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Connectivity and ecological indicators analysis of tropical forest landscape in Batang Toru watershed - Indonesia

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Abstract: Connectivity is one of the important issues in the context of natural resources due to its potential in preventing the impact of habitat fragmentation. Landscape forest connectivity facilitates organism movement, genetic exchange, and other ecological material flows. Loss of connectivity may result declining of ecosystem production and cut the material flows within the forest ecosystems. Connectivity degree is needed to determine the management strategy of forest landscape as a wildlife habitat. This paper defines connectivity index of forest landscape in Batang Toru watershed, and describes correlation between connectivity with ecological indicators, biophysical and anthropogenic factors. Landsat satellite imageries acquired in 1989, 2001 and 2013 were used to detect land cover in several different years. Fragstat was used to generate landscape metrics. Landscape metrics were analyzed using a scoring method to determine the connectivity index of forest landscape. A Pearson correlation analysis was performed to obtain a correlation between connectivity index and the distance from roads, the distance from rivers, elevation and slope. The study found that the landscape connectivity tend to decline over the period from 1989 to 2013. The lowest connectivity index was found in the downstream area of Batang Toru watershed. Areas with low connectivity index were identified as having a relatively low diversity index of tree species. The connectivity index of forest landscape has a positive correlation with the distance from roads and the distance from rivers.

Keywords: Fragmentation, Species Diversity Index, Fragstat, Ecosystem

1. Introduction

Connectivity has become a primary issue in various studies due to its potential in mitigating the impacts of habitat fragmentation [1, 3]. Improving ecosystem connectivity is one of the main objectives of forest landscape management [36] besides maintaining the stability and integrity of natural ecosystems [10]. As was shown in the study [41], the establishment of certain bird community was supported by the change in the surrounding landscape, not in the site where the animals live. Forest landscape connectivity can be evaluated and improved through reforestation around the forest [18, 19].

The measures of landscape connectivity were influenced by different aspects of landscape structure [20] and landscape connectivity is a poorly defined concept and the same landscape may have different connectivity values when different measures of landscape connectivity were used. Nevertheless there are two general predictions that are able to explain landscape connectivity measures, i.e. (1) a significant increase in inter-patches distance decreased landscape connectivity, and (2) the effect of constituent elements of landscape connectivity was smaller than the effect of habitat elements. Landscape connectivity is as a degree of spatial connectivity among landscape elements such as patches, corridors, and matrix [16, 17]. Patch connectivity emphasized on a number as well as a series of habitat patches and the Euclidean distance or effective distance between the patches [4]. Corridor connectivity indicated a linear connection and its distribution can be improved through connectivity restoration [9, 21]. Connectivity matrix can be used to evaluate overall landscape mosaic, including landscape matrix to maintain maximum landscape continuity of non-built areas [27]. Thus, landscape mosaic is important as a whole, not only as landscape counterparts [1].

Connectivity is related to the functional connectivity within the landscape and not merely a physical connection among landscape elements. Connectivity is actually more than just a physical connection but also include a resistance to movement due to barrier or land use type. In general, landscape connectivity emphasized not only the spatial characteristics but also the ecological processes and the organism movement (functional connectivity). There is a tendency to focus how landscape structure was spatially and simply managed through its mapping, than to see what the landscape is and how will it be. However the challenge is the lack of understanding of ecology during planning, while the ecological effect within the network is quite real. This can be resolved by linking the scientific characteristics of functional connectivity when designing sustainable landscape planning.

Some studies and literatures only emphasized natural landscape study at local scale. However if we take a look at its relation as well as its effects on existing lives inside it, there is connection that geographically cover a much larger area, for instance at regional scale or a watershed. The restoration of habitat connectivity is the application of landscape ecology concept and metrics. Connectivity is extremely important and is a tangible characteristic of landscape. This is a parameter of landscape functions and is a major issue in assessing as well as planning biodiversity conservation. A well-understood fact is that connectivity is important for the disturbance on plants and animals in a fragmented landscape [27, 28].

