Spatial alteration of fragmented forest landscape for improving structural quality of habitat: a case study from Radhanagar Forest Range, Bankura District, West Bengal, India

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ABSTRACT
Anthropogenic pressures create a complex pattern of forest habitat shape structure in Radhanagar Forest Range (RFR) in Bankura district. Habitat landscape design controls existing bio-geographical process. High fragmented and more complex habitat make imbalance in ecological process in the study area. Therefore, a measure is very urgent to control fragmentation process. Spatial alteration is one of the best methods to improve habitat quality which reduces habitat shape complexity. Fragmentation and structural composition of habitat will be understood through the interpretation of several geometric indices like perimeter area ratio (PAR), shape index (SI), and fractal dimension (FD). These indices are used to know the nature of habitat fragmentation in Radhanagar Forest range. The main objective of the study is to reduce habitat shape complexity by spatial alteration. Therefore, two types of map, one is existing forest land cover and another is selected areas altered forest land cover of Radhanagar Forest Range are prepared using ERDAS 9.3 and ArcGIS 10.3 version software. Then these maps are analyzed through FragStat 4.2 version software to get above mentioned indices. The study compares the indices values to know the structural quality of forest shape from both maps. The comparison address that altered forest habitat structural quality is better than existing forest landscape habitat quality. Therefore, landuse alteration in a forest matrix is obviously area specific in respect of its shape structure.

1. Introduction
Fragmentation and loss of habitats are the most significant reasons for the loss of biodiversity on Earth (Ilkka, 2009; Weldon & Haddad, 2005). Landuse alteration by anthropogenic activities is the main cause of it. Alterations in the spatial arrangement of the landscape are consequently affecting species population and ecosystem processes (Liu, Jiang, & Zhang, 2006, Wu, 2009). Fragmentation is occurred due to development activities like settlement expansion, industrial establishment (Jetz, Wilcove, & Dobson, 2007), transport line progress, agricultural expansion at the edges of the forest (Fahrig, 2003). All these activities related to landuse alteration. Landuse alteration by forest plantation is one of the ways to increase habitat quality. But it is interesting to know that unscientific plantation leads habitat fragmentation. Unscientific plantation increases habitat isolation and shape complexity (González-Moreno, Quero, Poorter, Bonet, & Zamora, 2011). Habitat shape structure is the key concept to comprehend the nature of habitat fragmentation (Bogaert, 2001, Bogaert et al., 2008; Ramachandra, Setturu, & Chandran, 2016).

Habitat shape structure controls several ecological processes like animal movement and colonization (Luque, Pastur, Echeverría, & Pacha, 2011). Forest interior species are much more sensitive to patch shape (Devictor, Julliard, & Jiguet, 2008) because it determines the amount of interior or core areas of the habitat (Mandal & Chatterjee, 2018). Therefore, habitat encroachment by other landuse intensifies both structural and ecological function of the landscape (Bogaert et al., 2008; Echeverría, Newton, Lara, Benayas, & Coomes, 2007). Another component patch size is the most critical piece of information in the study of fragmentation. More complex shape of patch is prone to enhance the edge-interior ratio (Götmark, 2013; McGarigal & Cushman, 2005) which is intolerable for species colonization. Fragmentation is a spatial process by which patch is broken into smaller patches and these must lose the amount of same habitat (Collinge & Forman, 1998; Ewers & Didham, 2006; Fahrig & Paloheimo, 1988; Forman, 1995). Therefore, habitat fragmentation must be related with loss of habitat which is related to negative effects on biodiversity (Fahrig, 2003). It is also responsible for habitat isolation (Forman, 2014). Isolated habitat patches do not offer a suitable ecological environment for species colonization rather it enhanced species extinction rate. So clustering larger
habitat patches are more significant for regional biodiversity than scattering smaller patches. Also, during scattering forest plantation, the number of patches usually increases, whereas the average size of patches tends to decrease (Rahman, Jashimuddin, Islam, & Nath, 2016). According to Island Biogeography Theory large fragments require more species and small fragments require less because extinction is high in small fragment and low in large fragments (MacArthur and Wilson’s 1967). For this reason, fragment size and isolation of the habitat are the important concept for empirical and theoretical studies (Gardiner, Bain, Hamer, Jones, & Johnson, 2018). To measure or quantify fragment size and isolation at fine scale must be considered fragment composition and configuration in landscape level (Andren, 1994; Fahrig, 2003; Fahrig & Palohelmo, 1988; Uddin et al., 2015, Farina, 2006).

