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Identification of Javan Hawk-Eagle (*Nisaetus bartelsi*) and Its Habitat on the Island of Bali

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Abstract

The Javan Hawk-Eagle (*Nisaetus bartelsi*), an endemic species of Java, has been occasionally observed in Bali, prompting the need for scientific verification due to its critical conservation status. This study aimed to confirm the presence of the Javan Hawk-Eagle in Bali and map its potential distribution based on habitat suitability using an integrated spatial-ecological approach. A probability distribution model was developed using logistic regression with NDVI (Normalized Difference Vegetation Index), slope, and elevation as predictor variables. The resulting probability map was subsequently delineated using land cover, land use data, and information obtained directly from key informant interviews to produce a refined predicted suitable habitat patches map for the Javan hawk-eagle. To confirm its reliability, we conducted patch occupancy surveys to confirm the Javan Hawk-Eagles existence in patches that have historical occurrence of Javan Hawk-Eagle. Logistic regression modeling identified the Javan Hawk-Eagle's potential distribution area of 1,069.4 km². Using this model and information from key informants, forest function maps, and land cover maps, 14 predicted habitat patches were delineated. Subsequent patch occupancy surveys confirmed three of these patches as actual habitats for the Javan Hawk-Eagle on Bali, namely West Bali Protected Forest, Batukaru and Batukahu Area, and Buyan-Tamblingan Lake Tourism Forest. These findings provide the first empirically validated confirmation of the Javan Hawk-Eagle's presence in Bali, supported by direct photographed observations verified by experts, and delineate key habitat patches for future conservation planning.

Keywords: Bali Island, Habitat Suitability, Javan Hawk-Eagle, Logistic Regression, Patch Occupancy

1. Introduction

Javan Hawk-Eagle (*Nisaetus bartelsi*) is a diurnal bird of prey endemic to the island of Java and belongs to the family Accipitridae [1,2]. On the island of Java, Javan hawk-eagles are distributed in primary and secondary tropical forests on steep slopes [3,4]. Between 1989 and 2023, the Javan Hawk-Eagle population on Java is projected to increase to 511 pairs, distributed across 36 occupied patches [5–7]. Despite this trend, the wild populations of the Javan Hawk-Eagle have declined due to hunting, illegal trade, habitat conversion, and deforestation [8]. The IUCN Red List has classified the Javan Hawk-Eagle as globally endangered. Recognizing the critical conservation status of this species, the Indonesian government has taken steps to protect it through regulations such as the Ministry of Environment and Forestry Regulation No. P.106/MENLHK/SETJEN/KUM.1/12/2018 and the Director General of Conservation of Natural Resources and Ecosystems Decree No. 200/IV-KKH/2015 [6,9].

Bali, an island covering 5,590 km² [10], features diverse landscapes and ecosystems, making it a potential habitat for raptors. Research on raptors in Bali has been conducted, such as studies on the migration of raptors in the eastern part of the island, specifically at Gunung Sega within the Seraya Karangasem Mountain Range [11–14]. Raptor research has also been conducted in the Danau Buyan-Danau Tamblingan Nature Tourism Park (Taman Wisata Alam Danau Buyan-Tamblingan) [15]. In recent years, questions have arisen regarding the potential presence of Javan Hawk-Eagles on Bali. Although no peer-reviewed scientific studies have

confirmed its existence on the island, anecdotal and observational records have been reported in areas such as SPTN 1 West Bali National Park, Lempuyang Temple, and Sega Mountain in Karangasem [16,17]. The absence of peer-reviewed studies limits our understanding of the distribution of this species in the region.

The lack of scientifically verified data on the species' existence in this region may lead to the under-representation of its habitat in conservation planning, thereby reducing the effectiveness of future strategies [18]. Furthermore, considering the species' globally threatened status and its designation as a conservation priority by the Director-General of Natural Resources and Ecosystem Conservation (Decree No. 200/IV-KKH/2015), research aimed at verifying its presence in Bali is imperative for practical conservation. To address this gap, mapping the predicted distribution of the Javan Hawk-Eagle and confirming its presence in Bali are essential steps to ensure appropriate and targeted conservation action [19]. This study aimed to map the potential distribution of Javan Hawk-Eagles, identify predicted suitable habitat patches, and confirm the species' occurrence in Bali. The resulting information will serve as a foundational reference for future conservation initiatives targeting the Javan Hawk-Eagle in the region.

2. Materials and Methods

2.1. Study Area

This study was conducted on the main island of Bali, located within the administrative province of Bali, Indonesia (Figure 1), between January and May of 2024. Bali is situated between 8°3'38" and 8°50'56" south latitude and 114°25'53" and 115°42'39" east longitude, covering a total area of 5,590 km². According to the Ministry of Environment and Forestry (KLHK) data in 2019, Bali's land cover primarily comprises dryland forests (both primary and secondary), primary and secondary mangrove forests, shrubs, plantation forests, settlements, plantations, dryland agriculture, grasslands, paddy fields, fish ponds, bare land, airports, and ports. Paddy fields dominate Bali's land cover, accounting for 25.32% of the total area (370.53 km²). The 2024 DEMNAS satellite imagery shows that Bali's elevation varies from 0 to 2,900 meters above sea level (masl). The most extensive elevation range is below 200 masl, covering 36.25% (1,951 km²) of the island area. Furthermore, the 2024 DEMNAS satellite imagery revealed diverse slope gradients on Bali, ranging from gentle to steep, with slopes between 8% and 15% dominating 23.31% of the total land area (1,252 km²).

2.2. Tools and Equipment

The tools employed in this study included binoculars, a DSLR camera, a GPS device, structured interview questionnaires, and software such as ArcGIS 10.8, and Microsoft Office. Binoculars, a DSLR camera, and a GPS device were used to support the field confirmation of Javan Hawk-Eagle encounters through visual observation, photographic documentation, and georeferencing of sighting locations. Structured interviews with local informants further aided in validating potential occurrences and in identifying areas of interest. Spatial analysis utilized geospatial datasets, including Landsat 8 OLI satellite imagery and high-resolution national elevation data (DEMNAS), which enabled the topographic characterization of the study area. Land cover data were derived from the 2019 dataset provided by the Ministry of Environment and Forestry (KLHK), and the delineation of protected areas was based on the 2024 World Database on Protected Areas (WDPA).

