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GIS-BASED HABITAT MODEL OF JAVAN HAWK-EAGLE (*SPIZAETUS BARTELSI*) USING INDUCTIVE APPROACH IN JAVA ISLAND, INDONESIA

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ABSTRACT

The Javan Hawk-Eagle (JHE) is categorized in the IUCN Red List of Threatened Species (CITES Appendix 2) as one of the world's rarest and most endangered raptors in the remaining original natural forests of Java, Indonesia. Since it is not feasible to conduct complete field surveys for a landscape-scale, this paper proposes a GIS-based extrapolation model based on local-scale model in order to generate a map of potential and present habitat suitability for JHE in the entire landscape. Using autologistic regression, we developed a GIS-based habitat model for JHE in Java Island and subsequently estimated the population number of JHE. The obtained model will be the most useful for the wildlife management conservation planning process in order to help identify "hot spots" that are most likely to harbor JHE. Most of the predicted suitable habitats in Java Island are distributed in the mountainous area. The area with the largest proportion of suitable habitat for JHE is located in East Java, and then followed by West Java and the last in Central Java. Totally, about 41 locations (85%) of 48 historical localities recorded were recognized as suitable habitat. The estimated number of JHE pairs based on model extrapolation would place the population size about 108-542 (median = 325) pairs. Although this estimated population is higher compared to other

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studies, JHE had always been described as either rare or very rare. The apparent discrepancy between this estimated population and others, which might not suggest an increase in present JHE, may be explained by several reasons such as increased accessibility to formerly unexplored habitat and more recent satellite imageries and GIS techniques application used in estimation of suitable habitat of JHE and finally will allow a better population estimate.

1. INTRODUCTION

The Javan Hawk-Eagle (Spizaetus bartelsi) is an endemic raptor and evergreen-forest specialist in the remaining original natural forests of Java, Indonesia [1]. The Javan Hawk-Eagle (JHE) is categorized in the IUCN Red List of Threatened Species (CITES Appendix 2) as one of the world's rarest and most endangered raptors. Small population size, severe habitat loss, forest fragmentation, and illegal hunting have all contributed to the "endangered" status of this species [2, 3]. However, population estimates until very recently have been very low, based on the amount of suitable habitat remaining divided into the estimated size of individual territories. Various authors have estimated the population size differently; "Not more than 60 breeding pairs" [4] , "67–81 pairs" [5], "81–108 pairs" [6], "270–600 (median = 435) pairs" [7].

Predictive modeling commonly uses deductive and inductive approaches. Deductive models are based on theories about the behavior of the prehistoric population. Inductive models, which are more commonly used, are based on observed patterns in ground surveys or other data. One of the more powerful and widely used inductive techniques coupled with Geographic Information Systems (GIS) in habitat modeling is logistic regression [8, 9, 10]. Preliminary predictive habitat models were developed for a restricted portion of the JHE distribution in Gunung Gede-Pangrango National Park (TNGP) and its surrounding areas using logistic and autologistic regression model and successfully validated in the Southern part of West Java [11]. This method provided a useful quantitative "first step" for modeling endangered species distributions where specific habitat requirements are difficult to obtain.

Large-scale conservation planning requires the identification of priority areas in which species have a high likelihood of long-term persistence. This typically requires high spatial resolution data on species and their habitat. Such data are rarely available at a large geographical scale, so habitat distribution modelling is often required to identify the locations of suitable habitat. GIS can be used to construct spatially explicit habitat models for both common and rare wildlife species especially for a large geographical scale based on inductive approach [12, 13]. GIS technology provides the ability to construct models of habitat that rely on existing or readily obtained information (e.g., remotely sensed images, digital elevation models, topographic maps, etc.). With adequate data collection, such models often can analytically identify specific habitat characteristics across wider landscapes with high predictive power and therefore provide considerable utility. Such models offer the possibility of being able to minimize field work, and GIS-based models are easily updated as new information becomes available.

