Habitat patch connectivity of Javan Hawk-Eagle (*Nisaetus bartelsi*) in Eastern Part of Java, Indonesia

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Abstract. Javan Hawk-eagle, JHE (*Nisaetus bartelsi*) is an endemic raptor species of Java Island which is currently threatened due to habitat destruction, forest fragmentation, and illegal poaching. Eastern part of Java Island is the largest remaining habitat for JHE which consisted of 28 patches with an area of 4766.26 km². Connectivity in the landscape plays a role in facilitating inter-patch movement, and as long-term conservation of biodiversity. This study was aimed to determine the degree of connectivity between habitat patches in eastern part of Java. The patches were analyzed using conefor sensonide 2.6 to determine the probability of connectivity between patches using connectivity indices. Three fractions namely PCintra, Pcflux, Pccon were used for determine the connectivity index. The results showed that seven patches were identified as core patches which was 70.32% (2965.94 km²) located inside the protected area. Thirteen patches that had PCcon under 10% as stepping stones among the patches around them. There were eight patches isolated from other patches because they had PConnector = 0, and small patch size for supporting viable JHE population. These results will be useful for decision makers to decide the conservation priorities action in order to maintain the connectivity habitat of JHE in eastern part of Java.

1. Introduction

Javan Hawk-eagle, JHE (*Nisaetus bartelsi*) is an endemic raptor species in the natural forest of Java Island. Its population has experienced spatially separated due to forest fragmentation. JHE has a wide range distribution area therefore can act as an umbrella species that has the role in saving other species underneath if proper conservation management is carried out [1]. In addition, JHE is also very sensitive to environmental changes that cause the population to be disrupted if the quality of the environment is disturbed [2]. This species occupies a habitat of tropical forests, primary and secondary forests, and mostly are in places that difficult to access, i.e., sharp slope in the valley area or hills [3]. JHE has a small and fragmented population, that is declining due to severe disturbance such as forest fragmentation and poaching [4, 5, 6].

JHE habitat in Java Island is currently spatially separated between sub-populations with a diverse habitat area. This condition is related to metapopulation theory. Eastern part of Java Island was the largest remaining habitat for JHE with the recent validated distribution habitat separated into 28 patches which covered about 4766.26 km² and increased by 2156.14 km² of the total area occupied by JHE’s in 2009 [7]. There were 189 pairs of JHE in Eastern part of Java or 58% from 325 pairs throughout Java based on the population prediction on 2009 [7].
Metapopulation is a spatially separated population group of the same species and interacts at several levels [1]. Metapopulation can prevent degradation of resources in the core habitat, but can also lead to isolation habitat from one another if there are no connecting corridors between those habitats. Connectivity depends on the structure landscape and ability of species to spread from one to another place [8]. Connectivity becomes a determinant in conservation because species movement plays an important role in population dynamics [9]. Therefore, it is very important to know the habitat patch categories such as core, stepping stone, and isolated patch in order to draw up a habitat conservation plan that suits the habitat condition. The dynamics in JHE habitat patches, such as habitat lost and emergence of new habitats as a result of changes in land cover had caused forest fragmentation, habitat destruction, and inter-patch connectivity to be interrupted. Therefore, those dynamics became a consideration for this research. Connectivity in the landscape plays a role in facilitating inter-patch movement, supporting ecological flows, and as long-term conservation of biodiversity [10]. This study aims to determine the habitat patch categories eastern part of Java so that habitat management can be carried out by the patch categories of each habitat.

2. Methods
2.1. The Study Area
This study focused on the eastern part of Java Island (figure 1) which cover about 47,922 km² area (latitude 7.12” and 8.48’, longitude 111.0’ to 114.4’). We evaluated the habitat patch connectivity from 28 patches (4766.26 km2) [7] which was obtained from updated predicted probability model of the previous study [3].

