Landscape Characterization of Sariska National Park (India) and Its Surroundings

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Abstract   Landscape characterization gives an overall information on the status of Land Use and Land Cover (LULC), changes in its composition and the impact of natural and human influences operating at different spatial and temporal scales. This information can be used to monitor changes in natural forest resources and protected areas, delineate potential conservation areas and can serve in effective management of ecologically fragile landscapes. In the present study, geo-spatial tools were used to characterize the landscape of Sariska National Park and its surroundings. Satellite data was used to prepare LULC maps for 1989 and 2000, change detection analysis and computation of landscape metrics. Climatic data, field records and modeling tools were used to map the potential spread of two invasive species, Prosopis juliflora and Adhatoda vasica. The results show that the forest area increased from 1989 to 2000, indicating better management practices. Landscape metrics (PAFRAC, PLADJ and AI) also support this argument. Improvements in the degraded forest can further enhance this effect. The entire reserve however is suitable for the invasion of *P. juliflora* and *A. vasica* but is more pronounced in Boswellia serrata and Anogeissus pendula – Acacia catechu (open) forests. A detailed landscape characterization map can help forest managers to make important policy decisions concerning issues such as invasive species.

Keywords   image geo-spatial tools; invasion; landscape analysis; vegetation; LULC

CLC number   P208

Introduction

One of the first steps towards a scientific approach to any problem is quantification of the properties of concern. If one cannot measure it, it is impossible to know whether it is changing or responding to other related variables.[1] Land Use and Land Cover (LULC) is such a property. Land Cover (LC) refers to the physical characteristics of the earth's surface, captured in the distribution of vegetation, water bodies, soil and other physical features of the land, whereas Land Use (LU) refers to the way land is used by humans, usually with an accent on the functional role of land for economic activities.[2] Information on the status of LULC, the changes and impact of natural and human influence operating at different spatial and temporal scales, is termed landscape characterization. Landscape characterization using scientific principles and tools has an important role in the regional and macro/micro-level planning of natural resources.

Deforestation and degradation of LC leads to both

habitat degradation and changes in the landscape.[3,4] Such changes subsequently lead to the loss of biodiversity[5,6] and the spread of competing invasive alien species, inhibiting the regenerative capability of a landscape.[7,8] Monitoring and assessment to quantify such changes and characterize the landscape will enhance the capability to predict future landscapes and devise more effective landscape management strategies.[9,10] Temporal remote sensing data analysis, mapping and change detection techniques can provide information about the structure of landscapes.[11-13] Landscape structures can be quantified using landscape metrics.[14-17] These metrics further refine the interpretation of changes and reduce the subjectivity inherent in change analysis.[11,18] Invasion can be modeled using habitat characteristics and environmental variables.[19] This information in turn can be used for planning natural landscapes,[20] biodiversity conservation[4] and natural resource management.[21]

The present study aims at demonstrating a methodology for an integrated application of geospatial tools, landscape ecological principles and ecological modeling in characterizing a protected landscape area. The landscapes of the Sariska National Park (SNP) have not been analyzed in previous studies. However, a preliminary study on the general vegetation of the area was prepared.[22,23] This present study is aimed at preparing LULC maps, change detection analysis and computation of landscape metrics. It also attempts to map the potential spread of Prosopis juliflora and Adhatoda vasica using climatic data, field records and modeling tools.

1   Study area

SNP is located between $27^o13'$ to $27^o31'$ N latitude and $76^o15'$ to $76^o33'$ E longitude. The area falls in the administrative district of Alwar (Rajasthan State). The total area covered by the reserve is 866 km², of which 492 km² has been designated as the Sariska Wildlife Sanctuary and the remaining 374 km² includes forest ranges of the adjoining Alwar and Rajgarh areas. There are 25 forest blocks within the Sariska Wildlife Sanctuary, out of which 12 blocks are of the reserved forest, while 13 are of the protected forest.

The climate of the area is subtropical, characterized by distinct winter, summer, monsoon and spring sea-

sons. Temperature ranges from 0℃ in winter to 41.5℃ in summer. The summer season commences from the middle of March and becomes intense in April. Hot westerly winds known as "LOO" are common during the summer season. The rainy season begins from late June and continues until the middle of October. Average annual rainfall is 650 mm, mostly during the monsoon months (July-August). Soil differs depending on the underlying rocks. Comparatively rich fertile and dark-colored soil occurs in plains and foothills. The tract is mainly hilly with big plateaus and numerous valleys. The hills stretch out from northeast to southwest, in more or less parallel lines.

