

# The landscape structure change of the tropical lowland forest and its possible effect on tree species diversity in South Sumatra, Indonesia

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**Abstract.** Zulfikhar, Zulkifli H, Kadir S, Iskandar I. 2017. *The landscape structure change of the tropical lowland forest and its possible effect on tree species diversity in South Sumatra, Indonesia. Biodiversitas 18: 916-927.* The forest fragmentation is a spatial structure change, resulted in a reduction of the number and size of forest patches, and a subdivision and breaking up of the areas into smaller parcels. The key scientific challenges concern the significant gaps exist in our ability to understand the relationships between landscape structure, biodiversity and the output of ecosystem services at different spatial and temporal scales. The objective of this study was to examine the possible effect of changes in a spatial pattern of habitat against the changes of the tree species diversity. We apply a landscape structure analysis of the forest fragmentation, and then determine the principal component of the landscape metrics. We analyzed multitemporal satellite imageries from 1989 to 2013, that have been clipped as a sampling area. Thirty-two circular sampling areas with a radius of 2,500 meters were used. We conducted observations in 32 unit sample plots of biodiversity in the size of 20 meters by 50 meters, at a midpoint of the clip of area sampling. The results of a test of inter-correlation of all variable data showed that there were 15 of 23 landscape metrics of natural forest, reliable for the next analysis. We reduced the number of variables into three new variable groups using Principal Component Analysis (PCA). We produce three of six models of principal component multiple-regression were significant ( $p < 0.05$ ) to predict the composition and diversity of tree species caused by a change of landscape metrics, namely the species richness index, species equity index, and basal area of a tree stand. The prediction models are beneficial in the planning of biodiversity conservation and restoration of the fragmented natural forest.

**Keywords:** Diversity indices, landscape metrics, landscape modification

## INTRODUCTION

The loss of biodiversity is one of the major environmental problems and is currently attracting worldwide interest, as stated in The World Conference on Biological Diversity in Nagoya 2010 and 2012, as well as in the United Nations Biodiversity Conference, in Cancun, Mexico, 2016. The issue also has become the subject on The Fifth Session of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES-5) held on 7-10 March 2017, in Bonn, Germany. IPBES is the intergovernmental body, with the mission to strengthen the science-policy interface for biodiversity and ecosystem services for the conservation and sustainable use of biodiversity, long-term human well-being and sustainable development (Global Policy Unit-IUCN 2017).

On a national level, biodiversity concern has been conducted by the deliberations of the revision of the Republic of Indonesia Act No. 5 Year 1990 concerning Conservation of Biodiversity of Natural Resources and their Ecosystems. The Government of Indonesia has launched the Indonesia Biodiversity Strategy and Action Plan 2015-2020 (IBSAP) and as guidelines and references

for the sub-national level (Darajati et al. 2016).

The forest fragmentation is the process of spatial changes, modifying the structure dynamically. It reduces the size of forest patch, it divides and splits the patch into smaller packages, and this process causes the edge effect, patch isolation, reduction of the habitat and populations of species, as well as the loss of biodiversity (Fahrig 2003; Lindenmayer and Fischer 2006; Walz 2011). In addition, fragmentation also reduces the size of the population and diversity of shade tolerant tree species and promotes the presence of generalist and pioneer plant species (Fischer and Lindenmayer 2007). So, the ability to understand the relationship between the structure of the landscape, biodiversity and the output of ecosystem services on time and space scale is necessary (Haines-Young 2009; Hakkenberg et al. 2016).

A crucial key to biodiversity loss is consideration of changes in land use and landscape structure (Haines-Young 2009). Landscape structure determines biodiversity in two ways: through the diversity of biophysical conditions and patterns of land use. Landscape metrics at the ecosystems and landscape levels can be used to describe their diversity, and to establish how they relate to

species diversity (Walz and Syrbe 2013). However, most researchers do not separate the effects of habitat loss from the configurational effects of fragmentation, and this leads to ambiguous conclusions regarding the consequences of habitat configuration on biodiversity (Fahrig 2003).

Biological diversity, in all dimensions and facets, is tied up to habitats, which means that it needs a particular section of the earth's surface for their existence. Biological diversity is therefore always defined for a particular reference zone; and landscape structure is a fundamental element for the understanding of species diversity, and the dynamics of natural processes, such as the changing distribution patterns of species and habitats in space and over time, which are also a part of biological diversity (Walz 2011).

The development of mathematical tools to predict the dynamics of natural processes, such as tree species diversity is very useful because it provides early warnings to forest management unit and regulators to reduce the number of measuring sites. Accordingly, IUCN Species Survival Commission's Action Plan gives the direction of enhancing the necessity of developing prediction models (Supriatna 2008). Yet, tree species diversity has been tough to model because of different interactions between biotic and abiotic variables (Walz 2011).

The PCA has been used in recognizing environment patterns; in this case, it configurationally effects fragmentation phase. The PCA has some advantages, which can eliminate the correlation (correlation = 0), so that the problem of multicollinearity may completely be resolved in clean; and it can be used on various research conditions and types of data. In addition, it can be used without reducing a variable number of the origins. Although the regression analysis with PCA has a higher difficulty level, the conclusion, however, is more accurate (Soemartini 2008). The multivariate statistical technique transforms the original data set into a set of linear combinations of the original variables. The uncorrelated new variables, designated by principal components, account for the majority of the variance (Sousa et al. 2007).

Nowadays, tropical lowland forest of Sumatra is diminishing rapidly. An average of about 100,416 hectares per year (1.75% per year) of primary forest of Sumatra has lost within 12 years (Margono et al. 2014). Amongst remaining forest areas in Sumatra Island, the Meranti Dangku landscape is one of the remnant forest areas in South Sumatra. The rate of deforestation in 1989 to 2013 is in the range of 4.32 to 12.75 % per year (Zulfikhar et al. 2017). Deforestation, especially of the near-primary forest, causes biodiversity losses that are impossible to be compensated with other land uses (Clough et al. 2016).

There are at least three ecosystem functions of the Meranti-Dangku landscape, namely the habitat area for wildlife conservation, the area for restoration of natural forest, and the area allocated for the forest plantation. Up to now, the fragmentation and habitat loss still continue. This landscape could become an essential ecosystem, which is rich in biodiversity, but it is increasingly threatened and driven to the extinction.

