Maxent modelling of habitat suitability for the endangered javan gibbon (*Hylobates moloch*) in less-protected Dieng Mountains, Central Java

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Abstract. Dieng highland in Central Java provides high potential habitat for the endemic Javan gibbon. In order to conserve the sustainability of Javan gibbon population and its habitat in Dieng, the conservation priority for high suitable habitat should be maintained. This study aimed to identify the HSM for Javan gibbon in Dieng highland and the most contributing biophysical variables. Medium-resolution variable layers, which interpret the biophysical environment of gibbon habitat, were derived and pre-processed from Sentinel-2 image and Indonesian elevation model product. A total of 305 occurrence data recorded in extensive field survey non-correlated variables were maintained for HSM in presence-only machine learning, maximum entropy (MaxEnt). Suitable gibbon habitats were predicted as 81.286 km². The area under the curve value estimated to be 0.971 and 83.516 % of validating points was on suitable habitat. The final model pointed out that the suitable areas were fragmented. Relatively large of the suitable patch for Javan gibbon located in Sokokembang, Linggoasri-Mendolo, and western of Kembanglangit were considerable to get the conservation priority. The most contributed variables were a natural forest, elevation, distance to cropland and land surface temperature, which are important factors to be considered when generating a conservation strategy for Javan gibbon.

Keywords: conservation, dieng highland, habitat suitability model, javan gibbon, maxEnt,

1. Introduction

Javan gibbon (*Hylobates moloch*) is a rainforest dependent species which endemic to the most human-populated island, of Java. This seed-disperser primate is listed in IUCN Red List as Endangered species due to deforestation and hunting pressure [1] and listed in the 25 endangered animals as a priority to increase its population size in 2019 by Indonesian government [2]. Approximately, about 4000-4500 gibbon survive in the 29 remaining natural forests which severely fragmented among the urban area of Java [3, 4]. About 7 largest habitats of Javan gibbon are protected under national parks...
and nature reserves and the remaining habitat stand outside the protected area network [4]. The Dieng mountain, a relatively large area of remaining rainforest in Central Java, is one of the “biodiversity hotspot” which is not protected under the conservation area. The Javan gibbon population in Dieng mountain was listed as the second biggest population after the population in Halimun-Salak National Park, West Java [3, 5].

All forested area in Dieng mountain is administratively managed by Perum Perhutani mainly to produce forest products such as sap from pine, rubber, and dammar plantation, instead of log. However, several relatively large forest patches are kept in natural as protection forest in order for soil and water conservation [6, 7], unfortunately, activities to conserve species including Javan gibbon have been neglected. In comparison to other large Javan gibbon habitat which is managed under conservation area, habitat in Dieng mountain is more threatened by the agriculture expansion, illegal logging, and non-timber extraction. Moreover, the survival of the Javan gibbon population in this region has also threatened by illegal hunting [5].

In the order to conserve the sustainability of Javan gibbon population and its habitat in Dieng Mountain, the conservation priority for high suitable habitat should be maintained. The understanding of the species response to its environment is also important for generating effective conservation strategies [8]. Many of researchers have been generated the habitat suitability modelling (HSM) or species distribution modelling in part of threatened species conservation such as for yellow-cheeked crested gibbon in Cambodia [9], chimpanzee in Western Africa [10, 11], Bornean orangutan [12–14], Javan leopard [15], Javan Hawk-Eagle [16] and many others. HSM for Javan gibbon has also been performed in several habitats and implemented for generating the conservation strategy, those were in the Gunung Halimun-Salak National Park [17, 18], Gunung Tilu Nature Reserve [19], and Gunung Gede-Pangrango National Park[20]. In contrast to those protected-habitat, the habitat suitability assessment in Dieng mountains has not been conducted, therefore the assessment on the HSM for Javan gibbon in this area at current condition is urgently needed.

Habitat suitability modeling based on presence-only data in the maximum entropy framework is globally performed in threatened species [21–23]. This method does not need absence data, which others method required, and frequently outperforms other HSM methods [24, 25]. The HSM method, which builds in MaxEnt program, allow us to model the wide spatial scale with relatively limited data and more various type of data, even categorical data[26]. In considering reasons mentioned above, this study conducted to predict the habitat suitability for Javan gibbon in Dieng mountain through the MaxEnt modeling, so the priority area can be defined. The key factors, related to the terrain, anthropogenic activities and vegetation quality, which influence the probability of Javan gibbon presence in Dieng mountain, were also identified for consideration in landscape management.

