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RESEARCH ARTICLE

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Shared Habitat Distribution of Javan Hawk-eagle, Javan Leopard, and Javan Gibbon in Gunung Halimun Salak National Park, Indonesia

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ABSTRACT

Gunung Halimun Salak National Park (NP) is recognized as an important habitat for rare or key species of Java Island such as the Javan Hawk-eagle, Javan leopard, and Javan gibbon. Although these species exhibit different movement patterns (aerial, arboreal, and terrestrial), their spatial overlap within the landscape suggests potential ecological interactions, particularly within the trophic structure which is rarely integrated before. This study aims to identify, describe, and provide recommendations for the management of key species shared habitats based on spatial approach. Spatial analysis was used to examine the distribution of shared habitats and their biophysical characteristics, including land cover, elevation, and slope. A literature and policy review was conducted to align the findings with existing Conservation Strategies and Action Plans, based on applicable regulations and NP zonation. The analysis reveals that habitat distribution within the NP is categorized into 28.78% two key species and 55.84% three key species shared habitat. Biophysically, key species shared habitat is primarily found in forested areas between 500–1,500 meters above sea level (masl), and mostly located on steep slope around 25–45%. In terms of Gunung Halimun Salak NP zonation, two key species and three key species habitats are mainly located within the core, forest, and use zones of the Gunung Halimun Salak NP. The recommendations are developed aligned with the Conservation Strategy and Action Plan, regulations, and NP zonation for the comprehensive and integrated habitat management strategies of the key species shared habitat.

Introduction

Javan hawk-eagle (*Nisaetus bartelsi*), Javan leopard (*Panthera pardus melas*), and Javan gibbon (*Hylobates moloch*) are endemic and keystone species of Java Island's tropical rainforests. According to the Decree of the Director General of Natural Resources and Ecosystem Conservation No. 200/2015, these species are classified as endangered and have been designated as priority species for conservation, with a target of increasing their populations by 10%, upon their biological characteristics and habitat availability. Furthermore, these species are legally protected under the Ministry of Environment and Forestry Regulation No. P.106/2018 concerning the Second Amendment to Ministry of Environment and Forestry Regulation No. P.20/2018 on Protected Flora and Fauna and Government Regulation No. 7/1999 concerning the Conservation of Plant and Animal Species. Based on the IUCN Red List of Threatened Species, these three key species are included in the endangered species category due to anthropogenic factors [1,2] such as land fragmentation [1,3], deforestation, forest degradation [1,4], illegal hunting, and wildlife trade.

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These three key species are naturally distributed across the tropical rainforest of Java Island, despite differing in movement patterns (aerial, arboreal, and terrestrial), their habitat is spatially interconnected within the landscape. The Javan hawk-eagle as aerial species inhabits the tropical montane and hill rainforests of Java Island at elevation from 0 to 3,000 meters above sea level (masl) [5–8]. The Javan gibbon, an arboreal primate endemic to Java Island, occupies a habitat ranging from Ujung Kulon to the Dieng Mountains and Mount Slamet, in lowland to montane forests at elevations of 0–1,600 masl [3]. The Javan leopard, a predatory species on terrestrial inhabits both conservation and non-conservation areas across Java Island, from its western to eastern regions, primarily in primary and secondary natural forests with steep to moderately steep topography [9–12].

These interconnected habitats support ecological connectivity by facilitating interaction among the three key species, particularly through competition and predation dynamics. Competition occurs when species interact to acquire food [13], while predation involves the relationship between predators and their prey within an ecosystem [14,15]. Within the trophic structure, the Javan hawk-eagle and Javan leopard function as carnivorous predators, whereas the Javan gibbon, as herbivore, occupies the role as prey. Predators of the Javan gibbon include the Javan leopard, snakes and raptors [16]. Based on the Strategy and Action Plan for the Conservation of the Javan leopard (*Panthera pardus melas*) for 2016–2026 [17], the Javan gibbon is one of the possible preys for the Javan leopard, and Javan gibbons will also produce different sounds when they sense the movement of a predator such as a Javan leopard nearby. The Javan hawk-eagle as a raptor has almost the same prey preferences as the Javan leopard, such as arboreal mammals or primates that are small to medium in size [18].

Although there's potential interconnected interaction among the three key species, spatially and tropic structure. The limited information of these shared habitats is a significant factor. Although that these species are commonly found in conservation areas, such as Nature Conservation Areas (KPA) or Nature Reserve Areas (KSA) in Java, particularly within Gunung Halimun Salak National Park (Gunung Halimun Salak NP/TNGHS) where these three key species designated as flagship species based on Grand Design for Research and Development of Science in TNGHS (2002–2027). Unlike previous studies that focused only on individual species distributions, this study integrates spatial analysis of shared habitats for three key species in Gunung Halimun Salak NP to understand spatial overlap and its implication for multispecies conservation management. Nevertheless, the scope of this study is limited to spatial analysis and does not examine interspecific interaction, particularly competition and predation among the three key species. This study introduces an approach by aligning shared habitats within the NP zonation framework and other relevant conservation regulations, offering a new perspective for multi-species conservation management that is rarely applied. Based on this approach, the study aims to generate data that can support the development of more holistic and integrated habitat management strategies for key species. The primary objectives include identify the key species shared habitats distribution, describe the key species shared habitats, and propose recommendation for managing the key species shared habitats.

Materials and Methods

Location

The study area is located within the patch habitat of the Javan hawk-eagle, Javan leopard, and Javan gibbon in Gunung Halimun Salak NP. Gunung Halimun Salak NP is one of the largest protected forest areas in Java, covers an area of approximately 87,699 ha. It spans across three administrative regions of Sukabumi and Bogor District in West Java Province, as well as Lebak District in Banten Province. The park is known for its high biodiversity and ecological significance, particularly for rare and endemic species. The study area can be seen in Figure 1.

Database

The tools have already been done in this research include maps and other relevant spatial data. Software applications namely Microsoft Office, ArcGIS 10.8, and ERDAS Imagine 2014 were used to support the data processing and analysis. These tools were used to conduct spatial analyses and visualize key species habitats within the study area. The material consisting of objectives, data, methods, and outputs is presented in Table 1.