In this study, effects of habitat loss were differentiated from configurational implications of the fragmentation phase, so it would not result in inevitable ambiguous conclusions regarding the effects of habitat configuration of the landscape metrics on biodiversity. The objective of this study is to examine the possible effect of changes in the spatial pattern of habitat continuum in Meranti-Dangku landscape structure on the changes of the tree species diversity.

## MATERIALS AND METHODS

### Study area

The study was conducted in Meranti-Dangku landscape, which was a tropical lowland forest ecosystem in South Sumatra Province, Indonesia. This landscape was located at 103°00'-103°50' East and 2°05'-2°35' South, or, in UTM Coordinate System, it was at Zone 48S; 278000-380000 Easting and 9765000-9710000 Northing, within an area of 209,619 hectares (Figure 1). The Meranti-Dangku landscape covers forest with two different functions, i.e. as a production forest (covering an area of 157,228 hectares) and as a wildlife conservation forest (covering an area of 52,392 hectares).

### Research procedures

The initial phase of the study was to carry out an assessment of configurational effects on fragmentation to find out the principal components of the spatial transformation process towards landscape metrics configuration in fragmentation phases. The framework and the stages of research methodology is presented in Figure 2.

There were two main activities undertaken, first, the identification of the landscape structure, which was done by performing data interpretation of Landsat imagery to produce a map of land cover, and by making an example area in the form of a circle with a radius of 2.500 meters to analyze the indicators of metrics landscape. Second, the identification of forest structure, to get the composition and diversity of tree species. At this moment, it was conducted the creation of field sample plot, in the size of 20 x 50 meters and with the position at the midpoint of circular clips.

Identification of landscape structure was to assess the configurational effects of fragmentation at habitat level. Thirty-two units of sampling area in a circular clip were created on multi-temporal land cover maps, which were based on the medium resolution of Landsat satellite imagery, and on object-based image analysis method to generate multi-temporal characteristics of landscape metrics with composition and configuration indicators of landscape structure of natural forest changes.

Identification of forest structure was to assess the habitat loss effects and to measure of species diversity, namely the index of richness, abundance, and equity, basal area and stands density of trees species.

Landscape metrics were used more and more frequent as integrative indicators at the landscape scale to assess the state of biodiversity, to monitor landscape change, and to evaluate the impact of land use change on biodiversity. They were also used for habitat modeling. Targeted indices can provide specific information about the underlying processes (Walz and Syrbe 2013).

The next step was regression analysis of tree species diversity as a dependent variable, and configurational effect

of forest fragmentation on independent variables, using the principal component multiple linear regression models.

The process of data analysis in this research is supported by software for object-based images analysis (OBIA), FRAGSTATS ver 4.2 for the analysis of the spatial structure of landscape metrics, GIS software for spatial data processing and mapping, and statistical packed software.

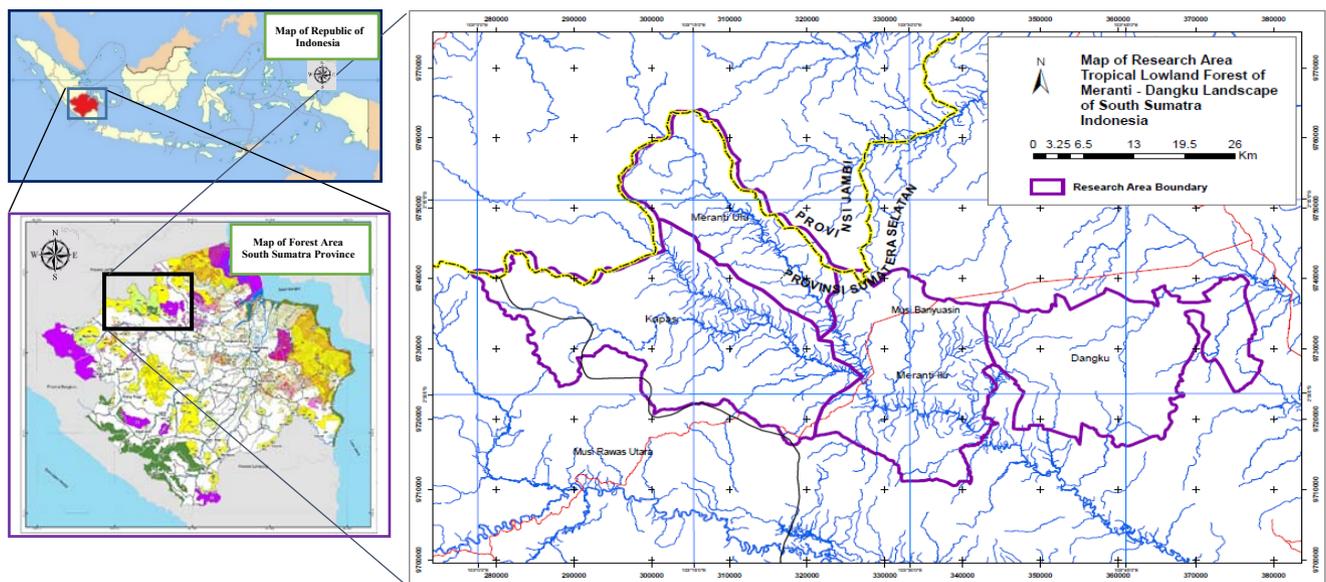


Figure 1. The tropical lowland forest ecosystem of Meranti-Dangku landscape, district of Muli Banyuasin, South Sumatra Province, Indonesia