2. Materials and methods

2.1. Study area

Dieng is known as a complex volcano with numerous craters which are administratively located in Banjarnegara Residence, Central Java Province, however, larger mountainous area is connected to Dieng complex and extend to the western, which refers to Dieng Mountains. The study was carried out in the remaining 175 km² of fragmented natural forest which mostly cover the northern part of the mountains. It mainly encompasses three administrative areas, namely Pekalongan, Batang, and Banjarnegara Regencies. The altitudinal range of forested area is 250-2500 meters above sea level covering from lowland to montane tropical rainforest. The area has hilly terrain, complex riverine, valley, and ridge (figure 1).

Most of the natural forest patches are secondary forest due to logging in the past and current non-timber extraction (shade-grown coffee planting, honey collecting, firewood collecting, etc), however, the other forest patches are topographically inaccessible. The natural forest is home for a variety of flora and fauna, especially for all primates of Java. Those are Macaca fascicularis (Least Concern), Trachypitechus auratus (Vulnerable), Presbytis fredericae (Endangered), Nicticebus javanicus
(Critically Endangered) and *Hylobates moloch* (Endangered). Administratively, the forested areas are managed by Perum Perhutani (Indonesia state-owned forestry enterprise) which mainly responsible for forest production. The plantation forest, such as pine tree, rubber tree, and dammar tree, were therefore generated throughout the area and mostly adjacent to the natural forest. Several relatively flat areas among the forest patches were built as settlement and cropland, such as dry crop and rice field. Moreover, many of naturally potential area was developed as tourism park and road lines were therefore built up to support the transportations.

![Figure 1. The study area of Dieng mountains, Central Java, is indicated by red square, refers to spatial extent processed in this study. (Basemap: Sentinel-2 imagery on 6 July 2018 which has topographically corrected by Illumination modeling [27]).](image)

2.2. Occurrence data

Data on gibbon occurrence were collected from preliminary field surveys in January 2018 and during population survey in August to December 2018 mainly along the transect lines. The point where the gibbon was firstly seen and all points for every minimum of ten meters of their natural movement were recorded using Garmin eTrex 10 GPS receiver by applying GPS + GLONASS satellite system with horizontal accuracy up to 3 meters. However, in Dieng mountains, most of the gibbon is not habituated, they will immediately flee once they detect human presence and sometimes it was difficult to detect wild gibbon in dense forest. For this reason, fecal samples, predictive gibbon location from vocalizations, and sighting information from trusted villagers were considered as indirect evidence to obtain a robust occurrence data [11]. The total of 305 data was recorded during data collection.

2.3. Maxent modelling

2.3.1. Running model. The suitability habitat model was built by MaxEnt 3.4.1 software based on the maximum entropy framework [28]. The MaxEnt algorithm can perform well for modeling habitat suitability from presence data only [24]. The total of 70% of occurrence data (214 points) was used in modeling, and the remain of 30% was used for model validation. The parameters of MaxEnt were set to 30 % of random test percentage, 10000 maximum background points, 10 times replicate, "subsample" as the replicated run type, and 10 percentile training presence as the threshold rule.
Maxent result was visualized as a gradient map which scores the probability of gibbon presence from 0 to 1. The gradient map was then converted into a binary map which delineated the suitable and unsuitable habitat. The maximum threshold of the suitable area was defined by a selected threshold rule, which is 10 percentile training presence logistic threshold. It is selected to cover some possible bias from the used data of this study [29]. The MaxEnt was also used to analyze how the variables contribute to the model by creating response curves. Response curves resulted from MaxEnt, explained how each variable influence the probability of gibbon presence. The amount of how much each variable contribute to the model was measured by percent contribution and the amount of how the area under the receiver operating characteristic curve (AUC) changes when a variable is removed from the model was measured by permutation importance.