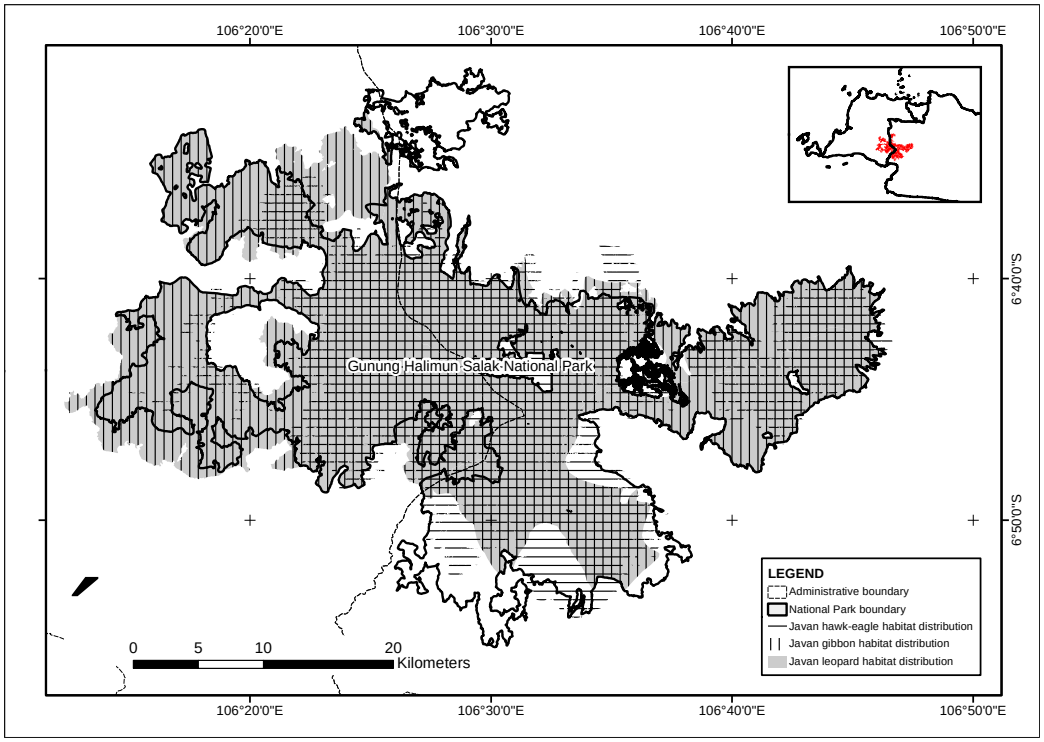

Figure 1. The study area is focused on the patch habitat of the Javan hawk-eagle, Javan leopard, and Javan gibbon. The location was determined of the key species distribution within the boundary of Gunung Halimun Salak NP. (source: BTNGHS, Syartinilia et al. [19], and MoEF [17,20]).

Table 1. The table presents a matrix that links the research objectives, data, data sources, methods, and expected outputs. It illustrates how each component of the study is systematically connected to support the overall research framework.

No.	Objectives	Data	Data source	Method	Output
1.	To identify the key species shared habitats distribution	Javan hawk-eagle, Javan leopard, and Javan gibbon habitat distribution	Syartinilia et al. [19], MoEF [17,20]	Overlay spatial data	Key species shared habitat distribution
2.	To describe the key species shared habitats	Key species shared habitats distribution, administrative boundary, national park zonation, land cover, slope, elevation	Analysis result, BTNGHS, Geospatial Information Agency (vector), DEMNAS (Geospatial Information Agency, raster, resolution 8 x 8 m), Sentinel (Copernicus, raster, resolution 10 x 10 m), and secondary data	Spatial data analyst (e.g., supervised classification) and overlay spatial data	Overview of key species shared habitat
3.	To propose recommendation for managing the key species shared habitats	Analysis data from previous objectives, regulation, documents	Analysis result, and secondary data	Descriptive and literature review	Recommendation for managing the key species shared habitats

Note: Spatial data coordinate system is projected to WGS 1984 UTM Zone 48 South and aligned to the Gunung Halimun Salak NP boundary

Method

The overall analysis in this study only used secondary data, including maps and other relevant spatial data, without field verification. The data were analyzed using spatial application tools. Three steps were conducted in this study: data inventory, analysis, and synthesis. Each step contributed to identifying and understanding the shared habitats of key species in the study area. The overall analytical workflow is shown in Figure 2.

