In this study, four pairs of white-rumped vultures built nests earlier than the other four pairs. Easy transport of nesting materials to the nest site and a favourable location for constructing nests are advantageous for nest construction. However, bringing nesting material into the dense canopies and building nest on weak support may require a significant effort to construct nest, ultimately affecting breeding success. Fast and earlier nesting allows vultures to lay eggs sooner, thereby increasing offspring survival (Barash, 1975). Food shortage, improved carcass disposal, and European conservation policy brought changes in behaviors of Eurasian Vultures (Donazar *et al*., 2010).

In contrary to this study, the daily activities of captive white-rumped vultures were predominantly roosting (56.3%) (Islam *et al*., 2018) because of different observation periods. The greater estimation of the breeding activities as compared to previous study (i.e., Islam *et al*., 2018) was including sitting and roosting together with courtship displays under the breeding activities in this study. White-rumped vulture invested more time in breeding than in the foraging and roosting activities in present study. Consuming carcasses were not recorded and only soaring was included under the foraging in this study. Therefore foraging was caused the less recorded of foraging. The topography of the study site also limited the observation of soaring which reduce study times the foraging times in this study. The overall time spent in different activities may influence by inclusion of the entire diel period. The internal and external environmental factors may determine the daily activities of white-rumped vultures (Bjorklund & Kipp, 1996). Other influential factors in nest failure and daily activities are infertility (Jamieson & Ryan, 2000), predation (Feare *et al*., 2017), modification of nesting habitat (Evans, 2004), and human disturbances

(Bamford *et al*., 2009). This model could be useful for understanding the reproductive success in white-rumped vultures alongside the factors influencing the success.

The two incidents of white-rumped vultures attacking live animals in the safe feeding station raise several questions regarding its feeding behaviors. First, do the safe feeding sites alter the behaviors of white-rumped vultures? Second, are white-rumped vultures a facultative or obligate scavenger? Third, how do white-rumped vultures discriminate between dead vs frail animals? The answers to these questions help to interpret and explain the behaviors that this study has documented. Among five species of vultures recorded at the site, only white-rumped vultures being involved in the attack of live animals needs further investigation. Is this due to their sheer number compared to other vulture species or just the change in their behaviors? Frequent interactions with the weak and old cattle in the safe feeding sites might prompt vultures to kill the animals before they die naturally. The predatory behavior as noticed on the white-rumped vultures can raise questions to the scientists and managers. More follow up research is warranted to make a definite conclusion on whether the safe feeding sites alter the behaviors of wild white-rumped vultures

4.5 CONCLUSIONS

The direct field observation study investigated 20 different behaviors of white-rumped vulture. These behaviors were grouped into three different categories: breeding, foraging, and roosting. It was observed that white-rumped vulture used more time in breeding than foraging and roosting behaviors. For Markov chain modeling, direct observation data were utilized to establish the initial probability distribution matrix. Subsequently, the transitional probability matrix was derived from this data. Computational outcomes were cross-checked against field data to ensure accuracy and efficiency. Pairs of white-rumped vultures spending more than 70% of their time engaged in breeding behaviors with each nest showing a high probability of producing offspring indicate successful reproductive events. The developed model is useful for predicting reproductive success along with the factors influencing the success. Understing these behaviors is crucial for developing management plan for species conservation, thereby enhancing conservation efforts across diverse species.

CHAPTER 5

PREFERENCE OF TREES FOR NEST BUILDING BY CRITICALLY ENDANGERED WHITE-RUMPED VULTURES *Gyps bengalensis* IN THE GANDAKI RIVER BASIN, NEPAL

Abstract

White-rumped vultures (*Gyps bengalensis*) are critically endangered species, and protecting their habitats, particularly the nesting trees, may have a positive impact on their reproductive success. For a better understanding of vultures' habitat the characteristics of nesting trees should be accounted. In this paper, the characteristics of the trees with vultures' nests with those that didn't have nests by randomly selecting a control tree within a 10 m radius of the nesting trees. Nest of white-rumped vulture was extensively searched and trees species with nests were closely between the breeding seasons from 2006/07 to 2021/22. The characteristics of sampled trees such as their height, girth, canopy spread, branching orders, and whorls were measured. A total of 873 nests of white-rumped vultures were recorded in 165 trees belonging to 18 species. White-rumped vultures preferred the kapok trees for nest construction than other tree species (χ^2= 115.38, df = 1, p < 0.001) as 67.88% of nests were built on them. In the logistic regression model, the number of whorls on a tree, canopy spread, and the height of the first branch were considered to determine whether a nest was present on a tree or not. These results help to prioritize the tree attributes in a habitat conservation plan for vultures.

Keywords: bird, breeding success, habitat conservation, nesting tree, nests

5.1 INTRODUCTION

The characterization of nesting habitats plays a crucial role in comprehending the habitat needs of vultures (Yarrow, 2009; Mölder *et al*., 2020). An in-depth knowledge of the characteristics of preferred nesting trees and nest survival are key factors in determining the reproductive success of vultures (Francis *et al*., 2011; Chiavacci *et al*., 2014). Predation, natural disasters such as storms, and anthropogenic disturbances such as cutting down the nesting trees and collection of chicks are some reasons for nesting failure in vultures (Newton, 1998; Keyser, 2002, Baral *et al*., 2005, Baral &

Gauam, 2007). The availability of large nesting and roosting trees is crucial for vulture survival as they provide a good vantage point to locate food sources and reduce the risk of predation by land animals (Vogel *et al*., 2014; Kendall *et al*., 2018).

The logging of large trees that has caused habitat loss is the major threat to the survival of vulture species because it leads to reproductive failure (He & Hubbell, 2011; Fletcher *et al*., 2018). In Nepal, three out of nine vulture species, namely red-headed vulture (*Sarcogyps calvus*), slender-billed vulture (*Gyps tenuirostris*), and white-rumped vulture (*G. bengalensis*) are typically tree nesters while the Egyptian vulture (*Neophron percnopterus*) builds nests on a tree on rare occasions (Ali & Ripley, 1987; Chhangani, 2002). These species require mature and tall trees for nesting (Siders & Kinnedy, 1996; Thakur, 2015; Majgaonkar *et al*., 2018; Ghimire *et al*., 2019; Ahmad *et al*., 2020).

The wild vulture population has been declining in South Asia due to the use of diclofenac in veterinary practices (Prakash *et al*., 2007; Chaudhary *et al*., 2012; Khan, 2013; Ahmad *et al*., 2020), food shortage (Shah *et al*., 2019), unintentional poisoning (Clements *et al*., 2013), human persecution (Hla *et al*., 2011; Clements *et al*., 2013), collision with power lines and electrocution (Hamal *et al*., 2023), and breeding habitat loss (Hla *et al*., 2011; Gautam & Baral, 2013). As a result, the Nepalese government banned the production, distribution, and sale of diclofenac for veterinary use in 2006 (Prakash *et al*., 2012). To support the recovery of vulture populations, various conservation programs were initiated, including captive breeding and release programs, the establishment of vulture safe feeding sites and zones, public awareness campaigns, and declaration of diclofenac-free zones (DNPWC, 2015). Making sure of the availability of suitable nesting and roosting trees in the wild is crucial for the long-term survival of vultures (Pain *et al*., 2003; Baral *et al*., 2013). However, insufficient information exists regarding what constitutes the suitable trees for nesting or roosting. The problem is further exacerbated when the existing nesting trees are cut down to implement development activities such as road and building construction in Nepal (Gautam & Baral, 2013).

In Nepal, white-rumped vultures are found below 1,800 m above sea level, and they were the most abundant and widespread species prior to the 1990s (Ali & Ripley, 1987; Grimmett *et al*., 2016). White-rumped vulture has been listed as a critically endangered species in the Red Data Book by BirdLife International due to the drastic population decrease in the wild since 2000 (BLI, 2021). Following the significant drop in wild population, the white-rumped vulture is now found patchily distributed across Nepal (Baral *et al*., 2005; Gautam & Baral, 2013; Rana *et al*., 2019; Bhusal *et al*., 2020). Despite the effective ban on diclofenac, the survival of the species is declining. The species continues to suffer from food shortage, human persecution, unintended poisoning, and habitat destruction (Baral *et al*., 2005; BLI, 2021). Habitat destruction has been the primary cause of local colony extinction (Baral *et al*., 2005; Baral *et al*., 2013). The choice of tree species for nesting by white-rumped vultures can vary between sites (Ghimire *et al*., 2019; Bhusal *et al*., 2023). They usually prefer to nest on tall and mature trees (Subedi, 2008; Ghimire *et al*., 2019; Bhusal *et al*., 2020). Acquired information on the characteristics of preferred trees sheds light into the ecological requirements of vultures (Sharma *et al*., 2023) and helps in formulating effective vulture conservation strategies (Majgaonkar *et al*., 2018; Beyer & Manica, 2020). Furthermore, the managers, policy makers and scholars can have a better understanding of the specific habitat needs of vultures (Polak, 2016) and determine about the most suitable habitats for conservation efforts. Therefore, the objective was to undertake a comprehensive evaluation of the characteristics of nesting trees with the goal of informing future habitat restoration and management initiatives for fostering the rejuvenation of the declining population of white-rumped vultures in the wild.

5.2 METHODS

5.2.1 Study area *(see* Chapter 2)

5.2.2 Data collection

Between the breeding seasons from 2006/07 to 2021/22, the number of nests of white-rumped vultures was recorded in the study area following the protocols used by Baral *et al*. (2005, 2013) and Gautam and Baral (2013). The location of nests were marked, and noted the nesting tree species. In 2022, the tree characteristics were recorded such as the girth at breast height, longest branching order, number of tree whorls, canopy spread, tree height, first branch height, nest height, nest branching order for those trees where white-rumped vulture constructed the nest. Tree species were identified in the field and herbarium were made for unidentified tree species which were later identified by the experts at the Central Department of Botany, Tribhuvan University, Kirtipur, Nepal.

In this study, we established a 10 m radius plot around the nesting tree, and randomly selected non-nesting trees based on preset 160 random angles (0 to 360° in the increment of 5°) (Yang & Burkhart, 2019). If the non-nesting tree was absent at the preset random angle, we used the next random angle to locate a tree. If a tree was absent in the second iteration, we did not measure the non-nesting trees. We recorded the spatial coordinates of the nesting and non-resting trees using hand-held Geographical Position System (GPS; accuracy <5 m). In this way, a randomly selected control pair was established for each nesting tree to compare and contrast their characteristics.

In addition, the number of nesting tree lost was tallied in the vulture colonies between 2006/07 and 2021/22. The causes of nesting tree loss were determined, and categorized them into natural and anthropogenic causes.

5.2.2.1 Measurement of tree characteristics

In the study, several characteristics of the trees were measured, including the girth at breast height (GBH), longest branching order (LBO), tree whorl (TW), canopy spread (CS), tree height (TH), and the first branch height (FBH). For white-rumped vulture nesting trees, additionally the nest branching order (NBW), nesting whorl (NW), and nest height (NH) were measured (Appendix IV).

5.2.2.1.1 Girth at breast height (GBH)

It is the measurement of the circumference of the tree trunk at a standard height of 1.5 m from the ground surface, and it was accurately determined using a measuring tape.

5.2.2.1.2 Longest branching order (LBO)

The branching order is the arrangement of the tree branches or segments. Among the various methods applied for measuring the longest branching order, a centrifugal system was used instead of numbering the branching order from the tip toward the stem of the tree segments (Horton, 1945; Strahler, 1957; Uylings *et al*., 1975). The branching order was recorded as Order 1 axis (the trunk), Order 2 axis (the branch growing directly from the trunk), Order 3 axis (branches growing on Order 2 axes), and so on. The centrifugal ordering system was used to locate nests and the longest branching pattern of the trees. The dead, broken, pruned or logged branches were excluded for this recording.

5.2.2.1.3 Tree whorl (TW)

The total number of whorls was recorded by counting the presence of live branches arising from the main tree axis or main stem (Kidombo & Dean, 2018). The node without live branches and the dead main axis were excluded. However, the whorl was recorded as a one whorl tree if no live branches are present below and above the branches. The first branch was recorded as the first whorl, successively upward second, third and so on.

5.2.2.1.4 Canopy spread (CS)

The longest and shortest canopy spreads of the tree were measured by using a measuring tape. The widest crown spread was measured from the ground at the longest axis of the crown and the shortest crown spread by making right angle to the widest crown spread following Blozan (2006). The average of widest and shortest extents of the crown was used for the canopy spread.

5.2.2.1.5 Tree height (TH)

The tree height is the measure of a tree from the ground to the top. The tree height was measured with the help of a clinometer and a measuring tape. The basal distance from the observer to the tree was measured with the measuring tape and the tree top angle was recorded with the clinometer. A 1.5 m height stick was used to take angle of inclination to tree top. The height was calculated using the formula, tree height (m) = basal distance (m) $\times$ tanα + 1.5 m. Where, α is the angle of inclination on the clinometer.

5.2.2.1.6 First branch height (FBH)

The first branch height is the measure of height from the ground to the first live branch. The same procedure was applied for the tree height (sans direct measurement).

5.2.2.1.7 Nest branching order (NBO)

Like the branching order, the centrifugal method was used to find the nesting branching order if the branch has a nest. If the nest was located on the trunk it was recorded as nesting branching Order 1. Further, if the nest was located on the branch raised from the trunk, it was noted as two and so on (Suzuki & Suzuki, 2009).

5.2.2.1.8 Nest whorl (NW)

The measurement of nest whorl was noted from lower to top. If nest was located on the branch raised from the first whorl, it was considered as the nest on the first whorl. If the nesting branch raised from the second whorl, it was a nest on the second whorl and so forth.

5.2.2.1.9 Nest height (NH)

The nest height was measured as a distance from the ground to the nest. The nest height was measured with the help of a clinometer and a measuring tape as applied in the measurement of tree height.

5.2.2 Data analysis

The data were tested for normality test using the Shapiro–Wilk test. Most of the variables were not normally distributed (Royston, 1995, Razali & Wah, 2011). Therefore, the Mann-Whitney U Test was performed to examine whether the characteristics of nesting and non-nesting trees differ (Neuhäuser, 2010). After performing bivariate analyses, a logistic regression model was built to determine the relative strength of the variables that influence whether a nest is built on a tree or not. The data met the major assumptions required for logistic regression. Taking the binary presence or absence of nest on a tree as a response variable, and the explanatory variables such as the girth at breast height, longest branching order, tree whorl, canopy spread, tree height, and the first branch height, the logistic regression model was fitted. After fitting the model, the variance inflation factor was examined for multicollinearity, and it was found to be <10 (O'brien, 2007; Schreiber-Gregory *et al*., 2018) (Appendix V). The DHARMa Moran's I test was performed for distance-based autocorrelation (Hartig, 2022), and found no statistically significant autocorrelation in the spatial distribution. All analyses were performed in R Program (R Core Team, 2022).

5.3 RESULTS

White-rumped vulture constructed 873 nests on 165 trees of 18 tree species in west Nepal during the breeding season between 2006/07 and 2021/22 (Appendix VI, VII).

The number of nests and the total number of nesting trees showed a U-shaped trend over the study period, meaning that their number declined in the middle range of the study period. The total number of tree species used for nesting had remained more or less constant through the entire length of the study (Figure 14).

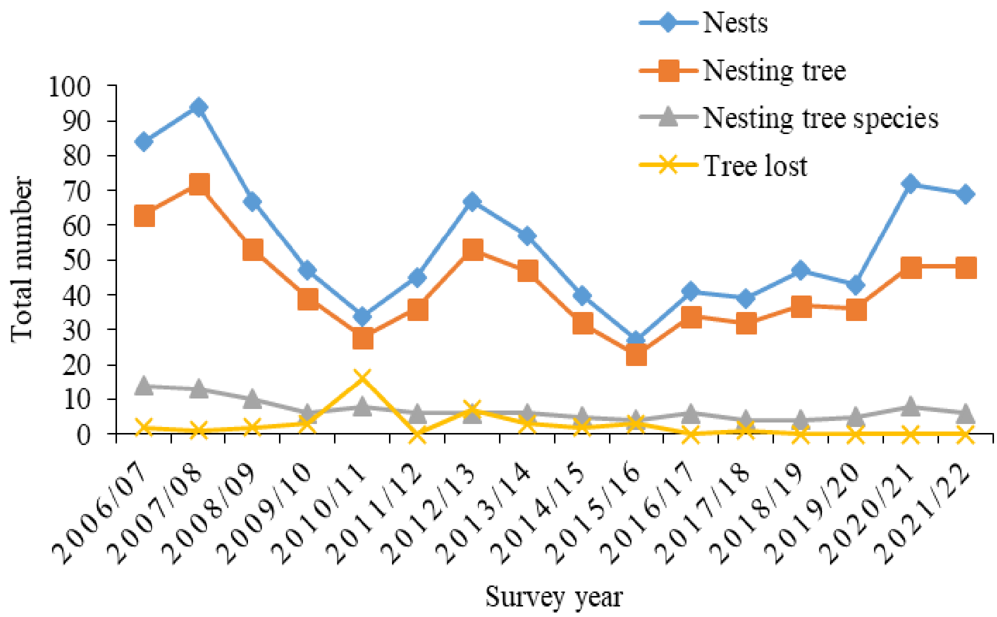

Figure 14: Number of nests, total nesting tree, nesting tree species, and tree lost in the Gandaki River Basin, Nepal

The kapok tree harbored the highest number of nests (68.48%, n = 113) followed by quassia wood trees (*Picrasma javanica*) (7.22%, n = 12), Silver grey wood (*Terminalia tomentosa*) (3.63%, n = 6), and cutch tree (*Senegalia catechu*) (2.42%, n = 4), sal (*Shorea robusta*) (2.42%, n = 4), and the other 13 different tree species (15.76%, n = 26). Kapok trees were more preferred for nest construction by white-rumped vulture as compared to other tree species (χ^2 = 115.38, df = 1, p < 0.001). Among the 45 tree species recorded in the white-rumped vulture colonies, comparatively fewer tree species (42.22%, n = 19) were utilized by the vultures for nesting (Appendix VIII).