Present landscape spatial information in Radhanagar forest range represents higher fragmentation with more patch shape complexity (Chatterjee, 2016; Mandal & Chatterjee, 2018). Forest fragmentation due to agricultural expansion and scatter plantation in barren land rapidly changed the forest shape and size in the entire district (Chatterjee, 2016). Forest core also losses its ecological character due to encroachment by others landuse in this forest range. Agricultural expansion inside the forest interrupts the habitat function of core dependant species. This continuous process is damaging the quality of the entire forest habitat. As a result of it, core dependant species becomes extinct and multi habitat species movement becomes haphazard which rises the high risk of conflict in this region (Kulandaivel, 2010; Mandal & Chatterjee, 2018).

Therefore, scientific landuse planning is very essential to manage this situation in RFR. According to some ecologists proper landuse management raises the regional habitat quality and mitigates several ecological issues like man-animal conflict, species extinction (Desai & Hedges., 2010; Fernando, et. al. 2008; Inkoom, Frank, Greve, Walz, & Fürst, 2018). It may be possible if the existing forest patch is restruicted by suitable land alteration, it will raise habitat quality (forest core and shape). Present study altered the forest habitat shape structure in RFR using spatial techniques. After that, the study analyzes both shape structures through ecological indices to find out which forest shape will be qualitative in the question of forest habitat structure.

2. Materials and methods

2.1 Study area

RFR in Bankura district, West Bengal extends from 23°16’39.83”N to 23°6’4.72”N and 87°14’50.4”E to 87°24’29.73”E. Geographical area of the RFR is 20380.940331 hectares (Figure 1). Most of the forest habitat had been planted with sal (Shorea robusta) trees. The landscape of RFR is under enormous agricultural practice with patchy forest. Progress of horticulture in this region and clearing of forest is also responsible for complex habitat shape (O’Malley, 1908). In RFR forest patch edges adjacency are maximum with agricultural patch. Therefore the edge of the forest habitat is sharp with a clear outline border. Habitat shape has now become more fragmented than before due to plantation in barren land and open area in the forest (Mandal & Chatterjee, 2018). It causes various ecological circumstances and creates species dispersal related activities.

2.2 Data source and data use

The present work is completely related to landuse and land cover character. Thus landuse map was prepared from IRS LISS-III P-6 satellite image. After that, this map was reclassified through ERDAS 9.3 and ArcGIS 10.3 version software to get polygon shape of forest land cover. To measure and understand forest habitat patch fragmentation, many reliable geometric indices are used and run through the FragStat 4.2 interface tool of same software ArcGIS 10.3 version.

2.3 Methods

Two types of categorical maps were prepared (to measure and compare) for understanding the forest landscape fragmentation character of RFR. One is the present forest landuse map (Figure 1) and another is forest patch shape altered map (Figure 7). In an altered map, some selected forest encroach areas are converted into forest cover by shape editing. Study thinks that if selected encroach areas are converted into forest cover by plantation then it will be less fragmented than present forest landscape. To justify this concept study calculates fragmentation by using ecological indices like Perimeter Area Ratio (PAR), Shape Index (SI), Fractal Dimension (FD) concept by (Mandelbrot (Mandelbrot, 1977, 1982)), for comparing both present and altered forest landuse map. After getting the indices value, a comparative analysis has been done in respect of a standard shape fragmentation (circle). All geometric indices calculated either class level or patch level depending on the objective of the study. Theoretically, increases of shape complexity indicate high fragments of patch structure (Ceausu, Gomes, & Pereira, 2015). For better understanding, the study conducts two types of analysis one is class level (only forest patches in the landscape) and next is patch level (some
individual selected patch). The whole study is continued step by step that points out in Figure 2.