2.3. Methods

The methodology is divided into three main approaches (Figure 2): Mapping the Probability Distribution Area, Identifying Probable Habitat Patches, and Conducting a Patch Occupancy Survey. These methods are a combination of spatial modelling and field surveys. The spatial modelling was used for predicting the distribution of Javan Hawk-Eagle and identify its probable patches, while the field survey used for confirming its presence in predicted patches. The study began with a spatial analysis to model the probability distribution of the

Javan Hawk-Eagle (*Nisaetus bartelsi*) in Bali, using geospatial data processed through a

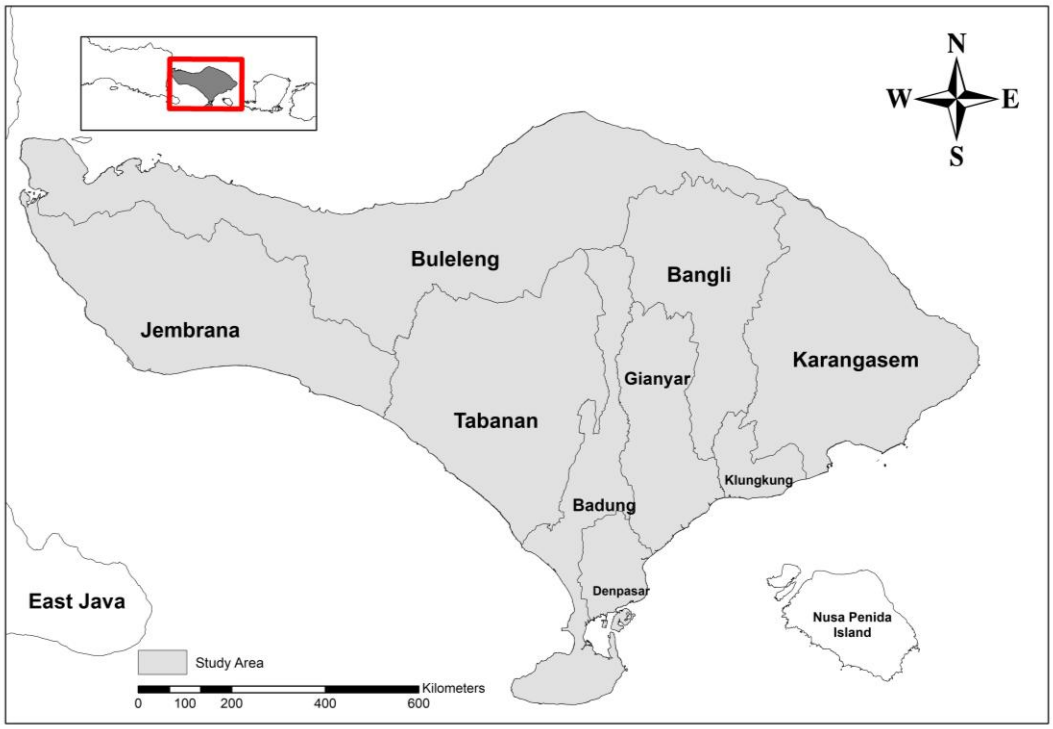

Figure 1. Map of the study area which indicated by grey colour. Nusa Penida Island was excluded in our study.

logistic regression model developed by Syartinilia and Tsuyuki [7]. Following the generation of probability distribution maps, potential habitat *patches* were identified based on land cover delineation, land use classifications, and information obtained from experienced informants, such as academic experts, Javan Hawk-Eagle conservation practitioners, trained birding guides with substantial field experience minimum 5 years of experiences, as well as representatives from local government and conservation law enforcement agencies responsible for wildlife protection and management. Subsequent stages involved field surveys conducted between 2023 and 2024 to confirm the species' presence in the identified areas. In addition to confirming occurrences, habitat suitability assessments were performed for each surveyed *patch*. The outcomes of these surveys include the updated distribution status of the Javan Hawk-Eagle in Bali and evaluations of habitat suitability within the surveyed *patches*. All findings were then used as the foundation for developing environmental management recommendations concerning the presence of the Javan Hawk-Eagle in Bali.

2.3.1. Mapping the Probability Distribution of Javan Hawk-Eagles in Bali

Spatial modeling used to map the probability distribution of Javan Hawk-Eagles was based on the study by Syartinilia and Tsuyuki [7], who developed a distribution probability model using pseudo-absence data in Gede Pangrango National Park. This model has also been utilized in other studies, such as mapping the potential habitats of *Javan Hawk-Eagles* in Central Java [4], modeling the species' remaining habitats in West Java [20], and estimating the population of Javan Hawk-Eagle*s* across Java Island [6].

The probability distribution of the Javan Hawk-Eagle in Bali was conducted by overlaying a digital elevation model (DEM) derived from DEMNAS satellite imagery, a slope map generated from DEMNAS satellite imagery, and a Normalized Difference Vegetation Index (NDVI) map derived from Landsat 8 satellite imagery. Javan Hawk-Eagles usually use an area that have steep slope (>45% gradient), with elevation in range of 0-2000 masl and highly vegetated area, which demonstrated with high level of NDVI [4,6,20].

