The Jahangirnagar Review: Part II: Social Science, Vol. 48, No. 1, 2024
ISSN 1682-7422

Predicting the Potential Distribution of *Apis Dorsata* Using MaxEnt Model in Sundarbans, Bangladesh

Tanjinul Hoque Mollah[1]
Md. Raysul Islam Jony[2]
Monalisha Ferdous[3]
Md. Masuk Mowla Aunkur[4]
Atia Ibnat[5]

Abstract: The Sundarbans, the largest single tract of mangrove forest in the world, is famous for its economically and ecologically important flora and fauna. The Sundarbans of Bangladesh is the main natural home of the giant honeybee, Apis dorsata, commonly known as the *giant honeybee*. However, this iconic pollinator species faces mounting threats. This study aims to predict the potential distribution of *Apis dorsata* within the Sundarbans region. To fulfil the aim, comprehensive data on climatic variables, relevant environmental factors and chronological distribution of *Apis dorsata*, were collected and analyzed. Using species distribution modeling techniques, the current and potential habitats of *Apis dorsata* were mapped. Besides that, potential changes in the species distribution were evaluated using environmental variables such as temperature, rainfall, evapotranspiration, and soil nutrients such as nitrogen, potassium, phosphorus and soil pH. Anthropogenic factors such as deforestation and land use changes were considered in the analysis to account for human-induced effects on the ecosystem. For this study 285 questionnaires, 5 FGDs and 3 KII were conducted randomly with a 95% confidence level and 5% error margin. The result indicates that climatic conditions are likely to exert a considerable influence on the distribution of *Apis dorsata* in the Sundarbans region. This model predicts a shift in suitable habitat zones, potentially leading to both range expansions and contractions. Besides that, this study emphasizes the urgency of implementing adaptive management strategies to conserve *Apis dorsata* and its habitat in the face of environmental changes. Conservation efforts should focus on preserving and restoring critical habitats, adopting sustainable land use practices, and mitigating greenhouse gas emissions. Furthermore, engaging local communities in conservation initiatives is essential to ensure the successful protection of this ecologically valuable species and its associated ecosystem services.

Keywords: *Apis dorsata*, Distribution, MaxEnt model, Sundarbans, Bangladesh.

---

1 Professor, Department of Geography and Environment, Jahangirnagar University, Savar, Dhaka-1342 Bangladesh, thmollah@juniv.edu

2 Research Student, Department of Geography and Environment, Jahangirnagar University, Savar Dhaka-1342, Bangladesh.

3 Research Student, Department of Geography and Environment, Jahangirnagar University, Savar Dhaka-1342, Bangladesh.

4 Research Student, Department of Geography and Environment, Jahangirnagar University, Savar Dhaka-1342, Bangladesh.

5 Research Student, Department of Geography and Environment, Jahangirnagar University, Savar Dhaka-1342, Bangladesh.

1.0 Introduction

The Sundarbans represents a distinctive ecological system situated within the deltaic expanse of the Ganges, Brahmaputra, and Meghna rivers in the country of Bangladesh. The mangrove forest under consideration is the largest in the world, harboring a wide range of plant and animal species. The honey hunters, known as *Mowallis*, residing in the southwestern region of Bangladesh, rely entirely on the economic sustenance derived from the collecting of honey in the Sundarbans. A significant number of *Apis* colonies are evenly scattered throughout the Sundarbans region. Environmental changes have a negative impact on several elements, including rising temperatures, prolonged periods of drought, increased flood occurrences, and enhanced extreme climatic events. These variables all contribute to the alteration and reduction in the distribution patterns of *Apis* species (Murshed et al., 2022).

Bees are often recognized as the most significant insect species on the planet (Iwasaki and Hogendoorn, 2021). This little insect is responsible for sustaining seventy percent of global agriculture. *Apis dorsata*, commonly referred to as the giant honeybee, is a significant species inhabiting the Sundarbans region, where it fulfils a vital ecological function by facilitating the pollination of various plants and trees. Honey bees, known by their scientific name "*Apis*," hold significant commercial importance. They generate a substantial quantity of honey and wax (Mitra et al., 2013).

The honey bee, an essential pollinator of both cultivated crops and natural flora, is a species of significant concern in relation to the impacts of environmental change (Erwin, 2009). The Sundarbans region in Bangladesh harbours the endangered species *Apis dorsata*, and it is anticipated that environmental change would exert a notable influence on the species distribution and population size (Reddy et al., 2012). The current environmental change dilemma has led to an increased focus on the influence of large-scale environmental patterns on the distribution of *Apis dorsata* (Ruttner, 2013).

Sundarbans is currently experiencing rising sea levels, rising temperatures, and shifting rainfall patterns. These environmental changes are anticipated to exert a substantial influence on the geographical dispersion of *Apis dorsata* and other species (Ortolano et al., 2017). Its habitat loss has major consequences for the ecosystem and neighboring populations that rely on the honey bee for pollination and honey production as environmental variables changes. To successfully address this issue, it is essential to understand the potential effects of environmental factors on the geographical distribution of *Apis dorsata* inside the Sundarbans (Karthik, 2021). Thus, this study aims to predict the potential distribution of *Apis dorsata* within the Sundarbans region of Bangladesh. Therefore, this research has major two key goals. These are (1) map the current and potential distribution of *Apis dorsata*; and (2) identify the probable impact of environmental change on *Apis dorsata*.

