Sustainability and Biodiversity Conservation

Species diversity and distribution patterns of Hornbills (Bucerotiformes: Bucerotidae) in Pulau Banding, Perak, Malaysia

Aainaa Syazwani Mohamad Amir Hamzah*, Thalut Haqqi Aden, Muhammad Firdaus Abdul Karim, Kamarul Ariffin Kambali Hambali, Amal Najihah Muhamad Nor, Marinah Muhammad

Animal and Wildlife Research Group, Faculty of Earth Science, Universiti Malaysia Kelantan, Kelantan, Malaysia
Email: syazwani@umk.edu.my

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Abstract

Hornbills (Aves: Bucerotidae) play a crucial role in seed dispersal, essential for maintaining tropical rainforest biodiversity. This study aimed to document hornbills' species diversity and distribution patterns in Pulau Banding, Perak, Malaysia, part of the Royal Belum State Park and the Belum-Temenggor Forest complex. Conducted in March 2023, the study established eight observation points spaced 600 meters apart. Hornbill species were identified through visual observations using Nikon Monarch 5 binoculars and by recognizing bird calls. The Morisita index was used to analyze distribution patterns, revealing an overall clumped distribution (Id = 1.60) across the island. The study recorded 45 individual hornbills representing five species: Oriental Pied Hornbill (*Anthracoceros albirostris*), Black Hornbill (*Anthracoceros malayanus*), Rhinoceros Hornbill (*Buceros rhinoceros*), Bushy-crested Hornbill (*Anorrhinus galeritus*), and Wreathed Hornbill (*Rhyticeros undulatus*). Variation in sightings across observation points was attributed to resource availability, habitat preferences, and human disturbances. Points with abundant food resources, like fig trees, and lower human activity had higher hornbill sightings. Based on the findings, several conservation actions are recommended: habitat preservation, water resource management, anti-poaching measures, ecotourism development, community involvement, and GPS tracking and remote sensing technologies. This study provides valuable data for local conservation initiatives and supports global efforts to mitigate the decline of hornbill populations. The findings can influence policy and conservation efforts, ensuring the continued presence of hornbills and promoting Pulau Banding as a sustainable area that benefits both the community and the ecosystem. Future research should focus on long-term monitoring and detailed ecological studies to further explore hornbill ecology and interactions in Pulau Banding.

Keywords: Morisita Index, Conservation Strategies, Seed Dispersal, Ecotourism, Habitat Preservation

Introduction

Hornbills (Aves: Bucerotidae) are a diverse group of birds characterized by their distinctive casques and considerable body size, ranging from 45 to 125 cm in length and weighing between 475 to 2,840 grams. These birds play a crucial role in seed dispersal, which is essential for maintaining the biodiversity of tropical rainforests (Carvalho et al., 2021). Globally, there are 62 hornbill species, with Peninsular Malaysia hosting at least 10, while Sabah and Sarawak support eight species (Kueffner, 2023). The ancient ecosystem of Pulau Banding, part of the Royal Belum State Park, offers a rich and diverse habitat that supports a wide variety of plant and animal life, making it an ideal environment for hornbills. Hornbills are particularly significant in seed dispersal due to their ability to consume and transport large seeds over long distances, thereby aiding in forest regeneration and maintaining plant diversity (Corlett, 2021). Despite their ecological importance, hornbill populations are declining due to habitat loss, poaching, and environmental disturbances such as noise, light, and air pollution. In Malaysia, most hornbill species are classified as vulnerable by the IUCN Red List and are legally protected (Mohd-Azlan et al., 2023). However, they continue to face threats from hunting for ornamental purposes, pet trade, and consumption as a food source. Pulau Banding, situated within the Belum-Temenggor Forest complex, provides an optimal habitat for hornbills due to its rich biodiversity, large-trunked trees, and abundance of fig fruits, which are a key food source for these birds. Previous studies in the region, such as those by Philovenny and Mohd-Azlan (2023), have highlighted the critical habitat requirements and threats faced by hornbills, underscoring the need for targeted conservation strategies. Despite these efforts, comprehensive data on species diversity and distribution patterns in Pulau Banding remain limited. This study aims to document the species diversity and distribution patterns of hornbills in Pulau Banding, enhancing our understanding of their ecological requirements and informing conservation strategies (Squires, 2023). These efforts contribute significantly to maintaining the ecological balance and supporting the diverse species that inhabit the area, including hornbills (Francis et al., 2024). By investigating the diversity and distribution of hornbills in this region, our research builds on previous work and contributes to broader efforts to conserve these essential avian species (Rose, 2021). This study not only provides valuable data for local conservation initiatives but also supports global efforts to mitigate the decline of hornbill populations.