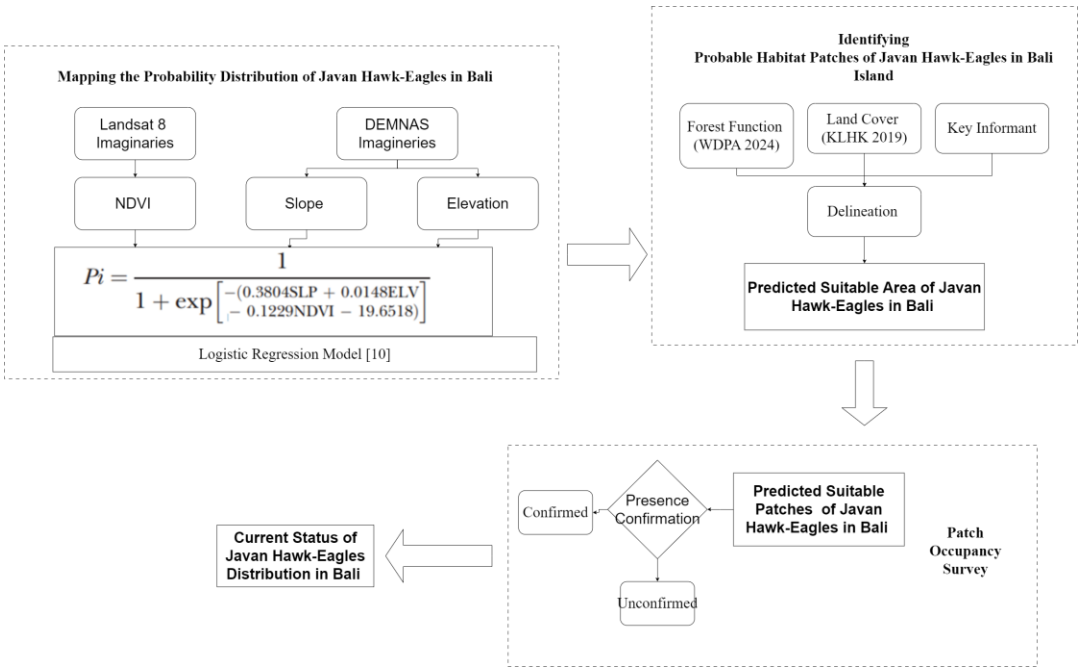

Figure 2. Research Methodology Flowchart. Methodology of this research divided into three phases, consist of mapping the probability distribution, identifying probable habitat patches and patch occupancy survey to the probable habitat patches.

The model used in this study was a logistic regression model. This study adopted logistic regression (LR) for species distribution modelling, following Syartinilia and Tsuyuki's model [7]. The LR equation employed is as follows:

$$Pi = \frac{1}{1 + \exp\ [-((0.3804\ \times \mathrm{SLP}) + (0.0148 \times \mathrm{ELV}) - (0.1229 \times \mathrm{NDVI}) - 19.6518)]} \quad (1)$$

Where :

Pi : Probability of Javan Hawk-Eagle distribution

SLP : Slope Value

ELV : Elevation Value

NDVI : Normalized Difference Vegetation Index

The logistic regression equation applied to Bali was derived from the original dataset from Gede Pangrango National Park where pseudo-absence values were generated from environmentally unsuitable areas outside known presence locations. No new pseudo-absence points were generated for Bali. The threshold value used to interpret the model outputs was set to 0.5. Areas with predicted probability values above 0.5 were classified as potential distribution areas for the Javan hawk-eagle, indicating a higher likelihood of species occurrence based on environmental suitability. Conversely, areas with values below 0.5 were categorized as having a non-potential distribution, suggesting unsuitable conditions for the species. The modelling results generated predicted suitable areas for the distribution of Javan-Hawk Eagles in Bali.

2.3.2. Identifying Probable Habitat Patches of Javan Hawk-Eagles on Bali Island

According to Syartinilia et al. [6], this model has certain limitations. Specifically, it only predicted suitable areas for Javan Hawk-Eagles in highland regions, potentially overlooking habitats in lowland areas. Therefore, it is essential to include additional analyses to identify probable areas or habitat patches that the model may not capture. To address this, a supplementary spatial analysis was conducted to identify potentially suitable habitats beyond those predicted. The first step involved gathering qualitative data from six key

informants, which includes academic expert, government agencies responsible for wildlife and habitat conservation (Bali Natural Resources Conservation Agency, West Bali National Park Authority), two experienced local birdwatchers, and non-governmental organizations engaged in Javan Hawk-Eagle conservation. These insights were subsequently organized through descriptive analysis, and integrated with spatial data, including the 2019 National Land Cover Map (KLHK) and the 2024 Forest Function Map from the World Database on Protected Areas (WDPA). By overlaying these datasets onto the predicted suitable areas generated by the logistic regression model, a refined delineation of the predicted suitable habitat patches was produced. This integrative approach provides a more comprehensive view of the potential habitat distribution of the Javan Hawk-Eagle in Bali, including areas that may not be detected by statistical modeling alone.

2.3.3. Patch Occupancy Survey

Patch occupancy surveys were conducted on predicted suitable habitat patches, with surveyed site selection based on two criteria: (1) the patch was predicted to be suitable by the probability distribution of Javan Hawk-Eagle maps or mentioned by key informants, and (2) the patch had a historical record of Javan hawk-eagle presence as reported by key informants, with accessibility by road considered an operational prerequisite. The objective of these surveys was to verify the current presence of the Javan Hawk-Eagle in areas where both spatial modelling and local ecological knowledge overlapped. Confirmation was sought through direct observations, documented and undocumented nest sightings, and information from residents and field officers from national parks and the Bali Natural Resources Conservation Agency (BKSDA) between 2023 and 2024. Surveys were carried out between 09:00 and 14:00 local time, coinciding with the peak activity period of the Javan Hawk-Eagle [21], and involved scanning large areas from a single vantage point with a wide field of view. Patches were categorized as "occupied" if the presence of the Javan Hawk-Eagle was confirmed, "unoccupied" if no evidence of the species was found, and "unsurveyed" if the patch could not be surveyed. This survey resulted in a table of the current distribution status of the Javan Hawk-Eagle in Bali.

3. Results

3.1. Mapping the Probability Distribution of Javan Hawk-Eagles in Bali

Figure 3 shows the areas predicted to be suitable for Javan Hawk-Eagles based on logistic regression modeling. The model was developed using logistic regression with three key environmental predictors: slope, elevation, and NDVI values. These parameters reflect the ecological preferences of the species, as reported in previous habitat studies. According to Figure 3, the predicted suitable areas for the Javan Hawk-Eagle were concentrated in the forest with mountainous regions located in several districts, namely Jembrana, Buleleng, Bangli, Karangasem, Badung, and Tabanan, encompassing a total area of 1,069.4 km2. Moreover, the largest contiguous suitable habitat was found in western and northern Bali (Jembrana and Buleleng), while smaller and more fragmented patches appear in the eastern regions (Karangasem and Bangli). These predicted areas provided the basis for field verification.

