INTERNATIONAL JOURNAL OF CONSERVATION SCIENCE

ISSN: 2067-533X Volume 15, Issue 2, 2024: 1009-1020 www. ijcs. ro

DOI: 10. 36868/IJCS.2024.02.17

FUTURE RISK AND ITS IMPACT ON ORANGUTAN HABITAT IN KATINGAN-KAHAYAN CORRIDOR, CENTRAL KALIMANTAN

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Abstract

The Katingan-Kahayan Corridor is currently one of the remaining habitats for Pongo pygmaeus wurmbii in Central Kalimantan, likely to be managed as an Essential Ecosystem Area. This area faces a high risk of deforestation in the future, as it is located outside protected or conservation zones. This study aims to project future deforestation in the Katingan-Kahayan Corridor from 2019 to 2050 and model its impact on orangutan habitat under two scenarios: (1) Business-as-Usual (BAU), and (2) implementation of an Essential Ecosystem Area (EEA). The deforestation risk model was built using the Random Forest Regression algorithm, while the orangutan habitat model was run using Maxent. The results of the deforestation projection model based on the two scenarios showed that by 2050, the Katingan Forest will become an isolated orangutan habitat with almost no connectivity to other large habitats around it. The secondary forest mosaic in the north of the Katingan Forest was likely to become highly vulnerable to deforestation and thus needs to be a conservation priority. The BAU deforestation scenario projected a decrease in the orangutan population in the Katingan-Kahayan Corridor by up to 68% by 2050, while the EEA implementation scenario can reduce the potential for population decline to 35%.

***Keywords**: Landscape corridor; Deforestation; Business-as-usual; Essential ecosystem area; Maxent; Scenario; Species distribution model*

Introduction

Kalimantan (Indonesian Borneo) has lost approximately 8 million hectares of natural forest over the last twenty years, most of which were lowland and wetland forest types [1–3]. Deforestation has become the main cause of habitat loss for the umbrella species in Kalimantan, the orangutan (*Pongo pygmaeus*) [4–8]. Approximately 1 million hectares of orangutan habitats in Kalimantan were converted to oil palm plantations between 2000 and 2010 [5].

The total population of *Pongo pygmaeus* is currently estimated at about 56,500 individuals [9]. At present, nearly 80% of the orangutan population resides in habitats outside protected forest areas [8], and many of them are found in fragmented habitats [10]. However, orangutans are known to be adaptive animals that can survive in disturbed habitats [6, 7, 11, 12]. Nevertheless, these degraded habitats cannot be guaranteed to the long-term survival of the orangutan population in the future [8, 9].

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The Katingan-Kahayan watershed in Central Kalimantan is one of the remaining habitats of the Bornean orangutan subspecies, *Pongo pygmaeus wurmbii*. Currently, the orangutan population in the area is estimated at approximately 4,000 individuals, which is threatened to decrease by up to 86% in the next 100 years [9]. This area is threatened by future deforestation for several reasons: (1) its location is in the outside of the protected forest areas, and (2) it is a lowland area, which is ideal for developing new plantations [13].

At a multi-stakeholder meeting held by Heart of Borneo in Kinabalu in 2016, an initiative was launched for the Katingan-Kahayan Corridor, a conservation priority landscape connecting Bukit Baka-Bukit Raya National Park and Sebangau National Park [13]. The landscape, which stretches for 180 km, aims to maintain the connectivity of natural forest cover to protect biodiversity, with the orangutan as the flagship species. The Katingan-Kahayan Corridor was planned to be managed as an Essential Ecosystem Area (EEA), a designation for areas outside Nature Reserves, Nature Conservation Areas, and Hunting Parks that were important for biodiversity. This designation was established by the government of Indonesia with Perdirjen KSDAE No. 2/2021. In 2019, a working group was formed to develop a management plan for the Katingan-Kahayan Corridor.

This research projected the future deforestation in the Katingan-Kahayan Corridor from 2019 to 2050. An analysis of the species distribution model was also conducted to model the impact of projected deforestation on the dynamics of the orangutan's habitat. The deforestation projection was carried out under two scenarios: (1) Business-as-Usual (BAU), and (2) implementation of the Katingan-Kahayan Corridor as an Essential Ecosystem Area (EEA).

