ORIGINAL RESEARCH

Nesting habitat preference and breeding of Asian Woollyneck (*Ciconia episcopus*) in Nepal

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Abstract

Background: Asian Woollyneck *Ciconia episcopus* is large wading bird whose conservation status has been recently down-listed, despite a lack of general knowledge on its nesting ecology and breeding success. Thus, in this study we conducted the most comprehensive survey on the nesting ecology of this species to date.

Methods: We located 39 nesting sites across 18 districts of Nepal and recorded nest tree characteristics for the nine tree species they nested in. We also used Maxent modelling to further understand factors important for nesting habitat suitability and to identify new areas for future surveys.

Results: They most commonly nested in Simal *Bombax ceiba* (n =21), followed by Sal *Shorea robusta* (n=6) and Salla *Pinus roxburghii* (n=4). The mean height of the nesting tree, nest height and tree diameter were 29.8 ± 5.8m (±SD), 1.03 ± 0.35m & 25.3 ± 5.8 m respectively. Nesting and fledging success were additionally recorded from 31 nesting attempts at 19 of these nesting sites between 2016 and 2020. Woollyneck had an estimated nesting success probability of 0.81 ± 0.07 and a mean fledging success of 1.94 ± 0.25 (±SE) chicks per nest. MaxEnt modelling identified a total potential suitable nesting habitat area of 9.64 % (14228km^2) of total area in Nepal, with this located within 72 districts (out of 77), mostly in the western part of Nepal. The modelling parameters suggest that slope, land-use, precipitation and forest were important determinants of nesting habitat suitability.

Conclusions: The most likely district reported by the model for Woollyneck nesting habitat has not previously reported nests which suggests additional survey effort in this region is warranted. We recommend that priority should be given to conserve taller trees close to settlements and cropland, and future studies should consider the potential impact of climate change on nesting suitability of this species.

KEYWORDS Asian Woollyneck, Breeding success, Maxent modelling, Nepal, Nesting habitat

1. INTRODUCTION

Understanding the biotic and abiotic factors that influence a species' reproduction is important for not only describing its ecology, but also for conservation planning related to population regulation (Lewis et al., 2017). This involves both an understanding of the natural history of a species' breeding cycle (e.g. the timing of breeding, nest site selection and reproductive rates) and the factors that influence its fecundity(Martin, 1995). Of these factors in birds, nests are critical because they are sensitive to habitat change and are directly linked to population persistence (Jimenez-Franco et al., 2018). Thus, the natural history of nest site selection and the factors regulating nesting success are of prime interest for bird ecology and conservation (Ishtiaq et al., 2004).

Nesting structure components such as nesting materials(Tryjanowski et al., 2000) nesting trees, height, and diameter(Lõhmus, 2006) and their location within the landscape (Cuervo, 2004) may strongly influence the breeding success of nesting birds. In addition to this, climatic variables are emerging as important factors determining bird breeding distributions (e.g. White Stork *Ciconia ciconia* (Huntley et al., 2007; Tortosa & Castro, 2003), which has impacts for both conservation in relation to land-use and consequences of climate change. Therefore, because land-use is changing rapidly in many parts of the world, studies of habitat selection for nesting birds has significant implications for evidence-based conservation and management intervention.

The Asian Woollyneck *Ciconia episcopus* is a large wading bird species resident within Asia (BirdLife International, 2020). Its conservation status has recently been downgraded to near-threatened from vulnerable (BirdLife International, 2020) despite limited knowledge of its natural history and current distribution (Ghimire et al., 2021). In Nepal, this conspicuous stork is distributed throughout the lowlands and mid-hills up to an altitude of 915 m, with few occasional high altitudinal movements (Ghale & Karmacharya, 2018; Inskipp et al., 2016). Less is known about its status, distribution and ecology (Ghimire & Pandey, 2018) with no population surveys. It has a national 'near-threatened' status and is reported to nest in the lowlands and mid-hills along river basins (Inskipp et al., 2016). Its long-term persistence is threatened because of hunting, collection of its eggs and nesting tree degradation; with a paucity of information on this species escalating threat to its survival. Studies on nesting and breeding of Asian Woollyneck are sparse and are mostly reported from single or only a few nest site observations (Banerjee, 2017; Ghimire et al., 2020; Hasan & Ghimire, 2020; Kularatne & Udagedara, 2017). The only structured survey of its breeding distribution is from 2004 (Ishtiaq et al., 2004) creating a serious gap in our knowledge on the nesting behaviour, distribution and fecundity of this species (Ghimire et al., 2021). It is with this in mind that we undertake the most comprehensive study on nesting of the Woollyneck to date, and use this information to make predictions on where its nesting distribution is most likely located in Nepal.

