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CONSERVATION AND MANAGEMENT STRATEGIES FOR THE SUSTAINABILITY OF RAPTORS IN A HUMAN-MODIFIED LANDSCAPE

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Abstract

Raptors are indicators of biodiversity, environmental health and habitat quality because of their sensitivity to human disturbance and environmental contamination. Nest site selection can have important nesting success consequences in raptors. In relation to this, a spatial analysis was undertaken to assess the relationship between landscape structure and the presence of predator nests in the human-modified landscape of Panaruban and Telaga Warna, West Java, Indonesia. The methods used in the study were qualitative (descriptive analysis) and quantitative (using Fragstats v.2.0). The study employed four circular buffers at distances of 250, 500, 750 and 1000m around each nest tree in order to analyse the relationship between raptor nest occurance and landscape structure. The results showed that the landscape of Panaruban and Telaga Warna is a mosaic consisting of natural and artificial vegetation of different structures. The four species of raptors identified were the Javan hawk eagle (Spizaetus bartelsi), the changeable hawk eagle (Spizaetus. cirrhatus), the crested serpent eagle (Spilornis cheela) and the Indian black eagle (Ictinaetus malayensis), which tend to select nesting sites that have alow degree of landscape contrast for a distance of 250m around the nest. In terms of landscape complexity, however, there were no great differences among the nesting sites at a distance of 250m. The edge density around the Indian black eagle nest was higher than for the other nests at distance of 250–1000m. Characteristic differences in nest site selection may be due to landscape structure at different scales around the nest. Certain management strategies should be undertaken, step by step, in order to maintain the sustainability of the raptor population and, at the same time, contribute positively to the local people living in the human-modified landscape in Panaruban and Telaga Warna.

***Keywords**: Landscape; Nesting site; Raptor conservation; Spatial analysis; Sustainability*

Introduction

Beyond the well-documented ecosystem services provided by scavengers and predators [1], raptors serve as cultural symbols, are indicators of biodiversity and environmental health [2], and can structure biological communities [3, 4]. Their high trophic level and generally slow life history make raptors more sensitive to anthropogenic threats [4, 5] and extinction [6] than most other bird species.

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Raptors have been good indicators of habitat quality because of their sensitivity to human disturbance and environmental contamination [7, 8]. Raptors are categorised as a focal species, being sensitive to environmental change, such as impacts to their ecosystems, and vulnerable to pollution, so they serve as an icon for conservation intiatives. Population declines in certain raptor species indicate dysfunctional ecosytems because the population dynamics of the highest-order predators often reflect the health of the ecosystems they inhabit [7, 9-12]. Thus, it has been recommended that raptors be included in the management and conservation plans of any region, especially in threatened habitats [10, 11]. The conservation of raptors is an effort to protect and maintain the health of broader ecosystems, which in turn will have a direct impact on the environmental conservation important in maintaining human well-being.

The importance of raptors in applied conservation comes from several conceptual qualities that they possess. Firstly, raptors are considered to be so-called ‘umbrella’ species, with low population densities and large individual home ranges, so that, by protecting these species, we protect all the species on which they depend, or the species with similar requirements, but smaller home ranges. Therefore, top predators like raptors are a key taxon in conservation planning and environmental impact assessments [13, 14]. Secondly, they can act as a valuable indicator species for changes and stresses in urban ecosystems, as they are relatively sensitive to changes in habitat structure and fragmentation, and have a high susceptibility to local extinctions [15-18]. Thirdly, complex or expensive conservation efforts are more easily undertaken by management agencies when oriented to flagship species like raptors because applied land-planning that focuses on their preservation usually implies an improvement in effective protection for the entire region they occupy (the umbrella effect [13, 19]).

Anthropogenic activities are leading to broad-scale, non-random changes in bird community compositions [20, 21]. This is not a new phenomenon, as human pressures, mainly through persecution and the modification of habitats, have historically had consequences for bird populations all around the world. One of the critical factors for all species is their habitat sustainability and availability [22, 23]. Furthermore, understanding what constitutes suitable habitat for particular species is important for recognising the impact of landscape changes on those species [24]. Knowledge of habitat preferences is critical for understanding the needs of, and interactions among, sympatric avian species and for implementing successful management and conservation projects.

Human-modified landscapes are highly dynamic, in terms of spatial configuration, composition and between-landscape structural connectivity. They tend to be periodically disturbed and biologically isolated at regional scales in the absence of restrictive land-use regulations. Translating these land-use trends to the context of the conservation value of such landscapes, it is reasonable to argue that human landscapes are unlikely to accumulate native species over time, as local species loss is expected to exceed species gain [25].

At the present time, the study of raptors in Indonesia is mainly focused on aspects of the presence, ecological behaviour, distribution and community of the raptors. More practical research, aimed at establishing conservation strategies and mechanisms, is infrequently carried out, especially studies using landscape ecological approaches. The implementation of a landscape ecological approach in nature conservation is very effective because it is comprehensive, and able to analyse problems over broad and complex spatial scales [26]. Meanwhile, Mortberg *et al.* [27] determined that the landscape ecological approach could be used as conceptual framework in analysing the long-term impacts of development activities on natural biodiversity caused by landscape change. From another perspective, Leitao *et al.* [28] expressed that landscape management and planning need a sustainable approach based on the spatial dimensions involved. He further pointed out that landscape ecology has several finite parameters that make it easier to analyse all potential problems in natural management and planning.