Material and methods

Study Area

Our research, conducted in March 2023, focused on the distribution of hornbills in Pulau Banding, located in Perak, Malaysia. Pulau Banding lies within the Banding Lake/Temenggor Dam area along the East-West Highway between Perak and Jeli (5°34'09" N 101°24'42" E). Covering 240 hectares, this region is ideal for nature tourism due to its rich biodiversity and pristine tropical rainforest, which has existed for over 130 million years, making it one of the oldest rainforests globally, surpassing even the Amazon and Congo in age. Recognizing its ecological significance, the Malaysian government designated this area as a protected region in 2007 (Talaat & Asma, 2020). This protection status preserves its unique biodiversity, making it a critical site for both conservation efforts and ecological research. Specific conservation measures already in place include the establishment of the Royal Belum State Park, which encompasses Pulau Banding and the larger Belum-Temenggor Forest Complex (Ramli et al., 2024). This designation not only provides legal protection against deforestation and poaching but also promotes sustainable tourism and research activities. Conservation programs in the region focus on habitat restoration, anti-poaching patrols, and community engagement to ensure the long-term preservation of its rich biodiversity.

Observation and identification

Eight observation points were strategically established within Pulau Banding, spaced 600 meters apart, to ensure a comprehensive and representative sampling of hornbill distribution across the study area (Figure 1). This spacing was carefully chosen to balance the need for extensive coverage with the necessity of minimizing overlap in observations, which could lead to double-counting individuals. The selection of eight points was based on the island's topography, habitat diversity, and the mobility patterns of hornbills, ensuring that the observation points effectively captured the range of habitats frequented by different hornbill species (Borah, 2023).

Figure 1. Eight observation points of hornbill in Pulau Banding

The 600-meter spacing strikes an optimal balance between the potential risks of overlap and under-sampling. Closer spacing could increase the likelihood of observing the same individuals at multiple points, thereby inflating population estimates. Conversely, wider spacing might result in under-sampling, where individuals in areas between points are missed, leading to inaccurate estimates of population density and distribution. The chosen distance was thus determined to be effective in reducing these risks, ensuring a robust estimation of the hornbill population and distribution in Pulau Banding (Mokhter et al., 2022). Each observation period lasted 40 minutes, with 30 minutes dedicated to active observation and 10 minutes allocated for transit between points. This duration was sufficient to observe and identify hornbill species at each point, given the species' behavior and the environmental conditions. The three-week fieldwork period, conducted in March 2023, provided ample time to account for daily and weather-related variations in hornbill activity, further enhancing the reliability of the data collected.

Hornbill species were identified using Nikon Monarch 5 binoculars (8x42 model), known for their high optical clarity, which is crucial for distinguishing subtle morphological differences among species. Identifying hornbills also involved recognizing bird calls, a task that posed challenges due to the similarity of vocalizations among certain species (Wee et al., 2024). These challenges were addressed through the following measures:

- Utilizing high-quality binoculars to improve visual clarity and detail.
- Cross-referencing bird calls with audio samples from the Xeno-Canto website to confirm species identification.
- Consulting "A Field Guide to the Birds of Malaysia and Singapore" for morphological verification.
- Recording observations meticulously and cross-checking doubtful sightings with subsequent observations.

Distribution Analysis

The Morisita index was chosen for distribution analysis due to its robustness in handling variations in population density and its ability to distinguish between different distribution patterns (random, uniform, and clumped) (Butturi-Gomes & Petrere, 2020). This index is particularly useful in ecological studies where species are not evenly distributed, making it suitable for analyzing the distribution patterns of hornbills in a heterogeneous environment like Pulau Banding (Munian et al., 2023).

