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Cover Page Footnote
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Full Length Article

Forest landscape and its ecological quality: A stepwise spatiotemporal evaluation through patch-matrix model in Jhargram District, West Bengal State, India

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Forest fragmentation
Biodiversity

A B S T R A C T

Landscape conversion becomes a continuous process in a natural landscape for any strategic development. In a forest landscape mosaic, the conversion from non-forest land to forest land implies a constructive approach. Various bio-geographic processes are enriched and developed when the land was converted to forest land in a given landscape matrix. The present study evaluated how the increased forest cover improves the ecological quality of forest in Jhargram District of West Bengal State, India, from 1985 to 2015. The quality of forests includes dominance, fragmentation and connectivity, which are the basis ecological indicators of habitat structure. To address this issue, we extracted forest cover maps of 1985 and 2015 from land use/land cover classification. A grid framework was overlaid on these forest cover maps for patch-matrix model analysis. Reliable landscape ecological indices were used for the measurements of forest landscape quality in 1985 and 2015. Then a simple linear regression model was used to compare the results. Temporally, forest cover increased in Jhargram District from 1985 to 2015. The comparison of measurement indices depicts that although only a small amount of land was changed into forest land in the study area, this small change has greatly improved the structural compositional quality of the forest land. Compared with 1985, the forest land area increased by about 6930.56 hm² in 2015. This increased forest cover improved the basic landscape ecological characters, such as inter patch connectivity, forest core area, forest habitat dependence, forest habitat dominance and forest edge effect. As a result, the ecosystem function in Jhargram District has been improved, which again attracts wildlife and enriches biodiversity.

1. Introduction

Landscape ecology is a unique science to evaluate ecosystem function (Farina, 2008; Termorshuizen and Opdam, 2009; Naveh and Lieberman, 2013). Space-species interaction is a prime concept in landscape ecological studies. So, land or space is a very important segment of this study. Ecosystem function is determined by land characters, such as the nature, structure, position, and so on. Therefore, a definite land or habitat becomes a unit of such kind of study. It is a new branch of science that deals with structure, composition and configuration of a unit landscape and its ecological function (Turner, 2005). The issue of wildlife management mostly gives stress in existing landscape (Gülçin and Yilmaz, 2020), because landscape plays a significant role in biological processes and patterns. These biological processes and patterns are directly related to landscape fragmentation, habitat regeneration, habitat modification and habitat
connectivity. All these biological processes and patterns are depending on landscape diversity (Lindenmayer and Fischer, 2006; Mortelliti et al., 2010; Niemeyer et al., 2020). Diversity in the form of land use type includes forest cover, agricultural land, water body, built-up area, etc. Forest cover is one of the most important land use types in biodiversity management (Ramachandra et al., 2018; Shen et al., 2019), because there is a strong relationship between wildlife in forest and forest landscape.

Remote sensing information, especially satellite data, are enormously used in the field of landscape analysis. Model analysis through image processing and preparation is now being a common way to flourish any specialization. At the same time, methodological development and geometric approach help to create landscape ecology as a distinct field (Frazier, 2019). Patch-matrix model is a very useful method that combines spatial entity with ecosystem function in this field (Frazier and Kidron, 2017; Kidron et al., 2018; Palmero-Iniesta et al., 2020). This model carries out several ecological indices, which can quantify landscape from a spatial background and present its ecological value (McGarigal and Marks, 1995; Lamine et al., 2018). Several researchers from different fields of ecology used this model to evaluate landscape ecological significance. The present study also recommends and uses this model to clarify the forest landscape quality of Jhargram District in West Bengal State of India.

Landscape heterogeneity is the focal theme in landscape ecological research. Generally, more heterogeneous landscape creates more complexity (Forman, 1995; Arroyo-Rodríguez et al., 2017; Piña et al., 2019). More complex or diversified landscape leads to more imbalance in existing ecosystems (Sirami, 2016). Diversified landscape is created from fragmentation, reclamation, regeneration and isolation processes. Forman (1995) and Lindborg et al. (2014) clarified that landscape becomes diversified into smaller units due to fragmentation and isolation processes, which contributes to the imbalance of the ecosystem. Chazdon and Guariguata (2016) believed that sometimes regeneration process like forest regeneration can improve landscape homogeneity. In both cases, anthropogenic demand is responsible for landscape heterogeneity (Crouzeilles et al., 2017). Historically, anthropogenic activities have divided the virgin land into different land units by different purposes (Randolph, 2004; Cushman, 2006). Separation and transformation process restructures the structure and composition of the existing landscape, exerting an impact on ecological processes and patterns.