2.0 Methodology

2.1 Selection of the study area

The Sundarbans, a UNESCO World Heritage Site, is unique to many species despite being vulnerable to storms and rough seas (Mahadevia Ghimire and Vikash, 2012). It runs from southwestern Bangladesh to eastern India at 21°30'N to 22°30'N latitude and 88°05'E to 89°55'E longitude. In Bangladesh's Khulna and Barisal Divisions, it affects districts including Khulna, Bagerhat, and Satkhira. This unusual terrain is bordered by rivers and water bodies in the north and mangrove islands in the south along the Bay of Bengal. The western boundary is marked by the Khulna Division, and the eastern boundary meets India's in West Bengal. The Sundarbans' dynamic waterways, mudflats, and mangrove islands demonstrate its remarkable environment (Board, 2021). The giant honeybee, *Apis dorsata*, important species of Sundarbans is focused due to its fascinating biology and ecological value.

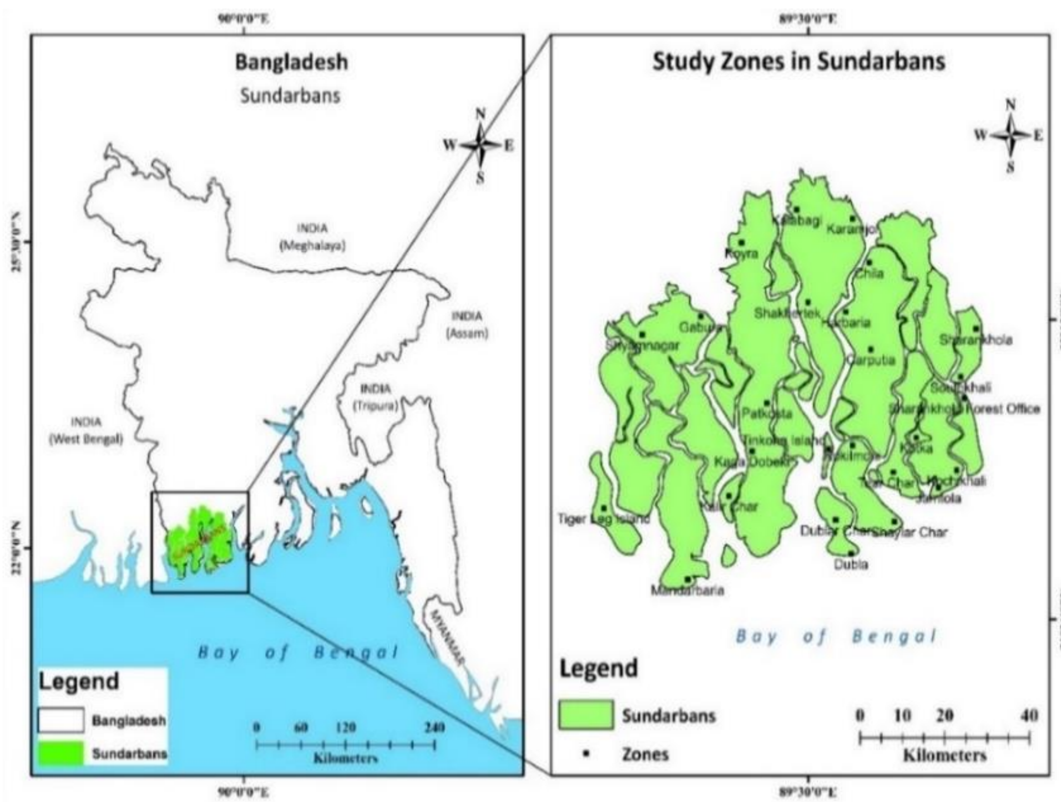

Figure 1: Sundarbans, Bangladesh (Data collection zone also included)

Source: Compiled by Authors, 2023

2.2 Sources of Data

Primary data are those that are gathered straight from the field through questionnaire surveys, focus group discussions, and KIIs—without the use of any intermediary sources. Usually, it is gathered expressly for a study and disseminated for use in additional research studies. Primary data is usually trustworthy, real, and unbiased as long as it was gathered to solve a particular study issue (El-Shimi, 2012).

a. Selection of local respondents: There are 285 questionnaires and 5 FGDs (each group consists 7 to 8 respondents whereas male was 4 to 5 and female was 2 to 3), were conducted randomly with a 95% confidence level and 5% error margin.

b. KII: 3 Key Informant Interviews (KIIs) were also conducted for data collection from the local communities and the Bangladesh Institute of Development Studies (BIDS).

c. Data collection: The primary information's such as age, sex, education, experience, seasonal variation in collecting honey, information's about *Apis dorsata* were collected from the respondents.

An extensive understanding of the study objectives is provided through the variety of secondary data sources that support this research. High-resolution satellite imagery reveals the changing topography over time, while Google Earth insights improve mapping accuracy. The CRU's environmental data, which includes rainfall, temperature, and evapotranspiration, shed light on the region's climatic patterns. Elevation data comes from USGS data. SoilGrids250m data sources provide important soil properties such as pH levels and nitrogen content, which are critical for determining soil quality and fertility. Furthermore, relevant information obtained from various publications, articles, and journals adds potassium and phosphorus levels to the dataset. This collection of data sources provides a solid foundation for performing an in- depth assessment.