3.2. Identifying Probable Habitat Patches of Javan Hawk-Eagles on Bali Island

Information provided by key informants (Table 1) indicates that Javan Hawk-Eagles in Bali are present in mountainous and lowland regions. The lowland region where Javan Hawk-Eagles were present was in West Bali National Park. Only four key informants contributed confirmed and usable interview data for this research. Attempts to obtain supplementary confirmation from governmental conservation agencies (e.g., BKSDA, national park management) did not yield additional verified information; thus, the interview component is based exclusively on the four key informants.

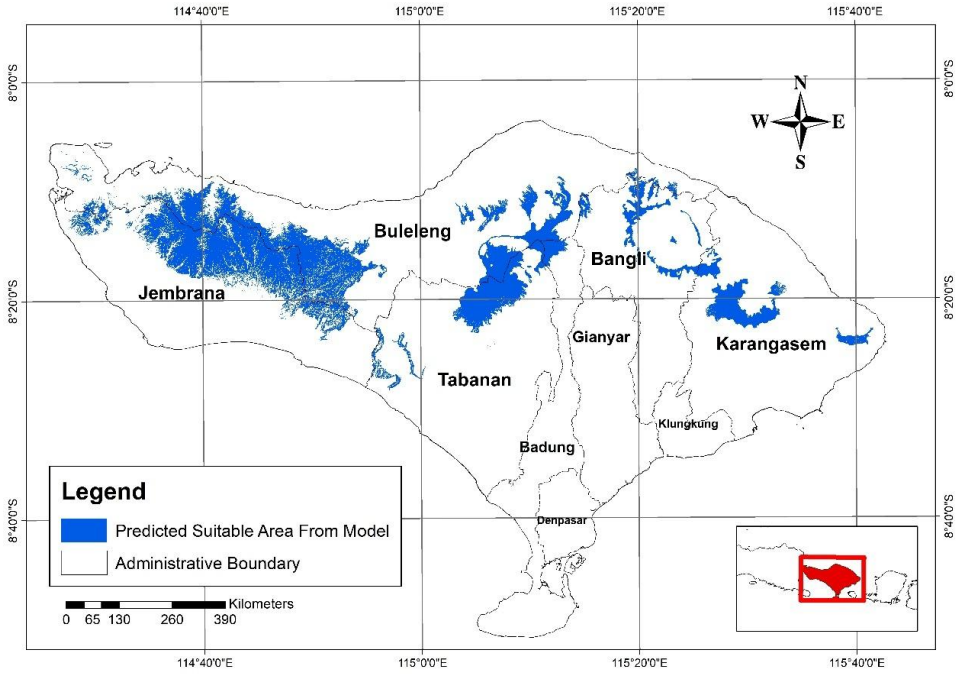

Figure 3. Prediction of suitable areas using the logistic regression model in Bali. Blue area indicated the predicted suitable areas according to logistic regression model.

Table 1. Results of Key Informants Interviews on the Presence of Javan Hawk-Eagle in Bali. Key informants indicated that Javan-Hawk Eagles in Bali have been sighted in six different places, spanning from 1994 until 2022.

Location	Years of Discovery	Description of Observation	Key Informant
Batukahu Nature Reserve (Eka Karya Bedugul Botanical Garden)	Unknown	Javan Hawk-Eagle observed soaring above mixed montane forest	KI1
West Bali National Park (SPTN I)	1994	Historical record noting the presence of Javan Hawk-Eagle within park boundaries	KI2
Buyan–Tamblingan Lake Nature Tourism Park	2005–2007	Javan Hawk-Eagle reported attempting to prey on domestic chickens and subsequently trapped in a local snare	KI2, KI3
Mount Sega, Karangasem	2012–2018	Javan Hawk-Eagle observed soaring; potentially associated with seasonal raptor movement	KI3, KI2
Lempuyang Temple, Karangasem	2012–2018	Javan Hawk-Eagle spotted flying across the forest edge near the temple area	KI3
Batukahu Nature Reserve (Eka Karya Bedugul Botanical Garden)	2019–2021	Javan Hawk-Eagle frequently sighted perching on tall emergent trees	KI3, KI2
West Bali Learning Forest	2021–2022	Javan Hawk-Eagle recorded soaring above secondary forest matrix	KI4

*Note: KI1 is a professor in the Biology Department at Udayana University; KI2 is a practitioner involved in Javan Hawk-Eagle conservation programs in Java; KI3 and KI4 are birding tour guides in Bali with at least five years of experience in birdwatching, assisting ornithological research, and birdwatching tourism.

Reports from key informants indicate that Javan Hawk-Eagles continue to be detected across both protected and unprotected forest areas in Bali, with most sightings involving birds soaring above the canopy. A small number of accounts included context-specific events, such as interactions with local livestock or temporary capture in human-made snares, while others described detections in forest stands containing suitable tall emergent trees. These compiled records show that the species has been intermittently detected on the island over a broad

temporal range, from 1994 through 2021, reflecting irregular but persistent occurrences across multiple sites.

Key informants also identified several factors reported to influence the conservation of Javan Hawk-Eagles in Bali. Informants reported that habitat fragmentation across the island remains a major issue, particularly in areas undergoing rapid land-use change. They also noted a potentially notable pattern in which Javan Hawk-Eagles have recently been observed at elevations below 1000 meters above sea level. In addition, persistent pressures related to hunting and wildlife trade were described as continuing to affect raptor species in Bali. Informants further indicated that several bird species, including protected raptors, remain targets of poaching activities.

Figure 4 presents the predicted suitable habitat patches based on delineating suitable areas from the model, forest cover, and information from key informants, overlaid with protected areas according to the WDPA. A total of 14 suitable habitat patches for the Javan Hawk-Eagle were identified on Bali Island. These patches are distributed across upland and lowland forested areas on Bali Island.

