Analysis of Forest Landscape Fragmentation in Samosir Island, North Sumatra

Samsuri\(^1\), A Zaitunah\(^2\) and J. F Manurung\(^3\)

\(^1\)Forestry Faculty – University of Sumatera Utara, Kampus USU Padang Bulan, Medan 20155, Indonesia
\(^2\)Forestry Faculty – University of Sumatera Utara, Kampus USU Padang Bulan, Medan 20155, Indonesia
\(^3\)Leuser Ecocystem Institute Medan 20155, Indonesia

E-mail: samsuri@usu.ac.id

Abstract. Forest coverage has changed regarding to structure and size, which further causes forest fragmentation. Forest cover change of Samosir Island disrupts the forest ecosystem. This research were aimed to determine the land cover changes in Samosir Island of year 2005, 2011 to 2015 and to determine fragmentation degree in Samosir Island’s forest. This research was carried out in four step such as delineation of watershed, image analysis, land cover changes analysis, and fragmentation analysis. The four sub-watershed of Samosir Island were divided into four aspect maps. Research found that during the period of 2005 to 2015, Samosir Island had 10 land cover classes; there were water body, forest, mixed garden, dry land farming, bare land, grassland, settlements, swamp, paddy field, and shrubs. Within the period of 2005 to 2011, the largest land cover change was 3.912,02 Ha of converted forest into mixed farm. During the period of 2011 to 2015, the change from forest to shrubs was 3.334,671 Ha and during period 2005 to 2015, the change from forest to shrubs was 4.137,277 Ha. The Samosir Island’s forest in 2005 – 2015 was classified as the lowest class fragmentation of the west sub-watershed, moderate class fragmentation of the South sub-watershed, and highest-class fragmentation of the north sub-watershed.

1. Introduction
Deforestation and forest degradation lead to forest fragmentation. Forest fragmentation occurs because large interconnected forests are separated into smaller blocks due to road, agriculture, urbanization or other development aspects. Consequently, the function of the forest as a home range of plant and animal species is reduced. Fragmentation can be caused by the removal of vegetation on a large area and the construction of a separated path habitat [1-3].

The changes of shape and forest extent that occur in the forests of Samosir Island lead to disruption of forest ecosystems. Reduced forest area resulted in decreased of land capability to sustain ane absorb run off. Reduced forest is triggered by forestlands conversion. Economics benefit is one of the reasons for the community to land forest conversion. To prevent and reduce the damage caused by forest fragmentation, it requires efforts to control the level of forest fragmentation. The degree of the fragmentation rate is required to determine the strategy of forest fragmentation control. Therefore, it is necessary to analyse the degree of fragmentation [4].
Fragmentation occurs through loss of habitat. Otherwise, habitat loss may be viewed as the result of fragmentation. However, fragmentation may be accompanied by habitat loss as large habitat pockets divided into smaller and more isolated habitat pockets. If habitat loss and fragmentation are separately observed, the loss of habitat has a more significant impact on species survival than fragmentation. However, since fragmentation and habitat loss occur together, it is extremely difficult to determine which is more important for habitat change [5-7].

Measuring fragmentation is an interesting action. Many sizes can be used to view habitat fragmentation. For measuring aspects of landscape structure, three indices such as (1) landscape composition (2) landscape configuration and (3) patch form within the landscape can be used. The composition shows the number of different closure types found in the landscape. Compatible patch analysis program with ArcGIS is reliable enough to calculate fragmentation statistics, as it is a modification of Fragstat and can be used to calculate spatial statistics, either polygon or raster files [5, 8].

The analysis of land cover and degree of forest fragmentation on Samosir Island was carried out using remote sensing method and Geographic Information System. This study aimed to determine the change of land cover in Samosir Island from 2005, 2011 to 2015 and to examine the degree of fragmentation in watershed of Samosir Island.

2. Method
The research was conducted on April - August 2016 in Samosir Island, Samosir district, North Sumatra Province. Processing and data analysis was completed at Forest Management Laboratory, Faculty of Forestry, and University of Sumatra Utara, Indonesia.