Specifically we focus on identifying Woollyneck nesting sites and recording information about the nesting tree and the nesting success where possible. From this information we ask the following questions: (1) does the Asian Woollyneck favour particular tree species for nesting, (2) what are the physical dimensions of the nesting trees and the height of their nest, and (3) do Woollyneck reuse their nests for subsequent nesting? These questions are important for understanding their nesting habitat requirements and the potential for conservation planning related to nest tree retention in agricultural areas. We also examine: (4) what is the nesting success of Woollyneck in Nepal, and (5) when nests are successful, how many chicks do they fledge? These questions are important for understanding the current fecundity of the species in Nepal and the potential for population growth in areas where their nesting is protected. Finally we use the information collected from the area around the nesting trees (based on GIS) to model predictions of suitable habitat in Nepal using a presence-only modelling approach (MaxEnt; (Heinanen et al., 2012) to identify the potential of areas that have not been previously surveyed for this species (Sheehan et al., 2017). Such an approach will help with future survey design for both population monitoring and assessing the extent of their breeding distribution in Nepal.

2. MATERIALS AND METHODS

2.1 Study Area

Nepal is a landlocked diverse biogeographic region of 147,516 km^2 that encompasses an extreme habitat range from hotter lowlands to the snow-capped Himalayas. Thus, within a small area, Nepal harbors an unusually high diversity of plants and animals (Paudel et al., 2012). Within this area 28.75 % of the land is used for agriculture, with 83% of population dependent upon it (CBS, 2011; Trading Economics, 2020). Open agricultural lands and natural wetlands are factors thought to influence the presence of large wading birds such as the Asian Woollyneck. However, modification in agricultural land-use, removal of large trees and the decline of wetlands poses threats to these wetland depending species (Inskipp et al., 2016; MoFE, 2018a). Nest search surveys were carried out in the Rupandehi District of the lowlands, and the Pyuthan, Arghakhanchi and Dhading Districts of the mid-hills of Nepal.

2.2 Nesting data collection and analysis

Firstly, we outlined potential nesting areas after informal discussion with bird watchers, conservationists as well as local people. Secondly, we surveyed these potential sites and identified 16 nesting sites in above mentioned districts. We combined these data with our opportunistic observations, information forwarded by colleagues and from the Bird Conservation Nepal database. This provided us with 39 nesting sites with information about their location, and tree species where the nest was located in the tree. These nest sites were located in the mid-hills region of Nepal (28 nests from the districts of Arghakhanchi,

Pyuthan, Salyan, Dhading, Jajarkot, Surkhet, Kabhrepalanchowk, Sindupalchowk, and Kaski) and in the Nepal lowlands (10 nests from the districts of Chitwan, Rupandehi, Banke, Bardia, Kailali and Kanchanpur) (Fig 1a). At 29 of the 39 nesting sites we could also collect information about the height of the tree and height of the nest (18 trees also have diameter at breast height (DBH) measures of the nesting tree). Tree height and nest height were measured using Abney's level, while DBH was measured using a diameter tape.

We were also able to collect data on nesting and fledging success from 31 nesting attempts at 19 of these nesting sites from 2016-2020. Because a number of these nesting attempts were from the same individuals in the same tree in different years, we used GLMMs to calculate the expected nesting success (using a logit-link binomial) and fledging success (using a log-link poisson) by incorporating the identity of the breeding pair as a random effect in the model to account for potential non-independent sampling. These analyses were undertaken in R (R Core Team, 2019).

2.3 Modelling potential suitable habitat

We used Maximum Entropy Modelling (MaxEnt) for mapping potential suitable nesting habitat of the Asian Woollyneck (Phillips et al., 2004) as a means of identifying where survey effort could be focused in future studies to ensure key breeding areas are not overlooked. MaxEnt modelling is known to be effective even when few presence points are available (Thibaud et al., 2014; Wisz et al., 2008)which allowed us to make predictions despite the limited nesting data we have for this species in Nepal. Our data comprise from lowlands to mid-hills from far western to central Nepal where nesting of species has been known so far. Therefore, we attempt to use these nesting presence points to analysis and predict nesting suitability habitat of Asian Woollyneck in Nepal.

Nesting presence data of Asian Woollyneck was added along with 15 environmental variables (for details see Appendix Table S1) into the MaxEnt software for modelling. Our analysis included 10 replicates and selected bootstrap replicated run type recommended for handling small number of occurrence data with other default selections in logistic format to generate the map (Phillips & Dudík, 2008). Model performance was assessed using Area Under Curve (AUC) of the Receiver-Operating Characteristic (ROC) where AUC score of 1 indicates perfect prediction whereas the values equal to 0.5 indicates random prediction. For model evaluation, True Skill Statistics (TSS) were used where the value of TSS (TSS = Sensitivity + Specificity − 1) equals to 1 indicates a perfect fit and values less than 0 indicate a performance no better than random (Allouche et al., 2006). From this we extracted the probability of occurrence of suitable nesting habitat of Asian Woollyneck in Nepal and a used a threshold value (0.202 see Appendix Table S2) that maximized the sum of sensitivity and specificity to calculate the TSS, and thus convert the continuous probability map generated by the model into a binary presence/absence map of potential suitable nesting habitat (Liu et al., 2013).

