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Research article

Ecosystem engineering: Rufous-bellied woodpecker *Dendrocopos hyperythrus* (Vigors, 1831) modifying tree shapes of Himalayan broadleaved forests

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Abstract

The study, conducted from 2005 to 2018, encompassed twelve sites in Nepal, including both protected and non-protected areas. The primary focus of the observations was on tree species, their shapes, structures, and their interactions with the rufous-bellied woodpecker. The rufous-bellied woodpecker in Nepal's Himalayas predominantly utilized specific tree species, notably oak (*Quercus semecarpifolia* and *Q. glauca*), birch (*Betula utilis*), Himalayan holly (*Ilex dyperina*), and maple (*Acer species*). These trees displayed a remarkable diversity in girth sizes, ranging from 0.5 meters to almost 2.5 meters, with tree heights varying from 5 to 30 meters. Among these, *Quercus semecarpifolia* was the preferred choice. Notably, rufous-bellied woodpeckers exhibited a distinctive behavior of drilling numerous small holes around tree trunks, often forming ring-like structures. These "sap-wells" were meticulously created by drilling dense rows of small holes encircling the tree trunks and served as the primary food source for the woodpeckers. They attracted a wide array of insects and offered a valuable source of protein. This continuous interaction between the woodpeckers and the trees resulted in unique modifications to the trunks of old-growth forest trees. Over time, the trees developed swollen trunks, and some trunks even displayed bending and deformations due to the woodpecker's sap-well chiselling activities. Furthermore, the study observed several other bird species benefiting from these sap-wells created by the rufous-bellied woodpeckers. This observation underscores the broader ecological significance of these structures, benefiting a diverse range of species within the ecosystem. In essence, this study sheds light on the rufous-bellied woodpecker's role as an "ecosystem engineer" and an indicator of forest health in the temperate Himalayas, emphasizing its critical ecological importance.

Keywords: Ecosystem engineering; Himalayan temperate forests; Sap-wells; Tree modifications; Biodiversity indicator

1 | Introduction

Rufous-bellied woodpecker *Dendrocopos hyperythrus* is a widely distributed bird in Asia, recorded in 14 countries: Bangladesh, Bhutan, Cambodia, China (including Hong Kong), India, Lao People's Democratic Republic, Myanmar, Nepal, Pakistan, Russia, Thailand, Vietnam, North Korea, and South Korea (Gorman 2014; BirdLife International 2016). Although there is evidence of a decreasing population trend, it does not appear to be declining rapidly enough to meet the criteria for Vulnerable status under the population trend criterion (>30% decline over ten years or three generations) of the IUCN Red List of Threatened Species. Consequently, the species is globally assessed as "Least Concern" (BirdLife International 2016).

Rufous-bellied woodpecker is composed of four recognized subspecies (del Hoyo et al. 2002):

1. *D. h. hyperythrus*: Found from Nepal eastwards to northeast India, Bhutan, west and southwest China (including east and southeast Tibet).
2. *D. h. marshalli*: Occurs in northeast Pakistan and northwest India, including Kashmir.
3. *D. h. annamensis*: Found in southeast Asia, considered a separate subspecies, with a status ranging from scarce to common resident (Robson 2009). It is uncommon in Thailand, extremely rare in Cambodia, and possibly breeding in Lao PDR, with its first recorded presence in 2006 (Eve 2007).
4. *D. h. subrufinus*: Breeds in Manchuria and Ussuriland (parts of China and Russia) and migrates south to winter in southern China. It is

the northernmost population and also reported as a rare vagrant in the two Koreas (Gorman 2014; BirdLife International 2016).

With the exception of *D. h. subrufinus*, all other subspecies are considered residents exhibiting some vertical movements (del Hoyo et al. 2002).

The majority of the rufous-bellied woodpecker population is concentrated in the Himalayas, China, and Russia (BirdLife International 2016). In China, its status varies depending on the region. In Russia, the species is listed in the Russian Red Data Book, indicating its threatened status (Heim et al. 2016). In India, it is resident in the Himalayas and in northeast India (Ali and Ripley 1987; Inskipp et al. 2011; Rasmussen & Anderton 2011). In Nepal, the National Red List Assessment categorizes the species as "Least Concern" and so not yet threatened, taking into account its wide distribution throughout Nepal, but acknowledging some decline due to habitat loss (Inskipp et al. 2016).

