The Javan Gibbon (*Hylobates moloch*) Habitat Changes and Fragmentation in the Dieng Mountains, Indonesia

Salmah Widyastuti[1], Dyah Perwitasari-Farajallah[2,3]*, Lilik Budi Prasetyo[4], Entang Iskandar[3]

[1]Animal Biosciences Graduate Program, Department of Biology, Faculty of Mathematics and Natural Sciences, IPB University, Gedung Biologi, Jl. Agatis, IPB Dramaga Campus, Bogor, Indonesia 16680
[2]Department of Biology, Faculty of Mathematics and Natural Sciences, IPB University, Gedung Biologi, Jl. Agatis, IPB Dramaga Campus, Bogor, Indonesia 16680
[3]Primate Research Centre, IPB University, Jl. Lodaya II No. 5, Bogor, Indonesia 16680
[4]Department of Forest Resources Conservation and Ecotourism, Faculty of Forestry and Environment, IPB University, Academic Ring Road IPB Dramaga Campus, Bogor, Indonesia 16680

Abstract

The endangered javan gibbon (Hylobates moloch) has been threaten by massive habitat loss and fragmentation in Java. The survival of the second largest population which inhabited unprotected Dieng mountains faced greater risk to habitat conversion and fragmentation. The landscape-level habitat monitoring using spatiotemporal quantification is crucial as a baseline data for javan gibbon conservation. Here, the land-use and land-cover (LULC) change of the Javan gibbon habitat during 1994–2009–2021 and its fragmentation in the Dieng mountains were quantified. This study revealed there were no significant decline in the total of forest. However, its quality was degraded in the interior of forest block. The forest has more fragmented from large patches into smaller patches and increased forest edge. The higher fragmentation happened in the areas that traversed by road. Six suitable forest blocks were identified with varying level of connectivity. Protection and restoration both in the forest and in the interior forest is immediate need, especially in the main forest block. The extra effort is also crucial in the connected forest but traversed by road. The blocks which closely isolated by road could be potentially reconnected by artificial canopy bridge, while the other distantly isolated block might need habitat restoration for corridor.

Keywords: *LULC change, landscape metrics, primate conservation, connectivity, habitat monitoring*

*Correspondence author, email: *witafar@apps.ipb.ac.id, tel./fax. +62-251-8622833*

Introduction

Small apes (Hylobatidae) comprise 20 species and live in evergreen forest throughout Southeast Asia (Roos et al., 2014; Fan & Bartlett, 2017). The javan gibbon (*Hylobates moloch*) is one of the small ape species which endemics to Java, one of the most densely populated places on earth (Nijman, 2004). The distribution is restricted in the western half of Java. The major composition (>60%) of the javan gibbon's diet are forest fruits (Kim et al., 2011). Like the other small apes, as an obligate canopy dweller, it spends most of the daily activity in the middle and upper canopy of the rainforest and rarely descends to the forest floor (Cannon & Leighton, 1994; Whittaker, 2009; Marshall, 2010). As a result, this frugivorous and strictly arboreal primate exclusively depend on a rainforest which provides the diverse fruit trees and the continuous canopy structure as their habitat (Kappeler, 1984; Kim et al., 2011).

These specific characteristics address the loss, the degradation and the fragmentation of the natural forests became the main drivers of the decline in javan gibbon populations in addition to poaching (Nijman, 2004, 2013; Supriatna, 2006; Setiawan et al., 2012; Smith et al., 2018). The forest loss due to conversion to other land uses can directly reduce the carrying capacity of the javan gibbon

population (Smith et al., 2018). Although the rate of permanent forest loss in Java has been lower after Indonesia's independence period (Whitten et al., 1996; Nijman, 2004; Supriatna, 2006), the degradation of forest ecosystems due to human activities has been continuing and degrading the quality of javan gibbon habitat until recent days (Supriatna, 2006; Setiawan et al., 2012). Forest fragmentation or separation into smaller patches may have relatively minor negative impacts or even positive impacts for some species (Fahrig, 2003; Jackson & Fahrig, 2013). However, for gibbon species, a 510 m linear gap in canopy cover can even block their movement to reach the opposite forest (Cheyne et al., 2013; Asensio et al., 2021). This can inhibit a mating between individuals from different patches, thereby interrupt gene flow and in long-term period will lead to reduced adaptive-variation and/or inbreeding depression (Spielman et al., 2004; Frankham, 2005; Markert et al., 2010; Ralls et al., 2018). These two potential negative events can decrease the population growth rate and then lead to the extinction (Johnson & Dunn, 2006; Allendorf et al., 2010). Thus, forest fragmentation can have a devastating impact on javan gibbon populations.