However, to be effective in the long term, JHE habitat management should not be confined only to the local and regional scale, but must also address the landscape-scale, i.e. the scale at which population processes occur. Therefore, a method is needed that allows identification of probability model of JHE habitat distribution efficiently over large areas. In addition, the method must be able to produce spatially explicit habitat suitability maps at the landscape level, which will be an important tool for the habitat management of this species. Since it is not feasible to conduct complete field surveys for a landscape-scale, GIS-based extrapolation models using an inductive approach can be used to generate maps of potential and present habitat suitability for JHE in the entire landscape.

Therefore, our primary objective was to extrapolate the predicted probability model of JHE habitat distribution from the local-scale model to landscape-scale model in order to generate maps of potential and present habitat suitability for JHE in the entire landscape. Subsequently, population number of JHE will be estimated.

2. METHOD OF ANALYSIS

In order to generate the present habitat suitability of JHE in Java Island, we extrapolated the best model that was developed in nest-site scale (Gunung Gede-Pangrango National Park (TNGP) and validated in regional-scale (southern parts of West Java) [11]. Subsequently, the result was compared with the historical localities record of JHE for model accuracy. Afterward, predicted suitable habitat was used for calculating the population estimation of JHE in whole Java Island.

2.1 Study Area

Java Island of about 132,000 km2 is administratively divided into four provinces (Banten, West Java, Central Java, and East Java), one special region (DI Yogyakarta), and one special capital district (Jakarta) (Figure 1). The population of Java Island in 2007 was estimated to be about 130 million with a density of 985 inhabitants/km2 [14]. Java is almost entirely of volcanic origin (about 43 mountains) that formed an east-west spine which has at one time or another been active volcanoes. The highest volcano in Java is Mount Semeru (3,676 m) in East Java and the most active volcano in Java and also in Indonesia is Mount Merapi (2,914 m) in Central Java [15]. Further mountains and highlands help to split the interior into a series of relatively isolated regions suitable for wet-rice cultivation. The average annual temperature varies between 22°C and 27.5°C and the annual mean rainfall ranges from 1,000 mm up to 6,000 mm. We obtained climate data courtesy of the Meteorological and Geophysical Agency of Indonesia (BMG) for 1993–2002.

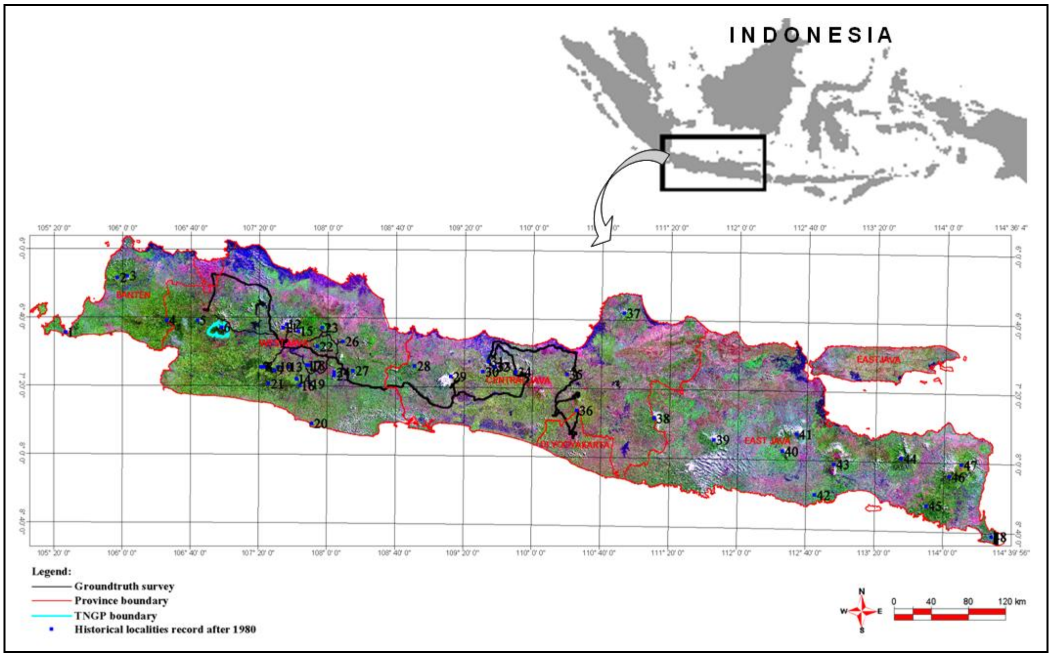

Figure 1. Study area: Java Island (Source: GeoCover Landsat mosaic, S-48-05_2000, S-50-05_2000).

