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Assessment of Forest Fragmentation of Rajaji National Park, Uttarakhand

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ABSTRACT

The geospatial landscape characterization of Rajaji National Park (RNP), Uttarakhand, exhibited Forest as the largest patch among the four land-use classes of Forest, Scrub, Water channels, and Non-Forest. The Land Use Land Cover (LULC) changes for 10 years from 1995 to 2005 depicted a decrease in forested area by 17% and water area by 20%. On the other hand, non-forest areas increased by 35% and scrub area increased by 172%. However, in the next 10 years, from 2005 to 2015, new management practices in the park resulted in an increase in the forest by 2% and water areas by 32%, respectively; there was a decrease in the non-forest area by 38%. However, the scrub area had increased again by another 15%. Overall, in 20 years, from 1995 to 2015, there was 212% increase in area under scrub and 15% decrease in area under forest. The steady increase in area under scrub resulted in greater patchiness of the RNP landscape that impacted qualitative indices such as Shannon's diversity index, contiguity, connect and fractal dimensions of the Park landscape from 1995 to 2015. The invasive character of the scrub was primarily due to the presence of the invasive species *Lantana camara,* which was one of the driving forces that fragmented the forests of RNP. The scrub not only increased in number and size but also exhibited multi-directional dispersion. The invasive attribute of the scrub exhibited a tendency to coalesce its random patches and engulf the forested areas. The regular monitoring, assessment and remodelling of the scrub would be critical in combating the forest fragmentation of RNP. Hence, this study brings forth the use of geospatial tools as an effective medium for studying the quantitative and qualitative changes in land use patterns of large protected areas. Such studies are important to ensure the ecosystem services of a National Park for in-situ biodiversity conservation.

Key words: Connectedness, Conservation, Fractal dimension, Invasive species, LULC, Patchiness, Scrub

INTRODUCTION

In recent years, there has been an ongoing global discussion about the large-scale deforestation of Tropical forests driven by activities having short term goals. In the long run, the rapid deforestation of tropical forests has led to the fragmentation of such ecosystems and the rapid loss of biodiversity (Geist and Lambin 2002). Unfortunately, habitat degradation and biodiversity erosion have resulted in the loss of essential ecosystem services that have a widespread and cascading impact on the local ecosystems and the global environment (Rindfuss et al. 2004). The negative impacts of biodiversity loss are not limited to only natural systems. It also greatly impacts the world's social and economic systems, leading to many natural and man-made disasters (Carleton and Hsiang 2016). Invasion by different alien species is another threat to forest fragmentation, which is affected by ecosystem heterogeneity, geographical uniqueness, and human interferences (Kumar et al. 2019). Geospatial tools can provide solutions for the large-scale characterisation of various ecosystem at landscape level. It can also help better understand the pattern of interactions of various ecosystems of an area for biodiversity management. Satellite remote sensing data provides specific and accurate need-based information about forest cover, vegetation type, and land use changes in a given area. It helps in various conservation programs in accessible and inaccessible terrains. This assessment approach is cost-effective, time-saving and safe method of monitoring land use land cover (LULC) changes in large areas. Among various mechanisms, establishing the protected area network has been the most efficient means for managing and monitoring the land use land cover changes of any given area. So much so that, 9% of the earth's surface, covering over 100,000 protected areas, had already been established across the globe by the end of the 20th century. The number of national parks in India increased from 8 to 85 between 1975 and 1998.

Rajaji National Park (RNP) in Uttarakhand, India, is one such initiative for biodiversity conservation. Rajaji National Park, primarily a tiger reserve, is situated along the Shivaliks at the foothills of the Himalayas. In 1983, Motichur, Chilla, and Rajaji wildlife sanctuaries were merged into one as Rajaji National Park. However, the park ecosystem had degraded, restricting the regeneration of many important plant species. The degradation of the park ecosystem was considered mostly due to anthropogenic activities by Gujjars (nomadic community) and elephant-induced destructions. Simultaneously, urbanization and industrialization were considered as other main anthropogenic activities in the National Park (Joshi et al. 2011). Hence, the objective of the present study was to analyse the land use land cover changes in the park over a period of 20 years by using geospatial tools. The study aimed not only to quantify the land use changes but also to have a qualitative insight into the ecosystem functioning of the Park landscape by using geospatial tools.

MATERIAL AND METHODS

Study area

Rajaji National Park is situated at 29°15' to 30°31' N latitude and 77°52' to 78°22' E longitude, covering an area of 820.42 km^2 along the Shivalik. The park is situated between the lesser Himalaya and the upper Gangetic plains at 302-1000 m asl. (Fig. 1). Rajaji National Park has gained ecological importance for its rich flora and also for conserving the tigers and Asian elephants in their natural habitat.

In the past, the anthropogenic pressures from the pastoral Gujjars who lived within and adjacent to the park to feed their livestock severely threatened the forest ecosystem of the park. Earlier, the Gujjars would migrate to the Himalaya in summer along with their buffaloes and other livestock, and return to the foothills in the winter. However, later, they were forced to stay in the foothills continuously due to the opposition from the hill people. The round the year habitation of the Gujjars with their animals at the foothills induced sustained stress on the natural resources of the Park ecosystem.