Connectivity is fundamental to spatial concept that supports some land-use planning and conservation strategy [42]. Connectivity metrics can be applied to model ecological processes, e.g. to obtain average isolation and predict relative connectivity of habitat islands [22, 37]. Connectivity metrics are based on network theory [27, 28]. Connectivity can be improved through landscape restoration. Restoration can be considered to speed up the succession. A restoration decision making can be made through landscape modeling [44] as well as landscape connectivity approach. In some cases, most of the analysis methods of connectivity metrics were supported by spatial data [38]. Sites in areas of high landscape connectivity level will be given a priority in conducting restoration activity. These can be identified through the application of landscape ecology principles focusing on population dynamics, to provide information on each stage of restoration decision-making process [32]. Nevertheless, it is practically difficult to assess which landscape ecosystem that deserves to be main priority for restoration. However this can be solved if the potential ecological characteristics in the context of its ecosystem structure and function can be recognized during ecological restoration [7, 21]. Thus the purpose of this study is to obtain landscape connectivity indices and its correlation with forest landscape ecology indicators, biophysical and anthropogenics factor.

2. Material and Methods

2.1. Study Area

The study was conducted in Batang Toru watershed which consists of Puli, Sarula and Batang Toru Hilir sub-watersheds, Sumatera Utara Province-Indonesia. The study area was located between 1º 10’ 36.6” – 1º 10’ 36.47” N and 98º 23’ 48.22” - 98º 49’ 15” E (Fig. 1). The study was conducted from September 2013 to January 2014. The study area covered an area of 202,277 ha at elevation of around 0 to 2,000 m above the sea. Based on its topography, the study area consists of flat area (0% - 1 %) of around 75.66% of the total area and a quite steep to steep area (> 15%) of around 24.34% of the total area. Oldeman’s climate classification type divides the study area into 3 climate types, namely A (Tapanuli Utara), D1 (Tapanuli Selatan) and A (Tapanuli Tengah). Based on the Decree of the Indonesia Minister of Forestry No. 44 Year 2005, the study area consists of Conservation Forest (0.06%), Nature Reserve Forest (6.27%), Production Forest (39.10%), Protection Forest (2.93%), Limited Production Forest (12.55%) and other uses (39.08%). Nature reserve forest, protection forest and conservation forest were managed by the Ministry of Forestry and were important sites for the diversity in the Sumatra Island. It is also a habitat of Sumatera orang utan (*Pongo abelii*). Batang Toru forest has biodiversity richness as a home of thousand species of flora and fauna such as 67 mammals species, 287 birds species, 110 types of herpetofauna, and 688 plant species [33, 34]

2.2. Materials

The study used satellite imagery, i.e. Landsat TM 1989, Landsat ETM 2001 and Landsat 8 OLI 2013 path/row 128/059, contour map, road network map, and river map. In addition, vegetation data from field measurements was used as supporting data. Data on vegetation was measured on a plot that has a size of 50 m x 50 m which was divided into 4 quadrants that has a size of 25 m x 25 m respectively. Field survey activity used GPS, haga hypsometre, phi band, compass, and talley sheet. While data analysis tools consisted of Erdas Imagine 9.1 that was used to interpret satellite imagery, Arc GIS to perform spatial data analysis, Fragstat 3.3 to create landscape metrics, Excel and SPSS vers 16 to perform statistical data analysis.

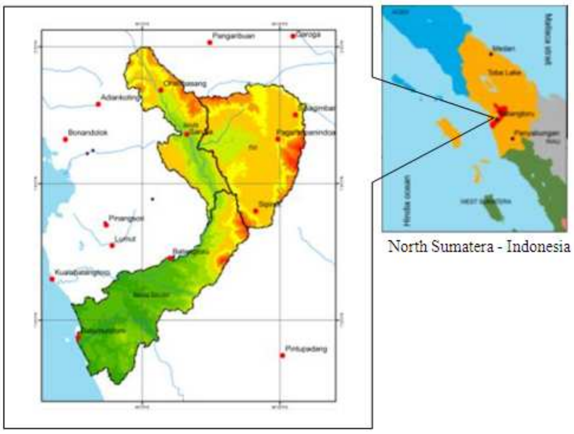

Figure 1. *Study area*

2.3. Data Analysis

For the interpretation of satellite imagery, a supervised classification method was used. The result of satellite imagery interpretation was examined for its accuracy using *Overall accuracy* and *Kappa accuracy* [23]. Accuracy test was performed using 140 field check-points to test the accuracy of 2013 landsat image classification. Land cover map data of 1990 and 2001 published by the Ministry of Forestry of Republic of Indonesia were used to validate accuracy of image classification of 1989 and 2001.

