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Modeling suitable habitats of Edible-nest Swiftlet (*Aerodramus fuciphagus*) to support ecotourism in karst ecosystem of Karang Bolong, Kebumen, Indonesia

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Abstract. *Wibowo AA, Ningrum FU. 2023. Modeling suitable habitats of Edible-nest Swiftlet (*Aerodramus fuciphagus*) to support ecotourism in karst ecosystem of Karang Bolong, Kebumen, Indonesia. Intl J Trop Drylands 7: 112-119.* The karst ecosystem plays a vital role as a habitat for the Edible-nest Swiftlet (*Aerodramus fuciphagus* (Thunberg, 1812)) (synonym: *Collocalia fuciphaga*) due to the availability of caves for roosting sites. Additionally, factors such as vegetation cover and drought influence the presence of *A. fuciphagus* in karst ecosystems. Karang Bolong in Kebumen, Indonesia is identified as a karst ecosystem inhabited by *A. fuciphagus*. However, there is limited information regarding potential suitable habitats for this species. This study aimed to model the potential habitat for *A. fuciphagus* using Species Distribution Modeling, considering vegetation cover variables represented by NDVI and drought represented by NDMI. The habitat suitability was assessed using the AUC metric, with values ranging from 0.875 to 0.968, indicating a good model fit for depicting potential habitats for the species. In Karang Bolong, the suitability of habitats was constrained by drought conditions. The model suggests suitable habitats are concentrated in caves along the Kebumen Coasts. This information is valuable for identifying areas suitable for ecotourism and providing an alternative to swiftlet nest cultivation/harvesting. Regarding ecotourism activities, birding and observing Edible-nest Swiftlets in their natural coastal habitats, featuring scenic coastal views, could be attractive options to support the tourism industry within the karst ecosystems of Karang Bolong and Kebumen.

Keywords: AUC, avian conservation, NDMI, NDVI, species distribution modeling, sustainability, TSS

Abbreviations: AUC: Area Under the Curve, NDMI: Normalized Difference Moisture Index, NDVI: Normalized Difference Vegetation Index, SDM: Species Distribution Modelling

INTRODUCTION

The *Aerodramus fuciphagus* (Thunberg, 1812) (synonym: *Collocalia fuciphaga*) belongs to the Apodidae, a family predominantly composed of cave-dwelling species. Apodids build their nests within caves using leaves and saliva. The species that use saliva in nest-building adds significant value, as these nests are edible and marketable. Consequently, the nests possess commercial importance and are harvested for sale. The majority of swiftlet species that are targeted for hunting and rearing, particularly for the production of swiftlet nests, are the *A. fuciphagus* (Suriya et al. 2004); *A. fuciphagus* (synonym: *C. fuciphaga*) has a wide distribution in South China and Southeast Asia, including Indonesia. Indonesia is among the world's leading producers of swallow nests, with swiftlet nest cultivation tradition dating back to the 18th century. The nests of the Edible-nest Swiftlet (*A. fuciphagus*) (Sankaran 2001) rank among the most expensive animal products in the world, leading to extensive exploitation of their nests across Asian regions, including India's Andaman and Nicobar Islands. In the Kebumen District, West Java, the caves along the coast serve as a habitat for *A. fuciphagus* (Daud and Hikmah 2021).

Three swallow species are renowned for their consumable nests: the white swiftlet (*A. fuciphagus*), the black swiftlet (*Collocalia maxima* Hume, 1878), and the linchi swiftlet (*Collocalia linchi* Horsfield & F.Moore, 1854) (Amin 2021). Edible-nest Swiflets construct nests entirely from saliva. Black swiftlets create nests in limestone caves on the coast. These nests consist of a mixture of saliva and black feathers, with the predominant presence of feathers giving the nest a black coloration. On the other hand, linchi swiftlets produce nests with mixed saliva and additional materials like pine leaves, twigs, or palm fiber. Hence, it is also known as grass-type nests. Swiftlets primarily feed on insects, with their diets predominantly composed of Hymenoptera, followed by Diptera, Hemiptera, and a small portion of Coleoptera and Isoptera. Among Diptera, *Megaselia scalaris* (Loew, 1866) was the most preferred diet for swiftlets. Carbohydrates serve as the primary energy source for swiftlets, while fats support growth, enzymes aid in nest construction, and tissues contribute to development (Ahmad et al. 2019).