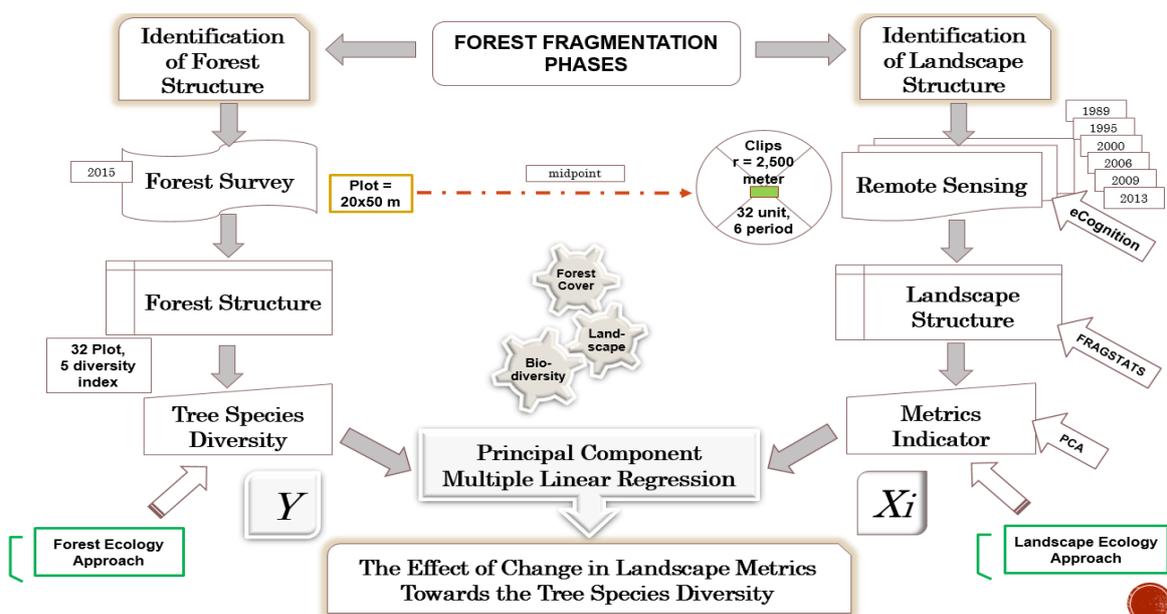


Figure 2. The framework and the research procedures

**Table 1.** Types of satellite imagery and date of acquisition used in this study.

Satellite imagery	Path-row	Data type	Date of data acquisition
Landsat 5. TM.	125-062	L1, T	September 6, 1989
Landsat 5. TM.	125-062	L1, T	March 19, 1995, and September 11, 1994 (subset for cloud cover free)
Landsat 5. TM.	125-062	L1, T	May 25, 2000
Landsat 5. TM.	125-062	L1, T	May 15, 2006
Landsat 5. TM.	125-062	L1, T	November 9, 2009
Landsat 5. TM.	125-062	L1, T	August 7, 2013

### Materials

Land-use and cover type map resulted from the interpretation of satellite imagery data. The satellite imagery data of Landsat 5 Thematic Mapper (TM) that has sourced from the National Institute of Aeronautics and Space (LAPAN) were used in this research (Table 1).

Other data were obtained from the forest survey, namely to measure the diameter of all tree stands greater than or equal to 10 centimeters, while botanical identifications of tree species were conducted in the Research Center for Biology, Indonesia Institute of Sciences (LIPI), Cibinong, Bogor, West Java, Indonesia. Data is used for checking the results of the land cover type classification, either from the secondary data or field survey data.

### Procedures

The analysis was conducted based on changes in vegetation's coverage and land use from a series of satellite imagery maps on a medium resolution. The change detection method of the land cover type "again-being" was done in post classification (post-classification comparison = PCC), namely comparison analysis of land cover classification at the time  $t_1$  and  $t_2$  (Liu et al. 2004; Liu and Zhou 2004).

The Object Base Image Analysis (OBIA) method was used in the satellite image analysis and was processed using eCognition Developers 64 software (Trimble). The pre-requisite for classification was segmentation of the image, which was done by subdividing the image into a separate area (Blaschke 2010; Frohn et al. 2011). In the setting of the scale parameters, colors, and shapes, and in the data processing, multi-resolution segmentation algorithm was used, with the scale parameter = 10, the color and shape factor = 0.1, and the compactness and smoothness = 0.5 (Weih and Riggan 2010; Laliberte et al. 2004).

The ground truthing for land use type classification was checked with Global Positioning System (GPS) Garmin™ Oregon 550 series, work map, and a draft of land use type classification map from the satellite imagery. Total 620 random points were planned on the map for a field inspection plan, 510 points were observed in the field and used as a training area, the rest 110 points could not be accessed, and 444 points were used for testing the accuracy of forest cover mapping.

The objects classification was done by using the nearest neighbor classifiers method, based on the user-selected samples, which was obtained from the training area in field survey (ground truth), and the land use type classification for interpretation of image analysis was using the Indonesian National Standard (National Standardization Agency of Indonesia 2014).

To analysis the accuracy of an image, Matrix Error was used on the map of object-based classification results, which included overall accuracy, producer's accuracy and user's accuracy for each class of the coverage, and the accuracy of the Kappa (Liu and Zhou 2004; Vorovencii 2014).

### Forest landscape metrics

In this research, the spatial structure change of the landscape metrics was investigated entirely using 43 indicators at Class level. It was grouped as follow: Area-Edge has 7 indicators, Landscape Shape has 6 indicators, Core Area has 7 indicators, Isolation has 2 indicators, Subdivision has 5 indicators, Aggregation has 7 indicators, and at Landscape level grouped in the Diversity has 9 indicators. Initially, all indicators of the landscape metrics were screened by removing the zero value and unavailable (N/A) data to get the indicators that will be used in a next analysis process. The indicators of landscape metrics were used to determine composition and configuration of the landscape structure. Afterward, they were used to determine fragmentation level, changes of the forest connectivity, and the occurrence of forest habitat isolation, in the respective series of the years of satellite imagery data acquisitions, according to Forman (1995), and software FRAGSTATS ver 4.2 was used (McGarigal et al. 2002).

All parameters of the forest fragmentation were measured and analyzed within 32 units of the circular clip of the sampling area, with a radius of 2.500 meters (area of 1.964,29 hectares) on the multi-temporal of land cover type map. We used 6 series data acquisition and 32 units of the circular clip, so total samples were 192. For computation of the landscape metrics, the land cover patch was delineated by applying 8 neighbor rules to guarantee that linear patches along a direction diagonal to the grid axes were identified as a single patch. Each circular clip was analyzed separately, and the circular boundaries were not counted as edges. The Proximity and Similarity Metrics, as well as the Connectance Index, were computed using search radii and threshold distances of 2.500 meters, respectively (Schindler et al. 2008; Schindler et al. 2013)

### Reduction of the landscape metrics indicator

Factor analysis attempts to identify underlying variables, or factors, that explain the pattern of correlations within a set of observed variables.