Every land unit (i.e., patch) has a significant role in ecosystem function (Forman, 1995; Farina, 2008; Lovell and Johnston, 2009; Paudel and Yuan, 2012). Some land components play a dominant role than others, such as forest patch in an agricultural matrix. Forest patch is considered as a suitable habitat for wildlife (Wheatley, 2010). Its characters such as size, amount, orientation, position and structure reflect the complexity, dominance and heterogeneity of forest landscape (Garmendia et al., 2013); these characters are also connected to ecological processes such as species colonization, movement, survival capacity, contrast, extinction, etc. Therefore, structural composition of the forest cover is a prime subject in landscape ecological analysis (Geri et al., 2010; Pan et al., 2013; Magioli et al., 2019).

Landscape of Jhargram District and its adjoining area was once full of wildlife and wilderness (O’Malley, 1914). For this, the district with surrounding area was known as ‘Jungle Mahal”—land of forest. After independence of the country (India), massive forest destruction fundamentally altered the forest landscape, which restructured the forest patch shape (Gupta and Mishra, 2019). Forests have been destroyed due to agricultural expansion, industrial setup, road network development and high demand for forest products. These activities negatively impacted the entire ecosystem function and partially destroyed the ecological balance (Das and Ghosh, 2014). As a result of forest destruction, many wildlife becomes rare, vulnerable and irregular in this region in the second half of the 20th century (Singh et al., 2002). But after 1980, forest destruction intensity gradually decreased due to the successful forest management process. Reforestation and regeneration of forests in open land, barren land and vacant land increased the area of forest cover and restructured the forest patch shape by the implementation of “Joint Forest Management Program” (Sarker et al., 2006). At the beginning of the 21st century, wildlife movement was once again found in the district’s forests (Mandal and Das Chatterjee, 2019; Khatua et al., 2020). Species richness gradually enriched, in particular, large size mammals were found in surroundings areas of this district (Mandal and Das Chatterjee, 2018). Events such as migration, colonization and predation are common currently. Now the question is why did these activities start and why does wildlife prefer this area for their residence again? Moreover, it is necessary to find out the responsible factors behind this phenomenon.

The present study considered that the temporal landscape ecological quality difference is responsible for the changing situation because forestry programs have been continued for two decades in this district. These forest regeneration processes restructured and recomposed the regional landscape. Satellite images showed that forest cover increased by 6930.56 hm² during 1985–2015. These restructured forest patches are important for the ecological restoration and the understanding of forest patches is the primary objective of this study. Therefore, our study evaluated the landscape of Jhargram District for both the past (1985) and present (2015) periods to obtain answers to this certain question. Further, the correlation between forest habitat structure and its ecological quality can be obtained through technical comparison analysis.

2. Materials and methods

2.1. Study area

Jhargram District (21°52’54’’—22°48’24’’N, 86°34’49’’—87°20’35’’E) is located in the southwestern part of West Bengal State, India. It covers an area of 3037.64 km², of which agricultural land is the first dominant land use type (2682.49 km²) and forest cover is the second dominant land use type (594.97 km²). The district is the extended part of Chhotanagpur Plateau. Geo-morphologically, the region gradually tilts eastwards, with a greater tilt in the northwest. It is bounded by the Kangsabati River and partly by the Subarnarekha River from the western border of Khagragarh Division. The forest type of Jhargram District is tropical dry deciduous forest (Das and Das, 2016). Sal (Shorea robusta) is the dominant tree species in this area. The planted forests are mostly open in nature. The old-age or mature forests are mixed with miscellaneous species like Piasal (Pterocarpus marsupium), Palash (Butea monosperma), Kusum (Frazier, 2019).
(Schleicheria oleosa), Mahua (Madhuca longifolia), Neem (Azadirachta indica), Arjun (Terminalia arjuna), etc. Recently, Sonajhuri (Acacia auriculiformis) and Eucalyptus (Eucalyptus globulus) trees are widely planted for their faster growth and high economic demand.