The flow chart below depicts different categories of data used in the study-

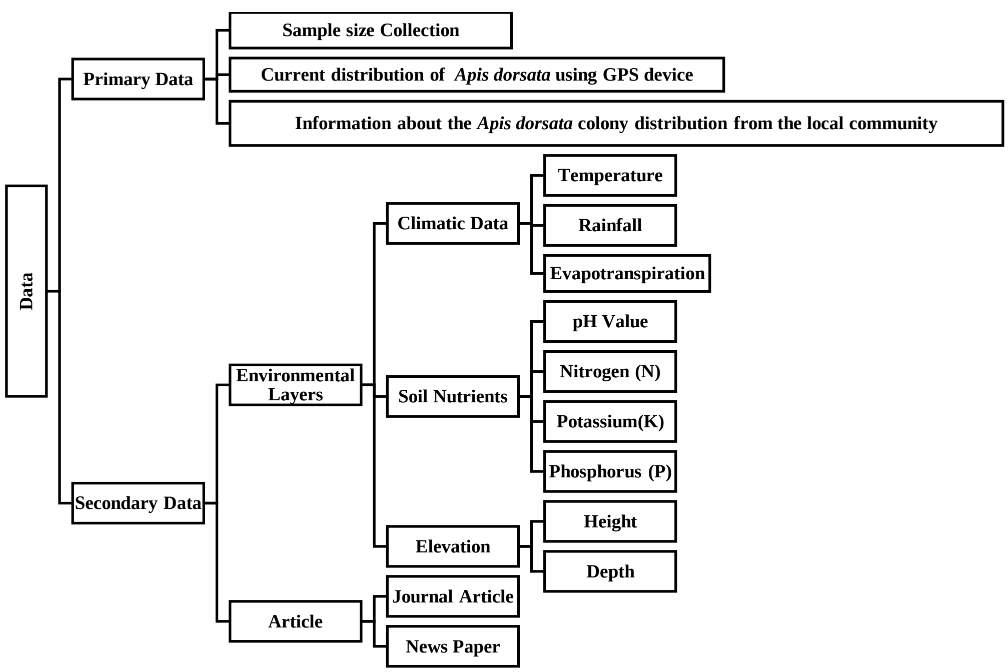

Figure 2: Data types used in the study

Source: Compiled by Authors, 2023

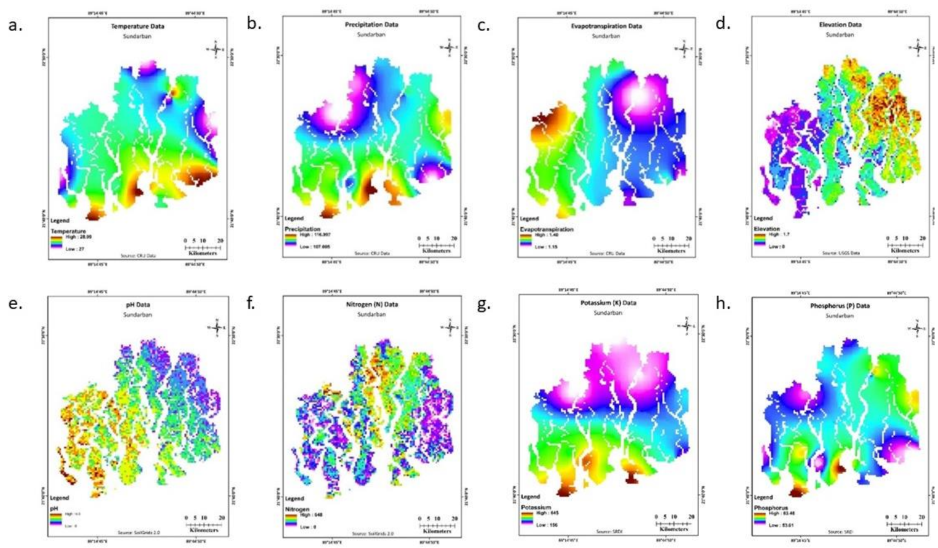

Figure 3: a. Temperature Data, b. Precipitation Data, c. Evapotranspiration Data, d. Elevation Data, e. pH Data, f. Nitrogen (N) data, g. Potassium (K) data, h. Phosphorus (P) data.

Source: Compiled by authors, 2023

A planned and efficient research process is ensured by the flow chart provided below, which details a systematic way to doing the study from topic selection to final output.

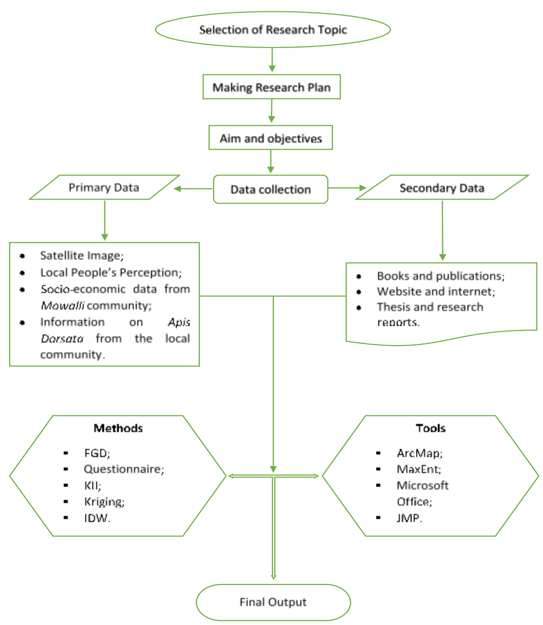

Figure 4: Methodological framework which includes data collection, methods and tools.