The javan gibbon is listed as endangered in the International Union for Conservation of Nature (IUCN) Red

List based on suspected 50% or more population decline over the course of three generations (2001–2045) (Nijman, 2020). Currently, the population has remained at around 4000-4500 individuals and has separated into approximately 30 fragments (Nijman, 2004; Malone et al., 2014). The recent population viability model predicted high probabilities of extinction (85–100%) within 100 years for three largest remaining javan gibbon populations (Ujung Kulon National Park [NP], Gunung Halimun-Salak NP, and Dieng mountains) under the scenario of continuing deforestation, fragmentation, and hunting (Smith et al., 2018). Dieng mountains remains the largest rain forest in Central Java and hold the second largest populations of javan gibbon after Gunung Halimun-Salak NP. Contrastingly, among the other largest habitat it is not protected under conservation area (Nijman & Van Balen, 1998; Nijman & Setiawan, 2001; Nijman, 2004; Setiawan et al., 2012; Widyastuti et al., 2023). Moreover, the landscape consisted of heterogenous mosaic land-uses and receive a greater risk to forest conversion and fragmentations (Nijman, 2004). In this case, habitat monitoring at the landscape-level is crucial to maintain the long-term survival of the local population and against the deforestation and fragmentation.

Based on rough estimation that there were 20% decline of javan gibbon habitat during 1980–2000 (Nijman, 2004), it assumed that deforestation rate in Java was 1% year^{-1} (Smith et al., 2018). As deforestation is significantly driven by several factors such as road density, human population density, and population that have income from agriculture (Prasetyo et al., 2009), the deforestation rate will differ at different site. Therefore, monitoring the forest cover change in a landscape level is important to provide a baseline data for gibbon habitat protection (Sarma et al., 2021). The previous study with rough estimation suggested that javan gibbon habitat in Dieng have been fragmented into roughly four forest blocks (Setiawan et al., 2012). However, more precise quantification of forest cover as habitat is needed to identify the forest fragment or block. Moreover, quantification of forest fragmentation within the blocks and the connectivity between the blocks have not been measured, therefore its impact on javan gibbon conservation is still unclear. This study aimed to quantify the dynamic change of forest during 1994–2009–2021 and its fragmentation in the javan gibbon habitat in the unprotected Dieng mountains in order to investigate the habitat loss and degradation. We measured the land-use and land-cover (LULC) change in general and also specifically look at the forest loss and gain. This study also investigated the temporal and spatial pattern of forest fragmentation, identified the suitable forest block and the present connectivity between the suitable forest block for javan gibbon.

Methods

Study area The study was conducted in Dieng mountains, Central Java Province, Indonesia (E109°32'–109°56' and S7°04'–7°13'). This landscape is mountainous area that connected to the complex of Dieng volcanoes. The study was concentrated in the forested area that remain in the northern part of the mountains encompassing lowland to submontane forest (250–2,500 m asl) (Figure 1). The forested area consists of a mixture of natural rain forest and plantation

forests dissected by a large number of secondary roads, and most relatively flat areas among the forest patches were built as settlements and croplands. The natural forest is home to diverse of flora and fauna, especially for the endemic javan gibbon. The others protected species and endemic to Java are also recorded in this area such as javan leopard, javan hawk-eagle, javan blue-banded kingfisher, and etc. (Nijman & Van Balen, 1998; Chan & Setiawan, 2019). Although it is the largest biodiversity hotspot in Central Java, this area received less protection for biodiversity conservation. All forested areas are administratively managed by Perum Perhutani and Perusahaan Perkebunan Negara (an Indonesian state-owned forestry and plantation enterprise), which are mainly responsible for forest production. Some forest blocks are *hutan lindung* (protection forest), which are not converted to plantation to maintain soil fertility and prevent landslides (Nijman & Van Balen, 1998). Plantation forests such as pine, agathis, rubber, and tea plantation are generated in the surrounding the area, mostly adjacent to the natural forest.

Land-use and land-cover classification and change analysis As the javan gibbon depend on a rainforest which provides the diverse fruit trees and close canopy (Kappeler, 1984; Kim et al., 2011), we defined rain forest cover as
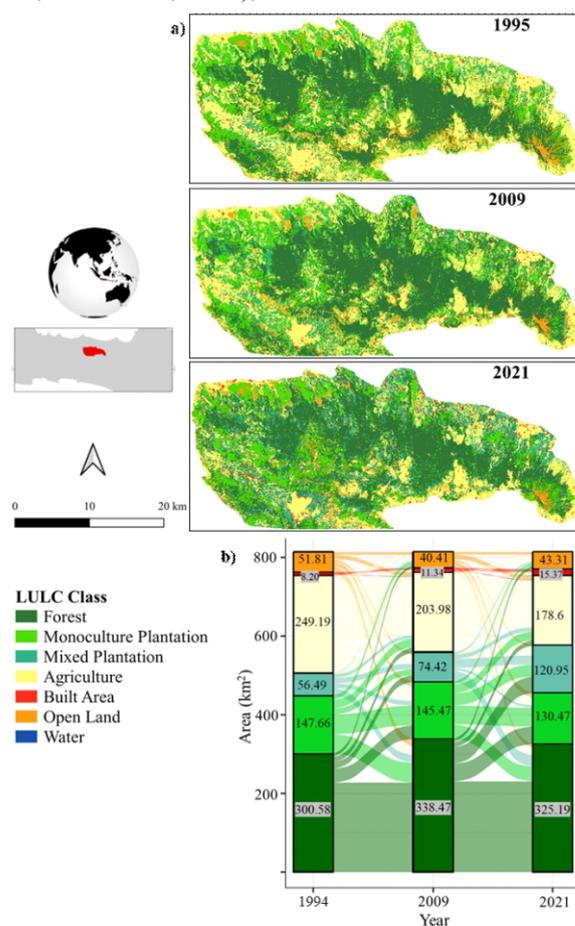

