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Evaluating Biodiversity and Spatial Simulation of Land-Cover Change in the Tropical Region of Western Ghats, India

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1. Introduction

Excessive alterations of the global environment by human activities have led to various changes in global biochemical cycles, and transformation of land, and have increased the mobility of the biota. These anthropogenically-induced changes have triggered the sixth major extinction event in the history of life on earth, and have caused widespread changes in the global distribution of organisms (Sala et al., 2000; Midgley et al., 2002; Parmesan & Yohe, 2003; Root et al., 2003). With an increase in resource requirement, more and more natural areas (virgin forests/landscape) is being encroached upon by humans and their resources are exploited, thus leading to a loss of biological diversity. Much of the attempt is on the study and documentation of forest degradation in the tropics, and is not actually related to a quantitative spatial assessment of species loss and composition. It is therefore necessary to determine accurately the rate of such loss, and its spatial patterns to formulate sustainable strategies for conserving and monitoring relatively undisturbed landscapes.

Conservation approaches primarily focus on targeting vegetation types, economic/ ecological species, habitats and landscape units. In any region, land conversion forces the declining population towards the edge of their species range, where they become increasingly vulnerable, and collapse if exposed to further human impact (Channell & Lomolino, 2000). Temporal and spatial mapping and modeling of potential species distribution (e.g. *Ephedra gerardiana*; *Porwal* et al., 2003, *Hippophae rhamnoides*; Roy et al., 2001) helps to quantify and understand the current status, and to assess species loss to specific habitats and landscape. Amarnath et al., 2003, have also shown that conjunctive analysis of patch characteristics and species distribution can be used in identifying the areas of priority in terms of eco-restoration and conservation in wet evergreen forests of India. Thus, a systematic planning is necessary to conserve large areas (Margules & Pressey, 2000), to ensure viability and long-term persistence of species in situ. In practice, the management of reserves is inadequately funded, unplanned and often threatened by illegal extraction of forest products and commercial activities in the tropics (James, 1999). Thus conservation management of naturally occurring undisturbed areas should ensure that the natural values are retained in the face of internal natural dynamics, disturbances from the outside, and varied anthropogenic pressures.

Long-term ecological monitoring sites such as large-scale biosphere atmosphere (LBA) experiment, establishment of biological dynamics of forest fragment projects (BDFFP), and minimum critical size of ecosystem projects (MCSEP) to evaluate the species losses and composition are very few in the tropics (Laurance et al., 2004). Such sites coupled with habitat and landscape characterization enable us to understand the processes regulating biological diversity. In the absence of such intensive data in spatial and temporal domain, satellite remote sensing helps to address habitat loss and analyze probable changes in species composition, based on the extrapolation of spatial changes in species pattern between intact and changed habitats. These studies indicate that conservation approaches based on spatial and temporal information derived from satellite-based platforms, can help identify remnant areas of rich biodiversity.

The present study proposes an approach for monitoring the conservation of phytodiversity using remote sensing and GIS in the Kalakad–Mundanthurai Tiger Reserve, Tamil Nadu (India), an ecological hotspot. The focus is on identifying the remnant patches of intact evergreen forest using multi-temporal satellite data for delineation of vegetation types and their likelihood of sustenance in the coming decades, studying the compositional changes in vegetation in these patches through the conjunctive use of satellite data and phytosociology, analysing the processes regulating the changes, and identifying the conservation areas and monitoring parameters in one of the ecologically sensitive biodiversity hotspots.

2. Materials and methods

2.1 Study site secondary heading, left justified

Kalakad–Mundanthurai Tiger Reserve (KMTR) is located at the southern end of the Western Ghats (hereafter 'WG'), Tamil Nadu, India (Fig 1), and lies between $8^0$21′ - $8^0$52′ N latitude and $77^0$10′ - $77^0$33′ E longitude in the biogeographic provinces (Udvardy, 1975) 4.1.1 (Malabar rainforest) and 4.14.4 (Deccan thorn forest). The area falls in two districts, namely Tirunelveli and Kanya Kumari of Tamil Nadu and is bound in the west by the state of Kerala.