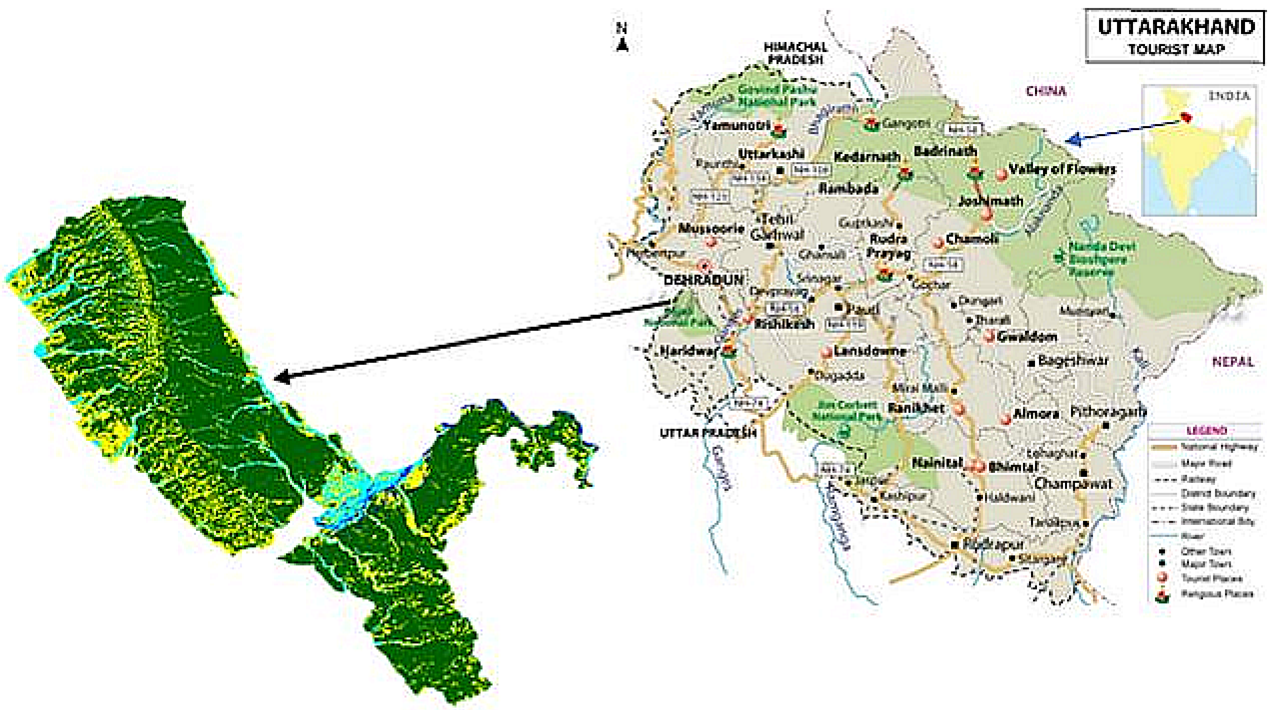


Figure 1. Map of Rajaji National Park in Uttarakhand, India

Methods

Remote Sensing assesses and monitors categorical and continuous vegetation cover changes. Such studies allow spatial and temporal assessment of deforestation, fragmentation, and degradation of any ecosystem. The characterization of the Rajaji National Park landscape was done by a combination of Remote Sensing and GIS techniques involving (1) Selection of satellite data for the study period, (2) Image pre-processing, (3) LUCL map generation, (4) Accuracy assessment, and (5) Change detection analyses. Satellite data from the years 1995, 2005, and 2015 were utilized for the study, maintaining an interval of 10 years to assess the land cover changes in the park. The satellite maps used were LANDSAT 4-5 TM for the study years of 1995 and 2015. In 2005, Landsat was not working, so LISS III satellite maps of RNP were used. As the resolution of the LISS III map was 23.5 m and that of the LANDSAT 4-5 TM image was 30 m, there was a need for uniformity in resolution. Hence, resampling was done for the LISS III image to resolve 30 m (Fig. 2a). Google Earth Maps of RNP were used for cross checking the characteristics of non-forest areas. ERDAS Imagine 2014, Arc Map 10.1, IDRISI Taiga, FRAGSTAT 4.2, and Microsoft Excel were the software utilized in the present study. ERDAS Imagine 2014 was used for image stacking, image rectification, pre-processing, classification (unsupervised), accuracy assessment, and land use change. Unsupervised classification of Raster Map was employed to generate the Land Use Land Cover (LULC) Map of RNP (Fig. 2b). Fifty classes were taken as thresholds, and 10 iterations were carried out for each classification.

The four major land use classes identified were (a) Forest, (b) Scrub, (c) Water channels, and (d) Non-Forest areas. Accuracy was tested on the classified land use cover of the images. For the accuracy test, 100 points were taken as threshold. Data were taken from the attribute table for further analysis in Microsoft Excel. A pivot table was used to make a matrix of changes among the selected land use classes.