Figure 1 Land use land cover (LULC) change analysis of Dieng mountains in 1994, 2009, and 2021. a) LULC maps and b) the Sankey diagram of LULC transition.

habitat. The forest changes were quantified as an approach to represent the habitat changes of the javan gibbon. In this study, we used the term of forest as dry tropical rain forest which can be from both natural-growth forest or secondary succession forest, with assumption that forest is an area which covered by indigenous tree species higher than 5 m with a minimum 30% of canopy cover (Margono et al., 2012). However, later in the supervised classification of the land-use and land-cover (LULC), the reference polygons of classes were assigned and sampled based on visual interpretation from the color and the tone of the spectral band reflectance.

This study classified and mapped three-time-points LULC in Dieng mountains. The seven LULC classes including forest and other six LULC classes were defined based on the observation in the field (Table1). We divided the LULC classes into two categories, which were the canopied classes and non-canopied classes, to see the spatial pattern of LULC surrounding the javan gibbon habitat in Dieng mountains. The canopied classes consisted of forest, monoculture plantation, and mixed plantation, which at least enabled the javan gibbon to move through these LULC classes. While the non-canopied classes consisted of agriculture, built area, open land, and water body, which isolated the canopied classes or become barriers for javan gibbon movement.

Satellite imageries data preparations The time points of the satellite imageries were selected on the basis of the three survey years of the javan gibbon population conducted in Dieng mountains (Nijman & van Balen, 1998; Setiawan et al., 2012; Widyastuti et al., 2023), which were 1994–1995, 2009–2010, and 2021. Henceforth, these representing years were simplified to be 1994, 2009, and 2021. The multi-temporal satellite imageries from the Landsat Collection 2 Surface Reflectance product (Landsat 5 for years 1994 and 2009; Landsat 8 for year 2021) with the spatial resolution of 30 m retrieved from and preprocessed in Google Earth Engine (GEE) (Gorelick et al., 2017). The image for each representing year were filtered by a range of filter-date, cloud-masked using quality assessment band and statistical filtered by median pixel values before further analysis. In order to obtain clear images after applying cloud-masking, the filter-dates for each year were adjusted and extended to the range which gave least cloud cover. They were "1994-01-01 to 1995-12-31", "2009-01-01 to 2009-12-31" and "2020-06-01 to 2021-12-31", which represented the 1994, 2009 and 2021 images, respectively. Topographical correction was

also performed based on a modified sun—canopy-sensor topographic correction (SCS+C) algorithm to reduce the effect of shading from the sun in undulating terrain (Soenen et al., 2005; Poortinga et al., 2019).

LULC classification and change analysis A machine learning supervised classification based on Random Forest algorithm was performed in GEE to classify the LULC (Breiman, 2001). A total of seven LULC classes were decided for Dieng mountains which were described in Table 1. In addition to reflectance bands of Landsat images, four vegetation indices including NDVI, NDBI, SAVI and EVI were also employed for classification (da Silva et al., 2020). The total of 13161, 13306 and 14047 pixels were sampled assigning seven land cover class for images in 1994, 2009 and 2021, respectively. Random splitting of 80% and 20% were applied for training and testing, respectively. overall accuracy and Kappa co-efficient from the confusion matrix were used to assess the classification accuracy (Rosenfield & Fitzpatrick-lins, 1986). The focal mode function in GEE was then applied on the classified images to reduce the salt-and-pepper effect in the land cover results (Tassi & Vizzari, 2020; Tassi et al., 2021).

The LULC change-transition matrix was computed using R program to quantify the change. The Sankey diagram was used to visualized the transition and to identify what the major cause of forest lost and gain during 1994–2009–2021 (Cuba, 2015). The spatial pattern of forest lost and gain were also visualized and quantified in maps using ArcMap and QGIS.