Swiftlets select roosting sites, with caves being the preferred choice. A prior study noted that approximately 2% of the population did not return to the caves, while the majority did. Several variables influenced the preferred roosting sites within the caves, including predators, the breeding cycle, and even the lunar phase (Mane and Manchi 2017).

A crucial habitat for *A. fuciphagus* is the karst ecosystem, known for its numerous caves that swiftlets use for nest-building. In Southeast Asian regions, including Indonesia, karst ecosystems exhibit high species diversity and endemism levels (Clements et al. 2006). Karst formations serve as roosting sites for large aggregations and substantial numbers of swift species (Biancalana 2014). Swifts usually form breeding colonies in wet caves and areas near water sources. Asian karst ecosystems, with their caves, have been identified as one of four regional priorities for conservation research (Kingston 2008; Furey et al. 2010). Indonesia boasts a vast karst area, signifying a great repository for karst biodiversity (Sulistiyowati et al. 2021). Simultaneously, Kebumen is a region endowed with a vast karst ecosystem and holds biodiversity potential, especially for swift species (Muntofingah 2017).

In Central Java, the Ayah Sub-district and Menganti Coast in Kebumen District still have karst ecosystems with caves within their regions (Kholid 2020). Despite most karst ecosystems in Kebumen being located in the northern areas, the southern parts of Ayah Sub-district in the south west in Karang Duwur, and the south-east parts that bordered with Buayan Sub-district in areas known as Karang Bolong are still within karst ecosystems (Laksono 2019).

These caves served as habitats for *A. fuciphagus*, yet information regarding suitable habitats for *A. fuciphagus* within this karst ecosystem remains limited. This study aims to assess and model the suitable habitats of *A. fuciphagus* in this karst ecosystem. The findings of this study can be instrumental in supporting the conservation efforts for *A. fuciphagus* and promoting ecotourism in the Kebumen karst region. The key predictors employed in this study to model suitable habitats for *A. fuciphagus* include forest cover and soil moisture index, recognized as important variables for *A. fuciphagus* by providing natural habitats and a stable water supply.

MATERIALS AND METHODS

Study area

The study focussed on the karst ecosystem in Central Java, Indonesia, specifically the Ayah Sub-district and the Menganti Coast in the Kebumen District (Figure 1) (Afifah et al. 2023). Ayah Sub-district is geographically located at 7°39′36″-7°46′18″ S and 109°23′43″-109°27′27″ E. The topography of the Ayah Sub-district varies in altitude from 0-331 meters above sea level (masl), featuring an extensive coastline spanning 1,785.6 m. The area of Ayah Sub-district is characterized by hilly terrain, and numerous caves have developed within these areas. Notable caves include Karang Bolong Cave (7°45'33"S, 109°27'07"E) in the eastern part bordered with Buayan Sub-district and Siwowo (7°45'30"S 109°23'56"E) and Karang Duwur Caves (7°45'36"S 109°23'53"E) in the western region near Menganti Coast. Ayah Sub-district encompasses a total area of 76.37 km^2, of which 19.62 km^2 was an intact forest. Most of the region retains a stable water supply, including ground and surface water sources. However, a seasonal disparity in spring availability exists, attributed to changes in land use that alter its function. This transformation, coupled with large surface runoff and reduced rainfall, has led to soil water storages.

Procedures

Survey of A. fuciphagus

The survey for *A. fuciphagus* in the Ayah Sub-district, Kebumen, was conducted in August 2023. The survey employed visual encounters, repeated surveys, and random visits as designated procedures. Observations were conducted at various times throughout the day, with direct observations aided by binoculars or unassisted eyes. To align with *A. fuciphagus* activities, the survey spanned from 05.30-7.00 am and resumed from 04.00-06.15 pm.