Of the 681 nesting trees, most trees (78.85%, n = 537) had one nest followed by trees of two nests (16.59%, n = 113), three nests (2.64%, n = 18), four nests (1.32%, n = 9), and five nests (0.59%, n = 4).

Among 165 nesting trees, the tree characteristics were measured of 112 nesting trees because 46 trees were found lost and 7 trees were difficult to access due to topographical conditions. In the case of non-nesting trees, only 86 trees were measured because in the remaining 26 cases, there was not any tree for the measurement. The characteristics of white-rumped vulture nesting and non-nesting trees were found varying (Table 9). The average girth at breast height (GBH) of trees in the study area was 2.57 ± 1.93 m (nesting tree: 3.95 ± 1.43 m; non-nesting tree: 0.76 ± 0.33 m). The average highest number of branching pattern order of trees 9.70 ± 3.04 (nesting tree: 10.91 ± 2.58; non-nesting tree: 8.10 ± 2.87). The average number of tree whorl was found 6.23 ± 3.38 (nesting tree: 7.31 ± 2.86; non-nesting tree: 4.82 ± 3.49), and average tree canopy spread 13.56 ± 7.83 m (nesting tree: 19.08 ± 5.72 m; non-nesting tree: 6.38 ± 2.65 m).

Table 9: Comparison between white-rumped vulture nesting and non-resting trees in the Gandaki River Basin, Nepal. Variables girth at breast height (m), longest branching order (number), tree whorl (number), canopy spread (m) tree height (m), first branch height (m), nest branching order (number), nest branching whorl (number), and nest height (m)

Variable (unit)	Nesting tree (n =112)		Non-nesting tree (n = 86)		Man-Whitney U Test	P
	Mean (SD)	Range	Mean (SD)	Range		
GBH (m)	3.95 (1.43)	1.26-8.50	0.76(0.33)	0.30-2.10	9615.5	0.001
LBO	10.91 (2.58)	6-19	8.10(2.87)	3-14	7217	<0.001
TW	7.31 (2.86)	1-14	4.82(3.49)	1-22	7123.5	<0.001
CS	19.08 (5.72)	4.08-37.75	6.38(2.65)	1.38-13.75	9436.5	<0.001
TH (m)	23.61 (5.79)	13.42-36.37	12.03(4.87)	3.00-25.06	9134	<0.001
FBH (m)	9.71 (4.01)	0.80-18.30	3.33(2.60)	0.40-11.50	8608.5	<0.001
NBO	2.91(1.83)	1-13	-	-	-	-
NW	5.68(0.27)	1-13	-	-	-	-
NH	18.46(0.42)	8.50-36.12	-	-	-	-

- Non-nesting trees did not bear nest

The average height of trees in the study area was 18.43 ± 7.40 m (nesting tree: 23.61 ± 5.79 m; non-nesting tree: 12.03 ± 4.87 m) and average first branch height 6.93 ± 4.70 m (nesting tree: 9.71 ± 4.01 m; non-nesting tree: 3.33 ± 2.60 m).

The number of tree whorls, canopy spread and the first branch height were statistically significant explanatory variables to determine whether a nest would be built on a tree. The odds of a tree harboring a nest increased with the number of tree whorls and the increasing height of the first branch, but the odds decreased with the wider canopy spread (Table 10).

Table 10: Logistic regression model for factors affecting the occurrence of white-rumped vulture nests in the Gandaki River Basin, Nepal. Variables nest presence/absence used as response variables and girth at breast height (m), longest branching pattern order (number), tree whorls (number), tree height (m), first branch height (m), canopy spread (m) as predictive variables for the model

Variable	Estimate	SE	T	P
Intercept	-0.328	0.075	-4.373	0.001
Girth at breast height	0.003	0.004	0.727	0.468
Longest branching order	0.005	0.008	0.581	0.562
Tree whorl	0.021	0.006	3.404	0.001
Tree height	0.002	0.005	0.47	0.638
First branch height	0.035	0.005	7.796	<0.001
Canopy spread	-0.328	0.075	-4.373	0.001

Within the 10 m radius of the nesting trees, we recorded 969 trees belonging to 45 species (*see* Appendix IX). The most frequent tree was rohituka (*Aphanamixis polystachya*) (15.48%, n = 150) which was followed by small flower crape myrtle (*Lagerstromia parviflora*) (12.07%, n = 117), tiger's milk spruce (*Sapium insigne*) (10.63%, n = 103), potka siris (*Albizia lucidior*) (8.98%, n = 87), fever pod (*Holarrhena pubescens*) (5.88%, n = 57), bhellar (*Trewia nudiflora*) (5.78%, n = 56), karma (*Adina cordifolia*) (4.95%, n = 48), garuga (*Garuga pinnata*) (4.44%, n = 43), sage-leaved (Alangium *salviifolium*) (3.30%, n = 32), and wind killer (*Premna integrifolia*) (2.79%, n = 27). There were other less frequent 249 trees belonging to 35 species.

The white-rumped vultures used more trees for nesting in community forest (60.82%) than in the vicinity of human settlements (39.17%) during the study period. Of the 165 nesting trees, 40 nesting trees were lost: 21 nesting trees were cut down in community forests and 19 nesting trees were cut down in the vicinity of human settlements. Humans fell down 27 nesting trees whereas 13 nesting trees were destroyed by natural causes such as old age of the trees and storms. Among the lost tree species, most (18 trees) belonged to kapok followed by quassia wood (8), mango (1), khiar (2), red cedar (3), garuga (2), sacred fig (2), sal (2), baheda (*Terminalia bellerica*) (1), and butter tree (1) (Appendix XI).

5.4 DISCUSSION

White-rumped vultures are a selective tree nesting species, and their choice of nesting trees may be influenced by safety considerations. In the study area, rohituka trees are the most abundant trees, but vultures used kapok trees for building nest most often. Previous studies have documented that white-rumped vultures tend to use crocodile bark tree (*Terminalia tomentosa*) and sal for nest building in lowland Nepal (Subedi, 2008; Bhusal *et al*., 2020), but chir pine (*Pinus roxburghii*) and kapok are found most commonly occurring nesting trees for this species in mid hills (Rana *et al*., 2019). In India, white-rumped vultures use chir pine for nesting in Himanchal Pradesh (Thakur, 2015), coconut palm (*Cocos nucifera*), mango and baheda in Western Maharashtra (Majgaonkar *et al*., 2018), and white murdah (*T. arjua*) in Tamilnadu (Ramakrishnan *et al*., 2014). It appears that white-rumped vultures preferred certain trees irrespective of the diversity and availability of other trees. In Nepal, the availability of suitable nesting and roosting habitats may be a limiting factor, as vulture colonies are often located outside the protected areas.

White-rumped vultures choose large-sized trees, and the trees that have longest branching orders for nest construction. These trees tend to be strong enough to support the vultures' body weight during takeoff and landing. The white-rumped vultures prefer taller trees for nest construction, so that they can easily detect carcasses directly or observe a long chain of descending vultures towards the carcass (Jackson *et al*., 2008; Rouviere & Ruxton, 2022). This minimizes the energy expenditure required for scavenging, which can be a crucial factor in maintaining optimal breeding conditions. Overall, it seems that choosing large and mature trees is the best option for nest building and breeding of white-rumped vultures.

The study suggests that the tree whorl, canopy spread and first branch height are important predictive variables for white-rumped vulture nest construction. More tree whorls might provide a wider space for nest placement and roosting to the vultures. That might increase breeding success. Not only white-rumped vultures, but also black-crowned night herons (*Nycticorax nycticorax*) construct their nest in those trees that having nine or more whorls (Wood & Wood, 1933). Furthermore, white-rumped vultures build more nests on trees with low canopy spread, probably that may provide easy access for nest establishment with minimum effort, thereby increasing nesting success and ultimately leading to a higher rate of fledgling success (Barash, 1975). The advantage of nesting and roosting on tall branch extends ensures safety and ease of nest construction.

The white-rumped vultures are usually found roosting and nesting near human settlements and community forests due to the availability of food. The food availability is often ensured by livestock farming and open carcasses disposal systems. However, for more economic benefits and infrastructure development, large and mature trees are decreasing in the study area. The reduction directly affects nesting and roosting habitats for vultures (Baral *et al*., 2005; Gautam & Baral, 2013). To protect white-rumped vultures, it is necessary to implement effective measures to conserve nesting and roosting trees, including controlling the harvesting of large and tall trees that have shorter canopy spread and more whorls.

Over the past decade, the total number of white-rumped vultures' productive nests has increased in Nepal. It was probably due to diclofenac ban and the establishment of vulture safe feeding sites and zones after 2006 (Prakash *et al*., 2012). The number of nests in active colonies have positive effect on the overall nests of the species in Nepal even though some trees which white-rumped vultures use for nesting are lost in the study area. The white-rumped vultures exhibit a consistent pattern of reusing nesting trees year after year *(*Ali & Ripley, 1987; Gautam & Baral, 2013). However, characteristics of both nesting and non-nesting trees were measured only one time between 2006/07 and 2021/22. This limitation might create some possibility of bias in the relationship between nest construction and the influence of tree characteristics.

5.5 CONCLUSIONS

White-rumped vulture preferred to construct nest on the trees with a larger girth at breast height, taller, long branching order, and high first branch height than neighbouring non-nesting trees. The construction of nests was increased with the number of tree whorls and the increasing height of the first branch, but it was decreased with the wider canopy spread. Out of 18 nesting tree species, white-rumped vulture preferred the kapok tree for builing nest than the other tree species. There have been decreased in the number of nests and nesting trees forming a U-shaped trend. However, no change in the nesting tree species. However, the loss of nesting trees resulted in a somewhat opposite trend depicted by a V-shaped graph, attributed to both by human logging and natural calamities. There was the high probability of logging nesting trees in the vicinity of human settlements than in the community forest due to the construction activities, harvest by land honor, boat construction, and fund raise. Protection of nesting trees may have contributed to prevent the colony desertion of white-rumped vulture.

CHAPTER 6

6 SUMMARY AND CONCLUSIONS

6.1 Summary

The white-rumped vulture (*Gyps bengalensis*), a once-widespread scavenger species in South Asia, experienced a population decline due to the lethal effects of the veterinary drug- the diclofenac. Little is known about the population trend of this critically endangered vulture species in Nepal after the 2006 national ban on diclofenac production and use. This study investigated population dynamics and breeding ecology of white-rumped vultures in Nepal across a 16-year period (between the breeding seasons from 2006/07 to 2021/22) through direct observations. Overall, the population size of white-rumped vultures declined over the last 16 years in the 19 colonies of the Gandaki River Basin of Nepal. The population of white-rumped vulture continued to decline after the diclofenac ban too. The population growth rate was also negative during the study period. The population structure is dominated by adult individuals of white-rumped vultures. The temperature and precipitation were major influencing factors on the population trends in which the average minimum temperature and rainfall had positive effect, whereas extreme temperature and excessive rainfall had a negative effect on the white-rumped vultures. Decrease in carcasses availability, and colony abandoment were major threats to the survival of the species in the study area.

In addition, nest productivity was an indicator of population growth, and it was increased by 3.7% in the study area. Nesting failure directly affects the breeding success. The highest rate of nest failure (24%) was found during the egg-laying followed by the incubation (16.84%) and fledgling (11.23%) periods in the last 16 years. Nesting tree logging and chick collection by artificial Breeding Centre, Chitwan National Park were main reasons of colony desertion in the beginning of the study period. The breeding success i.e., fledging of chicks from the nest was influenced by precipitation, and average maximum and minimum temperature. In addition, the white-rumped vulture spent > 70% time for breeding activities.

The white-rumped vultures used 18 tree species for nest construction. Among these, the kapok tree was most favored tree species for nest construction than other available tree species. They constructed single nest in majority of trees (78.85%, n = 537). The nest construction by white-rumped vultures was influenced by specific tree characteristics, such as the number of whorls, canopy spread, and tree height.

6.2 Conclusions

This study in the Gandaki River Basin of Nepal documented the white-rumped vulture population after the diclofenac ban in Nepal and neighbouring countries. Despite the ban, the population continued to decline, with a high proportion of adults and limited breeding success. While the intrinsic growth rate remained constant, nest failures were frequent, particularly during the egg-laying period. Breeding success was also influenced by environmental factors. White-rumped vultures exhibited a preference for specific nesting trees and dedicated significant time to breeding activities. However, human activities significantly reduced nesting habitat particularly due to human logging of nesting trees. These findings emphasize that diclofenac is not the sole threat. Conservation efforts must now focus on addressing cause of low breeding, potential behavioral disruptions, and critical nesting habitat loss to ensure the long-term survival of white-rumped vultures in Nepal.

6.3 Recommendations for further work

Based on the comprehensive information from this study, here are some recommendations for future research in order to increase the conservation efforts for white-rumped vultures in Nepal:

1. **Long-term monitoring:** Establish a continuous, long-term monitoring with incorporating additional techniques, such as satellite telemetry to track white-rumped vulture movements and identifying potential threats.

   Monitor trends in breeding success and nest occupancy to evaluate the effectiveness of conservation interventions.

   Conduct in-depth studies to identify the exact causes behind the high rate of nest failures, particularly during the egg-laying period.

   Explore potential factors of nutritional deficiencies in vulture parents which might affects breeding, predator activity near nests, and diseases impacting egg viability.

   Develop predictive models to assess the potential breeding disruptions due to climate change scenarios.

2. **Implement sustainable livestock practices:** Work closely with livestock owners and veterinary practitioners to promote the use of vulture-safe alternatives to diclofenac. Sustainable livestock practices that minimize the risk of vulture exposure to harmful drugs should be encouraged and monitored.
3. **Enhance nesting habitat protection:** Destruction of nesting trees was the main reason of colony desertion in Nepal so efforts should be given to protect and conserve nesting trees, especially kapok tree. Collaborate with local communities to promote awareness about the importance of nesting trees for the vulture and encourage sustainable forestry practices. This may involve community-based initiatives, legal safeguards, and habitat restoration programs.

   Explore the feasibility of habitat restoration programs to replace lost nesting sites with suitable trees.
4. **Integrated conservation planning:** Integrate the findings into a comprehensive conservation plan for the Gandaki River Basin. Consider the identified nesting tree characteristics, breeding behaviors and population structure in developing targeted conservation strategies.
5. **Conduct targeted studies:** Understand how human activities (e.g., tourism, infrastructure development) or other disturbances near nesting colonies might impact breeding behavior and chick survival.

By addressing these research areas, conservationists and policymakers can understand the challenges faced by white-rumped vulture population in the Gandaki River Basin, Nepal and ensure the population recovery as well as long-term survival.

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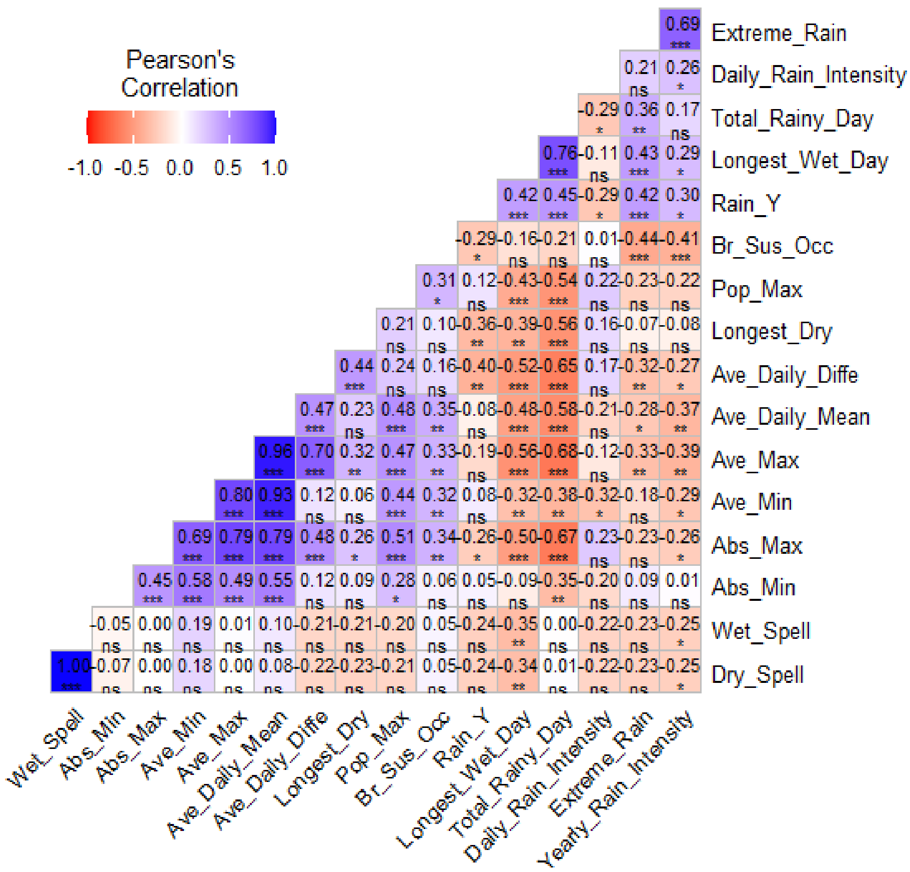
APPENDICES

Appendix I: Meteorological variables and their definition used to analyze the factors affecting population sizes and breeding success of white-rumped vulture in the Gandaki River Basin, Nepal

Variables	Definition
Average of maximum temperature	The mean value calculated from the highest temperatures recorded over a specified period (ºC)
Average of minimum temperature	The mean value calculated from the lowest temperatures recorded over a specified period (ºC)
Absolute maximum temperature	Record of the highest temperature in a specified period (ºC)
Absolute minimum temperature	Record of the highest temperature in a specified period (ºC)
Average daily mean temperature	The mean of the highest and lowest temperature recorded during 24 hours (ºC)
Average daily different temperature	The mean difference between the highest and lowest temperature recorded over a day (ºC)
Precipitation	Total amount of rain in a year
Long dry day	The period of longest continuous dry day(not rain) in the specified period (number)
Long Wet Day	The period of longest continuous rain in the specified period (number)
Dry spell	The frequency of dry (not rain) in the specified period (number)
Wet spell	Total frequency of rain in the specified period (number)
Total rain day	The total number of rain day in the specified period (number)
Extreme_rainfall	The highest amount of rain in a day (mm)
Daily rainfall intensity	The maximum amount of rain of a year divided by 24 hours (mm/hr)
Yearly rain intensity	Total amount of rain divided by total rain day of the specified year (mm/day)



Appendix II: Coefficient correlation of meteorological variables with breeding success and maximum abundance of white-rumped vultures in the Gandaki River Basin, Nepal. Extreme_Rain: The highest amount of rain in a day (mm); Daily_Rain_Intensity: The maximum amount of rain of a month divided by 24 hours (mm/hr); Total_Rain_Day: The total number of rain in the specified period (number); Longest_Wet_Day: The period of longest continuous rain in the specific period (number); Rain_Y = Total precipitation: Total amount of rain in a year (mm); Ave_Daily_Mean = Average daily mean temperature: Mean of daily maximum and minimum temperature (°C); Ave_Max = Average maximum temperature (°C); Ave_Min = Average minimum temperature (°C); Abs_Max = Absolute maximum temperature: Record of the absolute maximum temperature (°C); Abs_Min = Absolute minimum temperature: Record of the absolute minimum temperature (°C); Pop_Max = Maximum abundance of white-rumped vulture (number); Br_Sus_Occ = Breeding success of white-rumped vulture on the basis of occupied nest as primary unit (%); Longest_Dry = Longest dry day: The period of longest continuous dry day (not rain) in the specified period (number); Ave_Daily Diffe = Average daily different temperature: Record of maximum minus minimum temperature (°C); Wet_Spell: Total frequency of rain in the specified period (number); Dry_Spell: Total frequency of dry (not rain) in the specified period (number); and Yearly_rainfall_intensity: Total amount of rain divided by total rain day of the specified month (mm/day).