The Morisita index formula is (de Freitas Alves & de Santana, 2022):

$$Id = \frac{n\sum x^2 - (\sum x)^2}{(\sum x)^2 - \sum x}$$

Where:

- n = Number of plots
- $\sum x$ = Total number of individuals of a species in the community
- $\sum x^2$ = Sum of the squares of the total individuals of a species in the community

The Morisita index (*Id*) yields three possible indications of hornbill distribution (Krebs, 1989):

- $Id = 1$: Distribution is random
- $Id < 1$: Distribution is uniform
- $Id > 1$: Distribution is clumped

Coordinates of each observation point and individual hornbill sightings were recorded using Garmin GPSMAP 64s devices. These coordinates, along with the Pulau Banding map, were processed using ArcGIS software version 10.8 to create a detailed distribution map (Nor et al., 2022). This methodology ensures that the study is replicable and provides a clear framework for future research on hornbill distribution.

Results

This study recorded 45 individual hornbills representing five species in Pulau Banding: Oriental Pied Hornbill (*Anthracoceros albirostris*), Black Hornbill (*Anthracoceros malayanus*), Rhinoceros Hornbill (*Buceros rhinoceros*), Bushy-crested Hornbill (*Anorrhinus galeritus*), and Wreathed Hornbill (*Rhyticeros undulatus*) (Table 1).

Table 1. A quick reference to the family, IUCN status, and basic characteristics of each species of hornbill observed in the study

Species	Scientific Name	Family	IUCN Status	Basic Information
Oriental Pied Hornbill	*Anthracoceros albirostris*	Bucerotidae	Least Concern (LC)	Medium-sized hornbill with black and white plumage; found in forests, woodlands, and urban areas.
Black Hornbill	*Anthracoceros malayanus*	Bucerotidae	Vulnerable (VU)	Black plumage with a white-tipped tail; prefers lowland forests and often found in pairs or small groups.
Rhinoceros Hornbill	*Buceros rhinoceros*	Bucerotidae	Vulnerable (VU)	Large hornbill with a prominent casque shaped like a rhinoceros horn; inhabits tropical and subtropical forests.
Bushy-crested Hornbill	*Anorrhinus galeritus*	Bucerotidae	Near Threatened (NT)	Smaller hornbill with a bushy crest of feathers; typically found in small flocks in dense forests.
Wreathed Hornbill	*Rhyticeros undulatus*	Bucerotidae	Vulnerable (VU)	Large hornbill with a distinctive wreathed casque; prefers lowland and montane forests.

Distribution Analysis

Using the Morisita index to calculate the distribution of hornbills on Pulau Banding, index values ranged from 0.01 to 0.72 at each observation point (Table 2), with an overall index value of 1.60 for the entire island. These results indicate a uniform distribution pattern at individual observation points and a clumped distribution pattern when considering the island as a whole.

Table 2. Morisita Spread Index at each observation point

Observation Point	*Id*	Hornbill Distribution
1	0.52	Uniform
2	0.22	Uniform
3	0.08	Uniform
4	0.01	Uniform
5	0	-
6	0.01	Uniform
7	0.01	Uniform
8	0.72	Uniform
Points 1-8	1.60	Clumped

Note: The Morisita Spread Index (*Id*) is used to determine the distribution pattern of hornbills across observation points (Kriswanto et al., 2024). An *Id* value less than 1 indicates a uniform distribution, where individuals are evenly spaced across the area, suggesting minimal competition for resource territory. An *Id* value greater than 1 indicates a clumped distribution, where individuals are aggregated in certain areas, often due to the availability of resources like food or nesting sites. An *ID* value of 1 indicates a random distribution. In this study, while individual observation points showed a uniform distribution, the overall distribution across the island (Point1-8) was clumped, reflecting localized areas of higher hornbill density,

The following table (Table 3) provides detailed data on the number of hornbill individuals observed at each point:

Table 3. Number of hornbill individuals at each observation point

Point	Oriental Pied Hornbill (LC)	Black Hornbill (VU)	Rhinoceros Hornbill (VU)	Bushy-crested Hornbill (NT)	Wreathed Hornbill (VU)
1	5	4	1	2	
2	7		1		
3	5				
4	2				
5					
6	2				
7					2
8	9			5	
Total	**30**	**4**	**2**	**7**	**2**

LC: Least Concern; VU: Vulnerable; NT: Near Threatened

Distribution Map

The results also include a comprehensive distribution map of hornbills in Pulau Banding, generated using ArcGIS software version 10.8. This map provides a visual representation of the spatial distribution of the five hornbill species across the island. The map highlights areas of higher hornbill density, particularly around observation points with clumped distributions. The clumped distribution pattern is closely associated with the availability of key resources, such as fig trees and nesting sites, which are concentrated in certain parts of the island. This map not only illustrates the current hornbill distribution but also serves as a valuable tool for identifying critical habitats and informing conservation strategies (Wee et al., 2024). It can be used by future researchers to

monitor changes in hornbill populations over time and by conservationists to target areas for habitat protection and restoration efforts. The map also marks key locations, such as UMK TRaCe and the Belum Rainforest Resort, where hornbill sightings were frequent, suggesting these areas as prime spots for birdwatching and ecotourism development (Figure 2). Additionally, the map includes GPS coordinates of individual sightings (Table 4), providing precise data for further analysis and field studies.