KMTR covers an area of 907km^2, with hills towering to majestic heights ranging from 100 to 1880m (Agasthiar peak). Agasthyamalai hills at the southern end of the WG are known for high species diversity, harbouring about 2000 flowering plant species with 7.5% endemism (Henry et al., 1984). The mid-elevation zone (700 – 1400m) makes up the tropical wet evergreen forest of the Cullenia–Mesua–Palaquium series (Pascal, 1988). The climate of the area is typically wet with a minimum rainfall of 1200mm and a maximum of 5000mm. The annual average temperature ranges from 13.5°C in the evergreen to 23°C in the deciduous forests. The dry period lasts for 3–5 months and the number of rainy days is in the order of 89–92 days (Pascal, 1982). Forest types such as tropical evergreen, tropical semi-evergreen, tropical moist deciduous, tropical dry deciduous, grasslands and secondary succession exist in the study area. The common trees species are Cullenia exarillata, Mesua ferrea, Palaquium elliptium, Myristica dactyloides, Aglaia bourdillonii in the evergreen forest, while the deciduous species includes Anogeissus latifolia, Terminalia chebula and Terminalia bellirica. Major invasive species includes Lantana camara, Ageratum conyzoides and Eupatorium species.

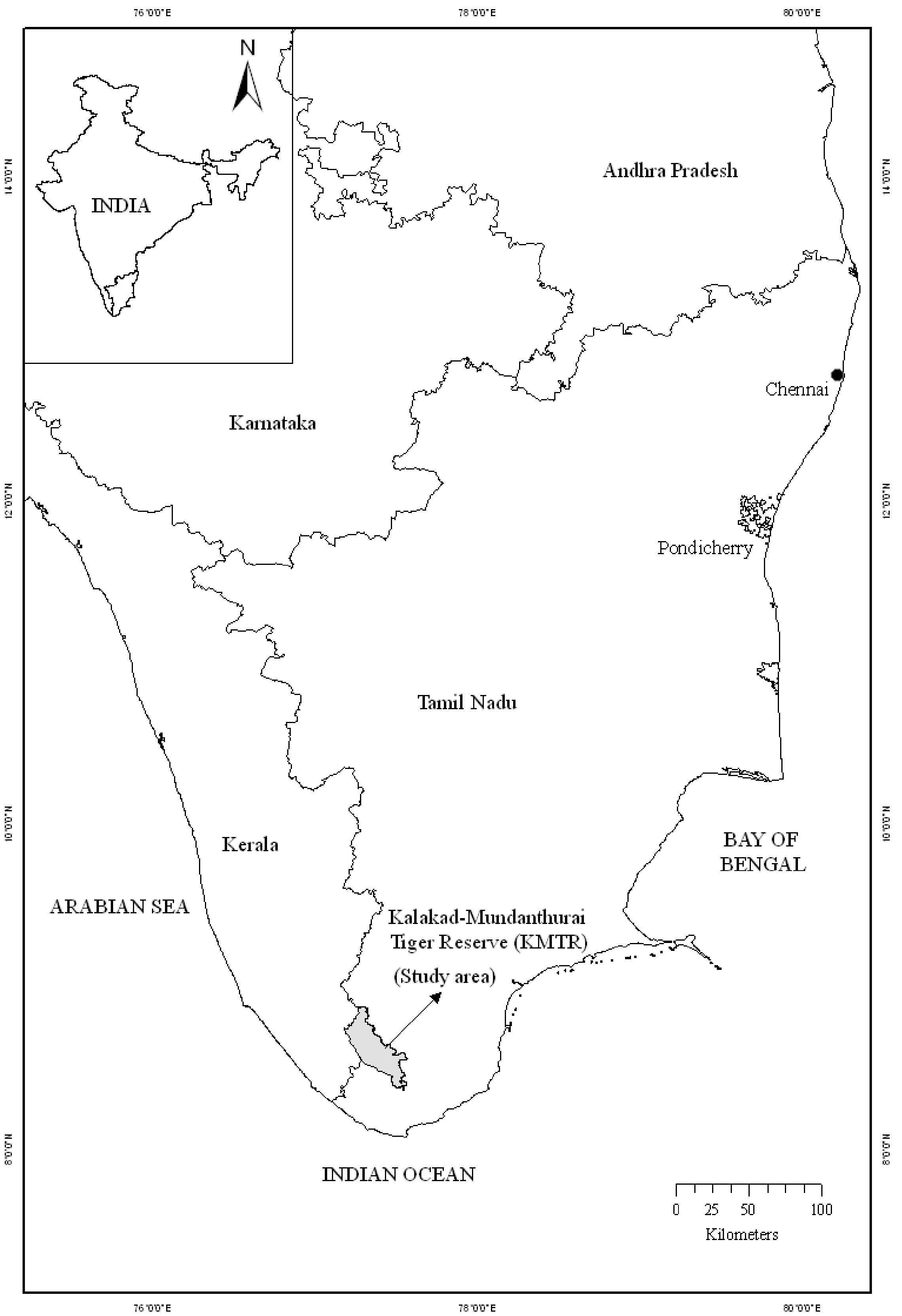


Fig. 1. Map showing the geographic position of Kalakad–Mundanthurai Tiger Reserve, Southern Western Ghats, in the Tirunelveli and Kanykumari districts of Tamil Nadu, India.

2.2 Study site