Appendix III: Total occupied nests, productive nests and failed nest of white-rumped vultures in the Gandaki River Basin, Nepal

Year	Failed nest during egg laying period	Failed nest during incubation period	Failed nest during fledgling period	Productive nest
2006/07	29	8	20	27
2007/08	12	16	21	45
2008/09	20	14	8	25
2009/10	18	9	6	14
2010/11	5	4	4	21
2011/12	5	4	7	29
2012/13	20	12	6	25
2013/14	16	7	4	30
2014/15	9	11	4	16
2015/16	2	6	2	17
2016/17	8	6	4	23
2017/18	9	4	4	22
2018/19	14	2	1	30
2019/20	14	5	2	22
2020/21	14	17	0	32
2021/22	10	19	3	28

Appendix IV: Nesting trees characteristics of the white-rumped vulture in the Gandaki River Basin, Nepal

Variable	Description
Girth at Breast Height (GBH)	Measurement of the girth of the tree at breast height (m)
Longest Branching Order (BO)	Measurement of the longest branching pattern of a particular tree (number)
Nest Branching Order (NBO)	The branching pattern order which holds the nest (number)
Total Number of Tree Whorl (TW)	Measurement of the total whorl number of a particular tree (number)

Canopy Spread (CS)	Mean of longest and shortest canopy spread measure of a particular tree(m)
Tree Height(TH)	The estimated height of a particular tree from the ground (m)
First Branching Height (FBH)	The estimated height of the first branch of a particular tree from the ground (m)
Nest Height (NH)	The estimated height of the nest from the ground (m)
Nest Whorl (NW)	Measurement of nest bearing whorl (number)

Appendix V: Variance inflation factor between the variables of nesting and available trees around 10 m radius of white-rumped vulture's nesting trees in the Gandaki River Basin, Nepal

Variable	VIF
Girth at Breast Height	1.11
Longest branching order	1.74
Tree whorl	1.04
Canopy spread	2.64
Tree height	2.25
First branch height	1.82

Appendix VI: Number of nest per tree used by white-rumped vulture in the Gandaki River Basin, Nepal

Survey year	Single nesting tree	Two nesting tree	Thee nesting tree	Four nesting tree	Five nesting tree	Total nesting trees	Total occupied nest
2006/07	46	15	0	2	0	63	84
2007/08	57	10	3	2	0	72	94
2008/09	43	8	1	0	1	53	67
2009/10	32	6	1	0	0	39	47
2010/11	23	4	1	0	0	28	34
2011/12	28	7	1	0	0	36	45
2012/13	42	9	1	1	0	53	67
2013/14	38	8	1	0	0	47	57
2014/15	25	6	1	0	0	32	40
2015/16	20	2	1	0	0	23	27
2016/17	29	4	0	1	0	34	41

2017/18	27	4	0	1	0	32	39
2018/19	28	8	1	0	0	37	47
2019/20	30	5	1	0	0	36	43
2020/21	35	7	3	1	2	48	72
2021/22	34	10	2	1	1	48	69

Appendix VII: Nesting tree species of white-rumped vulture in the Gandaki River Basin, Nepal

SN	Local name	Comman name	Scientific name	Number
1	Aap	Mango	*Magnifera indica*	1
2	Barro	Bastard myrobalan	*Terminalia bellerica*	1
3	Chhatiwan	White cheese wood	*Alstonia Scholaris*	3
4	Chilaune	Needlewood tree	*Schima wallichii*	3
5	Dabdabe	Grey downy balsam	*Garuga pinnata*	3
6	Karang	Yellow teak	*Adina cardifolia*	2
7	Katush	Chestnut	*Castapopsis indica*	2
8	Kavro	Java fig	*Ficus lacor*	2
9	Khair	Cutch tree	*Senegalia catechu*	4
10	Lokate	Jungle cork	*Holoptelia integrifolia*	1
11	Padke	Potka siris	*Albizia lucidor*	2
12	Peeple	Sacred fig	*Ficis religiosa*	2
13	Sal	Sal	*Shorea robusta*	4
14	Saj	Silver grey wood	*Terminalia tomentosa*	6
15	Simal	Kapok	*Bombax ceiba*	113
16	Swami	Weeping fig	*Ficus benjamina*	1
17	Tiju	Quassia wood	*Picrasma javanica*	12
18	Tuni	Redcedar	*Toona ciliata*	3

Appendix VIII: Non-nesting tree species found around the nesting trees of white-rumped vulture in the Gandaki River Basin, Nepal

SN	Local name	Common name	Scientific name	Number
1	Chuletro	Chuletro	*Brassaiopsis hainla*	7
2	Chilaune	Needlewood tree	*Schima wallichii*	26
3	Katush	Chest nut	*Castanopsis indica*	16
4	Kutmiro	Yati	*Listea monopetala*	16
5	Bhalupayile	Chinese alangium	*Alangium chinense*	18
6	Khirro	Tiger's milk spruce	*Sapium insigne*	103
7	Kurau	Fever pod	*Holarrhena pubescens*	57
8	Bedulo	Bedulo	*Ficus subincisa*	1
9	Tiju	Quassia wood	*Picrasma javanica*	17
10	Aurelu	Aurelu		9
11	Sal	Sal tree	*Shorea robusta*	8
12	Gideri	Wind killer	*Premna integrifolia*	27
13	Khaniyo	Dropping fig	*Ficus semicordata*	5
14	Thotne	Hairy fig	*Ficus hispida*	15
15	Dabdabe	Garuga	*Garuga pinnata*	43
16	Amara	Tree of heaven	*Ailanthus excelasa*	2
17	Saj	Bastard myrobalan	*Terminalia elliptica*	24
18	Kavro	Java fig	*Ficus lacor*	19
19	Bar	Banyan	*Ficus benghalensis*	3
20	Rukhakatahar	Jack tree	*Atrocarpus heterophyllus*	2
21	Simal	Kapok	*Bombax ceiba*	14
22	Padke	Potka siris	*Albizia lucidior*	87
23	Khayar	Cutch	*Senegalia catechu*	10
24	Chhatiwan	Black board tree	*Alstonia scholaris*	3
25	Rohini	Red berry	*Mallotus philippensis*	4
26	Aap	Mango	*Magnifera indica*	1

27	Pipal	Sacred fig	*Ficus religiosa*	5
28	Lokte/Daje	Jungle cork	*Holoptelia integrifolia*	6
29	Swami	Golden fig	*Ficus benjamina*	3
30	Sunkauli	Indian bay leaf	*Cinnamomum tamala*	1
31	Lakuri	Himalayan mannaash	*Fraxinus floribundax*	1
32	Badahar	Monkey fruit	*Artocarpus lakoocha*	2
33	Ramriththo	Bhellar	*Trewia nudiflora*	56
34	Lasune	Rohituka tree	*Aphanamixis polystachya*	150
35	Taki	Butterfly tree	*Bauhinia purpurea*	1
36	Budhodhayero	Small flower crape myrtle	*Lagerstromia parviflora*	117
37	Nibuwa	Lemon	*Citrus lemon*	1
38	Pakhuri	Pakhuri	*Ficus glaberrima*	1
39	Tuni	Red cedar	*Cedrela tuna*	2
40	Asare	Sage leaf alangium	*Alangium salviifolium*	32
41	Karang	Karma	*Adina cordifolia*	48
42	Belapatra	Golden apple	*Aegle marmelos*	1
43	Nibaro	Nibaro	*Ficus rosenbergii*	2
44	Gaya	Gaya	*Bridelia retusa*	2
45	Chiuri	Butter tree	*Aesendra butyraceae*	1

Appendix IX: Causes of white-rumped vulture nesting tree lost in the Gandaki River Basin, Nepal

Causes of nesting tree lost	Total nesting tree lost	Total nesting tree (n = 165) (%)
Natural death	13	7.88
Destroyed by human		
Harvest by land honor	13	7.88
Construction activities	8	4.85
Boat construction	3	1.82
Raising fund	3	1.82
Total	40	24.25

Appendix X: Participation in Conferences from 2020 to 2023

1. Gautam, R., Baral, N., & Sharma, H. P. (2020). Long-term population monitoring of white-rumped vulture (*Gyps bengalensis*) in west Nepal. First National Conference on Zoology: Biodiversity in Changing World (28 to 30 November, 2020), Central Department of Zoology, Tribhuvan University, Kathmandu, Nepal.
2. Gautam, R., Sharma, H. P., Baral, N., & Gautam, B. P. (2021). Behavior analysis and modeling of white-rumped vulture (*Gyps bengalensis*) by using Markov chain modeling. International Conference on Zoology 2021: Himalayan Biodiversity in the Face of Global Change (9 November to 1 December, 2021), Central Department of Zoology, Tribhuvan University, Kathmandu, Nepal.
3. Gautam, R., Baral, N., & Sharma, H. P. (2023). Are white-rumped vultures (*Gyps bengalensis*) scavengers of predators at Vulture Safe Feeding Site of Nepal? National Conference on Multidisciplinary Innovation (7 to 8 April, 2023), Research Management Cell, Birendra Multiple Campus, Chitwan, Nepal.

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Are white-rumped vultures (*Gyps bengalensis*) scavengers or predators at a vulture safe feeding site of Nepal?

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Abstract. *Gautan R, Baral N, Sharma HP. 2022. Are white-rumped vultures (*Gyps bengalensis*) scavengers or predators at a vulture safe feeding site of Nepal?. Biodiversitas 23: 3808-3812.* Establishing safe feeding sites has been promoted as a strategy to conserve wild vultures following the population crash in South Asia due to the contamination of natural food by veterinary diclofenac. Several feeding sites have been established in the region, including Nepal and it is important to evaluate their effectiveness. One aspect that is not clear yet is whether such safe feeding sites change the behaviors of wild vultures in South Asia. Here, we report incidents of White-rumped Vultures *Gyps bengalensis* attacking live animals at the Vulture Safe Feeding Site in Ghachok village in central Nepal. Even though a carcass was available nearby to feed upon, three White-rumped Vultures attacked an adult cow and a calf at the feeding site. The vultures' attack served as an ancillary cause of the calf's death in this case. These two incidents of vultures' attacking live animals at the safe feeding site may allude to changing behaviors and cast doubt on their status of being classified as an obligate scavengers. The findings suggest alteration of vulture behaviors at the safe feeding site. Further research is needed to test the hypothesis of vulture behavior change.

Keywords: Behavior change, carcass, foraging, supplementary feeding, unproductive livestock

INTRODUCTION

All the 16 species of Old World Vultures, including White-rumped Vultures *Gyps bengalensis*, are considered to be obligate scavengers that feed upon dead animals only (Hunter et al. 2007). But some species of the New World Vultures, such as Black Vulture *Coragyps atratus* and Turkey Vulture *Cathartes aura* are considered facultative scavengers because they also prey upon other live animals for feeding (Toledo et al. 2013; Platt et al. 2021; Gula 2022). Not only the feeding behavior but also the food search strategy of these two groups of vultures is different: Old World Vultures find carcasses mainly through sight and the New World Vultures using both sight and smell to locate the carcasses (Houston 1974; Potier et al. 2019). The change from obligate scavenging feeding behavior to facultative is noticed in some of the Old World Vultures, including Cinereous Vulture *Aegypius monachus*, Bearded Vulture *Gypaetus barbatus*, Eurasian Griffon *G. fulvus*, and White-headed Vulture *Trigonoceps occipitalis* in their range states (Lowney 1999; Murn 2014; Duriez et al. 2019). Several factors might contribute to such behavioral changes, but a body of empirical research reports factors such as food scarcity, changes in livestock farming practices, and safe carcass disposal policy to be responsible for the behavioral change in vultures (Cortés-Avizanda et al. 2014; Margalida et al. 2017). The finding such as this highlights the need for regular monitoring of any conservation intervention to detect unintended consequences in a timely manner.

In response to the South-Asian vulture crisis leading to a more than 95% decrease in wild populations of three *Gyps* vultures due to the contamination of livestock carcasses by diclofenac (Oaks et al. 2004; Shultz et al. 2004), the vulture range state governments have adopted three major interventions for vulture conservation: (1) the ban on veterinary use of diclofenac; (2) initiation of captive breeding and release programs; (3) establishment of safe feeding sites. The Government of Nepal adopted the Vulture Conservation Action Plan in 2009 to avert the potential local extinction of wild vulture populations, incorporating all three major vulture conservation interventions. As per the action plan, one of the major conservation measures is to provide diclofenac and poison-free carcasses to wild vultures by establishing vulture-safe feeding sites and expanding the vulture-safe zones throughout the country (DNPWC 2015). The vulture safe zone is defined as the diclofenac and other vulture toxic non-steroidal anti-inflammatory drugs free area, which is declared to ensure the safe environment for vultures to feed and the initiative draws upon advocacy, monitoring and community involvement to make the program successful (Paudel 2013). Currently, the vulture safe feeding zone comprises 101,160 km^2 of the total land of 147,516 km^2 and covers 46 out of 77 administrative districts of Nepal (DNPWC 2015). Besides Nepal, this conservation approach is also implemented in India, Pakistan, and Bangladesh where vultures' distribution range overlaps (Mukherjee et al. 2014). The shortage of food for vultures in the wild due to changes in traditional farming and livestock raising methods and carcasses disposal practices in Nepal lends further support for such conservation measures (Baral et al. 2005; Baral and Gautam 2007). So far, seven community-managed Vulture Safe Feeding Sites have been established in Nepal (DNPWC 2015). The concept of safe feeding sites was originally initiated in the 1960s in European and African countries to supply stable livestock carcasses in the wild to feed scavengers which became necessary due to legal restrictions on the open disposal of livestock carcasses (Bijleveld 1974). Although the merits and demerits of such safe feeding sites are hardly debated on rigorous scientific grounds, they have become one of the famous conservation tools for vulture conservation worldwide. This argument is supported by the increasing number of safe feeding sites throughout the world, for example, 143 active sites are recorded in South Africa only (Brink et al. 2020). At the safe feeding site, the food is constantly, consistently, and predictably available to vultures, which can prevent food shortage or routinely increase the frequency of food supply to the vultures (Kane et al. 2015; Fluhr et al. 2017).

A standard practice in these supplementary safe feeding sites is that they collect old, abandoned, unproductive and dying cattle in discounted prices or free of charge and feed them to vultures after their natural death. No in-depth research on the potential positive or negative impacts of safe feeding sites on the behaviors of wild vultures has been conducted in Nepal. Nonetheless, the safe feeding sites have attracted more vultures and the number of roosting and nesting vultures has increased near such safe feeding sites (DeCandido et al. 2012; Fluhr et al. 2017; Dhakal et al. 2022). Generally, wild vultures detect food by four mechanisms. Vultures find the food resources on their own without relying upon the activities of other individuals (Cortés-Avizanda et al. 2014). Vultures follow the scavengers, which are gathering in and around the carcass and find the food. Vultures observe the flight activities of other vultures and follow them when others dive fast towards a carcass after a short circle over it (Cortés-Avizanda et al. 2014). Vultures also find food by forming a chain of vultures flying towards or following the individual vultures which had previously visited the carcass site (Cortés-Avizanda et al. 2014; Rouviere and Ruxton 2022). These natural foraging behaviors of vultures might be altered by the establishment of safe feeding sites where vultures sit and wait for food rather than engage in active search in the wild (Zuberogoitia et al. 2013). The presence of safe feed sites leads to a decrease in the efforts of vultures to travel long distances to search for food or a reduction in the long wait time for food (Kane et al. 2015; Fluhr et al. 2017). Scholars and practitioners report that safe feeding sites might provide conditions favorable for vultures to attack live animals kept there. For example, one study claims that sometimes the food signal available in the feeding sites also motivates vultures to attack the live individuals (Black Vultures attack on calf; Toledo et al. 2013). In some instances, vultures are seen to attack non-aggressive, weak/small animals for feeding at such sites (Duriez et al. 2019). We also noticed similar unusual behavior of White-rumped Vulture at the Vulture Safe Feeding Site Ghachok, Kaski, Nepal. Therefore, we followed the White-rumped Vultures' activities at the safe feeding site to record whether there was any change in the behavior of wild White-rumped Vultures.