Before PCA, a test of inter-correlation of all variables was conducted, with the requirement that all the inter-variable correlation test should be correlated very significant ( $p = 0.01$ ). The variables that did not meet very significant inter-variable correlation ( $p = 0.01$ ) was removed from dataset. Further testing in the PCA with the following proviso: all elements input with Kaiser-Meyer-

Olkin on a measure of sampling adequacy must be higher than 0.5 ( $> 0.5$ ), Bartlett's Test of Sphericity with significance test must be higher than 0.005 ( $< 0.005$ ), and Communalities of each variable must be higher than 0.600. If a variable did not meet the above requirement, then that variable was discarded, and the process of PCA was repeated.

To determine the principal component of the factors, the variable was extracted using PCA method. The eigenvalue of the factor should be greater than 1.0, rotation method of Varimax of the axes with Kaiser Normalization and Rotation converged in 5 iterations. The metrics with the highest absolute loading more than 0.500 was defined as a representative and included in following analysis (Schindler et al. 2008).

PCA attempts to identify underlying variables, or factors, that explain the pattern of correlations within a set of observed variables. PCA is often used in data reduction to identify a small number of factors that explain most of the variance; that were observed in a much larger number of manifest variables, in determining the principal component of factors of forest landscape metrics changes.

### The vegetation analysis

The vegetation analysis in this research was done using primary data from the observation of the field of sample plot, i.e. the tabular data and the quantitative method of vegetation analysis, and the data processing software used Microsoft Excel 2013 and Pivot Table.

Species accumulation curves show the rate at which new species are found within a community and can be extrapolated to provide an estimate of species richness. This plots the cumulative number of species recorded as a function of sampling effort (i.e. collected number of individuals or a cumulative number of samples). The order in which samples was included in a species accumulation curve will influence the overall shape (Henderson 2003).

Biodiversity indicators can be divided into indicators relating to species diversity (number and distribution of species) and those that describe the characteristics of ecosystem diversity on the basis of land use structure (Walz and Syrbe 2013).

The diversity is fewer than the notation of the effective number of species present, and the entropy, which is the logarithm of diversity numbers, is equivalent but is less easy to be visualized and consequently less suitable for general use (Hill 1973; Chao et al. 2014).

$$Na = (p_1^a + p_2^a + \dots + p_n^a)^{1/(1-a)}$$

Where:

$Na$  = Hill's Diversity Number

$a$  =  $-\infty, 0, 1, 2, \dots, \infty$

$p$  = proportional abundance of each species ( $pi$ )

$i$  = species-1, 2, 3, ..., n

The summary of the general rule is as follows:

$N_{-\infty}$  = reciprocal of the proportional abundance of the rarest species.

$N_0$  = indicates species richness a total number of species present in sample plot.

$N_1$  =  $\exp(-\sum pi \ln(pi)) = \exp(H)$ , where  $H$  is Shannon's entropy.

$N_2$  = reciprocal of Simpson's dominance index: i.e.  $1/(p_1^2 + p_2^2 + \dots + p_n^2)$ .

$N_{\infty}$  = reciprocal of the proportional abundance of the commonest species. It is also called as the dominance index.

$N_0$  indicates species richness,  $N_1$  indicates an effective number of species (true diversities), where  $N_1$  gives less weight to the rare species than  $N_0$ , which, in fact, has equal weight with all species, independent of their abundance.  $N_2$  indicates abundance distribution of species, and  $N_2$  gives more weight to the abundance of common species than  $N_1$ . An important consequence is that for the description of the community, we should express measures of diversity on a uniform scale. That is to say; we should use the reciprocal of Simpson's index  $N_2$  or conceivably the generalized entropy  $H_2 = \ln(N_2)$  (Hill 1973).

## RESULTS AND DISCUSSION

Factor analysis attempts in identifying underlying variables or factors explain the pattern of correlations within 23 observed variables of the landscape metrics indicator, and the reduction of the variable data are to identify a small number of factors that explain most of the variance that found in a much larger number of manifest variables.

### Reduction of the landscape metrics indicator

Factor analysis attempts to identify underlying variables, or factors, that explain the pattern of correlations within a set of observed variables.

Inter-correlation test of all variables subtracted 23 original variables into 15 variables. Subsequently, the PCA reduced 15 variables into 3 principal components (PC), which was based on initial eigenvalues = 1.741, and the percentage of cumulative variance = 84.28%. It means, the three factors having an eigenvalue of 1.741 can be described as 84.28% of total communalities. The eigenvalues showed the relative importance of each factor in calculating the variance of the 15 analyzed variables. The fourth factor has an eigenvalue of 0.988 (less than 1).

The scree plot displayed the eigenvalues associated with a component in descending order versus the number of the component. We can use scree plots in PCA to visually assess which components explain most of the variability in the data (Figure 3).

The rotated component matrix and component's matrix score tables were utilized in defining the new variables for the respective component, were declared as a new variable and as a function of the variables in each component, which were used for following analysis (Table 2).

The results showed the principal component of the factors of change in landscape metrics, and they determined 3 components, as representative of original 15 variables of the landscape metrics indicators, which have significant roles in the change of spatial structure in the forest fragmentation phases.

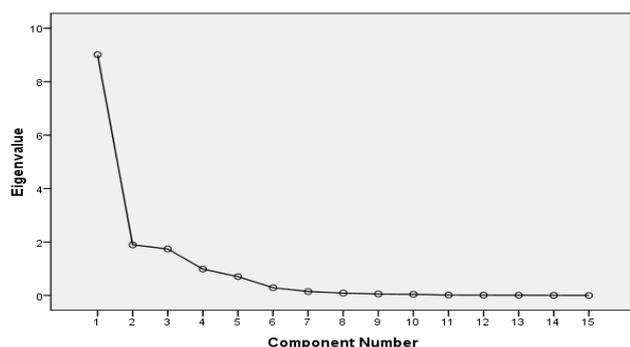


Figure 3. Scree plot

By using the data in the Component's Matrix Score (Table 2), the multiple regression models for each principal component were created. Thus, even though it has produced a new variable in the variable group of the principal component, it still can be analyzed to understand each variable contribution of the origin of the new variables.

#### Description of new variables of the landscape metrics after PCA

The definition of new metrics measures of each component factors of the metrics that were resulted from PCA was a series of definitions of variables incorporated in the group variables as follows:

##### Dimension metrics ( $PC_1$ )

$PC_1$  had a group of 6 variables, and the new variable is called as a Dimension Metrics. The original variables consisted of Simpson's equity index (SIEI), Simpson's diversity index (SIDI), Contagion Index (CONTAG),

Division (DIVISION), Effective Mesh Size (MESH), and Largest Patch Index (LPI).