The evergreen forests of KMTR have a long history of change in the forest cover and land-use type over the last 250 years. Ramesh et al., (1997), have pointed out that there has been a significant loss of biological rich areas between 1960 and 1990 – 85.6km^2 to plantation, 42km^2 to encroachment and 36.4km2 to reservoirs. A total of 28 enclaves have been identified within the KMTR (Ali & Pai, 2001). A total of 189 eco-development villages are in the immediate vicinity of the park in the eastern perimeter in a 5km broad strip. Ecological damage due to forest fires, invasion of reeds and erosion are some of the major causes, which may have led to the change in floristic composition, degeneration and loss of endemics.

2.3 Classification using satellite data and land-cover change

Cloud-free data of LANDSAT Multispectral Scanner (MSS) of March 1973 covering path and row 154/54 was obtained from USGS, EROS Data Center, Sioux Falls, SD; IRS-1B LISS II satellite data of April 1990 and IRS-P6 LISS III satellite data of March 2004 covering path and rows viz. 101/67 and 101/68 from National Remote Sensing Agency, Hyderabad (Fig. 2); LANDSAT-MSS data with a spatial resolution of 80m and the spectral wavelength (B1 0.5 – 0.6, B2 0.6 – 0.7, B3 0.7 – 0.8 and B4 0.8 – 1.1μm); IRS-1B LISS I with a spatial resolution of 72.5m and the spectral wavelength (B1 0.45 - 0.52, B2 0.52 - 0.59, B3 0.62 - 0.68 and B4 0.77 - 0.86μm) and IRS-P6 LISS-III with a spatial resolution of 24m and the spectral wavelength of four bands (B2 0.52 – 0.59, B3 0.62 – 0.68, B4 0.77 – 0.86 and B5 1.55 – 1.70μm) were analysed in the study.