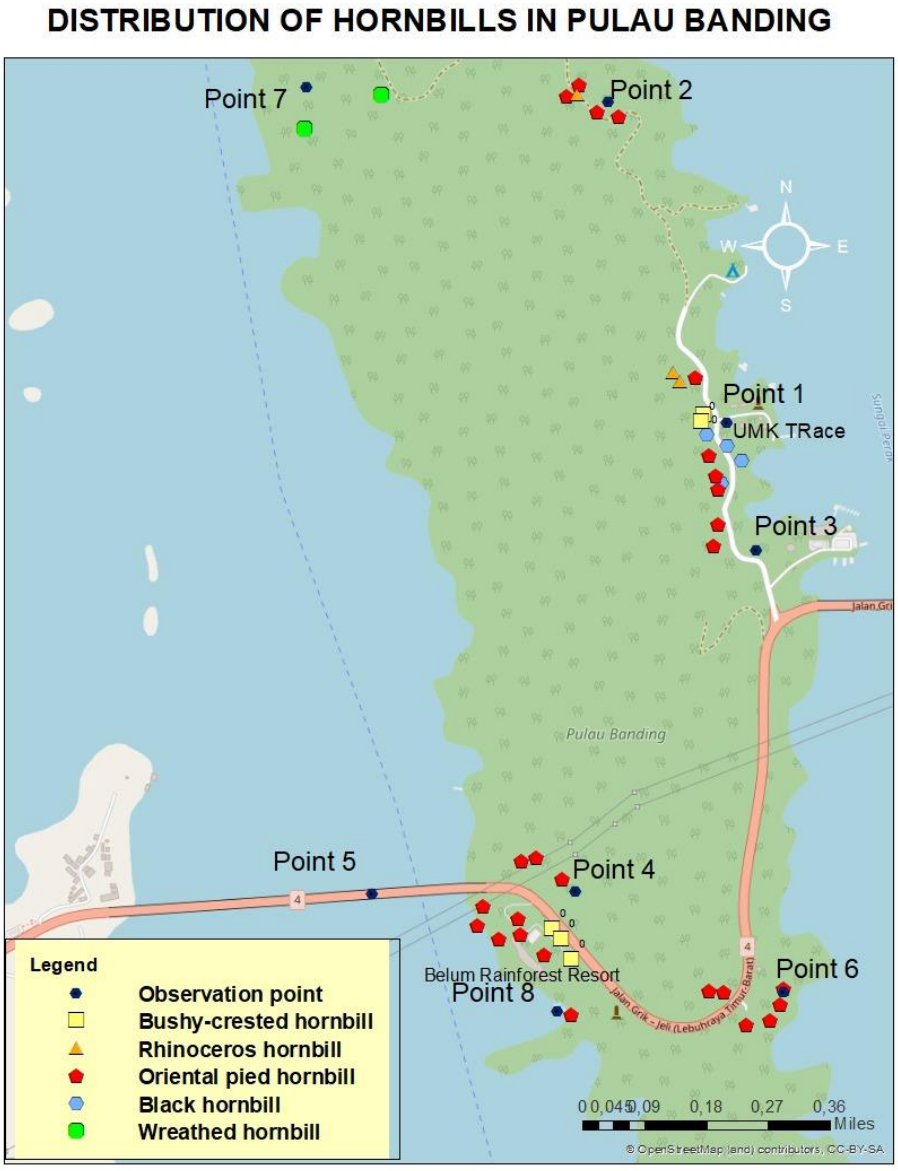

Figure 2. UMK TRaCe and the Belum Rainforest Resort as prime spots for birdwatching and ecotourism development

Table 4. GPS coordinates of individual sighting

No	Oriental Pied hornbill	Bushy-crested hornbill	Rhinoceros hornbill	Wreathed hornbill	Black hornbill
	5°33'22"N	5°32'36"N	5°33'20"N	5°33'37"N	5°33'12"N
1	101°20'38"E	101°20'27"E	101°20'37"E	101°20'10"E	101°20'39"E
	5°33'12"N	5°32'36"N	5°33'21"N	5°33'38"N	5°33'12"N
2	101°20'40"E	101°20'28"E	101°20'36"E	101°20'16"E	101°20'42"E
	5°33'11"N	5°32'33"N	5°33'39"N		5°33'11"N
3	101°20'40"E	101°20'29"E	101°20'30"E		101°20'43"E
	5°33'11"N	5°33'16"N			
4	101°20'41"E	101°20'38"E			
	5°33'05"N	5°33'15"N			
5	101°20'42"E	101°20'38"E			
	5°33'06"N				
6	101°20'42"E				
	5°33'37"N				
7	101°20'32"E				
	5°33'37"N				
8	101°20'33"E				
	5°33'39"N				
9	101°20'31"E				
	5°33'39"N				
10	101°20'31"E				
	5°33'40"N				
11	101°20'31"E				
	5°33'37"N				
12	101°20'32"E				
	5°32'32"N				
13	101°20'46"E				
	5°32'30"N				
14	101°20'47"E				
	5°32'29"N				
15	101°20'44"E				
	5°32'28"N				
16	101°20'44"E				
	5°32'31"N				
17	101°20'42"E				
	5°32'31"N				
18	101°20'41"E				
	5°32'29"N				
19	101°20'30"E				
	5°32'33"N				
20	101°20'28"E				
	5°32'35"N				
21	101°20'26"E				
	5°32'38"N				
22	101°20'25"E				
	5°32'37"N				
23	101°20'26"E				
	5°32'37"N				
24	101°20'23"E				
	5°32'38"N				
25	101°20'23"E				
	5°32'37"N				
26	101°20'24"E				
	5°32'40"N				
27	101°20'30"E				
	5°32'43"N				
28	101°20'24"E				
	5°32'44"N				
29	101°20'24"E				

Potential Reasons for Variation in Sightings

The observed variation in hornbill sightings across different observation points is likely influenced by several key ecological and environmental factors:

1. Resource Availability: The distribution of hornbill sightings appears to be closely correlated with the availability of critical food resources, such as fig trees and mayflies. Observation points with higher hornbill activity, particularly Point 8, are located in areas where these resources are abundant. This suggests that resource-rich environments are crucial for sustaining hornbill populations, as they provide essential nutrition and support hornbill foraging behavior.
2. Habitat Preferences: Hornbill species exhibit specific habitat preferences, which may influence their distribution patterns (Combrink et al., 2020). For instance, species that favor large-trunked trees and dense canopy cover are more likely to be observed in areas where these habitat features are prevalent. Such environments provide suitable nesting sites and protection, which are essential for the reproductive success and survival of hornbills (Stander et al., 2021). The variation in habitat characteristics across observation points may, therefore, explain the differing frequencies of hornbill sightings.
3. Human Disturbances: The proximity of observation points closer to human activities significantly impacts hornbill presence. For example, point 5, located near the bridge connecting Pulau Banding to the Gerik area, recorded no hornbill sightings, likely due to disturbances from human infrastructure and activity. This finding aligns with studies indicating that hornbills are sensitive to human encroachment, which can disrupt their natural behaviors and lead to habitat avoidance (Teampanpong et al., 2024). The absence of hornbills in areas with high human activity underscores the importance of minimizing disturbances in critical habitats to protect hornbill populations (Pawar et al., 2021).