In Nepal, the species can be found from Dadeldhura, Baitadi, Darchula in the west to Ilam, Panchthar, and Taplejung districts in the east, essentially spanning the entire country from east to west (Figure 1). Rufous-bellied woodpecker is described as a fairly common breeding resident in Nepal (Grimmett et al. 2016; Inskipp et al. 2016).

This paper focuses on the feeding activities of the rufous-bellied woodpecker, which play a crucial role in shaping tree trunks of a few dominant tree species, in the Himalayan temperate forests. The resulting tree shapes from this distinctive bird behavior have not been previously described. This paper also discusses other associated changes due to such physical structure of these particular trees and implications on overall biodiversity.

2 | Materials and methods

Between 2005 and 2018, fieldworks were conducted across twelve distinct sites in Nepal, strategically spaced up to 800 km apart. Study sites comprised six locations within protected areas of Nepal and an additional six in landscapes located outside the boundaries of the protected areas (Figure 1, Table 1). During this period, the observations were focused on tree species, shapes (including girth size estimate), structures, and their associations with the rufous-bellied woodpecker. These observations were made opportunistically, and whenever feasible, photographs of the trees were taken.

3 | Results

Details of the main tree species used by rufous-bellied woodpecker in the Nepal Himalayas are given in Table 2. The girth size of the trees varied from 0.5 meter to nearly 2.5 meters. Tree heights ranged from 5 to 30 metres, the tallest being *Quercus semecarpifolia*. The most frequent