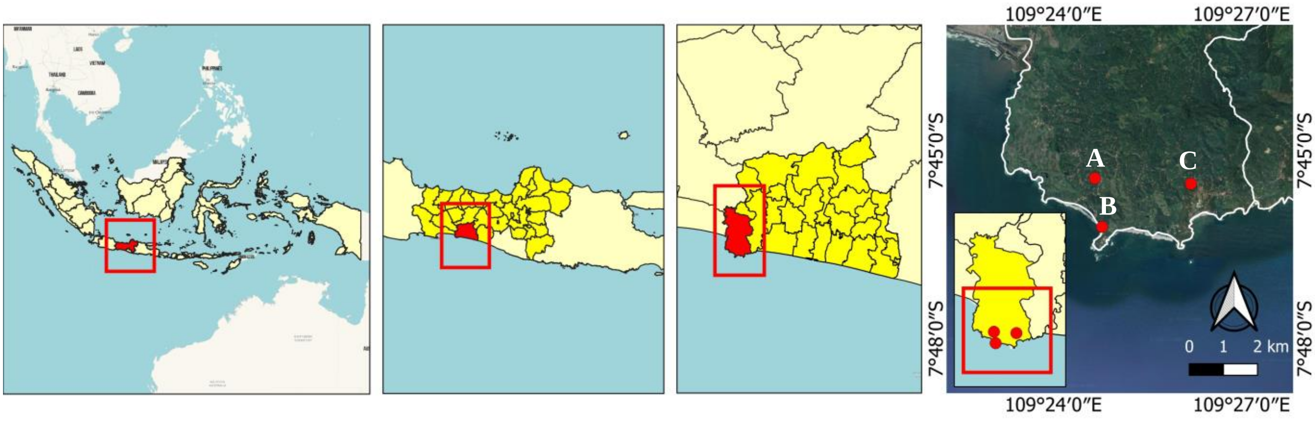

Figure 1. A map of the study area shows stations covering karst ecosystem and cave formation, including Karang Duwur (A) and Siwowo (B) Caves in the Western part of Ayah Sub-district within Menganti Beach, and Karang Bolong Caves (C) in the Eastern part of Ayah Sub-district bordered with Buayan Sub-district, Kebumen District, Central Java Province, Indonesia

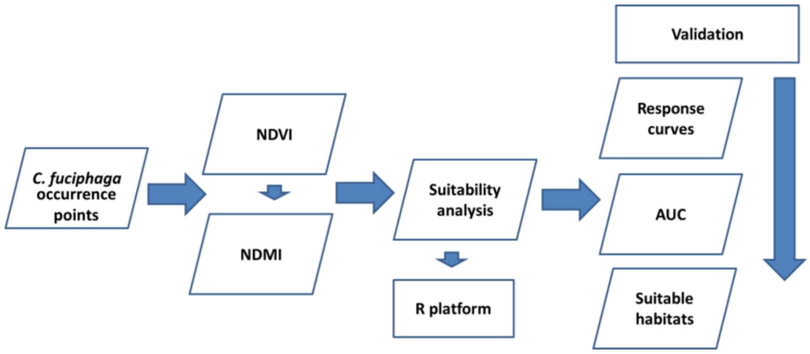

Figure 2. A chart of suitability analysis using the SDM method

The *A. fuciphagus* survey focused on three distinct study areas, each representing karst ecosystem and cave formation that served as roosting sites for *A. fuciphagus*. These locations included Karang Duwur and Siwowo Caves in the western part of the Ayah Sub-district within Menganti Beach and Karang Bolong Caves in the eastern part. Within each cave, three replicated stations were established, totaling nine stations. The swiftlet was identified using a dedicated bird identification book and field guide (MacKinnon and Phillipps 1993). Subsequently, the presence and occurrence point of *A. fuciphagus* were documented and tabulated for Geographical Information System (GIS) mapping purposes.