Eastern part of Java has the largest area among 6 provinces in Java, and has the second largest population in Indonesia after West Java. Eastern part of Java is bordered by the Java Sea to the north, the Bali Strait to the east, the Indian Ocean to the south, and the Central Java Province to the west. Eastern part of Java region also includes Madura Island, Bawean Island, Kangean Island and a number of small islands in the Java Sea (Masalembu Islands), and Indian Ocean (Sempu Island, and Nusa Barung).

![Figure 1. Study area (Source: Murad 2016)](image)
2.2. Method of analysis

This study used the Probability of Connectivity (PC) analysis method [12]. Connectivity probability index is the probability of two animals randomly placed in the landscape and reaching each habitat so that they are interconnected in a collection of habitat patches that have a degree of connectivity (pij). The Probability of Connectivity (PC) index formula is as follows:

$$PC = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij} \cdot p_{ij}}{A_L^2}$$

The habitat patch is shown in black and the dotted line shows the connectedness between patches to a certain degree (pij > 0). When patches do not directly be connected, it will have a degree of pij = 0.

Conefor Sensinode 2.6 software was used to measure connectivity indexes between patches. Conefor Sensinode 2.6 is software that is used to measure the importance of a habitat and surrounding habitats for management and improvement of connectivity between landscapes, so that the impact of habitat change and land use on connectivity can be known. Conefor analysis can be used in conservation policy decisions and landscape planning, such analysis that can be used by identifying the priority habitats for inter-patches ecological connectivity [11].

The data from this study was the Euclidean distance between each patch. The result of this stage was the patch function obtained by three factions, namely dPCintra, dPCflux, and dPCconnector [12]. These three PC values indicated the contribution of each patch to connectivity and the overall landscape. dPCintra shows the contribution of the patch to connectivity between patches or the weight of the patch itself which will be connected to other patches, even though isolated patches still have weight. dPCflux shows the ability of patches as initial patches or final patches in the process of species distribution. dPCconnector shows patch contribution as a connecting factor or stepping stone between habitat patches.

Measuring connectivity in landscapes was conducted by using PC connectivity/ index probability which was resulted in three index values namely PC Flux, PC Intra, and PC Connector [12]. The values on the PC index showed three main index results, namely PCflux, PCintra, and PCconnector. Values at each of these indices could determine the function of patches as core habitats and isolated habitats. The core habitat were determined by the highest values of PCflux and PCintra, while isolated patches were determined by the value of PCconnector = 0.

3. Results and Discussion

Connectivity between habitat patches requires habitat availability and the distance between patches as a consideration to determine the degree between each other, so that the patch function can be known. The distribution of habitat patches used in this connectivity analysis was 28 patches with a resolution of 250 m. Dispersal distance used in this analysis assumed a median home range of 2523 ha from a maximum home range of 2000 ha. Among habitat patches in eastern part of Java, patch 11 was the patch that had the largest contribution of 25.03% based on the total patch area of 4766.26 km². Patch 11 was located in Bromo Tengger Semeru National Park. The second largest patches were patch 18 (Mt. Raung-Ijen) which was 722.19 km², patch 9 (Mt. Kawi-Arjuna) was 658.34 km², patch 15 (Yang-Mt. Argapura) was 587.86 km², and patch 17 (NP. Meru Betiri) was 527.56 km². From the total of 28 JHE habitat patches in eastern part of Java, patch 5 (Sambit) was the location with the smallest patch area with only 4.01 km².

The results of Probability of Connectivity (PC) analysis shows that from 28 patches of JHE habitat in eastern part of Java, there were 7 core patches which were patch 11 (Bromo Tengger Semeru National Park), patch 18 (Mount Raung Ijen), patch 9 (Mount Kawi-Arjuna-Welirang), patch 15 (Yang-Mount Argapura), patch 17 (Meru Betiri National Park), patch 25 (Alas Purwo National Park), and patch 2 (Mount Liman-Wilis). This was concluded based on the results of the six PC patches.
which had the highest value among the other patches. The next level of importance was patch 1 (Mt. Lawu), patch 16 (Tegalampel), patch 7 (Mt. Kelud), patch 24 (Kondang Merak-Ngeliyep), patch 23 (Sanggaria Beeach), patch 19 (Bandar), patch 13 (Tiris), patch 28, (Jolosuto Beach), patch 27 (Mt.Budeg), patch 8 (Kasembon), patch 4 (Badengan), patch 6 (Karangan), and patch 20 (Pule).