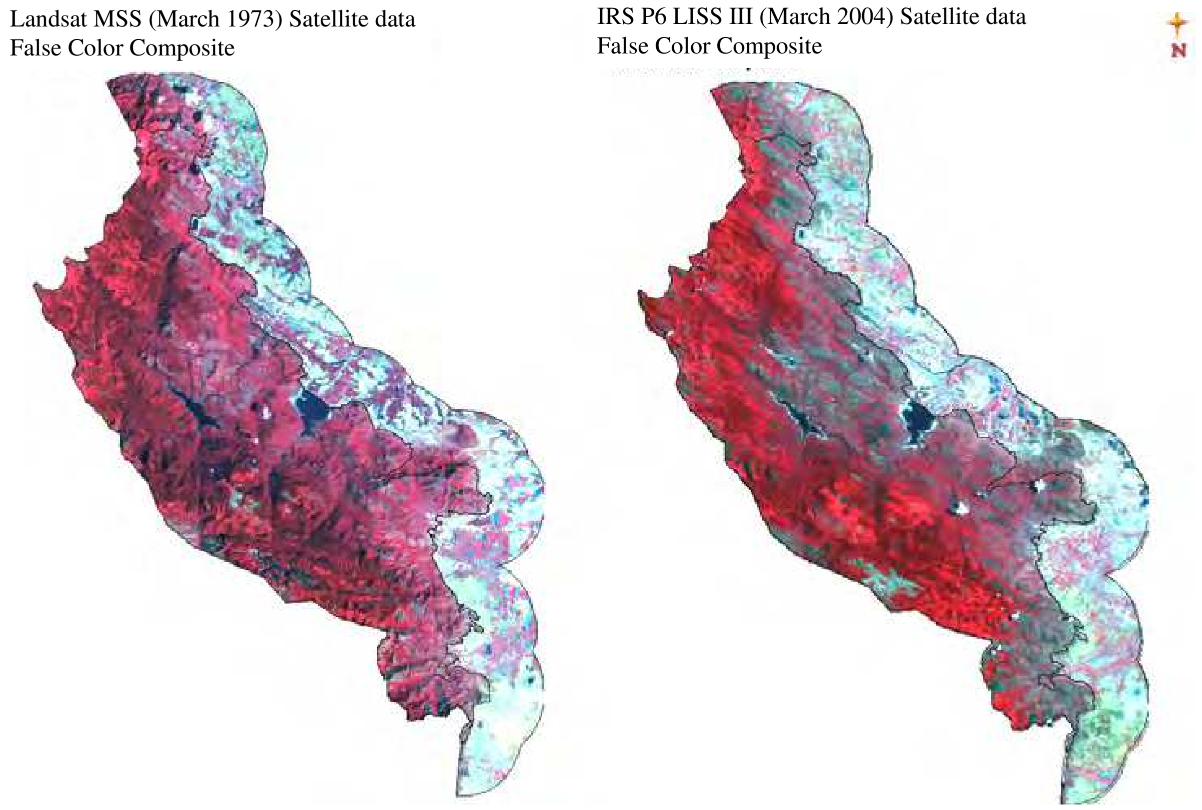
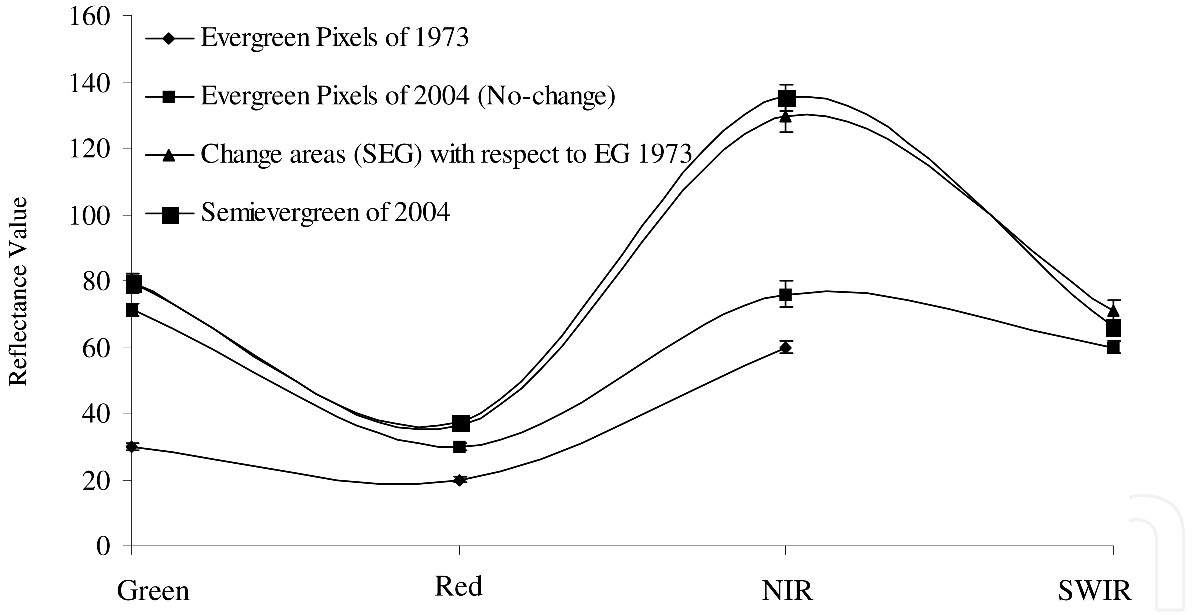