Fragmentation analysis Habitat fragmentation is the breaking apart of habitat into several smaller pieces (Fahrig, 2003; Jackson & Fahrig, 2013). Thus, in this study, habitat fragmentation is indicated by the change from the large patch of forest cover into several smaller patches. These several smaller patches can be separated by the other LULC classes or such barriers which may inhibit the javan gibbon movement (i.e. dissecting road or river). In order to measure the fragmentation of the javan gibbon habitat, we qualitatively and quantitatively analyzed the three-time-points of forest cover.

The isolated forest blocks were identified to describe and clearly explain the spatial pattern of fragmentation and to assess the habitat connectivity which represents fragmentation. This is identified based on the LULC maps and large roads that have been dissecting the forest. It then

Table 1 Land use land cover classes defined for classification

Category	LULC class	Descriptions
Canopied classes	Forest	Combination of primary natural forest and secondary succession forest as potential habitat for javan gibbon. The trees are taller than 5 m and canopy cover more than 30%
	Monoculture plantation	Plantation forest such pine, rubber, agathis, *sengon* wood
	Mixed plantation	Plantation forest or planted tree area which consists of multispecies tree with <5 m of tree height
Non-canopied classes	Agriculture	Dry crop, rice field, vegetables, tea plantations
	Built area	Buildings such as settlements, farmhouse, public buildings, traditional market, etc.
	Open area	Grass land, baren land
	Water body	Large river, lake

overlaid by the habitat suitability model for javan gibbon from previous study on the forest blocks layer (Widyastuti, 2021; Widyastuti et al., 2023) to identify the suitable forest blocks for the javan gibbon. The connectivity between the suitable blocks were characterized based on the relative distance to each other and the presence of existing corridor, which is plantation forests. In addition, we also identified several parts of the road that traversed within blocks but still have some points of connected canopy, which at the high risk to isolate this block if the canopy gap is wider in the future.

Furthermore, this study used landscape metrics available in Landscapmetrics R package to measure and analyse spatiotemporal pattern of the fragmentation process (during 1994, 2009, 2021) (Hesselbarth et al., 2019). The seven common landscape metrics were calculated as a whole landscape for each time point to see the temporal change of forest fragmentations in 1994, 2009, and 2021, which were class area (CA), largest patch index (LPI), mean patch size (Area_MN), number of patches (NP), patch density (PD), edge density (ED), and landscape shape index (LSI) (McGarigal et al., 2023). In order to see the spatiotemporal pattern of forest patch in Dieng mountains, the squared 1 km^2 grid was applied on the forest patch layers of three time points (Rivas et al., 2022). The landscape division index was then quantified for each square (Jaeger, 2000). The size of 1 km^2 was defined on the basis of the daily path length of javan gibbon (Kim et al., 2011).

Results and Discussion

LULC dynamics The classification of the seven classes of the LULC around the javan gibbon habitat in Dieng mountains for the year of 1994, 2009, and 2021 resulted fairly good overall accuracy (OA) and Kappa co-efficient (K) (OA = 0.745, K = 0.716; OA = 0.733, K = 0.702; OA = 0.781, K = 0.756; respectively) (Figure 1). From 1994 until 2021, the landscape was dominated by canopied classes, but non-canopied classes randomly fragmented the canopied classes (Figure 1). Generally, the canopied classes gradually increased over three time points, and non-canopied classes decreased. These came from the increase of the mixed plantation, increase of forest and decrease of agriculture (Figure 1). The forest cover over three time points were the most dominant class (Figure 1). For non-canopied classes, agriculture is the largest barrier, 249.19 km^2 in 1994, but over three time points it gradually decreased, loss of 45.21 km^2 in 1994–2009 and 25.38 km^2 in 2009–2021 (Figure 1). The built areas were mostly distributed all over the landscape with small size area. However, the total of built area was gradually increased, from 8.20 km^2 in 1994 to be 11.34 km^2 in 2009 and to be 15.37 km^2 2021.

Forest cover change Dieng mountains remain in unprotected status, although several previous studies have concluded that this remaining forest was an important habitat for the survival of some endangered species such as javan gibbon and others (Nijman & Van Balen, 1998; Setiawan & Nijman, 2001; Setiawan et al., 2012; Chan & Setiawan., 2019). Surprisingly, this study indicates that during 1994-2021 the size of forest cover was relatively stable or even increased with slight fluctuations. The total of forest cover

was 300.58 km^2 in 1994, increasing 37.89 km^2 in 2009 and then decreasing 13.12 km^2 in 2021 to be 325.19 km^2 (Figure 1).