Experimental part

The deforestation projection and its impact on orangutan habitat in the Katingan-Kahayan Corridor in this study were carried out using two main spatial models: a deforestation model and a species distribution model. The deforestation model was run using *Random Forest regression* [14, 15], while the orangutan habitat distribution model was analyzed using *Maxent model* [16]. The deforestation modeling was conducted to observe historical deforestation during the period from 2001 to 2018, and the deforestation projections were done for the period from 2019 to 2050.

Study area

This study was conducted in the Katingan-Kahayan Corridor, which is administratively located in the Katingan, Gunung Mas, and Palangka Raya regencies in Central Kalimantan, Indonesia (Fig. 1). This 115-thousand-hectare area was to be managed as a connecting corridor between Sebangau National Park and Bukit Baka-Bukit Raya National Park. The Katingan-Kahayan Corridor was dominated by heath forest, with a transition towards peatland on the southern side and lowland forest on the northern side [17, 18]. Although it was considered a low-nutrient ecosystem and not an ideal habitat for orangutans, this heath forest in the Katingan-Kahayan Corridor is currently one of the remaining habitats for *Pongo pygmaeus wurmbii*, with a density of around 0.5-1.0 individuals/km² [12, 19].

Materials

Deforestation model

Landsat 5 Thematic Mapper Collection 1 T1 (30-meter spatial resolution) was used to create a natural forest cover basemap for 2000/2001. At least 10,000 forest and non-forest sample points were collected as input for the natural forest cover classification model.

Historical deforestation data from 2001 to 2018 were obtained from global tree cover loss data [20]. In addition to historical deforestation point samples, the deforestation model incorporated several environmental factors as predictor variables. These factors represent drivers of deforestation, including landscape metrics, topography, disturbance levels, and land use policy (Table 1).

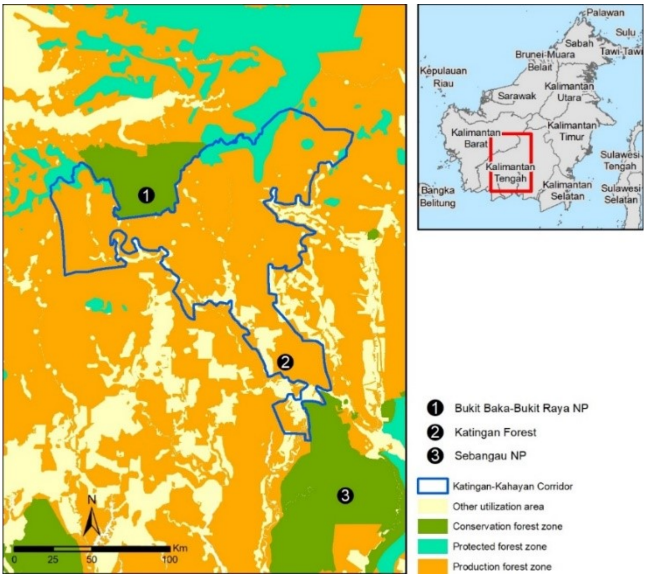

Fig 1. Map of the study area at Katingan-Kahayan Corridor

Table 1. The predictor variables in spatial deforestation model

Variables	Aspect	Description	Source
PLAND	Landscape metrics	Percentage of forest cover area in 100 km^2 filter window	Natural forest cover map previously made
DEFPERC	Landscape metrics	Percentage of last 10 years previously deforested area in 100km^2 filter window	Natural forest cover map previously made
ELEVATION	Topography	Surface elevation above sea level	SRTM [21]
IZIN	Landuse policy	Designated area for planned deforestation (logging and plantation concession) and protected area	Ministry of Environment and Forestry, Indonesia
ED	Landscape metrics	Percentage of edge dentity in 100km^2 filter window	Natural forest cover map previously made
SETT	Disturbance	Percentage of settlement area in 900km^2 filter window	Global settlement map [22]
MEAN_BURNED	Disturbance	Average of last 10 years burned areas in 100km^2	MODIS monthly burned area [23]
ROAD	Disturbance	Road network density in 100km^2	OpenStreetMap