Given this overview, the aims of this study were to: (i) discover the relationship between landscape structure and the presence of raptors in the human-modified lanscape of Panaruban and Telaga Warna; (ii) design a conservation and management strategy for sustainability in a landscape experiencing intensive human intervention (human-modified landscape), most specifically with respect to endangered raptors.

Experimental

Materials

The study was conducted in the Panaruban and Telaga Warna areas, located in West Java Province. Panaruban and Telaga Warna are two of the areas on Java Island that have a moderate climate and mountainous tropical forest vegetation, which hosts a rich biodiversity; this is why the area is ecologicaly important.

Methods

A spatial analysis was undertaken to discover the relationship between landscape structure and raptor species diversity. For that purpose, calculations of heterogeneity and landscape connectivity were performed, including the composition and configuration of landscape elements, diversity index, dominance, complexity, degree of contrast and edge density around the nest [29]. Also, in terms ofthe raptors, the study focused on their presence in the landscape, the beneficial elements for the raptors in the landscape and the over population situation in the landscape. To this end, mapping and spatial analysis of the nests was undertaken. Based on the landscape and raptor data sets, spatial analysis was used to determine the relationship between landscape structure and raptor diversity in the study area. Data that correlated with the landscape was collected from both SPOT-5 satellite maps and direct observation. The data were then analysed for landscape structure quantification using Fragstats v.2.0 [30].

Results and discussion

The number of pairs of raptors occupying the Telaga Warna area is relatively high compared to Panaruban. The number of raptors in the Telaga Warna area is 12 pairs, consisting of five pairs each of Javan hawk eagles and Indian black eagles, one pair and one child of changeable hawk eagles and one pair of crested serpent eagles. In Panaruban, there are only four pairs, one pair each of each type of eagle studied.

Land coverage type was used to classify the distinct areas around the nests of the raptors under study within a radius of 250–1000m. Seven types were identified in Panaruban: natural forest; mixed gardens; tea plantations; rice fields; settlements/residential areas; open land; and craters. The total number of nests found in the Panaruban landscape and analysed spatially was five, for four species of raptor. These included one active nest each for the Javan hawk eagle, the Indian black eagle and the crested serpent eagle, and one active and one inactive nest for the changeable hawk eagle. These four types of raptor in the Panaruban landscape located their nests in different landscape elements, so that even though there was overlap in the nesting sites of three of the species, these overlaps occurred in a radius greater than 500m. Therefore, in a radius of less than 500m, the four kinds of raptor in the Panaruban landscape had their own land coverage classes, which differ in terms of the area surrounding the nest.

The Telaga Warna landscapes around the three types of raptor nests were grouped into four types of land coverage: natural forest; mixed gardens; tea plantations; and open land. The total number of nests analysed spatially was 12 for the three species of raptor: five active and one inactive Javan hawk eagle nests, five active Indian black eagle nests, and one active changeable hawk eagle nest.

Diversity index and dominance value of landscape around the nest

This index shows the diversity of landscape elements and the spread of areas of each element. The diversity index for the five eagle nests in Panaruban shows considerably high variations, ranging from 0 to 1.18, within a radius of 250–1000m. The highest diversity index range of all the observed nests within a radius of 250–1000m is the inactive changeable hawk eagle nest, with a diversity index ranging from 0.6 to 1.18. This is followed by an active changeable hawk eagle nest at 0.1–0.9 and an Indian black eagle nest at 0–0.89. The lowest range of diversity index values in a radius of 250–1000m was a Javan hawk eagle nest with a value of 0.2–0.3. The diversity index indicates landscape heterogeneity; in general, the landscape heterogeneity in Panaruban was relatively high, giving a reason for it being inhabited by four species of raptor. The heterogeneity of the landscape has an impact on the diversity and abundance of raptors [31, 32]. A comparison of the diversity indices of all of the nests in Panaruban for the four types of raptor within a radius of 250–1000m can be seen in figure 1.

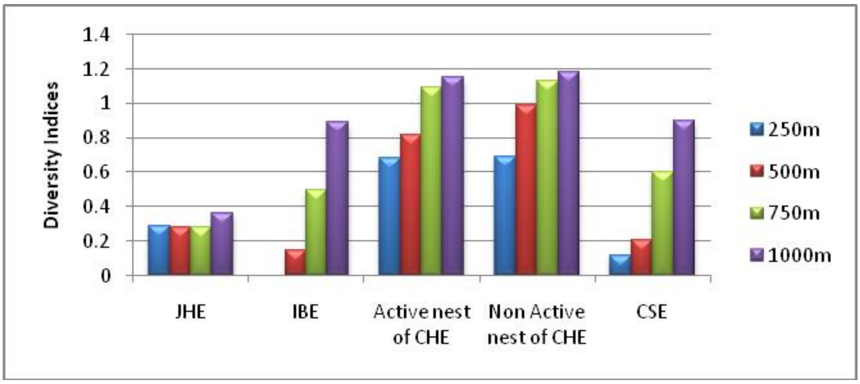

Fig. 1. Comparison of the diversity indices of five raptor nests in the Panaruban landscape within a radius of 250–1000m