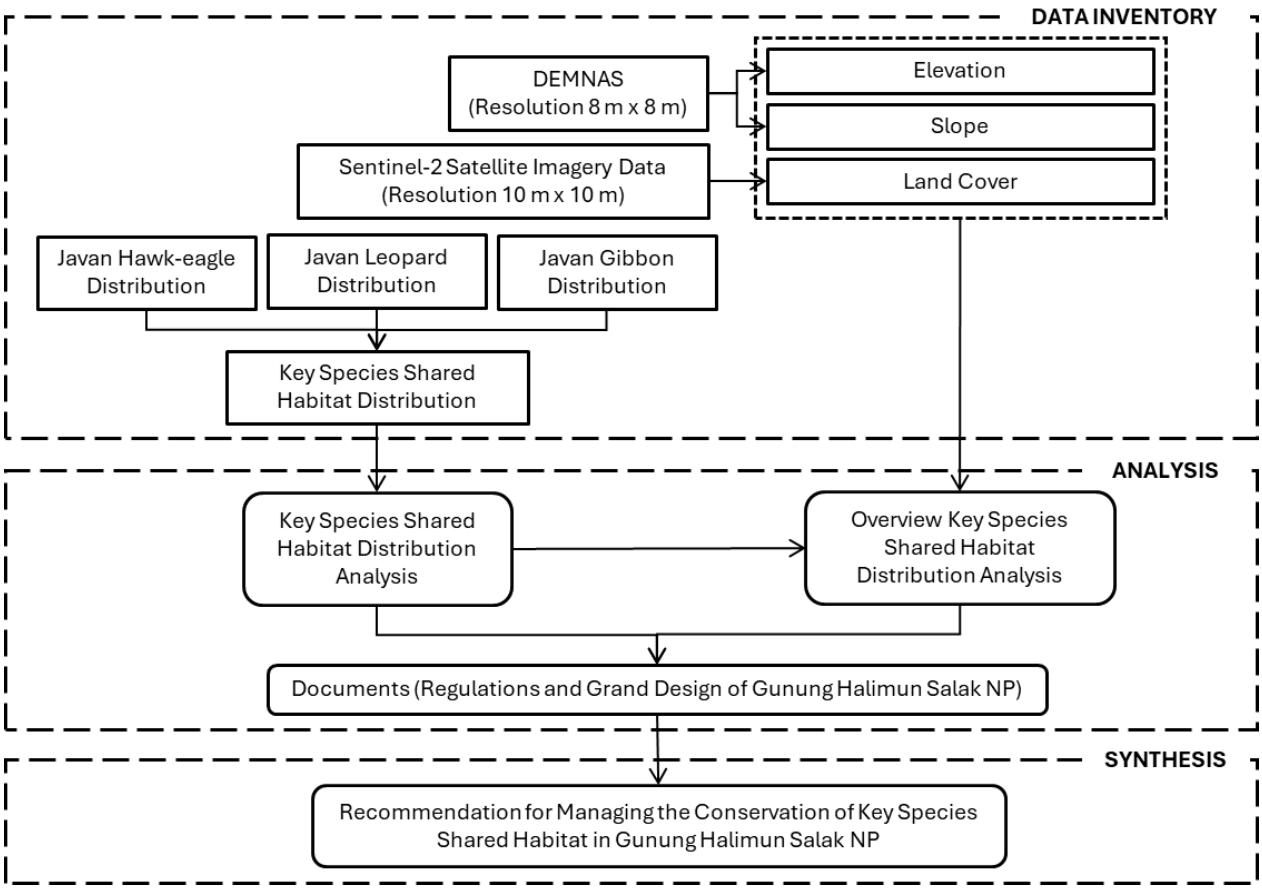

Figure 2. This analytical workflow illustrates the integration of spatial data, species distribution data, and environmental variables through stages of data inventory, analysis, and synthesis. The process leads to recommendations for managing the conservation of key species' shared habitats within Gunung Halimun Salak NP.

Key Species Shared Habitat Distribution Analysis

The analysis of habitat distribution for key species was conducted by processing vector-format spatial data representing the habitat distribution of the Javan hawk-eagle, Javan leopard, and Javan gibbon within Gunung Halimun Salak NP (data source from Syartinilia et al. [19] and MoEF [17,20]). Given the endangered status of the key species, all spatial data used in this study were presented at a generalized scale to prevent the disclosure of sensitive location information that could pose risks to species conservation. Key species habitat distribution data were processed using the union overlay function in ArcGIS 10.8, which merged three spatial feature datasets. The union function generated new spatial data from two or three feature datasets to combine the attributes and data, where all feature data were utilized in the new feature, resulting in overlapping and non-overlapping areas [21]. This method provides a replicable approach for identifying multi-species habitat intersections using standard GIS tools. The union method was selected because it enables the merging of all habitat polygons from the three key species into a single feature, allowing for the inclusion of every possible spatial overlap in a single comprehensive output layer. This approach facilitated the identification of all areas where the key species habitats intersect.

The spatial overlay process produced a key species shared habitat distribution map within the study area. This overlay process resulted in a distribution map of key species shared habitats in Gunung Halimun Salak NP, which were categorized into two types of shared habitats based on the number of overlapping species. The two categories were shared habitats for two and three key species. The shared habitat for two key species refers to areas where the habitat distributions of the two key species overlap spatially. In contrast, the shared habitat of the three key species represents areas where the habitats of all three key species intersect within the same space. The key species shared habitat distribution analysis workflow is shown in Figure 3.

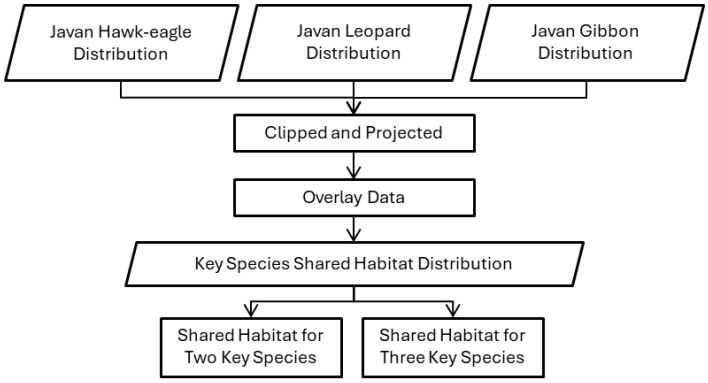

Figure 3. The analysis workflow showed the process the key species shared habitat distribution through overlay analysis. The output identifies areas of shared habitat for two key species and for all three key species.

Overview of Key Species Shared Habitat Analysis

The next step involved describing the characteristics of the shared habitat distribution for key species according to the outcomes of the spatial overlay analysis. This overlay was performed using biophysical spatial data, including land cover [22–25], elevation [24–26], and slope [25,26]. The key species that shared habitats from previous analyses were then overlaid with land cover, slope, and elevation data using the union overlay function in ArcGIS 10.8. Land cover analysis was performed using supervised classification with Sentinel-2 satellite imagery data with a resolution of 10 × 10 m (S2A_MSIL2A_20231220T030131_N0510_R032). The training area was divided into training areas in Supervised Classification analysis and for accuracy assessment [27,28], with a total of 525 training area samples utilized for the Supervised Classification process and 240 points for validation/accuracy assessment (the number of training area points is shown in Table 2).

Table 2. This table presents the number of training area points used in the land cover analysis. The training area used for supervised classification and accuracy assessment across different land cover class. The samples were derived from Google Earth and random sampling points from land cover data provided by Gunung Halimun Salak NP.

Land cover	Training area for supervised classification analysis	Training area for accuracy assessment
Forest	354	120
Build-up areas	30	20
Bare soil	51	20
Agricultural land	62	60
Plantation area	28	20

Source: Google Earth and random sampling point from land cover data in Gunung Halimun Salak NP, provided by BTNGHS

Slope and elevation data were analyzed with DEMNAS (Digital Elevation Model Nasional (DEMNAS) with a spatial resolution of 8 × 8 m. Elevation analysis was conducted in ArcGIS 10.8 by extracting elevation values across the study area to classify habitat based on altitudinal ranges (e.g., 0–500 masl, 500–1,000 masl, 1,000–1,500 masl, 1,500–2,000 masl, and > 2,000 masl). For slope analysis, the DEMNAS raster was processed using the Slope tool in ArcGIS Spatial Analyst and then reclassified into specific slope categories (e.g., 0–15%, 15–25%, 25–45%, and >45%). Additionally, an overlay of the habitat distribution with the administrative boundaries and Gunung Halimun Salak NP zonation was created using the union overlay function method, which allowed for the integration of multiple spatial datasets into a single layer. This analysis was conducted to determine the area and percentage of shared habitats within the two datasets. The output provided detailed spatial information on the distribution of key species shared habitats across different management zones and jurisdictions. These results provide a valuable basis for developing conservation strategies aligned with local governance and regulations.