2.2 Model Extrapolation

GIS-based landscape model was developed to evaluate habitat suitability of JHE in Java Island because it was not possible to conduct nest-site scale field surveys for the entire Java Island. This landscape-scale model was developed based on extrapolation of the best model obtained from the previous study [11] that was an autologistic regression model which calculated 1,500m of neighborhood size (ALR_50). This model accounted spatial autocorrelation through the addition of autocovariate variable. The best model retained the explanatory environmental variables, i.e. slope (SLP), elevation (ELV), normalized different vegetation index (NDVI) and autocovariate (AUTOCOV).

Probability of the JHE habitat (*Pi*) is explained by the equation below.

$$Pi = \frac{1}{1 + \exp\left[-\left(0.2371SLP - 0.0070ELV + 0.0189NDVI + 19.8063AUTOCOV - 6.8592\right)\right]}$$

SLP and ELV data were derived from Shuttle Radar Topography Mission (SRTM) Digital terrain elevation data of 2000. While, NDVI data obtained from MODIS NDVI 250m of 2002. For model extrapolation, 250*250 m pixel size was used.

Then, threshold the probability value at 0.5 is performed in order to produce the habitat suitability model. Subsequently, this model was compared with the historical localities record after 1980 (Table 1) [3, 16, 17, 18] for model accuracy.

2.3 Population Estimation

The number of breeding pairs of this species has been estimated by dividing the area of presumed suitable habitat by assumed home-range size. Suitable habitat was obtained from thresholding the predicted probability of JHE habitat at probability value of 0.5. In order to avoid the overestimate of the population size, we excluded the habitat patches with area below the 50 km^2. In this study, the population size was estimated using minimum and maximum home range size. Minimum home range size was based on result of the best model of habitat distribution in TNGP and its surrounding areas [11] which assumed to have a high quality habitat and also agreed with the current approximate distance between nests in TNGP [19] and the median home range size in Java [7]. Even though the exact minimum home range size obtained was 225 ha, but we used 400 ha for population estimation. Home range size of 2,000 ha was selected as maximum home range size in this study, since several researchers had been used it for estimating population number of JHE [17, 18, 20, 21].

Table 1. Historical localities of JHE record in Java Island after 1980

No	Location	Prov.	No	Location	Prov.
1	Ujung Kulon National Park	WJ	25	Mt. Galunggung	WJ
2	Mt. Aseupan	WJ	26	Mt. Jagat	WJ
3	Mt. Karang	WJ	27	Mt.Sawal	CJ
4	Gunung Halimun National	WJ	28	Mt. Segara	CJ
5	Mt. Salak	WJ	29	Mt. Slamet	CJ
6	Gunung Gede-Pangrango	WJ	30	Mt.Cupu/Simembut	CJ
7	Situ Patengan	WJ	31	Linggoasri	CJ
8	Cimanggu	WJ	32	Mt. Lumping	CJ
9	Mt. Patuha	WJ	33	Lebakbarang	CJ
10	Mt. Tilu	WJ	34	Mt. Kemulan	CJ
11	Mt. Burangrang	WJ	35	Mt. Ungaran	CJ
12	Mt. Tangkuban Perahu	WJ	36	Mt. Merapi-Merbabu	CJ
13	Mt. Malabar	WJ	37	Mt. Muria	CJ
14	Mt. Puntang	WJ	38	Mt. Lawu	CJ
15	Bukit Tunggul	WJ	39	Mt. Liman-Wilis	EJ
16	Mt. Papandayan	WJ	40	Mt. Kawi	EJ
17	Kawah Kamojang	WJ	41	Mt. Arjuno	EJ
18	Mt. Guntur	WJ	42	Lebakharjo	EJ
19	Mt.Cikuray	WJ	43	Mt. Bromo Tengger Semeru	EJ
20	Leuweung Sancang Wildlife	WJ	44	Yang highland	EJ
21	Mt. Simpang	WJ	45	Meru Betiri National Park	EJ
22	Mt. Masigit Kareumbi Hunting	WJ	46	Mt. Raung	EJ

Table 1. (continued)

23	Mt. Tampomas	WJ	47	Mt. Ijen	EJ
24	Mt. Talaga Bodas	WJ	48	Alas Purwo National Park	EJ

Note: Prov, Province; WJ, West Java; CJ, Central Java; EJ, East Java.