Fig. 2. False color composite for the study region (1973 & 2004) showing different vegetation formations, and also the variation in tone and texture in the Southern Western Ghats, Tamil Nadu, India.

Supervised classification technique was used to classify satellite image of 2004 (LISS-III) based on the information of terrain, topography and species database collected during the landscape-biodiversity characterization program for the Western Ghats region (Anonymous, 2002). Using the 2004 vegetation and land cover map, an area of interest (AOI) was selected for the evergreen patches of 1973 using MSS data assuming that these patches of 2004 had remained unchanged from 1973. The reflectance properties of the evergreen and semi-evergreen patches for the both the satellite images showed similar trends (Fig. 3). Taking into consideration of the above criteria, the 1973 MSS image and LISS-III 2004 image were used to generate the LULC maps of 1973 and 2004. Likewise, all the spectral classes were assigned training sets from the geometrically corrected images and were then classified. The maximum likelihood algorithm was used to classify these scenes (Lillesand & Kiefer, 2000). Major forest types delineated were tropical evergreen, semi-evergreen, moist deciduous, dry deciduous, dry evergreen, grasslands, scrubs, reeds (Ochlandra sp.), and orchards. The tone and textural differences in these forest types can be clearly seen in the satellite imagery (Fig. 2). The classified vegetation map was validated by verification on ground and found to be 85% accurate. Finally, IRS LISS-III dataset were resampled to 80m (equivalent to MSS) to facilitate comparison.



* Short wave infra red (SWIR) of IRS P6 LISS III (March 2004) was used to analyse the pixel differentiation

Fig. 3. Spectral reflectance value (X-axis has spectral bands and Y-axis has reflectance value) differentiating evergreen and semi-evergreen forest types of KMTR, Southern Western Ghats of Tamil Nadu, India.

A brief methodology describing land-cover change analysis carried out for the present study is given in Fig 4. It combines information on phytosociology (no-change and change- areas plots) and land-cover information, modelling evergreen change using spatial drivers to identify areas for biodiversity monitoring and prioritization.