MATERIALS AND METHODS

Study area

The behavioral study of the White-rumped Vulture was carried out at the Vulture Safe Feeding Site Ghachok (28º06′N and 84º12′E), which lies within the Annapurna Conservation Area, Nepal. The Vulture Safe Feeding Site Ghachok is a community-based initiative started in 2010 to provide safe food for vultures by taking care of and letting the old and unproductive livestock to die naturally at the site. The safe feeding site, with an area of five hectares (50,000 m^2), is about 15 minutes walking distance from the human settlement on the west bank of the Seti River. The Vulture Safe Feeding Site is fenced by a large stone wall, and the area within in the periphery appears to be enough for stocked livestock to range freely. The management of the safe feeding site is partially supported by Machhapuchchhre Rural Municipality and Bird Conservation Nepal for feedstock to livestock, equipment, training and salary to staff. The villagers voluntarily supply old, abandoned and unproductive cattle to the Vulture Safe Feeding Site. Altogether 18 adult cows, an ox, and three calves were present at the site when the fieldwork was conducted. After livestock dies of natural death, they are skinned and the carcasses are left in the open for vultures to feed upon.

Seven species of vultures, namely Egyptian Vulture *Neophron percnopterus*, Himalayan Griffon *Gyps himalayensis*, Red-headed Vulture *Sarcogyps calvus*, Slender-billed Vulture *G. tenuirostris*, White-rumped Vulture *G. bengalensis* Cinerous Vulture *Aegypius monachus*, and Eurasian Griffon *G. fulvus* are recorded from the feeding site (Dhakal et al. 2022). We recorded five species (sans Cinerous Vulture and Eurasian Griffon) during the field visit. The White-rumped Vulture inhabits in tropical and subtropical regions of Nepal within the elevation of 1500 m above sea level (Grimmett et al. 2016). Its population is estimated to be 4000 to 6000 individuals in its range countries, including Bangladesh, Bhutan, Cambodia, India, Myanmar Nepal, Pakistan, and is categorized as a critically endangered species in the Red Databook by BirdLife International (2021). In Nepal, the population of White-rumped was estimated as 2000 individuals in the wild (DNPWC 2015). The White-rumped Vultures build nests and roost in colonies on tall trees near human settlements.

Methods

For the research purpose, the first author has been visiting the Vulture Safe Feeding Site Ghachok since February 2020 to count the number of vultures feeding at the safe feeding site and observe their feeding activities and other behaviors of the vultures. In our visit to the site on October 25, 2021, we observed unusual feeding behaviors of vultures that cast doubts on them being obligate scavengers. To delve into the issue, we took detailed field notes, photos and videos in a systematic manner on October 25 and 26, 2021. Observations with naked eyes and binoculars (60×10) were made from 7:00 hr to 17:30 hr. We then analyzed the descriptions of the field notes and synthesized them into a coherent narrative to present the findings and develop hypotheses.

RESULTS AND DISCUSSION

On October 25, 2021 there was one dead cow at the safe feeding site. At 8:05 AM three White-rumped Vultures came near the cow carcass but did not attempt to feed on it at first, probably due to the presence of an employee who was cleaning the shed. Immediately the employee left the shed after cleaning, seven White-rumped Vultures and two Himalayan Griffons started feeding on the carcass from the anterior and posterior parts. Within 30 minutes, the number of vultures feeding on the carcass reached 10, with an additional White-rumped Vulture and two Himalayan Griffons. By 2:00 PM, there were 44 vultures in total feeding on the carcass (35 White-rumped Vultures; six Red-headed Vultures; two Himalayan Griffons; and one Slender-billed Vulture). As the number of vultures increased, aggressions between individuals while feeding also increased.

There was an adult cow (around 12 years old) resting in the cowshed, which was approximately three meters away from the carcass on which vultures were feasting. At 2:30 PM, a sub-adult White-rumped Vulture approached the adult cow and started to tug in the head's upper jaw region (Figure 1A). The adult cow moved its head sideways to discourage the vulture (Video 1). The vulture's persistence in pecking the upper jaw and eye seemed to annoy the adult cow. After two minutes, the adult cow moved away from the place. Based on this observation, we suspected that the vulture was attacking a live adult cow.

Because of these unusual activities of the White-rumped Vulture, we visited the same site the next day (October 26, 2021) with the intention of gathering further information. At 8:30 AM, the caretaker started skinning a cow carcass to make it ready for vultures to feed on. We observed 15 vultures (12 White-rumped Vultures and one each of Himalayan Griffon, Red-headed and Slender-billed Vulture) waiting for the food. It took almost 45 minutes for the caretaker to skin the carcass and by that time 24 White-rumped, three Red-headed and one Egyptian Vultures arrived at the safe feeding site to feed. The highest number of 54 vultures of five different species (38 White-rumped Vultures, seven Red-headed Vultures, four Slender-billed Vultures, 3 Egyptian Vultures and 2 Himalayan Griffons) was recorded at the cow carcass. They consumed the carcass within two and quarter hours (135 minutes). By 4.00 PM several vultures were seen soaring, basking or just resting on the ground and trees at the safe feeding site. We observed 13 individuals (nine White-rumped Vultures and four Himalayan Griffons) tugging with the remaining part of the carcass on the ground. Around that time, an adult White-rumped Vulture landed on the ground of the safe feeding site. Instead of moving towards the carcass remains, the adult vulture approached a frail calf that was lying on the ground nearby. The White-rumped Vulture started to peck the calf's body surface from head to tail at around 4:10 PM (Video 2). The calf seemed to lack the energy to fend away the vulture. When the calf moved the tail, the anal region was exposed to the vulture (Figure 1B).

At that moment, the White-rumped Vulture started to pull the anal sphincter muscles with a great jerk. Another sub-adult White-rumped Vulture joined and started to pull the calf's intestine. Then the adult WRV tugged the calf's eye. Another sub-adult White-rumped Vulture, joined the band at 4:20 PM to attack the calf, and it consumed the blood flowing from the calf's eye. When the calf reacted by shaking the heading and the body, the three White-rumped Vultures became alert and backed off to a safe distance. They raised their legs and spread wings towards the calf simultaneously. Because the calf could not stand, change its posture or walk, the vultures immediately attacked the calf, one vulture pulling its tongue and the other two working on anal sphincter muscles and eye. When the vultures consumed the calf's anal sphincter muscles, eyes, and tongue, the calf took its last breath at 4:25 PM. White-rumped Vultures' attack appeared to be an ancillary cause of the calf's death. Immediately after the calf's death, three more White-rumped Vultures joined and ate the dead body.

The staff of the Vulture Safe Feeding Site Ghachok also mentioned that there were a couple of incidents in the past in which White-rumped Vultures attacked immobile cattle. When we inquired other researchers and field assistants, they also reported a few incidents of White-rumped Vultures attacking live cattle elsewhere during winter.

Discussion

We have documented two incidents of White-rumped Vultures attacking live animals in the safe feeding station. These observations raise several questions regarding White-rumped Vultures' feeding behaviors. First, do the safe feeding sites alter the behaviors of White-rumped Vultures? Second, are White-rumped Vultures facultative or obligate scavengers? Third, how do White-rumped Vultures discriminate between dead vs frail animals? The answers to these questions help to interpret and explain the behaviors that we have documented. Among five species of vultures recorded at the site, only White-rumped Vultures being involved in the attack of live animals need further investigation. Is this due to their sheer number compared to other vulture species or just the change in their behaviors? The probability of finding food in the vulture-safe feeding sites is greater than finding carcasses in the natural habitats (Zuberogoitia et al. 2010; Fluhr et al. 2017). We wonder whether White-rumped Vultures' attack on live animals at the safe feeding site is prompted by habituation conditioned by the abundant supply of "easy" food. White-rumped Vultures are soft organ feeders and fall under the gulper feeding group of vultures (Linde-Medina et al. 2021).

A B

Figure 1. A. A White-rumped Vulture tried to tear soft part from live cow; B. White-rumped Vulture attacking a live calf at Vulture Safe Feeding Site Ghachok, Kaski, Nepal

What appeared to be a predatory behavior of White-rumped Vultures during this study is interesting and new to behavioral science. There might be various reasons for this behavior. They might be habituated to consuming soft organs from anal and mouth regions. That might be the reason of the first attempt from the face and anal region. White-rumped Vultures might be habituated to feeding on the carcasses at the safe feeding site. If the carcasses are not available at the safe feeding site, then they might be motivated to attack old, frail, immobile and dying animals. We suspect that a cow lying on the ground nearby the carcass might have provided false information on the cow's death to the vultures. In our case, the immobility of the calf might have served as a signal of the calf's death to vultures (Duriez et al. 2019). The presence of carcasses and cows lying on the same ground might provide false information on the death of an animal to the vultures. Vultures often take immobile eyes and ears and unshaken tails as indications of animals' death and appear to check these signs probably by body surface biting (Duriez et al. 2019). But, the White-rumped Vultures attacked the calf and cows even though they moved their body parts during the body surface biting in this case. Similar incidences are also recorded on Black Vultures, which attack cows and neonates in the calving sites in Brazil, but the attack is probably triggered by an opportunity to feed upon the fetal membrane and placenta present on the body of cows and neonates rather than killing them (Toledo et al. 2013). Or Black vultures might have been habituated for getting food during the parturition period at the calving sites and can attack to cows and calves while they are weak. White-rumped Vultures might attack old, frail and immobile animals in the wild, but the probability of recording and reporting such incidents is low, so we hardly know how the behavior we saw at the safe feeding site compares with vulture behavior in the wild in a similar situation. In the literature, some cases of obligate scavengers killing weak and diseased animals are reported. For instance, Black Vulture, Eurasian Griffon and Turkey Vulture prey upon the newly born defenseless and weak calf and sea lion pups (Toledo et al. 2013; Murn 2014). When vultures come in close contact with livestock and humans frequently at safe feeding sites, their behaviors might be altered due to limited home range size, movement and foraging abilities (Zuberogoitia et al. 2013; Cortés-Avizanda et al. 2016).

In conclusion, frequent interactions with the weak and old cattle in the safe feeding sites might prompt vultures to kill the animals before they die naturally. The predatory behavior as noticed in the White-rumped Vultures can raise questions to scientists and managers. More follow-up research is warranted to make a definite conclusion on whether the safe feeding sites alter the behaviors of wild White-rumped Vultures.

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Analyzing White-rumped Vulture breeding behavior using Markovian modeling

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Abstract Understanding wildlife behavior, including accurate identification, processing, and interpretation of activities or cues, is important to behavioral biology and corresponding conservation strategies. We characterized the breeding activities of the critically endangered White-rumped Vulture *Gyps bengalensis* following a sequential pattern from courtship to fledging. We recorded 4,160 visual observations of 20 behaviors of eight pairs of White-rumped Vultures from September 2021–April 2022 and constructed Markov chain models to model three composite behaviors (i.e., breeding, foraging, and roosting). We found that vultures at four nests displayed >70% of the time in breeding behavior, and each nest produced offspring, indicating a potential correlation between breeding behavior and successful reproductive outcomes. Our model explained each composite behavior with high accuracy. Identifying behaviors White-rumped Vulture have practical applications for developing management plans for their conservation, including the timing of critical reproductive events. Our findings and approach can improve our understanding of White-rumped Vulture behavioral ecology and conservation and have applications for other species.

Keywords: behavior, markov, modeling, simulation, White-rumped vultures

1. Introduction

The White-rumped Vulture *Gyps bengalensis* is endemic to Southeast Asia (Ali and Ripley 1968). In Nepal, the species is resident and inhabits tropical and subtropical areas <1500 m above sea level (Dhakal et al 2023; BLI 2021; Grimmett et al 2016). White-rumped Vultures were the most common vulture species throughout its geographical range. Still, following rapid population declines during the mid-1990s (Prakash 1999), it is currently listed as Critically Endangered on the IUCN Red List of Threatened Species and Appendix II list of CITES (BLI 2021). A dominant cause of this population decline is the veterinary use of diclofenac (Oaks et al 2004; Shultz et al 2004), where White-rumped Vultures die of kidney failure after consuming the drug in treated livestock carcasses (Oaks et al 2004; Shultz et al 2004). Other causes of population decline include habitat loss and human persecution (Baral et al 2005; BLI 2021; Loveridge et al 2019).

Knowledge of White-rumped Vulture behavior can provide insights into their behavioral biology to improve conservation actions. Correct identification, processing, and interpretation of activities or cues are important aspects of behavioral biology (Kappeler 2021*).* The behavior of White-rumped Vultures varies within and among individuals and in response to environmental conditions (Bell et al 2009; Dingemanse et al 2010; Gautam et al 2022). Also, White-rumped Vulture behavior can be grouped into breeding and non-breeding seasons (Ali and Ripley 1968; Baral et al 2005), and breeding activities are sequential from courtship to nest-building, egg laying, incubation, nestling, and fledgling. Such complex behaviors require accurately characterizing activities concerning surrounding environmental factors and interaction with conspecifics and other species (Pimm et al 2015). These complex behavior activities of White-rumped Vultures can also be categorized broadly as feeding, breeding, and roosting activities, each with intermediate and more specialized behaviors.

Knowledge of species' behavior is essential to predict the likelihood of future behavioral states, which can be enhanced using mathematical models (Atherton and Kerbyson 1999; Baltrusaitis et al 2016; Crall et al 2015; Taha et al 2014). Such methods may reveal information crucial for conserving threatened species (Gautam et al 2020; Noldus et al 2002). Relying on mathematical models for ethological studies should be used cautiously, and field observations can provide information to validate behaviors (Knopff et al 2009). Previous studies of White-rumped Vultures in Nepal have included their distribution, population status, and breeding (Baral et al 2005; Baral et al 2013; Chaudhary et al 2012); however, protection of nesting and roosting sites and understanding their behavior has not yet been investigated. We collected data from field observations to construct Markov chain models (MCMs), to estimate the behavior states of White-rumped Vultures in Nepal. Specifically, we used *Gyps* breeding futures, an enhanced Markov chain

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analysis that can predict the different dynamics of individuals. As reproduction's success affects species' population viability (Anthony and Blumstein 2000), knowledge of reproductive behavior is important for conserving threatened species like White-rumped Vultures.

The application of MCMs offers a novel insight into species behavior. Our goal was to use MCMs to estimate transition probabilities between different states of vulture behavior and predict the likelihood of vultures being in a particular state at a given time based on their previous state. To our knowledge, no previous studies have used this mathematical model to study White-rumped Vulture behavior. Therefore, we aimed to identify behavioral patterns and their relationship to each other to assess vultures' breeding behaviors accurately and offer a consistent and standard observational framework for future vulture behavioral studies.

2. Materials and Methods

2.1. Study area and data collection

We conducted the study in Gaukha (N 28° 2′ 3.1″, E 83° 52′ 31.8″), Syangja District, Nepal (Figure 1). Gaukha has subtropical forests including Chestnut *Castanopsis indica*, Coromandel Ebony Persimmon *Diospyros melanoxylon*, Hill Sal *Shorea robusta*, Needle Wood *Schima wallichii*, and Kapok *Bombax ceiba*. White-rumped Vultures roosted and nested in Coromandel Ebony Persimmon and Kapok trees in a sacred grove and private lands in the study area.

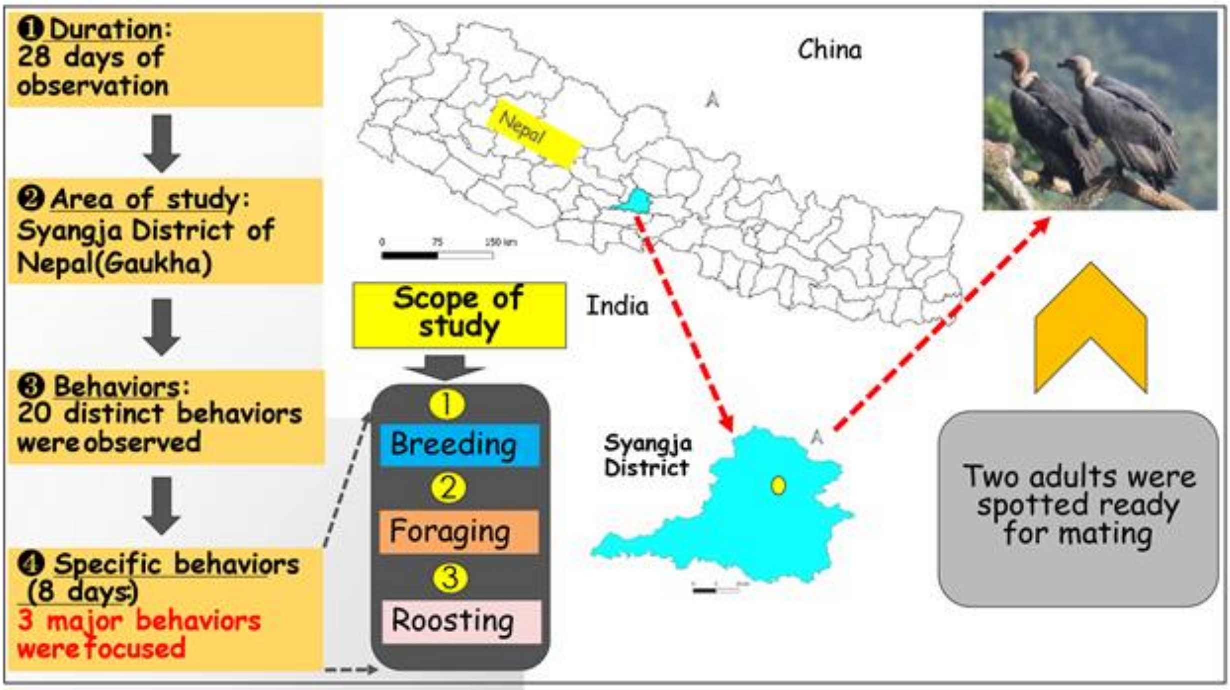

Figure 1 Study area and duration of White-rumped Vulture behavior study.

During the 2021–2022 breeding season, we monitored eight breeding pairs of White-rumped Vultures using augmented focal sampling (AFS), a modification of a focal sample (Altmann 1974) in which a pair of White-rumped Vultures were observed as opposed to an individual. This method was appropriate to our study because individuals shared nesting activities, behaved as a pair, and we could not discern individuals of a nesting pair.