Recommendation for Managing the Key Species Shared Habitats Analysis

Recommendations for managing the conservation of key species shared habitats in Gunung Halimun Salak NP were formulated based on the outcomes of previous spatial analyses and a comprehensive review of relevant documents and regulations. The document/regulation review focused on key policies for the conservation of key species habitats or population management. The documents/regulations used include

[17,20,29,30] and the Grand Design for Research and Development of Science in TNGHS (2002–2027). The Conservation Strategy and Action Plan was identified and compiled through a literature review of these documents and regulations. These Conservation Strategies and Action Plans identified through the literature review were further examined with the national park's zonation activity. The national park's zonation activity is stated in [30], which served as a central consideration in structuring these recommendations. Each Conservation Strategy and Action Plan was matched with the type of activities allowed within each zonation in Gunung Halimun Salak NP. The results will ensure that management actions address both ecological requirements and comply with legal and policy frameworks.

Results

Key Species Shared Habitat Distribution

Overlay analysis revealed two key species with shared habitat distributions in Gunung Halimun Salak NP (Figure 4). These shared habitats are categorized into two types: shared habitats involving the habitat distribution of two key species and those involving the habitat distribution of three key species. The analysis indicates that the shared habitat distribution involving two key species, the Javan gibbon and Javan leopard, covers 28.78% (25,243.89 ha) of the total area of the Gunung Halimun Salak NP. Spatial overlay analysis revealed that the only overlap in shared habitats between the two key species occurred between the Javan leopard and Javan gibbon, whereas no overlaps were detected for the other key species pairs. Meanwhile, the shared habitat of all three key species Javan gibbon, Javan leopard, and Javan hawk-eagle accounts for 55.84% (48,971.77 ha) of the NP.

Overview of Key Species Shared Habitat

Gunung Halimun Salak NP located in the two Provincial administrative, West Java and Banten Province. As for the key species shared habitat, the two and three key species shared habitat were mostly located in West Java Province. Gunung Halimun Salak NP zonation mostly categorized as core zone with 35,479.45 ha and forest zone with 18,274.35 ha, followed by use zone, rehabilitation zone, special zone, traditional zone, and religious/historical/cultural zone. The analysis of shared habitat distribution based on the zonation of Gunung Halimun Salak NP indicates that habitats involving the two key species are primarily located in the use zone, followed by the forest and rehabilitation zones. In contrast, shared habitats encompassing all three key species were most prevalent in the core and forest zones, with smaller proportions in the use and rehabilitation zones (Figure 4 and 5).

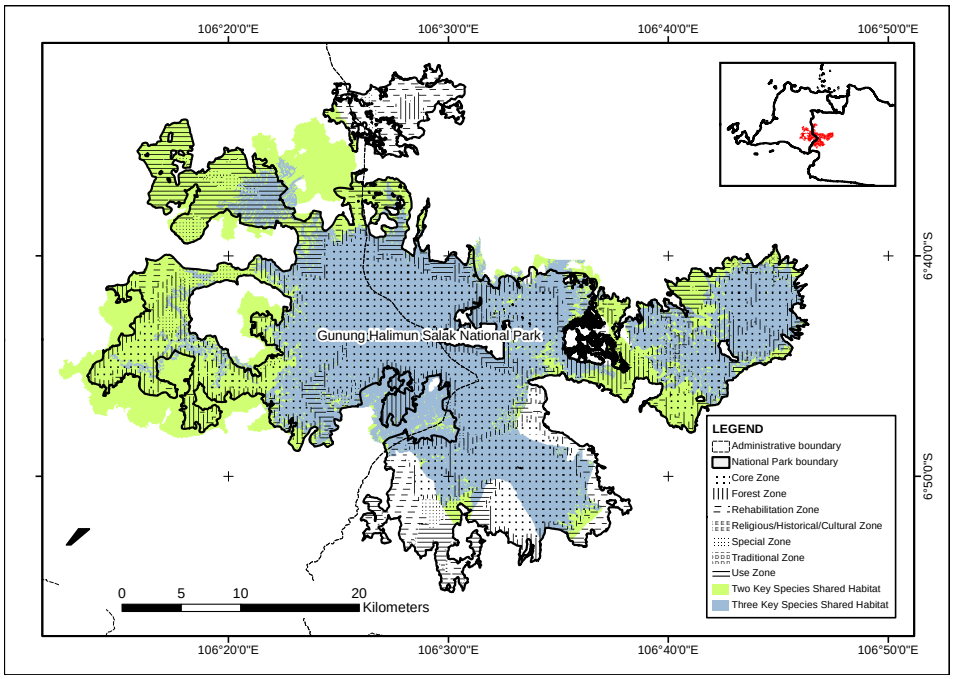

Figure 4. Key species shared habitat distribution overlay with the Gunung Halimun Salak NP zonation. The overlay highlights the illustration on how the distribution of key species shared habitat correspond to the NP zonation management (source: BTNGHS, Syartinilia et al. [19], and MoEF [17,20]).

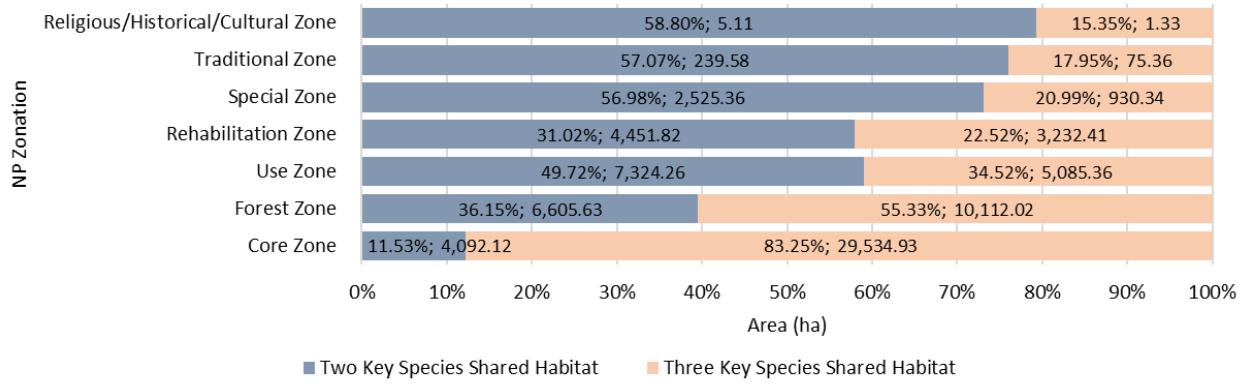

Figure 5. Distribution of key species shared habitat based on the Gunung Halimun Salak NP zonation. The chart shows the proportion and area (ha) of shared habitats within each NP zonation.