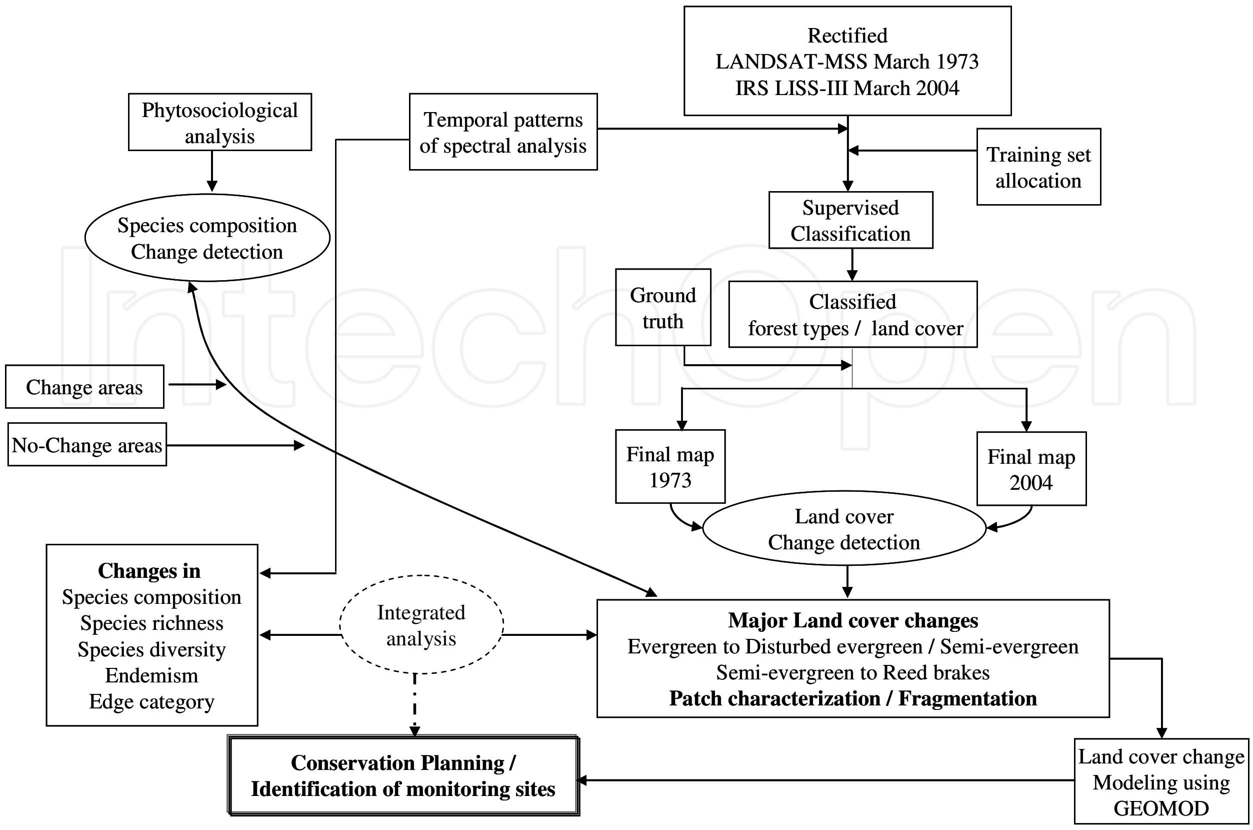


Fig. 4. Methodology used for the study region combining satellite based land-cover and phytosociological information to characterize areas for conservation planning

2.4 Landscape analysis

Landscape is defined as "an aggregation of heterogeneous elements, which interact with each other". Landscape has three intrinsic properties: structure, function and change. These can be explained in terms of porosity, fragmentation, patch density, patchiness, interspersion, juxtaposition, contagion etc (Forman & Godron, 1986). In the present study the following landscape metrics have been studied to assess landscape changes and forest fragmentation patterns.

2.4.1 Fragmentation modeling

Land-cover map with a spatial resolution of 80m was used to characterize the fragmentation levels around the evergreen and semi-evergreen forests pixel. To perform the fragmentation calculations, we used a "moving window" algorithm developed by Riitters et al., (2000). The model was designed to identify patterns of forest fragmentation using coarse and fine scale resolution land-use and land-cover information.

To implement the fragmentation model, the size of the analysis window had to be determined. After considering the resolution of the data, delineation of the forest features having the smallest areas, and practicality assessment of various window sizes, a 5x5 window was found to maintain an adequate representation of the proportion (Pf) of pixels in the window and also to maintain interior forests at an appropriate level.