These factors collectively highlight the complex interplay between resource availability, habitat preferences, and human disturbances in shaping hornbill distribution patterns in Pulau Banding. Further research is recommended to quantify these influences and develop targeted conservation strategies to mitigate the impact of human activities on hornbill habitats (Suttidate, 2022).

Comparison to Other Regions

Hornbill distribution patterns in Pulau Banding are consistent with findings from other tropical regions (Table 5), where hornbills typically exhibit clumped distribution patterns. These patterns are primarily driven by the availability of essential resources such as food sources and suitable nesting sites, as well as the degree of human disturbance in their habitats.

Factors Contributing to Hornbill Distribution

1. Food resource availability: Hornbills are highly dependent on specific food sources, particularly fig trees, which provide both nutrition and breeding opportunities (Wijerathne et al., 2023). Studies in tropical regions, such as those conducted in Thailand and Southern Ghana, have shown that hornbills tend to cluster in areas where these critical resources are abundant (Su et al, 2024). For instance, Kitamura et al. (2008) found that hornbills in Thailand were concentrated in regions with high densities of fig trees, leading to a clumped distribution pattern. Similarly, Dzitse (2014) reported that in Southern Ghana, hornbill distribution was closely linked to the availability of large fruiting trees and nesting sites, reinforcing the clumped nature of their distribution.
2. Nesting Site Availability: The presence of large, mature trees is crucial for hornbill nesting. Research has consistently shown that hornbills prefer areas with an abundance of such trees, which offer safe nesting cavities (Naniwadekar et al., 2021). In Westen Ghats of India, for example, the availability of large trees was a key factor influencing hornbill distribution (Pawar et al., 2021). This preference for specific nesting sites contributes to the clustering of hornbills in suitable habitats (Reintar et al., 2022).
3. Human Disturbance: Hornbills are sensitive to human activities and are often found in areas with minimal disturbance (Pradhan et al., 2024). Hidayat et al. (2020) observed that in west Sumatra, hornbills were concentrated in forest patches with low levels of human interference, where their preferred resources were more accessible. This pattern is consistent with the observations in Pulau Banding, where hornbills were less frequent in areas closer to human infrastructure, suggesting that disturbance plays a significant role in their distribution (Rheindt et al., 2020).

Table 5. Factors influencing hornbill distribution in Pulau Banding

Factor	Description	Examples from Other Regions
Food Resource Availability	The high density of fig trees and other fruiting species	Clustering in areas with abundant fig trees in Thailand (Kitamura et al., 2008; Dzitse, 2014)
Nesting Site Availability	Presence of large, mature trees suitable for nesting	Clumped distribution near large trees in the Western Ghats of India (Pawar et al., 2021; Dzitse, 2014)
Human Disturbance	Reduced presence in areas with high levels of human activity	Concentration in undisturbed forest patches in west Sumatra (Hidayat et al., 2020)

These findings suggest that the clumped distribution pattern observed in Pulau Banding is not unique but rather a common characteristic of hornbill populations in tropical forests (Ong, 2021). The factors influencing this pattern – food resource availability, nesting site suitability, and human disturbance are consistent across different regions, highlighting the importance of these ecological drivers in hornbill conservation efforts.

Discussion

Hornbills, listed as threatened by the IUCN Red List, face significant challenges in Malaysia (Wee et al., 2024). Vulnerable species found on Pulau Banding include the Black Hornbill (*A. malayanus*), Rhinoceros Hornbill *(B. rhinoceros*), and Wreathed Hornbill (*R. undulatus*) (Aik & Chye, 2020). The Oriental Pied Hornbill (*A. albirostris*) and Bushy-crested Hornbill (*A. galeritus*) are classified as Least Concern (LC) and Near Threatened (NT), respectively.