2. RESULTS

3.1 Nest location

The 39 recorded nesting sites were located across 18 districts of Nepal, which included 10 districts in the mid-hills (500-1434 m.a.s.l) and 8 lowland districts (75 – 250 m.a.s.l) (Fig 1; Table 1). Asian Woollyneck nests were found in nine tree species (Table 1) with more than half of all nests being located in Simal *Bombax ceiba* (n =21), and other preferred nesting trees included Sal *Shorea robusta* (n=6) and Salla *Pinus roxburghii* (n=4), Peepal *Ficus religiosa* (n=2), Mango *Magnifera indica* (n =2) and one each in Karam *Haldina cordifolia* Jamun *Syzygium cumini*, Kadam *Mitragyna parviflora*, and Utis *Alnus nepalensis.* The heights of nesting trees varied from 19-41m, with a mean height of 29.8 ± 5.8m (±SD) and a mean diameter at breast height (DBH) of 1.03 ± 0.35m (range 0.56-2.0m). Nests were usually located 3-6 m from the top of the tree (mean 4.5 ± 2.6m) meaning that nests were, on average, 25.3 ± 5.8 m above ground (Table 1).

We compared nesting heights and diameters between their preferred nesting tree (i.e. Simal) and all other trees. On average, Simal nesting trees were taller and broader than other tree species (height of Simal versus other: 31.9 ± 6.1 m versus 27.7 ± 4.8 m; DBH of Simal versus other: 1.14 ± 0.18 m versus 0.94 ± 0.43 m). And correspondingly, nest height in Simal trees was higher on average than in other trees (26.5 ± 4.9 m versus 23.9 ± 6.5 m; Table 1). Although statistically the evidence for differences between these two tree groups was relatively weak (p-values for the between-group differences based on a t-test was 0.05, 0.22 & 0.22 respectively).

There was clear evidence that Woollyneck showed site fidelity in their nesting behaviour, with birds often returning to the same tree and reusing the same nest in consecutive years. Of the 38 nests identified during the study, 27 were still active in 2019, while the others had been destroyed or abandoned. Three of the currently active nests observed in this study were at least ten-years-old, with one of the nesting pairs being first observed using their current nest in 2008. Another pair built a new nest in the same tree after their original nest was depredated (see details in Ghimire et al., 2020).

3.2 Nesting period and breeding success

The timing of breeding appeared to differ between the mid-hills region and the lowlands in Nepal. In the mid-hills, breeding started in December (winter season) and chicks fledged up until June (monsoon) while in the lowlands breeding was observed from March (summer) to November (spring) through the monsoon. In both areas at least part of the nesting period coincided with the heavy monsoon period.

Nesting and fledging success were recorded from 31 nesting attempts from 19 nesting sites between 2016 and 2020. Six out of 31 nesting attempts failed (Table 1), with an estimated nesting success rate of 0.81 ± 0.07 (±SE; from our GLMM modelling). From GLMM estimates from all 31 nests, the mean fledging success was 1.94 ± 0.25 (±SE) chicks per nest, with this increasing to 2.4 per nest when only successful nests were considered; 48% of successful nests fledged 2 chicks, 28% fledged 3 chicks, and 12% each fledged 1 or 4 chicks (Table 1). While the raw data suggested the possibility that nesting and fledging success was higher in the mid-hills versus lowland regions, the GLMM analyses did not find clear evidence of this (p-values for regional differences >0.3).

3.3 Nesting habitat suitability

We obtained good accuracies (AUC=0.919 +/- 0.039 and TSS = 0.733+/- 0.102; Appendix Table S2) for the MaxEnt analysis which predicted that 9.64 % (14,228 sq. kilometers) of the total area in Nepal is potential suitable nesting habitat for Asian Woollyneck (Fig.1b). The variables that were most important in determining the potential for good nesting habitat were areas of gentle slope, cropland, closer to settlements, ~4 mm of precipitation during the driest month and highly forested areas (see Appendix Figs S1-6).

Our model predicts that 72 districts of Nepal (out of 77) have suitable nesting habitat of which Dang has the highest suitable area (9.79 %, 1394 sq. km) followed by Kailali (7.12%,1014 sq.km) while Taplejung, Sankhuwasabha, Solukhumbu, Mustang and Dolpa districts appear largely unsuitable for Woollyneck nesting (Table 2).