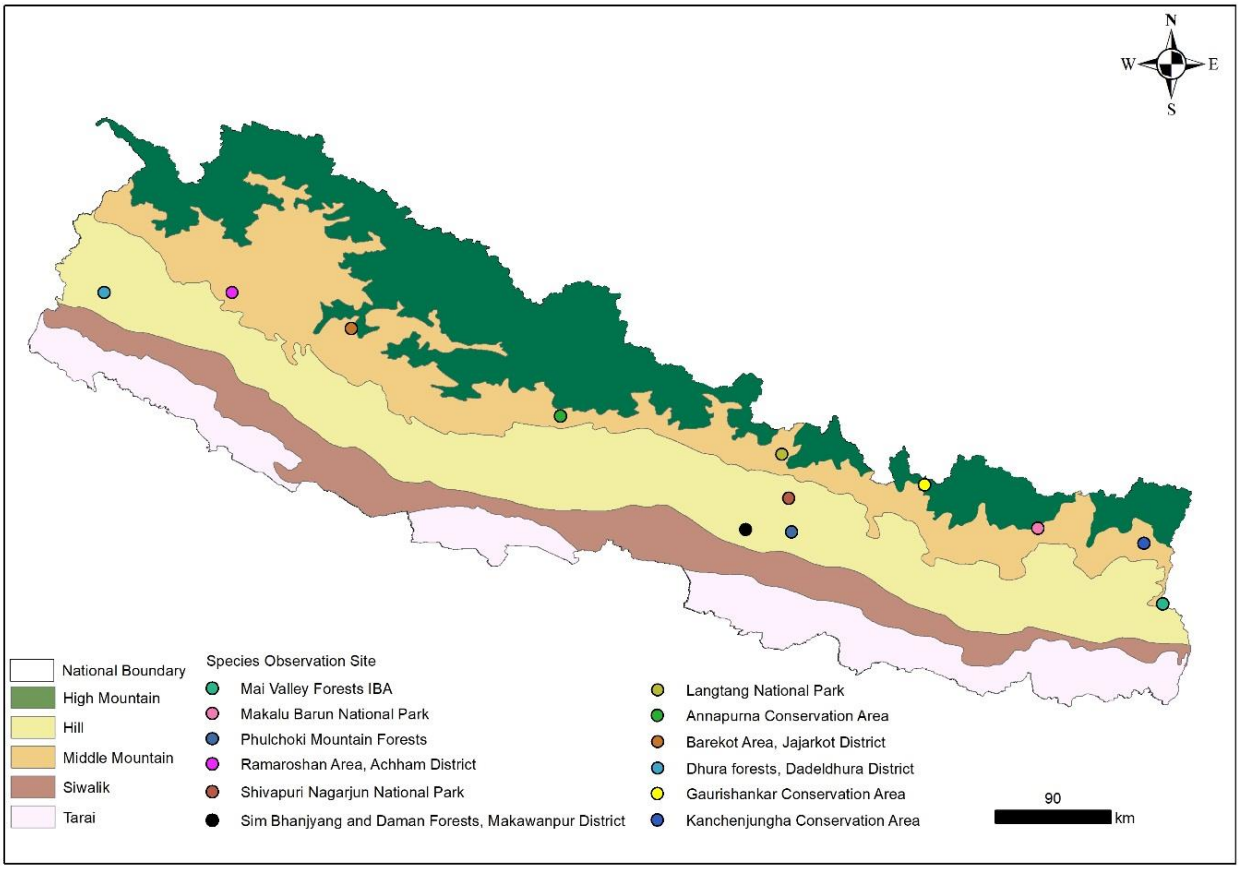

Figure 1. Map of Nepal showing the study sites.

Table 1. Description of the study area, district with coordinates and year visited

Description of the study area	Coordinates	Year of observation	Remarks
Mai Valley Forests IBA, mainly around Dobate, Kainyakatta and above Hangetham, Ilam District. Temperate broadleaf forests.	27°04'10.57"N 87°59'49.11"E	September 2010	Dobate
Kanchenjungha Conservation Area, mainly above Lelep on the way to Ghunsa, Taplejung District. Temperate broadleaf and coniferous forests.	27°29'34.12"N 87°51'56.22"E	April 2011	Lelep
Makalu Barun National Park, around Saisima and Chaurikharka, Sankhuwasabha District. Temperate broadleaf forests.	27°35'56.16"N 87°07'21.39"E	November 2005	Chaurikharka /Saisima
Gaurishankar Conservation Area, mainly areas before Beding, Dolakha District	27°54'12.99"N 86°19'40.60"E	May-June 2011	Below Beding
Langtang National Park, around Lama Hotel to Ghoratabela as well as above Thulo Syafru Rasuwa. Temperate broadleaf and conifer forests.	28°06'57.69"N 85°19'50.46"E	April 2006	Below Chandanbari
Shivapuri Nagarjun National Park, mainly upper slopes, Kathmandu District. Temperate broadleaf forests.	27°48'33.08"N 85°22'39.78"E	2013	Towards the Shivapuri top
Phulchoki Mountain Forests, mainly the slopes from mid-point upwards, Lalitpur District. Temperate broadleaf forests.	27°34'26.46"N 85°23'52.66E	2005 onwards	Mid elevation
Sim Bhanjyang and Daman Forests, in oak tree areas, Makawanpur District. Temperate broadleaf forests.	27°35'21/71"N 85°04'40.24"E	January 2015	Stretch between Daman-Sim Bhanjyang
Annapurna Conservation Area, around and above Ghandruk, Kaski District. Temperate broadleaf forests.	28°23'01.05"N 83°46'45.75"E	December 2016	Above Ghandruk Village
Barekot Area, Jajarkot District. Temperate broadleaf and conifer forests.	28.998879° N 82.313933°E	October 2013	Lagana, Barekot
Ramaroshan Area, above Rame and the lake area, Achham District. Temperate broadleaf forests.	29°14'58.67"N 81°28'50.92"E	April 2014	Main ground area above large lake
Dhura Forests, extensively on the highest parts stretch west of the Dhangadhi – Dadeldhura road, Dadeldhura District. Temperate broadleaf and conifer forests.	29°14'58.16"N 80°34'55.14"E	May 2010	West of Sahu Kharka

tree species (75% of the localities) used by rufous-bellied woodpecker was also *Q. semecarpifolia*. Most activities of these birds were confined to mature trees that were found mostly in primary undisturbed forests. Birds preferred to stick to the denser stands as isolated trees which were otherwise suitable for woodpeckers were not used by the birds.