Pulau Banding, part of the Royal Belum State Park and the Belum-Temenggor Forest complex, is crucial for hornbill conservation, hosting all ten hornbill species found in Malaysia (Ramli et al, 2024). Our study identified the Oriental Pied Hornbill as the most prevalent species, indicating the island's significance as a nesting site. Other species, such as the Black, Rhinoceros, and Wreathed Hornbills, were less frequently observed, suggesting they primarily visit for foraging (Sibarani et al., 2020).

Specific Conservation Needs

The less frequently observed species, such as the Black Hornbill, Rhinoceros Hornbill, and Wreathed Hornbill, require targeted conservation strategies (Wee et al., 2024). These species are vulnerable, and their low sightings suggest they may be at greater risk. Conservation efforts should focus on:

- Habitat Preservation: Ensuring the protection of large trees necessary for nesting, particularly for the Rhinoceros and Wreathed Hornbills (Sibarani et al., 2020).

- Foraging Resources: Maintaining and increasing the availability of fig trees and other fruiting plants to support their dietary needs.
- Anti-Poaching Measures: Enhancing patrols and enforcement to prevent illegal hunting.

Factors Contributing to Clumped Distribution

The clumped distribution pattern observed in our study is influenced by several factors:

- Availability of Resources: Hornbills tend to cluster in areas where food sources, such as fig trees and mayflies, are abundant (Long, 2020). The fig tree fruiting season, from late June to mid-July, attracts hornbills in large numbers as they forage in colonies (Francolin, 2022).
- Human Disturbances: Areas with lower human activity, such as Point 8 in the Belum Rainforest, had higher hornbill numbers. Conversely, locations near human infrastructure, like Point 5 on the bridge connecting Pulau Banding to the Gerik area, had no sightings, suggesting that human disturbances might deter hornbills from settling and foraging there.

Implications of the Clumped Distribution Pattern

The observed clumped distribution pattern of hornbills has several implications for conservation strategies (Naniwadekar et al., 2021):

1. Habitat Fragmentation: The clumped distribution suggests that hornbills may be reliant on specific habitats within Pulau Banding (Ong, 2021). This reliance indicates the need to protect and possibly expand these critical habitats to prevent fragmentation.
2. Resource Availability: Clumped distribution often correlates with the availability of key resources such as food and nesting sites. Conservation strategies should focus on ensuring these resources are abundant and protected (Acreman et al., 2020).
3. Conservation Prioritization: Areas with higher concentrations of hornbills should be prioritized for conservation efforts (Hidayat et al., 2020). This prioritization can help allocate resources more efficiently and effectively to support hornbill populations.
4. Human Disturbance Mitigation: The clumped pattern may indicate areas more susceptible to human disturbances such as tourism or logging. Conservation measures should include strict regulation of human activities in these zones to minimize impact.

Overall, understanding the distribution patterns of hornbills is crucial for developing targeted and effective conservation strategies to protect these important avian species in Pulau Banding (Noor-Faezah et al., 2023).

Specific Conservation Actions

Based on our findings, several specific conservation actions are recommended to ensure the continued presence of hornbills in Pulau Banding (Mokhter et al., 2022):

1. Habitat Preservation: Protect and restore critical habitats, particularly large-trunked trees and fig trees, which are essential for feeding and mating. This includes reforestation programs and protecting existing old-growth trees.
2. Water Resource Management: Ensure the preservation of water bodies and surrounding areas that support the ecological needs of hornbills (Mudereri et al., 2021). This involves maintaining water quality and minimizing human disturbance around these critical resources.
3. Anti-Poaching Measures: Strengthen anti-poaching laws and enforcement to protect hornbills from illegal hunting (Kragt et al., 2020). Increased patrolling and monitoring can help deter poachers and protect vulnerable species.
4. Ecotourism Development: Promote sustainable ecotourism, particularly birdwatching, which can raise awareness and provide economic incentives for conservation (Blanton et al., 2024). National and private entities can develop birdwatching tourism on the island, leveraging established observation points. UMK TRaCe and Belum Rainforest Resort are ideal spots for observing hornbills due to the high frequency of sightings.
5. Community Engagement: Involve local communities in conservation efforts through education and participation in sustainable practices. This can foster a sense of ownership and responsibility towards preserving the island's biodiversity.
6. Legislative Support: Enhance protection measures through stronger legislation to prevent habitat destruction and ensure long-term conservation of hornbill populations. Government policies should support sustainable development practices that benefit both the community and the ecosystem.