Source: Compiled by the Authors, 2023

2.3 Data Processing and Analysis

Primary and secondary data are collected from distinct sources and separately analyzed. The MS-Excel has been utilized to analyze the primary data. Data layers was analyzed using ArcGIS 10.8. MaxEnt Model was utilized to determine the potential distribution area for *Apis dorsata* within the study area. In addition, quantitative and qualitative data were analyzed using SPSS and Unscrambler X.

Data verification and validation were conducted using kappa statistics in this study. Google Earth Pro was cross-validated using reference data ground control point. The samples were utilized to calculate the accuracy. The producer, user, overall, and Kappa coefficients were calculated using the error matrix table. Producer accuracy is calculated by dividing the number of accurate pixels in one class by the total number of pixels generated from reference data; user accuracy is calculated by dividing correctly classified pixels by the total number of pixels.

The formula of Cohen's kappa coefficient:

$$K = \frac{PO - Pe}{1 - Pe}$$

Where,

K= Kappa Coefficient;

PO= relative observed agreement among raters;

Pe= the hypothetical probability of chance agreement.

3.0 Results and discussions

3.1 Impact of environmental elements

Honeybees are sensitive to environmental changes, including weather patterns (Cunningham et al, 2022). The distribution of *Apis dorsata* within the Sundarbans region of Bangladesh is influenced by a variety of environmental elements, which consequently helps or disturbs the Bee colonies and honey production (Vyas, 2012). Which are: Rainfall, Temperature, Humidity and Elevation.

These elements individually and collectively determine the distribution of bee colonies in any region. Firstly, rainfall has a significant impact on the distribution and behavior of *Apis dorsata*. Sufficient amount of rainfall is beneficial for *Apis dorsata* by providing a greater abundance of nectar and pollen sources (Ali et al., 2017). Besides that, rainfall leads to increase flowering of plants, which means more food resources for the bees (Abou-Shaara and Hossam, 2016). On the other hand, excessive rainfall and flooding might displace or destroy colonies, impacting their distribution (Woyke et al., 2008). 2,754.74 mm of yearly precipitation is the amount that *Apis dorsata* requires. The wettest month's ideal rainfall for *Apis dorsata* is 1,553.60 mm. And the warmest month's rainfall is 896.11mm (Atlas, 2021). If there are long-term changes in rainfall patterns due to environmental change, it could lead to shifts in the distribution of ecosystems, affecting the habitats available to *Apis dorsata* (Environmental Change Widespread, Rapid, and Intensifying – IPCC — IPCC, 2021).

Secondly, temperature is also a critical environmental factor that have a significant impact on the distribution and behavior of *Apis dorsata*. *Apis dorsata* have specific thermal tolerance ranges, meaning they can only survive within certain temperature limits. Extremely high or low temperatures stresses or even kill the bees. Moreover, temperature influences the choice of nesting sites for *Apis dorsata* (Buchwald et al., 2008). They prefer nesting sites that provide optimal temperature condition for colony development, to regulate the internal conditions of the nest and to ensuring the survival of brood and adults. Temperature influences the timing of mating flights and the success of reproduction within the colonies (Abou-Shaara et al., 2012). The most suitable seasonal temperature for *Apis dorsata* is 19.83°C and the most suitable mean temperature of coldest quarter for *Apis dorsata* is 24.15°C (Atlas, 2021). Long-term changes in temperature due to environmental change can significantly impact the distribution of species like *Apis dorsata*. If the temperature shifts beyond the bee's tolerance range, it could force them to migrate to more suitable areas or result in local extinctions (Atlas, 2021).

Thirdly, humidity levels play a role in the construction and maintenance of nests by *Apis dorsata*. Proper humidity helps to maintain the structural integrity of the nest and prevent it from drying out or becoming too moist. Humidity is crucial for the development of bee brood (eggs, larvae, and pupae) (Ellis, 2008). Therefore, maintaining the right humidity is crucial for regulating temperature and creating a suitable environment for the brood and adults (Moniruzzaman et al., 2013). Average maximum humidity of Sundarbans is recorded 80% in the month of September and 35% in the month of March (Atlas, 2021).

Finally, elevation in the Sundarbans of Bangladesh subtly influences the distribution of *Apis dorsata*. In this coastal mangrove ecosystem, elevation affects nesting site choices, environmental variations, resource availability, flooding risks, and microenvironments. Bees seek areas with optimal conditions for nest building, foraging, and colony protection (Nassir et al., 2022).

The distribution of *Apis dorsata,* in the Sundarbans of Bangladesh is influenced by the types of trees present in the ecosystem. These trees provide nesting sites, food resources, production of honey and overall habitat for the bees (Nishat and Chowdhury, 2019). Bees prefer to establish their colony and collect honey from short distances. The availability and distribution of these trees influence the production of honey (Akter et al., 2020). While the Sundarbans is primarily dominated by mangrove trees, here are some tree species namely Khalisha, Keora, Gewa, and Bain that affects the distribution of *Apis dorsata*.