- Perimeter area ratio (PAR) (McGarigal & Marks, 1995)

\[
 PAR = \frac{\sum P_{ij}}{\sum a_{ij}}
\]

Pij is the perimeter (m) of j focal patch in i class and aij is the area (ha) of j focal patch in i class. PAR value m/ha increasing approaches indicate higher complexity of the patch shape. It is the simplest measure of shape complexity. A problem in this metric is that it varies with the size of the patch. For example, holding shape constant, an increase in patch size will cause a decrease in the perimeter - area ratio.

- Mean shape index (MSI) for class level and shape index (SI) for patch level (McGarigal & Marks, 1995)

\[
 MSI = \frac{\sum P_{ij}}{\sqrt{\sum a_{ij}}} \text{adjusted by circle standard}
\]

Pij is the perimeter (m) of j focal patch in i class and aij is the area (ha) of j focal patch in i class. N is the total number of focal patch. MSI is equal to 1 when the shape of all patches become circular (for polygons) and it increases with increasing patch shape irregularity. SI (for single patch) is broadly applicable in landscape ecological study (Forman & Godron, 1986).

Figure 1. Existing landuse and land cover map of Radhanagar forest range. From IRS LISS-III P-6 satellite image 2015.
Mean Patch Fractal Dimension (MPFD) for class level and Fractal Dimension (FD) for patch level (McGarigal & Marks, 1995)

\[
\text{MPFD} = \frac{\sum 2 \ln p_i}{\sum \ln a_i} \text{ adjust by circle standard}
\]

Pij is the perimeter (m) of the focal patch and aij is the area (ha) of the focal patch. N is the total number of focal patch. Mean patch fractal dimension (MPFD) is another measure of shape complexity. It nears 1 when patch shapes are “simple” such as circles and it approaches 2 as patch shape perimeter complexity increases.

Upper mentioned indices values indicate the condition of patch shape structure whether it becomes standard or more complex. Simple or near standard shape has less edge with minimum coves and lobes (Figure 3). Patch is more complex when structural fragments of the patch become high and it deteriorates species ecological core function and promotes edge effect.

3. Results and discussion

After combining the calculated indices values, the nature of forest fragmentation of RFR is understood. The MSI value of both existing and altered forest landscape structure is 1.6869 and 1.5775, respectively. Both values deviated from circle shape (constant value-1), and the deviation value is 0.6869 and 0.5775. In case of altered shape, MSI value is decreased, that means shape complexity is decreased also. It proves that the habitat structural quality is better in altered forest shape than in existing forest shape. Another fragmentation measuring index MPFD value is 1.3954 for existing forest shape and 1.3916 for altered forest shape. A declining tendency is also found in case of altered landscape MPFD value (Figure 4). The total perimeter of the forest patches is 249116.92185 m and area is 7338.84.29 ha for the existing forest landscape. So the PAR is 33.9449 m/ha. In case of altered forest shape PAR is 23.7698 m/ha which decreases from existing forest patch shape (Figure 4). Habitat edge sinking is an important objective for habitat management. A positive relation was found between larger mammals’ frequent movement and habitat edge proportion (Chisholm et al., 2018). Similar concept is found that conflict and species extinction chance will become less when the edge or perimeter of the forest habitat decreases (Bhardwaj & Kumar, 2019). Ultimately, habitat edge proportion in the landscape regulates habitat quality. Altered forest shape in RFR edge length per area is less than the existing landscape so it will improve habitat quality and it also may decline edge effect.

To understand the relationship between patch size and shape, the Pearson Correlation method is applied. It is cleared from this analysis that patches area when increased, PAR decrease. It means that larger patches have less proportion of edge than small patches. Fractal nature of the larger patches also follows the same trend (Figure 5). This result presents the large patches become qualitative than a small patch in the landscape. Same argument and result were found in the work of (Legese, Bekele, & Kiros, 2019) in Gurage zone, Ethiopia and (Campos, Charters, & Verdade, 2018) in south eastern Brazil. But in case of forest patch shape complexity or irregularity in RFR, the relation is found positive to patch area (Figure 6). It means larger forest patches have more shape complexity. Larger more complex patch ecologically become threatened (Mohandass, Hughes, Campbell, & Davidar, 2014) because it holds the
maximum population (Legese et al., 2019) and creates more edge contrast. Therefore, four large patches (Figure 7) in RFR are considered for further specific analysis.