Suitability analysis

This study employed Species Distribution Modelling (SDM) analysis using R platform version 3.6.3 (Mao et al. 2022) (Figure 2) to generate predicted suitability maps of *A. fuciphagus* along Karang Duwur and Siwowo Caves within Menganti Beach and Karang Bolong Caves. The notable R packages used to generate the suitability maps comprise dismo, sp, maptools, rgdal, raster and so on. (Lemenkova 2020; Bivand 2022; Khan et al. 2022). The covariates for conducting SDM included rasters of forest cover, moisture, and drought variables. These variables were selected due to a linkage of swiftlet distribution with NDVI, forest cover (Ito et al. 2021), and drought (Burhanuddin and Hafidzi 2017). The main principle in SDM is to search for a probability distribution that is most spread out subject to the constraints imposed by the available information on species' occurrence and the associated environmental variables across the study area. SDM uses a deterministic sequential-update algorithm that iteratively picks and adjusts weights of predictors, which is guaranteed to converge to the most spread out probability distribution. SDM employs a probability distribution algorithm that belongs to the family of Gibbs distributions (exponential distributions), where these probability distributions are derived from a set of features $f_1 \ldots f_n$, parameterized by weights $\lambda_1 \ldots \lambda_n$ (Tesfamariam et al. 2022). SDM predicts occurrence rates as a function of the environmental variables at that location. These occurrence rates (P*(z(xi))) take the form as follows (Merow et al. 2013):

$$P^*(z(x_i)) = \exp(z(x_i)\lambda)/\Sigma_i \exp(z(x_i)\lambda)$$

Where: z is a vector of *J* environmental variables at location x_i, and λ is a vector of regression coefficients, with $z(x_i)\ \lambda = z_1(x_i)^*\ \lambda_1 + z_2(x_i)^*\ \lambda_2 + \ldots + z_J(x_i)^*\ \lambda_J$. These occurrence rates sum to unity across the study area because the denominator is a sum of the occurrence rates over all grid cells in the study (called normalization). Normalization ensures that the occurrence rates are, relative.

NDVI and drought (NDMI) variables

The Normalized Difference Vegetation Index (NDVI) of the Ayah Sub-district was measured following the methodologies outlined by Philiani et al. (2016), Kawamuna et al. (2017), and Sukojo and Arindi (2019). NDVI serves as a straightforward graphical indicator utilized to interpret remote sensing data, often derived from space satellite platforms, to determine the presence of live green vegetation within the observed target. The calculation of NDVI involved assessing the wavelengths of a satellite image obtained from the Landsat 8 Operational Land Imager (OLI), specifically capturing images of vegetation such as forest covers. This measurement is feasible due to the cell structure of vegetative leaves, which substantially reflects near-infrared light wavelength ranging from 0.7 to 1.1 microns. The NDVI for each vegetation pixel was calculated as follows:

NDVI = near invisible red wavelength – red wavelength / near invisible red wavelength + red wavelength

The NDVI ranged from 0, indicating no vegetation, to 1, representing high vegetation density. Employing GIS technology, the NDVI values were overlaid and mapped onto the land cover layers of the Ayah Sub-district. After this analysis, the forest covers were systematically categorized and classified based on the NDVI as outlined below:

- if $0 < NDVI < 0.3$, the forest covers < 50%;
- if $0.31 < NDVI < 0.4$, the forest covers are 50-69%;
- if $0.41 < NDVI < 1.0$, the forest covers are 70-100%

Drought variables were assessed by measuring the moisture index, developed utilizing Landsat 8 satellite data, and denoted as Normalized Difference Moisture Index (NDMI). NDMI leverages near-invisible red and short-wavelength infrared bands to display moisture levels. The short-wavelength infrared band captures changes in the spongy mesophyll structure and the vegetation water content within vegetation canopies. Simultaneously, the near-invisible red reflectance is influenced by dry matter content and the internal structure of the leaf rather than by water content. The combination of the near-invisible red and the short wavelength infrared mitigates variations induced by the leaf's dry matter content and internal structure, thereby enhancing the accuracy of assessing the water content of vegetation. Water availability in the internal leaf structure significantly governs spectral reflectance in the short-wavelength infrared segment of the electromagnetic spectrum. Short-wave infrared reflectance demonstrates a negative correlation with leaf water content. Consequently, NDMI proposed by Gao (1996) is a valuable tool for monitoring changes in leaf water content. NDMI is computed using the near-infrared and the short-wave infrared reflectances as follows:

NDMI = near invisible red wavelength – short wavelength infrared/near invisible red wavelength + short wavelength infrared