The growth of these tress depends on some basic soil nutrients such as pH (Soil pH), N (Nitrogen), K (Potassium), and P (Phosphorus) (Ren et al., 2023). The acidity or alkalinity of soils is determined by the pH of the soil. Neutral pH is 7.0 on the pH scale. Above 7.0 is basic or alkaline, and below 7.0 is acidic. Plant growth nutrients are influenced by the pH of the soil. While calcium, phosphorus, and magnesium are less accessible to plants in very acidic soil, manganese and aluminum became more available and poisonous to plants. Phosphorus and the majority of micronutrients become less accessible in very alkaline soil (Williams et al., 1971).

Table 1. Required Soil pH for Plant Growth

Soil pH	Plant Growth
> 8.3	Too Alkaline for most Plants
7.5	Iron availability becomes a problem on alkaline soils
7.2	6.8 to 7.2 – near neutral 6.0 to 7.5 acceptable for most plants
7.0	
6.8	
6.0	
5.5	Reduced soil microbial activity
< 4.6	Too acid for most plants

Source: Compiled by the Authors, 2023

There wouldn't be life as we know it without nitrogen. To ensure maximum yields, crops require nitrogen. Because it is a key component of chlorophyll, which is the substance that allows plants to use solar energy to convert carbon dioxide and water into sugars, Nitrogen (N) is extremely important. This process is known as photosynthesis (Muñoz-Huerta, 2013). It also constitutes a sizable portion of amino acids, which are the building blocks of proteins. Compounds that transport energy, such adenosine triphosphate (ATP), include nitrogen. Lastly, nucleic acids, like DNA, which include nitrogen, are essential for the growth and reproduction of cells and eventually whole plants. There are three main kinds of nitrogen found in soil: nitrate ($NO3_3^+$) ions, ammonium (NH_4^+) ions, and organic nitrogen molecules (Buchler et al., 1992).

The most prevalent inorganic cation is potassium (K), which is necessary for healthy plant development (White and Karley, 2010). Numerous crucial enzymes, including those involved in protein synthesis, sugar transport, N and C metabolism, and photosynthesis, are activated by K. It is crucial to the development of improved production and quality (Marschner, 2012; Oosterhuis et al., 2014). An essential part of ATP, or plant "energy unit," is phosphorus (P) (Mitran, 2018). With phosphorus in its structure, ATP is created during photosynthesis and is used in activities ranging from seedling development through grain formation and maturity (Malhotra, 2018). Phosphorus is therefore necessary for all plants to be healthy and powerful in general. Stimulated root development, improved flower formation and seed production, improvements in crop quality, increased resistance to plant diseases, development throughout entire life cycle are some particular growth factors that have been linked to phosphorus (Yudaniayanti et al., 2018).

3.2 Potential distribution of *Apis dorsata*

The MaxEnt Model is used for measuring the potential distribution of *Apis dorsata* in this study. It shows a higher value of 0.92 and a lower value of 0.09 which indicate the high potential area to low potential area. The potential area also shows that the distribution of *Apis dorsata* is dense between the habitable area and the coastal area. Because it indicates the deep forest area where anthropogenic disturbance is relatively lower than the other part.

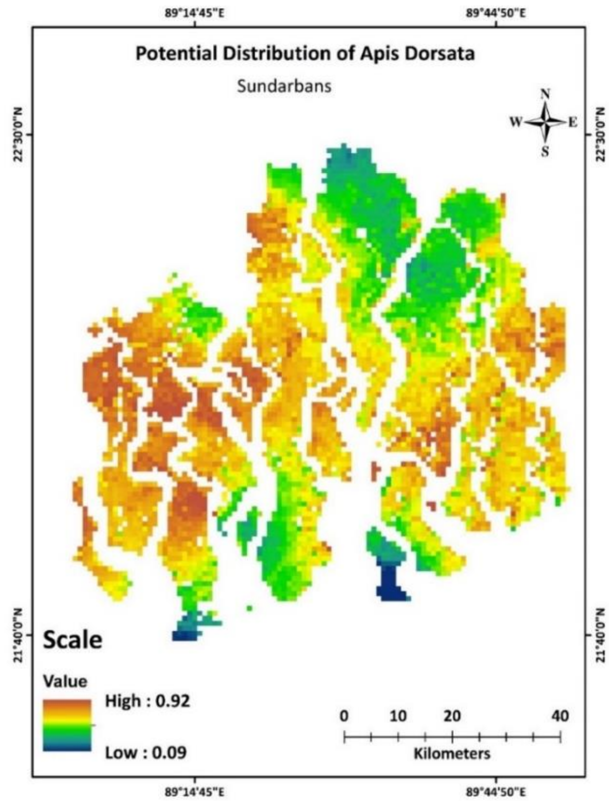

Figure 5: Potential Distribution Map for *Apis dorsata*, 2023 using MaxEnt model of the Sundarbans, Bangladesh.