2.3.2. Model assessment. The model performance was assessed with the calculating area under the receiver operating characteristic curve (AUC) which automatically calculated in MaxEnt. The AUC describes how strong the model discriminates the value of presence cell than the background cell, higher value is for the presence cell [30]. The AUC value of 0.5 shows that model predictions are not better than random; 0.5–0.7 indicates poor performance; 0.7–0.9 is reasonable/moderate performance; and above 0.9 is high performance [26, 31]. The final model was then validated by overlaying the 30% of the all occurrence data, 91 points, on the binary suitability map. The validity of the habitat suitability model in this study was referred to as the proportion of the overlaid points which located on the predicted suitable area compared to the total overlaid points.

| No | Variables                                      | Data Source and Spatial Resolution                      |
|----|------------------------------------------------|--------------------------------------------------------|
| 1  | Elevation                                      | DEMNAS digital elevation model, 8.33 m                 |
| 2  | Slope                                          | DEMNAS digital elevation model, 8.33 m                 |
| 3  | Aspect                                         | DEMN1AS digital elevation model, 8.33 m               |
| 4  | Normalized difference vegetation index (NDVI)  | Sentinel-2 satellite imagery, 10 and 20 m              |
| 5  | Land Cover of Natural Forest                   | Sentinel-2 satellite imagery, 10 and 20 m              |
| 6  | Land Cover of Plantation Forest                | Sentinel-2 satellite imagery, 10 and 20 m              |
| 7  | Distance to Plantation Forest                  | Sentinel-2 satellite imagery, 10 and 20 m              |
| 8  | Distance to Settlement                         | Sentinel-2 satellite imagery, 10 and 20 m              |
| 9  | Distance to Cropland                          | Sentinel-2 satellite imagery, 10 and 20 m              |
| 10 | Distance to Road                               | Rupa Bumi Indonesia vector layer                       |
| 11 | Distance to River                              | Rupa Bumi Indonesia vector layer                       |
| 12 | Land Surface Temperature (LST)                 | Thermal band of Landsat 8 satellite imagery, 30 m     |

2.4. Predictor variables.
Environmental variables on Javan gibbon suitability habitat were selected from some previous modeling for the same species in other habitats [17–20] and from other variables which were related to Javan gibbon ecology. A total of 12 spatially variables dealing with landscape, resources for the gibbon, and anthropogenic threat, were pre-processed from several data sources which mainly have a high resolution as specified in table 1. Several variables (natural forest, plantation forest, distance to settlement, and distance to cropland) were derived from land-use/land-cover (LULC) which classified from Sentinel-2 imagery (obtained on July 6, 2018). The Sentinel-2 imagery has been corrected topographically by illumination modeling [27]. The supervised classification was established in Erdas Imagine 2014 program using the maximum likelihood method. The LULC was processed by Euclidean distance toolbox in ArcMap 10.5 program to obtain those variables as well as vector layers from Badan Informasi Geospasial (BIG) to obtain distance to river and distance to the road. Elevation, slope, and aspect were extracted from Digital Elevation Model Nasional (DEMNAS) using the toolbox in ArcMap 10.5. Normalized difference vegetative index (NDVI) and land surface temperature (LST)
were calculated in ArcMap 10.5. All variables were prepared at UTM WGS 84 projection, 10-m spatial resolution, and the same extent covering 1133.592 km² of raster layers. The total of 12 variable layers was extracted on 100 random points and was tested using Pearson correlation and VIF in R 3.5.3 to ensure there were no highly correlated variables. The highly correlated variables, with a high value of \( r > 0.7 \) and VIF (VIF > 10), were considered to be excluded in the further modeling process.

3. Results

3.1. Correlation analysis

The high correlated variables were elevation and distance to plantation forest \((r = 0.76)\), but the VIF values were less than 10 (4.497 and 5.389, respectively). However, this study only allowed the dependent variables, so one variable of the correlated pair should be excluded. In the initial model using all variables, distance to plantation forest had much lower permutation importance and percent contribution than elevation, therefore all variables were included in the model except distance to plantation forest (table 1).

3.2. Predicted habitat suitability model

The maxent model of Javan gibbon habitat suitability in Dieng mountain was successfully built with strongly high performance. The AUC value was 0.96 ± 0.004 indicating that the model could correctly discriminate the presence with a higher value than non-presence sites in 0.96 % of probability [32]. Additionally, the overlay of 30 % of occurrence data (91 points) on the predicted suitability map proved that 83.5 % points were in a suitable area. The gradient map showed the value of gibbon-presence probability (0–0.946) which explained the value of habitat suitability (figure 1). After applying the 10-percentile training presence (0.1979), the binary map showed a small portion area was suitable for Javan gibbon, which was predicted as 81.286 km² (figure 2). The suitability map shows that the suitable areas were fragmented and mostly distributed in Pekalongan Regency with a smaller area in the western part of Batang Regency rainforest. The largest suitable patch was surrounding Sokokembang, while the other relatively large suitable patches were located in Linggoasri-Mendolo and western of Kembanglangit (figure 3).