Orangutan distribution model

The orangutan presence data were used to model the geographic distribution and suitability of orangutan habitat with Maxent. These data were collected through transect surveys, which were conducted by the World Wildlife Fund (WWF) Indonesia Central Kalimantan program from December 2017 to June 2018 [19]. These observations were conducted from morning until noon (06:00 AM to 01:00 PM). The records of orangutan nests were used as dependent data in the species distribution model. The environmental factors were used as predictor variables in this model, which were based on two main aspects: habitat preference and disturbance intensity (Table 2). The habitat preference aspects were represented by the percentage of canopy cover, distance to the rivers or the water sources, elevation, forest morphology, and climatological data. The disturbance intensity aspects were represented by the variable distance from the edge of the forest to the center of the forest.

Table 2. The predictor variables in orangutan habitat distribution model

Variables	Aspect	Description	Source
Treecover	Habitat preference	Percentage of tree canopy cover in 900m^2 grid mapping unit	Global tree cover loss [20]
Temp	Habitat preference	Annual mean temperature in °C	WorldClim [24]
Slope	Habitat preference	Degree of topographic slope	SRTM [21]
Rainfall	Habitat preference	Annual precipitation in mm	WorldClim [24]
Ed_settlement	Disturbance	Euclidean distance from nearest settlement	Global settlement map [22]
Ed_road	Disturbance	Euclidean distance from nearest roads	OpenStreetMap
Ed_river	Habitat preference	Euclidean distance from river	On-screen delineation on Sentinel-1 images
Ed_forest_edge	Disturbance	Euclidean distance from forest edge	Natural forest cover previously made

Methods

Planned and unplanned deforestation

In this study, deforestation was categorized into two forms: planned and unplanned deforestation. The planned deforestation refers to the conversion of natural forests to non-forests for activities sanctioned by the government. This can be undertaken by communities and corporations under the land management concession permits given by the government. These concessions permit can be in the form of logging (*Hak Pengusahaan Hutan/HPH*), industrial forestry plantations (*Hutan Tanaman Industri/HTI*), and *Hak Guna Usaha* (HGU) for oil palm plantations permits. In contrast, the unplanned deforestation includes all forms of deforestation that occur outside government planning, such as deforestation in conservation and protection areas, as well as production forest areas without concession permits.

Deforestation model

The natural forest cover baseline mapping for 2000/2001 was produced using the Random Forest supervised classification algorithm. The Random Forest is an ensemble machine learning method for classification and regression that combines multiple decision trees to improve accuracy [25]. The Landsat 5 TM image channels were used as data input included Short Wave Infrared 2, Near Infrared, and Red. These three channels are relatively unaffected by atmospheric disturbances, such as haze, which often affects the blue and green channels. The RGB combination was then transformed into HSV form to minimize atmospheric effects [26, 27]. The Random Forest classification was carried out using the R programming language, specifically with the "raster" package [28] and "randomForest" [29]. Historical deforestation mapping was conducted by overlaying the 2000/2001 natural forest cover with tree cover loss data from 2002 to 2018 from the *Global Forest Change* dataset [20].

The Random Forest regression approach was used to reveal the spatial relationship between historical deforestation from 2001 to 2018 and several environmental factors (Table 1). This model has two main outputs: variable importance, which indicates the significance of each variable in influencing deforestation, and a deforestation probability map (0-100%). The deforestation probability map serves as a reference for projecting deforestation from 2019 to 2050. The higher the probability of deforestation, the greater the likelihood of deforestation occurring in the future. The allocation of projected deforestation areas was based on two different scenarios: (1) The Business-as-Usual (BAU) and (2) the implementation of the Katingan-Kahayan Corridor as an Essential Ecosystem Area (EEA).

The BAU scenario assumed that trends and projections of deforestation rates from 2019 to 2050 will follow the deforestation history of 2001 to 2018. In contrast, the EEA deforestation projection scenario assumed that implementing the EEA with sustainable forest management practices, especially in planned deforestation areas, will reduce the rate of deforestation in the Katingan-Kahayan Corridor by up to 50%.