Forest landcover type was analyzed using Fragstat 3.3, to obtain forest landscape metrics [29, 30]. Then each forest landscape metrics was classified into 5 (five) classes and was scored using Likert scale. Landscape metrics for determining the connectivity of forest landscape was the interconnectedness between forest patches (*connectance*) as well as the extent and compactness of forest patches (*radius of gyration*) (Table 1). The scores were summed algebraically. Equation 1 is used to convert the total score into 0 – 1 value [24]. Meanwhile the vegetation measurement data was analyzed to obtain species diversity index value, basal area factor and stand density [25, 26].

$$Ind\_FLC = \frac{(score_{total} - score_{min})}{(score_{tot-max} - score_{tot-min})}\,(ind\_FLC_{max} - ind\_FLC_{min}) \quad (1)$$

Notes :

- Ind_FLC = index value of forest landscape connectivity
- $score_{total}$ = total score as input
- $score_{tot-min}$ = minimum value of total score
- $score_{tot-max}$ = maximum value of total score
- ind_FLC_{max} = maximum index of forest landscape connectivity (converted value)
- ind_FLC_{min} = minimum index of forest landscape connectivity (converted value)

The result of connectivity index calculation was further classified into 5 (five) forest landscape connectivity degree (FLC). Each class used the same value range of 0.2 so that the five classes are as follows: very low FLC (0 – 0.2), low FLC (0.21 – 0.40), moderate FLC (0.41 – 0.60), high FLC (0.61 – 0.80) and very high FLC (0.81 – 1.00). In order to obtain a correlation pattern between FLC and the ecological indicators, trend analysis correlation between diversity indices and forest patch size with FLC value was conducted.

Table 1. *Landscape metrics used in the connectivity analysis of forest landscape.*

Metric	Code	Description	Value	Score
Connectance	CONN	Connectance is defined on the number of functional joining between patches of the same type, where each pair of patches is either connected or not based on a user-specified distance criterion. Connectance is reported as a percentage of the maximum possible connectance given the number of patches.	<20	1
			20 – 40	2
			40 – 60	3
			60 – 80	4
			>80	5
Radius of gyration	GYRATE	Radius of gyration is a measure of patch extent; thus it is effected by both patch size and patch compaction. Note that the choice of the 4-neighbor or 8-neighbor rule for delineating patches will have an impact on this metric.	<200	1
			200-400	2
			400-600	3
			600 – 800	4
			>800	5

3. Results and Discussions

3.1. Landscape Metrics of Batang Toru Watershed

Fragstat analysis generated value of connectivity parameter, i.e. connectan index of landscape, and radius of gyration. It can explain connectivity of forests landscape [11]. Forest connectivity decrease during period of 1989 - 2013. The decrease was depicted by the landscape metric value of *radius of gyration* that decrease from the range of 400-700 m in 1989 to around 50 – 200 in 2013 (Fig. 2-a). The *connectance* value also tend to decrease from around 3 – 9 % in 1989 to around 0-2 % in 2013 (Fig. 2-b).

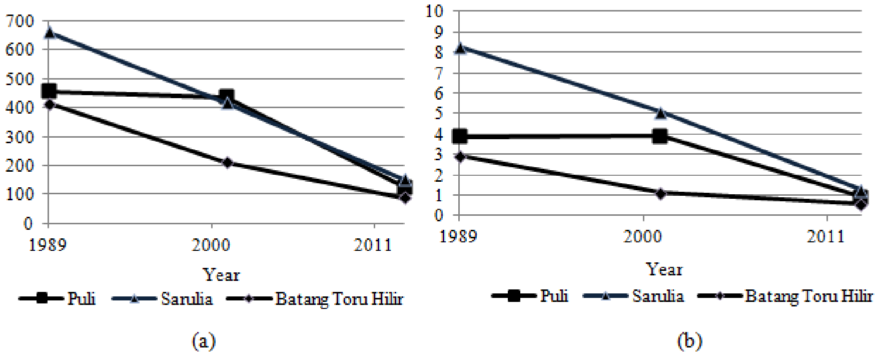

Figure 2. *Landscape metric values of radius of gyration (a) and connectan (b) during 1989 – 2013*

3.2. Connectivity Index of Forest Landscape and Ecological Indicators

Connectivity index was developed based on landscape metrics of c*onnectan* and *radius of gyration index.* Forest landscape connectivity map show that most of the forests in sub-watershed of Puli have high (index value of around 0.6-0.8) and very high connectivity (connectivity index > 0.80). High forest landscape connectivity (0.6-0.8) was found distributed along Sumatra road that through Sipirok and Sarula city. If the forest landscapes have been restored, it will connect forests around them. The connectivity will enhance the functional relationship of forest ecosystem. High connectivity degree was usually found in more compact forest, while low connectivity was found in the fragmented forests.