2.2. Data sources

Satellite images are often used to analyze landscape characters. More recently, ecologists have used satellite images to detect spatiotemporal change of landscape and evaluate landscape characters (Skidmore et al., 2011). In same manner, the present study collected satellite images from the United States Geological Survey (USGS) Global Visualization Viewer (GloVis) (http://glovis.usgs.gov/). Landsat TM data of 1985 and Landsat 8 (OLI/TIRS) satellite data of 2015 were used in the study area, and the spectral resolution of both is 30 m. For land use/land cover (LULC) classification, supervised techniques (Pal and Mather, 2004, 2005; Bouaziz et al., 2017), including Spectral Angle Mapping (SAM) and Support Vector Machine (SVM) algorithm, were applied to analyze the images (1985 and 2015). Based on spatial coverage of the study area and the field investigation, we divided a single forest class into 14 points. We chose five LULC classes for classification, i.e., agricultural land, forest cover, built-up area, barren land and water body (Fig. 1). The classified maps in 1985 and 2015 were further cross verified with field investigation. Finally, we addressed these maps for consideration when the classification accuracy was more than 90% based on the Kappa coefficient (Smits et al., 1999).

2.3. Methods

After classifying the images, we only extracted forest cover class for both the images (LULC and grid framework images) to evaluate the forest landscape by patch-matrix model. For precise and better accuracy assessment, we divided the entire district into grids (5 km × 5 km for each) by using Fishnet tool in ArcGIS 10.3 (Esri, USA). This grid frame was intersected with forest cover map to obtain grid wise forest cover land (Fig. 2). Then, this forest grid map was compiled for patch matrix analysis.

2.4. Level of landscape ecological analysis by patch-matrix model

Ecologically, the hierarchy of the landscape is composed of patch, class and landscape. Patch is the homogeneous unit of land that is separated from surroundings (Forman, 1995). Similar patch type in the landscape is considered as a class. All classes within a specific boundary are considered as a landscape. The present study considered class level (single corresponding forest patch) for evaluating the ecological quality of forest landscape using patch matrix model, when the grid information is the smallest unit in the study area. This model uses several indices to interpret landscape ecological significance (Table 1), i.e., largest patch index (LPI), mean core area (MCA), total core area index (TCAI), mean patch size (MPS), total edge index (TEI), edge density index (EDI), area weighted mean shape index (AWMSI), area weighted mean patch fractal dimension (AWMPFD), mean nearest neighborhood distance index (MNN) and mean proximity index (MPI). Geometrically, most of the indices can be used to calculate patch size, structure and its location. The study extracted ecological index values from grid forest class as a whole by using FragStat 4.2 software (United States Department of Agriculture and Pacific Northwest Research Station, USA).

2.5. Significance of ecological indices

The present study measured different ecological indicators in a forest landscape, such as habitat dominance, connectivity and fragmentation. These landscape ecological index values depend on habitat structure, amount and position. The patch size and patch core

![Fig. 1. Spatial distributions of land use/land cover (LULC) in Jhargram District in 1985 (a) and 2015 (b).](image-url)
have significant impacts on ecological processes and patterns, especially in species colonization and habitat performance (Fahrig, 2013; Velázquez et al., 2018). Forest patch dominance was measured by LPI, MCA, TCAI and MPS. The class dominance was increased with the increasing of all index values. Forest patch fragmentation is another significant indicator considered in this study. The higher the degree of landscape fragmentation, the worse the ecological quality (McGarigal and Marks, 1995; Mandal and Das Chattarjee, 2018). In this study, ecological fragmentation was measured by TEI, EDI, AWMSI and AWMPFD. The higher the index values, the higher the degree of landscape fragmentation. Forest patch connectivity is also another important criterion for ecological study, which relates to animal movement patterns (Gustafson and Parker, 1994). Connectivity was measured by using physical connectedness of corresponding forest patches (Dramstad et al., 1996; Gutzwiller, 2002; Fahrig, 2013) and calculated by MNN and MPI of the forest class. The higher the MNN value, the lower the connectivity, as it represents the distance between corresponding forest patches. Further, when the MPI value is high, it indicates that the corresponding forest patches are compact in nature and support the free movement of species.

3. Results

The main objective of the study is to assess and compare the forest landscape quality in Jhargram District between 1985 and 2015. The present study attempts to represent the comparative results hierarchically from landscape level to patch level. Landscape level means the total forest cover of Jhargram District as a whole. Grid wise forest cover quality was described and explained by various landscape indices.