Orangutan distribution model

The orangutan distribution and habitat suitability model was built using the Maxent model [16]. Maxent is a species distribution model that uses only species presence data. Species absence data is assumed to be pseudo-absence, which is constructed randomly based on the predictor variable dataset used (Table 2). The Maxent analysis output in "cloglog" format was used in this study, as it directly describes the probability of species presence within the range of 0-1 [30].

Habitat suitability levels can then be interpreted in a binary way to distinguish high suitability habitats from low suitability habitats. The determination of the threshold value in this study used the "no omission rate" and "spec sens" reference values [31]. The "no omission rate" threshold was determined by the maximum value limit where no omission was found, which can be either false positive or false negative. This can be interpreted as the range of habitat conditions required by orangutans. The "spec sens" threshold was determined by the limit value where the maximum sum of the values of sensitivity (true positive rate) and specificity (true negative rate) was located, so that it can be interpreted as optimal habitat for orangutans.

Results and discussion

Historical deforestation during 2001-2018

During 2001-2018, the Katingan-Kahayan Corridor lost 160 thousand hectares of natural forest cover, accounting for around 10% of the total deforestation in Central Kalimantan. In the last five years of the study period, 2013-2018, planned deforestation became more dominant. This was evidenced by the increasing rate of deforestation in Production Forest areas licensed for Industrial Plantation Forests (*Konsesi HTI*). Although the increase was significant, the proportion was relatively small compared to other permit concessions. Logging activities were considered the main driver of deforestation in the Katingan-Kahayan Corridor during 2001-2018, in both planned and unplanned deforestation schemes (Fig. 2).

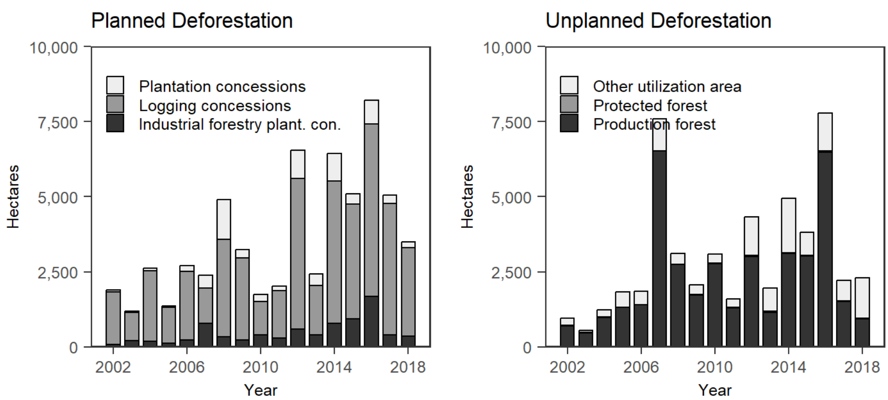

Fig 2. The distribution of historical-planned deforestation (left) and unplanned deforestation (right) in the Katingan-Kahayan Corridor during 2001-2018. The planned deforestation appears to have increased significantly in the last 5 years under HPH concession

The Random Forest regression's explained variance value of 0.64 indicated that the combination of predictor variables could account for 64% of historical deforestation. In contrast, the remaining 36% was influenced by spatial randomness or other variables not included in this model. The Random Forest variable importance analysis identified the following four most important variables in describing deforestation from 2002-2018: PLAND, DEFPERC, ELEVATION, and IZIN. These variables described different aspects of deforestation causes: landscape metrics (PLAND), disturbance (DEFPERC), topography and land suitability (ELEVATION), and land use policy (IZIN).

The PLAND and DEFPERC variables described the intensity of forest fragmentation. Lower percentages of forest canopy cover and higher percentages of previously deforested areas increased the likelihood of future deforestation. These results aligned with the modeling results of *G. Vieilledent et al.* [32] and *S.A. Cushman et al.* [33]. The ELEVATION variable represents land suitability for various land uses. Plantations, both large and small scale, agriculture, and settlement infrastructure require lowland topographical conditions, making lowland forests the most vulnerable to deforestation.

Historical deforestation from 2001-2018 also increased forest fragmentation in the secondary forest-oil palm plantation mosaic, a transition zone from lowlands to hilly areas on the northern side of the Katingan Forest. This landscape is crucial as it serves as a connectivity corridor between the Katingan Forest and the hill forests of Bukit Baka-Bukit Raya National Park on the northern side of the Katingan Corridor.