However, the forest loss and gain during those intervals were happened (Figure 2). The total forest losses tended to be balanced by the total forest gains in different places during 1994–2009 and 2009–2021. In the 1994–2009, the total loss of 73.04 was balanced by the total gain of 110.93 and in the 2009–2021 the total loss of 107.75 was balanced by the total gain of 94.64 km^2. Most of the forest loss was due to converted into monoculture plantation (34.81 km^2 in 1994–2009 and 44.80 km^2 in 2009–2021) and into mixed plantation (17.30 km^2 in 1994–2009 and 41.53 km^2 in 2009–2021). Uniquely, the amount of forest gains from the same land-use classes were balanced the forest losses. The forest gains from monoculture plantation were 50.27 km^2 in 1994–2009 and 37.25 km^2 in 2009–2021; and from mixed plantation were 19.86 km^2 in 1994–2009 and 28.94 km^2 in 2009–2021 (Figure 1). In 1994–2009 the loss mostly happened in a large block in the western side of the landscape but the gain happened much larger in the north side. Contrastingly, in 2009–2021, the loss is larger than the gain and wide spread through the landscape, while the gain mostly happened in the location where the most of loss happened during 1994–2009 (Figure 2).

In general, the forest cover slightly increased 24.61 km^2 during 26 years (1994–2021). The increase is possibly due to the secondary succession proses of monoculture plantation (40.7%), agriculture (27.4%), mixed plantation (17.7%) and open area (13.2%) during this period. Although the Dieng mountains was not protected under the conservation area, the habitat abundance during 1994–2021 remained stable or even slightly increased. This can be associated to the awareness of local communities in protecting forests. In the last decade, forest communities in several locations in the Dieng mountains have been involved in conservation efforts which initiated by a non-government organization (NGO), SwaraOwa. This NGO has been helping the community to manage sustainable product from the forest. The villagers were also involved as local guide in gibbon watching tourism and as a guide in every field conservation research. An ongoing practice is the development of sustainable shade grown coffee agroforestry and sustainable honey-farming from wild stingless bees (Supriatna et al., 2022; Smith et al., 2023), so that communities have been educated to conserve forests and were most likely to contribute to the stability of forest cover. These programs are examples of community-based natural resource management (CBNRM) that the local communities can take benefits from natural resources and ecosystems without damaging, depleting, and permanently reducing the quality of natural resources (Roe et al., 2006; Fabricius & Collins, 2007). This CBNRM approach has also been shown to have positive impacts on some habitats and wildlife populations outside of conservation areas in southern Africa (Reyers, 2013).

This study detected the increase of mixed plantation cover inside the forest patch in 2021 (Figure 1a). As the class of mixed plantation assigned by planted multispecies tree which lower than 5 m, it possibly that the newly-growth of forest area due to degradation was classified as mixed plantation.
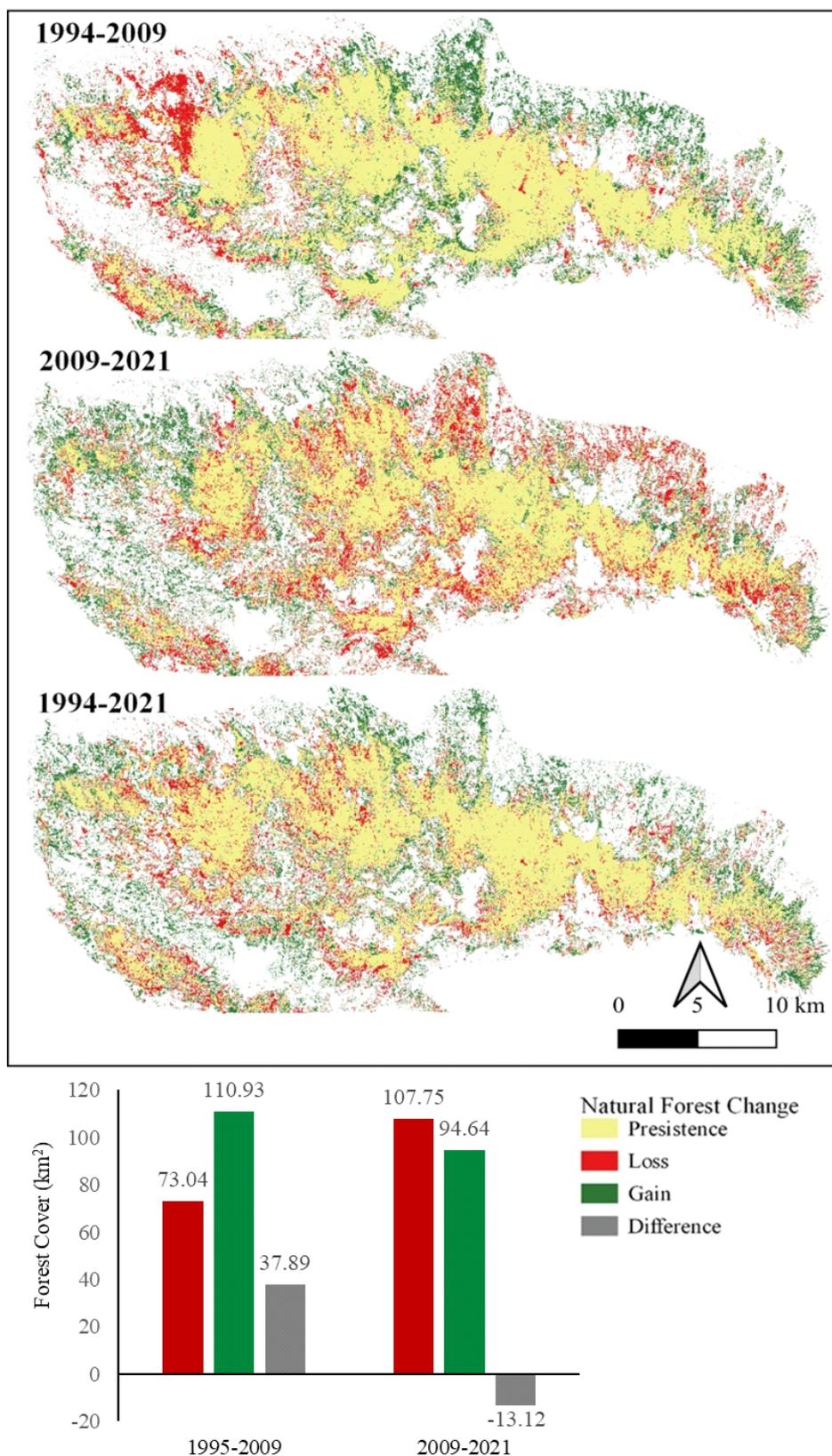
Figure 2   The distribution of loss, gain and persistence of forest in the Dieng mountains between 1994, 2009, and 2021 and the total gain, loss and difference.