Rufous-bellied woodpeckers exhibited a distinctive behavior of drilling multiple small holes around the trunks of these tree species, often forming ring-like structures around the entire tree trunk (Figures 2a & 2b). These rings were single or multiple, with most trees showing the presence of multiple rings. In old-growth forests, the majority of observed ring-holes appeared to be older, where the trees had recovered from chiselling of the woodpeckers. This made it challenging to accurately measure the depth of these holes. However, the depth ranged from a very shallow peck up to 3.3cm. On average the deepest holes observed were in oak trees. The number of individual sap-wells in a ring varied from tree to tree, from a handful to over 80. Larger diameter trees had a larger number of sap-wells mostly arranged in a linear ring fashion.

Field observations confirmed that the woodpeckers are engaged in repeated drilling and chiselling activities on the tree trunks. It's important to note that sap-wells were not observed on side branches however large they were. Fresh sap-wells were relatively rare, suggesting that the birds preferred to work on existing sap-wells. I also observed the birds chiselling older sap-wells, possibly to maintain hole depth and permanence. This re-chiselling would be necessary to ensure the gap is not resealed as a natural defence by trees and to maintain a desirable continuous flow of sap, which served as the primary food source chiefly for the rufous-bellied woodpecker. The flowing sap also attracted various insects, providing a source of protein for not only the woodpeckers but also other beneficiaries (Table 3). In some instances the sap exuded from the ring of wells, could not be contained only on the wells, so naturally sap was seen dripping down the trunk indicated by moist stripsstrips (Fig. 2g, note the dark spots due to sap flow).

Over time, as a result of repeated chiselling and the tree's natural ability to recover from wounds, trees developed thicker bark and added more tissues around the rings. Trees continued to add tissues to recover from chiselling,

Table 2. List of trees used for boring holes by rufous-bellied woodpecker in Nepal Himalayas

Tree name (Tree samples with holes)	Height (range, m)	DBH (range, m)	No. of rings in a tree (range)
Oak *Quercus semecarpifolia* (86)	6–30	0.8–2.4	6–80
Oak *Quercus glauca* (17)	7–18	0.7–1.6	5–16
Birch *Betula utilis* (31)	5–18	0.5–1.3	6–60
Himalayan holly *Ilex dipyrena* (24)	8–25	0.7–2.1	3–18
Maple *Acer* species (14)	11–25	0.7–1.5	3–9

Table 3. List of species seen feeding on the sap-wells (other than rufous-bellied woodpecker) Bird names follow eBird nomenclature (www.ebird.org)

English name	Scientific name
Darjeeling woodpecker	*Dendrocopos darjellensis*
Crimson-breasted woodpecker	*Dryobates cathpharius*
Rufous sibia	*Heterophasia capistrata*
White-browed fulvetta	*Fulvetta vinipectus*
Rufous-winged fulvetta	*Schoeniparus castaneceps*
Hoary-throated barwing	*Actinodura nipalensis*
Chestnut-tailed minla	*Actinodura strigula*
Blue-winged minla	*Actinodura cyanouroptera*
Buff-barred warbler	*Phylloscopus pulcher*
Lemon-rumped warbler	*Phylloscopus chloronotus*
Ashy-throated warbler	*Phylloscopus maculipennis*
Grey-hooded warbler	*Phylloscopus xanthoschistos*
Green-backed tit	*Parus monticolus*
Yellow-browed tit	*Sylviparus modestus*
White-tailed nuthatch	*Sitta himalayensis*
Green-tailed sunbird	*Aethopyga nipalensis*

while the birds persistently pecked at the thicker bark. It is likely that the presence of such thick bark around the trunk provided sap with higher nutrient content. Thick bark would hold comparatively larger amount of liquid sap which ensured a sustained flow of sap. The ongoing interaction between the birds and the trees over many years led to unique modifications on the trunks of old-growth forest trees in the temperate Himalayas (Figures 2c to 2d). These trunks became swollen at the sap-wells forming structures as if the trunks were wearing rings around them. Further, on multiple occasions, the tree trunks displayed were bent and deformed structures due to the sap-well chiselling activities.

On many occasions, several other bird species were observed feeding on sap-wells. A list of 16 species is provided in Table 3.

4 | Discussion

Rufous-bellied woodpeckers choose which species of trees to work on indicating their partiality to forage on certain types of trees. In this study, utilization of five tree species was observed by rufous-bellied woodpecker. However, another study has stated that at least seven native tree species were utilized in a west Himalayan national park (Shahabuddin et al. 2018). Osmaston (1916) and Ali (1968) mention *Pyrus malus* as well as *P. pashia* as trees where lines of holes in the form of rings have been noted. Further, the species is also known to have used three introduced tree species (Shahabuddin et al. 2018). Such instances have not been observed in Nepal but cannot be ruled out in more targeted studies in the future.