Projected deforestation in Katingan-Kahayan Corridor during the 2019-2050

Deforestation projections for the Katingan-Kahayan Corridor from 2019 to 2050, under both the BAU and the EEA scenarios, indicated that lowland forests in the corridor are the most vulnerable to deforestation. The projection results for both scenarios showed that by 2050, the Katingan Forest is expected to become an isolated "habitat island" (Figs. 3 and 4).

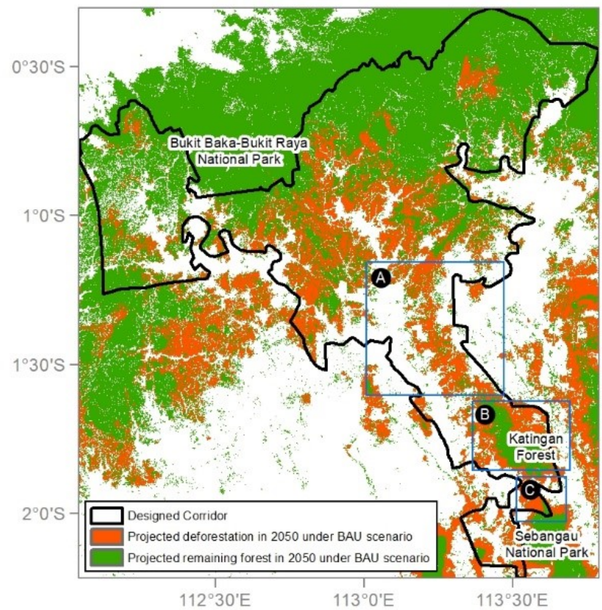

Fig 3. The projection of deforestation in Katingan-Kahayan Corridor for 2019-2050 under the BAU scenario: (A) The mosaic of degraded secondary forest that connects the Katingan Forest with the hill forest complex will be projected to be deforested; (B) Katingan Forest will also be projected to experience deforestation, leaving it as a Habitat Island around, as well as there will be not too many small habitat islands left; (C) It is projected that the edge of the Sebangau National Park forest will experience deforestation so that it will further widen the distance from the Katingan Forest

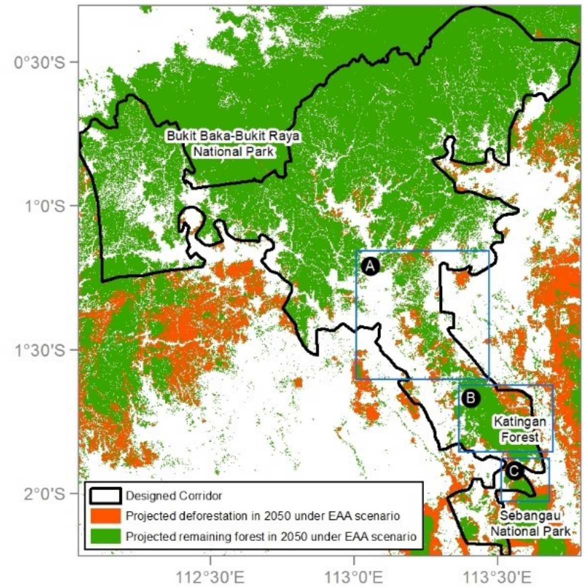

Fig. 4. The projected deforestation in the Katingan-Kahayan Corridor during 2019-2050 based on the EEA scenario: (A) Even though the deforestation rate is projected to decrease compared to the BAU scenario, the mosaic of degraded secondary forest in the north of the Katingan Forest remains an area that is prone to deforestation to form small habitat islands which is around; (B) the Katingan Forest which is projected to become a large habitat island; (C) The connectivity gap between Katingan Forest and Sebangau National Park is also projected to widen even though the rate of deforestation is not as fast as in the BAU scenario

This isolation was attributed to the loss of the secondary forest mosaic that functions as a corridor on the northern side, and which widened gap between the Katingan Forest and Sebangau National Park on the southern side. This secondary forest mosaic played a crucial role as a connecting corridor between the Katingan Forest and the transitional lowland forest to hill forest on the slopes of Bukit Baka-Bukit Raya National Park. To reduce the risk of future deforestation, thus the various conservation and restoration activities should be prioritized in this area.