![Figure 2](image_url)

**Figure 2.** The gradient map on the probability of Javan gibbon presence in Dieng mountains from Maxent modeling. The lowest value indicating the lowest probability of gibbon presence and opposites.
Figure 3. Javan gibbon habitat suitability map showing the distribution of suitable habitat throughout the Dieng mountain landscape as a binary model of “10 percentile training presence” threshold rule (0.1979).

Table 2. Percent contribution and permutation importance of each predictor variables used in creating Javan gibbon habitat suitability model.

| Variable                      | Percent contribution | Permutation importance |
|-------------------------------|----------------------|------------------------|
| Natural forest\(^{a}\)       | 42,0                 | 3,5                    |
| Elevation\(^{a}\)            | 17,1                 | 37,6                   |
| Distance to Cropland\(^{a}\) | 14,3                 | 5,5                    |
| LST\(^{a}\)                  | 10,6                 | 38,5                   |
| Distance to Settlement        | 4,5                  | 4,8                    |
| Aspect                       | 3,9                  | 2,0                    |
| Slope                        | 2,9                  | 3,5                    |
| Distance to Road              | 2,9                  | 1,9                    |
| Distance to River             | 1,4                  | 1,5                    |
| Plantation Forest            | 0,3                  | 1,0                    |
| NDVI                         | 0,2                  | 0,1                    |

\(^{a}\)The most contributed variable based on the percent contribution and permutation importance with cumulative contribution to be 84 %.

3.3. Contributed variable

According to the predicted percent contributions of variables and supported by the permutation importance, there were four variables which most contributed to the model. These variables are natural forest (42 %), elevation (17.1 %), distance to cropland (14.3 %) and land surface temperature (10.6 %) (Table 2). The cumulative contributions of these four variables are 84 % to the model, while the other variables only contributing less than 5 % for each variable. The response curve of natural forest indicates that the probability of gibbon presence is high in natural forest and very low in a non-natural forest (figure 4a). The response curve for elevation shows that the probability of presence was extremely peaked to approximately 500 m asl (above sea level) but it gradually decreases as the higher
elevation until around 1700 m (figure 4b). The response curve of distance to cropland indicates that the probability of presence increases with increasing distance to cropland (figure 4c). The response curve of LST shows that the probability of presence is peaked around 27-28 °C of LST (figure 4d).

![Figure 4](image)

**Figure 4.** Response curves of MaxEnt for the most contributed variables in habitat suitability model Javan gibbon. (a) Response curve for natural forest, (b) Response curve for elevation, (c) Response curve for distance to cropland, and (d) Response curve for land surface temperature (LST).

4. Discussion

Data on habitat suitability and influencing environmental variables for Javan gibbon in the potential but less protected habitat are needed for defining the area which addressed to be conservation priority and what conservation strategy should be implemented. This study has been modeled the habitat suitability for the Javan gibbon in Dieng mountain and identified the most important habitat variables contributing to habitat suitability. The modeled suitability habitat of Javan gibbon in Dieng mountain was performed with outstanding AUC value of 0.971. This value indicates that the model is very effective in measuring the site with Javan gibbon presence and without gibbon presence (pseudoabsence). A high value of AUC was also performed on the maxent modeling of proboscis's monkey (*Nasalis larvatus*) [33] which has a relatively small range size [34]. If looking to the home range size of Javan gibbon, which is about 12-37 ha [35, 36], this study supports the argument that the high AUC value is higher for species with relatively small range size [24, 37]. This study also used 30% of recorded data to validate the predicted suitability habitat. A total of 91 points were overlaid on the predicted map, and a high portion of occurrence points was on suitable habitat. The AUC calculation and manual validation were statistically supported that the predicted habitat suitability map is robust to be interpreted.
The final model shows that a suitable area predicted to be 81.286 km² (figure 2). It shows the smaller area than the defined potential habitat of Javan gibbon in Dieng mountain on previous studies which ranged 90-167 km² [7, 38]. In comparison to previous studies using a different method, predicted suitable area in this study is smaller than others habitat. The moderate to high suitable area predicted to be 127.41 km² in Gunung Gede-Pangrango National Park [20], 147.36 km² in Gunung Tilu Nature reserve [19], and 369.36 km² in Gunung Halimun-Salak National Park [17]. The predicted map shows that the suitable areas were fragmented and mostly distributed in Pekalongan Regency with a smaller area in the western part of Batang Regency rainforest. The largest suitable patch was surrounding Sokokembang, while the other relatively large suitable patches were located in Linggoasri-Mendolo and western of Kembanglangit (figure 3). These suitable patches were considered to be prioritized for Javan gibbon and its habitat conservation.