In a broad sense, the area bears two major forest types: the dry tropical forest communities of hills and side slopes and the more open woodland, bush land and wooded grassland communities of broader flat valleys. Dense forest patches are found in valleys where better soil and moisture exists. The dominant tree species is Dhok (Anogeissus pendula). Salar (Boswellia serrata) and Gurjan (Linnea corommendelica) grow on rocky and dry areas. Khair (Accacia catechu) is common in valleys and Bamboo (Dendrocalamus strictus) grows in well-drained reaches of the streams and moist and cooler aspects of the hill.[23,24] On the basis of structural attributes, two major forest types "Tropical Dry Deciduous Forest" and "Tropical Thorn Forest"[25] are present in the area.

2   Materials and methodology

This study was carried out in three phases. The first phase involved collection and pre-processing of satellite and collateral data. During the second phase, a field survey was carried out for image classification and GPS locations of invasive flora were collected. The third phase involved database creation, landscape characterization and ecological modeling. In this study, the Erdas Imagine 9.3, ArcGIS 9.3, Fragstats and Genetic Algorithm for Rule-set Production (GARP) computer software were used for data processing and analysis.

2.1   Satellite data

Satellite data of Landsat TM 5 dated 9 October 1989 and 13 September 2000 for Path- 147 and Row- 41,

with a ground resolution of 30 m were downloaded from the Global Land Cover Facility (www.landsat. org). These were radiometrically and geometrically (ortho-rectification with the UTM/WGS 84 projection) rectified. The data were imported into Erdas Imagine 9.3. A subset of the Area Of Interest (AOI) was made using topographic sheets. The Normalized Difference Vegetation Index (NDVI) was computed using Red and NIR bands. A stack of raw datasets and NDVI layer was subjected to Iterative Self-Organizing Data Analysis (ISODATA) clustering for image classification.

Digital Elevation Model (DEM) data of Shuttle Radar Topographic Machine (SRTM) was downloaded from the website (http://www. srtm.usgs. gov/). The dataset was imported to Arc-Map for producing aspect and slope maps. The projection was set as UTM-WGS 84 for carrying out further analysis.

2.2　Climate data

Climate data was collected from the Worldclim site (http://www.worldclim.org). The data included: Bio 1-Bio 19, Temperature (12 months) and Precipitation (12 months). The data were converted from .bil to GRID format and projected to UTM-WGS 84. The precipitation data for all the 12 months were added to compute annual precipitation. The study area was clipped from the data using AOI. The clipped climate data, LULC map, aspect and slope were then stacked together.

2.3　Field survey

For the fieldwork, satellite data and clustered images were used for cross-verification. Various clusters formed as a result of ISODATA clustering analysis were visited to collect ground variation and class information. GPS locations for invasive flora (Prosopis juliflora and Adhatoda vessica) were also collected. The GPS data were collected in three combinations: (1) pure stands of *P. juliflora*, (2) pure stands of *A. verssica* and (3) mixed stands of *P. juliflora* and *A. verssica*. Random transects of a of total 20 km were surveyed and 100 point locations were recorded.

2.4　LULC mapping

After the fieldwork, the cluster map was converted to a class information map. Each cluster was given an appropriate name (legend) as per the collected ground truth field data. For some of the classes like agriculture, long fallow(LF) land and scrub forest visual interpretation and interactive editing was carried out. Maps prepared for the two time periods were compared with the ground truth data, reflectance values and interpretation keys to locate converging evidence. The maps produced were also discussed with the local forest administration for validation and inputs.

2.5　Change analysis

Change matrices were generated to analyze changes in the area covered by different LULC classes. This was done by comparing the number of pixels falling into each class of LULC in one time period with the categorization of the same pixels in the same/different class in the previous time period.

$$\text{Change in classes} = \text{Matrix (time 1, time 2)} \quad (1)$$

The data gathered from the generated matrix was further rearranged to prepare the change matrix. Changes in LULC classes between two years were analyzed through the change maps generated.

2.6　Landscape analysis

The LULC maps were subjected to median filtering to reduce the salt and pepper affect. Landscape indices were computed using Fragstats. A thorough review of literature was carried out to find the list of indices expressing attributes of configuration and composition of the patches.[26] In this study, Class Area (CA), Largest Patch Index (LPI), Number of Patches (NP), Landscape Shape Index (LSI), Perimeter Area Fractal dimension (PAFRAC), interspersion and juxtaposition (IJI) and Aggregation Index (AI) were used. These metrics were selected because they represent statistically significant changes over time in LULC for SNP.