Arc Map 10.1 was used to calculate the fractal dimension of RNP landscape. It was calculated as

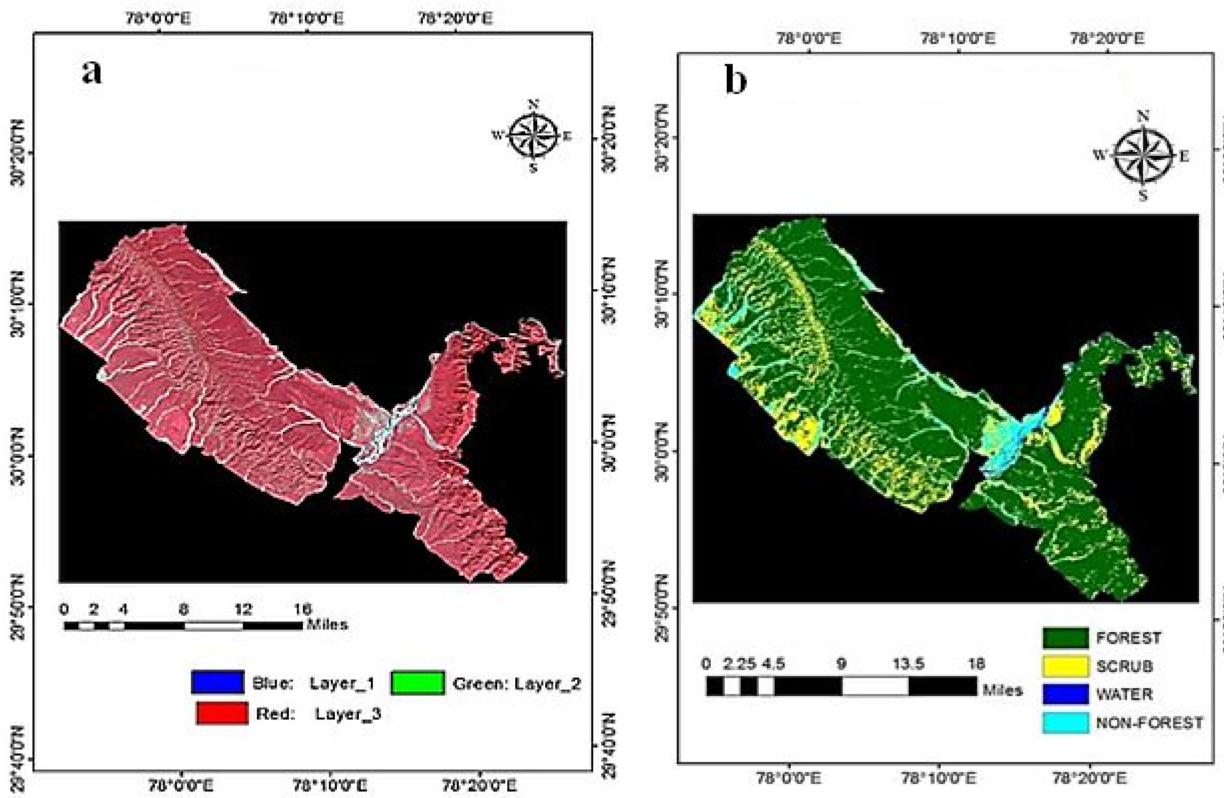


Figure 2. Rajaji National Park (a) FCC map, and (b) Land Use-Land Cover map

FD = 2 x (LN (Perimeter)/ LN (Area)). IDRISI Taiga was employed to predict the magnitude of changes in the LULC area for 20 years with 10-year intervals from 1995 to 2015. FRAGSTAT 4.2 was utilized to analyse the composition and configuration of the landscape. In the FRAGSTAT application, the geospatial tools enabled the analysis of Patch density, Shannon's Diversity Index, Evenness Index, Connect, Contiguity, and other patch attributes. It provided the contrast and similarity tables for calculating the landscape composition and configurations of the 1995, 2005, and 2015 land use maps.