In the study area, 76,935.95 ha were identified as forest cover based on supervised classification analysis using Sentinel data (Figure 6). The overall accuracy of the analysis was 83.82%, while the Kappa Accuracy was 75.69, indicating that the land cover classification was considered reliable and performed well when compared with the reference data. The land cover in Gunung Halimun Salak NP is dominated by forest cover (approximately 87.73%; 76,935.95 ha), followed by plantations (6.10%; 5,347.52 ha). There are also agricultural areas (2.96%; 2,595.46 ha), bare soil (1.89%; 1,656.89 ha), and built-up areas (0.60%; 525.91 ha). The shared habitat based on land cover in the 2023 data shows that the distribution of both two key species and three key species shared habitat is dominated by forest cover. For the three key species habitats, 45,336.40 ha of the 48,971.77 ha are located in forest cover, while the rest are categorized as non-forest cover (plantation, built-up areas, bare soil, and others). For the two key species habitats, 21,425.25 ha of the 25,243.89 ha were categorized as forest cover.

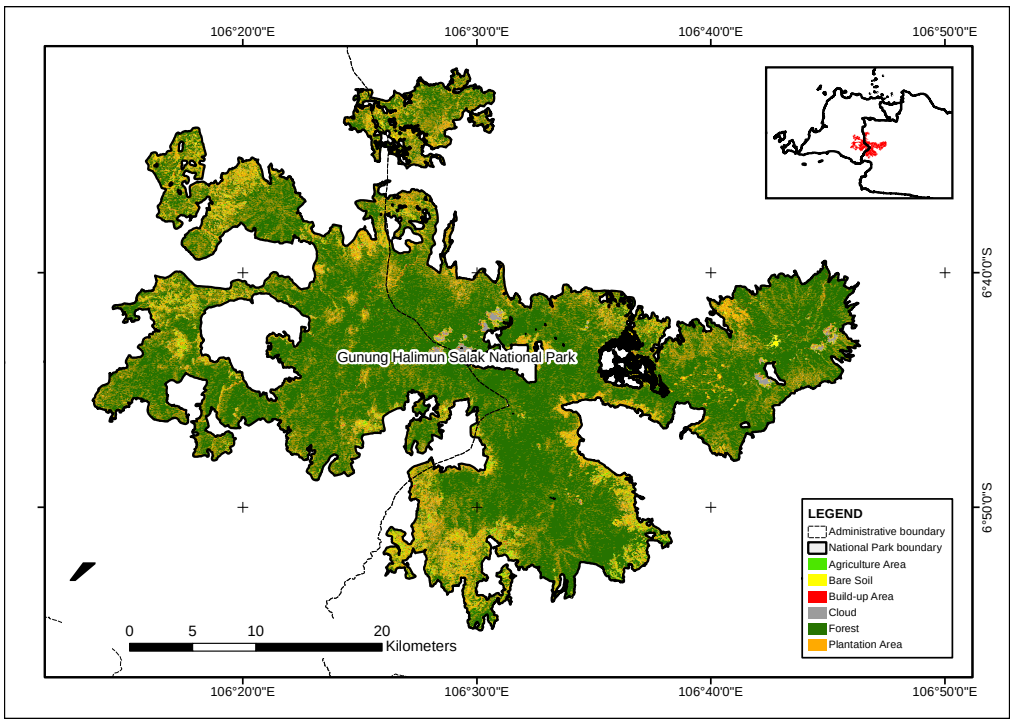

Figure 6. Land cover distribution map of Gunung Halimun Salak NP. The land cover consists of six classes derived from the supervised classification analysis using Sentinel imagery data.

As for the elevation, Gunung Halimun Salak NP is largely dominated by altitudes between 500–1,000 masl (44.44%; 38,973.13 ha) and 1,000–1,500 masl (41.66%; 36,539.03 ha). This elevation range reflects its montane forest characteristics and supports a rich diversity of flora and fauna adapted to these mid-elevation

zones (Figure 7). The shared habitat distribution, based on elevation data, indicates that areas supporting two key species shared habitat are predominantly found at elevations of 500–1,000 masl, covering 19,551.87 ha. In comparison, shared habitats involving all three key species are most concentrated at elevations of 1,000–1,500 masl, accounting for 31,575.35 ha.

Approximately 48.85% (42,841.20 ha) of the Gunung Halimun Salak NP area located in the slope is categorized as 25–45%, indicating predominantly hilly terrain in the area. This was followed by areas with slopes of 15–25%, which covered approximately 27.19% (23,845.83 ha) of the Gunung Halimun Salak NP (Figure 7). The analysis of shared habitat distribution based on slope data revealed that areas with slopes of 25–45% were predominant for both two-key-species and three-key-species shared habitats, covering approximately 11,482.72 ha and 24,632.55 ha, respectively. The 15–25% slope category represents the second largest area, with approximately 12,579.22 ha allocated to habitats for three key species and approximately 7,644.17 ha for habitats with two key species.

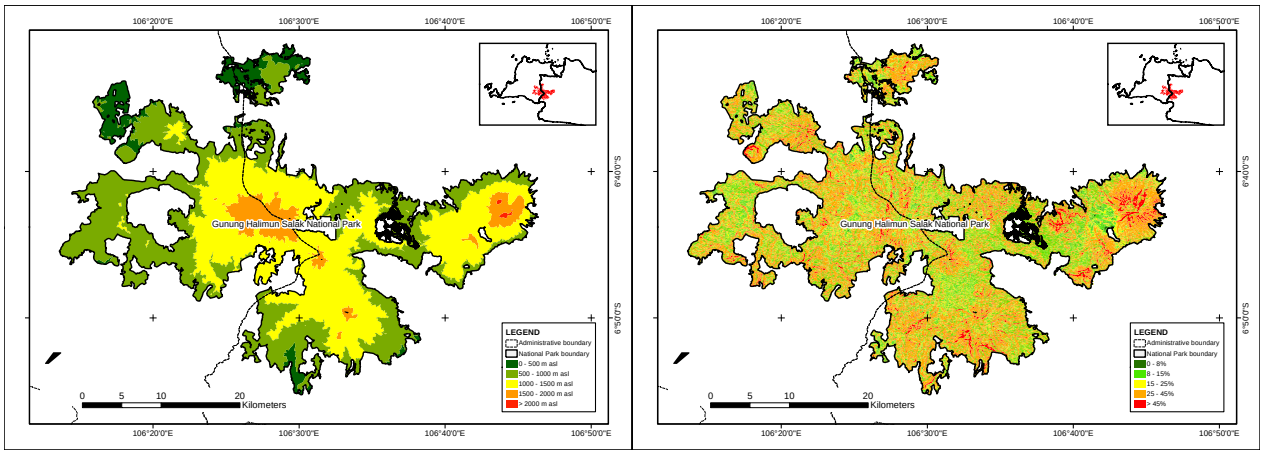

Figure 7. Elevation (left) and slope (right) distribution maps of Gunung Halimun Salak NP. Each map consists of five classes derived from analysis using DEMNAS data.