3. DISCUSSION

To date there have been no structured studies on nesting habitat preference of Asian Woollyneck except for (Ishtiaq et al., 2004). However, observational notes on single or multiple nest sites have increased since 2010, reflecting an increasing awareness and interest in this species. Asian Woollyneck have previously been found to nest in *Albizia saman, Dalbergia sissoo, Eucalyptus* sp., *Ficus religiosa, Magnifera indica, Mitragyna parviflora, Salmalia malabarica, Bombax ceiba, Tamarindus indica, Artocarpus heterophyllus, Alstonia scholaris, Ceiba pentandra, Ailanthus excelsa, Shorea robusta* (Banerjee, 2017; Choudhary et al., 2013; Ghimire et al., 2020; Greeshma et al., 2018; Ishtiaq et al., 2004; Katuwal et al., 2020; Kularatne & Udagedara, 2017; Roshnath & Greeshma, 2020) . Our study reports three new species preferred as nesting trees which are *Pinus roxburghii*, *Alnus nepalensis,* and *Syzygium cumini.* Based on the overwhelming number of nests in Simal Trees, this suggests a clear nesting preference for this tree, with one explanation for this preference being it offering an advantage of nesting height.

In addition to trees, Asian Woollyneck have been found nesting in artificial structures such as rock cliffs and cell phone towers (Greeshma et al., 2018; Hasan & Ghimire, 2020; Rahmani & Singh, 1996; Vaghela et al., 2015; Vyas & Tomar, 2006). This has been assumed as an adaptation to urbanization and a corresponding lack of suitable nesting trees (Vaghela et al., 2015), although the availability of nesting trees in these areas is not reported. Average nest height is 19 m on cell phone towers (Greeshma et al., 2018; Hasan & Ghimire, 2020; Vaghela et al., 2015) which is less than we observed in the tree-based nests in our study and more similar to nest heights observed in (Ishtiaq et al., 2004). We suggest that nest height is unlikely to be the only factor driving nest-site selection in this species, as substrate and stability might also be important. Nesting on towers is also potentially risky in other ways, including visibility to predators, exposure to wind and rain and disturbance by regular tower maintenance activities (Hasan & Ghimire, 2020). One piece of supporting information here is the nesting period is October to March in mobile towers (Greeshma et al., 2018; Hasan & Ghimire, 2020; Vaghela et al., 2015) possibly to avoid monsoon exposure in these places. Our study observations lie outside protected areas, which could explain the higher average nest heights when compared with (Ishtiaq et al., 2004), as nests in our study areas might be higher to avoid disturbance or because the preserved trees in these regions are biased towards only very large ones. compared to undisturbed habitat within protected area (Ishtiaq et al., 2004). We did not measure the dimension of nests to prevent disturbance to the breeding birds; however, we could see that older nests were relatively larger than new nests due to the accumulation of new nesting materials in each subsequent year.

Our observations of the breeding season of Asian Woollyneck varied as per the geographical regions. Similar variations can be observed around its distribution range: e.g., in northern India, they breed from July to September; in southern India from December to March (Ali & Ripley, 1987; BirdLife International, 2020; Del Hoyo et al., 1992). This variation is similar to variations observed in Nepal viz. Northern Mid-hills and Southern lowlands. This interesting breeding season variation should be further investigated to understand underlying factors responsible for this. Another interesting finding of our study is use of old nests (> 10 years). Site selection and nest building are energy consuming activities (Mainwaring et al., 2014), so storks tend to re-use older nests if not disturbed. Asian Woollyneck also re-uses abandoned nests (eg. Grey heron, (Banerjee, 2017)). When its nest is predated (e.g. (Ghimire et al., 2020), a pair of Asian Woollyneck brood same tree another year making nest in slightly greater height and within abundant cover within same tree. These findings also show that the species prefers nesting in older trees possibly due to lack of suitable nest sites.

Habitat quality influences breeding success (Kostrzewa, 1996) and the relatively high breeding and fledging success in our study (e.g. 1.94 chicks per nest compared to 1.29 chicks for the Lesser adjutant Stork *Leptoptilos javanicus* in Nepal. Karki & Thapa (2013) suggests that these birds have access to good quality habitat. Direct anthropogenic influence to nest sites is low within our study area which can be attributed to conservation awareness activities conducted (Ghimire & Pandey, 2018). However, there are two things that need to be highlighted here. The first is that our measure of nesting and fledging success is likely to be biased high, because nests that fail early are less likely to be reported than those that are successful (simply because of the time available to observe the nesting birds; (Mayfield, 1975)). The second is that even if the high nesting success in these areas reflects good habitat, it is not certain that these critical nesting trees are protected, and may soon be lost through development of a lack of growth of new trees to replace them. Thus there needs to be a focus on the availability of nesting trees, and their long-term viability in future habitat studies of this species. Geomorphology is also known to influence the breeding success through elevation as in White Stork where higher altitude resulted low chick numbers (Fasolă-Mătăsaru et al., 2018). However, such a relationship was not observed in this study.