2.1. Research site
Samosir Island is a peninsula connected by a 200-meter length of lands with west side area of Lake Toba. In 1906, the Dutch government built a canal on this land so that the land of Samosir was separated into an island. Samosir Island is located in Samosir District. Geographically, Samosir Island is located within 2°35' North and 98°49' East. Samosir district consists of nine sub districts where six of them are in Samosir Island and three in the outer ring of Lake Toba (Figure 1). The island has an area of 63,000 Ha. The 6-sub districts of Samosir Island are Simanindo, Pangururan, Ronggurnihuta, Palipi, Nainggolan and Onan Runggu.

![Figure 1. Map of Samosir island in Samosir district](image_url)
2.2. Tools and Research Data
The data used in this research were Landsat TM 5 (path/row 129/58) for 2005 and 2011 and Landsat 8 OLI imagery for 2015 (path/row 129/58). Image were acquired from the site (Http:\\www.USGS.EarthExpoler.com), administrative map of Samosir regency 2015 with scale 1: 250.000 (Ministry of Environment and Forestry), forest area map of Samosir district issued by Ministry of Environment and Forestry by scale 1: 250.000 (Ministry of Environment and Forestry). The tools used in this research are Personal Computer, Arc GIS, ENVI, and ERDAS IMAGINE, Fragstat, Global Mapper, Geographics Positioning System (GPS) and camera.

2.3. Research Procedure
The study was carried out in four step those were (1) watershed delineation, (2) land cover analysis, (3) land cover change analysis, and (4) fragmentation degree analysis.

2.3.1. Watershed delineation
It comprised of hill shade creating and fill sink. The hill shade functions to produce a clearer picture of topographic conditions. This function describes the Digital Elevation Model (DEM) with its topographic effects. The fill-sink function eliminates depression or sinks where conditions vary greatly with elevated area coverage.

2.3.2. Analysis of land cover
2.3.2.1. Image correction
Before further processed, correction was carried out to obtain a clear object on the image. It also facilitated visual image interpretation activities [9]. This correction was completed with EDAS version14 software, which consists of radiometric, and geometrics correction. Radiometric correction is a process for improving the visual quality of images and improving pixel values that do not match the actual reflectance values or spectral objects. One of the corrections used in the image is the histogram correction. Geometric correction was performed because there are geometric errors occurring at the time of recording. Geometric correction aims to rectify or justify the image coordinates to match the geographical coordinates. The raw data from the Landsat image consistently has geometric errors. Correction was carried out by defining projection and Geo referencing function. The selection of this projection was adjusted to the area division of the Universal Transverse Mercator (UTM) system. Samosir Island belongs to North Sumatra, which is located at UTM 47 zone and datum World Geographic System 84 (WGS 84).

2.3.2.2. Field checking
The field sample plot was collected on Samosir Island with a Garmin 62S GPS to assist in rectification of image classification included in the image analysis process.

2.3.2.3. Subset image
Subset Image was carried out using ERDAS 14 software since the Landsat image acquired from website http:\\: www.USGS.EarthExpoler.com not only covers Samosir Island but also area surrounding Samosir Island. Subset areas were constructed based on the Samosir Island administration map.

2.3.2.4. Supervised classification
The images from years 2005, 2011 and 2015 were interpreted using a supervised classification. The method used in this research is visual image interpretation method [9, 10]. In this method, there are considerations of various factors, including the opportunity of a pixel or the appearance of the image to be explained into a particular class or category.

Image classification of Samosir Island was conducted for three time series of years at 2005, 2011 and 2015. Classification was performed for Landsat images such as Landsat TM 5 year 2005 and 2011 and Landsat 8 OLI image for year 2015. The combination of bands used for true colour composite on Landsat TM 5 was a combination of 321 as opposed to Landsat 8 OLI combination of 432 with RGB format (Red, Green, Blue) and using supervised classification. Digitization on screen was performed to assist image analysis in ERDAS 2014 to obtain land cover identification in the study area.