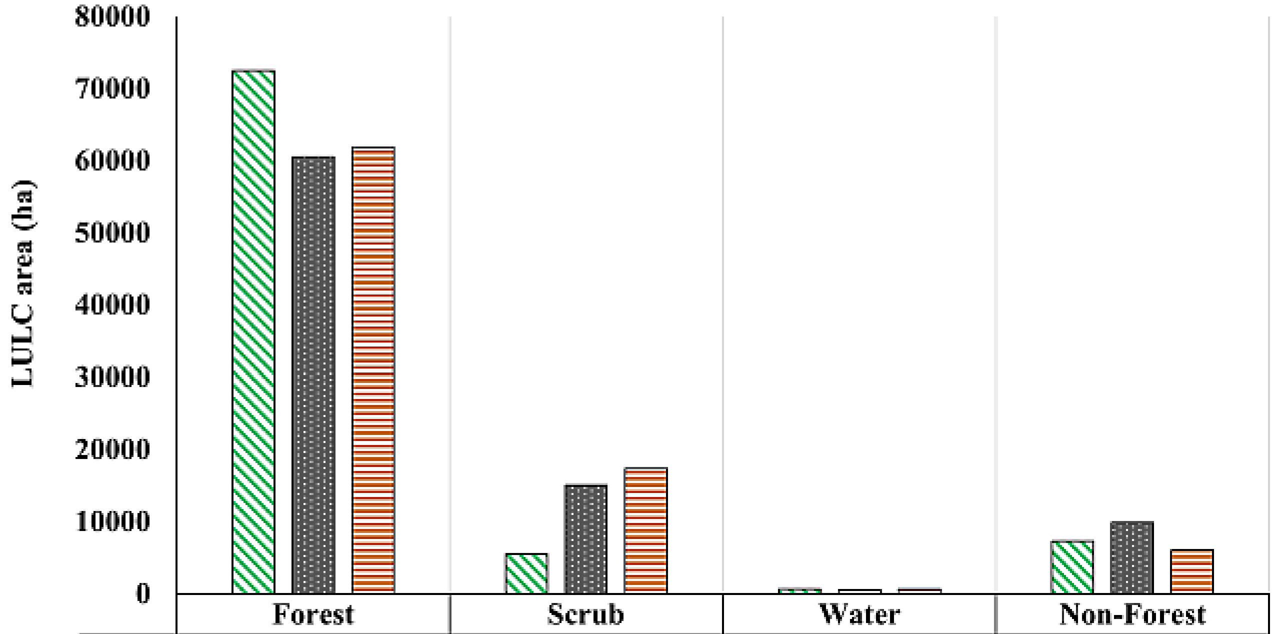
RESULTS AND DISCUSSION

Land use land cover (LULC) change detection

The Land Use Land Cover changes can be studied from the composition and configuration of landscape elements of a satellite map. The composition of a satellite map gives an account of the number and occurrence of the different patch types or LULC types. On the other hand, configuration encompasses the physical distribution or spatial characters of LULC types on a satellite imagery. Such quantification refers to the measurements of homogeneity or heterogeneity of the landscape. The accuracy of the LULC Maps of RNP for the years 1995, 2005 and 2015, having four classes, i.e., Forest, Scrub, Water channels, and Non-forest areas, were 88, 87, and 88%; along with acceptable Kappa Values of 0.73, 0.74, and 0.79; respectively.

The unsupervised classification of imageries from 1995, 2005, and 2015 exhibited maximum area under forest cover i.e. 84, 70, and 72%, respectively. However, the forest cover decreased from 1995 to 2005 (Fig. 3). More than 17% of the forest area and 20% of water channels were degraded during this period. It is important to note that 172% of the scrub and 35% of the non-forest area had increased during the same period (Fig. 4). The excessive increase in the scrub vegetation in the RNP landscape could be a result of a sudden outbreak of scrub around 2005 or a gradual increase in scrub vegetation since 1995. The increase in scrub and non-forest areas indicate a weak biodiversity monitoring system in Rajaji National Park from 1995 to 2005.

From 2005 to 2015, there was about 2% increase in the forest area and 32% increase in the area under water channels. Fortunately, the non-forested areas



	Forest	Scrub	Water	Non-Forest
1995	72500	5545	628	7300
2005	60534	15074	501	9864
2015	61929	17345	662	6073

Figure 3. Changes in LULC area (ha) of RNP from 1995 to 2015 (20 years)

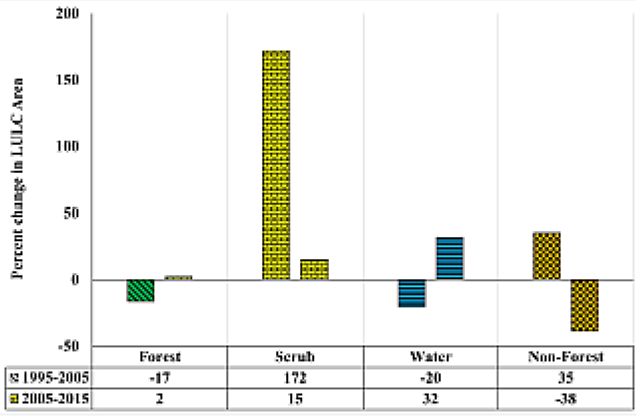


Figure 4. Changes in landscape classes and explosion of scrub at RNP during 1995 to 2015 (20 years)

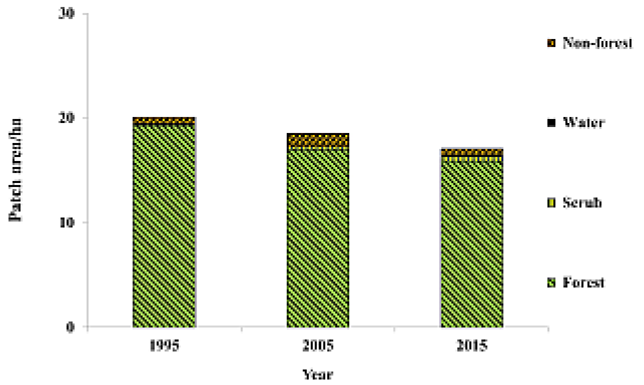


Figure 6. Patch index of the LULC classes from 1995-2015

had decreased by 38% during the same period. However, in the 10 years from 2005 to 2015, the area under scrub increased yet again by another 15% (Fig. 4). Overall, the forest area had decreased by 15% and the scrub area had increased significantly by 213% during the entire study period of 20 years from 1995-2015. The increase in the scrub area is alarming and is of major concern in protected areas such as national parks.

