GIS-based approach for quantifying landscape connectivity of Javan Hawk-Eagle habitat

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Abstract. Javan Hawk-Eagle (Nisaetus bartelsi; JHE) is a law-protected endemic raptor which currently faced the decreased in number and size of habitat patches that will lead to patch isolation and species extinction. This study assessed the degree of connectivity between remnant habitat patches in central part of Java by utilizing Conefor Sensinode software as an additional tool for ArcGIS. The connectivity index was determined by three fractions which are infra, flux and connector. Using connectivity indices successfully identified 4 patches as core habitat, 9 patches as stepping-stone habitat and 6 patches as isolated habitat were derived from those connectivity indices. Those patches then being validated with land cover map derived from Landsat 8 of August 2014. 36% of core habitat covered by natural forest, meanwhile stepping stone habitat has 55% natural forest and isolated habitat covered by 59% natural forest. Isolated patches were caused by zero connectivity (PCcon = 0) and the patch size which too small to support viable JHE population. Yet, the condition of natural forest and the surrounding matrix landscape in isolated patches actually support the habitat need. Thus, it is very important to conduct the right conservation management system based on the condition of each patches.

1. Introduction
Javan Hawk-Eagle is an endemic raptor species from Java Island [1]. The habitat preferences used by juvenile and immature differ from mature Javan Hawk-Eagle. The adult eagle selects the evergreen forest and secondary forest. Juvenile eagles tend to scatter out of their home territory and appear in less suitable areas as their habitat, whereas the immature eagles tend to choose habitats similar to adult eagles as a way to build new breeding territories [2]. These requirements are currently experiencing a major problem that threatens the sustainability of this species that is uncontrolled environmental damage. Currently only 675,000 hectares natural forest remains by 2013 in Java Island, a decrease by 32% from 2009. Moreover the remaining forest only cover 5% area compared to non-natural forest area [3]. This resulted in the predicted Javan Hawk-Eagle habitat being in a location far away from each other [4].

Connectivity plays an important role in the management of conservation of natural resources and wildlife [5]. Landscape connectivity has an understanding as the degree of ability of a landscape in facilitating the movement or dispersal of species between habitat patches [6,7]. While ecological connectivity can be interpreted as a connection or relationship that occurs between different landscape
elements, ranging from energy or information, nutrient cycles, the spread of pollen to the movement of flora and fauna and metapopulation [8]. Connectivity is dependent on the structure of the landscape and the species ability to disperse [9]. The main components of connectivity comprise the spatially-oriented components or functional features and functional components that are species behavior and habitat preferences [10].

The movement of species is the main thing in population dynamics so connectivity becomes decisive in conservation [11]. Habitats that are not connected will become isolated patches and increase the potential for inbreeding. Interconnected habitats with high degree of connectivity are able to avoid the negative impacts of fragmentation such as habitat isolation, diminishing patch size, to decreased genetic quality due to inbreeding [12-15]. Connectivity also allows an individual to use some habitat fragments even though they are small in size so that they do not have to rely on certain large fragments and patches that benefit not only a group of species but also other species [16].

Previous study on Javan Hawk-Eagle have been focused on determining the breeding biology, habitat use, home range and predicted population density on specific study site [1, 2, 4, 5, 24]. There has been no attempt to see the connectedness between dispersed habitats. Therefore, in this study we evaluated the presence or absence of a link between fragmented habitats. The aims of this study were to: (1) analyze the available connectivity between patches, (2) evaluate the contribution of each patch to the habitat network, and (3) identify the conservation priority that need to be conducted based on the characteristic of each patch.

2. Method

2.1. Study Area
Central part of Java Island of about ±37300 km² consists of Central Java Province and Special Region of Yogyakarta Province. It has three national park which are Merbabu National Park and Merapi National Park on the mainland. And also Karimun Jawa National Park as small archipelago located at Java Sea. Central part of Java has the least suitable habitat for Javan Hawk-Eagle compared to western part and eastern part of Java [4]. This region also suffered by environment degradation due to the loss of 80% of natural dryland forest which result in severely fragmented habitat [17]. Habitat suitability model based on 2014 Landsat 8 OLI/TIRS in 250 m resolution concluded that only 19 suitable patches remain for Javan Hawk-Eagle [18]. Those patches located far from each other scattered all over central part of Java.