2.3.2.5. Accuracy analysis
Accuracy is analysed using a contingency matrix, which is a square matrix containing the number of pixels classified. This matrix is called "error metric" or "confusion metric". The error matrix compares the information from the reference area with information from the classified image in selected areas. The square error matrix with elements in the matrix row represents the area in the classified image, whereas the elements in the matrix columns represent the area of the reference data. The reference data comes from a number of image pixels that have been identified through field checking or photo interpretation and are assumed correct. The error matrix is very effective at knowing the accuracy level of the classification result and the error occurring in the classification step. This accuracy is usually measured by the division of the point correctly explained by the total point used (the number of points within the diagonal of the matrix by the number of points used). Accuracy calculations by using this contingency matrix can also calculate the magnitude of the producer's accuracy and the user's accuracy. The systematically accurate calculation scheme [10] are as follows:

a. **User Accuracy**

\[
Z = \frac{100\%}{N}
\]

Note:
- \(N\) = the number of validation coordinate
- \(Z\) = the number of validated coordinate

b. **Procedure Accuracy**

\[
\frac{X}{N} \times 100\%
\]

Note:
- \(N\) = the number of validation coordinate
- \(X\) = the number of validated coordinate

c. **Overall Accuracy**

\[
\frac{M}{N} \times 100\%
\]

Note:
- \(N\) = the number of validation coordinate
- \(m\) = the number of validated coordinate

d. **Kappa Accuracy**

\[
\frac{N \sum X_{ii} - \sum X_{i} \cdot X_{i}}{N^2 - \sum X_{i} \cdot X_{i}} \times 100\%
\]

Note:
- \(X_{ii}\) = diagonal value of contingency matrix row-i and column-i
- \(X_{+i}\) = the number of point in column-i
- \(X_{i+}\) = the number of point in row-i
- \(N\) = the number of point

2.3.3. Analysis of land cover change.

Analysis of land cover change was carried out using ArcGIS 10.1. The analysis was carried out with land cover overlay for 2005, 2011 and 2015 in order to obtain three periods of land change data. It resulted in changes of extent and shape of the land cover class as it shifted its function to other area of use.

Fragmentation analysis. Data obtained from the classification, then processed using Fragstat 4.2 to obtain forest landscape metrics. It met with Janet et al [11] that stated that habitat fragmentation and forest loss could be examined by landscape metrics analysis [11]. Landscape metric as calculated was based on wildlife habitat such as macaca species [12-15]. Landscape matrix used to determine the
level fragmentation is the Area Patch Area (AREA), Patch Density (PD), Proximity Index (PROX), and Contiguity Index (CONTIG) [1, 5]. Each landscape metric is formulated as follows:

**Area patch**

Patch area was formulated:

\[
\text{Area} = a_{ij} \cdot \frac{1}{10000}
\]  

Note:

AREA = Area patch \((m^2)\), divided by 10,000 (convert to be hectare);

\(a_{ij}\) = area \((m^2)\) patch \(ij\)

**Patch density**

Patch density is the number of patch unit on area have 100 Ha as a landscape unit.

\[
\text{PD} = \frac{N}{A} (10000)(100)
\]  

Note:

PD = the number of patch per 100 Ha;

\(N\) = the number of forest patch, and

\(A\) = area of forest landscape

**Contiguity index**

Contiguity index (CONTIG) is spatial size of forest patch connected as single patch with other forest patch. The higher contiguity is more connected the forest patch.

\[
\text{CONTIG} = \frac{\sum_{i,j} c_{ij}}{V-1}
\]  

Note:

\(c_{ij}\) = contiguity value of pixel “r” in patch-ij;

\(V\) = the number of pixel value sized 3 x 3;

\(a_{ij}\) = area patch i \(ij\) in a number of cell

**Proximity index (PROX)**

Proximity index is a tendency of patch to be relatively isolated (e.g. distance) from other patches on adjacent or similar ecological classes.

\[
\text{PROX} = \sum_{g=1}^{n} \frac{a_{ij}}{b_{ij}}
\]  

Noted:

\(a_{ij}\) = area \((m^2)\) patch \(ij\) in surrounding of cell \((m)\) patch \(ij\);

\(b_{ij}\) = radius \((m)\) between patch \(ij\) and patch \(ij\), base on edge distance to edge patch. It calculated from cell centre to other cell centre

**Rescaling score.**

To define the standard fragmentation level then the total score of fragmentation transformed (rescaling) using the equation [16-17].

\[
\text{Ind}_{\text{FLF}} = \frac{\text{Score}_{\text{input}} - \text{Score}_{\text{min}}}{\text{Score}_{\text{tot-max}} - \text{Score}_{\text{tot-min}}} x (\text{Ind}_{\text{FLF}} - \text{Ind}_{\text{FLF}}_{\text{min}})
\]  

Noted:

\(\text{Ind}_{\text{FLF}}\) = fragmentation index

\(\text{Score}_{\text{input}}\) = total score as input

\(\text{Score}_{\text{tot-min}}\) = total score minimum

\(\text{Score}_{\text{tot-max}}\) = total score maximum

\(\text{Ind}_{\text{FLF}}_{\text{max}}\) = maximum fragmentation index

\(\text{Ind}_{\text{FLF}}_{\text{min}}\) = minimum fragmentation index
3. Results and Discussion

3.1. Division of the Watershed

The division of the watershed was carried out with hydrology function of DEM data. DEM is digital data describing the geometry of the surface shape earth. It depicts the value of ground surface without pay attention to the object on it. The DEM used for Samosir Island was sourced from http:\www.USGS.EarthExpoler.com and produced 4 (four) parts of the Samosir Island sub-watersheds.

The DEM data of Samosir Island was analysed using Arc Map 10.1. Furthermore, depressions or sinks were eliminated in pixels with different elevations with very striking area coverage using flow direction function generated flow direction at each pixel. Furthermore, the flow accumulation function using the flow direction produces an accumulated amount of water flow at each pixel in coverage of a particular region. The same accumulated value of each pixel having the same tendency flow direction produces a network of rivers or steam links. After the establishment of the network, the river Samosir Island was determined by the order of the river with Stehler and Shreve method to observe the connectivity of each river network in the different sub-watershed.

Generally, the pattern of river network in sub-watershed on Samosir Island in general was a dendritic pattern where tributaries tended to parallel the bloodstock. This model is like a tree having a branch structure and twigs as branches and its tributaries. Determination of watershed boundary was performed by watershed function [18-19]. This function is the most important in the delineation of watershed boundaries. This process works by searching for pixels that have a direction to the mouth of the river and separating other pixels.

The function of elimination polygon was done in sub region of watershed, which has area under 10 Ha. This function produces four sub watersheds in Samosir Island (Figure 2). To observe the difference of forest fragmentation level from each sub watershed in Samosir Island, each of these sub watersheds was divided into four directions namely North sub-watershed, Eastern sub-watershed, Southern sub-watershed and Western sub-watershed.

Figure 2. Sub watershed bordered

3.2. Classification of Land Cover

Based on classification results of Landsat imagery Samosir Island, 10 classes of land cover were founded. Land cover class conforms to the technical guidelines for the classification of low-resolution imagery by the Forestry Planning Board using a monogram of Sumatran landscape imagery. The
channel combination (Band) used was 345. The channel is appropriate to describe land cover in the field. Band 5 can differentiate between snow and cloud; band 4 can distinguish plant species, activities and to limit the body of water and band 3 is made to assist in viewing areas that absorb chlorophyll [9]. Band 3 can be used to assist in separating plant species, as well as for the observation of agricultural cultivation.

Land cover on Samosir Island in 2005, 2011 and 2015 was generally divided into 10 classes namely water agency, forest, mixed garden, fields, grasslands, settlements, swamps, rice fields, shrubs and clouds. Value Kappa accuracy was obtained from supervised classification for image of the year 2005 equal to 93.29%, for image of the year 2011 equal to 92.79% and for image of the year 2015 equal to 97.71%. It met with [10,20] that state that accuracy test using maximum likelihood aims to test the truth of the interpretation results obtained by checking in the field and measurements of several points selected from each form of land measurement. The level of accuracy is tested from the results of accuracy. The higher the accuracy of the results will be interpretation that is more accurate. Changes in shape and extent of land cover occur throughout the year. Additions and reductions occur on each land cover. The spatial distribution of the land cover was illustrated in Figure 3 for year 2005, Figure 4 for 2011 and Figure 5 for 2015 and the extent of land cover was presented in Table 1.