Source: Compiled by the Authors using MaxEnt model, 2023

Table 2. Potential area of *Apis dorsata in Sundarbans mangrove ecosystem, Bangladesh*

Class Name	Area (Ha)	Percentage
Very High	18,600.65	5.22%
High	69,224.42	19.42%
Moderate	89,244.13	25.04%
Low	115,991.9	32.54%
Very Low	63,347.63	17.77%

Source: Compiled by the authors using MaxEnt model, 2023

The table 2 illustrates the projected potential distribution area of *Apis dorsata* (Honey Bee) in the Sundarbans region of Bangladesh. The distribution is categorized into five classes: "Very High," covering 5.22% of the total area; "High," encompassing 19.42%; "Moderate," accounting for 25.04%; "Low," constituting 32.54%; and "Very Low," representing 17.77%. These classes indicate the varying degrees of suitability for the species across the region, offering insights into the potential impacts of environmental and anthropogenic factors on its distribution.

3.3 Response Curves

The MaxEnt model is used to find response curves. The variables impacting the distribution of temperature, precipitation, humidity, and elevation in this context are evaluated in figure 6. In the distribution of *Apis dorsata*, Temperature responses from 27-28.9 (°C), Rainfall responses from 107-116.9 (mm), Elevation responses from 0-17 (m) and evapotranspiration responses between 115 -119.9 (mm).

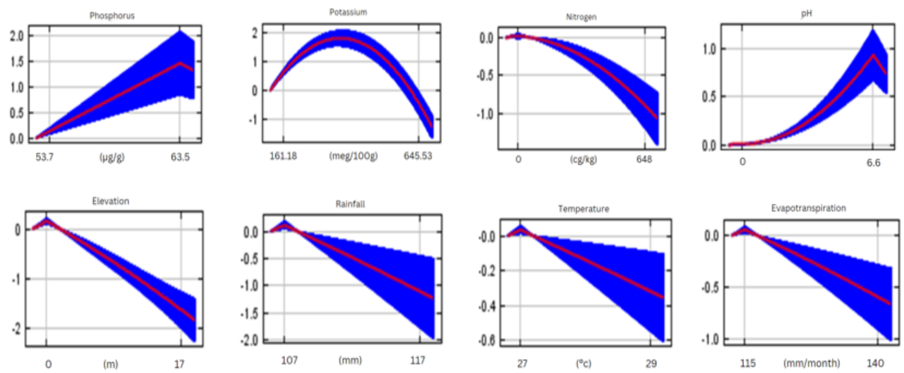

Figure 6: Response curves of Environmental layers and Soil Nutrients

Source: Compiled by the authors using MaxEnt model, 2023

Figure 6 shows the response curves of pH, N, K, and P, whereas pH responses between 0-66, Nitrogen responses in the range of 0-648, Potassium responses between 161.2-645.5 and Phosphorus responses between 53.7 -63.5.

3.4 Jackknife Curve

Jackknife curve shows the regularized training gain for *Apis dorsata*. Here the curves show individual response of the variables. Result shows for with all variables, with only variable and without variable. Here, Potassium shows the most response with only variables and temperature shows the less response with only variable.

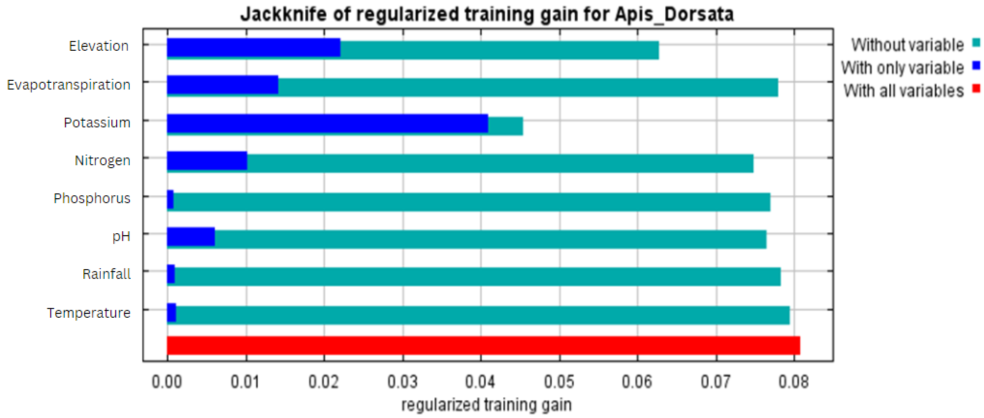

Figure 7: Jackknife test of the selected environmental layers using MaxEnt model, 2023
Source: Compiled by the Authors using MaxEnt model, 2023

3.5 Contribution Table

Table 3 shows the contribution of individual layers for distribution of *Apis dorsata*. Whereas Potassium has the most response and temperature, phosphorus and rainfall have the least response. Elevation has the second most contribution in the distribution of *Apis dorsata*. Soil pH and nitrogen have also contribution in the distribution of *Apis dorsata*.

Table 3. Contribution table of the selected environmental layers using MaxEnt model, 2023

Variable	Percent contribution	Permutation importance
Potassium (K)	42.7 %	32.1
Elevation	29.9 %	25.5
Soil pH	9.6 %	9.5
Nitrogen (N)	8.4 %	1.1
Evapotranspiration	3.3 %	4.1
Temperature (T)	2.7 %	0.5
Phosphorus (P)	1.9 %	5.5
Rainfall	1.5 %	21.8

Source: Compiled by the Authors using MaxEnt model, 2023

3.6 Accuracy Assessment/Validation

Table 4. User's accuracy, producer accuracy, overall accuracy, and kappa statistics for Potential Distribution Map of *Apis dorsata*

User's Accuracy	88.9%
Producer's Accuracy	92.3%

Overall Accuracy	89.9%
Kappa Statistics	0.85

Source: Compiled by authors, 2023

Table 4 presents the accuracy metrics for the Potential Distribution Map of Apis dorsata. With a user's accuracy of 88.9% and a producer's accuracy of 92.3%, the model exhibits robust performance in correctly identifying and predicting the presence of Apis dorsata. The overall accuracy of 89.9% indicates the model's effectiveness in classifying instances across all categories. Moreover, a kappa statistic of 0.85 signifies a substantial level of agreement between observed and chance accuracy, affirming the reliability of the model's predictions for the distribution of Apis dorsata.