The MaxEnt modeling revealed the four environmental variables which contributed most to predicted habitat suitability. These variables are the natural forest, elevation, distance to cropland, and land surface temperature (table 2). The most important variable in predicting Javan gibbon habitat suitability was the existence of natural forest. The response curve indicates the positive relationship between natural forest and probability of gibbon presence (figure 4a). The Javan gibbon is very dependent on the natural forest as their habitat which provides all required resources, such as food, connected canopy for movement and shelter [35]. In the field survey, almost all occurrence data were located in a natural forest, however, a little portion of gibbon occurrence was found in the other land cover which is plantation forest. The gibbon was observed in the branch of pine plantation when resting. The pine tree was adjacent to the food plant in a natural forest where their observed while feeding before.

Elevation was the second most influencing variable in predicting Javan gibbon habitat suitability in Dieng mountains. Rowe (1996) stated that Javan gibbon can live in the lowland forest as sea level up to the montane forest on the upper limit of 1500 m asl. It is very rare found above the altitudinal limit [35, 39]. Forest structure and composition vary with altitude [36, 40]). As increasing altitude, not only availability and diversity of gibbon food source decrease but also vertically branch system and attached epiphyte make gibbon difficult to brachiate [35]. The response curve for elevation was bell-shaped, which predicts the gibbon may occur around 400–1700 m asl in Dieng and the highest probability of gibbon presence is around 600 m asl (figure 4b). However, the previously recorded elevation range of Javan gibbon in Dieng mountains was at 270-1600 m asl [5, 41]. The remaining rainforest in Dieng covers from 200 m asl due to urban and agricultural expansion in lower altitude. Despite gibbon occurs up to 1900 m dpl in Mt. Slamet [5, 42–44], the rainforest in Dieng above 1700 m asl most likely to be not suitable for gibbon. On Java, dominant tree species differ among forests, even on similar elevation, for both climatic and historical reasons [40].

The Euclidean distance to cropland was the next most important variable in predicting Javan gibbon habitat suitability in Dieng mountain. In this study, cropland refers to agricultural land which planting non-canopy plantation such as paddy, corn, vegetables, tea, coffee, etc. Cropland as an open area is one of the sources of anthropogenic threat for the gibbon. In comparison to the other anthropogenic variables (i.e. distance to road, settlement, and plantation forest), cropland is the most dominant land use in Dieng landscape and mostly adjacent to the rainforest. The response curve of distance to cropland shows that probability of presence increases with increasing distance to cropland (figure 4c). The curve indicates that Javan gibbon avoids the existence of cropland. It may be caused by the high human activities on a relatively longer period in the cropland compared to the other anthropogenic variables (i.e. distance to road, settlement, and plantation forest). Although Javan gibbon could be habituated [36], naturally wild Javan gibbon more likely to avoid the area with high human use [45].

The other variable which gives the most contribution in the model is land surface temperature (LST). The response curve of LST shows that gibbon can occur between 22–31°C and the probability of presence is peaked around 27-28°C (figure 4d). It indicates the optimum temperature for gibbon habitat.
5. Conclusion
A total area of 81.286 km$^2$ was suitable for Javan gibbon in Dieng mountains. Relatively large of the suitable patch for Javan gibbon located in Sokokembang, Linggoasri-Mendolo, and western of Kembanglangit were considerable to get the conservation priority. The conservation strategy will be given in that area should considering the following environmental variables, the existence of undisturbed natural forest which provides the resources, the tolerated altitudinal and temperature range for Javan gibbon, and far enough distance from cropland.

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