**Table 1.** Land cover of Samosir island at 2005, 2011 and 2015.

| Land cover types         | Area (Ha) | Year 2005 | Area (Ha) | Year 2011 | Area (Ha) | Year 2015 |
|--------------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| Cloud and cloud shadow  | 2.617,27  | -         | -         |           | -         |           |
| Water body               | 600,32    | 541,70    | 404,25    |           |           |           |
| Forest                   | 26.366,32 | 23.665,76 | 25.147,54 |           |           |           |
| Mixed garden             | 1.466,04  | 11.615,81 | 11.912,51 |           |           |           |
| Dry land agriculture     | 11.161,99 | 4.016,03  | 93,83     |           |           |           |
| Bare land                | 1.082,89  | 1.246,50  | 915,43    |           |           |           |
| Grass land               | 1.797,05  | 6.080,02  | 7.234,32  |           |           |           |
| Settlement               | 1.309,40  | 4.325,00  | 6.373,00  |           |           |           |
| Swamp                    | 1.144,75  | 974,00    | 509,04    |           |           |           |
| Paddy field              | 16.026,13 | 7.409,04  | 4.799,72  |           |           |           |
| Shrubs                   | 841,60    | 4.539,90  | 7.023,82  |           |           |           |
| Total                    | 64.413,76 | 64.413,76 | 64.413,76 |           |           |           |

**Figure 3.** Land cover of Samosir islands at 2005
3.3. Forest Fragmentation

Fragmentation of forests generally occurs through loss of habitat. Otherwise, habitat loss can be viewed because of fragmentation [12, 30]. However, fragmentation may be accompanied by habitat depletion as resolving or distributing large habitat pockets into small and more isolated habitat enclaves [6, 22]. The degree of fragmentation can be expected by knowing the patch area, patch density, contiguity index, and proximity index [5, 7, 23]. The level of fragmentation can be grouped into 5 (five) classes namely lowest, lower, moderate, higher and highest.

3.4. Area

The area indicates the area of each forest patch. The forest is the largest area of land cover in Samosir Island. Within the period of 2005 to 2011, forest landscape of each sub-watershed decreased (Figure 7). The decreased occurred in western of sub-watershed have 2,341.91 Ha, southern part of sub-watershed of 259.32 Ha, eastern part of sub-watershed of 95.41 Ha and north sub-watershed of 14.44 Ha. The decreased was caused by the conversion of forestland and illegal logging.

Changes of forest patches area in 2011 - 2015 indicated the high increase in each sub watershed (Figure 6). The largest forest increase occurred in eastern part of sub watershed comprising a surface of 1,170 Ha followed by western part of watershed comprising a surface of 349.85 Ha, southern part of sub watershed comprising an area of 43.11 Ha, and northern part of watershed that has decreased...
for an area of 71.06 Ha. People chose to abandon the less productive land and select plants that are tolerant to the dry season such as pine because of the increased forest area.

3.5. Patch density
Patch density is the number of forest patches per 100 Ha viewed from the landscape metric values. Patch Density of eastern part of sub-watershed, Southern part of sub-watershed and northern part of sub-watershed have increased in the period of 2005 - 2011 because the forest was divided into smaller parts and the smaller compactness. Meanwhile, the sub watershed West has decreased value of patch density from 2005-2011 (Figure 6). During the period of 2011 - 2015, degradation of patch density has occurred in 3 (three) sub watersheds in Samosir Island namely North sub-watershed, Western sub-watershed and Southern part of sub watershed which show compactness and compact forests. Meanwhile, the increased occurred in Eastern part of sub-watershed.

Decreased of patch density value indicates that the compactness of forests is consistently high, while the increased of patch density indicates that the forest area has been fragmented into small patches and improves habitat isolation. It met with [3, 16, 24] that stated tropical forest fragmentation triggers a decline in biodiversity conservation function. Breaking the patches becomes smaller resulting in reduced number of species, smaller populations and higher rate of extinction [25].

3.6. Contiguity index
Contiguity index is a spatial measure of the connectedness of individual forest patches with other forest patches. During 2005 – 2011, the Northern part of watershed, Eastern Sub-Watershed, and Southern Sub-watershed had decreased value of contiguity index (Figure 7), while the Western part has experienced increased value of contiguity index. In 2011 - 2015, three sub-watersheds in Samosir Island namely Eastern part of sub-Watershed, Western part of sub-watershed and Northern part sub-watershed have experienced an increased value of contiguity index, while Southern sub-watershed had decreased value of contiguity index.
3.7. Proximity index