Therefore, the emergence of mixed plantation cover in the interior the forest is suspected as forest degradation. However, further investigation is needed to confirm it by higher scale analysis such vegetation structure and composition from field measurement or using high resolution remote sensing data.

Forest fragmentation Based on the LULC maps and identified dissecting roads, eight isolated forest blocks were identified for the year of 2021 (Figure 3). The six of eight were suitable for javan gibbon while the other two were not suitable. The suitable blocks were West Linggoasri, Kandangserang, Petungkriyono, Paninggaran, Pamutuh, and Mt. Prau forest blocks (Figure 3). The largest suitable forest block was Petungkriyono block, which encompasses several localities, from East Linggoasri, Lebakbarang, Petungkriyono, Bandar, Blado, Mt. Kamulyan, and delineated by the road from Bawang to Batur. The four suitable forest blocks of West Linggoasri, Paninggaran, Pamutuh, and Mt. Prau were adjacent and relatively close to Petungkriyono block, while the Kandangserang block was totally isolated from the Petungkriyono block and from others due to large non-canopied LULC classes in between them (Figure 3). The West Linggoasri forest block was isolated from the main block of Petungkriyono by approximately 5m-wide road. The Mt. Prau block was also

isolated from Petungkriyono block by a relatively small dissecting road (approximately 3m-wide) with larger canopy gap than the width of the road. The other two suitable forest blocks (Paninggaran and Pamutuh) were isolated by the other LULC classes in relatively longer distance (>500 m) to the Petungkriyono block.