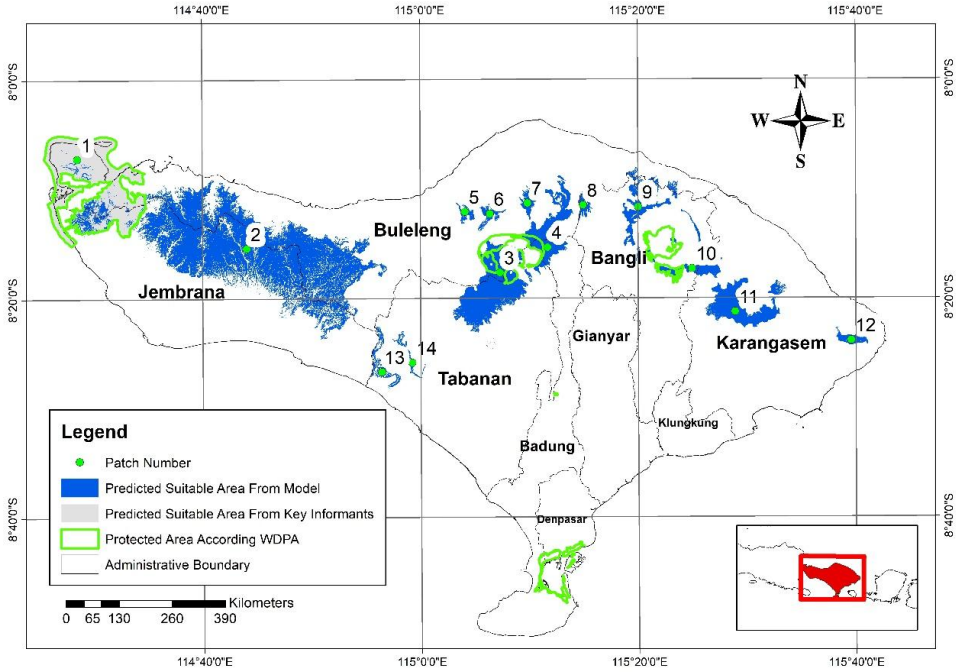

Figure 4. Predicted Suitable Habitat Patches of Javan Hawk-Eagles in Bali. Consist of 14 patches across Bali Island which four of the patches are inside protected areas according to WDPA, while 12 of them are outside the protected areas.

According to the World Database on Protected Areas (WDPA), Bali Island has seven protected areas: West Bali National Park (located in Patch 1), Batukahu Nature Reserve (part of Patch 3), Buyan-Tamblingan Lake Nature Recreation Park (located in Patch 4), Mount Batur-Bukit Payang Nature Recreation Park (part of Patch 10), Panelokan Nature Recreation Park (part of Patch 10), Sangeh Nature Recreation Park, and Ngurah Rai Grand Forest Park. Based on Figure 3, the protected areas predicted to be suitable habitats for the Javan Hawk-Eagle are West Bali National Park, Batukahu Nature Reserve, Buyan-Tamblingan Lake Nature Recreation Park, Mount Batur-Bukit Payang Nature Recreation Park, and Panelokan Nature Recreation Park.

Table **2** shows the areas of predicted suitable habitat patches and its forest status according to WDPA.

The total coverage of protected areas within the predicted suitable habitat patches of the Javan Hawk-Eagle (

Table **2**) indicates that 18.6% of the range is within protected areas, whereas 81.8% lies in non-protected areas. More specifically, the predicted suitable habitat patches of the Javan Hawk-Eagle within protected areas included 14.5% in West Bali National Park, 1.6% in the Batukahu and Batukaru areas, 1.7% in Buyan-Tamblingan Lake Nature Park, and 0.6% in the southern region of Mount Batur. The predicted suitable habitat patches of the Javan Hawk-Eagle in Bali outside of protected areas were as follows: 47.0% in the West Bali Protected Forest, 9.3% in Buyan-Tamblingan Lake Nature Park, 6.7% in the Batukahu and Batukaru areas, 4.0% in the northern regions of Mount Batur and Mount Agung, and 1.0% across Selat, Silangjana, Sambangan, Southern Mount Batur, Lempuyang Temple, and Mundeh. Additionally, 0.6% was found in Mundeh Kauh and 0.7% in Pengejaran.

Table 2. Area of Predicted Suitable Habitat Patches of Javan Hawk-Eagles in Bali. Total of the 4 patches included as protected area coverage are 199.1 km^2. 12 pathces which classified as non protected area coverage are 870.3 km^2.

Patch Number	Patch Name	WDPA Forest Status	Protected Coverage (km^2)	Non Protected Coverage (km^2)	Total Area (km^2)
1	West Bali National Park	Protected	155.9	0.0	155.9
2	West Bali Protected Forests	Non Protected	0.0	502.9	502.9
3	Batukahu and Batukaru Areal	Protected/Non Protected	17.6	72.3	89.9
4	Buyan-Tamblingan Lake Nature Park	Protected/Non Protected	18.7	94.7	113.4
5	Selat, Buleleng	Non Protected	0.0	10.9	10.9
6	Sambangan, Buleleng	Non Protected	0.0	15.4	15.4
7	Silangjana, Buleleng	Non Protected	0.0	11.3	11.3
8	Pengejaran, Bangli	Non Protected	0.0	8.0	8.0
9	Northern Mount Batur	Non Protected	0.0	53.4	53.4
10	Southern Mount Batur	Protected/Non Protected	6.9	13.2	20.1
11	Mount Agung	Non Protected	0.0	50.3	50.3
12	Lempuyang Temple	Non Protected	0.0	14.2	14.2
13	Mundeh, Tabanan	Non Protected	0.0	16.6	16.6
14	Mundeh Kauh, Tabanan	Non Protected	0.0	7.2	7.2
Grand Total of Areas			199.1	870.3	1069.4

3.3. Patch Occupancy Survey

A patch occupancy survey was conducted in six predicted suitable patches with historical confirmation of Javan hawk-eagle existence from key informants and accessible roads using vehicles. Of the six predicted patches surveyed, three were confirmed to have Javan Hawk-Eagles occurrence in the patches. Table 3 shows the location, area covered, and forest function of these patches, while Figure 5 shows a map of the surveyed locations. The six patches surveyed were patch 1: West Bali National Park, patch 2: West Bali Protected Forests, patch 3: Batukahu and Batukaru Areal, patch 4: Buyan-Tamblingan Lake Nature Recreational Park, patch 11: Mount Agung, and patch 12: Lempuyang temple. Three patches were confirmed to contain Javan Hawk-Eagles: patches 2, 3, and 4. In total, four individuals were observed in the patches. No nesting trees were found in these patches. Table 3 indicates that habitat patches with confirmed Javan Hawk-Eagle presence covered 36.3 km² within protected areas and 699.9 km² outside protected areas.