Model validation

The evaluation of this SDM adheres to the methodologies outlined by Reddy et al. (2015) and Song et al. (2023). Specifically, the model's performance was assessed through Area Under the Curve analysis (AUC). The size of the AUC and the Receiver Operating Characteristic Curve (ROC) were used to assess the accuracy of the SDM model predictions. Higher AUC values correspond to greater accuracy in the model's prediction outcomes, and the selection of SDM model parameters aligns with the methodology proposed by Zhao et al. (2018). The AUC is an efficient and independent threshold index for assessing the model's capacity to differentiate between absences and presences. Performance categories are delineated based on AUC values, with values falling within the range of 0.9 to 1 classified as "great," 0.8 to 0.9 as "good," 0.7 to 0.8 as "reasonable," 0.6 to 0.7 as "poor," and values below 0.6 as "failing" or indicating rare occurrences in real-life scenarios (Shcheglovitova and Anderson 2013). A Jackknife analysis was run to systematically exclude each variable and evaluate the significance of NDVI and NDMI variables in determining the potential distribution of species. The relationship between the potential habitat for the species and the NDVI and NDMI variables factors was determined through the response curve generated by the model (Vilà et al. 2012). The relative contributions, expressed as a percentage, of each environmental variable to the SDM model were calculated and presented in Figure 2. in addition to the AUC values, model validation was conducted using TSS (True Skill Statistics) (De et al. 2020). TSS, as described by Allouche et al. (2006), is expressed as Sensitivity + Specificity – 1 and ranges from −1 to +1. A TSS value of +1 indicates a perfectly performing model with no error, 0 with a totally random error, and -1 with a total error (Marcot 2012; Ruete and Leynaud 2015).

RESULTS AND DISCUSSION

NDVI

Figure 3 depicts the NDVI variable in Ayah Sub-district. Dense forest cover extends from Karang Duwur Cave and Menganti Coast in the west to Karang Bolong Cave in the east, indicating the presence of forest cover within the karst ecosystems in the Ayah Sub-district. The NDVI values in this karst area were close to 1, signifying a high vegetation density. Conversely, in the Northern part of the region, the karst ecosystem exhibits declining NDVI values. The NDVI was lower in the North, with values less than 0.5 and approaching 0. This suggests that the forest cover in the northern karst ecosystem has been subject to logging. In these Northern areas, the forest has been converted into settlements indicating land use changes in the form of deforestation and urbanization.

NDMI

Figure 4 depicts the NDMI variable in Ayah Sub-district. Most areas are characterized by wet conditions, corresponding to the prevalent forest cover. However, certain regions were experiencing drought. Similar to NDVI patterns, the northern parts of Ayah Sub-district, characterized by lower NDVI values, also exhibit low NDMI values close to 0. Interestingly, the coastal areas extending from Karang Duwur Cave and Menganti Coast in the West to Karang Bolong Cave in the East display low NDMI values despite having high NDVI values and forest cover. This suggests that the karst ecosystems in the Ayah Sub-district have patchy areas with low NDMI values, indicative of lower moisture content, despite having high NDVI values and forest covers. The observed low NDMI values in the cave's proximity signify the presence of karst formations within the ecosystems.

Model validation

Table 1 depicts the results of SDM model validations, assessing the performance based on the AUC and TSS values. The SDM models were constructed using the NDVI and NDMI variables. In the case of NDVI, the model achieved an AUC of 0.968 and came under 'great' model category (Figure 5) and had no error with a TSS value of 0.749. Similarly, the AUC value for NDMI was 0.875 and 0.999 for TSS.