There were 8 JHE patches habitat in eastern part Java which were included in the isolated patch category from the other patches because they had a PCconnector value of 0 (Figure 2). Those patches were patch 3 (Nawangan), patch 22 (Mt. Baluran), patch 10 (Mt. Penanggungan), patch 26 (NP. Sempu Island), patch 21 (Bungatan), patch 14 (Pakuniran), patch 12 (Candipuro), and patch 5 (Sambit). Of the eight isolated habitat patches, patch 5 (Sambit) was the smallest patch with an area of 4.01 km² from the total habitat patch area in eastern part of Java.

![Figure 2. PC connector index value.](image)

![Figure 3. PC flux, PC intra and PC index values.](image)

By combining the dPC, dPCflux, dPCintra, dPCconnector factors, the categories of each habitat could be obtained as shown in Table 1. Based on the results of the connectivity analysis, habitat patches of the remaining JHE in the east part of Java were categorized into 7 core patches, 13 stepping stone patches and 8 isolated patches. From those three categories of JHE habitat patches, 10 patches were in the protection forest area. Patch 18 in the core habitat category was a patch with the largest protected area of 696.44 km². Patch area in the protected area was only 1901.08 km² or 39.89% of the area.
Table 1. Habitat patch category

| Patch   | Location                | Patch Category | Total Patch Size (Km²) | Patch size |
|---------|-------------------------|----------------|------------------------|------------|
| Patch 2 | Mt. Liman-Wilis         |                | 347.06                 |            |
| Patch 9 | Mt. Kawi-Arjuna         |                | 658.34                 |            |
| Patch 11| Mt. Bromo TS            |                |                        |            |
| Patch 15| Mt.yang-Argapura        | Core patch     | 4217.8 km²             | 587.86     |
| Patch 17| NP. Meru Betiri          |                |                        | 527.56     |
| Patch 18| Mt. Raung-Ijen          |                |                        | 722.19     |
| Patch 25| NP. Alas Purwo          |                |                        | 437.84     |
| Patch 1 | Mt. Lawu                |                | 271.22                 |            |
| Patch 4 | Badengan                |                | 6.71                   |            |
| Patch 6 | Karangan                |                | 4.01                   |            |
| Patch 7 | Mt. Kelud               |                | 7.18                   |            |
| Patch 8 | Kasembon                |                | 52.11                  |            |
| Patch 13| Tiris                   |                | 7.73                   |            |
| Patch 16| Tegalampel              | Stepping stone patch | 465.87 km²   | 12.71     |
| Patch 20| Pule                    |                |                        | 7.26       |
| Patch 23| Sanggaria Beach         |                |                        | 20.72      |
| Patch 24| Kondang Merak-Ngeliyep  |                |                        | 25.98      |
| Patch 27| Mt. Budeg               |                | 9.49                   |            |
| Patch 28| Jolosutro               |                | 10.02                  |            |
| Patch 3 | Nawangan                |                | 21.36                  |            |
| Patch 5 | Sambit                  |                | 4.01                   |            |
| Patch 10| Mt. Penanggungan        | Isolated patch | 82.59 km²              | 12.57      |
| Patch 12| Candipuro               |                |                        | 5.22       |
| Patch 14| Pakuniran               |                |                        | 6.72       |
| Patch 21| Bungatan                |                |                        | 9.31       |
| Patch 22| Mt. Baluran             |                |                        | 13.53      |
| Patch 26| NP. Sempu Island        |                |                        | 9.87       |