Orangutan habitat preference in Katingan-Kahayan Corridor

The Maxent's analysis was successfully carried out with an Area Under the Curve (AUC) indicator of 0.8. Figure 5 illustrated the response of the spatial distribution of orangutan habitat to various environmental variables in the Katingan-Kahayan Corridor. The peaks of each curve represented the optimal conditions for orangutan habitat preferences in this corridor.

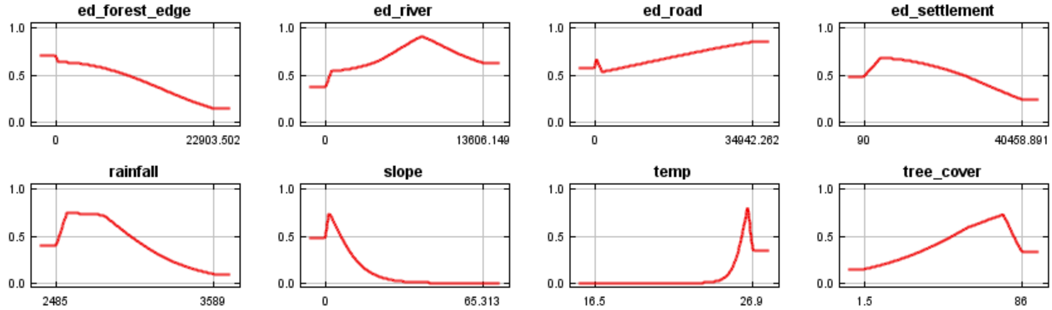

Fig. 5. The response curve of the spatial distribution of orangutan habitat to various environmental variables in Katingan-Kahayan Corridor – the narrow shape of the curve shows the narrow tolerance range of orangutans to these environmental variables

Orangutans in the Katingan-Kahayan Corridor had a relatively narrow range of habitat tolerance in terms of average annual air temperature, percentage of canopy cover, and slope gradient. In contrast, they tended to be adaptive to sources of disturbances, reflected in the wide tolerance range of orangutan habitat in terms of distance from the edge of the forest, distance from roads, and distance from settlements.

Average annual air temperature and annual precipitation affect the distribution of orangutan habitat, which corresponded to the distribution of vegetation types of fruit-producing trees, which were a source of food for orangutans. As the altitude increased, the average annual air temperature decreased and rainfall tended to be higher. Under such climatic conditions, there were fewer fruit-producing trees [12, 34] making these conditions less preferred for orangutans. Conversely, orangutan habitat preferences tended to be high in lowland areas, where the average annual air temperature was relatively low and annual rainfall frequency was not too high. In these conditions, fruit-producing trees had a relatively longer production season than those in hilly or mountainous areas.

Orangutans preferred habitats in trees with a large percentage of canopy cover. In these conditions, interlocking tree canopies facilitated movement and provided nesting sites [35, 36]. The canopy percentage can also represented the level of disturbance to orangutan habitat, as individual orangutan densities were often found in undisturbed forest conditions where the canopy gap was relatively small [7].

This Maxent's analysis also showed that orangutans in the Katingan-Kahayan Corridor had a habitat preference that got closer to the edge of the forest or ecotone zone. This aligned with the findings of *H.D. Rijksen and E. Meijaard* [12], who stated that orangutans tended to prefer ecotone zones. These zones had many young plants that served as secondary food choices for orangutans outside the fruit season. This preference was possibly due to the conditions in the peat swamp ecosystem, where there were fewer species of fruit trees as one got closer to the top of the peat dome, which resulted in fewer choices of fruit-producing trees [35].

Orangutan habitat distribution in the Katingan-Kahayan Corridor

In 2018, approximately 576 thousand hectares of natural forest cover in the Katingan Corridor could support orangutan habitat (Fig. 5). This estimation was based on Maxent's analysis with cloglog output converted into a habitat suitability class using the omission rate method. In contrast, the natural forest cover that could provided optimal habitat for orangutans, determined using the spec sens method, which was only around 205 thousand hectares. This was based on an individual orangutan density level of 0.59 per km² [19], and the minimum habitat area of 576 thousand hectares could support a population of approximately 3,400 orangutans (Table 4).