4.0 Recommendations and Conclusion

According to the findings, several recommendations is made to address the potential impacts of environmental changes on *Apis dorsata* and its habitat: A combined strategy is required to adequately protect *Apis dorsata* and its habitat. The preservation of essential habitats, the reduction of human disturbances, and the conservation of critical nesting sites are central to this effort. These activities must be supplemented by the promotion of sustainable land use practices, which will function as a barrier against habitat deterioration. Concurrently, addressing the major challenge of environmental change involves advocacy for the use of renewable energy sources and actively supporting worldwide efforts to reduce greenhouse gas emissions.

Local communities, particularly honey hunters and residents near the Sundarbans, play an important role in this initiative. It is critical to engage and educate these communities about the importance of *Apis dorsata* and the far-reaching effects of environmental change. Regular monitoring of the bees distributed and changing habitat conditions is critical for informed decision-making and adaptive conservation methods. Furthermore, empowering local populations through training in sustainable honey bee management practices not only supports the survival of the species but also protects their own livelihoods. This conservation objective demands collaborative efforts with a wide range of stakeholders, including organizations and governments, to develop and execute policies that prioritize biodiversity preservation while also effectively addressing the effects of environmental change on *Apis dorsata*. By taking preventative measures now, the vital contributions of this prominent pollinator can be preserved, ensuring biodiversity, building ecological resilience, and underpinning the long-term well-being of local inhabitants.

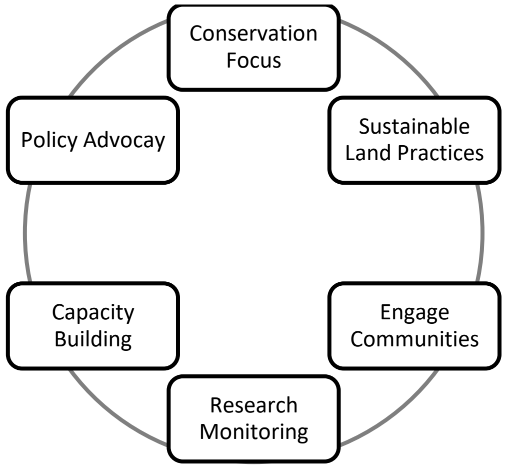

Figure 8: Recommendations on the conservation of *Apis dorsata* distributions.
Source: Compiled by authors, 2023

At the end, the study addressing the potential distribution of *Apis dorsata* in the Sundarbans. The study developed insights into the potential changes in the habitat suitability of *Apis dorsata* through the use of species distribution modeling techniques, such as the MaxEnt model, and the analysis of various environmental factors including temperature, rainfall, humidity, elevation, and soil nutrients. The results reveal that environmental factors along with anthropogenic factors are likely to influence the distribution of *Apis dorsata*, leading to shifts in suitable habitat zones, potential range expansions, and contractions. This could have significant ecological, economic, and societal implications, affecting plant-pollinator interactions, vegetation dynamics, and communities reliant on honey bee products.

References

Abou-Shaara, H. F., Al-Ghamdi, A. A., & Mohamed, A. A. (2012). Tolerance of two honey bee races to various temperature and relative humidity gradients. *Environmental and experimental Biology*, *10*(4), 133-138.

Akter, A., Biella, P., Batáry, P., & Klečka, J. (2020). Changing pollinator communities along a disturbance gradient in the Sundarbans mangrove forest: A case study on Acanthus ilicifolius and Avicennia officinalis. *Global Ecology and Conservation*, *24*, e01282.

Ali, M., Sajjad, A., & Saeed, S. (2017). Yearlong association of *Apis dorsata* and Apis florea with flowering plants: planted forest vs. agricultural landscape. *Sociobiology*, *64*(1), 18-25.

Board, B. T. (2021, January 19). *Sundarbans: The Largest Mangrove Forest of The Earth*. Sundarbans: The Largest Mangrove Forest of the Earth. https://beautifulbangladesh.gov.bd/newsletter/single/206#:~:text=The%20Sundarbans%20is%20a%20mangrove,the%20Baleswar%20River%20in%20Bangladesh

Büchler, R., Drescher, W., & Tornier, I. (1992). Grooming behaviour of Apis cerana, Apis mellifera and *Apis dorsata* and its effect on the parasitic mites Varroa jacobsoni and Tropilaelaps clareae. *Experimental & applied acarology*, *16*(4), 313-319.

Environmental change widespread, rapid, and intensifying – IPCC — IPCC. (2021, August 9). IPCC. https://www.ipcc.ch/2021/08/09/ar6-wg1-20210809-pr/

Cunningham, M. M., Tran, L., McKee, C. G., Polo, R. O., Newman, T., Lansing, L., ... & Guarna, M. M. (2022). Honey bees as biomonitors of environmental contaminants, pathogens, and environmental change. *Ecological Indicators*, *134*, 108457.