Figure 1. Study site and location of Javan Hawk-Eagle remnant habitat patches.
2.2. Analysis Tools
To perform connectivity analysis, this study used software called Conefor Sensinode 2.6 [5]. This software can be downloaded for free at http://www.conefor.org. Inside the software we use Probability of Connectivity (PC) index which is the probability or probability of two animals randomly placed on a landscape capable of reaching or reaching each habitat (interconnected) in a collection of habitat $n$ patches that have a linkage level in it [1]. The index formula (1) is as follows:

$$PC = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} a_i a_j p_{ij}^*}{A_L}$$  \hspace{1cm} (1)

Where $a_i$ and $a_j$ are the areas in the patch habitats $i$ and $j$, the $A_L$ is the total area of the study area landscape consisting of habitat and non-habitat patches. The result of the probability of a patch or path (where a path is made of a set of steps that does not pass the same patch twice) is the result of a $p_{ij}$ at each step in the path. While $p_{ij}^*$ is defined as the maximum probability outcome of all paths appearing between patches $i$ and $j$ (including single-step paths). If patch $i$ and $j$ are close enough then the maximum path probability result is just a step (direct movement between patch $i$ and $j$). If the distance between patch $i$ and $j$ farther, then the maximum probability path will consist of several steps through stepping stone enclosing $p_{ij}^*$.

The information required as input in this software is the node data contains a list of existing habitat nodes on the landscape along with its attributes. The habitat node data present in this method uses the first-stage patch analysis results. Attributes on the node are characteristics of the node itself considered to be related to the analysis to be used such as habitat area, habitat quality, and other attributes. Connection data contains the information needed to characterize connections between two nodes in the landscape. The data included in this study is Euclidean distance between each patch. The output of this stage is a patch function determined by three fractions ie $dPCintra$, $dPCflux$, and $dPCconnector$ [20]. This fraction shows the contribution of each patch to the connectivity and overall landscape. $dPCintra$ shows the contribution of the patch to the intrapatch connectivity or the patch weight itself if it connected to other patches. So although isolated the patch still has the weight, $dPCflux$ shows the patch capability level in its role as the initial patch or final patch in the species dispersion process. $dPCconnector$ shows the contribution of the patch as a connecting element or stepping stone between patch habitats.

Habitat availability and distance between patches were required to produce the degree of connectedness between patches. Only a patch of habitat remnant at a resolution of 250 m is used in the connectivity analysis. At this stage an edge-to-edge Euclidean distance method is used to obtain distance information between patches. Use of Euclidean distance assuming that birds can fly freely and move between habitat patches without taking into account the obstacles posed by different types of land cover. The dispersal distance used uses the median assumption of a home range of 2523 m from a maximum home range of 2000 ha [4]. The result of this stage is then validated with a land cover map to find any land cover characteristics on each patch contribution to the landscape habitat.

3. Result

3.1. Connectivity of Javan Hawk-Eagle remnant habitat patches in central part of Java
Nineteen patches generated from habitat suitability modeling can be ranked by the degree of importance of each patch in the overall habitat management (Figure 2). Patch 13 becomes the most important patch in the Javan Hawk-Eagle habitat in central Java ($dPC = 72.2\%$, $dPCflux = 21.5\%$, $dPCintra = 49.9\%$), followed by patch 16 ($dPC = 19.9\%$, $dPCflux = 17.3\%$, $dPCintra = 2.2\%$), patch 11 ($dPC = 11\%$, $dPCflux = 0.24\%$, $dPCintra = 10.8\%$), patch 19 ($dPC = 7.1\%$, $dPCflux = 0.001\%$, $dPCintra = 7.1\%$) and patch 18 ($dPC = 6\%$, $dPCflux = 1\%$, $dPCintra = 4.9\%$). These five patches are the largest ($dA > 10\%$) patch of all Javan Hawk-Eagle remnant habitat patches in central Java and can be the core habitat. The next order of the degree importance are patch 6, patch 7, patch 14, patch 8, patch 17, patch 1, patch 9, patch 5, patch 10, patch 12, patch 15, patch 4, patch 3 and the lowest rank patch is patch 2.
Among the 19 patches there are 6 patches isolated from other patches because they have \(dPC_{\text{connector}} = 0\) (Figure 3). These patches include patch 19, patch 17, patch 1, patch 10, patch 12, patch 3. Although the 19 patch is isolated but has an importance value on the 4th order of all patches. This indicates that there is a need for new habitat patches between patch 19 and the nearest patch which serves as a stepping stone or ecological corridor to help the Javan Hawk-Eagles move from patch 19 to other patches.