3.1. Forest ecological quality at the landscape level in Jhargram District

Geo-statistical analysis showed that ecological quality of forests in Jhargram District was improved over time, especially for forest cover. The area of forest cover was approximately $7.60 \times 10^4$ hm² in 1985 and increased to $8.29 \times 10^4$ hm² in 2015. Analysis also presented that the selected ecological indices functioned positively on forest cover from 1985 to 2015. In most cases, reforestation was implemented in the barren land areas, and adjoining forest areas were also being considered for forest regeneration. All these processes ultimately enriched the forest cover (Sudhakar and Raha, 1994; Das Chatterjee, 2016). Not only forest cover but other ecological quality also increased positively over time. Forest dominance, fragmentation and connectivity indicators were comparatively better in 2015 than in 1985. In terms of forest dominance, LPI, MCA, TCAI and MPS were all improved compared with 1985 (Table 2). For the forest fragmentation, only TEI value showed an increase trend among all the four selected ecological indices (TEI, EDI, AWMSI and AWMPFD); it was higher in 2015 than in 1985 due to the expansion of forest cover in Jhargram District. Specifically, the extra patch perimeter added by new patch formation during 1985–2015 directly led to the increase of TEI value; it is a general concept in geometry that the increasing in the amount of size would increase the shape perimeter. So, there is a positive relationship between patch edge and patch area. In the case of EDI, it was declined from 1985 to 2015. The results showed that the proportional edge length of forest patches decreased from 1985 to 2015, which is a better indication for forest ecological quality in the matter of forest fragmentation. Other fragmentation indices including AWMSI and AWMPFD were also lower in 2015 than in 1985 (Table 2). Forest patch connectivity in
3.2. Forest ecological quality at the patch level based on its number, size and amount in Jhargram District

Each forest patch has its specific structure and size, and owns its ecological significance (Dramstad et al., 1996). Any alteration in a landscape will change the structure and size of patches. Similar situation was also found in the forest patches of Jhargram District from 1985 to 2015. In order to determine the quality of the forest patches on the basis of their size, amount and position for the study period, the present study used grid wise forest cover information as independent variable. A simple linear correlation statistic ($r = a + bx$) was used to determine and compare the quality of the forest patches between 1985 and 2015. The theory of island biogeography suggests