Table 3 presents an overview of the main characteristics of the key species shared habitat in Gunung Halimun Salak NP. It summarized the spatial and biophysical attributes of the shared habitat, including area, NP zonation, land cover, elevation, and slope. The table also compares information within two key species and three key species shared habitats.

Table 3. Overview of the characteristic habitat of the key species shared habitat in Gunung Halimun Salak NP. The table compares area, NP zonation, land cover, elevation range, and slope associated in each key species shared habitat category.

Shared habitat	Two key species	Three key species
Key species	Javan leopard and Javan gibbon	Javan leopard, Javan gibbon, and Javan hawk-eagle
Area (ha)	25,243.89	48,971.77
Np zonation	Use Zone, Forest Zone, Rehabilitation Zone	Core Zone, Forest Zone, Use Zone
Land cover	Forest Cover	Forest Cover
Elevation	500–1,000 masl	1,000–1,500 masl
Slope	25–45%	25–45%

Recommendation for Managing the Key Species Shared Habitat

Recommendations for managing key species shared habitats are conducted by reviewing the Conservation Strategy and Action Plan within the documents/regulations. This process involved identifying and listing the Conservation Strategy and Action Plan from documents and regulations. The Conservation Strategy and Action Plan is adjusted to the relevant regulations, as shown in Table 4. The listed conservation strategies and action plans were then sorted based on [30] related to activities in NP zonation, as shown in Table 5.

Table 4. Conservation Strategy and Action Plan for key species linked to relevant regulations. The table shows how each Conservation Strategy and Action Plan is supported by specific legal framework in Indonesia.

Conservation strategy and action plan*	Regulation
Protection and security	Law No 5/1990; Law No 32/2009; Law No 32/2024; Presidential Instructions No 1/2023; Government Regulation No 28/2011; Ministry of Forestry Regulation No P.48/2014; Ministry of Environment and Forestry Instruction No 1/2022
Inventory, monitoring, and evaluation the natural resources	Law No 5/1990; Law No 32/2009; Law No 32/2024; Presidential Instructions No 1/2023; Government Regulation No 44/2004; Government Regulation No 6/2007; Government Regulation No 28/2011; Ministry of Forestry Regulation No P.48/2014; Ministry of Forestry Regulation No P.81/2014; Ministry of Forestry Regulation No P.49/2014; Regulations of the Director General of Natural Resources and Ecosystem Conservation No P.11/2016; Regulations of the Director General of Natural Resources and Ecosystem Conservation No P.14/2016; Ministry of Environment and Forestry Instruction No 1/2022
Habitat and population management	Law No 5/1990; Law No 32/2009; Law No 32/2024; Presidential Instructions No 1/2023; Government Regulation No 44/2004; Government Regulation No 6/2007; Government Regulation No 28/2011; Ministry of Environment and Forestry Instruction No 1/2022
Biodiversity or habitat preservation	Law No 5/1990; Law No 32/2009; Law No 32/2024; Presidential Instructions No 1/2023; Government Regulation No 28/2011; Ministry of Environment and Forestry Instruction No 1/2022
Improve the conservation knowledge and research	Law No 5/1990; Law No 32/2024; Presidential Instructions No 1/2023; Government Regulation No 44/2004; Government Regulation No 28/2011; Government Regulation No 108/2015
Wildlife release or reintroduction	Law No 5/1990; Law No 32/2024; Government Regulation No 7/1999; Government Regulation No 28/2011; Ministry of Environment and Forestry Regulation No 17/2024
Ecosystem or habitat restoration	Law No 32/2009; Government Regulation No 6/2007; Government Regulation No 28/2011; Ministry of Forestry Regulation No P.48/2014; Ministry of Forestry Regulation No P.49/2014; Ministry of Environment and Forestry Instruction No 1/2022
Ecotourism development	Law No 5/1990; Law No 32/2024
Facilities and infrastructure development	Law No 5/1990; Government Regulation No 18/1994; Ministry of Environment and Forestry Regulation No P.13/2020
Stakeholder collaboration and capacity improvement	Law No 32/2009; Law No 32/2024; Presidential Instructions No 1/2023; Government Regulation No 44/2004; Government Regulation No 28/2011; Government Regulation No 108/2015; Ministry of Environment and Forestry Instruction No 1/2022
Conservation funding	Law No 32/2009; Law No 32/2024; Presidential Instructions No 1/2023; Government Regulation No 6/2007; Government Regulation No 28/2011; Ministry of Environment and Forestry Instruction No 1/2022

*) Conservation Strategy and Action Plan compiled based on MoF [29], and MoEF [17,20,30], and Document Grand Design for Research and Development of Science in Gunung Halimun Salak NP.

Table 5. Conservation Strategy and Action Plan align with the NP zonation based on Ministry of Environment and Forestry Regulation No P.76/2015. The table indicates which Conservation Strategy and Action Plan are permitted within each NP zonation category.

Conservation strategy and action plan*	NP Zonation (Ministry of Environment and Forestry Regulation No P.76/2015)						
	Core Zone	Forest Zone	Use Zone	Traditional Zone	Rehabilitation Zone	Religious/Historical/ Cultural zone	Special Zone
Protection and security	✓	✓	✓	✓	✓	✓	✓
Inventory, monitoring, and evaluation the natural resources	✓	✓	✓	✓	✓	✓	✓
Habitat and population management	✓	✓	✓	✓	-	-	-
Biodiversity or habitat preservation	✓	✓	✓	✓	✓	✓	-
Improve the conservation knowledge and research	✓	✓	✓	✓	✓	✓	✓
Wildlife release or reintroduction	-	-	-	-	✓	-	-
Ecosystem or habitat restoration	-	-	✓	-	✓	✓	✓
Ecotourism development	-	✓	✓	✓	-	✓	-
Facilities and infrastructure development	✓	✓	✓	✓	✓	-	✓
Stakeholder collaboration and capacity improvement	-	-	-	✓	✓	✓	-
Conservation funding	-	-	-	-	-	-	-

*) Conservation Strategy and Action Plan compiled based on MoF [29], and MoEF [17,20,30], and Document Grand Design for Research and Development of Science in Gunung Halimun Salak NP

Discussion

Key Species Shared Habitat Distribution

Habitat distribution of Javan hawk-eagle [5,7,8,19], Javan leopard [9–11], and Javan gibbon [3] are located in Java Island tropical rain forest. Gunung Halimun Salak NP is among the national parks with natural forests that serve as a habitat for rare species of Java Island such as Javan hawk-eagle [31,32], Javan leopard [11], and Javan gibbon [33,34]. These three species are also known as key species and flagship species of Gunung Halimun Salak NP based on Grand Design for Research and Development of Science in TNGHS (2002–2027). Nearly half of the Gunung Halimun Salak NP area is identified as shared habitat for three key species. The key species shared habitat mostly located in the core and forest zone of Gunung Halimun Salak NP covers with forest area. Core and forest zone of NP is specifically designed as a place for species home range, territory, and protection [30]. It also serves as nesting site location [32] or territory of the targeted species [33].