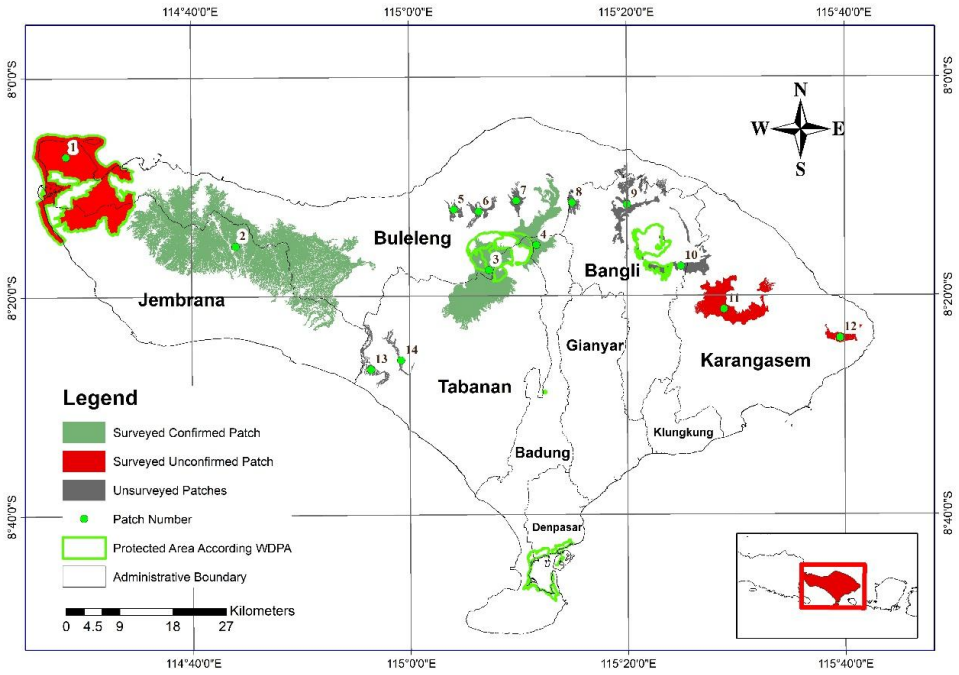

Figure 5. Current distribution status map of Javan Hawk-Eagles in Bali according to the patch occupancy survey. Six patches were surveyed according to historical confirmation from key informants. Javan Hawk-Eagles were encountered in three patches (Patch 2, 3 and 4).

Table 3. Current Distribution Status of Javan Hawk-Eagles in Bali Island. Six patches were surveyed according to historical confirmation from key informants. Javan Hawk-Eagles were encountered in three patches (Patch 2, 3 and 4).

Patch Number	Patch Name	WDPA Forest Status	Survey Results	Protected Coverage (Km^2)	Non Protected Coverage (Km^2)	Total Area (Km^2)
1	West Bali National Park	Protected	Unconfirmed	155.9	0.0	155.9
2	**West Bali Protected Forests**	**Non Protected**	**Confirmed**	**0.0**	**502.9**	**502.9**
3	**Batukahu and Batukaru Areal**	**Protected/Non Protected**	**Confirmed**	**17.6**	**72.3**	**89.9**
4	**Buyan-Tamblingan Lake Nature Recreation Park**	**Protected/Non Protected**	**Confirmed**	**18.7**	**94.7**	**113.4**
5	Selat, Buleleng	Non Protected	Unsurveyed	0.0	10.9	10.9
6	Sambangan, Buleleng	Non Protected	Unsurveyed	0.0	15.4	15.4
7	Silangjana, Buleleng	Non Protected	Unsurveyed	0.0	11.3	11.3
8	Pengejaran, Bangli	Non Protected	Unsurveyed	0.0	8.0	8.0
9	Northern Mount Batur	Non Protected	Unsurveyed	0.0	53.4	53.4
10	Southern Mount Batur	Protected/Non Protected	Unsurveyed	6.9	13.2	20.1
11	Mount Agung	Non Protected	Unconfirmed	0.0	50.3	50.3
12	Lempuyang Temple	Non Protected	Unconfirmed	0.0	14.2	14.2
13	Mundeh, Tabanan	Non Protected	Unsurveyed	0.0	16.6	16.6
14	Mundeh Kauh, Tabanan	Non Protected	Unsurveyed	0.0	7.2	7.2
Grand Total of Area				199.1	870.3	1069.4

Figure 6 shows the current conditions of the surveyed habitat patches. The survey revealed that these areas are forested and located in the highlands, namely, Patch 3 (Figure 6c), 4 (Figure 6d), 11 (Figure 6e), and 12 (Figure 6f), and the lowlands, namely, Patch 1 (Figure 6a) and 2 (Figure 6b). These patches also contain emergent trees, with a height of up to 40m such. An example of these emergent trees can be seen in Figure 5b, which also displays

Nyantoh (*Palaqium spp*.) that existed in patch 2. The trees in the surveyed patches also exhibit a Rauh architectural model, such as puspa (*Schima walichii*). Some of these patches (Patches 2, 3, and 4) are situated near water sources, such as rivers and lakes. Figure 6d shows that Patch 4 is situated very close to water sources, which is a lake.