The present study now focuses on patch level indices to understand the fine-scale fragmented situation. For this purpose, work overlooks four larger forest patches in RFR (Figure 7). The indices SI and FD (exclude PAR) value of both altered and existing forest shape structure are compared with each other as same as class level analysis. PAR index is not considered because the areas of selected four larger patches have not in same. The result of this analysis represents same approach which was taken as study objective.

The FD and the SI value of selected four larger patches of existing forest landscape and altered forest landscape are given in Table 1. It has been found that B patch is the largest patch with more complex and fragmented in nature. The SI value is 4.46009 and FD

| Patch name | SI-existing landscape | SI-altered landscape | FD-existing landscape | FD-altered landscape |
|------------|-----------------------|----------------------|-----------------------|----------------------|
| B          | 4.46009               | 2.60451              | 1.32350               | 1.25861              |
| C          | 4.39032               | 3.12504              | 1.32368               | 1.28255              |
| A          | 3.45919               | 2.75358              | 1.29927               | 1.27083              |
| D          | 2.20998               | 2.20998              | 1.26883               | 1.26883              |

Figure 4. Comparison of MSI, MPFD and PAR of existing patches and altered forest patches of RFR.

Figure 5. Correlation between FD and PAR with patch area in RFR existing forest landscape.

Figure 6. Correlation between SI with patch area in RFR existing forest landscape.

Table 1. Both existing landscape and altered landscape indices (SI and FD) values of four larger patches in RFR.
value is 1.32350. But after shape alteration, B patch loses edge length and gain more physical core (Figures 2–7) as a result of it SI and FD values decrease. Same indices values of four patches are gradually declining in respect of altered four patches (Figure 8). When these indices value decrease the shape quality of the forest patches will increase (Plieninger, 2006). This declining trend addresses that altered forest landscape will become less complex and for this it will more qualitative than present forest landscape in the question of shape complexity. It will improve species safe connectivity (Cabarga, et al. 2016; Mandal & Chatterjee, 2018) and enhance physical core area of the same habitat (Begotti, Dos Santos Pacífico, de Barros Ferraz, & Galetti, 2018).

After the alteration of some encroached area into the forest land, the shape complexity decreases in four large patches in RFR. It improves habitat fragment quality more than existing landscape condition. These spatial alterations decrease edge contrast (Rybicki & Hanski, 2013) and enrich patch structural quality in the questions of forest interior area (Didham & Ewers, 2012), edge length (Broadbent et al., 2008) and also patch area.

4. Conclusion
After presenting the result, it is understood that the existing forest shape of RFR becomes more irregular in larger forest patches especially. The present study proves that spatial alteration from the encroached area to forest land is one of the best landscape management methods to minimize structural fragmentation. This landuse alteration method not only minimizes shape complexity but also increases other habitat
qualities like core area, patch size, patch proximity etc. These increased habitat qualities will improve ecological balance in RFR which supports wildlife.

The present study recommends some proposals which are very appropriate for forest management. Firstly, spatial information (detail map) is very essential to manage forest landscape. Forest regeneration by plantation is the best way to increase forest area (Barlow et al., 2007). But the question is that where is the exact place for plantation? The present study helps to find out the exact landuse for it in RFR. If these selected areas will alter into forest land then forest habitat structural quality will improve. This improves forest habitat which will minimize ecological disturbances like man-animal conflict, species extinction and colonization etc. Generally, scattering method of plantation in vacant land must increase forest area but it also creates complexity (Bogucki et al., 2012) which is not good for habitat structure (Inkoom et al., 2018) as well as ecological balance. So land-use selection for plantation is a big factor for increasing and maintaining forest habitat structural quality in a fragmented forest landscape.

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No potential conflict of interest was reported by the authors.

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