The Contagion is high when a single class occupies a very high percentage of the landscape and vice versa. The division (DIVISION) is based on the cumulative patch area distribution and interpreted as the probability that two randomly chosen pixels in the landscape not situated in the same patch of the corresponding patch type. Effective Mesh Size (MESH) is based on the cumulative patch area distribution and it is interpreted as the size of the patches when the corresponding patch type subdivided into S patches, where S is the value of the splitting index. Largest Patch Index (LPI) quantifies the percentage of total landscape area comprised by the largest patch (McGarigal and McComb 1995; Walz 2011). This group represents a collection of metrics closely allied to the aggregation metrics that describe the degree of subdivision of the class level.

##### Shape metrics ( $PC_2$ )

$PC_2$  had group of 5 variables, and the new variable is called as a Shape Metrics; the original variables was namely: Contiguity index (CONTIG) indicating the size of spatial connectedness or transmission the patch of forest in forest patches of other individuals; the Number of Patches (NP) indicating a particular type of patch is a simple measure of the level of subdivision or the fragmentation of forest patch types; the Patch Density (PD) which is limited, but fundamental, indicating an aspect of landscape pattern.

Patch density has the same basic utility as an index, except that it expresses a number of patches per unit area that facilitates comparisons among landscapes of various size. The amount of information of a particular type of patch will be more meaningful if there are added information about the area, distribution, or a density of

Table 2. Rotated component matrix of the factors of the landscape metrics, and the multiple-regression models of new variable of the forest fragmentation phases

Component	Variable	Loading	Coefficient	New Variable	Multiple-regression Models
1	SIEI	-.936	-.300	$PC_1 = \text{Dimension Metrics}$	$PC_1 = -0.300 \text{ SIEI} - 0.292 \text{ SIDI} + 0.297 \text{ CONTAG} - 0.116 \text{ DIVISION} + 0.108 \text{ MESH} + 0.077 \text{ LPI}$
	SIDI	-.926	-.292		
	CONTAG	.921	.297		
	DIVISION	-.691	-.116		
	MESH	.673	.108		
	LPI	.622	.077		
2	CONTIG_MN	.853	.292	$PC_2 = \text{Shape Metrics}$	$PC_2 = 0.292 \text{ CONTIG\_MN} - 0.277 \text{ NP} - 0.276 \text{ PD} + 0.291 \text{ SHAPE\_MN} + 0.211 \text{ GYRATE\_MN}$
	NP	-.830	-.277		
	PD	-.828	-.276		
	SHAPE_MN	.805	.291		
	GYRATE_MN	.746	.211		
3	PLADJ	.925	.387	$PC_3 = \text{Aggregate Metrics}$	$PC_3 = 0.387 \text{ PLADJ} + 0.380 \text{ AI} + 0.185 \text{ CA} + 0.177 \text{ PLAND}$
	AI	.913	.380		
	CA	.694	.185		
	PLAND	.690	.177		

patch. Landscape Shape Index (SHAPE) is indicated by a standardized measure of total edge or edge density that adjusts the size of the landscape. The Radius of Gyration (GYRATE\_MN) is indicated by the size of an expansion patch, so it is affected by the size of the patch and patch density, so it gives the size of the continuity of the landscape (also known as the correlation length) that represents the average landscape transferability for an organism that is limited to remain in a single patch. In particular, it gives the average distance that an organism can move from a random starting point and travel in a random direction without leaving the patch (McGarigal and McComb 1995; Walz 2011).

#### Aggregate metrics ( $PC_3$ )

$PC_3$  had a group of 4 variables, and we call the new variable as an Aggregate Metrics, where the original variables, namely Percentage of Like Adjacencies (PLADJ), Class Area (CA), Aggregation index (AI), and Percentage of the Landscape (PLAND).

The percentage of like adjacencies (PLADJ) is calculated from the adjacency matrix, which shows the frequency of different pairs of patch types (including like adjacencies between the same patch types) appearing side-by-side on the map. Aggregation index (AI) is calculated from an adjacency matrix, which shows the frequency of different pairs of patch types (including like adjacencies between the same patch types) appearing side-by-side on the map. Class Area (CA) is a measure of landscape composition; specifically, how much the landscape is comprised of a particular patch type, and in addition, to its direct interpretive value. The percentage of the landscape (PLAND) quantifies the abundance of a proportional forest patch type in the landscape, more precisely by measuring the composition of the landscape rather than the broad classes of patches, to compare between the landscape of any size (McGarigal and McComb 1995; Walz 2011).

#### Diversity indices of forest tree species

Identification of diversity indices of forest tree species was presented on a community level, of which the indicators are measured as surrogates for the environmental end points, such as biodiversity.

The results of the calculation of the diversity index, abundance and forest tree species equity apportionment on each plot sampling are shown in Table 3.

The use of indicator species to monitor or assess environmental conditions is a firmly established tradition in ecology, environmental toxicology, pollution control, agriculture, forestry, and wildlife and range management, but this tradition has encountered many conceptual and procedural problems (Noss 1999).

#### Relations between landscape metrics and tree species diversity

The result of studies in the linkages and variables of the relationship, as a species diversity and patterns of species

distribution as the dependent variable, and the metrics indicators as independent variables at the community level and ecosystem is presented in Table 4.

The principal component regression models that were used in the analysis of relations between the dependent variables (Hill's Diversity Number) and 3 new variables, the  $PC_1$ ,  $PC_2$ , and  $PC_3$ , could be read as follows: the results of the multiple regression show that variables in Table 4 are statistically significant in predicting a dependent variable, with degree of freedom ( $df1$ ;  $df2$ ), F test value =  $n$ , significant level ( $p = i$ ), and coefficient of determination  $R^2 = d$ .

The variables added statistically significant to the prediction  $Y_1$ ,  $Y_4$ , and  $Y_6$ , ( $p < 0.05$ ), and but, they were statistically non-significant to prediction  $Y_2$ ,  $Y_3$  and  $Y_5$  respectively as the principal component regression model as in Table 4.