<table>
<thead>
<tr>
<th>Landscape ecological pattern</th>
<th>Index</th>
<th>Method</th>
<th>Description</th>
<th>Unit</th>
<th>Range</th>
<th>Ecological importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dominance</td>
<td>LPI</td>
<td>n</td>
<td>$a_i = \text{area (m}^2\text{)} \text{ of patch } i\text{ class}; A = \text{total landscape area (m}^2\text{)}$</td>
<td>%</td>
<td>$0 &lt; \text{LPI} &lt; 100$</td>
<td>Patch dominance over the landscape (the higher the value, the higher the importance)</td>
</tr>
<tr>
<td></td>
<td>LPI</td>
<td>$\max_{j=1}^{n} (a_{ij})$</td>
<td>$a_j = \text{core area (m}^2\text{)} \text{ of patch } j\text{ based on specified-edge depth (300 m); } n_i = \text{number of patches in the landscape of patch type (class) } i$</td>
<td>m$^2$</td>
<td>$&gt;0$, without limit</td>
<td>Amount of patch class core from entire the landscape (the higher the value, the higher the importance)</td>
</tr>
<tr>
<td></td>
<td>MCA</td>
<td>$\sum_{i=1}^{n} a_i / n_i (10000)$</td>
<td>$a_i = \text{area (m}^2\text{)} \text{ of patch } i\text{ class}; n_i = \text{total number of patches in } i\text{ class}$</td>
<td>m$^2$</td>
<td>$&gt;0$, without limit</td>
<td>Nature of patch class size from entire the landscape (the higher the value, the higher the importance)</td>
</tr>
<tr>
<td></td>
<td>MPS</td>
<td>$\sum_{i=1}^{n} a_i / n_i (10000)$</td>
<td>$a_i = \text{area (m}^2\text{)} \text{ of patch } i\text{ class}; n_i = \text{total number of patches in } i\text{ class}$</td>
<td>m$^2$</td>
<td>$&gt;0$, without limit</td>
<td>Patch class core dominance over the landscape (the higher the value, the higher the importance)</td>
</tr>
<tr>
<td></td>
<td>TCAI</td>
<td>$\sum_{i=1}^{n} a_i (100)$</td>
<td>$a_i = \text{core area (m}^2\text{)} \text{ of patch } i\text{ based on specified-edge depth (300 m); } a_i = \text{area (m}^2\text{)} \text{ of patch } i\text{ class}$</td>
<td>%</td>
<td>$0 &lt; \text{TCAI} &lt; 100$</td>
<td>Patch class core dominance over the landscape (the higher the value, the higher the importance)</td>
</tr>
<tr>
<td>Fragmentation</td>
<td>TEI</td>
<td>Sum of perimeter of all corresponding patches</td>
<td>m</td>
<td>$&gt;0$, without limit</td>
<td>Amount of patch class perimeter (the higher the value, the lower the importance)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>EDI</td>
<td>$\sum_{i=1}^{n} e_{ij} / A (10000)$</td>
<td>$e_{ij} = \text{total length (m) of edge in the landscape involving patch type (class) } i; A = \text{total landscape area (m}^2\text{)}$</td>
<td>m$^2$/m</td>
<td>$&gt;0$, without limit</td>
<td>Patch class edge proportion to the total patch area (the higher the value, the lower the importance)</td>
</tr>
<tr>
<td></td>
<td>AWMSI</td>
<td>$\sum_{i=1}^{n} \left( \frac{25p_i}{\sqrt{a_i}} \right) \left( \frac{a_i}{\sum_{i=1}^{n} a_i} \right)$</td>
<td>$p_i = \text{perimeter (m) of patch } i; a_i = \text{area (m}^2\text{)} \text{ of patch } i; n_i = \text{number of patches in the landscape of patch type (class) } i$</td>
<td></td>
<td>$&gt;1$, without limit</td>
<td>Patch class shape complexity of entire the landscape (the higher the value, lower the importance)</td>
</tr>
<tr>
<td></td>
<td>AWMPFD</td>
<td>$\sum_{i=1}^{n} \left( \frac{250s_i}{1000a_i} \right) \left( \frac{a_i}{\sum_{i=1}^{n} a_i} \right)$</td>
<td>$a_i = \text{area (m}^2\text{)} \text{ of patch } i; s_i = \text{perimeter (m) of patch } i; n_i = \text{number of patches in the landscape of patch type (class) } i$</td>
<td></td>
<td>$1 &lt; \text{AWMPFD} &lt; 2$</td>
<td>Fractal nature of the patch class of entire the landscape (the higher the value, lower the importance)</td>
</tr>
<tr>
<td>Connectivity</td>
<td>MNN</td>
<td>$\sum_{i=1}^{n} h_i / n_i$</td>
<td>$h_i = \text{distance from } i\text{ to a nearest neighboring patch of the same type (class) } i, \text{ based on patch edge-to-edge distance}; n_i = \text{number of patches in the landscape of patch type (class) } i$</td>
<td>m</td>
<td>$&gt;0$, without limit</td>
<td>Distance between nearest single class patch (the higher the value, the lower the importance)</td>
</tr>
<tr>
<td></td>
<td>MPI</td>
<td>$\sum_{i=1}^{n} \left( \frac{a_i}{h_i} \right) \left( \frac{h_i}{a_i} \right)$</td>
<td>$a_i = \text{area (m}^2\text{)} \text{ of patch } i\text{ within the specified neighborhood (m) of the patch } i; h_i = \text{distance (m) between patch } i\text{ and patch } j\text{, based on patch edge-to-edge distance}$</td>
<td></td>
<td>$&gt;0$, without limit</td>
<td>Compactness of single class patch (the higher the value, the higher the importance)</td>
</tr>
</tbody>
</table>

Note: LPI, largest patch index; MCA, mean core area; MPS, mean patch size; TEI, total edge index; EDI, edge density index; AWMSI, area weighted mean shape index; AWMPFD, area weighted mean patch fractal dimension; MNN, mean nearest neighborhood distance index; MPI, mean proximity index; $\cdot$, dimensionless.

2015 was improved compared with that in 1985. From the comparison of MPI and MNN, forest patches tended to cluster in 2015 (Table 2). In general, the comparative results of all the selected indices between 1985 and 2015 depicted that the quality of forest patches has been improved since 1985.
that larger forest patches have maximum dependence than smaller forest patches (MacArthur and Wilson, 1967). In the present study, a common positive trend was found for MPS, MCA and TCAI. The comparison results showed that the linear correlation coefficient value \( r \) was more confident in 2015 than in 1985 (Fig. 3). As a result, larger forest patches were more dependable in 2015 than in 1985. Thus, the dependence of larger forest patches was better in 2015 than in 1985 in Jhargram District.