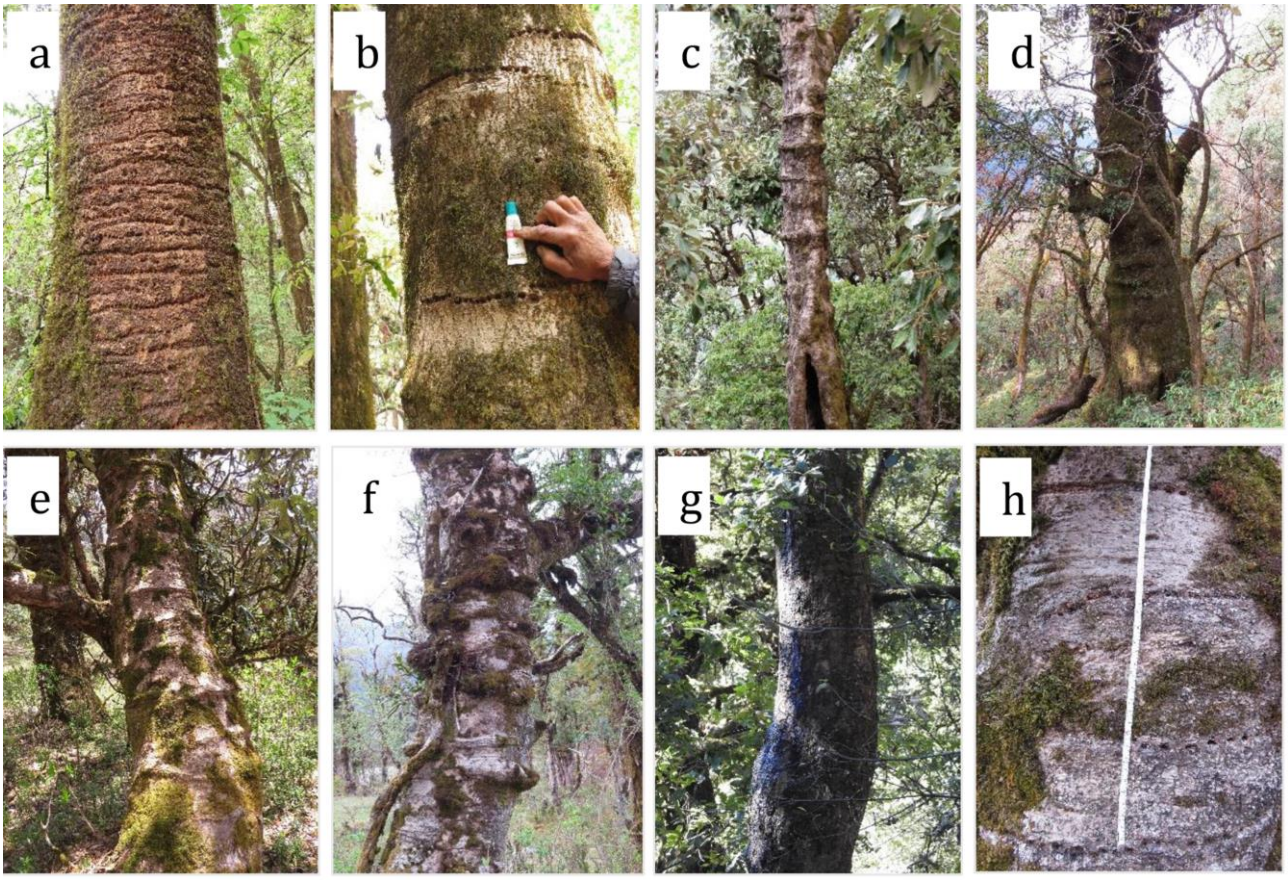

Figure 2. Photographic evidences showing ecosystem engineering by rufous-bellied woodpeckers. a- Tree trunk showing rather uninform rings of sap wells, Ramaroshan, Achham; b- Tree showing ring of sap-wells Ramaroshan, Achham; c- Tree showing bulges caused by the chiseling of sap-wells Dhura forests, Dandeldhura; d- Tree showing bulges caused by the chiseling of sap-wells Lagna, Jajarkot; e- Tree showing bulges caused by the chiseling of sap-wells Ramaroshan, Achham; f- Tree showing bulges on trunk caused by the chiseling of sap-wells Ramaroshan, Achham; g- Tree showing flowing of the sap from sap-wells, Phulchoki, Lalitpur; and h- Tree showing ring of sap-wells Langtang National Park, Rasuwa