The diversity index provides a proxy for the composition of the landscape from the perspective of the diversity of habitat types existing within a certain radius. The diversity index in Telaga Warna for the six Javan hawk eagle nests showed relatively high variation, ranging from 0 to 1.28 within a radius of 250–1000m. The diversity indices for the five Indian black eagle nests are 0.07–1.11, and for the one changeable hawk eagle nest is 0.11–0.78, both within a radius of 250–1000m. The highest diversity indices of all of the nests within that radius in Telaga Warna is Javan hawk eagle nest #5, with a range of 0.88–1.28, followed by Indian black eagle nest #1 at 1.06–1.11. The lowest index values are between 0 and 0.68 for Javanese hawk eagle nest #6, which was not active, and was only used once by a Javan hawk eagle pair that then moved to nest #1. It is possible that the low diversity index value at nest #6 caused the Javan hawk eagle pair to move to nest #1, leaving nest #6 to become inactive.

Although overlapping among species is likely to happen, it seems that the Javan hawk eagle in the Telaga Warna landscape preferred nests with tea plantation land cover within a radius of 250m. This is in contrast to the Indian black eagle, which only chose nests with forest and tea plantation land cover, and the changeable hawk eagle, which chose forest and mixed gardens, within a radius of 250m.

A comparison shows that the average diversity index of the Indian black eagle nest landscape was higher than that of the Javan hawk eagle nests and one of the changeable hawk eagle nests, within a radius of 250m. The high values around the Indian black eagle nest landscape possibly relate to the Indian black eagle not being significantly affected by the intensity of human activity, and being able to adapt more quickly to conditions around the nest to 250m. A comparison of the diversity indices of all of the nests of the three types of raptor, within a radius of 250–1000m, is shown in figure 2.

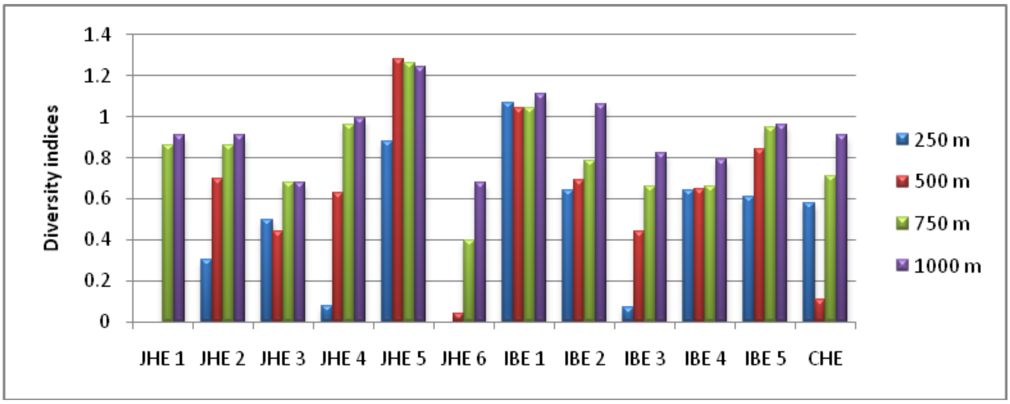

Fig. 2. Comparison of the diversity indices of 12 raptor nests in the Telaga Warna landscape within a radius of 250–1000m

All of the nests have dominance values that vary depending on the characteristics of each type of eagle. The highest dominance value for the Javan hawk and crested serpent eagles in Panaruban, within a 250–1000m radius, is for forest, while for the Indian black eagle it is mixed gardens. For the inactive changeable hawk eagle nest, within a radius of 250–1000m, the highest value is for mixed gardens, whereas, for the active changeable hawkeagle nest, the highest.

Values are for natural forest, within a radius of 250m, and mixed gardens, within a radius of 500–1000m. These values thus indicate that all of the types of eagles require natural forest cover for nesting sites, in addition to a site for searching for prey, such as open land and mixed gardens. The dominance values for the five eagle nests in Panaruban within a 250–1000m radius can be seen in Tables 1, 2 and 3.

Table 1. Comparison of dominance values for five raptor nests in the Panaruban landscape within a radius of 250–500m

Class	250 m				500 m					
	Natural forest	Fragmented forest	Mixed garden	Tea plantation	Natural forest	Fragmented forest	Mixed garden	Tea plantation	Paddy field	Housing
JHE	51.28	3.97	0	0	52.85	3.19	0	0	0	0
BE	0	0	57.32	0	0.36	0	56.15	0	0.72	0.04
CHE active nest	32.83	0	23.12	0	19.84	0.05	34.4	1.66	0	0
CHE inactive nest	19.54	0	37.25	0.29	19.48	0	26.1	7.88	0	0.04
CSE	56.07	1.48	0	0	55.14	0.79	0	0.53	0	0

Table 2. Comparison of dominance values for five raptor nests in the Panaruban landscape within a radius of 750m