We extended the observations in out study to look at predicting suitable nesting habitats areas of Asian Woollyneck in Nepal, for the first time. The area of suitable habitat defined by the model is low. This highlights the importance of conserving known breeding sites, until wider-scale surveys can be done and the factors driving population dynamics is better known. Our modelling found gentle slopes as one of the important variables for nesting habitat suitability. However, it is possible that slope is a proxy for the presence of suitable nesting trees, since only gentle slopes tend to support the taller tree species suitable for nesting Asian Woollyneck. Also, in our study, nesting was mostly reported from the mid-hills (28 out of 38), meaning that the model might contain some bias regarding slope as an important factor/variable. This does not necessarily invalidate our findings, but rather opens up the importance of considering geography in the selection of nesting sites by tree nesting birds. We also found precipitation in the driest month as another important variable (i.e., December to March) where breeding of Asian Woollyneck in both mid-hills and lowlands coincides. Precipitation significantly influences the breeding of other storks such as White Stork *Ciconia ciconia* (Kosicki, 2012) and Painted Stork *Mycteria leucocephala* (Tiwary & Urfi, 2016). Because of such precipitation, food availability for waterbirds increases subsequently stimulating breeding events (Kingsford, 2013; Kingsford & Johnson, 1998). Therefore, like Tobółka et al. (2015) indicates, such a finding suggests the climate change might have noteworthy effects on nesting distribution and breeding success of this stork. Agricultural lands are important habitats for Asian Woollyneck (Ghimire et al in press). Our study found cropland as key factor in predicting nesting suitability of Asian Woollyneck. One possible explanation for this is agricultural expansion and wetland shrinkage. Nepal lost 5.41% of its wetland coverage mainly due to expansion of croplands since 1990 (Li et al., 2017; MoFE, 2018b). Croplands are important habitat in such areas and are preferred by Asian Woollyneck for nesting (such as in (Ghimire et al., 2020; Hasan & Ghimire, 2020). Our study found species preferring nesting closer to settlements in highly forested area inferring forest edges to settlements are important. Nesting closer to settlements could be an adaptation and behavioral plasticity by the species in response in land-use change (Ghimire et al., 2021) or reflect the availability of nesting trees. Also, storks are found preferring sites closer to settlements, as they provide easy access for food resources along with reduced pressure from large predators (Schulz, 1998). Since 2010, there are many examples of Woollyneck breeding in cell phone towers closer to human settlements in South Asian countries (Greeshma et al., 2018; Hasan & Ghimire, 2020; Vaghela et al., 2015) . Locations of nests close to wetlands or river valleys provide easy access to feeding ground with abundant food resources (Janiszewski et al., 2014). However, in line with (Ishtiaq et al., 2004), our study also found presence of water around the nesting sites as less important factor comparatively. Stork breeds during monsoon when water is literally present everywhere likely reducing the importance of natural wetlands.

Interestingly, we found that suitable nesting habitat was distributed across 72 districts of Nepal, with some including larger areas and higher proportions than others (Table 2). Nesting suitability for this species appears higher in the west-central part of the country followed by western part, while eastern Nepal appears to be less suitable. This exactly coincides with the general distribution of this species which is lower in the east (Ghimire et al., 2021). The Dang district was predicted to have the highest suitability for the nesting of Asian Woollyneck in Nepal. Dang is an inner terai district comprised of lower tropical to subtropical climate including two valleys i.e., Dang and Deukhuri. However no nests have been observed in this district, but the Asian Woollyneck has been recorded in Deukhuri valley that lies on relatively lower altitude (Khanal et al. in press). There have been no such studies in Dang valley that lies mostly in the upper tropical and subtropical region. Hence, this region could be a potential stronghold habitat for the nesting of Woollynecks and worthy of additional surveys to assess this possibility. There are also other districts with higher potentiality (Table 2) which calls for research and conservation attention. Another interesting finding is nesting suitability being predicted in the Himalayan district i.e., Manang, where occasional observation records of Asian Woollyneck have been reported at 3540 m altitude (which is highest altitude record of species in south-Asia (Ghale & Karmacharya, 2018). Presence of nests at 1500 m altitude supports the arguments that this species makes upward movements in search of nesting habitat (BirdLife International, 2020; Inskipp et al., 2016).

Our study is the most comprehensive examination of nesting in the Asian Woollyneck to date, and highlights a number of key areas that warrant urgent attention if we are to better understand its ecology and distribution in Nepal, and other parts of its distribution range. In particular is its apparent reliance on large nesting trees and their long-term persistence in these areas. Also, is whether surveys like ours, can help highlight new likely distribution and nesting areas that can guide future survey and conservation efforts. Finally, is habitat suitability in higher altitudes and the influence of climatic variables especially precipitation. In this scenario, climate change is likely to impact the breeding success and distribution of this bird and threatening its local and region-wide persistence in some areas. We encourage similar research from other part of its distribution range to help improve upon what we have found in this study.