The available information means spatio-temporal variation is observed on the choosing of the tree species by rufous-bellied woodpecker in the Himalayan belt and far beyond (del Hoyo et al. 2002). The number of rings (up to 80 given for this study) should be interpreted with caution, as in other range states the number could easily go beyond 100 or so (refer picture in Ali 1968 and Shahabuddin et al 2018). Another study conducted in western Himalaya on breeding biology of this species has indicated bird's use of at least six species of trees including the *Q. semecarpifolia* (Bhatnagar 2022), which is according to our observation is a favoured tree for making the sap-wells.

Observation from this study confirm Shahabuddin et al. (2018) findings that the birds used only temperate species of trees. As most of these trees would be growing in mid-hills, rufous-bellied woodpecker is one of the 24 species of woodpeckers in Nepal that is confined to this belt. Its habitat range extends from 1800 to 3500 meters in elevation, primarily covering temperate and subalpine forests (Grimmett et al. 2016; Inskipp et al. 2016). This bird rarely makes an appearance below or above its normal ranges. This highlights the special requirement of this species and why it can be aptly termed as an indicator species (Shahabuddin et al. 2018).

This study is the first one to document that the tree-trunk chiselling behaviour of the rufous-bellied woodpecker can ultimately shape the physical structure of not only the trees but the entire forest system. Because the activities of rufous-bellied woodpeckers give rise to distinctive tree trunk structures, these birds can aptly be described as the "ecosystem engineers" of the temperate forests of the Himalayas. To an avid observer, it is difficult to overlook such unique structure of tree trunks. The entire physical structure of the trees and forests have been modified as a result of the woodpeckers' work. These modifications are crucial for the feeding and nesting of not only woodpeckers but also a diverse range of species inhabiting the temperate belt. Among the 24 species of resident woodpeckers and allies in the Picidae family in Nepal, the rufous-bellied woodpecker holds a special place due to its unique sap-sucking behavior.

References to sap-wells have been made previously by many scholars such as Fleming et al. (1984) who noted that the rufous-bellied woodpecker bores rows of holes in the bark of oak trees *Quercus semecarpifolia* to drink the flowing sap. They further mention that the woodpecker pokes its bill into "sap holes" and may spend up to half an hour at one tree, repeatedly visiting productive openings. Fleming et al. (1984) highlighted that several other species, especially sibias, also consume this sap. Notably, Roberts (1992) observed that, apart from puncturing the cambium layer of deciduous trees for sap-sucking, the woodpecker engages in typical woodpecker behavior by digging and probing bark for wood-boring insect larvae and will "lick-up" ants and termites (Isoptera). This species is known to feed on sap in spring and forage on tree trunks in the canopy, frequently probing, hammering, and gleaning. Del Hoyo et al. (2002) mentioned that the rufous-bellied woodpecker creates sap wells by drilling dense rows of 8-10 small holes encircling tree trunks. Rasmussen and Anderton (2011) noted that the bird pecks and probes in bark, crevices, and ant workings, rather than drilling, and drinks sap from closely spaced small wells on several deciduous tree trunks within its territory. Gorman (2014) stated that it also drills sap-wells in favored trees over several years. Most recently, Grimmett et al. (2016) reported that the bird often feeds by probing and pecking loose bark and in crevices. It also bores holes into oak bark to drink sap.

The rufous-bellied woodpecker has intrigued ornithologists for years, particularly its sap-drinking behavior and the creation of sap-wells. Osmaston (1916) provided an early detailed description of sap-wells, followed by Abdulali (1968). Zusi and Marshall (1970) offered a comparative analysis of the rufous-bellied woodpecker with American sapsuckers, shedding light on its ecological features, including "sap-wells." They also conducted a detailed anatomical analysis to compare similarities and differences with American sapsuckers from the Genus *Sphyrapicus*.