Class	750 m							
	Natural forest	Fragmented forest	Mixed garden	Tea plantation	Paddy field	Pines	Housing	Crater
JHE	53.05	2.18	0	0	0	0	0	0
BE	1.64	0.49	50.97	0	0.87	0.1	0.15	0.004
CHE active nest	16.87	0.84	27.79	10.22	0	0	0.02	0
CHE inactive nest	16.87	0.84	27.79	10.22	0	0	0.02	0
CSE	47.13	1.27	0.158	4.53	0	0	0	0

Table 3. Comparison of dominance values for five raptor nests in the Panaruban landscape within a radius of 1000m

Class	1000 m								
	Natural forest	Fragmented forest	Mixed garden	Tea plantation	Paddy field	Pines	Open land	Housing	Crater
JHE	50.56	1.23	0	0	0	0	0	0	0
BE	2	1.3	43.6	0	0.97	0.68	0	0.33	0.002
CHE active nest	17.4	0.47	27.19	10.49	0	0.009	0	0.14	0
CHE inactive nest	18.65	0.47	24.48	11.8	0	0	0.05	0.14	0
CSE	39.51	0.73	1.68	11.6	0	0	0	0.14	0

The highest dominance value in Telaga Warna for all the Javan hawk eagle nests, within a radius of 250–1000m, is for forest or tea plantations. For the Indian black eagle, the value is for four nests (#1, 2, 3, 4) for tea plantations or mixed gardens; for nest #5, the highest dominance value for a radius of 250–750m is for forest, whereas it is for tea plantations for a radius of 1000m. The highest dominance value for the changeable hawk eagle is natural forest, within a radius of 250m and 750m, and mixed gardens, within a radius of 500m and 1000m. These values indicate that all types of studied eagles in Telaga Warna require open land, such as tea plantations, to find prey, in addition to other hunting locations, such as forest and mixed forest. All of the dominance values for the 12 nests found in the Telaga Warna landscape, within a 250–1000m radius, are presented in Table 4.

Table 4. Comparison of dominance values for 12 raptor nests in the Telaga Warna landscape within a radius of 250–1000m

Class	250 m				500 m				750 m				1000 m			
	Natural Forest	Mix Garden	Tea Plantation	Open Land	Natural Forest	Mixed Garden	Tea Plantation	Open Land	Natural Forest	Mixed Garden	Tea Plantation	Open Land	Natural Forest	Mixed Garden	Tea Plantation	Open Land
JHE 1	0	0	49.77	0	0	0	77.09	0	13.08	115	14.28	0	8.99	2.55	13.71	0
JHE 2	27.43	0	2.71	0	22.68	0.14	13.28	0	13.63	1.2	14.87	0	9.26	2.63	14.13	0
JHE 3	15.44	0	60.66	0	15.8	0	21.61	0	23.25	0	17.14	0	24.25	0.07	12.45	0.15
JHE 4	1.1	0	75.74	0	4.86	1.22	28.6	0	5.58	3.99	22.68	0	6.94	3.87	18.28	0
JHE 5	23.05	1.7	12.98	16.86	10.6	3.4	13.35	8.53	9.62	2.27	14.02	5.5	7.92	4.47	15.33	3.56
JHE 6	0	0	76.84	0	0	0.26	35.68	0	0.8	1.96	35.15	0	5.39	4.8	60.24	0
IBE 1	16.95	31.14	26.99	0	14.14	33.06	28.74	0	5.11	16.47	12.75	0	5.52	16.22	10.57	0.37
IBE 2	16.61	0	47.75	0	25.71	0	0	41.51	7.76	1.08	20.81	0.05	6.45	3.41	20.29	0.28
IBE 3	1.04	0	71.63	0	5.33	3.76	69.05	0	4.09	3.62	31	0	4.94	3.72	27.32	0
IBE 4	26.1	0	50	0	12.65	0	22.01	0	24.12	0.24	42.96	0	10.16	1.53	21.11	0
IBE 5	51.56	0	14.88	0	19.59	1.66	10.34	0	13.7	2.71	10.36	0	9.09	2.47	11.42	0
CSE	10.73	2.08	0	0	0.86	37.14	0	0	42.18	31.97	0.2	0	19.65	16.81	0.18	2.28

Complexity, degree of contrast, and edge density around the nests

The complexity values of the landscape around the five nests in the Panaruban landscape vary widely, ranging from 1.0 to 5.7. The complexity values for the Javan hawk eagle nests, within a radius of 250–1000m, range from 1.85 to 4.36. The highest complexity value among all of the studied nests in Panaruban, within a 250–1000m radius, is around the Indian black eagle nests, at 1.0–5.7, involving seven classes of land coverage.

The complexity values for the changeable hawk eagle nests, active and inactive, within a radius of 250–1000m, ranges from 1.83 to 4.44 and from 1.64 to 4.48, respectively. The lowest and highest of these complexity values relate to the inactive nest within a 250m radius (at 1.64) and within a 1000m radius (at 4.48). The complexity values of the crested serpent eagle nests, within a radius of 250–1000m, range from 1.43 to 4.07.