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CONFLICT OF INTEREST

None declared.

AUTHOR CONTRIBUTION

Prashant Ghimire: Conceptualization (Lead), Data curation(Equal), Funding acquisition(Lead), Investigation(Equal), Methodology(Equal), Project administration(Lead), Resources(Equal), Validation(Equal), Writing-original draft(Lead) **Saroj Panthi:** Data Curation (Equal), Formal analysis(Lead), Methodology (Lead), Software(Lead), Visualization (Equal), Writing-review & editing (Equal) **Krishna Prasad Bhusal:** Conceptualization (Equal), Investigation (Equal), Methodology (Equal), Resources (Equal), Writing-review & editing (Equal) **Matthew Low:** Data Curation (Equal), Formal analysis (Equal), Investigation (Equal), Methodology (Equal), Supervision (Equal), Writing-review & editing (Lead) **Nabin Pandey:** Conceptualization (Equal), Data curation (Equal), Investigation (Equal), Project administration (Equal), Writing-review & editing (Equal) **Rojina Ghimire:** Conceptualization (Equal), Data curation (Equal), Investigation (Equal), Project administration (Equal), Resources (Equal), Writing-original draft (equal) Writing-review(equal) **Bhuwan Singh Bist:** Investigation (Equal), Methodology (Equal) Project administration (Equal) Resources (Equal) Writing-review & editing (Equal) **Sujan Khanal:** Formal analysis (Equal), Methodology (Equal), Resources (Equal) Writing-review & editing (Equal) **Laxman Prasad Poudyal:** Project administration (Equal), Supervision (Equal), Validation (Equal) Writing-review & editing (Equal)

DATA AVAILABILITY STATEMENT

All the data used in these analyses are provided in Table 1. This table have information on nest coordinates used for maxent modelling and nest outcome used for GLLM modelling. This data will be deposited to Dryad Digital Repository after the acceptance of the manuscript.

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Table 1: *Nest descriptions for the 39 nests recorded in this study, including the district the nest was located in and details of the nesting tree. For 19 of these nest sites we also recorded data on the nest breeding outcomes from 2017-2020. Here we were able to record the number of chicks observed fledging from the active nest.*

District	Coordinates		Tree Species	Tree height (m)	Nest height (m)	Dbh (cm)	Breeding outcomes			
	X	Y					2017	2018	2019	2020
Arghakhanchi	28.039686	83.017968	Mango	29	32	110	n/a	3	n/a	n/a
Arghakhanchi	28.031156	83.015616	Simal	36.79	31.74	121	2	0	4	n/a
Arghakhanchi	28.039429	83.030811	Simal	19	15	135	n/a	n/a	n/a	n/a
Arghakhanchi	28.043128	82.986044	Sal	19	15	73	n/a	2	3	n/a
Arghakhanchi	28.009801	83.133945	Simal	32	28	n/a	n/a	n/a	n/a	n/a
Arghakhanchi	27.999547	83.102951	Simal	37	32	n/a	n/a	2	n/a	n/a
Arghakhanchi	27.94687	83.23143	Salla	30	28	n/a	n/a	n/a	n/a	2
Arghakhanchi	27.999544	83.102946	Salla	30	28	n/a	n/a	n/a	n/a	n/a
Arghakhanchi	28.043062	82.986236	Simal	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Pyuthan	28.025041	82.973101	Simal	27	21	121	0	2	3	n/a
Pyuthan	28.132445	82.971057	Simal	24	22	74	n/a	2	0	n/a
Pyuthan	28.13299	82.972358	Simal	30	26	120	n/a	n/a	n/a	n/a
Pyuthan	28.164189	82.971555	Salla	23	16	56	n/a	1	2	n/a
Pyuthan	28.12831	82.97654	Pipal	27	25	n/a	n/a	n/a	n/a	n/a
Pyuthan	28.12831	82.97654	Simal	28	24	n/a	n/a	n/a	n/a	n/a
Pyuthan	28.1365031	82.96737299	Simal	28	22	n/a	n/a	n/a	n/a	n/a
Pyuthan	28.20231037	82.90382461	Simal	34	29	n/a	n/a	n/a	4	n/a
Pyuthan	28.133777	82.969675	Peepal	30	28	200	n/a	n/a	3	n/a
Salyan	28.582016	82.185647	Salla	26	15	58	n/a	1	n/a	n/a
Dhading	27.824892	84.913758	Simal	38	32	125	n/a	2	n/a	n/a
Dhading	27.766146	84.932913	Mango	30	25	120	n/a	n/a	n/a	n/a
Dhading	27.758253	84.937175	Karam	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Dhading	27.750194	85.053078	Simal	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Surkhet	28.533456	82.014388	Kamal	35	33	n/a	n/a	n/a	n/a	n/a
Jajarkot	28.699981	82.22916	Simal	30	26	n/a	n/a	n/a	n/a	n/a
Jajarkot	28.63184	82.186506	Salla	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Kabhrepalanchowk	27.560906	85.538167	Utis	22	18	70	n/a	n/a	4	n/a
Sindupalchowk	27.731508	85.627348	Simal	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Rupandehi	27.47994	83.301442	Simal	40	30	102	2	2	0	n/a
Rupandehi	27.662567	83.273692	Sal	36	32	108	2	0	0	2
Rupandehi	27.662086	83.289474	Sal	25	17	67	n/a	n/a	n/a	3
Rupandehi	27.656491	83.289009	Sal	31	27	78	n/a	n/a	3	n/a
Bardia	28.482138	81.270664	Simal	41	30	120	n/a	n/a	n/a	n/a
Banke	28.270489	81.677072	Simal	34	30	n/a	n/a	n/a	1	n/a
Kailali	28.690287	80.949612	Jamun	25	24	n/a	n/a	n/a	3	n/a
Chitwan	27.6199534	84.4374627	Sal	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Chitwan	27.54866627	84.32489931	Simal	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Kanchanpur	28.84414104	80.32641396	Sal	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Kaski	28.175222	84.083128	Simal	n/a	n/a	n/a	n/a	n/a	n/a	n/a

