INTRODUCTION

Asian tropics including Indonesia is one of the most serious regions suffering the decline of biodiversity due to the deforestation and forest degradation (Austin, Schwantes, Gu, & Kasibhatla, 2019; Bawa & Dayanandan, 1998; Carlson et al., 2012; Millennium Ecosystem Assessment, 2005), which also caused the increase of Global Green House Gas (GHG) emissions (Cadman, Maraseni, Ma, & Lopez-Casero, 2017). Hence, sustainable forest management has become a reference framework for national forest governance across many tropical and sub-tropical forest countries (Widhiono, 2015).

REDD+ (Reducing Emissions from Deforestation and forest Degradation in developing countries) is a global scheme to conserve forest ecosystems, and is expected to prevent the spread of deforestation in tropical regions (Lund, Sungusia, Mabele, & Scheba, 2017; Matsumoto, 2019; Paoli et al., 2010). However, as REDD+ strongly focuses on the enhancements of forest carbon sequestration (Hoang, Do, Pham, van Noordwijk, & Minang, 2013; Murray, Grenyer, Wunder, Raes, & Jones, 2015), monoculture plantations of fast-growing species is rapidly increasing associated with losses of biodiversity (Edwards et al., 2010). Recent intensive monoculture productions such as producing agro-fuels from palm oil and soy-based cattle food have affected the regional biodiversity and ecosystem service through conversion of forests to non-forest uses (de Oliveira et al., 2013).

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**ABSTRACT**

We examined a new method to detect the biodiversity hotspots in terms of complex patch mosaics at a regional scale in East Java, Indonesia, in order to develop the safeguard against further expansion of monocultures by REDD+. A land-cover map consisting of five major land-cover types (forest, agricultural land, bare land, water, and residential) was generated with a 30 m x 30 m resolution by the unsupervised classification of a Landsat8-OLI image. Shannon’s diversity index ($H'$) was calculated for each of 10.98 ha (11 x 11 pixels) landscape throughout the study area based on the dominance of the land-cover types by five calculation methods with different combinations of land-cover types. Then, the landscapes of upper 5% in $H'$ was selected as the potential hotspots in terms of highly complex patch mosaics. Among the five potential hotspots, the calculation of $H'$ with four land-cover types (forest, agriculture, water and bare land) was thought to be most suitable to set conservation targets at a regional scale, because the potential hotspots by this method showed aggregated distribution patterns, and was less sensitive to the small residential patches. While, no clear distribution trend was observed along the environmental gradients stage.
negative aspects of REDD+, criteria for biodiversity conservation and consideration for life of local inhabitants has been presented (Matsumoto, 2019). However, these criteria are set at a domestic scale. For valid safeguards, it is desired to develop effective strategy to conserve biodiversity and ecosystem services at a regional scale (Turner et al., 2007).

The “hotspot”, which often refers to areas where high diversity is available (Arnold & Lutzoni, 2007; Cimon-Morin, Darveau, & Poulin, 2013; Gorenflo, Romaine, Mittermeier, & Walker-Painemilla, 2012), is one of the useful ideas for the strategy to set the conservation targets within a region. In particular for REDD+ safeguards, the hotspots should consider not only the primary ecosystems such as old growth natural forests but also the secondary natures in traditional farming or forestry landscapes, because the pressure of extensive monoculture could target these landscapes (Edwards et al., 2010). The hotspots should basically be designated with assessment of diversity at species level. However, setting hotspots of secondary nature with species-level assessment at a regional scale might be quite difficult. As a substitute to the assessment at species level, land-cover types, which can be easily analyzed at broad scale based on geographic information, is the useful measure to identify the potential hotspots at landscape level, as land-cover changes are key drivers of the loss of biodiversity and ecosystem services (Schröter et al., 2005). In addition, habitat heterogeneity in terms of different land-cover types plays an important role in regulating the distribution of species (Benton, Vickery, & Wilson, 2003; Billeter et al., 2008; Harms, Conditt, Hubbell, & Foster, 2001; Tews et al., 2004). Thus, patch mosaic landscapes consisting of different land-cover types could be conservation targets as the potential biodiversity hotspots that encompass higher heterogeneity compared to extensive monoculture landscapes.