2.7　Niche modeling

The point locations on the distribution of invasive species obtained using GPS were converted to decimal degrees. A point coverage map was generated in ArcGIS. 24 climatic variables were used to carry out the niche modeling. These include altitude, aspect, slope, LULC, Bio 1-19 and mean precipitation. A

Principal Components Analysis (PCA) of 24 variables revealed the variables defining the species distribution. Only those parameters that were statistically significant and with a high loading factor were selected. The identified variables were altitude, aspect, bio4 [temperature seasonality (standard deviation× 100)], bio12 [annual precipitation], bio16 [precipitation of wettest quarter] and mean precipitation. GARP was executed using occurrence points of the selected species and selected variables. The rule set used for carrying out this study was "range rule".

3 Results and discussion

3.1 LULC mapping

LULC maps for two time periods (1989 and 2000) were prepared to visualize spatial distribution of forest cover types and other classes (Fig. 1). The area was classified into 10 classes, Dhok-Khair (dense) forest, Dhok-Khair (open), Salar forest, degraded forest, scrub forest, barren hill slopes, agriculture (agriculture 1 and agriculture 2), long fallow, settlements and water body. The area distribution of different classes in 1989 and 2000 is given in Table 1.

Dhok-Khair (dense) forest (DK-d) refers to an area dominated by *Anogeissus pendula* but with a presence of *Accacia catechu*, with more than 40% canopy density. This covers the maximum area and has not changed much between year 1989 and 2000. *Dhok-Khair* (open) forests (DK-o) have similar species, dominated by Dhok (*Anogeissus pendula*) trees and a canopy density less than 40%. Open forest has increased from 4.39% in 1989 to 12.81% in 2000. These changes are from the minor conversion of dense forest to open and plantation activities carried
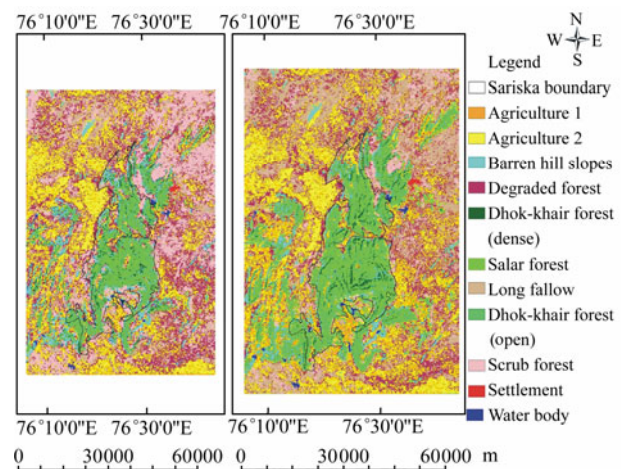

Fig. 1   LULC of Sariska (1989 and 2000)

Table 1   Area distribution of different LULC classes in 1989 and 2000

Land use and land cover	1989		2000	
	Area (km²)	Area (%)	Area (km²)	Area (%)
Dhok-Khair (dense) forest (DK-d)	266.80	4.40	254.67	4.20
Dhok-Khair (open) forest (DK-o)	266.54	4.39	777.77	12.81
Salar forest (SF)	227.49	3.75	297.24	4.90
Degraded forest (DF)	996.87	16.42	937.01	15.44
Scrub (Sc)	1601.39	26.38	762.78	12.57
Barren hill slopes (Brn)	446.19	7.35	445.52	7.34
Agriculture 1 (Ag1)	519.83	8.56	514.91	8.48
Agriculture 2 (Ag2)	1051.29	17.32	1004.90	16.56
Long fallow (LF)	675.63	11.13	1036.02	17.07
Settlement (Set)	4.42	0.07	16.57	0.27
Water body (Wb)	13.20	0.22	22.27	0.37
Total area	6069.65	100	6069.65	100

out by the forest department under a joint forest management scheme. Scrub (area having a canopy density less than 10%) was taken as plantation for the *Dhok* and *Khair* species. These species are also planted around the fringe and buffer zones of SNP. Salar Forests (SF) are pure stands of Salar (*Boswellia serrata*). This is a medicinal plant used for the treatment of Osteoarthritis. The forest area covered by