Table 4. Projection of remaining natural forest cover and projected condition of habitat area as well as estimated orangutan population in the Katingan Corridor in 2050 – Population estimation is calculated using the individual orangutan density figure of 0.59 ind/km^2

	Baseline (2018)	Projected 2050 - BAU	Projected 2050 - CORR
Forest cover	981,182 ha	642,719 ha	935,211 ha
High suitability habitat	576,418 ha	211,364 ha	371,825 ha
Estimated population size	3,400 ind.	1,250 ind.	2,200 ind.

The projection of the orangutan habitat distribution in the Katingan-Kahayan Corridor 2019-2050

The BAU deforestation scenario projected that the remaining natural forest cover in the Katingan-Kahayan Corridor will be about 642 thousand hectares in 2050 (Fig. 6B). The Maxent model results showed that only about 32% (211 thousand hectares) of this area would be considered optimal habitat for orangutans. Based on the reference density of orangutans per km² [19], the orangutan population in 2050 under the BAU scenario was projected to be approximately 1,250 individuals (Table 4). This represented a decrease of about 2,150 individuals (63%) from the current population. As previously mentioned, the BAU scenario projected the loss of forest fragments in the north and south of the Katingan Forest. These fragments could serve as stepping stones, which will connect the forest fragments for orangutan migration to other habitat patches.

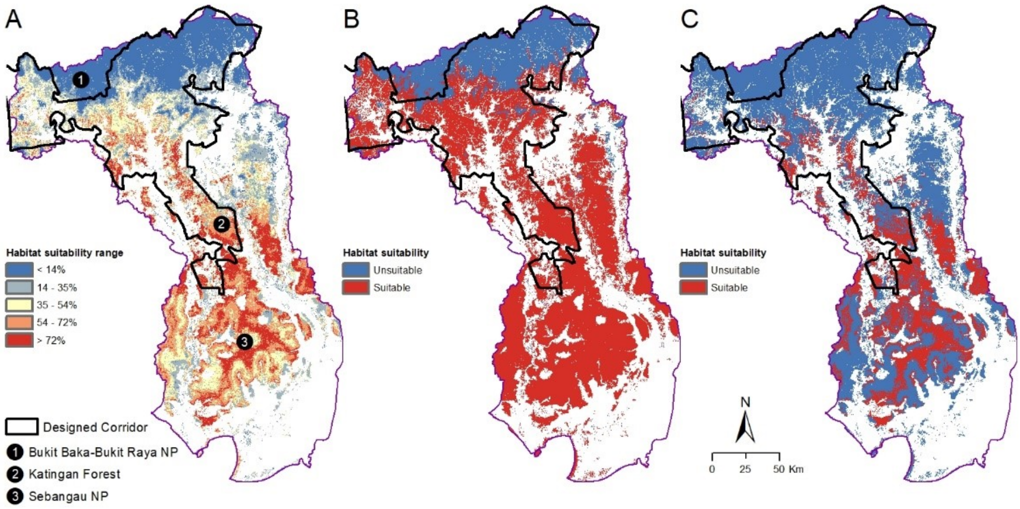

Fig. 5. The range of orangutan habitat in 2018 based on the results of Maxent's analysis:
(A) Percentage of suitable level of orangutan habitat based on Maxent's cloglog output;
(B) Range of orangutan habitat uses the "no omission rate" value limit;
(C) Optimal orangutan habitat refers to the "spec" value limit sens”