In this study, we aimed to examine a new method to detect the potential biodiversity hotspots in terms of complex patch mosaics of various land-cover types as the conservation targets at a regional scale in East Java, Indonesia. The specific objectives of this study were 1) to suggest the optimal combinations of land-cover types to detect the potential hotspots by applying Shannon’s diversity ($H'$) index for land-cover diversity, and 2) to examine the effects of environmental factors on the distribution of potential hotspots to discuss the major drivers of forming the potential hotspots.

**Case Study Site**

The research was conducted from September 2016 to July 2017 at Malang Regency, East Java, Indonesia ($7° 59' 2.0688''$ S and $112° 37' 17.0076''$ E) as the case study site (Fig. 1). Elevation of study area ranges from 473 to 3,300 m asl Malang City is the most high-lying city in East Java province, and the second largest city in East Java with a rapidly growing population. Malang Regency is located between two groups of mountains; Mount Semeru the highest mountain on Java, and Bromo-Tengger-Semeru national park to the east. The study area is approximately 3,052 km² and is comprised of numerous agricultural lands, agroforestry, and small forest fragments with a wide variety of forest types, including lowland, mountain and seasonal forests.

**Data Source**

A satellite image (Fig. 2) acquired by Landsat8-OLI/TIRS (path 118, row 66) on 16 June 2014 (in a rainy season) was used to interpret land-cover conditions. This image was selected from twelve images of the same region to have less than 10 % cloud cover for minimal cloud contamination. The selected image was geo-referenced according to the UTM coordinate on a geographic information system (Quantum GIS).

The 30-m resolution digital elevation model (DEM) provided by NASA and METI (ASTER GDEM, Tachikawa et al., 2011) was used for evaluating topographic features of each cell.

**Classification of Land-Cover Types**

The unsupervised classification method was used to classify the land-cover types. After clustering pixels of the Landsat image by unsupervised procedure by using a function in GIS (Semi-Automatic Classification Plugin), obtained classes were re-categorized into five main categories which might have effects on the formation of the potential hotspots (forest, agricultural land, bare land, water and residential area) by comparing actual land use (the ground truth) of randomly selected 241 sample points. For the ground truth data, Google Earth and ground photographs taken in 2015 was used to identify the corresponding land-cover types in each class to improve the accuracy of the classifications, because no official reference data on the actual land use or land cover was available for the study area.
Analyses of Land-Cover Diversity

For the evaluation of land-cover diversity, Shannon's diversity index ($H'$) was calculated for each pixel by using a 11 x 11 moving window, i.e., a landscape of 10.89 ha around the pixels, covering the whole study area. Pixels of outermost 5 rows and columns were excluded from the analysis. $H'$ was calculated by the following equation (Magurran, 2004):

$$H' = -\sum p_i \ln p_i$$

where, $p_i$ is the relative dominance of $i^{th}$ land-cover type within a given landscape. In order to detect the different effects of land-cover compositions on the evaluation of potential hotspots, $H'$ was calculated for following five methods using various combinations.
of land cover types (Table 1): Method-a) all five land cover types, Method-b) four land-cover types excluding residential, Method-c) forest, agriculture and bare land, Method-d) forest, agriculture and water, and Method-e) forest and agriculture. All the calculations were based on the dominance to all five land-cover types, that is, method b) - e) indicate partial values for the adopted land-cover types of the total $H'$ of five land-cover types.

**Table 1.** Land-cover types used in the five methods of $H'$ calculation

| Methods | Land-cover types                  |
|---------|----------------------------------|
| Method-a | forest, agriculture, water, bare land, water |
| Method-b | forest, agriculture, water, bare land |
| Method-c | forest, agriculture, bare land |
| Method-d | forest, agriculture, water |
| Method-e | forest, agriculture |

After the calculation of $H'$, the cells of upper 5% in $H'$ were adopted as the potential hotspots in terms of highly complex patch mosaics of land-cover types.

The distribution of the hotspots detected by the five calculation methods were compared each other in order to evaluate their appropriateness with reference to the following criteria which consider the requirements for setting effective conservation targets at a regional scale:

- **Criterion 1)**: to exclude properly the large cities and extensive monoculture landscapes,
- **Criterion 2)**: to exclude properly the patch mosaics affected by residential patches, which will not encompass high biodiversity,
- **Criterion 3)**: to show the contagious (aggregated) distribution of hotspots with a certain extent for setting the important area at a regional scale, and,
- **Criterion 4)**: to detect the universal hotspots without strong biases to a specific land use.