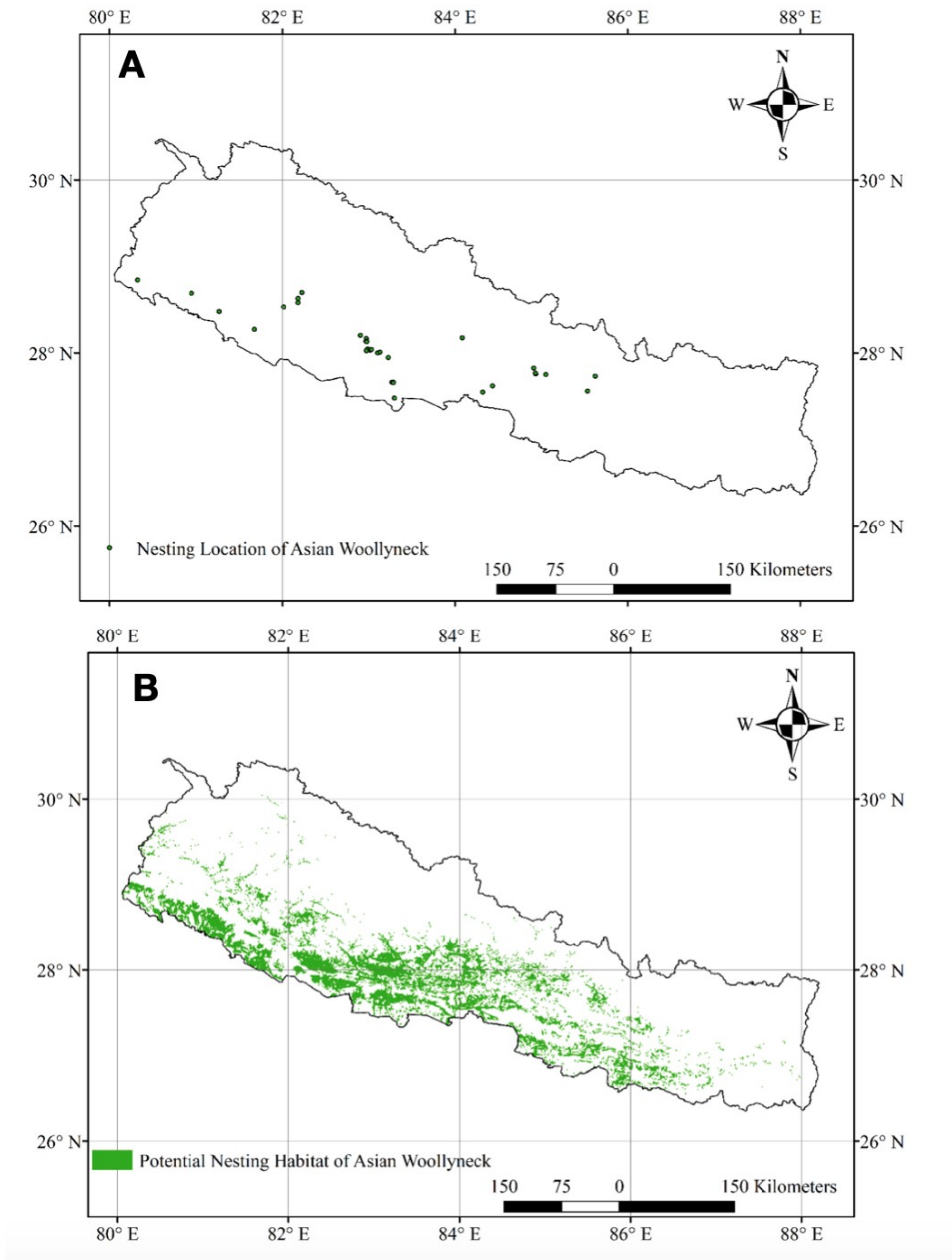

Figure 1: (A)outline of the country of Nepal with the relative locations (points) of all 38 Asian Woollyneck nests recorded in this study. (B) Predictions of potential suitable nesting habitat (green) based on MaxEnt modelling of the habitat characteristics identified from the 38 nests found in the study.