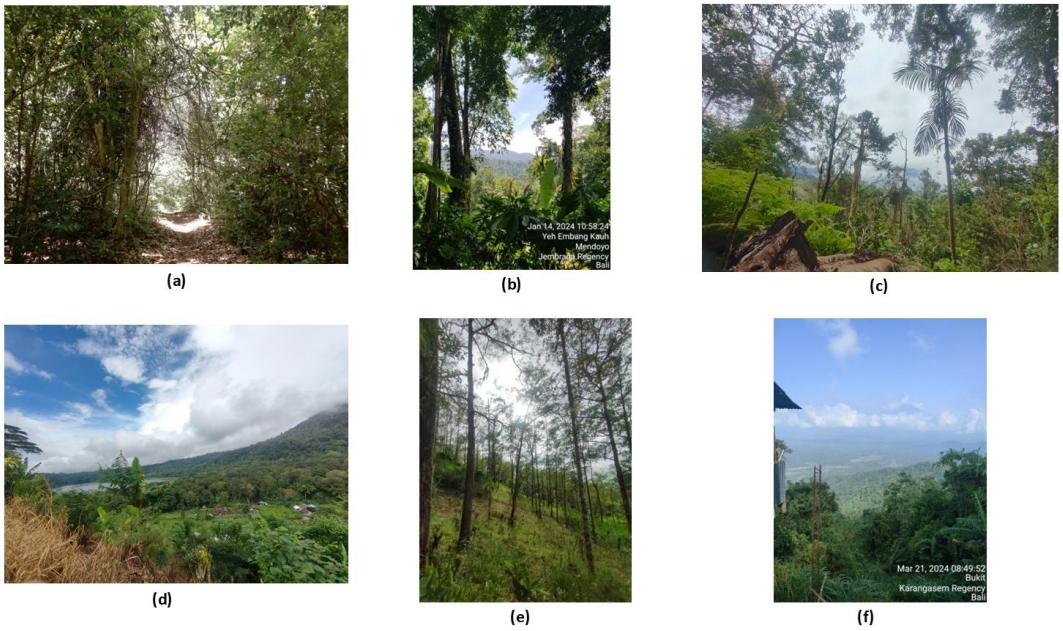

Figure 6. Current condition of habitat predicted as suitable Javan Hawk-Eagle habitat patches that were surveyed. (a) West Bali National Park (Patch 1); (b): West Bali Protected Forest (Patch 2); (c) Batukaru and Batukahu Area (Patch 3); (d) Buyan-Tamblingan Lake Nature Tourism Park (Patch 4); (e) Mount Agung (Patch 11); (f) Lempuyang Temple (Patch 12).

In total, four individuals were observed in the patches. One individual was sighted in patch 2, two individuals were sighted in patch 3, and one was sighted in patch 4. Javan Hawk-Eagles in patch 2 were recorded performing low-altitude flights between trees. **Figure 7** shows the Javan Hawk-Eagles soaring in Patch 3. Interview data indicated that these birds utilized Nyantoh trees (*Palaquium spp.*) as perches in patch 3, where an individual was observed soaring at 9:30 AM. Patch 3, situated at an elevation of 1300 meters, is a highland forest dominated by cemara gunung (*Casuarina junghuhniana*) and puspa (*Schima walichii*). The interviewees reported that patch 3 was the most common habitat for Javan Hawk-Eagles in Bali.

During the patch occupancy surveys, we also conducted interviews with policy authorities responsible for the surveyed areas, namely the West Bali National Park Authority, which oversees West Bali National Park (Patch 1), and the Bali Natural Resources Conservation Agency (BKSDA Bali), which manages the Batukahu Nature Reserve (part of Patch 3) and the Buyan-Tamblingan Lake Nature Recreation Park (Patch 4). According to the interviews, institutional challenges were also highlighted. Representatives from West Bali National Park (TNBB) and BKSDA Bali acknowledged that the absence of formal designation of the Javan hawk-eagle as a provincial conservation priority species limits policy-driven actions for its protection. TNBB pointed out that the lack of prioritization from central government directives constrains regional conservation planning in the state. Meanwhile, BKSDA Bali noted that while legal frameworks for species protection exist nationally, their implementation in Bali would benefit from a harmonized strategy that integrates customary law (*awig-awig*) and ecotourism development, particularly in community-managed forest areas where sightings have occurred.

Figure 7. Photo of presence of Javan Hawk-Eagles that was confirmed in the Batukaru and Batukahu areas (Patch 3). There are 2 different individuals in this photo, one with complete primary feathers, other individual is losing 2 primary feathers Photo was taken by M. Saifudin.

4. Discussion

This study was conducted using logistic regression based on the method described by Syartinilia et al [7]. The logistic regression model has also been used in several other studies in Java [4,6,20]. Logistic regression offers several advantages: it is computationally efficient, interpretable, and well-suited for cases where absence data are limited or uncertain [45,46] The use of pseudo-absence data makes it well-suited for modelling rare species such as the Javan Hawk-Eagle, particularly amid limited confirmed occurrences in Bali [7]. The results of this study demonstrate that suitable habitat for the Javan Hawk-Eagle on Bali approximately 1,069.4 km² of suitable habitat for the Javan Hawk-Eagle is distributed across 14 predicted patches spanning both protected (199.1 km²) and non-protected (870.3 km²) areas according to WDPA, underscoring the importance of non-protected landscapes for the species' persistence. Interview records revealed that the species has been intermittently detected on the island from 1994 to 2021, with observations occurring across both upland and lowland forests. Patch occupancy surveys conducted in six patches that have historic sighting according to key informants. It is confirmed that Javan Hawk-Eagle presence in three of the six surveyed patches, namely West Bali Protected Forests, Batukahu–Batukaru, and Buyan–Tamblingan, where four individuals were observed, while West Bali National Park, despite being the largest predicted protected habitat, yielded no confirmed detections.

From 14 identified patches, in total of 199.1 km² identified patches were included as protected areas according to the WDPA. Protected areas are crucial for the conservation of the Javan Hawk-Eagle, as this species is susceptible to environmental changes, such as land cover alterations [22], and is frequently subjected to illegal hunting and trading [23]. The presence of Javan Hawk-Eagles within protected areas, such as national parks and nature reserves, may represent core habitats that enhance their survival owing to higher prey availability and greater landscape stability [6,7,24]. For example, in West Bali National Park, conservation efforts for the Bali Myna (*Leucopsar rothschildi*), such as captive breeding and soft releases, have facilitated its recovery, with the population increasing from 14 individuals in 2011 to 559 in 2023 [25,26].

Despite being situated within protected areas, interview results with key informants (Table 1) indicated that the Mount Batur-Bukit Payang and Panelokan Nature Recreation Parks have no historical records of the presence of Javan hawk-eagles. This could be attributed to the lack of connectivity between these parks and areas with historical sightings of the Javan Hawk-Eagle, such as the Mount Agung and Batukahu Nature Reserve. Connectivity between patches allows the Javan hawk-eagle to move between patches [27]. Limited patch connectivity may restrict movement and gene flow, which is critical for maintaining population viability [28,29].