The overlay results revealed that the highest concentration of three key species shared habitats was found at elevations ranging from 1,000 to 1,500 masl followed by two key species shared habitat from 500–1,000 masl. The elevation of this shared habitat is consistent with information from previous studies, where this elevation not only suitable to serve a food source but also as resting and nesting sites for key species [32,34]. These three key species are found at elevations ranging from 0 to 3,000 masl [3,35,36], although some are concentrated only up to 2,000 masl. Based on Grand Design for Research and Development of Science in TNGHS (2002–2027), elevation range in Gunung Halimun Salak NP is suitable habitat for certain species such as rasamala (*Altingia excelsa*), puspa/needlewood (*Schima wallichii*), saninten/Javan shesnut-oak (*Castanopsis javanica*), kiriung anak/white oak (*Castanopsis acuminatissima*), pasang/oak (*Quercus gemelliflora*), Indonesian maple (*Acer Iaurinum*), ganitri/rudraksh (*Elaeocarpus ganitrusi*), fig (*Ficus spp*), kayu manis/cinnamon (*Cinnamomum sp.*), kileho (*Saurauia pendula*), kimerak (*Weinmannia blumei*), and others. Javan gibbon found in the elevation up to 1,600 masl [3] because at this elevation it is known to have a diversity of plant species that serve as a food source for the Javan gibbon (e.g., *Ficus variegata*). Javan leopard dominated found in the elevation up to 1,000 masl, while for Javan hawk-eagle up to 2,000 masl [32,35]. For the Javan leopard and Javan hawk-eagle, these elevations offer tree species that support the food chain by serving as resources for their prey. Additionally, within this elevation range, several tree species are suitable for the Javan hawk-eagle's nesting preferences (e.g., *Altingia excelsa*, *Schima wallichii*, *Litsea* sp.).

The analysis also reveals that the key species shared habitats are predominantly situated in areas with steep slopes. These areas mainly fall within the 25–45% and 15–25% slope categories. The three key species utilize steep slopes for nesting, shelter, and rearing their child. The Javan hawk-eagle uses slopes with steep to very steep inclines as nesting sites [35], as well as Javan leopard [9,10]. The use of slopes by the Javan hawk-eagle and the Javan leopard is known to serve as a place for sheltering and raising their child [31,36]. In the term of breeding habitat, the Javan hawk-eagle will choose the tallest tree with a Rauh architecture located on a steep cliff [32,36]. Meanwhile, the Javan leopard will use cavities or recesses in the cliff walls. This is mainly because breeding habitats typically need to offer a certain level of protection. Additionally, they must supply adequate food sources to meet the species' dietary needs [32,36], because the stream flow mostly located in the down valley providing a water source for potential prey of the key species [32,36].

Spatial overlap doesn't necessarily indicate direct ecological interaction, rather it serves as a proxy for potential interaction and shared habitat use as actual interaction (e.g., competition and predation) beyond spatial data. Our findings showed that, the existence of shared habitats among the key species, especially in areas with similar forest cover, elevation, and slope, could reflects a certain level of niche overlap. Despite differences in diet and movement patterns, the similarities in biophysical conditions imply that these species may depend on common ecological resources, such as particular tree species for food, nesting, or shelter [31,32,36]. Thus, this overlaps also consistent with the principles of spatial ecology, which explains how species can inhabit the same areas due to the suitability of the habitat and the availability of necessary resources. Examining relationship among species in shared habitat is to define their spatial boundaries which allows for exploration of their ecological roles through trophic interactions and resource [37]. This analysis reveals that the three key species share similar biophysical habitat conditions, especially in terms of meeting their dietary needs [38]. Competition occurs when species interact to acquire food [13], while predation involves the relationship between predators and their prey within an ecosystem [14,15]. Javan hawk-eagle and Javan leopard are classified as carnivorous predators, which may lead to competition between them as they hunt for prey within overlapping territories. They share similar prey preferences primarily targeting small to medium sized arboreal mammals or primates [18], Javan gibbon as herbivore could potentially become one of their prey. The Javan gibbon is considered one of the primary possible prey for the Javan leopard, and

it tends to produce distinct vocalizations when it detects the presence or movement of a nearby predator like the Javan leopard [17]. Although there is no scientific evidence confirming that the Javan gibbon is preyed upon by the Javan hawk-eagle, it remains a possibility, as existing records indicate that small primates are among the species commonly hunted by this raptor (e.g., *Trachypithecus auratus*) [36].

Recommendation for Managing the Key Species Shared Habitat

Recommendation for managing the key species shared habitat is arranged through the Conservation Strategy and Action Plan review guided by the activity based on NP zonation regulation [30] and other relevant regulation (can be seen in Table 4 and Table 5). Some recommendation is limited due to the limited activity in the NP zonation (e.g., ecotourism development). The recommendation for wildlife release or reintroduction for key species is not limited to the rehabilitation zone only. The key species release will take place in areas near forest cover or within the core and forest zone of the NP. This location is chosen to ensure the species are reintroduced into suitable and undisturbed habitat, which is resemble their natural habitat environment. The recommendation map can be seen in Figure 8.