By combining the three connectivity fraction we able to determined the patches categories. Core patch defined by medium to high \(dPC_{\text{flux}}\), high \(dPC_{\text{intra}}\) and low to high \(dPC_{\text{con}}\). Stepping stone patch defined by medium to high \(dPC_{\text{flux}}\), medium \(dPC_{\text{intra}}\) and medium \(dPC_{\text{con}}\). Meanwhile isolated patch defined by medium to high \(dPC_{\text{flux}}\), medium \(dPC_{\text{intra}}\) and low \(dPC_{\text{con}}\). This categorization was based on the fraction ranking of importance and overall connectivity. The distribution of patches category shown in Figure 4. The location of all patch defined by Table 1.
Figure 4. Patch categorization of Javan Hawk-Eagle remnant habitat patches.

### Table 1. List of patch and its category.

| Patch number | Location | Patch size (km²) | Patch Category |
|--------------|----------|------------------|----------------|
| Patch 1      | Mt. Muria | 46.36            | Isolated       |
| Patch 2      | Mt. Sagara | 9.00             | Stepping stone h |
| Patch 3      | Mt. Palasari | 6.61             | Isolated patch |
| Patch 4      | Mt. Subang | 23.8             | Stepping stone |
| Patch 5      | Mt. Ungaran | 37.16           | Stepping stone h |
| Patch 6      | Mt. Imus, Mt. Beser, Mt. Langit, Mt. Igirtipis, Mt. Bongkok, | 22.25 | Stepping stone |
| Patch 7      | Mt. Pesangon | 5.19             | Stepping stone |
| Patch 8      | Mt. Cupu, Mt. Kraton, Mt. Jaha | 13.25 | Stepping stone |
| Patch 9      | Mt. Beser, Mt. Butak, Mt. Malang, Mt. Tumbang, Mt. Bopong | 6.13 | Stepping stone |
| Patch 10     | Mt. Pogong | 5.09             | Isolated       |
| Patch 11     | Mt. Slamet | 238.2            | Core           |
| Patch 12     | Mt. Pandan | 4.50             | Isolated       |
| Patch 13     | Mt. Lumping, Mt. Lebakbarang, Mt. Kemulan, Mt. Sindoro | 511.2 | Core |
| Patch 14     | Mt. Telomoyo | 26.3             | Stepping stone |
| Patch 15     | Mt. Andong | 5.64             | Stepping stone |
| Patch 16     | Mt. Sumbing | 107.6            | Core           |
| Patch 17     | Southern hill of Mt. Sumbing | 4.43 | Isolated |
| Patch 18     | Mt. Merapi dan Mt. Merbabu | 160.7 | Core |
| Patch 19     | Mt. Lawu | 193.8             | Isolated       |

Patch source : [10]

### 3.2. Core patch

Each patch in the core category has different land cover types. The largest land cover on patch 11 is 68.93% (30.6 km²) of forest cover. While for shrub, dry farmland and built areas are 13.45% (32.04 km²), 8.14% (19.40 km²) and 7.94% (18.92 km²) respectively. Patch 18 has 34% (52.67 km²) forest
cover and 33% (51.26 km²) of field cover. Patch 18 is a patch located in the area of Mount Merapi, Mount Merbabu and its surroundings. As many as 57.1% (91.71 km²) belonging to the area of Mount Merapi National Park and Mount Merbabu National Park. Patch 13 and patch 16 each have dry farmland as the most dominant cover. Patch 13 (Dieng Plateau and its vicinity) has a farmland cover of 56% and only 18% of forest land cover. In patch 16 (Mount Sumbing) dry farmland cover is 40% and forest cover is only 24%.

3.3. Stepping stone patch

The land cover on the stepping stone patch is dominated by forest cover (Figure 6). Patch 4 has a forest cover of 76.59% (18.22 km²), patch 5 has forest cover 56.05% (20.84 km²), patch 6 has forest cover 50.49% (11.23 km²), patch 7 has forest cover 55.79% (2.89 km²), patch 8 has a forest cover of 81.76% (10.85 km²), patch 9 has 79.08% forest cover (4.84 km²) and patch 15 has forest cover 32.45% (1.83 km²). Patch 2 which has a shrub cover as a dominant land cover of 40.22% (3.62 km²). Patch 14 has a dominant mixture of mixed plantation of 35.53% (9.34 km²).