To apply AFS, we first established recording rules which were continuous recording for a discrete-time and defined the appropriate time interval for recorded observations. These rules were to normalize minor behaviors (i.e., behaviors with low frequency and effect) and later combine these into broader categories of behavior. We collected data on these eight pairs from nest building to fledgling phases. We observed vultures from 9:00 to 17:30 for two days in each stage, monitoring each pair for 10-minute intervals. Observations occurred from September 2021 to April 2022. We defined breeding activities as a stepwise process of pairing, nest construction, egg laying, incubation, and rearing young to a fledgling stage. At least two people collected frequency and transition behavioral data using binoculars and a video camera for observations. Five of the nests observed were constructed in a single Coromandel Ebony Persimmon, two nests in a single Kapok, and one in an adjacent Coromandel Ebony Persimmon tree. We observed White-rumped Vultures 100 m from nesting and roosting trees to reduce disturbances. We recorded 20 readily discernible minor behaviors (see Supplementary material).

We used R programming language to graph the MCMs visually and conducted cohort simulations in Excel to perform MCMs. Furthermore, we performed MCMs simulations using observational data and evaluated our approach using post hoc analyses.

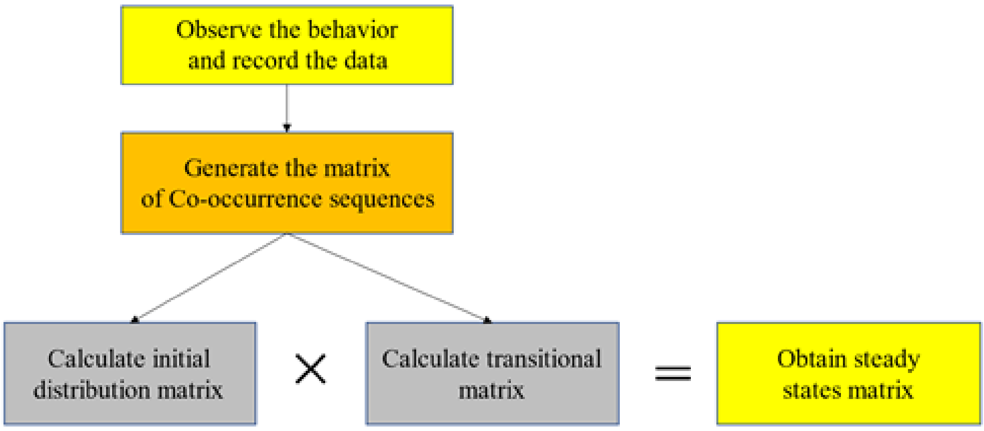

Figure 2 Conceptual model of White-rumped vulture behavioral model development.

Table 1 List of major and minor behaviors of White-rumped Vultures.

Foraging (F) (Sub-classifications)	Roosting (R) (Sub-classifications)	Breeding (B) (Sub-classifications)
S = Soaring	R = Resting	PR = Pairing
L = Landing	B = Basking	NB = Nest Building
W = Walking	P = Preening	I = Incubation
J = Jumping	PP = Pooping	N = Nourishing
T =Take Off	A = Aggression	M = Mating
E = Eating		ND = Nest Defending
		SN = Standing on Nest
		PN = Preening on Nest
		BN = Basking on Nest

2.2. Markovian approach and model setup

The MCMs is a discrete-time probabilistic model that can predict the current state's probability depending on the previous state. We used MCMs to build statistical models to investigate the breeding behaviors of White-rumped Vultures (Figure 2). The MCMs are stochastic and operate within a specific set of states that satisfy the Markov property and consider the prior probabilities of the specific state, and predict the future probabilities of that state (Geyer 1992; Grewal et al 2019; la Torre-Torres et al 2020). We considered three major behaviors (foraging, roosting, and breeding) of White-rumped Vultures for MCMs analysis. To analyze White-rumped Vulture behavior through MCMs, we first identified three key behaviors: the behavioral state space with possible values or states for a process. We then recorded transition operators, noting the probability of occurring from one behavioral state to another. Finally, we identified the probability distribution of the current behavioral state with the probability of being in any state.

In the MCMs, White-rumped Vultures' major behaviors (i.e., foraging, roosting and breeding) entered the model from state F and transitioned to state R at a rate of λ_F or to state B with rate μ_F (Figure 3). However, the activities of the White-rumped Vulture were retained in its current state without transition to form a self-feedback. In these modes of transition and process, we used the following mathematical equation (1) for the MCMs:

$$Pr(X_{t+1}|X_t, X_{t-1}, \ldots\ldots, X_1) = Pr(X_{t+1}|X_t) \quad (1)$$

We used standard notation with slight modification, representing the series of events (Et) from time t = 1 to time point t = T, where the possible events (Ot) values are used in a countable set O_t ∈1, 2,...,q. We defined events from the behavioral activities of White-rumped Vultures (Table 1) that served as model inputs and represented the range of potential outcomes for MCMs. For each event to be included in a MCMs, there could be sequences of events for all t = 0,1,2..., for some finite state of m within state space (S) such as S_0, S_1,S_2....S_t. In our case, the state space was a set of {foraging, roosting, and breeding}. In equation (1), we defined Pr(Xt = j) as the probability of Pr(X) at time t. The left side of the equation can be derived from the chain rule of probability, and based on this equation, we can summarize the future state, which depends only on the current state under the Markov property. Therefore, the system's state at time 't' depends only on the state of the system at time t-1. We note that transitional probabilities can change over time; however, our objective was to estimate the probability of breeding only. Therefore, we used the probability theorem of steady states, assuming the probability of White-rumped Vultures spending time in each state would not change and become the long-term behavior—however, the behavior of White-rumped Vultures before this steady state was considered transient (or short-term).

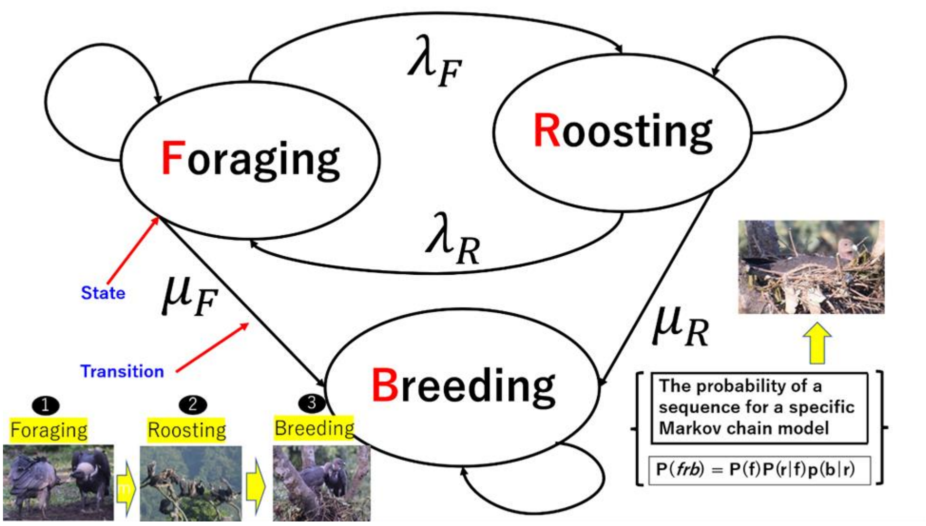

Figure 3 Markov process for characterizing behavior of White-rumped Vulture.

Let P be the transition matrix for an s-state MCMs for which there exists a vector:

$$\pi = (\pi_1, \pi_2, \pi_3, \ldots\ldots\ldots, \pi_s) \quad (2)$$

which is a steady-state distribution (equation 2). Each element in this vector is the state of White-rumped Vultures after a series of steps reaching the steady state. This steady state can be derived from the following calculations following the steady state theorem (equation 3):

$$\lim_{n\to\infty} p^n = \begin{pmatrix} \pi_1 & \pi_2\ldots\ldots\ldots & \pi_s \\ \pi_1 & \pi_2\ldots\ldots\ldots & \pi_s \\ \pi_1 & \pi_2\ldots\ldots\ldots & \pi_s \end{pmatrix} \quad (3)$$

And

$$\lim_{n\to\infty} p_{ij}(n) = \pi_j \quad (4)$$

In this situation, the steady state distribution is:

$$\pi_1 + \pi_2 + \ldots\ldots\ldots\ldots\pi_3 = 1 \ and$$
$$\pi(n+1) = \pi(n).P \leftrightarrow \pi = \pi P \quad (5)$$

where "P" refers to the one-step transition matrix. As we had data from vultures at eight nests and behavioral activities were observed in each nest for 10-minute intervals, we estimated the transition matrix for each nest. From this, we assessed each pair of White-rumped Vultures' time spent on breeding activities. The initial state matrix was:

$$(S_0^{n1}, S_0^{n2}, S_0^{n3}, S_0^{n4}, S_0^{n5}, S_0^{n6}, S_0^{n7}, S_0^{n8}) \quad (6)$$

which indicates the initial ratio for each state of foraging, roosting, and breeding of White-rumped Vultures for Nest 1 (equation 7):

$$S_0^{n1} = \begin{bmatrix} 0.019231 & 0.269231 & 0.711538 \end{bmatrix} \quad (7)$$

We also derived initial distribution matrices for all 8 nests from direct observations, then calculated transition matrices from these initial distribution matrices using the formula (equation 8):

$$S_i = S_0^{nj}.P^n \quad (8)$$

where, S_0 is the initial state distribution matrix, i is the number of steps from the initial steps to the steady states, and j is limited to 1 to 8 as we considered only eight nests. Similarly, P represented the transitional probability matrix for each nest.

2.2.1. Generating transition matrices

We used state sequences to generate transition matrices of the MCMs. We first established the number of transition probabilities between two states based on direct behavioral observations, using the 20 minor behaviors (Table 1). We combined these behaviors into three composite behaviors, including Foraging (F), Roosting (R), and Breeding (B) (Table 1), to simplify calculations during model development:

$$X = (x(S_i, S_j)) = \begin{pmatrix} x(S_1,S_1) & x(S_1,S_2) & x(S_1,S_3) \\ x(S_2,S_1) & x(S_2,S_2) & x(S_2,S_3) \\ x(S_3,S_1) & x(S_3,S_2) & x(S_3,S_3) \end{pmatrix} \quad (9)$$

If i, j = 1, 2, 3, and s_1 = F, s_2 = R, s_3 = B, then let x (s_i, s_j) be the number of pairs of states si, sj. The associated transition matrix X was obtained as below, and the transition matrix (1) can be written as:

$$X_{ij} = (X_{11}\ldots\ldots\ldots\ldots\ldots X_{ij}) \quad (10)$$

$$X = (x_{ij}) \quad (11)$$

Next, we calculated one-step transition probabilities (p_{ij}), where p_{ij} is defined by:

$$i, j \in S = \{1, 2, 3\} \quad (12)$$

which represents one-step transition probabilities from i to j given that each previous state is independent and each White-rumped Vulture must advance to one of the three states, with the sum of the row probabilities equal to one. The diagonal represents the likelihood of remaining in the same state. In a MCMs, a state k is considered absorbing if $p_{kk} = 1$, or all $p_{kj} = 0$ for j is not equal to k. The breeding state leading to offspring generation serves as the absorbing state.

$$p_{ij} = x_{ij} / \sum_{j=1}^{3} x_{ij} \quad (13)$$

3. Results

We made 4,160 observations of vultures at the eight nests during the eight days of observation. White-rumped Vultures, on average, spent 2.71 ± 3.04 hrs (31.20%) foraging, 1.68 ± 1.76 hrs (19.66%) roosting, and 4.25 ± 3.40 hrs (49.13%) for breeding activities (Figure 4). White-rumped Vultures engaged most often in nest-building activities (n = 57.50 hrs; 71.08%), followed by roosting activities (n = 31.00 hrs; 22.60%), and foraging activities (n = 8.87 hrs; 6.31%) during the nest building phase. Similarly, White-rumped Vultures spent more time in breeding activities (n = 116.00 hrs; 83.67%), followed by roosting (n = 15.50hrs; 11.16%), and foraging (n = 7.17 hrs; 5.17%) during the incubation phase. In contrast, White-rumped Vultures spent more time in foraging activities (n = 200.50 hrs; 48.20%), followed by breeding (n = 127.17 hrs; 30.57%), and roosting (n = 88.33 hrs; 21.23%) during the chick-rearing phase. During the breeding season, vultures at nests 1, 2, 6, and 7 spent more time in breeding activities, whereas nests 3, 4, 5, and 8 were engaged more in foraging (Figure 4). We noticed eggs in nests 2, 6, and 7, but chicks were raised only from nests 2 and 6.

Table 2 Initial distribution estimated during the White-rumped Vulture nest building phase from direct observations.

Nest ID	Foraging	Roosting	Breeding
Nest 1	0.000	0.212	0.789
Nest 2	0.000	0.192	0.808
Nest 3	0.038	0.135	0.827
Nest 4	0.000	0.231	0.769
Nest 5	0.000	0.192	0.808
Nest 6	0.000	0.058	0.942
Nest 7	0.000	0.173	0.827
Nest 8	0.003	0.016	0.019

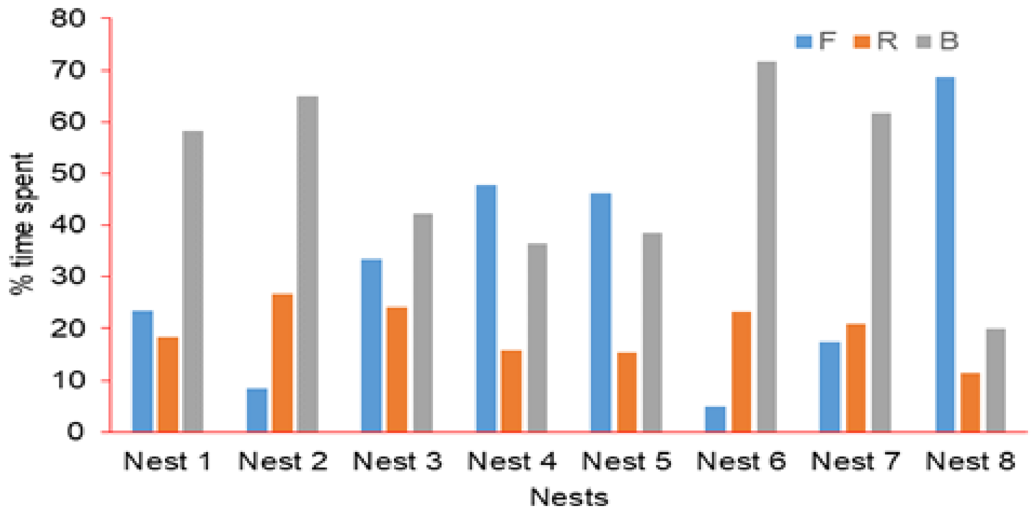

Figure 4 Total time spent by White-rumped Vultures during foraging (F), roosting (R) and breeding (B) activities during the breeding season.

3.1. Transitional matrix via direct observation

From the MCMs, we developed final transitional probability matrices for eight nests using state sequences of state transitions (List 1: see Supplementary material). We calculated the steady state transitions using matrix multiplication for any n-step transitions from these transition probabilities. All transitional matrices were multiplied by the corresponding initial state distribution (Table 2) derived from the pair of White-rumped Vultures at each nest. Finally, each nest's steady state of White-rumped Vultures was estimated using matrix multiplication until we obtained the steady state vector (Table 3).

Our results during nest building suggested that nests 1, 2, 3, and 6 had the greatest potential for success. During fledging, we conducted direct observation again to determine the initial distribution (Table 4) of White-rumped

Vultures to calculate transitional probabilities (List 1: see Supplementary material).

3.2. Model evaluation

We plotted observed behaviors of vultures and arranged them sequentially to create a matrix of co-occurrence sequence (Nests 1 and 8; Figure 5) from which we obtained transition probabilities. We plotted and assessed each nest's initial and transitional probabilities (Figure 6). All nests except Nest 6 followed patterns predicted by the MCMs, and Nest 6 followed absorbing MCMs, suggesting the pair at Nest 6 spent more time engaged in breeding activities (Table 5). The steady states differed among White-rumped Vultures at different nests. They suggested vultures at Nest 1, 2, 6, and 7 were more engaged in breeding activities (>70% of the time) than vultures at remaining nests, in turn suggesting the total duration for nest building by vultures from Nests 1, 2, 6 and 7 was less (see Table 5). We performed a post hoc analysis from these results and found that Nests 1, 2, 6, and 7 produced offspring, which validated our MCM results. We plotted the reoccurrence behavior in each phase for all nests during our observation and mentioned those behavior in heatmap (Figure 7).

4. Discussion

Understanding activities associated with reproductive events is important for further behavioral biology and conserving threatened and endangered species. Although subjective behavior related to reproductive events was frequently reported from field observations, no quantitative assessments applying MCMs have been made. We identified that White-rumped Vultures spent more time in breeding activities than foraging and roosting. We recognized the importance of breeding activities from our informed and validated model using direct observations. Our results suggest that the extent of parental investment (i.e., breeding behavior) corresponded with behaviors observed during nest construction, incubation, and chick rearing.

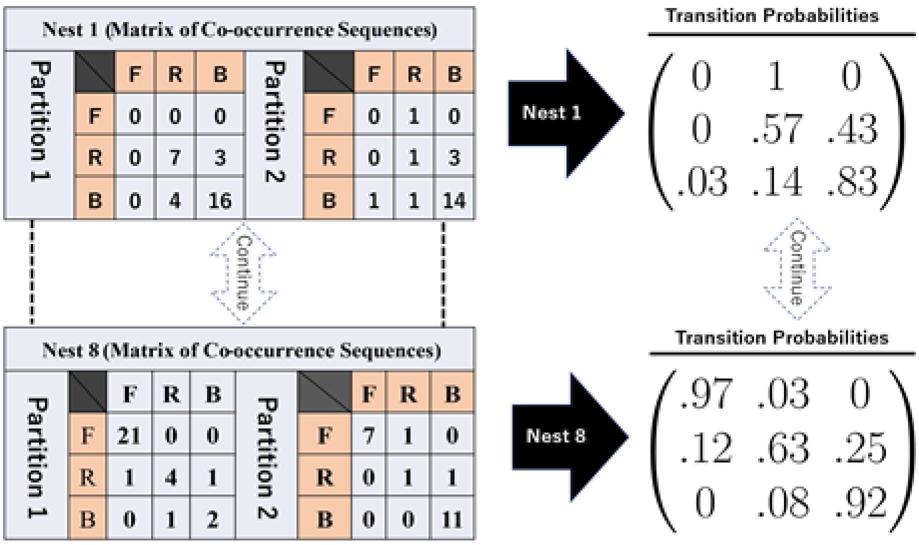

Figure 5 Matrices for state transitions of White-rumped Vultures.