**Table 3.** Index of biodiversity of tree species

Plot code	Hill's diversity number	True diversities	Abundance	Equity $E_{0.1} = N_0/N_1$	N/ha	BA $m^2/ha$
	$N_0$	$N_1$	$N_2$			
1	17.00	11.98	8.45	1.42	350	22.17
2	32.00	25.41	19.77	1.26	550	27.15
3	1.00	1.00	1.00	1.00	290	0.48
4	41.00	41.00	41.00	1.00	410	27.06
5	25.00	19.78	15.09	1.26	400	19.68
6	15.00	8.08	4.92	1.86	500	7.45
7	14.00	6.79	4.27	2.06	470	15.52
9	28.00	23.64	19.46	1.18	430	25.46
10	36.00	32.07	28.17	1.12	520	22.56
273	14.00	5.80	4.25	2.41	920	5.82
290	20.00	12.17	7.17	1.64	440	19.01
291	15.00	12.65	9.31	1.19	370	14.21
316	21.00	18.84	16.86	1.11	310	6.52
319	22.00	20.00	18.28	1.10	350	17.96
351	23.00	15.89	11.02	1.45	460	11.21
354	27.00	19.62	13.16	1.38	500	17.92
356	18.00	18.00	18.00	1.00	180	14.06
357	1.00	1.00	1.00	1.00	210	9.82
358	31.00	27.28	23.51	1.14	480	39.82
391	31.00	27.28	23.51	1.14	620	21.88
393	34.00	27.49	22.41	1.24	750	14.16
414	21.00	15.96	12.08	1.32	420	15.04
415	32.00	23.99	16.56	1.33	670	22.42
416	26.00	22.78	19.75	1.14	390	36.79
417	37.00	33.47	30.51	1.11	600	38.67
431	35.00	23.92	17.11	1.46	800	28.47
446	24.00	19.63	15.94	1.22	450	32.37
461	32.00	23.11	16.57	1.38	650	18.07
3211	16.00	12.11	9.93	1.32	530	14.32
3212	25.00	18.04	13.65	1.39	640	2.76
3221	6.00	4.06	3.20	1.48	630	28.44
3222	19.00	16.26	13.00	1.17	260	1.63

Note:  $N_0$  = number of species in sample plot or richness of species;  $N_1$  = effective number of species (true diversities);  $N_2$  = abundant of species distribution, N/ha = tree stand density, BA = Basal Area

**Table 4.** Analysis of Variance (ANOVA) of the principal component of multiple-regression models

Dependent variable	Principal Component Multiple-regression Models	df <sub>1</sub> ;df <sub>2</sub>	F	Significant	R <sup>2</sup>
Richness Index of Species ( $N_0$ )	$Y_1 = 20.812 - 5.251 PC_2$	1;28	4.242	<b>0.049</b>	0.132
Effective Number of Species ( $N_1$ )	$Y_2 = 19.425 - 1.343 PC_3$	1;28	1.199	0.283	0.041
Abundant Index of Species distribution ( $N_2$ )	$Y_3 = 16.461 + 1.572 PC_3$	1;28	1.821	0.188	0.061
Equity Index of Species ( $N_0/N_1$ )	$Y_4 = 1.252 - 0.087 PC_3$	1;28	5.094	<b>0.032</b>	0.154
Tree Density (N/ha)	$Y_5 = 574.758 + 134.963 PC_1$	1;28	8.897	<b>0.006</b>	0.241
Basal Area (m <sup>2</sup> /ha)	$Y_6 = 28,288.147 + 8,885.947 PC_1 + 4,331.086 PC_3$	2;27	4.551	<b>0.020</b>	0.252

Note: Testing the classical assumption of regression analysis has been done

## Discussion

### Landscape metrics for biodiversity assessment

The relationship between the structure of the landscape and regeneration of forest trees reflects the fact that a small change in the structure is possible in coinciding with the change in the composition of species. The succession of the stands is known to show a strong pattern of low diversity during the beginning phase of natural thinning, followed by an increasing gap opening of the canopy (Hakkenberg et al. 2016).

To find out how the influence of the change of landscape metrics against the composition and diversity of tree species, the deliberations of Table 2 and 4 were conducted, whereas a dependent variable is a parameter of the diversity of tree species, and is an indicator of forest landscape metrics that is used to explain the spatial change of habitat continuum. A multiple regression was run to detect the possible change of richness index of tree species ( $N_0$ ), an effective number of species or true diversities ( $N_1$ ), an abundance distribution of species ( $N_2$ ), tree density and basal area of trees stand.

#### *Effect of changes of landscape metrics in the richness index of tree species,*

The multiple-regression models of the richness index of tree species,  $Y_1 = 20.812 - 5.251 PC_2$ , are significant at  $p = 0.049$  and  $R^2 = 0.132$ , where the independent variable is Shape Metrics ( $PC_2$ ). It means that the multiple-regression models can be used to plan activities to increase the richness index of tree species on that tropical lowland forest. We can develop measurable efforts to reduce the complex shape of metrics, caused by an increasing in number and density of patches that bring to the reduction of the radius of gyration and patch contiguity.

The metrics of the patch shape group were particularly good indicators of overall species richness and diversity of woody plants, and several landscape metrics indicated overall species richness was much better than that of any single taxon (Schindler et al. 2013)

In the fragmented forests of Meranti Dangku, there were many parts of metrics which were dissipated and dissected by road construction and they were converted into other types of patches, so the number of patches increased, patch isolation also increased, and the richness index of species decreased.

The distance to viable habitats (isolation) also determines the composition and abundance of vegetation. The landscape fragmentation will reduce the radius of gyration and increased the complexity of the shape of patches so that isolate habitat will increase. Therefore, less isolated habitats have more frequent species-richness because they can be quickly settled (Walz 2011).

When forest areas have been reduced and fragmented considerably by logging, conversion and land-use change, or human-modified landscape, the first organisms to be impacted by deforestation and disturbance are plants. It is implied that the shape of complexity can be used to analyze the accuracy of the prediction of plant species richness (Sodhi et al. 2010).

There is a very important discovery from the regression equation, that there is a different phenomenon with Island Biogeography Theory (IBT), during the phase of fragmentation of dissipation and dissection, there should be a decline in tree species richness, but there was an increase in tree species richness, instead.

The forest rehabilitation and restoration activities should be directed to fill in the gap between patches, to reduce the number and density of patch, and also to increase the size of spatial connectedness or transmission of forest patches (patch contiguity).