**Total area** 4766.26

Based on these categories, the conservation action will be determined that JHE requires connectivity between habitats that is supported by connecting corridors for dispersal. Connectivity that occurs in the landscape takes into account patch variables, edges, continuity, and corridors [13]. Landscape connectivity can consider habitat availability widely to be integrated into landscape conservation planning. Connectivity in the landscape plays a role in facilitating or inhibiting movement between habitat patches, supporting ecological flows, and as long-term conservation of biodiversity [11]. Therefore, connectivity is one of the most important components in landscape management as a basis for conservation planning and analysis of landscape change.
3.1. Core patch

The core patch acts as important habitat to support distribution and breeding of JHE. Therefore, core patches must have high landscape quality to regulate the animal cycle [14]. If there is a change in the quality of the landscape in the core habitat, then this change can have a rapid impact on the decline in animal populations. The core habitat was formed by patch 11 (NP. Bromo Tengger Semeru), patch 18 (Mt. Raung Ijen), patch 9 (Mt. Kawi-Arjuna-Welirang), patch 15 (Yang-Mt.Argapura), patch 17 (NP Meru Betiri), patch 25 (NP Alas Purwo), and patch 2 (Mt. Liman-Wilis), which meant that the seven patches were the homereange of JHE nesting area and had a large influence on the surrounding patches. From overlay maps of protected areas, 70.32% of core patches were in protected area and the remaining 29.68% was in non-protected areas. The stepping stone patch included in the protected area.

Figure 4. Distribution of core patches in protected and non protectec area in East Java.

Figure 5. Habitat patch categories of JHE habitat in Eastern part of Java.
was only 0.65% or 3.04 km$^2$ from 465.7 km$^2$ of the total area, while the isolation patch included in
protected areas was only 11.95% or 9.87 km$^2$ from the total area of 82.59 km$^2$. The habitat patches of
JHE in non-protected area was in risk due to the increasing of the forest fragmentation caused by land
cover changes.

Core patches that were mostly located in protected areas need to be upgraded as a manifestation of
habitat conservation. Whereas the stepping stone patch, which was a buffer zone for the patches around it, needs to be improved for its maintenance and its plants diversity. For the isolated patches, the
quality of their habitat could be improved and a potential corridor could be used to support the
flow of connectivity between patches.

Connectivity allows one to use several habitats, even a small size habitat, so that the species does
not need to depend on certain large patches and the connectivity will also provide benefits for other
species [15]. An unconnected habitat will become an isolated patch and will increase the potential for
inbreeding. Habitats that are interconnected with high level of connectivity are able to avoid the
negative impacts caused by fragmentation such as habitat isolation, reduced patch size, and genetic
degradation due to inbreeding [16, 17, 18, 13].

Patch 11 (Bromo Tengger Semeru National Park), patch 17 (Meru Betiri National Park), patch 25
(Alas Purwo National Park), patch 2 (Mt. Liman-Wilis), patch 9 (Mt. Kawi), patch 15 (DT Yang-Mt.
Argapura), and patch 18 (Mt. Raung-Ijen) were core patches that located in a national park area that
means they were protected by the legal aspect. However, efforts were still needed to protect JHE
habitat on these core patches due to the threat by high tourism activities. For long-term management,
ecological corridor planning that connects core patches with isolation patches can also support
connectivity between patches.

3.2 Stepping stone patch
There were 13 varied patches in Eastern part of Java that acted as stepping stones to facilitate the
movement of JHE from one patch to another. The smallest stepping stone patch was patch 4 which
was located in Badengan with an area of 6.71 km$^2$ and the largest stepping stone patch was patch 1
which was located on Mount Lawu with an area of 271.22 km$^2$. Even though the smallest area, patch
4, had a very important role because patch 4 becomes a stepping stone for patch 3 which was isolated
from the surrounding patches. Patch 1 which had the largest area, was also important stepping stone
patch because it became a connecting corridor for JHE in other area in Central part of Java. Although
the area of the stepping stone patch was smaller than the core patch, the stepping stone patch had a
very important role as a corridor to support the increased of connectivity.