Land use change and prediction

The rapid increase in the scrub between 1995 and 2005 was also checked with the Markov Model Prediction Probability Matrix by utilizing the IDRISI Taiga software. The generated outcome was utilized in the CA Markov Model along with the base map to predict the change trends in the next 10 years. The outcome results predicted similar increase in the area under scrub and non-forest in 2015. As per the prediction model, the forest area was 574 km^2 in 2015, whereas the satellite map LULC of the same year showed 619 km^2 of forest area in the park.

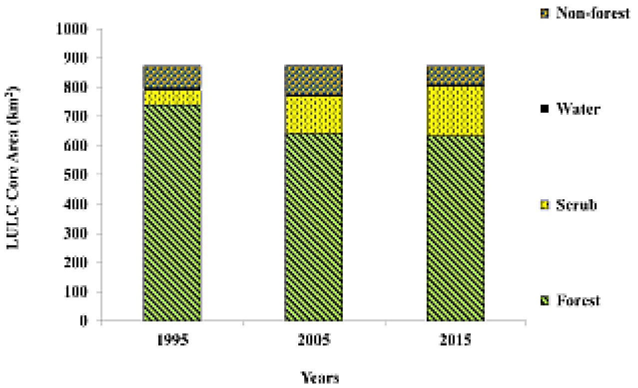


Figure 5. Core area (km^2) in each LULC class from 1995-2015

Hence, compared to the prediction, there was an increase in forest area by 7% on the ground. Similarly, compared to the prediction the scrub and non-forest areas had decreased by 10 and 40%, respectively. The water channels too had increased by 60%, against the predicted decline. Hence, it is clear that the management practices at RNP had changed for better from 2005 to 2015. However, these outcomes need to be treated with caution as the increase in size of the forest area does not shed light on the character and health of the forests.

Spatial pattern of the landscape

To analyse the quality and composition of the park's landscape, the four LULCs were characterized at landscape level by using the geospatial tool FRAGSTATS 4.2. It measured the core area in km^2 for all the LULC of RNP. The forest core area exhibited a significant decrease in 2005, with a similar increase in the scrub core area during the study period (Fig. 5). Fortunately, the forest core area remained the largest among the four land-use classes of RNP. This was a good sign for the park ecosystem as maximum coverage of the park area by forested land ensures a conducive environment for the park's fauna, especially the elephants and tigers. The forest patch index decreased continuously from 1995 to 2015 (Fig. 6). On the other hand, there was continuous increase in the patch index of the scrub from 1995 to 2015. This suggests that each patch of scrub increased its circumference in the landscape during the study period. The patchiness of the RNP landscape was observed to be maximum in 2005 (Fig. 7).

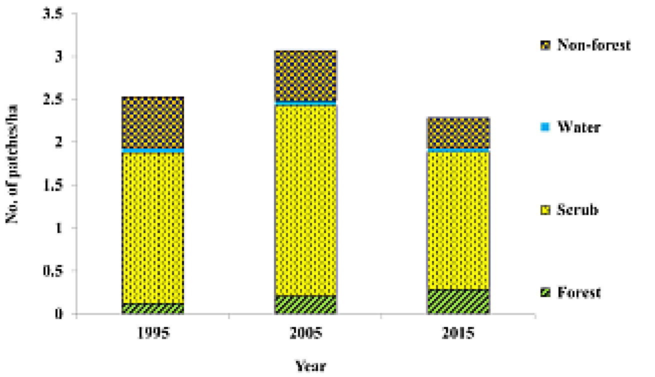


Figure 7. Patch density at class level from 1995-2015

The patch density of the scrub was maximum among the four LULCs, followed by the non-forest elements in all the imageries from 1995, 2005, and 2015 (Fig. 7). Moreover, the patch density of the forest too showed a steady increase from 1995 to 2015 suggesting an increase in fragmentation of the forest ecosystem. It is evident from this result that scrub patches would be largely responsible for the fragmentation of the forests.

The FRAGSTATS analysis not only corroborates the earlier findings through the ERDAS image regarding the forests occupying the maximum landscape of RNP, but it also supports the theory of possible increase in fragmentation of the park landscape due to the high increase in scrub and non-forest LULC patches.

The size and density of the patches do not give an idea of the LULC patch distribution pattern; it is not clear if these patches are localised to a particular area or scattered over the entire landscape of Rajaji? Whether these patches are adjacent to each other or far apart? The spatial layout of the different LULC patches in the park, would significantly affect the mobility and niche development of the various fauna and flora of the RNP landscape. The spatial layout of the different LULCs would further determine the metapopulations of various species, their distribution pattern, local extinction, and re-establishment.

Hence, the random or clustered distribution pattern of the LULC patches was assessed by examining the contiguity of the patches. Contiguity, that measures the spatial adjacencies of similar patch types, had decreased significantly at the landscape level from 1995 to 2005 (Fig. 8a), suggesting an increase in the interspersion of different patch types. While examining each LULC component, the forest represented the highest contiguity in all three study years. This is also because the forest is the largest LULC patch in the RNP landscape.