#### *Effect of changes in landscape metrics on the effective number of tree species*

The multiple-regression models of the effective number of tree species are  $Y_2 = 19.425 - 1.343 PC_3$ . Though, the  $p$ -value of 0.283 is above the significance level (e.g.,  $p < 0.05$ ), but the result doesn't attain statistical significance. It is implied that increasing measure of aggregate metrics of the landscape is not reliable enough to predict the effect of change of landscape metrics on an effective number of tree species (true diversity).

#### *Effect of changes of landscape metrics in the abundant index of tree species distribution*

The multiple-regression models of the abundant index of tree species distribution are  $Y_3 = 16.461 + 1.572 PC_3$ . Though, the  $p$ -value of 0.188 is above the significance level (e.g.,  $p < 0.05$ ), the result does not attain statistical significance. It is implied that increasing measure of aggregate metrics of the landscape is not reliable enough to

predict the effect of change of landscape metrics on an abundant index of tree species distribution.

*Effect of changes of landscape metrics in the equity index of tree species*

The multiple-regression models of the equity index of tree species is  $Y_4 = 1.252 - 0.087 PC_3$ , significant is at  $p = 0.032$ , so it is below the significance level (e.g.,  $p < 0.05$ ) and  $R^2 = 0.154$ . The independent variable is Aggregate Metrics ( $PC_3$ ). It means that the multiple-regression models are reliable and can be used to predict the value of the species equity index on that tropical lowland forest.

This research shows that when the aggregate metrics are decreasing, then the landscape increasingly has more fragmented, broken apart and converted into another land use type. According to multiple regression models, variable  $PC_3$  have a negative regression with an equity index of tree species ( $Y_4$ ). It is mean that fragmentation, breaking apart, decreasing in the degree of aggregation of the forest patch type will increase the equity of tree species. This finding seems to be the opposite of what was expected. Thus, it needs to understand how these parameters affect the metapopulational process (local extinction and recolonization), habitat preferences and dissemination capacities (Metzger 1997).

The equity index of species would be declined when a number of suitable habitats for these species reduced that were caused by the breaking apart of largest patches and an increase in a number of patches (Fahrig 2003; Lindenmayer and Fischer 2006).

Regarding to difficulty in interpreting indices, Li and Wu (2004) suggested specific improvements may be achieved in three areas, (a) combination of indices is most effective in a particular situation, (b) much easier to interpret the values of an index if the index is relative, ranging from 0 to 1 (or -1 to +1) and if the minimum and maximum values of the index have clear ecological meanings, (c) the ecological meanings of most landscape indices deserve further scrutiny.

Even though by doing the modification against of aggregate metrics ( $PC_3$ ), as demonstrated by the multiple-regression models, it is statistically significant with small determinant level, and the species equity index of fragmented forest patches could be improved, but it still has no clear ecological meanings.

Li and Wu (2004) states that the ultimate goal of the landscape pattern analysis should be to achieve better explanations and predictions of ecological phenomena based on established relationships between pattern and process.

*Effect of changes of landscape metrics in tree density*

The multiple-regression models of the tree density is  $Y_5 = 574.758 + 134.963 PC_1$ . Significant is at  $p = 0.006$ , so it is below the significance level (eg,  $p < 0.05$ ),  $R^2 = 0.241$ , where the independent variable was Dimension Metrics ( $PC_1$ ). It means that the multiple-regression models are reliable and can be used to predict the value of the density of the tree stand on that tropical lowland forest.

This research shows that when the dimension metrics are increasing, then the landscape is increasingly fragmented, broken apart and converted into another land use type.

With the equation of  $PC_1 = -0.300 SIEI - 0.292 SIDI + 0.297 CONTAG - 0.116 DIVISION + 0.108 MESH + 0.077 LPI$ , it means that in a landscape of forests that is increasingly fragmented, then the diversity of patches increased due to the conversion of patch of forests into another patch type, the contagion between patches is declining, a patch division increases, the effective mesh of the patches is declining, and the index of the largest patch is declining. If the dimension metrics of the fragmented forest is declining, then the estimated value of the tree density of the tree stand will decrease, and vice versa.

It means that by doing the modification at the variables of dimension metrics ( $PC_1$ ), there will be a significant influence, with the determination of 24.1%, and it will reduce the tree density of forest stands. The primary roles of other variables are productivity and stand conditions (Pokharel and Froese 2009).

*Effect of changes of landscape metrics in basal area of tree stand*

The multiple-regression models of the basal area of the tree stand is  $Y_6 = 28,288,147 + 8,885,947 PC_1 + 4,331,086 PC_3$ , it is significant at  $p = 0.020$  which is below the significance level (e.g.,  $p < 0.05$ ) and  $R^2 = 0.252$ , and the independent variable is Dimension Metrics ( $PC_1$ ) and Aggregate Metrics ( $PC_3$ ). It means that the multiple-regression models are reliable and can be used to predict the value of the basal area of the tree stand on that tropical lowland forest.

This research suggests that dimension metrics are going up and the aggregate metrics are going down, then the landscape is increasingly fragmented, broken apart and converted into another land use type.

With the equation of  $PC_1 = -0.300 SIEI - 0.292 SIDI + 0.297 CONTAG - 0.116 DIVISION + 0.108 MESH + 0.077 LPI$ , it is means that landscape of forests are increasingly fragmented, then the diversity of patches increased due to the conversion of patch of forests into another patch type, the contagion between patches is declining, a patch division increases, the effective mesh of the patches is declining, and the index of the largest patch is declining.

With the equation of  $PC_3 = 0.387 PLADJ + 0.380 AI + 0.185 CA + 0.177 PLAND$ , likewise, if the forest landscapes are increasingly fragmented, the aggregation patches decreases, the class area of forest patch type decreases, and the percentage of the proportional abundance of a forest patch is decreased too, there will be the aggregate metrics of the fragmented forest which is increasingly declining.

Based on the multiple regression models of the basal area of the tree stand, if the dimension metrics and the aggregate metrics of the fragmented forest are declining, then the estimated value of the basal area of the tree stand will be decreased.

Increment equations may predict growth or yield of the basal area or in diameter, but it should ensure reliable

predictions of all species are present (Vanclay 1995). It means that by doing the modification at the variables of dimension metrics (PC1) and aggregate metrics (PC3), a significant influence will happen. And with the determination of 25.2%, it will reduce the basal areas of forest stands. The primary roles of other variables are productivity and stand conditions (Pokharel and Froese 2009). This finding will contribute significant benefits in designing a silviculture system on lowland tropical forest restoration.