Grid wise forest cover and fragmentation indices (AWMPFD, AWMSI and EDI) were positively correlated in the regression analysis (Fig. 4), which means that forest class fragmentation is more profound in grids of the large forest patches than the small forest patches in Jhargram District for both 1985 and 2015. Paluch (2007) and O’Hara (2014) stated that high structural shape complexity of the large forest patches will cause the imbalance of ecological processes. The complexity of the larger forest patches in Jhargram District was higher in 1985 than in 2015. As a result, the correlation coefficient \( r \) of all the three indices gradually declined from 1985 to 2015 (Table 3). This declining trend indicated that the ecological quality of the large forest patches with structural fragmentation was partly improved after 1985.

In case of connectivity assessment, regression analysis depicted positive relationship between grid wise forest cover and MPI and negative relationship between grid wise forest cover and MNN in both 1985 and 2015 (Fig. 5). Generally, the large forest cover patches

### Table 2
Variations of ecological indices of forest cover class in Jhargram District from 1985 to 2015.

<table>
<thead>
<tr>
<th>Ecological pattern</th>
<th>Index</th>
<th>Unit</th>
<th>Forest class of</th>
<th>Forest class of</th>
<th>Comparative value between 1985 and</th>
<th>Ecological significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1985</td>
<td>2015</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dominance</td>
<td>LPI</td>
<td>%</td>
<td>5.18</td>
<td>5.35</td>
<td>+0.15</td>
<td>Positive</td>
</tr>
<tr>
<td></td>
<td>MCA</td>
<td>hm²</td>
<td>126.15</td>
<td>143.24</td>
<td>+17.09</td>
<td>Positive</td>
</tr>
<tr>
<td></td>
<td>MPS</td>
<td>hm²</td>
<td>274.37</td>
<td>298.31</td>
<td>+23.94</td>
<td>Positive</td>
</tr>
<tr>
<td></td>
<td>TCAI</td>
<td>%</td>
<td>40.17</td>
<td>42.83</td>
<td>+2.66</td>
<td>Positive</td>
</tr>
<tr>
<td>Fragmentation</td>
<td>TEI</td>
<td>×10⁶ m</td>
<td>2.33</td>
<td>2.39</td>
<td>+0.06</td>
<td>Negative</td>
</tr>
<tr>
<td></td>
<td>EDI</td>
<td>m/hm²</td>
<td>30.68</td>
<td>28.87</td>
<td>−1.81</td>
<td>Positive</td>
</tr>
<tr>
<td></td>
<td>AWMSI</td>
<td>–</td>
<td>1.99</td>
<td>1.98</td>
<td>−0.01</td>
<td>Positive</td>
</tr>
<tr>
<td></td>
<td>AWMPFD</td>
<td>–</td>
<td>1.08</td>
<td>1.08</td>
<td>0.00</td>
<td>None</td>
</tr>
<tr>
<td>Connectivity</td>
<td>MNN</td>
<td>m</td>
<td>761.20</td>
<td>740.70</td>
<td>−20.50</td>
<td>Positive</td>
</tr>
<tr>
<td></td>
<td>MPI</td>
<td>–</td>
<td>15.18</td>
<td>19.38</td>
<td>+4.20</td>
<td>Positive</td>
</tr>
</tbody>
</table>

Note: “+” in the column of comparative value between 1985 and 2015 indicates that the value of the index was higher in 2015 than in 1985; “-” indicates that the value of the index was lower in 2015 than in 1985; “-” means dimensionless.
were more proximity to each other due to short inter patch distance, i.e., the large forest cover patches were more clustered in nature than the small forest cover patches. The regression analysis results showed that the connectivity of the large forest patches had increased partly during 1985–2015 (Fig. 5), because the correlation coefficient values were positively significant in 2015 than in 1985.

### 3.3. Forest ecological quality assessment at the patch level in selected grid

Analysis of grid wise forest cover depicted that the ecological quality of the large forest patches became more profound than that of the small forest cover patches. The regression analysis results showed that the connectivity of the large forest patches had increased partly during 1985–2015 (Fig. 5), because the correlation coefficient values were positively significant in 2015 than in 1985.