Table 1. AUC and TSS values for NDVI and NDMI variables

Variables	AUC	TSS
NDVI	0.968	0.749
NDMI	0.875	0.999

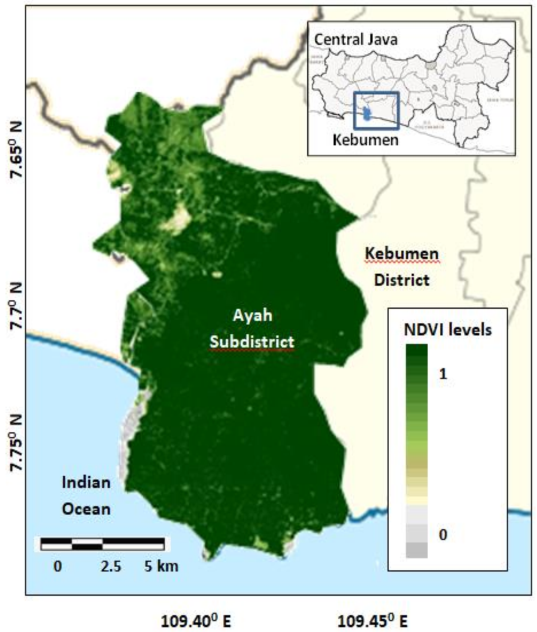

Figure 3. A map of NDVI variable of Ayah Sub-district, Kebumen District, Central Java Province, Indonesia

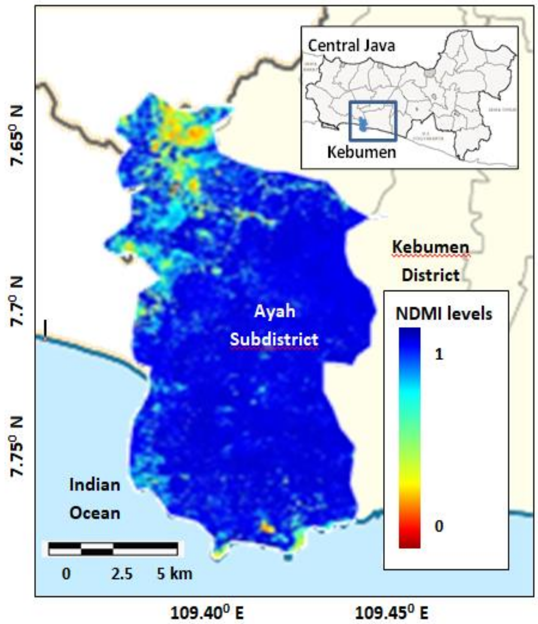

Figure 4. A map of NDMI variable of Ayah Sub-district, Kebumen District, Central Java Province, Indonesia

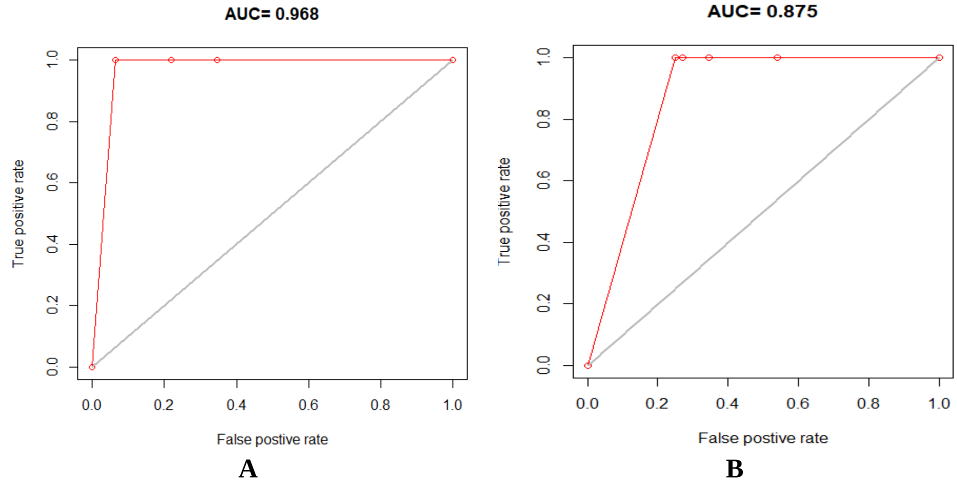

Figure 5. AUCROC values for A. NDVI (0.968) and B. NDMI (0.875) variables

Suitable habitat models

The SDM models for *A. fuciphagus* in Ayah Sub-district, Kebumen District, Central Java Province, Indonesia, are visually represented in Figure 6, highlighting projections based on NDVI and NDMI variables. When utilizing NDVI as a covariate, the model suggests that suitable habitats for *A. fuciphagus* are projected to be available across all areas of the Ayah Sub-district, including regions where the caves are uncommon. Conversely, the NDMI model indicates that suitable habitats for *A. fuciphagus* are more confined, with central parts of the Ayah Sub-district being deemed unsuitable. The middle region exhibits lower moisture levels, limiting the potential distribution of *A. fuciphagus*. In contrast, the models project that coastal areas are the most suitable habitats, with areas categorized as highly to very highly suitable predominantly concentrated in these coastal areas. These areas cover caves and beaches, contributing to their high suitability for *A. fuciphagus*.