Source: BirdLife International (2001); Setiadi et al., 2000; van Balen et al., 1999; 2001.

3. RESULT

3.1 Model Extrapolation of JHE Habitat Distribution

JHE habitat distribution in entire Java Island based on ALR_50 model (Figure 2) was obtained from extrapolation of predicted probability model in TNGP and its surrounding areas which was successfully validated in Southern parts of West Java.

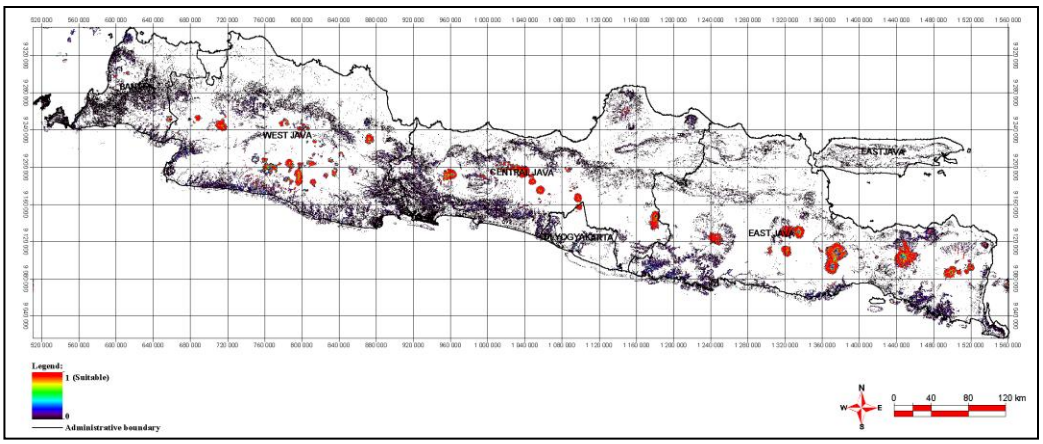

Figure 2.Predicted probability of JHE distribution in Java Island (extrapolation) based on ALR _50 model.

Subsequently, a habitat suitability model (Figure 3) was obtained from thresholding the predicted probability of JHE distribution at 0.5, and then the historical localities record after 1980 was overlaid to this model. Suitable habitat based on ALR_50 model covered about 3,107 km^2 and distributed in entire Java Island.

Totally, about 41 locations (85%) of 48 historical localities record were recognized as suitable habitat in this model and the rest of the locations (15%) were recognized as omission error, when the model predicts as an unsuitable habitat even though the species has indeed been found in that location that were Ujung Kulon National Park (locality number: 1), Leuweung Sancang Wildlife Reserve (No. 20), Mt. Tampomas (No. 23), Mt. Jagat (No. 26), Mt.Cupu/Simembut (No. 30), Meru Betiri National Park (No. 45), and Alas Purwo National Park (No. 48).