Only patch 1 (Mount Lawu) was located in protected area with an area of 0.65% (3.04 km$^2$) from
the total area of stepping stone patches. Therefore, in fact 12 stepping stone patches were located
outside the protected areas that would threaten the existence of JHE in the near future. Maintaining the
stepping stone patches would provide incredible benefits especially for connecting between isolated
patches and core patches. For example, increasing the form of greenways and greenbelts [19] on the
stepping stone patches could be used by JHE for dispersal and nesting site as well. Corridors could
help the movement of animals to cross a landscape safely to meet their daily needs, such as finding
food and breeding [20]. The concept of functional stepping stone was further described as follows: (a)
the size must be suitable for meeting conservation objectives; (b) crucial in the long-range distribution
of species or genotypes; (c) effective in reducing the impact of patch isolation in the habitat network
of study species [13].

3.3 Isolated Patch
There were 8 patches that had a value of PCcon = 0, which was categorized as an isolated patch. The
eight patches were patch 3 (nawagan), patch 22 (Mt. Baluran), patch 10 (Mt. Penanggungan), patch
26 (Sempu Island), patch 21 (Bungatan), patch 14 (Pakuniran), patch 12 (Candipuro), and patch 5
(Sambit). In an isolated habitat, the metapopulation system would not work and genetic movement
would not flow in and out. An isolated patch would occur when the distance between patches exceed
the roaming ability of a species, also when the patches around it that could act as a stepping stone patch was lost [21, 22]. The isolated patch with the smallest area was patch 5 which was located in Sambit with an area of 4.01 km² and the largest area was patch 3 which was located in Nawangan with an area of 21.36 km². Patch 22 which was located on Mount Baluran became a patch that had the farthest distance from the surrounding patches which was ±32 km away. This distance exceeded the maximum home range of JHE, which was 20 km². In patch 22 and patch 18 there was no stepping stone patch as dispersal facility. Patch 3 (Nawangan) which was adjacent located to Central Java, then played an important role for connecting the habitat between East and Central Java.

There were 2 stepping stone patches which had the closest distance to patch 3, namely patch 4 (Badengan) and patch 19 (Bandar). The two stepping stone patches could have an ecological corridor role that could support connectivity between patches especially in patch 3, and could support the movement of the JHE to be connected to the surrounding patches.

Patch 22 (Mount Baluran) and patch 26 (Sempu Islands) were the isolated patches included in protected areas. The total isolated patch area included in protected areas was only 11.95% or 9.87 km² of the total area of 82.59 km². Six patches that located not in protected areas would need an increase in their area status and a more supervision from the government. If the government does not increase the area status of the six isolated patches, there is a fear that the existence of JHE will be increasingly endangered. Recommendations for JHE based on ecotourism activities, that involving local communities, need to be carried out as an increase in public awareness about the conservation of JHE and their habitats. In addition, ecotourism activities could be a source of additional income for the local community.

The matrix between habitat patches generally had the same type and can affect the surrounding area. Matrices could be identified based on their size, shape, and quality in supporting species distribution [19]. The flow of genetic distribution was greatly influenced by the distance between patches so that patches that were too far from each other must be connected by corridors or stepping stones [23].

4. Conclusion
Based on the connectivity probability index (PC), the results show that there were 7 core habitat patches and 8 isolated patches. These results were obtained based on the function of three indices in PC analysis, namely PCflux, PCintra, and PCcon. The patch which was the core habitat had an overall patch area of 4217.8 km² and 70.32% of the total area of the core patch was located inside the protected area. From the total of 28 patches located in East Java, there were 13 patches that acted as a stepping stone corridor that could be a connecting corridor for patches isolated from the core patch. Through this research we showed how the use of software conefor sensoride 2.6 would help in the conservation of wildlife habitat. The use of connectivity indexes between habitat patches showed the network connection between core patch, stepping stone and isolated patch. This approach was useful in determining conservation actions that could be adapted to each patch. With this approach, researchers and policy makers could decide which patches could become the conservation priorities.

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