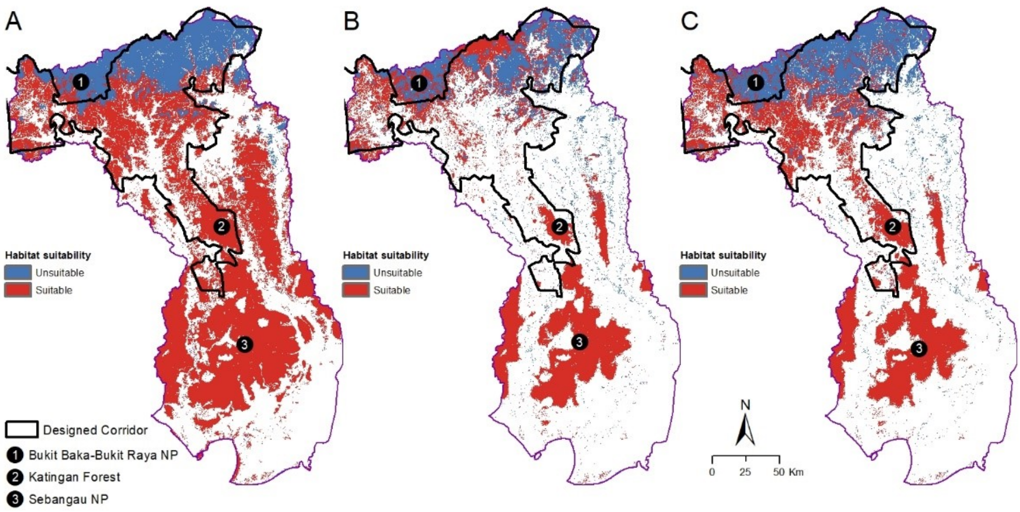

Fig. 6. The results of Maxent's analysis describing the range of orangutan habitat:
(A) baseline in 2018; (B) 2050 projections based on the BAU deforestation scenario;
(C) the projection for 2050 based on the implementation scenario of the Katingan-Kahayan corridor as an EEA area

The deforestation projection based on the implementation scenario of the Katingan Corridor as an Essential Ecosystem Area (EEA) was estimated to prevent around 293 thousand hectares of deforestation compared to the BAU scenario. The remaining natural forest cover area under the EEA scenario was projected to be 935 thousand hectares, with 39% considered optimal orangutan habitat. Based on this optimal habitat area, the orangutan population in 2050 was estimated to be 2,200 individuals. This represented a decrease of 1,200 individuals (35%) under the EEA scenario. The EEA scenario also predicted habitat fragmentation, particularly in the secondary forest mosaic in the north of the Katingan Forest. However, the fragmentation intensity was not as severe as in the BAU scenario.

Conclusions

Katingan Forest was one of the remaining orangutan habitat patches that should be a priority for conservation. The threat of deforestation in this area was very high, given its location within a production forest area and its flat topography. The logging activities, both legal and illegal, in production forest zones, had consistently caused deforestation over time. Orangutan movement was still possible from the Katingan Forest to the secondary forest mosaic on the north side of the Katingan Forest. This secondary forest mosaic formed a connecting corridor with the forest at the foot of the Muller-Schwaner Mountains to the north. However, the area had been intensively fragmented, which limited its ecological support for orangutans. In the future, this area will be highly vulnerable to further deforestation and fragmentation. The results of deforestation risk mapping and projections confirmed this condition.

The deforestation projection results using both the Business-as-Usual (BAU) scenario and the implementation scenario of the Katingan-Kahayan Corridor as an Essential Ecosystem Area (EEA) showed that the secondary forest mosaic on the north side of the Katingan Forest was the most vulnerable area to deforestation. The BAU scenario predicted that the forest in this area would be exhausted, leaving the Katingan Forest as a large, isolated habitat patch. The EEA scenario showed that although the rate of deforestation was assumed to decrease, fragmentation in the secondary forest mosaic area was inevitable. This illustrated that the implementation of the EEA in the Katingan-Kahayan Corridor would be not necessarily in maintaining orangutan habitat connectivity. The EEA implementation in the Katingan-Kahayan Corridor also needed to prioritize efforts to restore and protect the secondary forest mosaic. The role of these secondary forests was crucial in maintaining orangutan habitat connectivity in the Katingan-Kahayan Corridor. However, the remaining threat of future deforestation was very high.

Aknowledgments

We extend our heartfelt thanks to the Sebangau National Park Authority and WWF Indonesia's Central Kalimantan program for their support in providing the necessary data. We also express our gratitude to Prof. Dr. Suwarno Hadisusanto, M.Si., Prof. Dr. Satyawan Pudyatmoko, and Prof. Dr. Ig. L. Setyawan Purnama of Universitas Gadjah Mada for their valuable discussion in the preparation of the research.

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Received: Octomber 02, 2023
Accepted: M ay 24, 2024