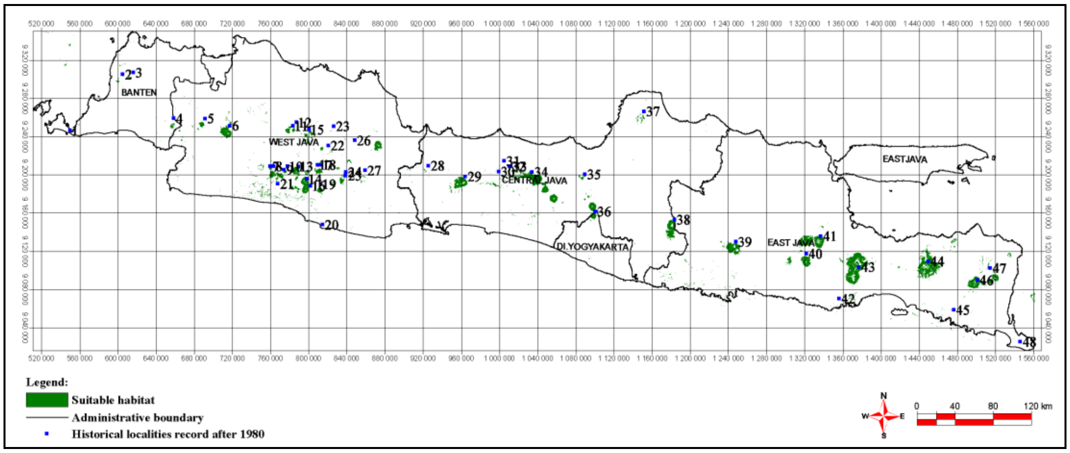

Figure 3. Habitat suitability model of JHE in Java Island (extrapolation) based on threshold of ALR_50 model at 0.5.

3.2 Population Estimation

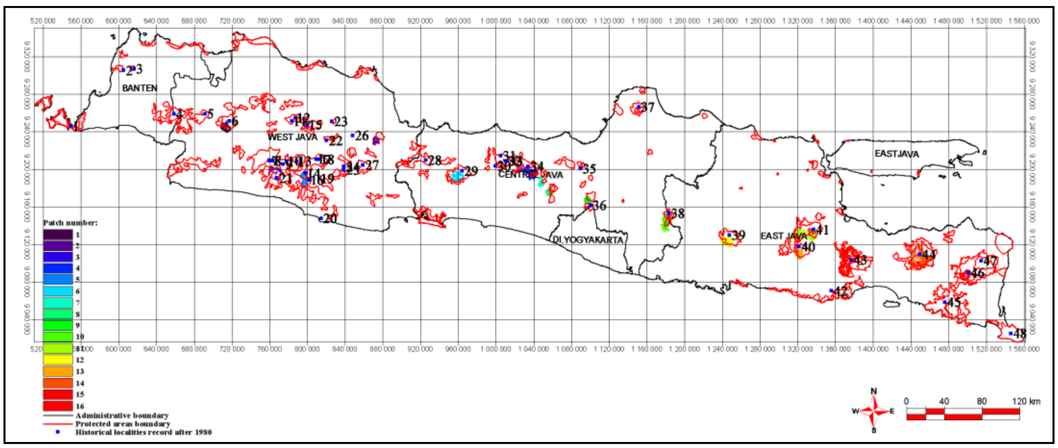

Figure 4. Distribution of habitat patches of JHE in Java Island.Comparing this to the protected area network which is produced by World Conservation Monitoring Centre in 1996, we found that 60.4% (1,309 km^2) of the habitat patches already existed inside the protected area network (Figure 5).

Totally about 16 patches (2,166 km2) with a predicted probability of JHE presence > 0.5 and area > 50 km2 were identified as habitat patch in our model, and then we used them for calculating the population of JHE (Figure 4).

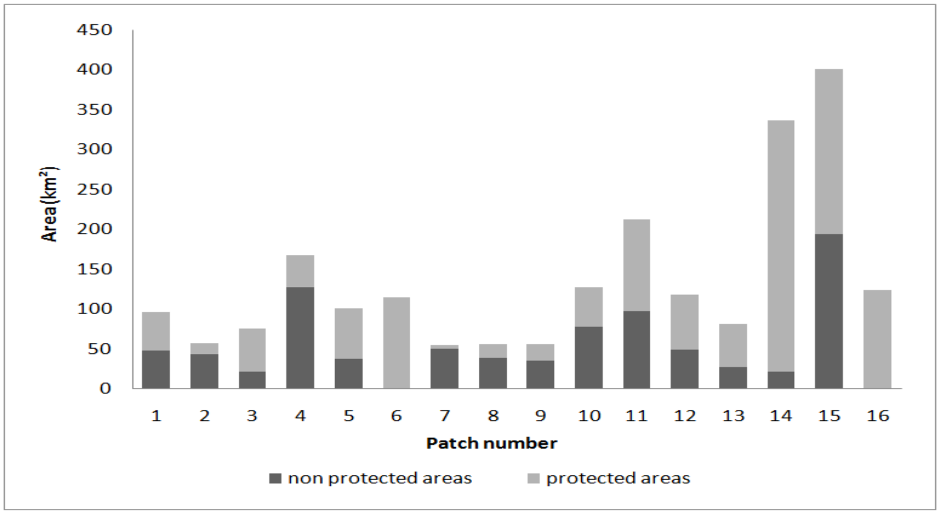

Figure 5. Proportion area of habitat patches which located inside and outside protected area network.