Using the results from the forest fragmentation model, further research was conducted to produce maps, which identify the state of forest fragmentation in a specified region. The purpose of the forest fragmentation index was to provide a quick means to assess the extent of forest fragmentation within a region, and to track trends in forest fragmentation to identify areas that would benefit from possible reforestation. Different indexes were used to generate forest fragmentation e.g. total forest proportion (TFP), forest continuity (FC) and weighted forest area (WFA). These can be referred from Civco et al., 2002; Vogelmann, 1995; and Wickham et al., 1999.

2.4.2 Patch analysis

Patch Size, Number and Shape: After classifying the forest type using satellite data, it was vectorised in the GIS domain to characterize the patches. The information on patch size and number was extracted from the vectorised classified data. A minimum of 3x3 pixel window was set for patch analysis. A simple measure of patch shape is the perimeter-to-area ratio. This measure is often standardized to the most compact form; either a square or a circle, and is taken as equal to 1. Higher perimeter value indicates increase of edge effect, an ecologically undesirable influence on most species population and communities.

Contagion: Contagion metric was first proposed by O'Neil et al., (1988), and later by several others (Gustafson & Parker, 1992; Herold et al., 2005; Li & Reynolds, 1993). It is a measure of clumping or aggregating the patches. It is used as an indication of the degree of fragmentation of a landscape.

Fractal Dimension: Fractal dimension has been used for measurement, simulation and spatial analysis in the mapping sciences (Despland, 2003; Krummel et al., 1987; Leduc et al., 1994). Changes in the fractal dimension of the remote sensing images, imply changes in the environmental conditions (Lam & Quattrochi, 1992). A number of studies have found that the fractal dimension of the landscape varies according to the type of land-use (Despland, 2003; Krummel et al., 1987).

Patch Per Unit (PPU): PPU is low when the landscape is not fragmented. As the landscape becomes more fragmented, the PPU increases (Frohn, 1998).

Landscape shape complexity: As an alternative to the use of fractal dimension for quantifying patch shape complexity, SqP has been introduced (Frohn, 1998). SqP considers the perimeter area relationship for raster data structures and normalizes the perimeter – area ratio to a value between 0 and 1.

Landscape Shape Index (LSI): Landscape shape index (LSI) provides a standardized measure of the total edge or edge density and adjusts for the size of the landscape. In contrast to total edge, LSI can be interpreted directly because it is standardised, and it is a measure of patch aggregation or disaggregations. An increase in LSI indicates an increase in disaggregation.

2.5 Predictive modelling of evergreen forest

An attempt has been made to model land-use and land-cover change (LULC) using GEOMOD, to predict future changes (Fig. 5). GEOMOD is a simple unidirectional linear change modelling tool (Pontius & Batchu, 2003) that uses suitability image/s, produced by combining a variety of driver images to predict locations of change for a given quantum of change between two time periods. After comparing its past and present performances, using satisfactory suitability image/s, one can actually simulate future change for various scenarios of change between two different time frames. The most interesting part of this type of change modelling is its ability to model location-specific changes for different quantities of change.