Salar has also increased from 3.75% in 1989 to 4.90% in 2000. This is attributed to better management of forests in SNP. Degraded Forests (DF) are the forest areas having a canopy density close to 10% with fragmented patches. These are identified as destroyed canopy cover with less human and livestock disturbance. These areas are also attributed with exposed bare soil, a rocky substratum and much less

vegetative growth. This resulted in the different spectral response to such patches. There was a decrease in area of the degraded forest from 996.87 km^2 in 1989 to 937.01 km^2 in 2000. Small plant saplings and scattered trees of Dhak (*Butea monosperma*), Bel (*Aegle maemelose*), Ber (*Zizypus Marutiana*), etc. form the scrub. There was a major decrease in the area covered by scrub forest from 26.38% in 1989 to 12.57% in 2000. The forest department has undertaken plantation in these areas resulting in forest cover increase.

Barren hill slopes (Brn) are locations formed from loose unconsolidated material and bare soil with no vegetation cover. These are unutilized pieces of land distributed widely throughout the study area without much change from 1989 to 2000. Agriculture fields (Ag1 and Ag2) are irrigated cultivated areas with one or more crops per year. The main crops grown include wheat (*Triticum* spp.), gram (*Vigna mungo* L), mustard (*Brassica* spp), bajra (*Pennisetum glaucum*), maize (*Zea mays* L), etc. Agriculture is divided into two categories, Agriculture 1 (Ag1) areas having bright red reflectance on standard FCC, indicating standing crops and Agriculture 2 (Ag2), a mix of pink and brown reflectance representing harvested fields. Not much change was observed in agricultural types. LF indicates fallow land that is not under cultivation. These are widely distributed throughout the study area. The area covered by LF land increased from 675.63 km^2 in 1989 to 1036.02 km^2 in 2000.

Settlements (Set) are human inhabited areas. The main settlement identified and mapped is Alwar. Settlements have also increased from 0.7% in 1989 to

0.27% in 2000. All freshwater rivers, lakes and reservoirs map as water bodies (Wb). No distinction has been made between natural and man-made water bodies. The water bodies include Siliserh and Jaisamand lakes and numerous perennial and seasonal streams like Kankwari, Channi, etc. There was an increase in area covered by water bodies from 13.20 km^2 in 1989 to 22.27 km^2 in 2000.

3.2 Change analysis

From the change matrix (Table 2), an increase in the forest cover is inferred. Parts of the area covered by Barren hill slopes in 1989 have been replaced by DK-d in 2000. Similarly, the area under degraded land was reduced and SF, DK-d and DK-o have replaced it. The scrub forest has mostly converted to SF, DK-o and DK-d between 1989 and 2000. LF has also been converted to SF and DK-o. The increase in forest cover from 1989 to 2000 shows implementation of better management practices.

3.3 Landscape analysis

A summary of landscape parameters analyzed is given in Table 3. CA shows improvement in the forest cover from 1989 to 2000. For DK-d, CA and NP, all have increased while the IJI and AI were reduced slightly. It could be interpreted that the structure of DK-d has improved over the periods. In the case of DK-o, LSI and PAFRAC have increased. The decrease in the value of LSI indicates that the particular patch type has become more disaggregated, while the increase in the value of PAFRAC indicates that there

Table 2   Change matrix for 1989 and 2000 (area in km^2)

	Class	DK-d	DK-o	SF	DF	Sc	Brn	Ag1	Ag2	LF	Set	Wb
						2000						
	DK-d	**74.63**	19.71	98.85	8.09	7.12	57.93	-	-	-	-	-
	DK-o	4.86	**132.47**	90.10	-	-	-	-	-	-	-	-
	SF	64.69	-	**201.59**	-	-	-	-	-	-	-	-
	DF	6.95	10.06	50.51	**928.77**	0.59	-	-	-	-	-	-
1989	Sc	32.60	71.09	209.55	-	**759.17**	-	-	-	524.01	3.62	1.34
	Brn	53.44	-	-	-	-	**387.54**	-	-	-	-	5.21
	Ag1	-	1.89	2.77	-	-	-	**514.91**	-	-	-	-
	Ag2	4.31	15.89	26.04	-	-	-	-	**1004.85**	-	-	-
	LF	12.93	46.13	98.16	-	-	-	-	-	**507.85**	9.70	-
	Set	-	-	-	-	-	-	-	-	-	**3.19**	-
	Wb	-	-	-	-	-	-	-	-	-	-	**13.20**

Note:DK-d-Dhok-Khair forest (dense); DK-o-Dhok-Khair forest (open); SF-Salar forest; DF-Degraded forest; Sc-scrub; Brn-Barren hill slope; Ag1-Agriculture (with crops); Ag2-Agriculture (without crops); LF-Long fallow; Set-Settlements; Wb-Water body.