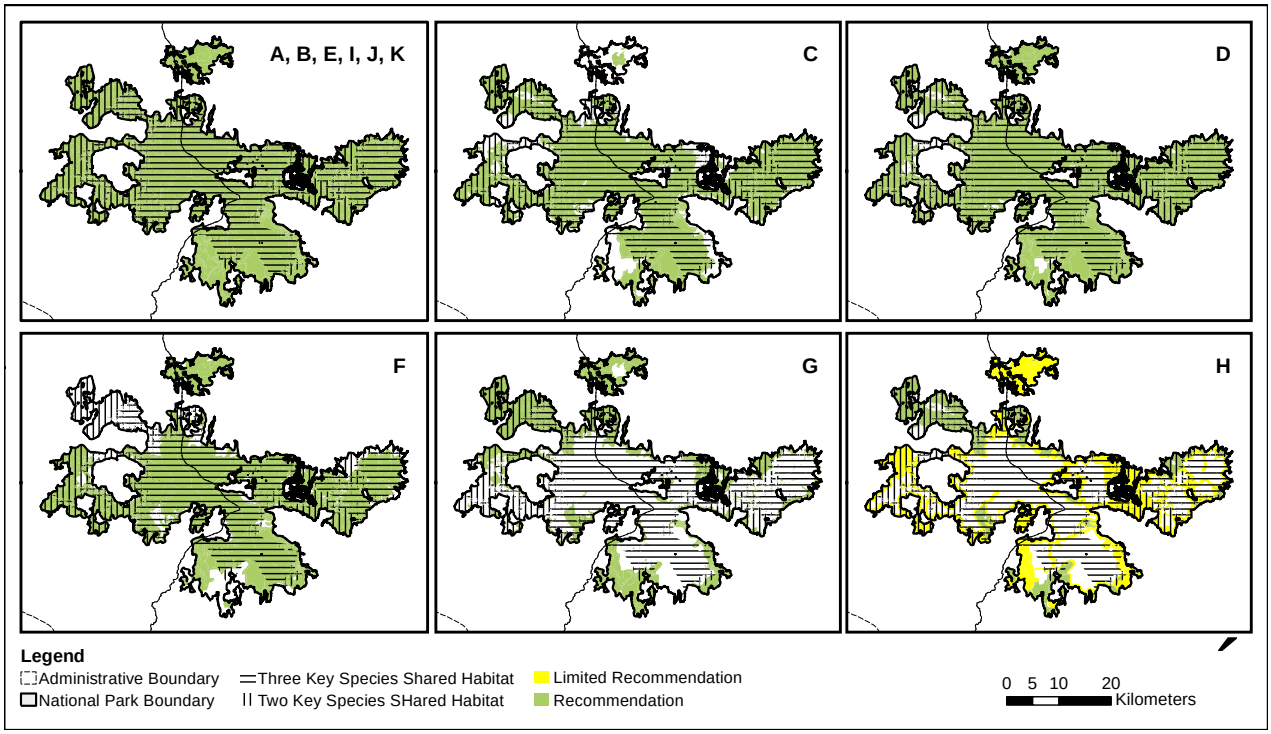

Figure 8. Recommendation map in Gunung Halimun Salak NP, such as (A) Protection and security, (B) Inventory, monitoring, and evaluation the natural resources, (C) Habitat and population management, (D) Biodiversity or habitat preservation, (E) Improve the conservation knowledge and research, (F) Wildlife release or reintroduction, (G) Ecosystem or habitat restoration, (H) Ecotourism development, (I) Facilities and infrastructure development, (J) Stakeholder collaboration and capacity improvement, and (k) Conservation funding.

Biophysically the three key species and two key species shared habitat are located in the forest cover within 500–1,500 masl and has steep slope around 25–45%. Basically, this condition directs to recommendation toward protection and security management aligning with the Conservation Strategy and Action Plan. The recommendation for two key species shared habitat are located in all zonation of the Gunung Halimun Salak NP, but dominated in use, forest, rehabilitation, and core zone. The recommendations shall prioritize population and habitat management, protection and security measures, biodiversity or habitat preservation, improve the conservation knowledge and research, and the development of supporting facilities and infrastructure to facilitate these activities. Limited ecotourism development is intended exclusively for the forest and use zones. Ecosystem restoration is recommended in the rehabilitation, use, and special zones, while wildlife release or reintroduction should be restricted to the core, forest, and rehabilitation zone only.

Then for recommendation for three key species shared habitat are located almost in all zonation of the Gunung Halimun Salak NP, but dominated in core and forest zone. The recommendations shall focus on

population and habitat management, protection and security measures, biodiversity or habitat preservation, improve the conservation knowledge and research, and the development of supporting facilities and infrastructure to facilitate these activities. It also appeared that it can be suggest for the limited ecotourism development in the forest and use zone, while wildlife release or reintroduction shall be restricted to the core, forest, and rehabilitation zone only. In addition to these recommendations, stakeholder collaboration and conservation funding are also essential for integrated management within the NP, particularly in areas of key species shared habitat. These efforts should not be limited to inventory, monitoring, or evaluation activities. They can also support the implementation more comprehensive, such as initiatives to extend the conservation action plan both in-situ and ex-situ sites across Java Island.

Another recommendation for managing key species shared habitat is to strengthen future research collaboration between academic institution and relevant conservation stakeholders, given the limitations in studying these three key species. Conservation collaboration is essential by securing the conservation funding to support the long-term research efforts, including the monitoring method and collaborative studies. The collaborative research efforts can also integrate the advance technologies (e.g., telemetry or camera trap) to improve understanding the movement pattern and direct documentation of key species presence or potential interaction within shared habitats.

Conclusions

In conclusion, Gunung Halimun Salak NP serves as a critical habitat for Javan hawk-eagle, Javan leopard, and Javan gibbon as key species in Java Island. Despite their differing movement patterns, the spatial overlap of these species within the landscape indicates potential ecological interactions, particularly in relation to the trophic structure. This study identified and analyzed shared habitats through spatial data and biophysical characteristics, revealing that these habitats are primarily located in forested areas at 500–1,000 meters above sea level and on steep slopes of 25–45%. The shared habitats categories into two key species shared habitat and three key species shared habitat, mostly located in core and forest zones of NP. By aligning the results with existing Conservation Strategies and Action Plans, regulations, and NP zonation, this study proposes integrated spatial approach and comprehensive management recommendations to support the long-term multispecies conservation shared habitats in Gunung Halimun Salak NP. The spatial framework and analytical approach used in this study have strong potential to be replicated in other Indonesian NP to support the multispecies conservation planning and management.

Author Contributions

RAS: Conceptualization, Methodology, Formal analysis, Visualization, Writing - Original Draft; **S**: Supervision, Resources, Writing - Review & Editing; **YAM**: Supervision, Writing - Review & Editing; **AA**: Supervision, Resources, Writing - Review & Editing.

AI Writing Statement

During the preparation of this work, the author(s) used ChatGPT to refine the manuscript's English language structure and clarity. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Conflicts of Interest

There are no conflicts to declare.

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