The estimated number of pairs per habitat patch based on ALR_50 model is presented in Table 2. In this study, the estimated number of JHE pairs using ALR_50 model extrapolation would place the population size about 108-542 (median = 325) pairs. Estimated population was obtained in this study compare to other studies is presented in Table 3.

Table 2. Habitat patches and population estimation of JHE in Java Island

Patch number	Location	Prov.	Area (km^2)	Edge (km)	Estimated population (pair)	
					Minimum homerange	Maximum homerange
1	Mt. Gede-Pangrango	WJ	95	128	24	5
2	Mt. Cireme	WJ	56	73	14	3
3	Mt. Simpang-Mt.Tilu	WJ	75	180	19	4
4	Mts. Dieng (Mt.Kemulan)	WJ	167	218	42	8
5	Mt. Papandayan	WJ	100	108	25	5
6	Mt. Slamet	CJ	112	137	28	6
7	Mts Dieng(Mt.Sumbing)	CJ	54	62	14	3
8	Mts Dieng (Mt.Sindoro)	CJ	55	55	14	3
9	Mts Merapi-Merbabu	CJ	55	54	14	3
10	Mt. Lawu	CJ	127	165	32	6
11	Mt. Arjuno-Welirang	EJ	212	312	53	11
12	Mt. Liman-Wilis	EJ	117	193	29	6
13	Mt. Kawi	EJ	81	89	20	4

Table 2. (continued)

14	Yang highlands	EJ	336	666	84	17
15	Mts. Bromo Tengger Semeru National Park	EJ	401	577	100	20
16	Mt. Raung	EJ	123	168	31	6
Sum			2166	3185	542	108
Mean			135			
Median					**325**	

Note: Prov, Province; WJ, West Java; CJ, Central Java; EJ, East Java.

Table 3.Estimated population of JHE in Java Island based on ALR_50 model and other studies

Source	Estimated population	
	Pairs	Median
ALR_50 model (this study)	**108-542**	**325**
Gjershaug et al. (2004)	270-600	435
van Balen et al. (1999, 2000, 2001)	137-188	-
Sözer and Nijman (1995)	81-108	-
van Balen and Meyburg (1994)	67-81	-
Meyburg et al. (1989)	60	-

4. DISCUSSION

For conservation and development planning, it is often necessary to evaluate a large area for possible alternatives/strategies. Landscape-scale models are effective for generating spatial distributions of potential and present habitat suitability for JHE over a large area using GIS and remote sensing-based data. The predicted probability of habitat suitability may not always be accurate at specific locations because probability itself does not mean present existence. However, they will provide critical information for research, planning, and management needs at landscape scales [22, 23]. Compared to corresponding nest-site scale models, landscape-scale models use coarser information that is acquired from satellite remote sensed data such as MODIS NDVI 250 m of data resolution.

Habitat suitability model of JHE in Java island obtained in this study may be the most useful in the conservation planning process to help identify "hot spots" that are most likely to harbor JHE. A general trend in the habitat distribution of JHE can be seen with this model. Most of the predicted suitable habitats in Java Island are distributed in the mountainous area. The area with the largest proportion of encountering suitable habitat for JHE is located in East Java, and then followed by West Java and the last in Central Java.

Three locations (Leuweung Sancang Wildlife Reserve (locality number: 20), Mt. Tampomas (No. 23), and Mt. Jagat (No. 26) located in southern parts of West Java were also recognized as omission error in model validation. The other three locations (Ujung Kulon National Park (No.1), Meru Betiri National Park (No.45), and Alas Purwo National Park (No.48)) are known as the relatively large remaining lowland forest area in Java Island [1]. Before World War II, the forest area in Meru Betiri National Park was continuous with those in Alas Purwo National Park to the east, but agricultural developments have now severed this link [1]. The last location, Mt. Cupu/Simembut (No.30) where the small fragments of natural forest remain is located at 350–1,000 m elevation and surrounded by either open ground or pine plantation [17]. The last observation in seven locations mentioned above was conducted in 1997, and undoubtedly all these locations have experienced similar threats, including forest conversion (illegal logging and agricultural expansion), illegal hunting, and isolation from other patches.