To examine the effects of environmental factors on the distribution of the potential hotspots, relationships of the $H'$ values to elevation, slope inclination and the urbanization index were analyzed. Elevation and slopes for each pixel were obtained from DEM. The urbanization index was calculated as the average of the population of seven cities within the study area (Fig. 3) divided by distance from the given pixel to the city. Thus, the larger value of this index means higher degree of urbanization. These factors were divided into four 25% quantiles of the number of pixels according to their values from small (class 1) to large (class 4). Then, the $H'$ values were compared between the classes for each environmental factor.

![Fig. 3. Land-cover map derived by the analyses of the Landsat8-OLI/TIRS image. Five land-cover types were shown by different colors of 30 m x 30 m pixels. Meanings of alphabets in the figure are explained in the text](image-url)
RESULTS AND DISCUSSION

Classification and Distribution of Land-Cover Types

Fifteen classes were distinguished by the unsupervised classification of the satellite image. By comparing with the sample points of ground truth data, these 15 classes were reclassified into five categories according to the relative frequency of actual land-cover types (Fig. 4).

Fig. 3 shows the land-cover map the five categories. Forest was the most dominant category of land cover occupying 43% of the study area (Fig. 5), followed by agricultural land (40%). Bare land and residential area counted up 7 and 10% of the study area, respectively. While, water occupied the smallest area (0.3%).

As the features of spatial distribution of land-cover types (Fig. 3), a large residential area (A in Fig. 3) was found around Malang City, which is the capital with the highest population density and lowest forest availability in the study area. Most of the other residential areas were aligned along the main national roads (black lines in Fig 4). The mosaics with small residential patches were also found the area surrounding the main national roads.

A distinctly extensive area of agricultural land was detected in the southern-central part of the study area (B) near Gondanglegi subdistrict (Fig. 3). Other major agricultural lands were distributed relatively close to the main roads. In contrast, major forest covers were found to be situated distantly from the main roads, around Mt Kawi in north-western part (C) and in southern part of the study area (D). On the lower slopes of Mt. Kawi, strip-shaped patches were found along the topography: forest patches along gullies, and agricultural or bare land patches on gentle ridges (Fig. 2 and Fig. 3). However, middle slopes were mainly covered by large forest patches. In contrast, in the eastern part of the study area (E), agricultural land was codominant with forest even distant from the main roads. In this area, which was a part of the slope of Mt. Bromo located in outside (east) of the study area, a lot of residential patches were scattered.

Bare land patches were also found in and around agricultural patches relatively close to the main road and cities. Water cover was mainly found in and around a dam lake located in south-western part of the study site.

Recategorized land-cover types

![Recategorized land-cover types](image)

**Fig. 4.** Relative frequency of the land-cover types in ground truth data for each class distinguished by the unsupervised classification of the satellite image. Fifteen classes by satellite image analyses were recategorized into five categories according to the dominant land-cover types
Fig. 5. Proportion of area of the five land-cover types in the study area

Fig. 6. Spatial distribution of landscape diversity index ($H'$) calculated based on the relative dominance of different combinations of land-cover types: a) all five types, b) agriculture, forest, bare land, and water, c) agriculture, forest, and bare land, d) agriculture, forest, and water, e) forest and agriculture. Panel f) was the land-cover map (same as Fig. 3) shown as a reference for comparisons. Meanings of alphabets in the figure are explained in the text.
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The spatial distribution of land-cover diversity index ($H'$) and the potential hotspots obtained by the different combinations of land-cover types were shown in Fig. 6 and Fig. 7, respectively. The $H'$ around Malang City was commonly low based on various used-methods, i.e., different combinations of land-cover types (A in Fig. 6). Consequently, the hotspots detected by the all methods uniformly excluded the Malang City (A in Fig. 7). Similarly, the area dominated by single land-cover type (agriculture) showed equally low $H'$ (B in Fig. 6), and was excluded from the potential hotspots by every method (B in Fig 7). These results suggested that all the methods tested here fulfill the criterion 1 (to exclude the large cities and extensive monoculture).