Connectivity forest landscape index was mapped as illustrated in Fig. 3. Connectivity index map of 1989 show distribution of connectivity degree of forest patch of Batang Toru watershed. High connectivity index was found mostly in sub-watershed of Sarula while very low connectivity index was found in sub-watershed of Batang Toru Hilir. Low connectivity index was found in small size forest patches. However, connectivity index map of 2013 show that most of Puli sub watershed area have medium connectivity degree, while high connectivity was found in forest patches in sub-watershed of Sarula.

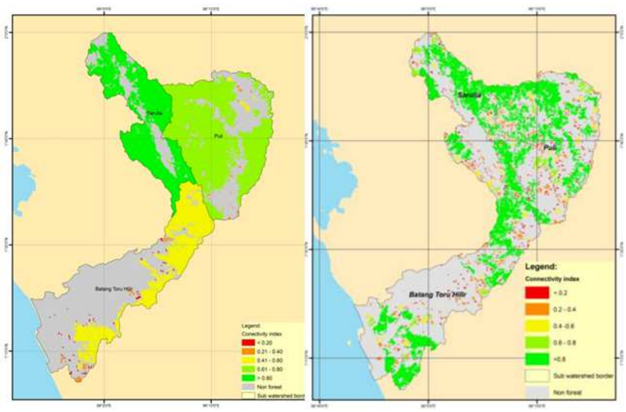

Figure 3. *Forest connectivity index in 1989 (a) and 2013 (b) in Batang Toru watershed*

Table 2 show that sub-watershed of Sarula has a relatively large area of very high connectiviy degree compared to sub-watersheds Puli and Batang Toru Hilir. While sub-watersheds of Batang Toru Hilir and Puli have connectivity degree about 2,490 ha and 2,533 ha respectively. Due the location of sub-watershed of Batang Toru Hilir which is in the downstream part of watershed, the distance between the remaining forests are getting farther. It is similar to sub-watershed Puli which is located in the upstream and middle parts of Batang Toru watershed.

Table 2. *Total area distribution of forest connectivity degree in each sub-watershed in 2013*

Degree of connectivity	Total area (ha)			Total
	Batang Toru Hilir	Puli	Sarulla	
Highest connectivity	2	4	16,646	16,655
High connectivity	17,306	2	1,560	18,878
Moderate connectivity	857	21,767	818	23,445
Low connectivity	2,490	2,533	0	5,024
Lowest connectivity	62,096	50,438	26,699	139,276
Total	82,751	74,743	45,724	203,277

Correlation analysis between ecological indicators and connectivity index shows correlation between connectivity index and ecological responses, that is species diversity index of Shannon-Whinner (H'). The relationship follow polynomial model. The equation was $y = 5.437x^2 + 6.967x - 0.217$ with a determination coefficient value of 64.4 %. The y was species diversity index value and x was forest connectivity index of each patch. Fig. 4 illustrated that the species diversity index value increase while the connectivity index increase close to 0.7. High connectivity will enhance the material flow and change the biological processes [12], reduce the threat of extinction and provide protection from interferences [35]. The connectivity index describes the existing condition of forest landscape. It can't ilustrate clearly the effect of connectivity index on species diversity in certain forest landscape. Landscape history is needed to more explain the correlation between species diversity and forest landscape connectivity [28].

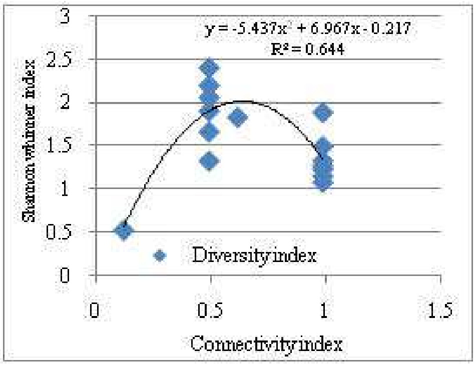

Figure 4. *Correlation between forest connectivity index and diversity index*

The loss of natural connectivity of an ecosystem is the biggest threat in the distribution of wildlife and the living capability, and biodiversity conservation in general. This required more serious attention especially on improving of connectivity in habitat conservation and landscape. The maintenance and restoration of landscape connectivity has become a central issue in ecology and biodiversity conservation because landscape connectivity facilitates organism movement, genetic exchange, and the flow of other ecological materials [8]. Organism movement that is considered in determining forest landscape connectivity of Batang Toru watershed is orangutan as its endemic species. The need for habitat among endemic flora and fauna is a central key in biodiversity conservation as well as the stability and integrity of natural ecosystem [6, 39, 40]. Thus it is highly important to consider connectivity as a basis in conservation planning and landscape change analysis.