3.4. Isolated patch

Land cover on isolated patches is as shown in Figure 7. Patch 1 has a forest cover of 66.12% (30.6 km²), patch 3 has 67.12% forest cover (4.43 km²), patch 10 has forest cover 54.22% (2.75 km²), patch 12 has forest cover 38.44% (1.73 km²), patch 17 has forest cover 73.81% (3.27 km²) and patch 19 has forest cover 37.42% (75.84 km²). Other landscape mosaics found in isolated patches include mixed plantation, shrubs, dry farmland, and open land.
4. Discussion

Based on the results of the connectivity analysis, the Javan Hawk-Eagle remnant habitat patches in central part of Java is categorized into 4 core patches, 9 patch stepping stones and 6 isolated patches. One of the goals set by Indonesian Ministry of Environment and Forestry in the eagle conservation action plan is to increase in the population of these rare species. In relation to population increase, habitat function generated by degree of connectedness can be adapted to Metapopulation theory. Metapopulation can be interpreted as a genetic and recolonisation flow system carried out by an individual when the rate of extinction is high [21].

4.1. Core patch

As a patch which supporting the availability of habitats for breeding and increasing the population, core patches must be of high quality [22]. The core patch is expected to have a broad and patch quality that is capable of supporting significant numbers of Javan Hawk-Eagle populations to help increase the dispersal current toward surrounding patches. Using the median home range of Javan Hawk-Eagle (n = 12 km²), it is estimated that the number of Javan Hawk-Eagles that can be supported by the core patch is 84 individuals or 42 pairs.

For raptors the success of nesting is limited to the availability of nesting sites [23]. The Javan Hawk-Eagle is a raptor that relies heavily on natural forests to build its nest [24]. With the wide size and different land use, not all patches have forest cover dominated by forests as habitat need for nesting.

Patch 11 and patch 18 have large availability of forests and adjacent landscape mosaics in the vicinity of agricultural areas that can serve as secondary habitats [24]. Yet, this condition is different from that occurred in patches 13 and 16. Based on interviews with sources from Raptor Indonesia, patch area 13 and 16 now has never been found again sightings of Javan Hawk-Eagle. This is consistent with the fact that the availability of natural forests is narrow and isolated from each other by expansion of horticultural and tobacco farming activities. The destruction of these forests has not only affected the habitat of the Javan Hawk eagle but also the environmental conditions. In patch 13, patch 16 and surrounding areas there is a decrease in water quality due to excessive use of pharmaceuticals and fertilizers for agriculture, severe droughts in the dry season and very high soil erosion [25]. Natural forest destruction on patch 13 and patch 16 began in the late 1980s and since 1997 the damage has been sharply driven by the expansion of tobacco farming into upland areas [26].

To avoid the isolation of the remaining natural forest patches, landscape restoration should be required on patch 13 landscape and 16 patches. Landscape restoration will produce sustainable and healthy mosaic landscapes, manage plant and animal diversity, protect ecosystems and community ecology, maintain genetic quality the best species, improved water quality, to reduce the level of soil erosion [27]. As a species indicator of the stability and sustainability of the ecosystem, the availability of a landscape structure that supports the habitat for Javan Hawks simultaneously supports the sustainability of other animal habitats.
Public awareness to maintain the sustainability of the Javan Hawk-Eagle in the core patch area is equally important. Javan Hawk-Eagle became one of the rare exotic animals whose level of illegal trade is very high. In the period of January to December 2015 there are 127 individuals of Javan Hawk-Eagles offered through online pages [28]. In addition to strong law enforcement, proper conservation education in the wider community can help to educate people not to hunt and maintain the Javan Hawk-Eagles.

4.2. Stepping stone patch
The main factor in the metapopulation system is the movement of species that is affected by quality, quantity and time [29]. The genetic flow rate is strongly influenced by the distance between patches so patches that are too far apart must be connected by corridor or stepping stone [30, 31]. Stepping stone can be defined as small vegetation patches scattered throughout the landscape [32].

In the remnant patches of Java Hawk-Eagle habitat there are 9 patches that serve as stepping stone with various width sizes. The smallest stepping stone patch is patch 7 cover 5.19 km² areas and the biggest patch is patch 14 measuring 26.30 km². The smallest stepping stone patch size meets the minimum width of the Javan Hawk-Eagle home range. So that the size of the stepping stone patch on Javan Hawk-Eagle remnant habitat in central Java meet the minimum size for conservation [33].