The complexity values for the Javan hawk eagle, active and inactive changeable hawk eagle, Indian black eagle and crested serpent eagle nests, within a radius of 250–1000m, thus show different patterns. A comparison of the complexity of the five nests in Panaruban, within a 250–1000m radius, is illustrated in figure 3.

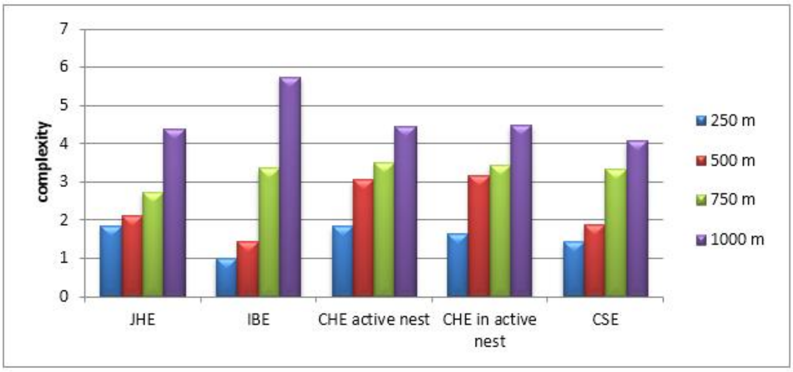

Fig. 3. Comparison of the complexity of the five raptor nest landscapes in Panaruban within a 250–1000m radius

The complexity of the landscape around the 12 nests found in the Telaga Warna landscape was also highly variable, ranging from 0 to 2.54. The complexity of the six Javan hawk eagle nest ranges from 1.0 to 2.54, within a radius of 250–1000m, the highest complexity relating to nest #6 (1.48–2.54), involving four classes of land coverage.

The complexity of the five Indian black eagle nests varies from 1.06 to 2.51, within a radius of 250–1000m, with the highest complexity relating to nest #1 (1.43 to 2.51), involving three classes of land coverage within a radius of 250–750m and four classes within a radius of 1000m.

The complexity of the changeable hawk eagle nest ranges between 1 and 2.1, within a radius of 250–1000m. The relatively small value of this complexity is because it involves only one class of land coverage within a radius of 250m, two classes within a radius of 500m and three classes within a radius of 750–1000m. A comparison of the complexity of the 12 nests studied in the Telaga Warna landscape, within a radius of 250–1000m, is presented in figure 4.

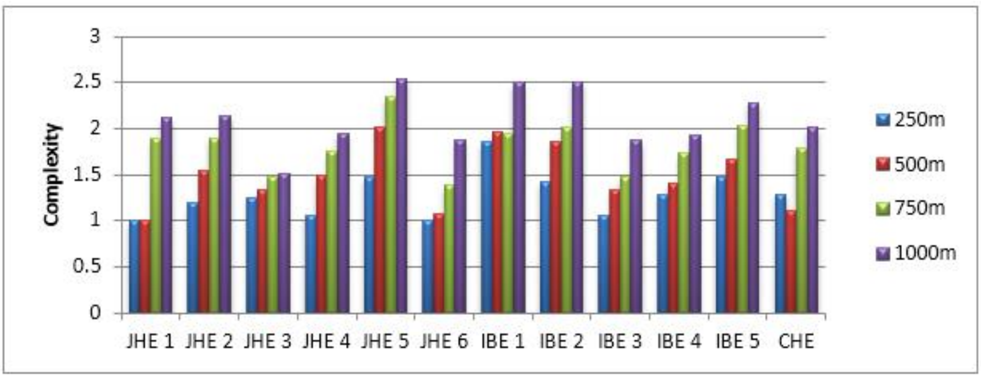

Fig. 4. Comparison of the complexity of the 12 raptor nest landscapes in Telaga Warna within a radius of 250–1000m

The degree of contrast is a value that indicates the amount of difference between two adjacent spaces (spots), based on the vegetation closing conditions.

Based on the differences among the values of each class of vegetation coverage for each Javan hawk eagle nest, it can be said that the degree of contrast within a 250–1000m radius is less than that of the Indian black eagle nest. The Javan hawk eagle nests have only two classes of land coverage (forest and degraded forest) within this radius, whereas the Indian black eagle nest has seven within the same radius, giving it a high degree of contrast. This may imply that the Javan hawk eagle requires a core element of natural forest, but that the presence of other elements is still needed to ensure the availability of prey, whilst the Indian black eagle requires a heterogeneous landscape around the nest and that it does not require a core element from any one of the elements in the existing landscape. The degree of contrast around the active and inactive changeable hawk eagle nests within a radius of 250–500m is greater than that around the nests within a radius of 750–1000m. A comparison of the degree of contrast values for the five nests of raptors in the Panaruban landscape within a 250–1000m radius can be seen in figure 5.