3.3. Forest Landscape Connectivity Index and Accessibility

Human factor and biophysical condition affect the forest landscape connectivity index. Human activities are generally supported by the presence of infrastructure to access the forest, i.e. road and river networks, as well as field biophysical condition that is slope and elevation. Pearson correlation can explain the correlation level forest landscape connectivity with the distance from road, distance from river, elevation and slope (Table 3).

Table 3. *Pearson correlation between connectivity index and species diversity index, distance from road, distance from river, elevation, and slope*

Variable	Sub watershed	Pearson correlation	Significant level
Shannon-winner index	Batang Toru Hilir	0.240	ns
	Puli	0.240	ns
	Sarula	0.240	ns
Distance from road	Batang Toru Hilir	0.863**	0.010
	Puli	0.868**	0.010
	Sarula	0.690*	0.050
Distance from river	Batang Toru Hilir	0.934**	0.010
	Puli	0.957*	0.050
	Sarula	0.944*	0.050
Elevation	Batang Toru Hilir	-0.563*	0.050
	Puli	0.539	ns
	Sarula	0.749**	0.010
Slope	Batang Toru Hilir	-0.551*	0.050
	Puli	0.540	ns
	Sarula	0.749**	0.010

The high correlation between connectivity index and the distance from road was found in Puli sub-watershed while the low correlation was found in Sarula sub watershed. However, the high correlation with the distance from river was found in Puli sub-watershed, the lowest correlation is in Batang Toru Hilir sub-watershed. Forest near the road and river has high distubance to the forest. The farther away from the road and river, the connectivity tends to be higher (Fig. 5 and Fig. 6). This is triggered by the river and road that has become an indirect cause of forest damage [39]. The road will attract human to change land use and land cover. Human will change the forest into cultivation land and gather forest products [43], thus trigger land use change. The high of deforestation degree is trigger by closeness of connection between forest and human settlement [31]. Its distribution and pattern follow the road, since the road trigger settlement establishment. Land forest clearing for agriculture was conducted near road and has left only a small part of forest among cleared land [2, 13, 15]. Further, the road increase connectivity among settlement centre that could threat forests sustainability [14, 31].