The Javan Hawk-Eagle is a species dependent on forests for nesting and protection. But the Javan Hawk-Eagle also requires the existence of landscapes outside the forest area to survive. Young Javan Hawk-Eagle is known to be able to scatter out of its original territory to other landscapes such as agricultural land, rice fields, tea plantations, fragmented small forests, up to stands of production trees [2]. Then by adulthood they are still looking for forests to be used as new territory breeding territory. The forest cover owned by each patch on the stepping stone patch can be a new shelter and nesting site. Farming areas and mixed gardens can be used as prey hunting sites. However, to be able to support the site as a new nesting place, the wide area becomes a factor that must be considered to avoid edge-effect and competition between species. One of the stepping stone patch that is estimated to become a nesting site is patch 5 (Mount Ungaran). Based on observations by Raptor Indonesia in 2016 there were sightings of some young eagle individuals in the patch 5. This indicates that as a stepping stone, patch 5 has the habitat quality and width which suitable for building breeding territory. Thus the diversity of landscape mosaics in the stepping stone patch is sufficiently appropriate to assist the dispersal of juvenile Javan Hawk-Eagle to find new mates and nesting places.

4.3. Isolated patch
There are 6 patches which not connected to other patches: patch 1, patch 3, patch 10, patch 12, patch 17 and patch 19. The metapopulation system will not work if the patch is isolated because there is no genetic flow of incoming movement. The cause of a patch being isolated is the distance between patches that goes beyond species dispersal capability and loss of patches around the isolated patch [17] [18]. Patch 1 (Mount Muria) and patch 19 (Lawu Mount) is a patch that has a great distance from the nearest patch. The closest patch of patch 1 is patch 5 ± 79 km distance. The closest patch of patch 19 is patch 18 ± 73 km. The distance exceeds the maximum range of Javan Hawk that is 20 km². In between patch 1-patch 5 and patch 18-Patch19 there is no stepping stone patch as dispersal facility. Patch 3, patch 10, patch 12 and patch 17 are detected as isolated patches in PC analysis because each patch has a small patch size (mean = 5.16 km²). This means the patch is too small and unable to facilitate movement to many different patches or dispersal paths are disconnected.

The availability of large enough forest relative to the area of each patch means that the landscape on the patches is actually suitable for Javan Hawk-Eagle habitat. Especially on patch 19 as one of the patches with high importance in remnant habitat of Javan Hawk-Eagle in central Java. Patch 19 is administratively located on the border of Central Java Province and East Java Province. Ecologically patch 19 plays an important role as a hub with habitat in eastern Java. Patch 3 also has the same functionality as patch 19. Patch 3 becomes the central Java liaison with western Java. However patch 19 and patch 3 require further connectivity review because patch 19 may not necessarily be isolated if it has connectivity with one patch in eastern Java. Patch 1, patch 10, patch 12 and patch 17 can serve as
a stepping stone toward the core patch. To connect the patches and minimize the impact of patch isolation it is necessary to construct an ecological corridor [29].

5. Conclusion
Through this study we show how appropriate software utilization can assist in wildlife habitat conservation activities. The use of connectivity index may indicate the connectedness of a fragmented habitat network. The index values of the fractions contained in the connectivity are able to help in determining the relationship of each patch with its ability as a facilitator of population dispersal. By applying this method into the remaining habitat patches of Javan Hawk-Eagle we able to specified the role or contribution of each patches in the habitat network which are core patch, stepping-stone patch and isolated patch.

This approach is very useful in determining appropriate conservation measures by adjusting to the conditions of each patch. Landscape restoration is necessary to recover and improve the quality of heavily degraded habitat at core patches. At stepping stone patches, maintaining the diversity of landscape mosaic is important to support its function in assisting the population dispersal of Javan Hawk-Eagle in a very disperse habitat. Meanwhile, to avoid isolation effect, ecological corridors are needed to build connectivity between patches. By utilizing this approach, managers and policy makers can decide which conservation priorities should be applied.

Acknowledgments
The authors would like to thank the Ministry of Research, Technology and Higher Education of Republic Indonesia under “Penelitian Unggulan Perguruan Tinggi” grant in fiscal year of 2016. Also thanks to Raptor Indonesia especially Asman A Purwanto for providing us the local information and guiding us during field survey.

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