It is implied that dimension metrics (PC1) and aggregate metrics (PC3) can be used to improve the accuracy of the basal area of a tree stand.

### **Implications for biodiversity conservation and forest restoration**

In the context of management of forest production, impacts of selective logging in Indonesia on tree species diversity seem to vary, showing little effect on tree species diversity or a negative impact (Sodhi et al. 2010). A study on the effects of selective logging on vegetation in Kalimantan (Indonesian Borneo) found that harvesting removed 62% of the dipterocarps basal area. However, a subsequent study from the same area showed that there was an increase in tree species diversity eight years after selective logging (Slik et al. 2009; Majumdar et al. 2014).

To truly understand the current status and forecast the future state of tropical diversity, we must also understand the levels and patterns of biodiversity in landscapes actively managed and modified by humans or a wide variety of traditional and commercial purposes, in promoting an effective environmental policies and landscape management practices, including biodiversity conservation (Amici et al. 2015; Chazdon et al. 2015).

In this research, a metrics landscape can be used in a prediction of the richness index, equity index, tree density and stamp basal area of tree species with statistically significant ( $p < 0.05$ ) and coefficients deterministic 13.2%, 13.1%, 24.1% and 25.2%, respectively, but it is not reliable enough to predict the effective number of species, and an abundance of tree species distribution.

Based on the principal component multiple-regression models on the basal area of trees stand, the results of this study, showed an action plan that is aimed to modify the landscape structure and to improve the tree density and basal area of forest structure, and it could be directed into two components of PC<sub>1</sub> and PC<sub>3</sub>. In order to enhance the dimensions metrics, some points should be undergone such as: (i) stop the conversion of forest patch into another patch type, (ii) re-arrange the activity that spatially will effect to decrease of the largest patch index, and (iii) increase the effective mesh size of forest patches, (iv) avoid the subdivision of patches, so the contagion of the patches will increase.

The other efforts to reduce the complexity of shape metrics that should be carried out, with some stressing point, are as follows: (i) to reduce the number and density of patches, (ii) to increase the contiguity between patches of the same type, (iii) to simplify the shape of the patches,

and the result is a radius of gyration of a core patch would be grown.

In the context of biodiversity conservation, availability of the map of land use and land cover may not be sufficient to predict species richness and abundance of tree species distribution (Walz 2011). Is there any possibility to derive the data of species diversity from landscape structure, by means of formulating the specific goals of a particular landscape management for the purpose of the biodiversity conservation and forest restoration? (Walz and Syrbe 2013).

Haddad et al. (2016) states that the effect of forest fragmentation on species diversity arises in part because of the many ways of each species responds to edge changes, patch configuration and metrics quality, and not just all species, all individuals of the same species responding in different ways (Cote et al. 2016).

However, the landscape metrics still can be used for the habitat modeling of individual species or groups of species. These relationships can be made comprehensible using landscape metrics (Morris 2014; Amici et al. 2015; Hakkenberg et al. 2016), which we are able to show local plant variety is satisfyingly predicted by relatively simple landscape metrics (Walz 2011).

To really understand the current status and prediction of the future diversity of tropical forests, we also have to understand the level and pattern of biodiversity in the landscape of activities managed and modified by humans for various purposes, including commercial and traditional biodiversity conservation (Anand et al. 2010; DeClerck et al. 2010; Neuschulz et al. 2011; Chazdon et al. 2015). Haddad et al. (2016) states from a new perspective on the loss of ecology due to habitat loss and fragmentation, metacommunity theory to understand and predict the properties of spatial networks of interacting species and abiotic factors should be done, i.e. the dynamic interaction between species, environment and abiotic space, since they all have a depth effect (separate and combination) on the coexistence of species, species diversity, and functioning of ecosystems.

In fragmented landscapes, human-modified habitats may enhance functional connectivity by providing suitable dispersal conduits for early successional specialists (Amaral et al. 2016). Landscape preservation is the key to biodiversity and species conservation (Morris 2014). Forest harvesting and other management practices should take into account the landscape structure of forests to benefit tree species diversity and its maintenance, for instance by avoiding opening too much the canopy cover (Torrás and Saura 2008). In addition, studies incorporating multiple measures of the landscape structure as a driver and indicator of biodiversity would further improve our understanding of how to best manage for ecosystem services provision (Schindler et al. 2013; Ziter 2016).

We recommend integrating forest inventory and landscape structure monitoring into forest management plans. This enhances the sustainability of the forest resources and promotes the evaluation of effects of forest management on a landscape structure, and vice versa (Torrás et al. 2008; Schindler et al. 2013). A design

following landscape ecology principles has permitted the development of a management plan and silvicultural activities (Navarro-Cerrillo 2012).

In summary, the effect of the change of landscape metrics, especially on the growth of regeneration and succession of secondary forest (especially for young trees class) in the sub-landscape of Meranti Ulu, Meranti Ilir and Dangku significantly influenced the richness and of tree species, and the growth of the density and basal area of tree species. Sub-landscape of Dangku has the average value of the Shannon-Wiener index which is relatively same with that of sub-landscape of Meranti Ilir, but, the tree species richness index, density of tree species and basal area in sub-landscape of Dangku is higher than Meranti Ilir. This indicates that the entropy of the natural succession process of the secondary forest ecosystems in the sub-landscape of Dangku was relatively steadier than in the sub-landscape of Meranti Ilir. The role of the interior forest is crucial, because although fragmentation has been stimulating the increase in the index of richness and equity of tree species, but the estimated value of species richness indices, the effective number of species, abundance distribution of species, and species equity in the sub-landscape of Kapas is higher than in Meranti Ulu, and successively is higher than in Dangku, and in Meranti Ilir. The change of landscape metrics leads to the decolonization of the composition and diversity of tree species in the succession process of the secondary natural forest, and significantly causes a rise in the tree species richness index. This phenomenon is deviating from the Island Biogeography Theory (IBT), and this is allegedly due to edge effects, shade-intolerant on the gap dynamics of forest canopies, connectivity between patches, and seed dispersal. The structure of landscape on the mosaics of remnants natural forest patches can be changed by modification of the landscape (human-modified landscape), by repairing the connection and habitat corridors between forest patches, by increasing contiguity and cohesion between patches, and unifying some patches into an aggregate of patch habitat, to make bigger patch size.

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