Table 2 District wise potential suitable habitat for nesting of Asian Woollyneck

SN	**DISTRICT**	**Area of District (sq. Km)**	**Suitable Area (sq. Km)**	**% of Suitable Area**	**No. of Nest**
		Total	14228		
1	DANG	3058.25	1394	9.80	
2	KAILALI	3283.66	1014	7.13	1
3	BARDIYA	1999.68	655	4.60	1
4	BANKE	1879.78	634	4.46	1
5	ARGHAKHANCHI	1239.66	628	4.41	9
6	KAPILBASTU	1651.72	627	4.41	
7	GULMI	1108.64	587	4.12	
8	PALPA	1463.73	553	3.89	
9	PYUTHAN	1321.12	481	3.38	9
10	NAWALPARASI_E	1428.52	478	3.36	
11	CHITAWAN	2245.13	461	3.24	2
12	TANAHU	1575.23	439	3.08	
13	KANCHANPUR	1616.90	395	2.78	1
14	SURKHET	2484.43	369	2.59	1
15	RUPANDEHI	1305.68	342	2.40	4
16	KASKI	2088.07	326	2.29	1
17	DHADING	1912.78	280	1.97	4
18	PARSA	1410.63	271	1.91	
19	MAKAWANPUR	2451.90	261	1.83	
20	DHANUSHA	1195.39	250	1.76	
21	SARLAHI	1269.13	246	1.73	
22	SYANGJA	1039.04	245	1.72	
23	SALYAN	1879.48	245	1.72	1
24	MAHOTTARI	1005.87	227	1.59	
25	SIRAHA	1146.60	215	1.51	
26	BAGLUNG	1837.05	209	1.47	
27	BARA	1276.93	189	1.33	
28	NAWALPARASI_W	727.15	166	1.16	
29	GORKHA	3656.46	163	1.15	
30	SINDHULI	2497.61	150	1.05	

31	KABHREPALANCHO K	1400.21	149	1.05	1
32	DAILEKH	1483.32	140	0.99	
33	RAUTAHAT	1042.31	123	0.86	
34	NUWAKOT	1197.43	119	0.84	
35	RUKUM_W	1212.98	112	0.79	
36	JAJARKOT	2221.52	108	0.76	2
37	RAMECHHAP	1573.30	103	0.72	
38	ACHHAM	1699.20	101	0.71	
39	LAMJUNG	1666.38	88	0.62	
40	ROLPA	1885.13	82	0.58	
41	PARBAT	542.27	82	0.57	
42	BAITADI	1491.77	77	0.54	
43	UDAYAPUR	2313.61	68	0.48	
44	SAPTARI	1291.00	52	0.36	
45	SINDHUPALCHOK	2502.84	48	0.33	1
46	DOTI	2049.25	29	0.20	
47	DARCHULA	2693.97	28	0.20	
48	DADELDHURA	1501.33	26	0.18	
49	JUMLA	2553.24	20	0.14	
50	MYAGDI	2287.08	20	0.14	
51	OKHALDHUNGA	1083.13	18	0.13	
52	DHANKUTA	907.00	15	0.10	
53	HUMLA	6005.08	13	0.09	
54	RUKUM_E	1682.37	12	0.09	
55	KATHMANDU	415.16	12	0.08	
56	KALIKOT	1639.00	12	0.08	
57	RASUWA	1506.95	11	0.08	
58	KHOTANG	1601.24	9	0.06	
59	BHOJPUR	1536.38	8	0.06	
60	PANCHTHAR	1260.99	7	0.05	
61	MUGU	3232.75	6	0.05	
62	ILAM	1704.00	5	0.04	
63	TERHATHUM	677.12	4	0.03	
64	MANANG	2325.44	4	0.03	
65	BAJURA	2296.53	4	0.03	
66	BAJHANG	3456.73	4	0.03	
67	SUNSARI	1202.36	3	0.02	
68	LALITPUR	398.32	2	0.02	
69	JHAPA	1621.79	2	0.01	
70	BHAKTAPUR	123.59	2	0.01	
71	DOLAKHA	2159.39	1	0.01	
72	MORANG	1840.08	1	0.00	