This study revealed that West Linggoasri and Mt. Prau forest blocks have started to be isolated from the main block of Petungkriyono due to dissecting road. Furthermore, the Petungkriyono block was traversed by some non-isolating roads that potentially become wider in the future and may isolate this main block into separated blocks (Figure 3). This indicates that the road is the significant anthropogenic feature which triggered habitat fragmentation (Prasetyo et al., 2009; Mehdipour et al., 2019) and can affect the movement dynamics of the primate species (Gibson & Koenig, 2012; Ramsay et al., 2019; Asensio et al., 2021). The ranging behavior of gibbon could be affected by the dissecting road. Although the gap above the road is narrow (approximately 5 m), gibbon is most likely not crossing the gap, moreover if the traffic is heavy such in Linggoasri's main road. In the Khao Yai National Park the two species of gibbons were observed to cross the <5 m gap above the road and did not cross the canopy gap of >5 m. The home range of the gibbon groups were then partially delineated by the road (Asensio et al., 2021).
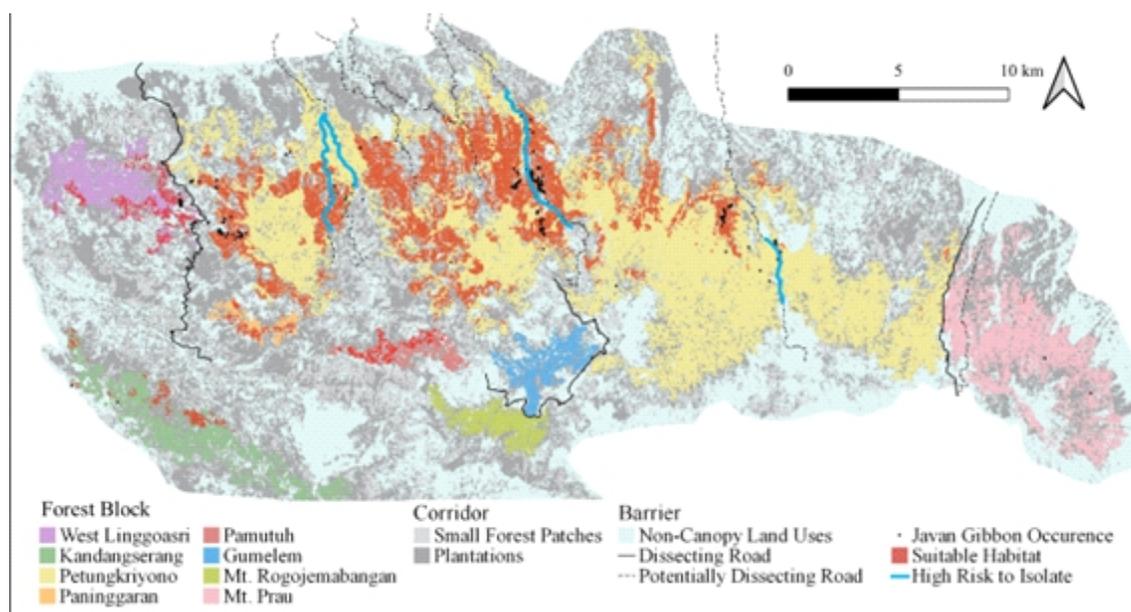

Figure 3 Identified forest blocks as habitat patches for javan gibbon overlaid by habitat suitability model, species occurrence record and identified road which at risk to isolate the patch.

Table 2 Forest fragmentation dynamics in Dieng mountains in 1994, 2009, and 2021

Aspect	Landscape metrics	Unit	1994	2009	2021
Size	Class area (CA)	ha	29,628	33,361	32,046
	Largest patch index (LPI)	%	42.30	45.30	33.20
	Mean patch size (Area_MN)	ha	3.85	3.46	2.98
Density	Number of patches (NP)	-	7,703	9,632	10,764
	Patch density (PD)	no. ha^{-1}	15.50	17.50	18.90
Shape	Edge density (ED)	M ha^{-1}	72.80	85.80	105.00
	Landscape shape index (LSI)	-	82.40	88.60	119.00

Despite there was a slight increase in total size of the forest during 19942021, it became more fragmented. During the study period, the LPI and Area_MN decreased, but the NP and PD increased. This indicates that the large forest patches have fragmented into a greater number of smaller patches. Additionally, the ED and LSI were becoming higher which means that the fragmentation process change the shape of the forest patches into more complex and increased the total forest edge (Table 2). The measurement of LDI in squared grid show that the forest in the center of the landscape was less fragmented than its surrounding (Figure 4). Some areas in the western part of the landscape were more fragmented during 1994–2021. The one was in between West Linggoasri and Petungkriyono blocks and the other one was in the east of Kandangserang block. The higher landscape division index was indicated in the areas that traversed by road (Figure 4).

Actually, the forest in western part of Java, including Dieng mountains, has been severely fragmented by the end of the 1800s due to massive deforestation, and the fragmentation pattern at the early of the 1900s was very similar to that seen today (Nijman, 2013). Thus, the fragmentation pattern in 1994 showed in this study was mainly driven by forest conversion into agriculture during colonialism period. Furthermore, this study is focus to see the change after 1994. Then the results highlight that the roads tended to trigger more severe fragmentation, which was observed between West Linggoasri block and Petungkriyono and also observed within Petungkriyono block.

Connectivity between seven blocks, namely West Linggoasri, Petungkriyono, Pamutuh, Paninggaran, Gumelem, Mt. Rogojembangan, and Mt. Prau, was not completely isolated. Rapid observations in the field suggest that there were still tree canopies with close gaps in some part of the dissecting road that may allow javan gibbons to cross between blocks. Monoculture and mixed plantations, identified through the LULC map, can also serve as natural corridors between these blocks, enabling gene flow or genetic exchange between subpopulations (Figure 3). A recent population genetics study conducted on javan gibbon in Dieng supports this idea, as it found evidence of gene flow between the Linggoasri (West Linggoasri block) and Kayupuring (middle of Petungkriyono block) subpopulations. Despite being separated by a straight-line distance of 16 km, individual from the West Linggoasri block and individuals from the Petungkriyono block shared their haplotypes (Bagasta, 2022), indicating that these subpopulations have not completely isolated from each other or not been isolated for a long time. Overall, the findings suggest that there is still some connectivity and potential for genetic exchange among javan gibbon subpopulations in the mentioned blocks.