Table 3 Final distribution of White-rumped Vulture behaviors estimated during incubation phase from direct observations.

Nest ID	Foraging	Roosting	Breeding	Steady state
Nest 1	0.000	0.229	0.771	24
Nest 2	0.000	0.240	0.760	9
Nest 3	0.047	0.041	0.912	24
Nest 4	0.000	0.240	0.760	24
Nest 5	0.000	0.196	0.804	28
Nest 6	0.000	0.059	0.941	10
Nest 7	0.000	0.218	0.782	32
Nest 8	0.000	0.005	0.030	4

We note that the limited number of nests and individual vultures could reduce the strength of our inference. However, behavior analysis composed of direct observation and MCMs were generally consistent and largely similar to previous studies (Gautam et al 2020; Jiang et al 2020). We suggest that our method can be applied in behavior analyses of species that may otherwise require substantial direct observation. Also, though we could not distinguish males and females during observations, our method allowed for analyses of both members of breeding pairs simultaneously. Finally, we caution that it is not always appropriate to consider the states from MCMs fitted to observational data as biologically significant as MCMs are frequently used in an unsupervised approach with state characteristics data-driven rather than pre-defined. Therefore, the most significant model patterns may not be ecologically relevant. However, the behavioral states we modeled in a supervised approach to predict vulture breeding successfully supported the importance of integrating behavioral data from direct observations.

Table 4 Final distribution estimated during White-rumped Vulture fledgling phase from direct observations.

Nest ID	Foraging	Roosting	Breeding	Steady state
Nest 1	0.000	0.361	0.428	85
Nest 2	0.015	0.000	0.773	4
Nest 3	0.000	0.159	0.571	25
Nest 4	0.000	0.060	0.729	20
Nest 5	0.000	0.085	0.684	9
Nest 6	0.000	0.015	0.773	5
Nest 7	0.031	0.015	0.742	14
Nest 8	0.257	0.220	0.312	90

Table 5 Final distribution of behaviors estimated during White-rumped Vulture breeding season from direct observations.

Nest ID	F (Foraging)	R (Roosting)	B (Breeding)	Steady state
Nest 1	0.021	0.277	0.702	12
Nest 2	0.020	0.216	0.765	9
Nest 3	0.059	0.373	0.569	21
Nest 4	0.137	0.333	0.529	54
Nest 5	0.118	0.412	0.471	48
Nest 6	0.000	0.176	0.824	15
Nest 7	0.098	0.176	0.726	33
Nest 8	0.446	0.123	0.431	211

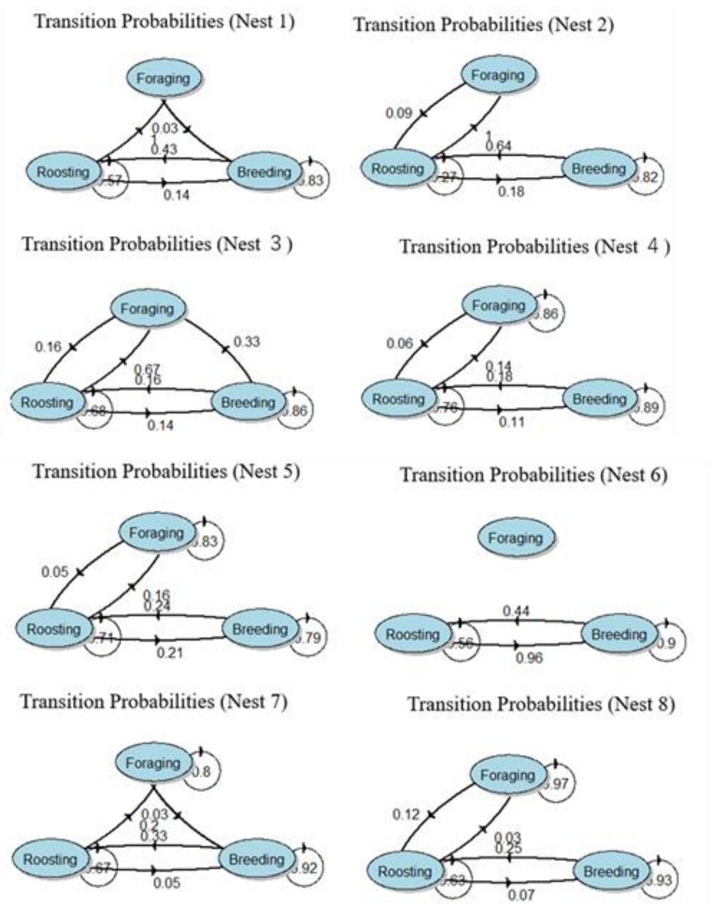

Figure 6 Transitional probabilities of White-rumped Vultures during breeding season.

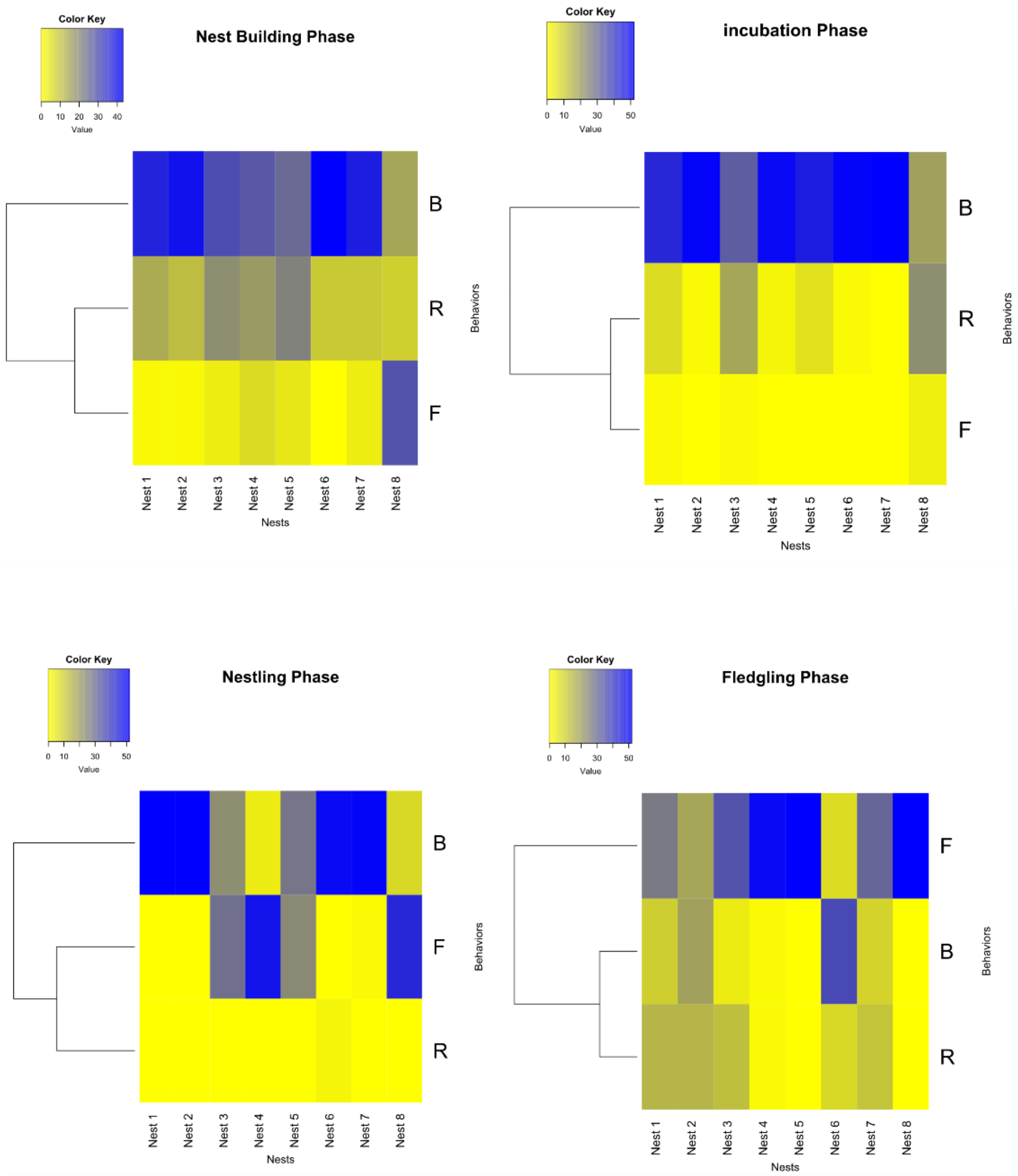

Figure 7 Behavior activity of White-rumped Vultures during breeding season. The color code yellow to low activity and increasing the color intensity to blue to represent higher occurrence of behavioral activity.

We demonstrated that White-rumped Vulture behavior varied among nesting pairs and breeding phases. This variation in behavior could be influenced by food availability, the presence of predators, or vulture age. However, we acknowledge that further research is needed to support these hypotheses. Further, other factors, such as nest quality and environmental conditions, can influence behaviors and breeding success.

Model development allowed us to draw inferences regarding White-rumped Vulture behavior and comparisons with other studies. For example, four pairs of vultures established nests earlier than the other four pairs, apparently a consequence of the effort required to transport nesting materials to the site (e.g., dense tree canopies) and to construct the nests (e.g., weak support of tree for nest material). Early nesting allows vultures to lay eggs sooner, which could increase offspring survival (Barash 1975). The behavior of Eurasian Vultures was altered due to food scarcity, improved carcass disposal, and European conservation policy changes (Donazar et al 2010).

In contrast to our study, diurnal activities of captive White-rumped Vultures were predominantly roosting (56.3%) (Islam et al 2018); however, the observation periods differed between studies. We also combined sitting and roosting during breeding season as courtship displays which could explain our greater estimates of breeding activities compared to a previous study (i.e., Islam et al 2018). The amount of observed foraging and roosting by White-rumped Vultures was less than the breeding behavior in our study. We included only soaring as foraging behavior in our observations. Furthermore, we did not observe any carcasses during our observations which could influence behavior, and topography in part also limited our observations of soaring, therefore, likely reducing estimated foraging times (see Islam et al 2018). We also did not include behaviors from the entire diel period which could alter overall time spent in various activities. The daily activities of vultures can vary due to internal and external environmental factors (Bjorklund and Kipp 1996) and support that the daily activities of White-rumped Vulture breeding pairs differed in this study. Factors including infertility (Jamieson and Ryan 2000), predation (Feare et al 2017), modification to nesting habitat (Evans 2004), and human disturbances (Bamford et al 2009) can cause nesting failure and alter behaviors. Our model could help understand breeding success in White-rumped Vultures and the factors influencing this success.

Based on our observations and heatmap representation, we can speculate that different nests of vultures have different patterns of behavior during each phase. For example, during the nest building phase, nest 4 and nest 8 had a higher occurrence of foraging activity, which could indicate that they have better access to food sources and therefore a higher likelihood of producing an egg. During the incubation phase, nest 8 had the highest amount of foraging activity, while nest 7 had the highest amount of breeding activity. In the nestling phase, nest 4 had the highest amount of foraging activity, while nest 6 had the highest amount of roosting activity and nest 1 and nest 2 had the highest amount of breeding activity. During the fledgling phase, nest 8 and nest 5 had the highest amount of foraging activity, nest 1 and nest 2 had the highest amount of roosting activity, and nest 6 had the highest amount of breeding activity.

5. Conclusions

MCMs can be used to explain complex systems, including animal behavior. We used MCMs to evaluate the probability of three states such as foraging, roosting, and breeding behavior of the critically endangered White-rumped Vulture in Nepal. Comparing behavioral observations with those obtained from computational results revealed our MCMs explained vulture behavior with high accuracy and efficiency. Our results can help to improve our understanding of White-rumped Vulture behavioral ecology in continuous and discrete time and have applications for other wildlife species. We conclude that direct observations of animal behavior are essential to ensure model reliability and appropriately characterize early transition probabilities. However, this process can be labor intensive, and we recommend further automation, including machine learning and computer visualization techniques.

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Ethical considerations

Data for this research was collected without handling or disturbing animals, so ethical permission for animal handling animals was not required.

Conflict of interest

We declare no conflict of interest.

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Supplementary Material

This supplementary material is linked to the article Gautam et al. (2023) *Analyzing White-rumped Vulture breeding behavior using Markovian modeling.* doi: https://doi.org/10.31893/jabb.23024

List 1 Transitional probability matrices of White-rumped Vultures during nest building phase.

a) Nest Building Phase

$$N1 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & .7 & .27 \\ 0 & .08 & .92 \end{bmatrix} \quad N2 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & .78 & .22 \\ 0 & .07 & .93 \end{bmatrix}$$

$$N3 = \begin{bmatrix} .5 & 0 & .5 \\ 0 & .43 & .57 \\ .02 & .03 & .95 \end{bmatrix} \quad N4 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & .75 & .25 \\ 0 & .08 & .92 \end{bmatrix}$$

$$N5 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & .8 & .2 \\ 0 & .05 & .95 \end{bmatrix} \quad N6 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & .33 & .66 \\ 0 & .04 & .96 \end{bmatrix}$$

$$N7 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & .75 & .25 \\ 0 & .07 & .93 \end{bmatrix} \quad N8 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & .14 & .86 \\ 0 & .14 & .86 \end{bmatrix}$$

b) Incubation Phase

$$N1 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & .89 & .11 \\ 0 & .09 & .91 \end{bmatrix} \quad N2 = \begin{bmatrix} 0 & 0 & 1 \\ 0 & 0 & 0 \\ .02 & 0 & .98 \end{bmatrix}$$

$$N3 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & .67 & .33 \\ 0 & .09 & .91 \end{bmatrix} \quad N4 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & .5 & .5 \\ 0 & .04 & .96 \end{bmatrix}$$

$$N5 = \begin{bmatrix} .5 & 0 & .5 \\ 0 & .25 & .75 \\ 0 & .09 & .91 \end{bmatrix} \quad N6 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & .02 & .98 \end{bmatrix}$$

$$N7 = \begin{bmatrix} 0 & .5 & .5 \\ 0 & 0 & .51 \\ .02 & .02 & .96 \end{bmatrix} \quad N8 = \begin{bmatrix} .93 & .07 & 0 \\ 0 & .83 & .17 \\ .05 & .06 & .89 \end{bmatrix}$$

c) Nestling Phase

$$N1 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad N2 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$N3 = \begin{bmatrix} .82 & 0 & .18 \\ 0 & 0 & 0 \\ .26 & 0 & .74 \end{bmatrix} \quad N4 = \begin{bmatrix} .98 & 0 & .02 \\ 0 & 0 & 0 \\ .25 & 0 & .75 \end{bmatrix}$$

$$N5 = \begin{bmatrix} .88 & 0 & .12 \\ 0 & 0 & 0 \\ .07 & 0 & .93 \end{bmatrix} \quad N6 = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & .04 & .96 \end{bmatrix}$$

$$N7 = \begin{bmatrix} 0 & 0 & 1 \\ 0 & 0 & 0 \\ 0 & .02 & .98 \end{bmatrix} \quad N8 = \begin{bmatrix} .95 & 0 & .05 \\ 0 & 0 & 0 \\ .25 & 0 & .75 \end{bmatrix}$$

d) Fledgling Phase

$$N1 = \begin{bmatrix} .96 & 0 & .04 \\ .07 & .93 & 0 \\ 0 & .10 & .90 \end{bmatrix} \quad N2 = \begin{bmatrix} .94 & .06 & 0 \\ 0 & .79 & .21 \\ .05 & .16 & .79 \end{bmatrix}$$

$$N3 = \begin{bmatrix} .91 & .03 & .06 \\ .23 & .77 & 0 \\ .25 & .25 & .50 \end{bmatrix} \quad N4 = \begin{bmatrix} .96 & .02 & .02 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \end{bmatrix}$$

$$N5 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \quad N6 = \begin{bmatrix} .43 & .14 & .43 \\ .25 & .38 & .37 \\ .06 & .11 & .83 \end{bmatrix}$$

$$N7 = \begin{bmatrix} .88 & .06 & .06 \\ .17 & .66 & .17 \\ .25 & .12 & .63 \end{bmatrix} \quad N8 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

Table 1 Behaviors of White-rumped Vultures.

Behavior	Description
Roosting	Perched on tree to rest or sleep
Foraging	Activities to search, find, and consume food
Breeding	All activities to produce offspring from courtship to fledging of offspring
Basking	Wings extended while perching
Preening	Cleaning feathers with beak at rest
Resting	Perching on tree while alert
Locomotion	Walking, Running, Flying, Soaring, Takeoff and Landing
Courtship	A pair of birds flying together in parallel, with one slightly above the other near roosting site pre-breeding and nest building season
Pairing	A pair of birds perched adjacent during pre-breeding season
Nest building	Collecting nest materials
Incubation	Adult sitting low in the nest during incubation period
Feeding	Adult feeding chick by mouth by regurgitation
Defecation/urination	Removal of undigested material from body
Aggressive/agnostic	Chasing or fighting individuals of same or different species which approach nest, roost, or foraging sites
Soaring	In flight with wings fully extended
Matting/copulation	Male on the back of female during the breeding season for sexual reproduction
Preening	Cleaning body part with their beaks

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RESEARCH ARTICLE

Preference of trees for nest building by critically endangered white-rumped vultures (*Gyps bengalensis*) in Nepal

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Abstract
White-rumped vultures (*Gyps bengalensis*) are critically endangered species, and protecting their habitats, particularly the nesting trees, may have a positive impact on their reproductive success. For a better understanding of vultures' habitat needs, the characteristics of nesting trees should be accounted. In this paper, we compare the characteristics of the trees that have vultures' nests and that do not by randomly select a control tree within a 10 m radius of the nesting tree. We extensively searched and monitored the white-rumped vultures' nests, nesting trees, and nesting tree species in Nepal between 2002 and 2022, and measured the characteristics of sampled trees such as their height, girth, canopy spread, branching orders, and whorls. We recorded 1161 nests of white-rumped vulture in total on 194 trees belonging to 19 species over the past two decades. White-rumped vultures preferred the kapok trees (*Bombax ceiba*) for nest construction than other tree species ($\chi^2 = 115.38$, df = 1, $p < .001$) as 66.49% of nests were built on them. In the logistic regression model, the number of whorls on a tree, canopy spread, and the height of the first branch determined whether a nest was present or absent on a tree. These results help to prioritize the tree attributes in a habitat conservation plan for vultures.