#### Table 3

<table>
<thead>
<tr>
<th>Ecological pattern</th>
<th>Index</th>
<th>Unit</th>
<th>1985</th>
<th>2015</th>
<th>Correlation coefficient (r) difference between 1985 and 2015</th>
<th>Ecological significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dominance</td>
<td>MCA</td>
<td>hm²</td>
<td>0.692</td>
<td>0.694</td>
<td>0.002</td>
<td>Positive</td>
</tr>
<tr>
<td></td>
<td>MPS</td>
<td>hm²</td>
<td>0.832</td>
<td>0.853</td>
<td>0.021</td>
<td>Positive</td>
</tr>
<tr>
<td></td>
<td>TCAI</td>
<td>%</td>
<td>0.845</td>
<td>0.856</td>
<td>0.011</td>
<td>Positive</td>
</tr>
<tr>
<td>Fragmentation</td>
<td>EDI</td>
<td>m/hm²</td>
<td>0.880</td>
<td>0.874</td>
<td>-0.006</td>
<td>Negative</td>
</tr>
<tr>
<td></td>
<td>AWMSI</td>
<td>–</td>
<td>0.670</td>
<td>0.652</td>
<td>-0.018</td>
<td>Positive</td>
</tr>
<tr>
<td></td>
<td>AWMPFD</td>
<td>–</td>
<td>0.618</td>
<td>0.604</td>
<td>-0.014</td>
<td>Positive</td>
</tr>
<tr>
<td>Connectivity</td>
<td>MPI</td>
<td>–</td>
<td>0.408</td>
<td>0.500</td>
<td>0.092</td>
<td>Positive</td>
</tr>
<tr>
<td></td>
<td>MNN</td>
<td>m</td>
<td>-0.154</td>
<td>-0.164</td>
<td>-0.010</td>
<td>Positive</td>
</tr>
</tbody>
</table>

Note: “-” means dimensionless; “r” indicates correlation coefficient between grid wise forest cover and selected ecological indices.

Fig. 4. Linear correlation of grid wise forest cover with AWMSI (a and d), AWMPFD (b and e) and EDI (c and f) in Jhargram District in 1985 and 2015. AWMSI, area weighted mean shape index; AWMPFD, area weighted mean patch fractal dimension; EDI, edge density index.

Fig. 5. Linear correlation of grid wise forest cover with AWMSI (a and d), AWMPFD (b and e) and EDI (c and f) in Jhargram District in 1985 and 2015. AWMSI, area weighted mean shape index; AWMPFD, area weighted mean patch fractal dimension; EDI, edge density index.
trend reflected that the forest quality of selected grid area was more balanced in 2015 than in 1985.

Core area of forest patches, especially the core area of the large forest patches has the capacity to hold and attract wildlife from surrounding areas (Forman, 1995). In this study, we observed that the core area of the large forest patches improved from 1985 to 2015 in selected grid area (Fig. 8). Habitat dominance and dependence are connected to the capacity within the forest or in the forest core area (Gardiner et al., 2018; McIntosh et al., 2018). At the edge depth of 300 m, the forest core area of selected grid area was 3067.62 hm² in 1985 and 5564.04 hm² in 2015, with the difference of 2496.42 hm² (Fig. 8). This result showed that the forest core area or interior area in selected grid area increased positively from 1985 to 2015. So, it can be seen that the ecological quality of selected grid area was
improved over time. Only by making reasonable or scientific land use change policy can we achieve this goal.

4. Discussion

4.1. Landscape pattern and its ecological function

Landscape ecological function is controlled by the structure and composition of landscape (Forman, 1995). Characters of ecological patterns and ecological processes are functioned by habitat structure and composition quality (Fahrig, 2013). Therefore, habitats such as forests play an important role in regional ecosystem. It is not uncommon for the number and structure of forests to change over time. In
this study, we found the same process in Jhargram District where forest cover increased from past by forest regeneration. It is very simple that the enlargement of forest cover is one of the important factors for improving the quality of forests (Mandal and Das Chattarjee, 2020a). However, in some areas, the quality of forest habitats has declined with increasing forest cover (Mandal and Das Chattarjee, 2020b), and the land use change policy does not maintain the structural quality. Generally, scattered forest plantation pattern is responsible for the above situation (Mandal and Das Chattarjee, 2020c). Scattered afforestation processes lead to increased fragmentation and loss of habitat dependence despite the increase in forest cover. However, in the study area, forest fragmentation process has been consistently managed from the past. Barren lands and deforested lands around the forest patches were planted in this district. As a result, areas of the forest patches increased with the increasing of forest cover, which can be observed from the forest class images of 2015; it is found that the increase in the areas of the forest patches was due to reforestation (Fig. 6). The process (reforestation) enriched the forest area without adding extra number of patches and forest fragmentations. For this reason, the ecological index values reflected the positive function in comparison analysis from 1985 to 2015. This approach ultimately facilitated to manage forest landscape rationally. As a result, this well managed forest landscape attracted wildlife in this district. Now, wildlife activities and colonization process have increased, depending on suitable patterns of forest structure.