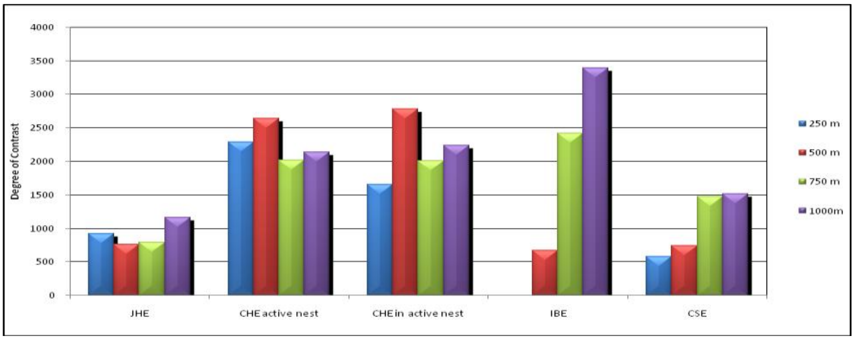

Fig. 5. Comparison of the degree of contrast among the five raptor nest landscapes in Panaruban within a radius of 250–1000m

The degree of contrast highlights the different vegetation structure for spots around the nest, within a radius of 250–1000m. The value of the degree of contrast is obtained after determining the value of each adjacent land's class, which were determined here based on the diversity of the vegetation structure. The values used to calculate the degree of contrast in the TelagaWarna and Panaruban landscapes were the same.

The degree of contrast for the Javan hawk eagle nests varies from 0 to 27.3, whereas those of the Indian black eagle nests ranges from 2.74 to 66.22, and the changeable hawk eagle nests ranges from 1.8 to 22.84.

Based on the differences in the values of each class of vegetation coverage in each Javan hawk eagle nesting site, the degree of contrast is less than that of the Indian black eagle nest. Two of the Javan hawk eagle nests had only one class of land coverage (tea plantations) within a radius of 250–500m. In contrast, all of the Indian black eagle nests had more than two classes within a radius of 250–1000m.

This relatively high degree of contrast in the Indian black eagle landscape is likely to be one of the factors why its nest distribution is more dispersed in comparison to that of the Javan hawk eagle. This is because the areas that have a high degree of contrast, with a more diverse vegetation structure, in the Telaga Warna landscape are not located adjacent to each other, and are relatively spread out in certain locations. All of the degree of contrast values for the 12 raptor nests studied in the TelagaWarna landscape, within a radius of 250–1000m, can be seen in figure 6.

Edge density is one of the metrics measured in this study to indicate the landscape heterogeneity and fragmentation. The edge density of all of the studied nests, within a radius of 250–1000m, in the Panaruban area is highly variable, ranging from 0 to 81.96. Around the Javan hawk eagle nest, it ranges from 37.9 to 58.06, around the Indian black eagle nest from 0 to 154, around the active changeable hawk eagle nest is 57.2 to 70.9, around the inactive changeable hawk eagle nest from 43.4 to 74.5, and around the crested serpent eagle nest from 29 to 53.3.

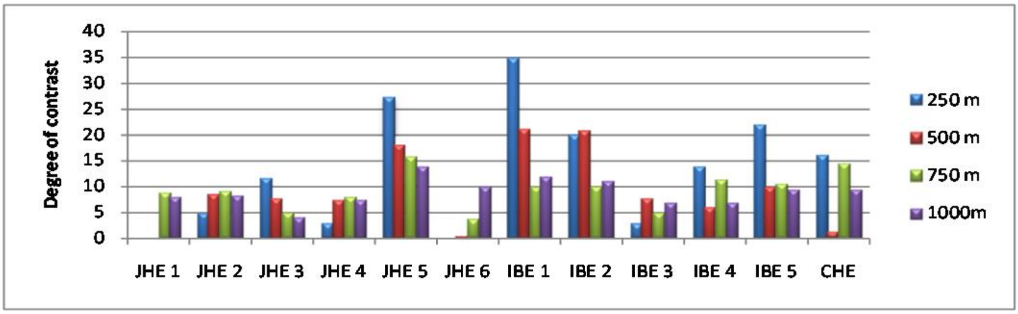

Fig. 6. Comparison of the degree of contrast among the 12 raptor nest landscapes in Telaga Warna within a radius of 250–1000m

The edge density around the Indian black eagle nest is 0 at a radius of 250m because, at that radius, there was only one spot and one coverage class (forest). An edge density value of 0 also indicates that there is no transition between land coverage classes within a given radius. The highest edge density belongs to the Indian black eagle nest within a 500m radius because, even though there were only four classes of land coverage, the boundaries between the spots were greater in length within the 500m radius. This indicates that the heterogeneity and habitat fragmentation of the space in that radius is high. The edge density of each type of eagle in Panaruban shows a different pattern for each species and different radius. A comparison of the edge densities of the five raptor nests in the Panaruban landscape can be seen in figue 7.