Petungkriyono forest block is the most important forest block which should be prevent to future fragmentation. Several parts of the four roads that traversed Petungkriyono block were identified as at higher risk to isolate this block if the canopy gap is wider in the future. They were located in the main street from Dusun Lolong to Lebakbarang, lane from Dusun Lolong to Dusun Mendolo and Kutorembet, main street from Doro to Petungkriyono, and main street from Bandar to Batur (Figure 3). Thus, it is important to prevent road widening in four potentially dissecting roads and
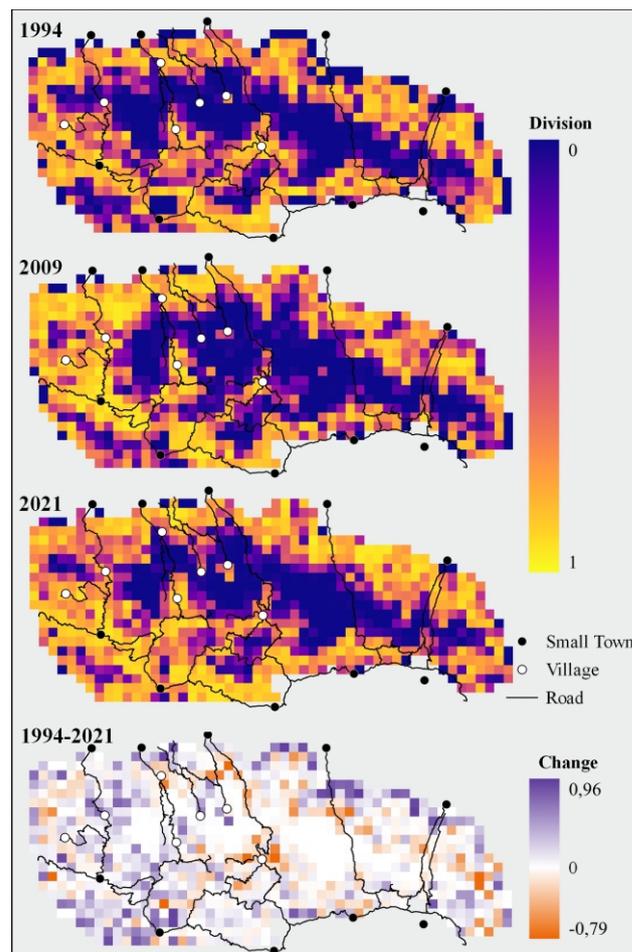

Figure 4 Spatial pattern of forest fragmentation in Dieng mountains in 1994, 2009 and 2021 measured using landscape division index in 1 km^2 squared grid, with road network of 2021.

maintain the canopy connection above the roads (Figure 3). Alternatively, installation of the artificial canopy bridge is also helpful for some crossing spot with broken canopy as implemented in other gibbon habitat (Das et al., 2009; Chan et al., 2020; Chetry et al., 2022). However, more study is needed to identify the prioritized area where the artificial canopy bridges are needed to reconnect the forest blocks. The other two unsuitable forest blocks for javan gibbon in Dieng is important to be prevented from the future loss and fragmentation as well, as these blocks could be the refugee for this species when climate change force them to shift their range (Walther et al., 2002; Chen et al., 2011).

Conclusion

This study revealed that even though Dieng mountains were not protected under conservation area, there were no significant decline in the total of forest due to balanced total forest loss and total forest gain into and from plantations and agriculture. The forest even has slightly increased, which possibly due to the secondary succession from others LULC classes. However, it predicted that the quality of forest structure was degraded in the interior of forest block. The forest has more fragmented during 1994–2021 from large

forest patches into smaller patches and increased forest edge. The higher fragmentation was indicated in the areas that traversed by road. Six suitable forest blocks were identified with varying level of connectivity. The largest and the main habitat for javan gibbon was Petungkriyono block.

Recommendation

In order to mitigate more serious habitat degradation or even significant deforestation which lead to more serious fragmentation in the near future, protection and restoration both in the forest and in the interior forest is immediate need, especially in the suitable larger forest block such Petungkriyono block. The extra conservation effort for the habitat also crucial in the forested area that still connecting the blocks but traversed by road as indicated in this study as at high risk to isolate. The closest adjacent two suitable blocks (West Linggoasri and Mt. Prau) could be potentially reconnected by the artificial canopy bridge crossing the dissecting road. While the other suitable blocks might need restoration work for habitat corridor to the main block. The community-based natural resource management is a promising conservation approach for biodiversity and its habitat, particularly for javan gibbons, in the Dieng mountains and possibly in other habitats outside conservation areas and it is recommended to be expanded to the other places in Dieng mountains.

Acknowledgment

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