However, despite having the largest patch, the Forest patch contiguity declined from 1995 to 2005. The contiguity of non-forest areas remained more or less the same from 1995 to 2015, suggesting localized growth of settlements (Fig. 8b). Interestingly, the scrub, which had high patch density suggesting randomly distributed patches all over the park, also expressed a consistent increase in the contiguity of its patches over the entire study period. This result indicates a mosaic landscape of RNP due to the intrusion and expansion of scrub cover into the forest landscape. Whether these adjacent like

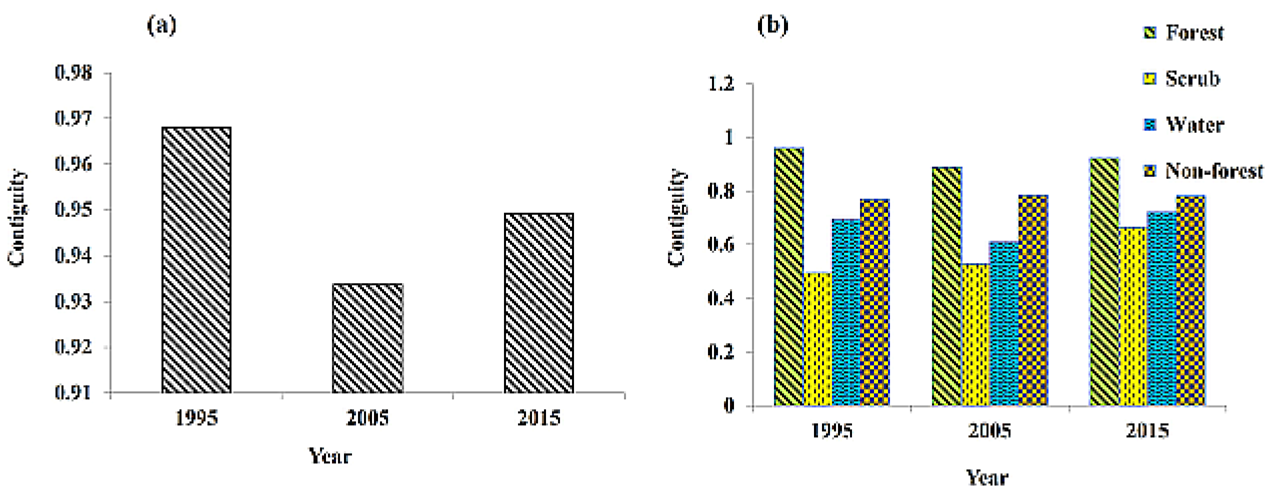


Figure 8. Contiguity of LULC classes of RNP from 1995 to 2015 at (a) landscape level and (b) within LULC classes

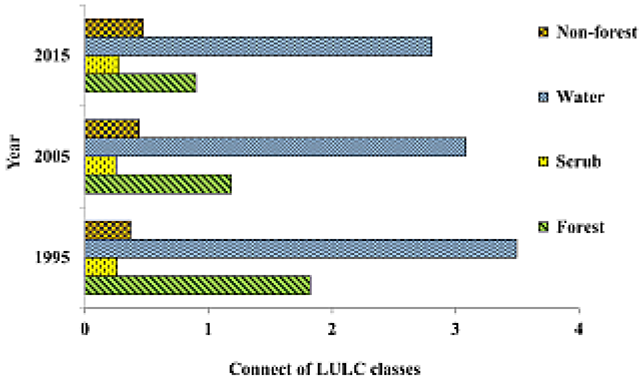


Figure 9. Connect in the LULC classes of RNP from 1995-2015

patches were functionally linked was assessed by the Connect analyses of the LULCs.

This is an important assessment as greater the connect of an LULC, higher is its neighbourhood affect or higher the efficacy of a particular ecosystem. The maximum connectance was observed between all water patches due to their fluid character, even though they occupied only 1% of the park landscape (Fig. 9). But, water connectance decreased over the 20 years from 1995 to 2015. Forest, having the largest core area, also expressed high connectance. The forest patch connectedness ensures that RNP's flora and fauna get functional migratory routes for completing their life cycle. However, forest patch connectivity decreased steadily from 1995 to 2015.

Unfortunately, there was a steady increase in the connect of scrub and non-forest during the study period, suggesting an increase in functional linkages within such patch types. The increase in the connectance of scrub would facilitate the spread of the scrub elements across the forest landscape and accelerate forest fragmentation. Hence, the scrub LULC had increased in number, size and dispersed randomly exhibiting an affinity of coalescing its patches with time across the entire Park landscape. Such a phenomenon poses future threat of severe fragmentation of the forest ecosystem of RNP Park.

Another tool to assess forest fragmentation of the Park is Shannon's Diversity Index (SDI) that depicts the diversity of the different LULC patch types in the Park landscape. The SDI of the RNP landscape increased from 1995 to 2015 in the Park ecosystem (Fig. 10). The Evenness index (EI), which depicts the equitable distribution of the LULC patches, also increased similarly. Such increase in SDI and EI of the Park would mean an increase in other LULC types at the cost of the forest which is the largest LULC of the Park ecosystem.