El-Shimi, A., Kalach, R., Kumar, A., Ottean, A., Li, J., & Sengupta, S. (2012). Primary data {Deduplication—Large} scale study and system design. In *2012 USENIX Annual Technical Conference (USENIX ATC 12)* (pp. 285-296).

Erwin, K. L. (2009). Wetlands and global environmental change: the role of wetland restoration in a changing world. *Wetlands Ecology and management*, *17*(1), 71-84.

Iwasaki, J. M., & Hogendoorn, K. (2021). How protection of honey bees can help and hinder bee conservation. *Current Opinion in Insect Science*, *46*, 112-118.

Karthik, S., Reddy, M. S., & Yashaswini, G. (2021). Environmental change and its potential impacts on insect-plant interactions. *The Nature, Causes, Effects and Mitigation of Environmental Change on the Environment*, *10*.

Mahadevia Ghimire, K., & Vikas, M. (2012). Environmental change–impact on the Sundarbans, a case study. *International Scientific Journal: Environmental Science*, *2*(1), 7-15.

Mitra, A., Sengupta, K., Chowdhury, M. R., Roychowdhury, G., Raha, A. K., Zaman, S., & Raha, A. K. (2013). Mangroves: a unique gift of nature. In *Sensitivity of mangrove ecosystem to changing environmental* (pp. 33-105). New Delhi: Springer

Moniruzzaman, M., Khalil, M. I., Sulaiman, S. A., & Gan, S. H. (2013). Physicochemical and antioxidant properties of Malaysian honeys produced by Apis cerana, *Apis dorsata* and Apis mellifera. *BMC Complementary and Alternative Medicine*, *13*(1), 1-12.

Muñoz-Huerta, R., Guevara-Gonzalez, R., Contreras-Medina, L., Torres-Pacheco, I., Prado-Olivarez, J., & Ocampo-Velazquez, R. (2013, August 16). A Review of Methods for Sensing the Nitrogen Status in Plants: Advantages, Disadvantages and Recent Advances. *Sensors*, *13*(8), 10823–10843. https://doi.org/10.3390/s130810823

Murshed, S., Griffin, A. L., Islam, M. A., Wang, X. H., & Paull, D. (2022). Assessing multi-environmental-hazard threat in the coastal region of Bangladesh by combining influential environmental and anthropogenic factors. *Progress in Disaster Science*, *16*, 100261.

Ortolano, L., Sánchez-Triana, E., & Ferdausi, S. A. (2017). Strategy for adapting to environmental change and conserving biodiversity in the Bangladesh Sundarbans. *Environmental and Development*, *9*(4), 325-336

Reddy, P. V., Verghese, A., & Rajan, V. V. (2012). Potential impact of environmental change on honeybees (Apis spp.) and their pollination services. *Pest Management in Horticultural Ecosystems*, *18*(2), 121-127.

Ren, J., Fang, S., Lin, G. et al. Tree growth response to soil nutrients and neighborhood crowding varies between mycorrhizal types in an old-growth temperate forest. Oecologia 197, 523–535 (2021). https://doi.org/10.1007/s00442-021-05034-2

Ruttner, F. (2013). *Biogeography and taxonomy of honeybees*. Springer Science & Business Media.

Vyas, P. (2012). *Biodiversity conservation in Indian Sundarban in the context of anthropogenic pressures and strategies for impact mitigation* (Doctoral dissertation, Saurashtra University).

Weather Atlas. (2021). Yearly & Monthly weather - Sundarban, Bangladesh. Weather Atlas. Retrieved August 26, 2023, from https://www.weather-atlas.com/en/bangladesh/sundarban-environmental

White, P.J., Karley, A.J. (2010). Potassium. In: Hell, R., Mendel, RR. (eds) Cell Biology of Metals and Nutrients. Plant Cell Monographs, vol 17. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-10613-2_9

Williams, S. T., Davies, F. L., Mayfield, C. I., & Khan, M. R. (1971). Studies on the ecology of actinomycetes in soil II. The pH requirements of streptomycetes from two acid soils. *Soil Biology and Biochemistry*, *3*(3), 187-195.

Yudaniayanti, I. S., Primarizky, H., & Nangoi, L. (2018, April). The effects of honey (*Apis dorsata*) supplements on increased bone strength in ovariectomized rat as animal model of osteoporosis. In *AIP Conference Proceedings* (Vol. 1945, No. 1). AIP Publishing.

Marschner, P. (2012) Marschner's Mineral Nutrition of Higher Plants. 3rd Edition, Academic Press, Cambridge, 649 p.

Oosterhuis D.M., Loka D.A., Kawakami E.M. & Pettigrew W.T. (2014) The physiology of potassium in crop production. Advances in Agronomy 126, 203–233.

Mitran, T., Kumar, P., Bandyopadhyay, P. K., & Basak, N. (2018). Effects of organic amendments on soil physical attributes and aggregate-associated phosphorus under long-term rice-wheat cropping. Pedosphere, 28(5), 823-832.

Malhotra, H., Vandana, Sharma, S., & Pandey, R. (2018). Phosphorus nutrition: plant growth in response to deficiency and excess. Plant nutrients and abiotic stress tolerance, 171-190.