Proximity index is a tendency of patch to be relatively isolated from other patches. Fragmentation may be accompanied by habitat loss along with splitting or dividing pockets of habitats into smaller and more isolated sizes [6]. In 2005 – 2011, the Northern part sub-watershed, Eastern part sub-watershed and sub-watershed had an increased value of the proximity index, as opposed to the Southern part sub-watershed (Figure 8). In 2011-2015, four-sub watersheds have a decreased value of proximity index. Increasing the value of the proximity index indicates that the forest area has been reduced and the isolation occurred, whereas if the proximity index value decreased the forest area increased and the insulation decreased.
Comparisons of forests changing during 10 years were illustrated in Figure 9. Compact forests in 2005 was separated into forest patches in 2011, while in 2015 forest areas became compact even though it is not similar with year 2005. The rescaling scores of fragmentation are grouped into five classes. Rescaling landscape fragmentation results of Samosir island forests in 2005 (Figure 10) showed the Eastern part of sub-watershed was dominated by highest class. Highest class of fragmentation degree in the Eastern part sub-watersheds was caused by the connection between decreased patches. The lack of compact forests leads to highest forest fragmentation.

Figure 9. Change of forest fragmentation

Figure 10. Map of the Samosir island forest landscape fragmentation degree year 2005
Moderate class dominates the degree of fragmentation of Northern part watershed, while low class dominates the fragmentation degree of Western part sub-watershed and Southern part sub-watershed. It can be concluded that the three sub-watersheds have compact forests and high connectivity. The degree of fragmentation in Eastern part sub-watersheds is dominated by high class, which indicates the occurrence of land conversion resulting in uncompact forests.

Figure 11. Map of the Samosir island forest landscape fragmentation degree at 2011

The rescaling score of forest metrics landscape of 2011 (Figure 11) showed that the fragmentation degree of Eastern sub-watershed and Northern sub-watershed were dominated by highest class. The highest degree of fragmentation was caused by the conversion of forest functions into rice fields and mixed gardens, resulting fragmented and separated forests. The sub-watersheds and Southern of watershed was dominated by low degree of fragmentations. It shows a compact forest with high connectivity between each forest patches.

Figure 12. Map of the Samosir island forest landscape fragmentation degree year 2015
The rescaling degree of forest fragmentation of 2015 (Figure 12) showed that the Eastern sub-watershed is dominated by highest-class fragmentation degree. In Eastern sub-watershed, highest fragmentation degree showed isolated and uncompact forests that are linked by low linkages between forest and reduced forest area.

The degree of fragmentation in Northern watershed was dominated by low value, while extremely low class dominated the Western sub-watershed and Southern sub-watershed. The low to very low fragmentation degree of three watersheds indicated a compact and connected forest. This is due to increased forest area and low habitat isolation. Population density and kinds of community livelihood determine the natural conditions in the region [13, 26]. Social statistic data of 2015 collected from the Central Bureau of Statistics of Samosir Regency shows the highest population density in Pangururan is about 250.91 individuals/km² followed by Onan Runggu 175.51 individuals/km² and Rongurnihuta 90.99 individuals/km². The main employment of Samosir Regency is 49,359 farmers, manufacture 1815 persons and service 18,199 persons [27].

Farmers are the most abundant in Samosir Island leading the increased of agricultural land. Local people would left unproductive land and cleared the land by burning method to convert land use from forest into rice fields, bare land and mixed gardens to meet the increasing economic needs [28, 26]. It proves that increased of landscape fragmentation was caused by human practice related to providing cultivation lands [29, 30]. If government and NGOs does not increase the education of local people, the community will continue to destroy and convert natural resources continuously without considering the future consequences.

4. Conclusion

During the period of 2005 – 2015, land cover on Samosir Island comprised 10 classes namely water body, forest, mixed garden, dry land farming, bare land, grassland, settlements, swamp, paddy field, and shrubs. The largest land cover area are forests with 26,366.32 Ha in 2005; 23,665.76 Ha in 2011 and 25,147.84 Ha in 2015. The largest land cover change in 2005 - 2011 was forests into mixed gardens of 3,917.02 Ha, in 2011 - 2015 forest into shrubs covering an area of 3,334.671 Ha, and in 2005 - 2015 from forests into scrubs covering an area of 4,134.277 Ha. The degree of forest fragmentation in Samosir Island from 2005 - 2015 was considered as low fragmentation class dominating the Western of sub-watershed. The Southern of sub-watershed was dominated by moderate fragmentation class while the Eastern of sub watershed and Northern of sub-watershed were dominated by highest fragmentation class.

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