KEYWORDS
bird, breeding success, habitat conservation, nesting tree, nests

TAXONOMY CLASSIFICATION
Population ecology

1 | INTRODUCTION

The characterization of nesting habitats plays a crucial role in comprehending the habitat needs of vultures (Mölder et al., 2020; Yarrow, 2009). An in-depth knowledge of the characteristics of preferred nesting trees and nest survival is key factor in determining the reproductive success of vultures (Chiavacci et al., 2014; Francis et al., 2011). Predation, natural disasters such as storms, and anthropogenic disturbances such as cutting down the nesting trees and collection of chicks are some reasons for nesting failure in vultures (Baral et al., 2005; Baral & Gautam, 2007; Keyser, 2002; Newton, 1998). The availability of large nesting and roosting trees is crucial for vulture survival as they provide a good vantage point to locate food sources and reduce the risk of predation by land animals (Kendall et al., 2018; Vogel et al., 2014).

The logging of large trees and habitat loss are major threats to the survival of vulture species as they lead to reproductive failure (Fletcher et al., 2018; He & Hubbell, 2011). In Nepal, three out of nine vulture species, namely red-headed vulture (*Sarcogyps calvus*), slender-billed vulture (*Gyps tenuirostris*), and white-rumped vulture (*G. bengalensis*) are typically tree nesters while the Egyptian vulture (*Neophron percnopterus*) builds nests on trees on rare occasions (Ali & Ripley, 1987; Chhangani, 2002). These species require mature and tall trees for nesting (Ahmad et al., 2020; Ghimire et al., 2019; Majgaonkar et al., 2018; Siders & Kennedy, 1996; Thakur, 2015). The wild vulture population has been declining in South Asia due to the use of diclofenac in veterinary practices (Ahmad et al., 2020; Chaudhary et al., 2012; Khan, 2013; Prakash et al., 2007), food shortage (Shah et al., 2019), unintentional poisoning (Clements et al., 2013), human persecution (Clements et al., 2013; Hla et al., 2011), collision with power lines and electrocution (Hamal et al., 2023), and breeding habitat loss (Gautam & Baral, 2013; Hla et al., 2011). As a result, the Nepalese government banned the production, distribution, and sale of diclofenac for veterinary use in 2006 (Prakash et al., 2012). To support the recovery of vulture populations, various conservation programs have been initiated, including captive breeding and release programs, the establishment of vulture safe feeding sites and zones, public awareness campaigns, and the declaration of diclofenac-free zones (DNPWC, 2015). Making sure the availability of suitable nesting and roosting trees in the wild is crucial for the long-term survival of vultures (Baral et al., 2013; Pain et al., 2003). However, insufficient information exists regarding what constitutes suitable trees for nesting or roosting. The problem is further exacerbated when the existing nesting trees are cut down to implement development activities such as road and building construction in Nepal (Gautam & Baral, 2013).

In Nepal, white-rumped vultures are found below 1500 m above sea level, and they were the most abundant and widespread species prior to the 1990s (Ali & Ripley, 1987; Grimmett et al., 2016). White-rumped vulture has been listed as a critically endangered species in the Red Data Book by BirdLife International due to the drastic population decrease in the wild since 2000 (BirdLife International, 2021). Following the significant drop in wild population, the white-rumped vulture is now found patchily distributed across Nepal (Baral et al., 2005; Bhusal et al., 2020; Dhakal et al., 2022; Gautam & Baral, 2013; Rana et al., 2019). Despite the effective ban on diclofenac, the species continues to suffer from food shortage, human persecution, unintended poisoning, and habitat destruction (Baral et al., 2005; BirdLife International, 2021), with the latter being the primary cause of local colony extinction due to habitat loss (Baral et al., 2005, 2013). The choice of tree species for nesting by white-rumped vultures can vary between sites (Bhusal et al., 2023; Ghimire et al., 2019). They usually prefer to nest on tall and mature trees (Bhusal et al., 2020; Ghimire et al., 2019; Subedi, 2008). Providing information on the characteristics of preferred trees sheds light on the ecological requirements of vultures (Sharma et al., 2023) and helps in formulating effective vulture conservation strategies (Beyer & Manica, 2020; Majgaonkar et al., 2018). Furthermore, managers, policymakers, and scholars can have a better understanding of the specific habitat needs of vultures (Polak, 2016) and determine the most suitable habitats for conservation efforts. Therefore, our objective is to undertake a comprehensive evaluation of the characteristics of nesting trees with the goal of informing future habitat restoration and management initiatives for fostering the rejuvenation of the declining population of white-rumped vultures in the wild.

2 | METHODS

2.1 | Study area

We conducted the study in the west Nepal's Kaski, Syangja, Tanahu, and Palpa Districts (83°15′ to 84°46′ E and 27°26′ to 28°36′ N) that comprised a total area of 5996 km^2 (Figure 1). The study area has a tropical to sub-tropical monsoonal climate, with the rainy season extending from June to September, cool-dry winter from October to January, and hot-dry summer from February to May. The absolute maximum and minimum temperature of the study area was 40.2 and 0.5°C recorded in May 2007 and January 2013, respectively. In the same period (2001–2020), the total amount of annual precipitation ranged from 2142.4 mm in 2005 to 3871.58 mm in 2020 and the average annual precipitation was 2661.22 mm. The elevation of white-rumped vulture nesting colonies ranged between 303 and 1168 m above sea level. The study area supports a mixed forest of sal (*Shorea robusta*), chestnut (*Castanopsis indica*), and needle wood (*Schima wallichii*). The majority of nesting trees used by white-rumped vultures were within the community forests area.

2.2 | Data collection

Between 2002 and 2022, we recorded the number of nests of white-rumped vultures in the study area following the protocols used by Baral et al. (2005, 2013) and Gautam and Baral (2013). We marked the location of nests, and noted the nesting tree species. In 2022, we recorded the tree characteristics such as the girth at breast height, longest branching order, number of tree whorls, canopy spread, tree height, first branch height, nest height, and nest branching order for those trees where white-rumped vulture constructed the nest. We identified tree species in the field and herbarium were made for unidentified tree species which were later identified by the experts at the Central Department of Botany, Tribhuvan University, Kirtipur, Nepal.

In this study, we established a 10 m radius plot around the nesting tree, and randomly selected non-nesting trees based on

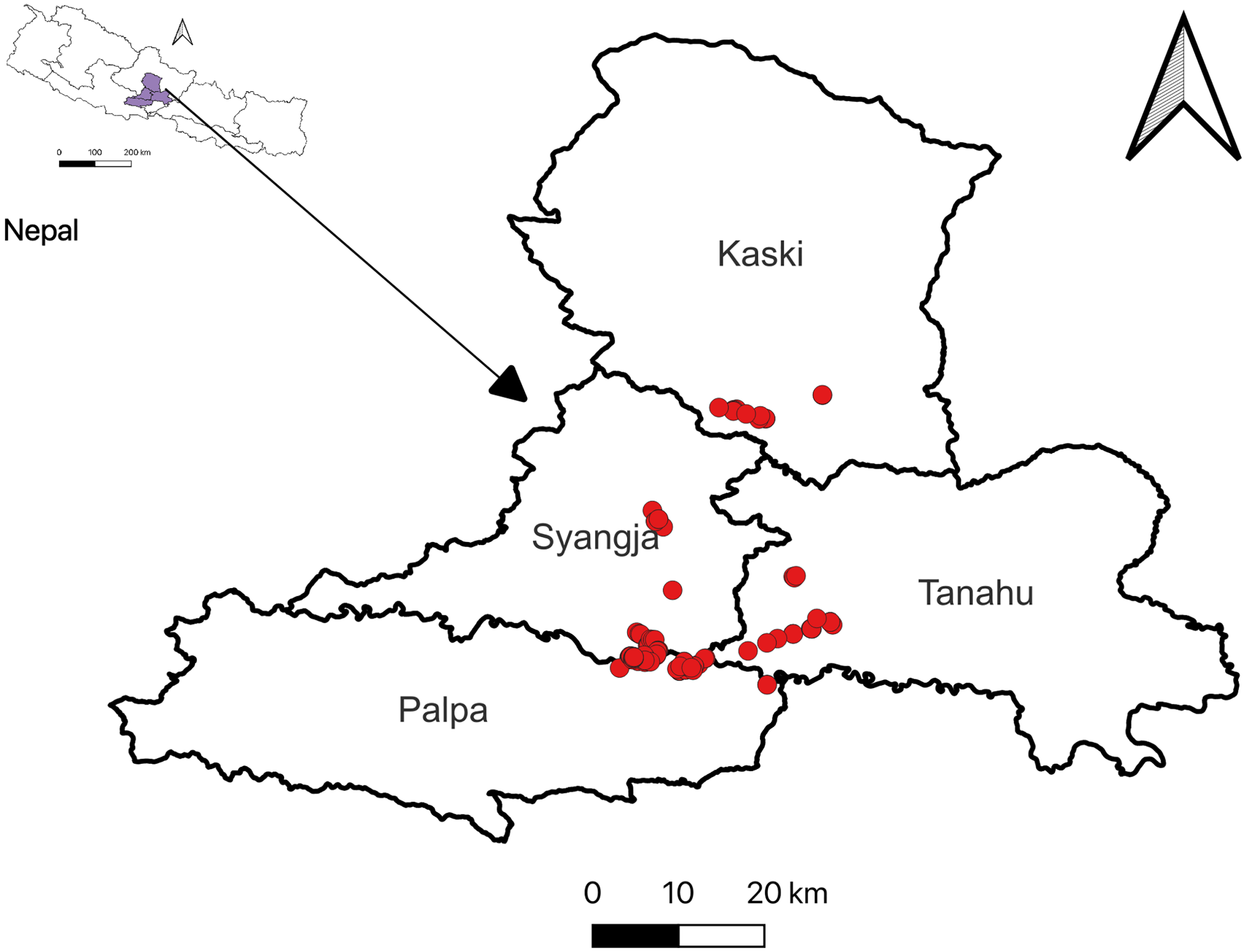

FIGURE 1 Location of white-rumped vultures' colonies within four districts (dots indicate study area) in Nepal.

preset 160 random angles (0–360° in the increment of 5°) (Yang & Burkhart, 2019). If the non-nesting tree was absent at the preset random angle, we used the next random angle to locate a tree. If a tree was absent in the second iteration, we did not measure the non-nesting trees. We recorded the spatial coordinates of the nesting and non-resting trees using a hand-held Geographical Position System (GPS; accuracy <5 m). In this way, a randomly selected control pair was established for each nesting tree to compare and contrast their characteristics.

In addition, we also tallied the number of nesting trees lost in the vulture colonies between 2002 and 2022. We also attempted to determine the causes of nesting tree loss, and categorized them into natural and anthropogenic causes.

2.3 | Variable measurement

In our study, we measured several characteristics of the trees, including the girth at breast height (GBH), longest branching order (LBO), tree whorl (TW), canopy spread (CS), tree height (TH), and the first branch height (FBH). For white-rumped vulture nesting trees, we additionally measured the nest branching order (NBW), nesting whorl (NW), and nest height (NH) (See Table S1).

2.3.1 | Girth at breast height

It is the measurement of the circumference of the tree trunk at a standard height of 1.5 m from the ground surface, which was accurately determined using a measuring tape.

2.3.2 | Longest branching order

The branching order is the arrangement of the tree branches or segments. Among the various methods applied for measuring the longest branching order, we used a centrifugal system instead of numbering the branching order from the tip toward the stem of the tree segments (Horton, 1945; Strahler, 1957; Uylings et al., 1975). We recorded Order 1 axis (the trunk), Order 2 axis (the branch growing directly from the trunk), Order 3 axis (branches growing on Order 2 axes), and so on. We used the centrifugal ordering system to locate nests and the longest branching pattern of the trees. We excluded the dead, broken, pruned, or logged branches for this recording.

2.3.3 | Tree whorls

We recorded the total number of whorls by counting the presence of live branches arising from the main tree axis or main stem (Kidombo & Dean, 2018). We excluded the node without live branches and the dead main axis. However, we recorded the whorl as a one whorl tree if no live branches are present below and above the branches. We recorded the first branch as the first whorl, successively upward second, third, and so on.

2.3.4 | Canopy spread

We measured the longest and shortest canopy spread of the tree using a measuring tape. We measured the widest crown spread from the ground at the longest axis of the crown and the shortest crown spread by making a right angle to the widest crown spread following Blozan (2006). The average of the widest and shortest extents of the crown was used for the canopy spread.

2.3.5 | Tree height

The tree height is the measure of a tree from the ground to the top. We measured the tree height with the help of a clinometer and a measuring tape. We measured the distance from the researcher to the tree. The clinometer was used to observe the treetop, and the angle of inclination was noted. A 1.5 m high stick was used to take angle with the help of a clinometer. We used the formula, i.e. height of the tree (m) = (basal distance in meter $\times \tan\alpha$) + 1.5 m (where, α is the angle of the treetop).

2.3.6 | First branch height

The first branch height is the measure of height from the ground to the first live branch. We applied the same procedure for the tree height (sans direct measurement).

2.3.7 | Nest branching order

Like the branching order, we used the centrifugal method to find the nesting branching order if the branch has a nest. We recorded nesting branching Order 1, if the nest was located on the trunk. Further, if the nest was located on the branch raised from the trunk, it was noted as two and so on (Suzuki & Suzuki, 2009).

2.3.8 | Nest whorl

The nest whorl was counted from lower to upper region of a tree. If the nest was present on the branch developed from the first whorl, it was considered as the nest present on the first whorl. If the nesting branch was from the second whorl, it was considered as a second nesting whorl and so on.

2.3.9 | Nest height

We measured the nest height as a distance from the ground to the nest. We measured the nest height with the help of a clinometer and a measuring tape as applied in the measurement of tree height.

2.4 | Data analysis

We tested the data for normality test using the Shapiro–Wilk test and most of the variables were not normally distributed. Therefore, we performed the Mann–Whitney *U* test to examine whether the characteristics of nesting and non-nesting trees differ (Neuhäuser, 2010). After performing bivariate analyses, we built a logistic regression model to determine the relative strength of the variables that influence whether a nest is built on a tree or not. The data met the major assumptions required for logistic regression. Taking the binary presence or absence of nest on a tree as a response variable, and the explanatory variables such as the girth at breast height, longest branching order, tree whorl, canopy spread, tree height, and the first branch height, we fitted the logistic regression model. After fitting the model, we examined the variance inflation factor for multicollinearity, which was found to be <10 (O'brien, 2007; Schreiber-Gregory et al., 2018) (Table S2). We performed the DHARMa Moran's *I* test for distance-based autocorrelation (Hartig, 2022), and found no statistically significant autocorrelation in the spatial distribution. All analyses were performed in the R Program (R Core Team, 2022).

3 | RESULTS

We recorded a total of 1161 white-rumped vulture nests on 194 individual trees belonging to 19 distinct tree species in the study area between 2002 and 2022 (Tables S3 and S4). The number of nests and the total number of nesting trees showed a *U*-shaped trend over the study period, meaning that their number declined in the middle range of the study period. The total number of tree species used for nesting had remained more or less constant throughout the study period (Figure 2).

The kapok tree (*Bombax ceiba*) harbored the highest number of nests (66.49%, *n* = 129) followed by quassia wood trees (*Picrasma javanica*) (7.22%, *n* = 14), mango trees (*Magnifera indica*) (3.61%, *n* = 7), silver gray wood (*Terminalia tomentosa*) (3.09%, *n* = 6), khair (*Acacia catechu*) (2.58%, *n* = 5), and the other 14 different tree species

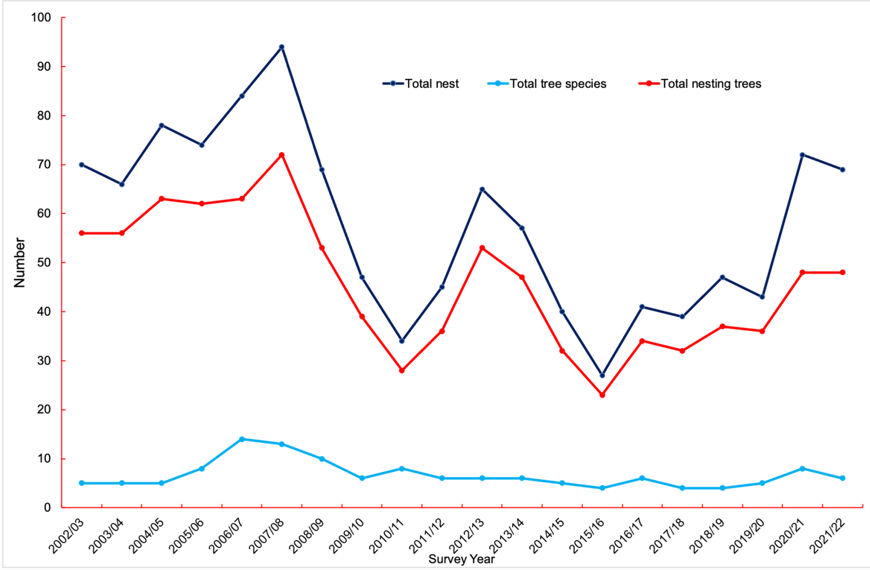

FIGURE 2 Number of nesting trees, tree species, and nests of white-rumped vulture in Nepal during the breeding season between 2002/03 and 2021/22.