Seasonal Changes and Hornbill Distribution

Seasonal changes can significantly affect hornbill distribution and behavior in Pulau Banding (Ng, 2020). During the fig tree fruiting season, hornbills are more likely to be found in areas with abundant fruiting trees, leading to higher densities in these locations (Pawar et al., 2021). Additionally, seasonal variations in weather can impact hornbill movements, with these birds possibly seeking shelter in denser forest areas during heavy rains or extreme heat. These seasonal

patterns highlight the need for continuous monitoring to better understand how seasonal changes affect hornbill distribution and to adapt conservation strategies accordingly (Combrink et al., 2020).

Distribution Map Analysis

Our data show an uneven distribution of hornbills across Pulau Banding (Aik et al., 2020) (Figure 2). Point 8, located in the Belum Rainforest area, had the highest number of hornbills (14 individuals), while Point 1, near the Pulau Banding Water Treatment Plant, had the greatest species diversity (12 individuals from four species). Point 5, located on the bridge connecting Pulau Banding to the Gerik area, had no hornbill sightings.

Conservation Strategies Based on Clumped Distribution

Based on the observed clumped distribution of hornbills, the following conservation strategies are recommended (Ardi & Suardi, 2020):

1. Habitat Preservation: Protect and restore critical habitats, particularly large-trunked trees and fig trees, which are essential for feeding and nesting.
2. Water Resource Management: Ensure the preservation of water bodies and surrounding areas that support the ecological needs of hornbills (Mudereri et al., 2021).
3. Anti-Poaching Measures: Strengthen anti-poaching laws and enforcement to protect hornbills from illegal hunting (Kragt et al., 2020).
4. Ecotourism Development: Promote sustainable ecotourism, particularly birdwatching, to raise awareness and provide economic incentives for conservation (Blanton et al., 2024).
5. Community Engagement: Involve local communities in conservation efforts through education and participation in sustainable practices.
6. Seasonal Monitoring: Implement continuous monitoring to understand seasonal changes in hornbill behavior and distribution, adapting conservation strategies accordingly (Combrink et al., 2020).

This study highlights Pulau Banding as a crucial habitat for hornbill conservation, especially for the Oriental Pied Hornbill (Squires, 2023) (Figure 3). The findings emphasize the importance of preserving fig trees and managing human activities to minimize disturbances, ensuring the continued presence of these magnificent birds. Effective conservation strategies should include habitat preservation, resource management, and enhanced protection measures to support the less frequently observed and vulnerable hornbill species (Mudereri et al., 2021).

Figure 3. Oriental Pied Hornbill (*A. albirostris*)

Conclusion

Pulau Banding is a critical habitat for several hornbill species, supported by abundant large-trunked trees, fig fruits, and a consistent water supply. While most hornbills frequent the island for feeding and mating, especially during certain seasons, the presence of key resources highlights the importance of habitat preservation (Wijerathne et al., 2023). Our study demonstrated the effectiveness of point count methodology in assessing hornbill distribution and population, with a clear preference for areas rich in fig trees and close to water. To ensure long-term conservation, regular monitoring, habitat assessments, community involvement, and the integration of technology are recommended. The findings provide a foundation for influencing conservation policies, guiding future research, and promoting Pulau Banding as a key site for both conservation and ecotourism (Bachri et al., 2021). By implementing targeted conservation actions, the continued presence of hornbills can be secured, benefiting both the local community and the broader ecosystem (Kemp et al., 2023).

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