Habitat deterioration and species extinction are common themes of biodiversity. In particularly, habitat fragmentation due to unscientific planning puts pressure on existing ecosystems, as stated by Bovendorp et al. (2019) and Padalia et al. (2020) that in humid and dry forest areas, native species becomes more vulnerable as forest habitats continue to be fragmented. The similar situation has been found in the adjoining areas of Jhargram District in southwestern Bengal State by Dutta et al. (2020). But only in the present study area, the situation is under the management of scientific planting plans. Therefore, the current forest cover in Jhargram District exhibits the ecological characteristics of species colonization, safe migration, increased species biodiversity, etc. Habitat dominance, connectivity and fragmentation processes play a more positive role in the existing landscape than in the past. The increase in the areas of the forest core creates a more suitable shelter for wildlife (Fig. 8). Forest fragmentation, an important way of managing forests, has also fallen. Because highly fragmented forest habitats create obstacles to the free movement of wildlife species as stated by Dramstad et al. (1996), it also leads to the problem of human-animal conflict (Mandal and Das Chattarjee, 2018). Das Chattarjee and Chatterjee (2014) and Mandal and Das Chattarjee (2018) argued that in the Dalma Wildlife Sanctuary in Jharkhand District, the existing ecosystems become fragile and wildlife becomes endangered due to the extensive fragmentation of forest habitats. Land conversion to forest land in adjoining forest patches in Jhargram District has a significant influence on biodiversity. This scientific way improves the overall structural quality of the habitat and contributes to the survival of native wildlife species; it further increases the diversity of the ecosystem in this district.

Fig. 9. Elephants in different forest habitats at day time in Jhargram District (photographed by Mr. Rakesh Singha Dev). (a), Kalabani forest; (b), Jitushole forest; (c), Kushbani forest.
4.2. Improvement of forest quality and species interaction

It is clear that the forest quality has been improved in Jhargram District. Wildlife activities, especially elephant activities, such as colonization and their movement, are found regularly in this district, depending on the quality of these improved forests. The wild elephants from surrounding habitats prefer these forest areas as their permanent habitat (Mandal and Das Chattarjee, 2020d). Not only elephant, but other common local species are getting richer in the present than in the past, as stated by Pandit and Chanda (2019); they also argued that the forest ecosystem is now better and more balanced. As a result, some extinct wild species come back into the forests. The improved larger forest patches provide suitable hiding and resting places for wild animals. They not only provide shelter, but also support a proper food source for elephants (Guha, 2017). During the field survey, local people told us that several elephants had recently been in the surrounding forests for a few days. They come out of the forests into the agricultural areas at night and returned to the forests from the nearest agricultural fields in the early morning. In the day time, they took rest in the forests. These statements by local people suggest that the current forest quality is sufficient to sustain the elephants’ needs, so they may not move or look for surrounding habitats for better shelter. It is interesting that some bull elephants have now become residents in nature in adjoining forests of this district (Fig. 9).

5. Conclusions

Landscape ecological quality is directly related to fragmentation process. Habitat fragmentation is a multi-dimensional process affecting regional ecosystem. This process is very common in nature. We found that the forest structure was more fragmented in Jhargram District in the past. Fragmentation occurred due to the destruction of forest patches that affected the structural composition of the habitats. The impact of this process was measured by the spatiotemporal analysis. Forest fragmentation has two major causes: destruction of forest and unscientific forest plantation. Unscientific land use change plays a more significant role in forest fragmentation and deterioration of ecological quality. Therefore, scientific and rational afforestation process is an urgent way to manage the structural quality of forest habitats as well as to save vulnerable species in a specific region. Specially, in the forest landscape, the encroachment area of plantation should be considered to improve the quality of patch structure. This has been found in Jhargram District, where adjoining land has been converted into forest land. This study discussed the relationship between the ecological quality of forest habitats and their structure. Therefore, if this type of alteration process is implemented in the surrounding areas of the study area, then the overall ecological quality of the region may be improved and this improved forest structure will contribute to the balance of the ecosystem, helping the survive of native wildlife species in this region and reducing the risk of extinction.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References