TABLE 1 Comparison between white-rumped vulture nesting and non-resting trees in Nepal.

Variable	Nesting tree (*n* = 112) Mean (SD)	Nesting tree (*n* = 112) Range	Non-nesting tree (*n* = 86) Mean (SD)	Non-nesting tree (*n* = 86) Range	Mann–Whitney *U* test	*p*
Girth at breast height	3.95 (1.43)	1.26–8.50	0.76 (0.33)	0.30–2.10	9615.5	.001
Longest branching order	10.91 (2.58)	6–19	8.10 (2.87)	3–14	7217	<.001
Tree whorl	7.31 (2.86)	1–14	4.82 (3.49)	1–22	7123.5	<.001
Canopy spread	19.08 (5.72)	4.08–37.75	6.38 (2.65)	1.38–13.75	9436.5	<.001
Tree height	23.61 (5.79)	13.42–36.37	12.03 (4.87)	3.00–25.06	9134	<.001
First branch height	9.71 (4.01)	0.80–18.30	3.33 (2.60)	0.40–11.50	8608.5	<.001
Nest branching order	2.91 (1.83)	1–13	–	–	–	–
Nesting whorl	5.68 (0.27)	1–13	–	–	–	–
Nest height	18.46 (0.42)	8.50–36.12	–	–	–	–

Note: Variables girth at breast height (m), longest branching order (n), tree whorl (number), canopy spread (m) tree height (m), first branch height (m), nest branching order (number), nest branching whorl (number), and nest height (m). "–" Non-nesting trees don't have nests.

TABLE 2 Logistic linear regression model for factors affecting the occurrence of nest of white-rumped vulture in Nepal.

Variable	Estimate	SE	*t*	*p*
Intercept	−0.328	0.075	−4.373	.001
Girth at breast height	0.003	0.004	0.727	.468
Longest branching order	0.005	0.008	0.581	.562
Tree whorl	0.021	0.006	3.404	.001
Tree height	0.002	0.005	0.47	.638
First branch height	0.035	0.005	7.796	<.001
Canopy spread	−0.328	0.075	−4.373	.001

Note: The response variable is the presence or absence of nests on a tree.

(12.88%, $n = 25$). Kapok trees were more preferred for nest construction by white-rumped vulture as compared to other tree species ($\chi^2 = 115.38$, df = 1, $p < .001$). Among the 45 tree species recorded in the white-rumped vulture colonies, comparatively fewer tree species (42.22%, $n = 19$) were utilized by the vultures for nesting, while the remaining tree species (57.78%, $n = 26$) were not utilized for nesting (Table S5).

Of the 194 nesting trees, most trees (66.49%, $n = 129$) had one nest followed by trees with two nests (26.80%, $n = 52$), three nests (4.12%, $n = 8$), four nests (1.03%, $n = 2$), and five nests (1.55%, $n = 3$).

3.1 | Tree characteristics between nesting and non-nesting trees

Among 194 nesting trees, we measured the characteristics of 112 nesting trees because 48 trees were lost and 34 trees were difficult to access due to topographical conditions. In the case of non-nesting trees, we measured only 86 trees because, in the remaining 26 cases, there were not any trees for the measurement. The characteristics of white-rumped vulture nesting and non-nesting trees were found to vary (Table 1). The average girth at breast height (GBH) of trees in the study area was 2.57 ± 1.93 m (nesting tree: 3.95 ± 1.43 m; non-nesting tree: 0.76 ± 0.33 m). The average highest number of branching pattern order of trees was 9.70 ± 3.04 (nesting tree: 10.91 ± 2.58; non-nesting tree: 8.10 ± 2.87). The average number of tree whorl was found to be 6.23 ± 3.38 (nesting tree: 7.31 ± 2.86; non-nesting tree: 4.82 ± 3.49), and the average tree canopy spread $13.56 \pm$ was 7.83 m (nesting tree: 19.08 ± 5.72 m; non-nesting tree: 6.38 ± 2.65 m). The average height of trees in the study area was 18.43 ± 7.40 m (nesting tree: 23.61 ± 5.79 m; non-nesting tree: 12.03 ± 4.87 m) and the average first branch height was 6.93 ± 4.70 m (nesting tree: 9.71 ± 4.01 m; non-nesting tree: 3.33 ± 2.60 m).

The number of tree whorls, canopy spread, and the first branch height were statistically significant explanatory variables to determine whether a nest would be built on a tree. The odds of a tree harboring a nest increased with the number of tree whorls and the increasing height of the first branch, but the odds decreased with the wider canopy spread (Table 2).

3.2 | Available nesting trees around 10-m radius of the nesting trees

Within the 10 m radius of the nesting trees, we recorded 969 trees belonging to 45 species (Table S5). The most frequent tree was rohituka (*Aphanamixis polystachya*) (15.48%, $n = 150$) which was followed by small flower crape myrtle (*Lagerstromia parviflora*) (12.07%, $n = 117$), tiger's milk spruce (*Sapium insigne*) (10.63%, $n = 103$), potka siris (*Albizia lucidior*) (8.98%, $n = 87$), fever pod (*Holarrhena pubescens*) (5.88%, $n = 57$), bhellar (*Trewia nudiflora*) (5.78%, $n = 56$), karma (*Adina cordifolia*) (4.95%, $n = 48$), garuga (*Garuga pinnata*) (4.44%, $n = 43$), sage-leaved alangium (*Alangium salviifolium*) (3.30%, $n = 32$), and wind killer (*Premna integrifolia*) (2.79%, $n = 27$). There were other less frequent 249 trees belonging to 35 species.

3.3 | Nesting tree lost

The white-rumped vultures used more trees for nesting in community forests (60.82%) than in the vicinity of human settlements (39.17%) during the study period. Of the 194 nesting trees, 48 nesting trees were lost during the study period: 24 nesting trees were cut down in community forests and 24 nesting trees in the vicinity of human settlements. Humans cut down 33 nesting trees while 15 nesting trees were destroyed by natural causes such as old age and storms. Among the lost tree species, most (20 trees) belonged to kapok followed by quassia wood (8), mango (6), khiar (3), red cedar (3), garuga (2), sacred Fig (2), sal (2), baheda (*Terminalia bellerica*) (1), and butter tree (1).

4 | DISCUSSION

White-rumped vultures are a selective tree nesting species, and their choice of nesting trees may be influenced by safety considerations. In the study area, rohituka trees are the most abundant trees, but vultures used kapok trees for building nests most often. Previous studies conducted document that white-rumped vultures tend to use crocodile bark tree (*Terminalia tomentosa*) and sal for nest building in lowland Nepal (Bhusal et al., 2020; Subedi, 2008), but chir pine (*Pinus roxburghii*) and kapok are found to be the most commonly occurring nesting trees for this species in mid hills (Rana et al., 2019). In India, white-rumped vultures use chir pine (*Pinus roxburghii*) for nesting in Himanchal Pradesh (Thakur, 2015), coconut palm (*Cocos nucifera*), mango (*Magnifera species*) and *Termenalia* in Western Maharashtra (Majgaonkar et al., 2018), and white murdah (*T. arjua*) in Tamilnadu (Ramakrishnan et al., 2014). It appears that white-rumped vultures preferred certain trees irrespective of the diversity and availability of other trees. In Nepal, the availability of suitable nesting and roosting habitats may be a limiting factor, as vulture colonies are often located outside the protected areas.

White-rumped vultures choose large-sized trees, and the trees that have the longest branching orders for nest construction. These trees tend to be strong enough to support the vultures' body weight during takeoff and landing. The white-rumped vultures prefer taller trees for nest construction, so that they can easily detect carcasses directly or observe a long chain of descending vultures toward the carcass (Jackson et al., 2008; Rouviere & Ruxton, 2022). This minimizes the energy expenditure required for scavenging, which can be a crucial factor in maintaining optimal breeding conditions. Overall, it seems that choosing large and mature trees is the best option for nest building and breeding of white-rumped vultures.

The study suggests that the tree whorl, canopy spread, and first branch height are important predictive variables for white-rumped vulture nest construction. More tree whorls might provide a wider space for nest placement and roosting to the vultures. That might increase breeding success. Not only white-rumped vultures, but also black-crowned night herons (*Nycticorax nycticorax*) construct their nest in those trees that having nine or more whorls (Wood & Wood, 1933). Furthermore, white-rumped vultures build more nests on trees with low canopy spread, probably that may provide easy access for nest establishment with minimal effort, thereby increasing nesting success and ultimately leading to a higher fledgling success rate (Barash, 1975). The advantage of nesting and roosting on the first branch of the trees extends beyond safety and ease of nest construction.

The white-rumped vultures are usually found roosting and nesting near human settlements and community forests due to the availability of food, which was supported by livestock farming and open carcasses disposal systems. However, for more economic benefits and infrastructure development, large and mature trees are lost in the study area, which reduces nesting and roosting habitats for vultures (Baral et al., 2005; Gautam & Baral, 2013). To protect white-rumped vultures, it is necessary to implement measures to conserve nesting and roosting trees, including controlling the harvesting of large and tall trees that have shorter canopy spread and more whorls.

Over the past decade, the total number of white-rumped vultures' nests has increased in Nepal. It was probably due to diclofenac ban and the establishment of vulture safe feeding sites and zones after 2006 (Prakash et al., 2012). The number of nests in active colonies has a positive effect on the overall nests of the species in Nepal even though some trees which white-rumped vultures use for nesting are lost in the study area. The white-rumped vultures exhibit a consistent pattern of reusing nesting trees year after year (Ali & Ripley, 1987; Gautam & Baral, 2013). However, we measured the characteristics of both nesting and non-nesting trees only one time between 2002/03 and 2021/22. This limitation might create some possibility of bias in the relationship between nest construction and the influence of tree characteristics. The reviewers raised an issue of spatial autocorrelation in the attributes of nesting and non-nesting trees. Trees in the neighborhood might share some similarities, but our focus was on examining why certain trees were chosen to build nests than others, given how similar or different the attributes of the trees found in the neighborhood. Based on the research design, the spatial autocorrelation is statistically controlled in our case.

AUTHOR CONTRIBUTIONS

Ramji Gautam: Conceptualization (equal); data curation (equal); formal analysis (equal); funding acquisition (lead); writing – original draft (equal); writing – review and editing (equal). **Nabin Baral:** Conceptualization (equal); data curation (equal); methodology (equal); supervision (equal); writing – review and editing (equal). **Hari Prasad Sharma:** Conceptualization (equal); data curation (equal); methodology (equal); supervision (equal); writing – review and editing (equal).

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CONFLICT OF INTEREST STATEMENT

Authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data are available at Dryad https://doi.org/10.5061/dryad.2ngf1vhtv and https://datadryad.org/stash/share/OhsNL3DyHD53Z3cIspG3J3cSOxv6A9b9EONUlBrVYWs.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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Supplementary Table 1. Nesting trees characteristics of the White-rumped Vulture in the study area.

Variable	Description
Girth at breast height (GBH)	Measurement of the girth of the tree at breast height (m)
Longest branching order (BO)	Measurement of the longest branching pattern of a particular tree
Nest branching order (NBO)	The branching pattern order which holds the nest
Total number of tree whorl (TW)	Measurement of the total whorl number of a particular tree
Canopy spread (CS)	Mean of longest and shortest canopy spread measure of a particular tree(m)
Tree height(TH)	The estimated height of a particular tree from the ground (m)
First branching height (FBH)	The estimated height of the first branch of a particular tree from the ground (m)
Nest height (NH)	The estimated height of the nest from the ground (m)
Nest whorl (NH)	Measurement of nest bearing whorl

Supplementary Table 2. Variance inflation factor between the variables of nesting and available trees around 10 m radius of White-rumped Vulture's nesting trees in Nepal.

Variable	VIF
Girth at Breast Height	1.11
Longest branching order	1.74
Tree whorl	1.04
Canopy spread	2.64
Tree height	2.25
First branch height	1.82

Supplementary Table 3. Number of nest per tree used by White-rumped Vulture in Nepal during the breeding season 2002/03-2020/22.

Survey year	Single nesting tree	Two nesting tree	Thee nesting tree	Four nesting tree	Five nesting tree	Total nesting trees	Total occupied nest
2002/03	43	12	1	0	0	56	70
2003/04	48	6	2	0	0	56	66
2004/05	52	8	2	1	0	63	78
2005/06	53	6	3	0	0	62	74
2006/07	46	15	0	2	0	63	84
2007/08	57	10	3	2	0	72	94
2008/09	43	8	1	0	1	53	67
2009/10	32	6	1	0	0	39	47
2010/11	23	4	1	0	0	28	34
2011/12	28	7	1	0	0	36	45
2012/13	42	9	1	1	0	53	67
2013/14	38	8	1	0	0	47	57
2014/15	25	6	1	0	0	32	40
2015/16	20	2	1	0	0	23	27
2016/17	29	4	0	1	0	34	41
2017/18	27	4	0	1	0	32	39
2018/19	28	8	1	0	0	37	47
2019/20	30	5	1	0	0	36	43
2020/21	35	7	3	1	2	48	72
2021/22	34	10	2	1	1	48	69
Total	733	145	26	10	4	918	1161

Supplementary Table 4. Nesting tree species of Whit-rumped Vulture and their frequency in west Nepal.

SN	Local name	Common name	Scientific name	Number
1	Aap	Mango	*Magnifera indica*	7
2	Barro	Baheda	*Terminalia bellerica*	1
3	Chhatiwan	White Cheese Wood	*Alstonia Scholaris*	3
4	Chilaune	Needlewood Tree	*Schima wallichii*	3
5	Chiuri	Butter Tree	*Aesendra butyraceae*	1
6	Dabdabe	Grey Downy Balsam	*Garuga pinnata*	3
7	Karang	Yello Teak	*Adina cardifolia*	2
8	Katush	Chestnut	*Castanopsis indica*	2
9	Kavro	Java Fig	*Ficus lacor*	3
10	Khair	Cutch Tree	*Acacia catechu*	5
11	Lokate	Jungle Cork	*Holoptelia integrifolia*	1
12	Padke	Potka Siris	*Albizia lucidor*	2
13	Peeple	Sacred Fig	*Ficis religiosa*	3
14	Sal	Sal	*Shorea robusta*	4
15	Saj	Silver Grey Wood	*Terminalia tomentosa*	6
16	Simal	Kapok	*Bombax ceiba*	129
17	Swami	Weeping Fig	*Ficus benjamina*	1
18	Tiju	Quassia Wood	*Picrasma javanica*	14
19	Tuni	Redcedar	*Toona ciliata*	4

Supplementary Table 5. Non-nesting tree species found around the nesting trees of White-rumped Vulture in west Nepal's Kaski, Syangja, Tanahu, and Palpa Districts of Gandaki and Lumbini Province.

SN	Local name	Common name	Scientific name	Number
1	Chuletro	Chuletro	*Brassaiopsis hainla*	7
2	Chilaune	Needlewood tree	*Schima wallichii*	26
3	Katush	Chest Nut	*Castanopsis indica*	16
4	Kutmiro	Yati	*Listea monopetala*	16
5	Bhalupayile	Chinese Alangium	*Alangium chinense*	18
6	Khirro	Tiger's milk spruce	*Sapium insigne*	103
7	Kurau	Fever pod	*Holarrhena pubescens*	57
8	Bedulo	Bedulo	*Ficus subincisa*	1
9	Tiju	Quassia wood	*Picrasma javanica*	17
10	Aurelu	Aurelu	*Flacourtia* sp.	9
11	Sal	Sal tree	*Shorea robusta*	8
12	Gideri	Wind Killer	*Premna integrifolia*	27
13	Khaniyo	Dropping Fig	*Ficus semicordata*	5
14	Thotne	Hairy Fig	*Ficus hispida*	15
15	Dabdabe	Garuga	*Garuga pinnata*	43
16	Amara	Tree of heaven	*Ailanthus excelasa*	2
17	Saj	Baheda	*Terminalia elliptica*	24
18	Kavro	Java Fig	*Ficus lacor*	19
19	Bar	Banyan	*Ficus benghalensis*	3
20	Rukhakatahar	Jack tree	*Atrocarpus heterophyllus*	2

21	Simal	Kapok	*Bombax ceiba*	14
22	Padke	Potka Siris	*Albizia lucidior*	87
23	Khayar	Cutch	*Acacia catechu*	10
24	Chhatiwan	Black board tree	*Alstonia scholaris*	3
25	Rohini	Red Berry	*Mallotus philippensis*	4
26	Aap	Mango	*Magnifera indica*	1
27	Pipal	Sacred Fig	*Ficus religiosa*	5
28	Lokte/Daje	Jungle cork	*Holoptelia integrifolia*	6
29	Swami	Golden fig	*Ficus benjamina*	3
30	Sunkauli	Indian bay leaf	*Cinnamomum tamala*	1
31	Lakuri	Himalayan Mannaash	*Fraxinus floribundax*	1
32	Badahar	Monkey fruit	*Artocarpus lakoocha*	2
33	Ramriththo	Bhellar	*Trewia nudiflora*	56
34	Lasune	Rohituka tree	*Aphanamixis polystachya*	150
35	Taki	Butterfly tree	*Bauhinia purpurea*	1
36	Budhodhayero	Small flower crape myrtle	*Lagerstromia parviflora*	117
37	Nibuwa	Lemon	*Citrus lemon*	1
38	Pakhuri	Pakhuri	*Ficus glaberrima*	1
39	Tuni	Red cedar	*Cedrela tuna*	2
40	Asare	Sage leaf Alangium	*Alangium salviifolium*	32
41	Karang	Karma	*Adina cordifolia*	48
42	Belapatra	Golden apple	*Aegle marmelos*	1
43	Nibaro	Nibaro	*Ficus rosenbergii*	2
44	Gaya	Gaya	*Bridelia retusa*	2
45	Chiuri	Butter tree	*Aesendra butyraceae*	1

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