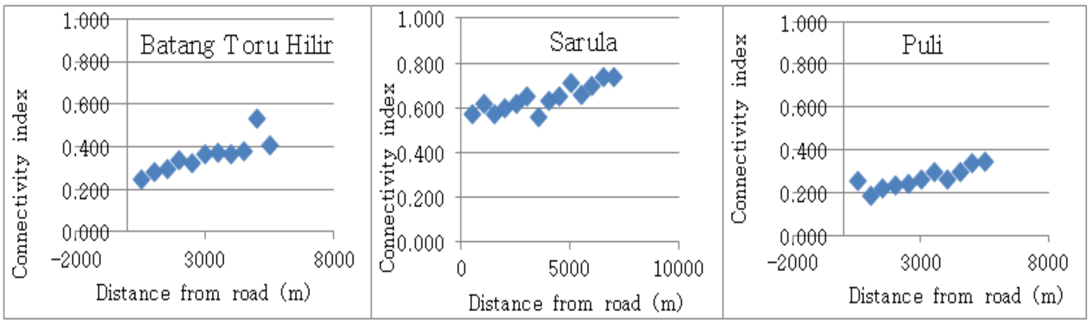

Figure 5. *Connectivity index and distance from main road*

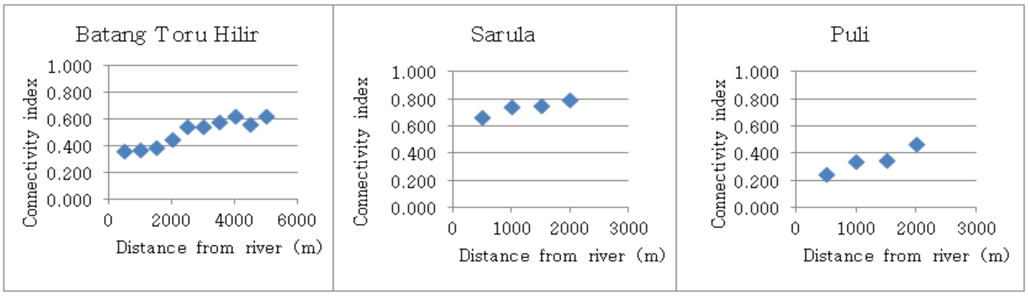

Figure 6. *Connectivity index and distance from river*

In Sarula sub watershed, connectivity index of forest landscape raise with the increasing of elevation (Fig. 7). Forest in steep and difficult accessibility area have less human disturbance [5]. A contrast situation was found out in Batang Toru Hilir sub-watershed that was the higher its elevation the lower its connectivity index. The remaining forests in Batang Toru Hilir sub-watershed have high elevation and were disturbed, while forests in low elevation were more maintenaced and monitored. Slope has no correlation with the connectivity index of forest landscape in Puli sub-watershed. A significant positive correlation between connectivity index of forest landscape and slope was found in Sarula sub-watershed. The higher of slope, the higher of connectivity index of forest landscape. Meanwhile, a negative correlation was found in Batang Toru Hilir sub-watershed that is the higher of slope, the lower of the connectivity index of forest landscape (Fig. 8). Forest landscape as a wildlife habitat should have high connectivity. Connectivity will be obtained from a relatively large and compact forest ecosystem. Effective conservation and restoration strategy would reinstate the forest ecosystem function [39].

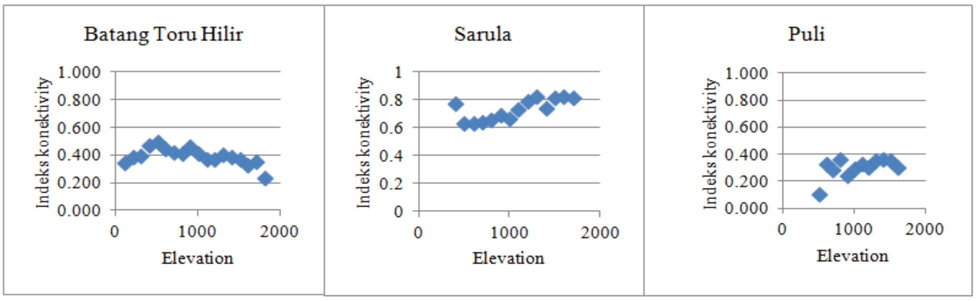

Figure 7*. Connectivity index and elevation*

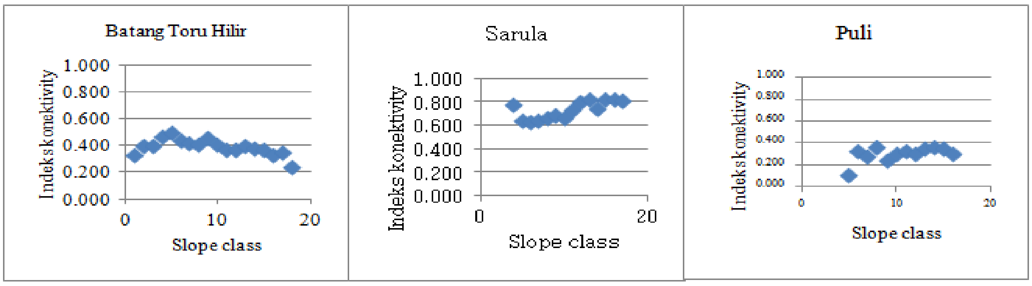

Figure 8. *Connectivity index and slope class*

4. Conclusion

The degree of forest landscape connectivity at Batang Toru watershed tend to decrease during 1989-2013. Sub watershed of Batang Toru Hilir has the low degree of forest connectivity. Ecological indicator i.e diversity index could be indicated by the degree of forest landscape connectivity. The accessibility to the forest increases the disturbance to the forest so that it will reduce the connectivity degree of forest landscape. However, as the wildlife habitat, Batang Toru forest landscape connectivity could be maintenance and enhanced by restoring or rehabiliting of fragmented forest.

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