Conversely, the Aggregation Index (AI) that depicts clusters of similar LULC patches decreased from 1995 to 2015 at landscape level at RNP (Fig. 11). In this context, it is already established that there was an increase in the area under scrub in 2005. However, the decrease in AI suggests that the increase in the area under Scrub was not localized. Rather, it was widespread and random over the forested areas. Though some improvement in park management is evident since 2005, the AI could not be improved proportionally compared to 1995. This result conclusively determines the fragmented nature of the Forests mostly driven by the Scrub elements of the Park.

So far, the changes in number, size and distribution pattern of the LULC classes was considered to

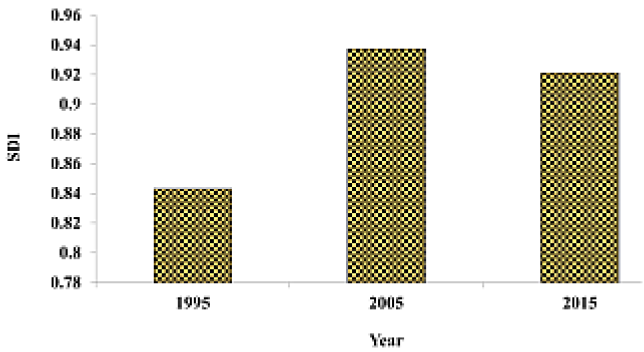


Figure 10. Shannon's diversity index (SDI) at the landscape level for 1995, 2005, and 2015

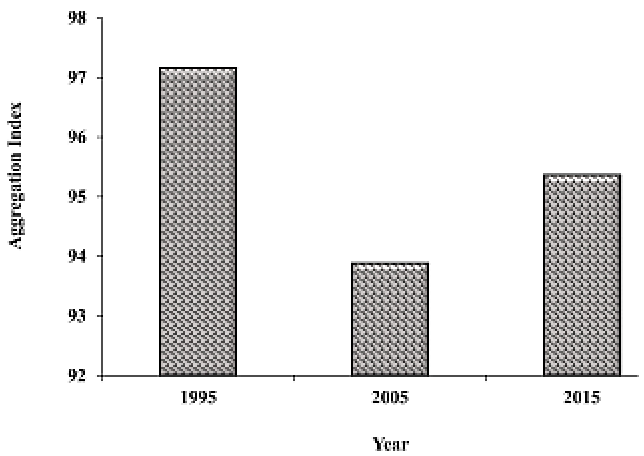


Figure 11. Aggregation index at landscape level in 1995, 2005, 2015 at RNP

understand the landscape changes over 20 years at RNP. It was further important to understand the quality of the changes within each LULC class in the park. Hence, the Fractal Dimension (FD) that calculates the complexity of the shapes of the LULC patches was examined. FD of patches is an important indicator of the ecological dynamics of a system.

Habitat fragmentation results in the formation of isolated patches of a particular LULC that increases its patch edge surface area and directly impacts its FD. The same is not true for the continuous edge of an unfragmented land use attribute (Imre and Bogaert 2004). Also, the FD of a system increases with increasing loss of forests because the cumulative loss areas become fragmented and disordered as they expand (Peptenatu et al. 2023, Sun et al. 2014). Similarly, the FD of agricultural plots, plantations, and settlements is low as they have low patch edge diversity.

The Fractal Dimension of Rajaji National Park ranged from 1.3-1.49 during 1995 (Fig. 12). The areas with high FD coincided with mixed forest areas, medium FD with Moist Deciduous Sal Forest, and low FD with scrub, non-forest and agricultural lands. Fragmentation and habitat loss could have resulted in the loss of pristine moist deciduous Sal forests of the Park. In 2005, the FD of many forested areas increased to 2.0 at landscape level likely due to anthropogenic activities and scrub intrusion. In 2015, FD of the Park ranged from 1.31 to 1.48, depicting some improvement in forest conditions due to the reduction of non-forest LULC by 38%. In the long run, such habitat degradation due to fragmentation threatens the genetic continuity of many species, especially large animals with a broader niche (Johnsingh et al. 2015).

It is thus imperative to understand the dynamics of Scrub LULC that was largely instrumental in the fragmentation of the Park landscape. Scrub areas are generally shallow or arid and support herbs, shrubs, and small woody trees. The scrub was composed of small trees (*Cassia fistula, Aegle marmelos, Erythrina suberosa, Zizyphus mauritiana,* and others) and shrubs (*Lantana camara, Nyctanthes arbor-tristis, Woodfordia fruticose,* and others). The scrub at RNP was dominated by *Lantana camara* which is a notorious invasive plant growing across India (Neena and Joshi 2007). *L. camara* is a tropical American shrub that has been reported to have maximum invasion in the Shivalik hills, Central India, and South Western Ghats. *L. camara* now threatens about 300,000 km^2 of Indian forests (Mungi et al. 2020). The predominance of *L. camara* in the scrub could explain its rapid increase in size and random distribution across the Park landscape.