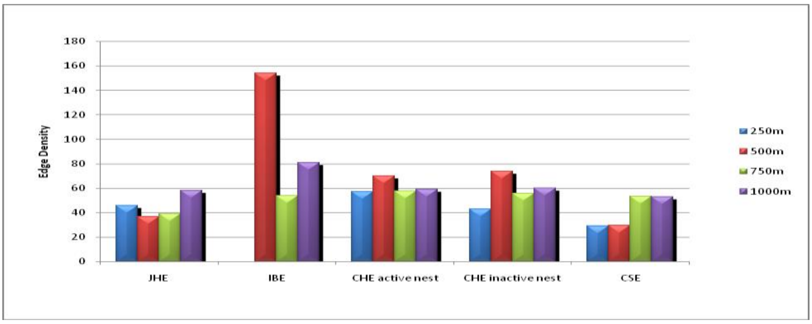

Fig. 7. Comparison of the edge density of the five raptor nest landscapes in Panaruban within a 250–1000m radius

The edge density of all of the nests in Telaga Warna is relatively highly variable, ranging from 0 to 66.23, with the six Javan hawk eagle nests ranging from 0 to 38.82, the five Indian black eagle nests from 4.57 to 66.23, and the changeable hawk eagle from 0 to 15.85, within a radius of 250–1000m.

Two Javan hawk eagle nests have edge densities of 0 within a radius of 250m and one at 750m. This is because, within that radius, there is only one spot and one land coverage class (tea plantations). Similarly, for the changeable hawk eagle, within a 250m radius, the edge density value is 0 because there is only one spot and one land coverage class (mixed garden). The highest edge density is around Indian black eagle nest #1 because, even though there are only three classes of land coverage, the boundaries between the spots are greater in length within a radius of 250m. This indicates that the heterogeneity of the spots and habitat fragmentation within that radius are high. A comparison of the edge density of the 12 studied raptor nests in the Telaga Warna landscape can be seen in figure 8.

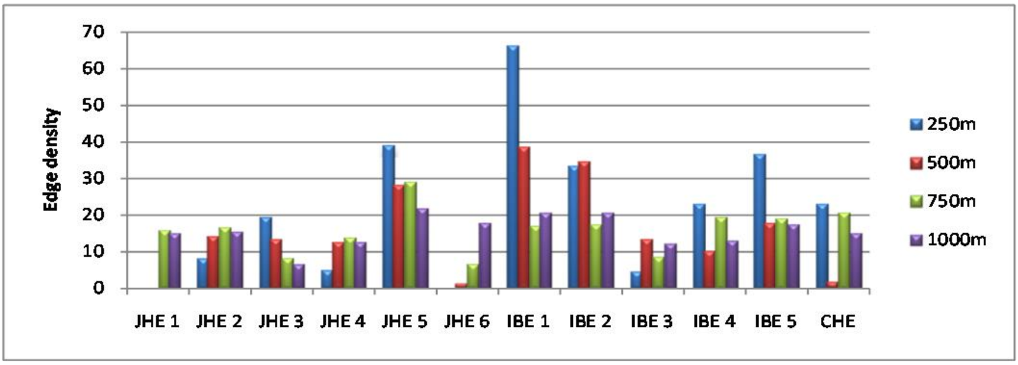

Fig. 8. Comparison of the edge density of the 12 raptor nest landscapes in Telaga Warna within a 250–1000m radius

Based on these results, it can be seen that the structure of the human-modified landscape in Panaruban and TelagaWarna shows some differences that have affected the nesting choices of the four types of raptor. The Javan hawk eagle sited its nests in the forest or tea plantation landscape elements, while the Indian black eagle sited its nests in forest, mixed gardens and tea plantations. The crested serpent eagle preferred to site its nest in the natural forest landscape element, while the changeable hawk eagle preferred the natural forest and mixed farms. This shows that the four raptors can live together in a landscape that has natural forest, mixed gardens and tea plantations.

Natural forest is the element required by all four raptors around their nests within a radius of 250–1000m, but other landscape elements are still needed for siting nests in, and to ensure the availability of prey. In general, the heterogeneity of the landscape surrounding the Indian black eagle nests is higher than that around the three other types of raptor nests.

The results of the spatial analysis of both landscapes indicate that the Indian black eagle had a tendency to site its nests in various types of landscape elements, compared to the three other types of raptor. This might explain the broad range of Indian black eagle on Java, ranging from the lowlands to the highlands.

The complexity, degree of contrast and edge density around the nests of the four species of raptor are highly variable, indicating that each species of raptor has its own reasons for siting a nest, which relate to these three structures of the landscape. The Indian black eagle exhibits greater complexity, degree of contrast and density in the landscape of Panaruban than the other three types of raptor. The range of complexity for all three types of raptor in TelagaWarna does not show significant differences, although the range of degree of contrast and edge density for the Indian black eagle is relatively much higher than those of the Javan hawk eagle and changeable hawk eagle in Telaga Warna.

The differences in the structure of the landscape surrounding the nests of these four raptor species in Panaruban and Telaga Warna were used as the basis for a conceptual framework for the conservation of protected raptors in Indonesia, using the principles of landscape heterogeneity in relation to the nature of the landscape elements.

Based on the results of this study, a conceptual framework for raptor conservation – raptors being protected by law in Indonesia – should be based on the following principles:

1. The principle of the integration of the natural and built ecosystem

One characteristic of raptors is that they have a very wide cruising range, using a variety of landscape elements, both natural and built, so that the protection of raptors cannot be done on one single element of the landscape. This is supported by the results of the landscape analyses performed in this study. To undertake the conservation of raptors, based on the principle of integration of natural ecosystems and the built landscape, it is necessary to consider the following strategies:

a. An integrated management of all elements of the human-modified landscapes in Panaruban and Telaga Warna by the stakeholders.
b. Institutional arrangements to achieve integrated management of all elements of the landscape.
c. Protection of natural ecosystems as an integral part of human-modified landscapes without reducing the ability of the locals to meet their basic needs.
d. Elements of the built landscape should not be solely intended for functional production, but should also maintain ecosystem integrity.