In recent years, the wide recognition of the effects that both threatening processes and climate change have on biological diversity, has enhanced the importance of acquiring knowledge on the patterns of species diversity [24]. Moreover, an understanding of the environmental factors that favor key species can guide the management of protected areas [25]. The categorization of habitat quality displayed in the spatial model can be used to prioritise areas requiring protection based on their value. This statement is made on the premise that the probability of species presence is positively correlated with the quality of the habitat [12]. Our model showed that 60.4% of habitat patches existed inside the protected areas and the remaining area extends far outside protected areas. The role of this area for the expansion of the JHE population is likely important. More attention should be paid to this evidence by several agencies (i.e. ministries, national parks, NGOs) to formulate a JHE conservation plan and to identify urgent conservation actions. Therefore, the result of this study may help to proactively manage habitat for JHE, providing the impact of harmful activities within the area to JHE habitat is assessed on a multi-level management scale.

These habitat distribution models were developed based on currently available and thus limited information. New knowledge gained in the future on the habitat requirements for this species may alter the assumptions for the habitat models. Efforts need to be made to update these models whenever new information on the habitat requirements of JHE becomes available. These models and associated documentation that synthesize the biology and ecology of the JHE provide a framework that will make the effort to update the knowledge and models effective.

Based on our habitat patches model of JHE, our population estimation is comparable to those of Gjershaug et al. [7] who reported the extrapolation to the entire forest habitat in Java would place the JHE population size about 270–600 (median = 435) pairs. However, other studies did not estimate similar population numbers [4, 5, 6, 17, 18, 21]. Although this estimated population is higher compared to other studies, the JHE had always been described as either rare or very rare. The apparent discrepancy between this estimated population and others, might not suggest an increase in present JHE. The increased accessibility to formerly unexplored habitat also undoubtedly contributed to more birds having been observed. Finally, more sophisticated field identification techniques have contributed to a larger number of positive identifications. At the same time, more recent satellite imageries and GIS techniques application used in this study will allow a more precise estimate of the extent of natural forest cover in Java and finally will allow a better estimate of its population number of JHE.

The landscape-scale models based on extrapolation of the site-scale model provide spatial explicit assessment of the potential and present habitat suitability at the scales of the greatest practical needs. These models provide effective tools for conservation and development planning as well as monitoring and management of JHE habitat.

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REFERENCES

1 Whitten, T., Soeriaatmadja, R.E., Afiff, S.A. (1996). *The ecology of Java and Bali: the ecology of Indonesia series, Vol. 2.* Singapore: Periplus Editions.

2 BirdLife International. (2000). Threatened birds of the world. Barcelona Spain: *Lynx Edicions and BirdLife International.*

3 BirdLife International. (2001). Threatened birds of Asia: the BirdLife International red data book. Cambridge, U.K: *BirdLife International.*

4 Meyburg, B-U., van Balen, S., Thiollay, J-M., Chancelllor, R.D. (1989). Observations on the endangered Javan Hawk Eagle Spizaetus bartelsi. In Meyburg, B-U., & Chancellor, R.D. (Eds.), *Raptors in the modern world* (pp. 279-299). Berlin, London and Paris: WWGBP.

5 van Balen, S., & Meyburg, B-U. (1994). The Javan Hawk Eagle Spizaetus bartelsi: results of recent research on distribution, status and ecology. In Meyburg, B-U., & Chancellor, R.D. (Eds.) Raptor Conservation Today (pp. 89-92). Berlin, London and Paris: WWGBP and *The Pica Press*.

6 Sözer, R., & Nijman, V. (1995). Behavioral ecology, distribution and conservation of the Javan Hawk Eagle Spizaetus bartelsi Stresemann, 1924. *Versl. Techn. Gegev*., 62, 1-122.

7 Gjershaug, J.O., Røv, N., Nygård, T. (2004). Home-range size of the Javan Hawk-Eagle (Spizaetus bartelsi) estimated from direct observations and radiotelemetry. *Journal of Raptor Research*, 38, 343-349.