In the calculation of Method-a (adopting five land-cover types) (Fig. 6a), the landscapes including small patches of residential area around Malang City (F1 and F2) or Mt Kawi along the road (F3 and F4) showed high $H'$ (Fig. 6), probably reflecting small patches of residential area (Fig. 3 and 6f). These high $H'$s resulted in the evaluation of many potential hotspots outside of the Malang City.
that were affected by small patches of residential area (Fig. 7a). Thus, this method was considered unsuitable with reference to the criterion 2 (to exclude the patch mosaics affected by residential patches).

The Method-b (without using residential areas) showed slightly different distribution of $H'$ (Fig. 6b) compared to the Method-a (Fig. 6a). The potential hotspots were not detected around the large city or the main roads (F1, F2, F3 and F4 in Fig. 7b). Instead, several potential hotspots were additionally detected at the boundary of agriculture- and forest-dominated areas in the southern part (G1 and G2 in Fig. 7b). Thus, this method is thought to be better than Method-a.

The distribution of $H'$ calculated by Method-c (adopting forest, agricultural land and bare land) was similar to those with the Method-B. The Method-c added only few and small potential hotspots at the north of the dam lake (H in Fig. 7c), where many small bare land patches were distributed. Therefore, this method could be applicable to the study area, though it was slightly sensitive to a single land-cover type.

The Method-d and Method-e generated lower contrast of $H'$ compared to the former three methods (Fig. 6d and 6e), resulting in widely scattered, small and many potential hotspots (Fig. 7d and 7e). These results suggested that Method-d and Method-e are unsuitable to set sizable conservation target areas referring to the criterion 3 (contagious distribution).

The comparison of the Method-c (using bare land) and Methods-D (using water) suggested that adopting one of bare land or water in the calculation of $H'$ would give contrasting results in detecting hotspots of specific targets. In the Methods-d, relatively large potential hotspots were detected at lake shore (I in Fig. 7d). However, these potential hotspots were not found by the Method-c (Fig. 7c). Bare land would be useful if the frequent disturbances, which made bare land, were important to set conservation target as the driver of biodiversity. On the other hand, aquatic or riparian ecosystem should be taken into account in detecting hotspots, water would be the key land-cover type. Thus, these two methods are thought to be useful when the specific conservation target was clear. However, the too strong bias to a specific land-cover type due to single use of these two types might not be suitable to set conservation area for a universal, broad range of biodiversity, referring to the criterion 4 (without strong biases to a specific land use). Thus, the landscape planners and managers should carefully deal with these land-cover types in the calculation of $H'$ as the indicator of hotspots.

In conclusion, the Method-b was considered to be the most optimal method to detect the potential biodiversity hotspots based on the landscape analysis, because this method was not too sensitive to a single land-cover type, and provided relatively universal hotspots for biodiversity with their contagious distribution for conservation target setting.

Possible Drivers of the Potential Hotspots

The $H'$ analyzed by the optimum method (Method-b) generally showed large fluctuations, and no clear relationship to the three environmental factors (Fig. 8). However, $H'$ had almost similar values for all classes of the urbanization index. This might be partly due to the large fluctuation of $H'$. Among those, $H'$ tended to have slightly lower values at higher elevation and steeper slope classes (Fig. 8a and 8b). This might be affected by the high dominance of forest patches in mountainous area where agricultural land use was limited.

The urbanization was expected to have effects on the distribution of potential hotspots, since the process would promote intensive agriculture with extensive monocultures around urban areas. According to this hypothesis, combined with the extensive forest in mountainous area, the potential hotspots could be between urban and remote areas. The landscape structure (Fig. 3) and the potential hotspots (Fig. 7) partly demonstrated these features. However, the hypothesis was not numerically supported by the urbanization index when the major cities were taken into account (Fig. 8c). This might be owing to the fine patch mosaics of forest and agricultural land in eastern part of the study area (E in Fig 4), which had contrasting landscape structure to the western and southern part (C and D in Fig. 3), in spite of similarly remote situation from the cities and the main roads. Therefore, further parameterization using more detailed or broad factors is needed to explain the effects of the natural and social environment on the land cover diversity at a regional scale.
CONCLUSION

The present study suggested that spatial distribution of land-cover diversity at a landscape level based on agriculture, forest, water, and bare land was an optimal method to detect potential diversity hotspots. For more accurate identification of the hotspots as a tool for the REDD+ safeguards, further researchers are still needed to examine the significance of a given patch mosaics and/or the edge between patches on the biodiversity at the species level by taking into account its functional aspects.

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