The result of this research also reveals that total of 870.3 km² predicted patches are located outside the formal protection boundaries. Nevertheless, these areas also contribute significantly to species persistence. Moreover, it underscores the critical importance of community-based conservation efforts. For example, in the Nusa Penida Islands, 46 indigenous villages (desa adat) implement traditional regulations (awig-awig) to protect the Bali Myna (Leucopsar rothschildi). According to Sudaryanto et al. [30], the Bali Myna population in the area increased from 49 individuals in 2006 to 84 in 2009, before fluctuating due to the demographic structure, and eventually reaching 64 in 2015. Based on Sudaryanto et al. (2019), awig-awig was identified as the most influential factor (47%) in Bali Starling conservation, surpassing welfare (23%), biodiversity (14%), tourism (12%), and local regulations (4%), highlighting the potential for culturally embedded regulations to support avian conservation beyond formally protected areas.

Patch occupancy survey confirmed the presence of Javan Hawk-Eagles in three habitat patches: West Bali Protected Forest (Patch 2), Batukaru and Batukahu Area (Patch 3), and Buyan-Tamblingan Lake Nature Tourism Park (Patch 4). These patches share key habitat characteristics that are ecologically suitable for these species. All are situated in hilly or mountainous areas, a landscape type preferred by Javan Hawk-Eagles because of their affinity for steep slopes [31,32]. The forests in these patches contain emergent trees with Rauh architectural models, an important structural feature that provides elevated vantage points for perching and safe nesting sites above the canopy [33,34]. Additionally, these areas are located near water bodies, such as rivers or lakes, which offer both a consistent water supply and diverse prey availability [35,36].

The occurrence of the four individuals of Javan Hawk-Eagle in some patches may be explained by a combination of natural dispersal, human-mediated introduction, and limited detectability during the surveys. Natural dispersal from nearby populations, such as those in Alas Purwo, Ijen, and Baluran National Parks, could result in immature individuals reaching Bali, especially given their broader-ranging behavior compared to adults, who defend territories to avoid intraspecific competition for prey [6,9,24]. These juveniles may follow migratory raptors that pass through Bali as bottlenecks [14]. Human-related factors may also contribute, including the accidental release of captive individuals kept as pets, as documented in cases of local handovers to the Bali Wildlife Rescue Centre and subsequent release in Baluran National Park [37–39]. The illegal trade of Javan Hawk-Eagles through online platforms, such as Facebook, further supports the possibility of anthropogenic introduction. It is estimated that 121 individuals of this species were sold among 7,514 raptors traded on these platforms [38,40]. Moreover, the absence of confirmed sightings in several surveyed patches, including West Bali National Park, Lempuyang Temple, and Mount Agung which may be influenced by seasonal variation in detectability. The survey conducted in April could have coincided with the species' non-breeding period, during which

vocalization and territorial behaviours are reduced [41]. Interactions with migratory raptors may also affect space use; temporary influxes of large-bodied raptors can displace resident species from preferred perches or hunting grounds, reduce their visibility, or cause them to alter their movement patterns to avoid interaction or defend their territory [42].

The results of this study indicate that the conservation of Javan Hawk-Eagles in Bali requires formal regulatory attention, as the species has not yet been designated a conservation priority within the province. According to key informants, the lack of official recognition within local mandates limits targeted conservation efforts. Regulatory frameworks are essential not only to mitigate anthropogenic threats but also to ensure habitat protection and guide effective biodiversity policies [43]. Complementing this, community-based conservation approaches offer substantial potential and have been successful in Bali. For instance, 46 customary villages (*desa adat*) in Nusa Penida have implemented *awig-awig*, traditional environmental regulations associated with the recovery of the Bali starling (*Leucopsar rothschildi*) population [30]. These initiatives demonstrate how local communities can merge traditional knowledge and ecological awareness into effective conservation. Strengthening such efforts, alongside formal protection, is vital for sustaining Javan Hawk-Eagle populations and maintaining ecosystem resilience in Bali [44].

There are some limitations needs to highlight in this research. As noted by Syartinilia et al. [6,31], the logistic regression model that being used in this research performs best in highland ecosystems because of its development based on occurrences in Gede Pangrango National Park (>1000 masl). Moreover, Bali's predominantly lowland and coastal geography further constrains the model's ability to predict suitable high-elevation habitats. It also excludes climatic variables such as temperature because of their modeling complexity. To address these constraints, we complemented the model with a patch occupancy survey to validate the predictions and assess the ecological feasibility of each patch, thereby improving the accuracy and reducing commission errors. This approach was also implemented by Syartinilia et al. [6], who confirmed 59.5% of the predicted patches and expanded the validated habitat area by 1,698 km².

It is also critical to understand the distribution of Javan Hawk-Eagles in Bali so that immediate conservation actions can be proposed to protect them. This study predicted its distribution using a logistic regression model [7] and confirmed the existence of Javan Hawk-Eagles in some of the predicted suitable habitat patches. Nevertheless, unsurvey patches need to be surveyed to confirm the suitability and existence of Javan Hawk-Eagles [6,47]. Future research also needs better spatial modelling that incorporates other variables, such as climatic (e.g., temperature and humidity), to predict the existence of Javan Hawk-Eagles more accurately [31]. It is also important to conduct genetic research on Javan Hawk-Eagles that exist in Bali, as it can provide vital insights into the conservation value of the Javan Hawk-Eagle population in Bali and inform more regionally tailored management strategies [48].

5. Conclusions

This study identified 1,069.4 km² of suitable habitat for the Javan Hawk-Eagle in Bali, distributed across 14 predicted patches. The survey carried out in six patches with historical confirmations verified the species' presence in three of surveyed patches. Four individuals of Javan Hawk-Eagles were sighted during the surveys. These findings indicate that parts of the predicted distribution and information from key informants are accurate. However, the modelling approach remains limited by its stronger performance in highland ecosystems and the exclusion of climatic variables that may influence habitat suitability. These constraints highlight the need for improved spatial modelling that incorporates additional environmental predictors. In additions, further surveys in unsampled patches and genetic assessments of detected individuals are also needed to clarify the species' origins and population structure in Bali.

Author Contributions

GOW : Conceptualization, Methodology, Formal Analysis, Investigation, Funding Acquisition, Visualization, Writing – Review and Editing. **S :** Conceptualization, Methodology, Formal Analysis, Supervision, Writing – Review and Editing. **YAM :** Conceptualization, Methodology, Formal Analysis, Supervision, Writing – Review and Editing.

AI Writing Statement

During the preparation of this work the author(s) used ChatGPT in order to translating. 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 is no conflict of interest to report.

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