8 Osborne, P.E., Alonso, J.C., Bryant, R.G. (2001). Modelling landscape-scale habitat use using GIS and remote sensing: a case study with great bustards. *Journal of Applied Ecology*, 38, 458-471.

9 Bailey, S.-A., Haines-Young, R.H., Watkins, C. (2002). Species presence in fragmented landscape: modeling of species requirements at the national level. *Biological Conservation*, 108, 307-316.

10 Engler, R., Guisan, A., Rechsteiner, L. (2004). An improved approach for predicting the distribution of rare and endangered species from occurrence and pseudo-absence. *Journal of Applied Ecology*, 41, 263-274.

11 Syartinilia, & Tsuyuki, S. (2008). GIS-based modeling of Javan Hawk-Eagle distribution using logistic and autologistic regression models. *Biological Conservation*, 141, 756-769.

12 Gibson, L.A., Wilson, B.A., Aberton, J.G. (2004). Landscape characteristics associated with species richness and occurrence of small native mammals inhabiting a coastal heathland: a spatial modeling approach. *Biological Conservation*, 120, 75-89.

13 Posillico, M., Meriggi, A., Pagnin, E., Lovari, S., Russo, L. (2004). A habitat model for brown bear conservation and land use planning in the central Apennines. *Biological Conservation*, 118, 141-150.

14 BPS, Bappenas, UNFPA. (2005). Indonesia population projection 2000-2025. Indonesia: BPS, *Bappenas, and UNFPA*.

15 Siebert, L., & Simkin, T. (2002). Volcanoes of the World: an Illustrated Catalog of Holocene Volcanoes and their Eruptions. 2002 [May, 2005]. Available from: URL: *http://www.volcano.si.edu/world/*.

16 Setiadi, A.P., Rakhman, Z., Nurwatha, P.F., Muchtar, M., Raharjaningtrah, W., 2000. Status, distribution, population, ecology and conservation Javan Hawk-eagle Spizaetus bartelsi Stresemann, 1924 on southern part of west Java. Final Report BP/FFI/*BirdLife International/*YPAL-HIMBIO UNPAD, Bandung.

17 van Balen, S., Nijman,V., Sözer, R. (1999). Distribution and conservation of the Javan Hawk-eagle Spizaetus bartelsi. *Bird Conservation International*, 9, 333-349.

18 van Balen, S., Nijman,V., Sözer, R. (2001). Conservation of the endemic Javan hawk-eagle Spizaetus bartelsi Stresemann, 1924 (Aves: Falconiformes): density, age-structure and population numbers. *Contributions to Zoology*, 70, 161-173.

19 Suparman, U. (2005). Konservasi Elang Jawa Spizaetus bartelsi Stresemann, 1924 di cagar alam Telaga Warna, Puncak 2000-2005: status, distribusi, ekologi dan aksi konservasi. Cianjur, Indonesia: *Raptor Conservation Society*.

20 Thiollay, J.-M., & Meyburg, B.-U. (1988). Forest fragmentation and conservation of raptors: survey on the Island of Java. *Biological Conservation*, 44, 229-250.

21 van Balen, S., Nijman,V., Prins, H.H.T. (2000). The javan hawk-eagle: misconceptions about rareness and threat. *Biological Conservation*, 96, 297-304.

22 Lindenmayer, D.B., & Possingham, H.P. (1996). Modeling the inter-relationship between habitat patchiness, dispersal capability and metapopulation persistence of the endangered species, Leadbeater’s possum in south-eastern Australia. *Landscape ecology*, 11(2), 79-105.

23 Wu, X.B., Smeins, F.E. (2000). Multiple-scale habitat modeling approach for rare plant conservation. *Landscape and Urban Planning*, 51, 11-28.

24 Heaney, L.R. (2001). Small mammal diversity along elevational gradients in the Philippines: an assessment of patterns and hypotheses. *Global Ecology and Biogeography*, 10, 15–39.

25 Manel, S., Williams, H.C., Ormerod, S.J. (2001). Evaluating presence–absence models in ecology: the need to account for prevalence. *Journal of Applied Ecology*, 38, 921–931.