Response curves

The correlations of the NDVI and NDMI variables with suitability levels are depicted in the response curves (Figure 7). The threshold for suitability levels was set at 0.6, designating habitats as moderately suitable. For NDVI, habitats were deemed suitable at suitability levels 0.6 when NDVI values exceeded 0.5. In the case of NDMI, suitable habitats were identified by NDMI values surpassing 0.2.

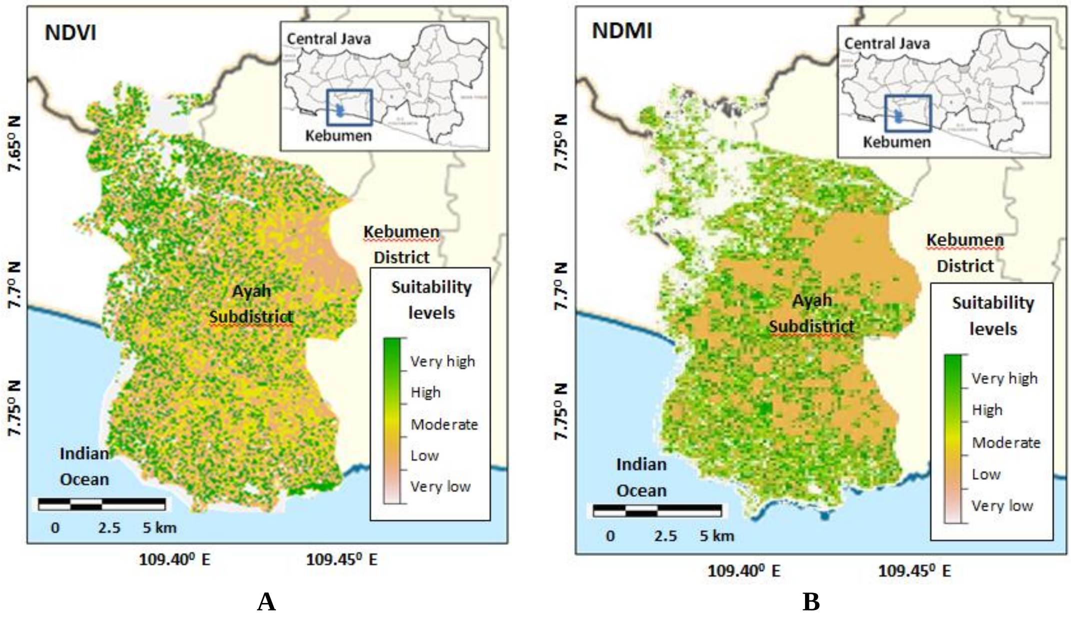

Figure 6. SDM models for suitable habitats *Aerodramus fuciphagus* in Ayah Sub-district, Kebumen District, Central Java Province, Indonesia for A. NDVI and B. NDMI variables