The invasive nature of the scrub triggered the fragmentation of the forest ecosystem in RNP between 1995 to 2005. Before 2004, the native pastoral communities, i.e., Gujjars, were reportedly given permits to cut grasses and lop trees for fodder and fuel wood in the Rajaji National Park (Joshi et al. 2009). In 2002, the Gujjars of Rajaji National Park were resettled from Chilla Range to Gaindikhali (Mishra and Singh 2011). The policy of shifting the Gujjars from the core areas of the park was considered an ecologically viable decision because a study reports that the evacuated areas had an increase in herbaceous cover and a decrease in weed

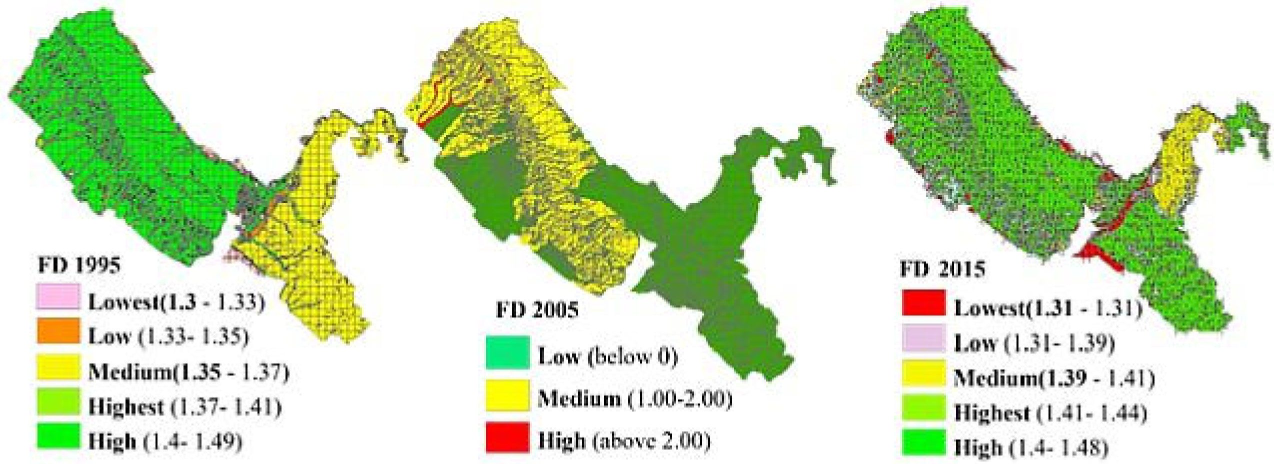


Figure 12. Fractal Dimension in the years 1995, 2005 and 2015

cover after 2-3 years from the resettlement (Adhikari et al. 2009). Another study reported a reduction in *L. camara* population between 2004 and 2008, though there was no increase in the canopy cover (Pandey et al. 2009). Conclusions based on such studies are challenging as they do not have a comparative baseline data. On the other hand, the present study clearly shows a many-fold increase in scrub during 2005 after the resettlement of Gujjars in 2002. It is likely that areas evacuated by the Gujjars became a host for the invasive species of the park and dispersed far and wide in the park ecosystem without its utilization as fuel wood and fodder by the Gujjars. Interestingly, the phenomenon of an increase in vegetation cover and spread of invasive species in abandoned areas of human settlement was also reported from a study carried out in Nepal (Jaquet et al. 2015).

The management of the invasive species is crucial for maintaining the ecosystem services of the Forests at RNP. *L. camara* population may be controlled by utilizing the species as food, fodder, and other value-added products. The uprooting of the entire plant before flowering and fruiting could be an effective technique of checking the invasion of the species. The Scrub undergrowth being primarily seasonal poses a threat of forest fires as its dry biomass can act as potent fuel. In other words, the Park Management needs to focus on maintaining the contiguity and connect of the forest LULCs, considering their vital role in facilitating the migration of animals from one end of the park to the other end in search of food, water, shelter, breeding, pollination, etc.

CONCLUSIONS

The geospatial analysis of Rajaji National Park landscape evinced a decrease in the area under forests from 1995-2015. The high patch density of scrub had increased the patchiness and fragmentation of the forest from 1995 to 2015. The forest management practices were unable to control the spread of Scrub LULC in the Park Landscape throughout the 20 years of study period. The spread of scrub was due to its invasive character contributed by the exotic species *L. camara*. The scrub patches of the Park increased in number, size and their access into the forest ecosystem leading to forest fragmentation. Fortunately, the rate of forest degradation had somewhat slowed down compared to the predictions since the inclusion of RNP under Uttarakhand State in 2001. Hence, further research needs to be carried out on the ground to monitor the composition of the scrub vegetation and its dynamics in the landscape ecosystem of Rajaji National Park. It is also imperative to understand that well-managed Scrub and its margins support a range of wildlife. In the present context, the park ecosystem needs to be conserved by remodelling its Scrub vegetation with long-term monitoring and phenology studies. Such studies will facilitate the removal or limit the spread of any invasive species that can catalyse the process of forest fragmentation. In the long run, the Park ecosystem could also be important in mitigating local adverse impacts of global warming and climate change through carbon sequestration. The geospatial study of Rajaji National Park in the year 2025 would give a comparative picture of the changes in the park ecosystem over the last 10 years since 2015.

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Author's contributions: DS worked out the Land Use Land Cover (LULC) changes of 10 years from 1995 to 2005. BG worked on the landscape characterization of Rajaji National Park from 2005 to 2015. Both the authors pooled their data and interpreted the present research output.

Conflict of interest: There is no conflict of interest as declared by the authors.

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