More recently, Shahabuddin et al. (2018) conducted the first ecological study on the species in the western Himalayas, identifying it as a possible indicator species for assessing high-quality oak forests in the Himalayan region. Woodpeckers and hornbills, primarily cavity-nesting species, are often regarded as sensitive indicators of forest ecosystems due to their dependence on mature old-growth forests (Baral & Hueittman 2020). Previous studies have underscored the significance of woodpeckers, including lowland cavity-nesting birds, as key forest species in Nepal (Bhattarai 1998; Baral 2011; Bhusal et al. 2015; Baral et al. 2018). Elsewhere, their important role in creating cavities in hard snags and decadent live trees, therefore also providing space to a number of other secondary cavity nesters have been discussed (Aubry & Raley 2002). This is a direct example of how some woodpeckers are helping others to complete their lifecycle, further highlighting the key indicator species role they exhibit. Therefore, a species so limited within the narrow belt, with limited choices of trees to feed on with sap-wells and not tolerating disturbance, rufous-bellied woodpecker may be well be a good indicator for not only the western Himalayan temperate forest but along its entire range as proposed (Shahabuddin et al. 2018).

The rufous-bellied woodpecker stands out in Asia for significantly incorporating more plant-based products into its diet compared to other woodpecker species. Most woodpeckers are primarily insectivores, but certain species of sapsuckers and the Genus *Celeus* woodpeckers in the Americas are known to supplement their diet with sap or fruit-based food sources (del Hoyo et al. 2002). In Nepal, some other woodpecker species from the Genera *Picus*, *Dinopium*, and *Dendrocopos* are often seen in flowering trees, especially on silk-cotton trees (*Bombax ceiba*). However, it is currently unknown what percentage of their diet comprises insects attracted to flower nectar

or nectar itself. In this context, the rufous-bellied woodpecker stands as the sole sapsucker in the Himalayas until further research is carried out on other species.

This study has shown that a suite of other bird species also benefit from sap-wells made by rufous-bellied woodpecker, the list provided in this article is by no means an exhaustive one. Spatial and temporal variations in the species benefiting from these resources are likely to exist, and further, long-term studies may reveal more species and additional insights to the behavior and ecology of this species. Nevertheless, the key takeaway message is that sap-wells offer substantial benefits to as many as 16 bird species and other fauna such as bees, butterflies and ants, extending beyond the rufous-bellied woodpecker.

5 | Conclusion

Although the current assessment in Nepal categorizes the species as "Not Threatened" (Inskipp et al. 2016), it is important to note that the forests where the rufous-bellied woodpecker resides are under significant pressure from degradation and loss, with threats similar to those identified in India (Shrestha et al. 2013, Shahabuddin et al. 2018, Inskipp and Baral 2019). The problem is compounded further as the rufous-bellied woodpecker does not show altitudinal movement like other species, therefore, it faces more threats due to habitat degradation and loss.

The study underscores the potential of the rufous-bellied woodpecker to serve as a valuable indicator species for high-quality oak forests, all along its entire distribution range in the Himalayas. Recognizing its significance, this research recommends adopting the species as an indicator for temperate Himalayan forests. Furthermore, it advocates for specific studies to deepen our understanding of the biology and behavior of the rufous-bellied woodpecker, providing a foundation for more targeted conservation efforts.

An intriguing aspect of this study is the parallel drawn between the woodpecker's foraging behavior and human practices of extracting pine resin. The woodpecker, seemingly without external monitoring or enforcement, engages in a more sustainable harvesting method, ensuring the persistence of trees that provide essential resources for its survival. This raises questions about the effectiveness of human regulatory measures in achieving sustainable practices. The contrast between the woodpecker's natural approach and the complex, regulated human practices highlights the need for a deeper understanding of the intricacies involved in sustainable resource management. Ultimately, this study suggests that observing and learning from the rufous-bellied woodpecker's practices could inspire more effective and sustainable conservation strategies in the face of growing environmental challenges.

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My observation of the tree-shapes in the temperate Himalayan forests has been inspired by Eric Dinerestein's paper published in 1979 on how the rhinos have contributed in shaping physical structure of vegetation of the lowland Nepal.

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Conflicts of interest

Author declares no conflict of interest.

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