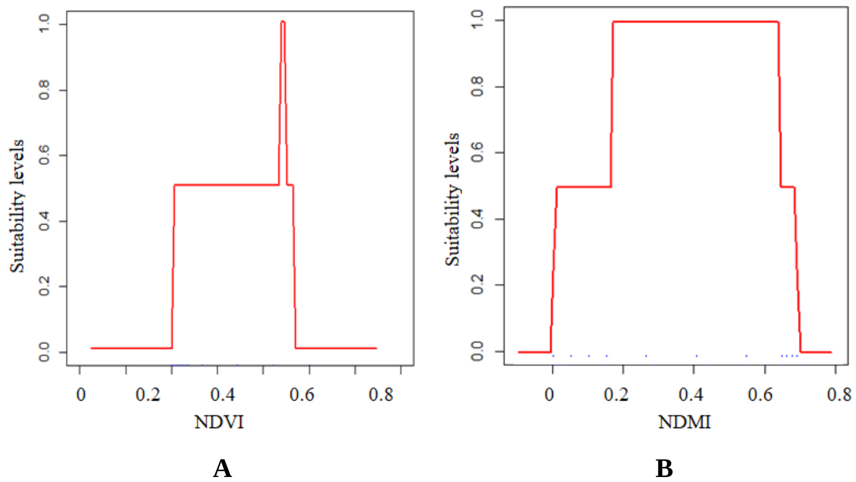

Figure 7. Response curves for suitable habitats of *Aerodramus fuciphagus* for A. NDVI and B. NDMI variables in Ayah Sub-district, Kebumen District, Central Java Province, Indonesia. The suitability level means are 0.5 both for NDVI and NDMI

Discussion

This study presents the first assessment of suitability levels for *A. fuciphagus* within the karst ecosystem using NDVI and NDMI values. Previous spatial studies on swiftlets, such as those by Margareta and Abdullah (2010) and Ayuti (2016), were limited to urban scales and omitted the forest cover or drought-related variables like NDVI and NDMI, respectively. Notably, the high NDVI values across the study areas indicated that these regions were generally suitable for *A. fuciphagus*. Conversely, lower suitability was observed in areas with low NDMI, suggesting reduced moisture or potential drought conditions. The relationship between NDVI and *A. fuciphagus* presence is indirect, where high NDVI indicates ample vegetation cover that attracts insects, a primary diet for *A. fuciphagus* (Ambrosini et al. 2011; Mursidah et al. 2021). The lush vegetation in Karang Bolong's karst ecosystems draws aerial insects, making these expansive areas suitable for *A. fuciphagus* due to their high NDVI values.

NDMI values, indicative of moisture levels, are crucial in determining swiftlet occurrence. The *A. fuciphagus*, known for constructing nests primarily from saliva, prefers habitats with higher moisture indexes. The absence of *A. fuciphagus* in regions with lower NDMI suggests their affinity to moist habitats, as reflected in their nest-building behavior. Surrounding ecosystems significantly influence nest type and avifauna (Briggs and Deeming 2021). Moreover, moisture conditions indirectly impact swiftlets by affecting insect presence; drought conditions can reduce insect populations, thereby affecting swiftlet presence (Frank 2021). Karst ecosystems, including those in Kebumen, are prone to droughts due to their low water retention capacity due to exposed rocks and shallow soils that influence soil water distribution (Luo et al. 2022; Mo et al. 2023). Some coastal areas, despite exhibiting lower moisture, remained favorable for *A. fuciphagus* due to their high NDVI values and the presence of numerous caves, such as Karang Duwur and Siwowo Caves in the West and Karang Bolong in the East, which is inhabited by the swiftlets.

The SDM indicates extensive suitable habitats for swiftlets across the region, encompassing areas far inland from the coasts and distant from known roosting sites, consistent with the findings of Petkliang et al. (2017), which that the foraging distances of Germain's swiftlet are 25 km from its breeding sites. In India's Andaman Islands, India, the edible-nest swiftlet *A. fuciphagus inexpectatus* exhibits foraging behaviors up to 1-2 km from breeding sites, favoring forested areas over open land.

While keeping and rearing swiftlets for their nests persists (Benjakul and Chantakun 2022), this unsustainable activity contributes to population decline and poses an extinction threat. An alternative industry, such as ecotourism, capitalizing on the region's valuable geological features, including caves, has potential in Kebumen. Bird watching of swiftlets, an ecotourism attraction, could be developed by combining cave exploration with observing swiftlet roosting (Fullard et al. 2010).

In conclusion, the study identifies the karst ecosystem, particularly the vegetation-rich Karang Bolong, as conducive to *A. fuciphagus* breeding and ecotourism. The proposed alternative bird watching industry, intertwined with cave exploration and coastal scenery, holds promise for sustainable ecosystem activities supporting swiftlet conservation.

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