Table 3   Landscape pattern analysis

Class	CA	NP	LPI	LSI	PAFRAC	PLADJ	IJI	AI	nLSI
DK-d	In	In	<1	<10	1.2	94.8→93.8	46→49	95.5→94.4	0.05
DK-o	Same	Dec	<1	<60	1.24→1.24	85→88.4	32	85→88.6	0.15→0.11
SF	Dec	Same	<1	<100	1.3	85	72→44	85.2→86	0.15→0.14
DF	In	Dec	2.6→6.4	<100>	1.45→1.43	86→88.5	58→65	86→88.6	0.14→0.11
Sc	In	In	<1	<100>	1.39→1.40	83.6→79.8	61→48	83.7→80	0.16→0.20
Brn	In	In	<1	119→133	1.32	74→78.5	38→33.5	74.3→78.6	0.26→0.21
Ag1	In	Same	2	170→186	1.36	86	43.6→46.8	86	0.13→0.14
Ag2	Dec	Same	5.4→2.7	224	1.43	83	47.5→38.6	83	0.16→0.17
LF	In	Dec	1.7→4.7	209→141	1.4→1.3	79.9→88.6	35.8→34	80→88.6	0.20→0.11
Set	Dec	Dec	4.8→1.3	103→83	1.24	91→85.5	27.8→15.6	91→85.6	0.09→0.14
Wb	In	In	<1	<10	NA (1.2)	96.5→91.9	26→16.6	98→93	0.02→0.07

In – increased, Dec – decreased.

CA (> 0, without limit), represents the value of the area covered by a class.

NP (⩾ 1, without limit), represents the number of patches of a particular class in the entire landscape.

LPI (0 ⩽ LPI ⩽ 100), approaches 0 when the largest patch of the corresponding patch type is increasingly small. LPI = 100 when the entire landscape consists of a single patch of the corresponding patch type; that is, when the largest patch comprises 100% of the landscape.

LSI (⩾ 1, without limit) is 1 when the landscape consists of a single square or maximally compact (i.e., almost square) patch of the corresponding type; LSI increases without limit as the patch type becomes more disaggregated (i.e., the length of edge within the landscape of the corresponding patch type increases).

PAFRAC (1 ⩽ PAFRAC ⩽ 2), approaches 1 for shapes with very simple perimeters such as squares, and approaches 2 for shapes with highly convoluted, plane-filling perimeters.

PLADJ (0 ⩽ PLADJ ⩽ 100) equals 0 when the patch types are maximally disaggregated (i.e., every cell is a different patch type) and there are no like adjacencies. PLADJ = 100 when all patch types are maximally aggregated (i.e., when the landscape consists of single patch and all adjacencies are between the same class).

IJI (0 < LPI ⩽ 100) approaches 0 when the distribution of adjacencies among unique patch types becomes increasingly uneven. IJI = 100 when all patch types are equally adjacent to all other patch types (i.e., maximum interspersion and juxtaposition); A fractal dimension greater than 1 for a 2-dimensional landscape mosaic indicates a departure from a Euclidean geometry (i.e., an increase in patch shape complexity).

AI (0 ⩽ AI ⩽ 100) equals 0 when the patch types are maximally disaggregated (i.e., when there are no like adjacencies); AI increases as the landscape is increasingly aggregated and equals 100 when the landscape consists of a single patch.

nLSI (0 ⩽ nLSI ⩽ 1), is 0 when the landscape consists of a single square or maximally compact (i.e., almost square) patch of the corresponding type; LSI increases as the patch type becomes increasingly disaggregated and is 1 when the patch type is maximally disaggregated (i.e., a checkerboard when $P_i ⩽ 0.5$).

have been changes in the shape of the patches from simple to highly complex and convoluted. Hence, a higher shape index represents greater shape complexity and is thus more vulnerable to change. These patches are more vulnerable to edge effect. SFs have also shown similar trends. Interestingly, AI (an indicator of aggregation) indicates improvement in the quality of SF and DF. Among the non-forest, CA under agriculture and settlements has also increased by 17.60% and 54.0%, respectively. The shape index for settlements has also increased because of the expansion of the area, i.e. urban sprawl.