The principle of the heterogeneity of landscape

The results of the landscape analysis showed that landscape heterogeneity in the human-modified landscapes of Panaruban and TelagaWarna is quite high, and that the presence of raptors is reliant on this. This must thus be maintained. This is consistent with the findings of Anderson [32] who explained that landscape heterogeneity greatly contributes to the diversity and abundance of raptors. This principle also applies to prey for the raptor.

Maintaining natural landscape elements is integral to raptor conservation. Three types of raptor in Panaruban sited their nests in forest, and one in mixed garden (the Indian black eagle); however, the latter still needed forest within a 500m radius. This is similar to what was determined in TelagaWarna. Although there was some overlap in nest sites in Telaga Warna, both within the same and among different raptor types, all of the raptors required natural forest within a radius of 250–1000m.

To maintain landscape heterogeneity, a disturbance spectrum management study should be performed, in order to avoid the same disturbance intensity occurring in the same landscape elements. The conservation value of human-modified landscapes should be increased via: (i) strict pre-deforestation land-use regulations to guarantee landscape configurations that are biodiversity friendly; (ii) controlled access to forest products, regardless of whether they are explored commercially or for subsistence; and (iii) permanent supervision of economic activities to avoid excessive turnover of the land-use regime and the resulting episodes of (local) species extinction every time landscapes are spatially reconfigured [25].

Based on a complete analysis of the landscape, it is known that the relocation of some eagle nests in Panaruban were caused by human activity intensifying around the nests, disturbing the raptors that likely did not then feel safe to nest in the area. On the other hand, the relocation of nests in Telaga Warna, based on a complete landscape analysis, was due to lack of food around the nest. These factors are in accordance with the results of Andrew *et al.* [33] for the bald eagle (*Haliaeetus leucocephalus*); they concluded that anthropogenic disturbance is not an important factor in nest site selection for the eagles. Some raptors can tolerate low-intensity, time-limited human disturbance around the nest, as long as food availability is unaffected and is far away from the area of intense human activity.

Some disturbances in Panaruban and Telaga Warna that threaten the presence of raptors are caused by intensive human activities in mixed gardens and vegetable gardens around the nest. In these places, intensive agricultural practices are performed by many local residents who live around the forest, opening up forested land for vegetable gardens to meet their economic needs.

Therefore, the strategies required to be undertaken under the landscape heterogeneity principle associated with the naturalness of the landscape and the disorder spectrum, are:

a. Reduce the drastic changes in land coverage in both landscapes, so there will be no homogenising of the landscape; for example, changing natural forests into managed ones on a large scale.

b. Maintain the existing landscape heterogeneity because it is enough to maintain the existence of the four types of raptor.
c. Retain the existing natural forest areas so that their range does not decrease due to conversion of these areas into planted forests, vegetable gardens or mixed gardens.
d. Reduce fragmentation in both landscapes, as this negatively affects the presence of raptors. Fragmentation divides a large population into two or more smaller populations, making them more vulnerable to extinction. Fragmentation can also change the microclimate in the divided areas, and can become an entry point for species originating from outside the area that can partition the native species, magnify the effects of the edges, and form a barrier to the spread of a population, in terms of migration and inhabiting a new site. Fragmentation in Panaruban is greater than in Telaga Warna, resulting in fewer raptor pairs in the former location. Fragmentation also resulted in relocation of the changeable hawk eagle nest in Panaruban.
e. Introduce environmentally-friendly farming practices that do not interfere with the presence of wildlife, such as raptors. Such practices would include the use of organic soil fertilisers, a reduction in pesticide use, and the cessation of using plastic covers as barriers to erosion in areas used as vegetable gardens so that it does not interfere with the presence of raptors and their prey.
f. Reduce human activity around raptor nests, especially during breeding season. The protection of nesting areas is fundamental in supporting breeding, and must be undertaken by the managers of the Panaruban and Telaga Warna landscapes.

Create a buffer zone to reduce the occurrence of high-intensity disturbance in natural forests or the areas surrounding raptor nests; for instance, in Panaruban, tea plants have been allowed to grow for many years to become *lancuran*, which can be used by locals as firewood.

Conclusions

The success of conservation measures often requires a combination of strategies that aim to improve several parameters simultaneously [34]. This means that the strategy for the Panaruban and Telaga Warna landscapes cannot be implemented all at once; rather, several steps need to be taken, based on a variety of planned management strategies. The management of the human-modified landscapes of Panaruban and Telaga Warna must not only protect raptors and their prey, but also agricultural practices conducted in both landscapes in a sustainable manner. The protection of the raptor, the prey and the area surrounding these birds may indirectly preserve the human-modified landscape in Panaruban and TelagaWarna, without reducing the benefits that can be taken by people who live in these locations.

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