Among all, the CA represents the changes in the area. NP indicates improved in DK-o and DF. However, SF has remained in a similar state with a degree of fragmentation in DK-d. LPI indicates a high fragmentation in the entire landscape and in all forest types. The variation in LPI also suggests that the degraded forest needs to be managed and long fallow needs to be brought under green cover. PAFRAC indicates better health of the forest areas over the period. PLADJ also supports the argument that forest

cover is increasing and the landscape has become more stable over the period. AI indicates overall improvement of the landscape in terms of aggregation of patches.

3.4   Niche modeling

The output from GARP was obtained in ArcInfo grids and the resulting maps with least commission and omission errors were selected. The results from the model predicted the potential spread of *Prosopis juliflora* and *Adhatoda vasica*. The distribution map shows the fundamental niche of both species. Both the species are distributed very explicitly and identifying a realized niche (competitive area) is very difficult in this landscape. The distribution is governed by the presence of moisture and shade. *P. juliflora* is distributed in and out of the protected area. The major colonies are found in the tiger reserve. *A. vasica* is concentrated inside the protected area only (Fig. 2). Both the species are distributed in SF and in fairly DK-o. Results from the landscape pattern analysis showed fragmentation in DK-o. Forest fragmentation

can be brought about by compositional change, i.e. loss in forest cover, or configuration change, i.e. changes in the arrangement of forestland cover. Invasion of these exotic species can induce further fragmentation by causing structural changes.
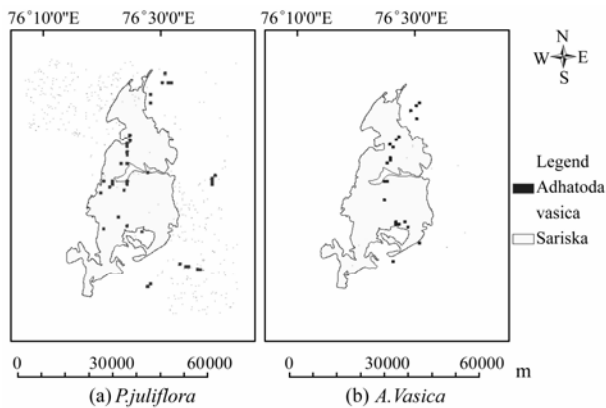

Fig. 2　Potential distribution

4　Conclusion

This study was undertaken to demonstrate a methodology for characterizing the landscape. It utilizes integration of geospatial tools, landscape ecological principles and ecological modeling. Geospatial tools (remote sensing and GIS) were used to prepare LULC maps and identify the changes that occurred over a decade. Landscape metrics were used to analyze the changes objectively. Ecological niche modeling was used to map the potential spread of *Prosopis juliflora and Adhatoda vasica* using environmental envelopes, field records and modeling tools.

The results indicate an overall increase in forest cover from 1989 to 2000. Increase in forest area occurred because of an increase in the reserve area from 800 km^2 to 866 km^2. Adding the forest ranges from the adjoining areas (as these were recognized as critical tiger habitat zones) of Alwar and Rajgarh is one of the reasons. Apart from this, an improvement in the management strategies of the reserve, restrictions on the collection of fuel wood and firewood, regulations on grazing and implementation of JFM have also brought about the improvement in forest cover. Of all the metrics computed, CA, NP, IJI and AI were found to be most suitable for carrying out the landscape change analysis as these metrics describe both the composition and the configuration of the landscape. PAFRAC, PLADJ and AI are equally important as they describe susceptibility towards change. The results from these landscape metrics indicated fragmentation in DK-d and DK-o.

Invasion of *P. juliflora* and *A. vasica* has also resulted in forest fragmentation by causing structural changes. In this study, ecological niche modeling was used to assess the potential spread of *P. juliflora* and *A. vasica*. It is a valuable tool in carrying out invasive species research because of its ability to forecast the potential distribution of invasives just on the basis of occurrence points and environmental variables. Information on LULC changes because invasive or anthropogenic activities give an overall perspective of landscape characteristics. The results showed that the forest area has increased from 1989 to 2000, indicating better management practices. Landscape metrics (PAFRAC, PLADJ and AI) also support this argument. Improvements in the degraded forest can further enhance this effect. The entire reserve was found suitable for the invasion of *P. juliflora* and *A. vasica* but was more likely in *Boswellia serrata* and *Anogeissus pendula − Acacia catechu* (open) forests. This information can be used to monitor changes in forested areas and natural resources. Therefore, this information can be used to delineate potential conservation areas and serve to support the effective management of ecologically fragile landscapes. This information can also be used in designing effective policies for the proper management of natural resources, thus leading to the sustainable use of resources.

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