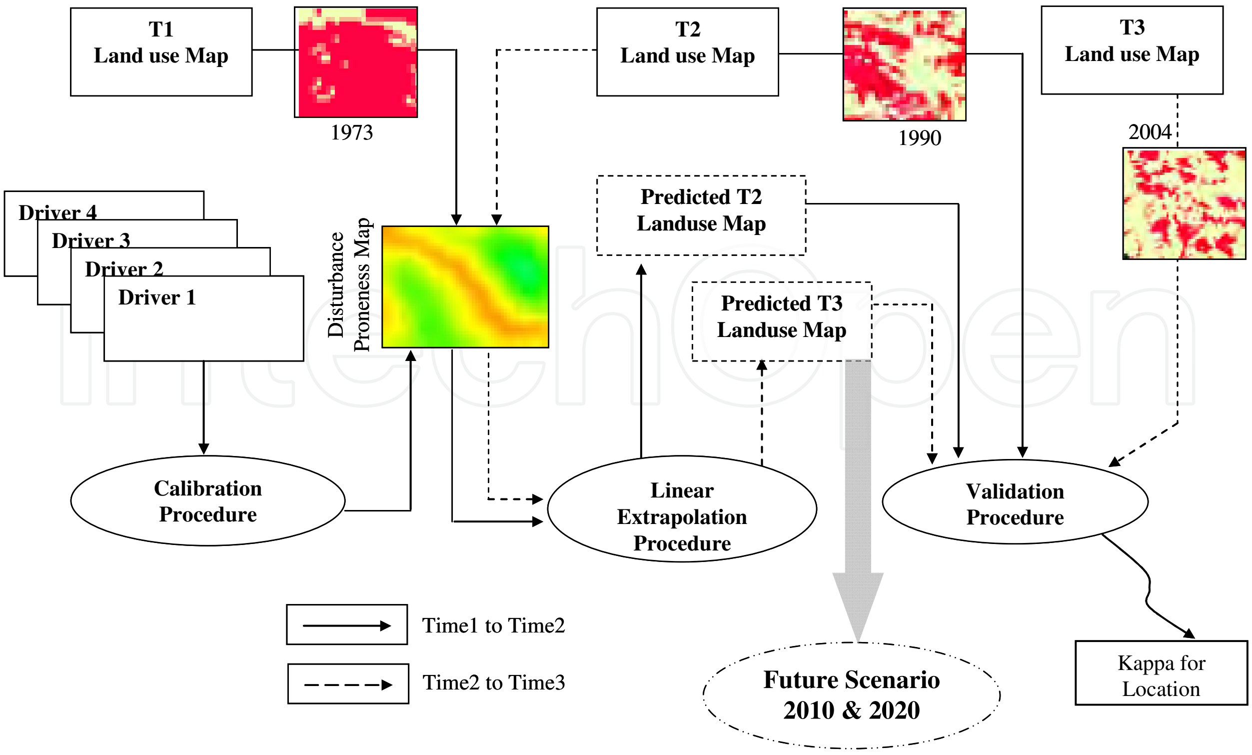


Fig. 5. GEOMOD based modeling of evergreen forest change using spatial drivers, extrapolation and validation procedure for the future evergreen forest scenario in KMTR

2.5.1 Reclassification of land-use types

GEOMOD can evaluate change in two land-use types at a time. Therefore, each of the vegetation and land-cover map was reclassified as evergreen (evergreen) and non-evergreen (semi-evergreen, deciduous and other land-cover) areas. The most common reclassification is to classify all undisturbed forest as type 1, and all other land-use types, which can be characterized as having undergone some human intervention, such as disturbed evergreen, orchards, and Ochlandra areas as type 2. Area estimation is done using reclassified data, to determine how many forest pixels existed for a particular time period. Future rate of change is calculated using the simple subtraction to find the area deforested during the interim period.

2.5.2 Spatial drivers of land cover change

Thirteen carefully chosen drivers (Fig. 6) including altitude, slope, aspect, proximity to protected area (PA) boundary, settlement, tea and coffee plantation, road and footpath, rainfall intensity and existing sites of Ochlandra reeds were integrated using appropriate fuzzy set membership functions into a single suitability image (Eastman, 2003). This suitability image was then used in GEOMOD to model change from 1973 to 1990, 1990 to 2004 and then from 2004 to 2020. The driver maps used for each calibration run are added together to create a (disturbance proneness area) suitability map (Fig. 6). GEOMOD uses this map of ranked potentials, or likelihoods, to simulate deforestation at a third point in time, the results of which are validated against the actual map of that same time period to test how well the drivers did in predicting the spatial pattern of deforestation. This 'test' is called the validation process and is discussed further below.

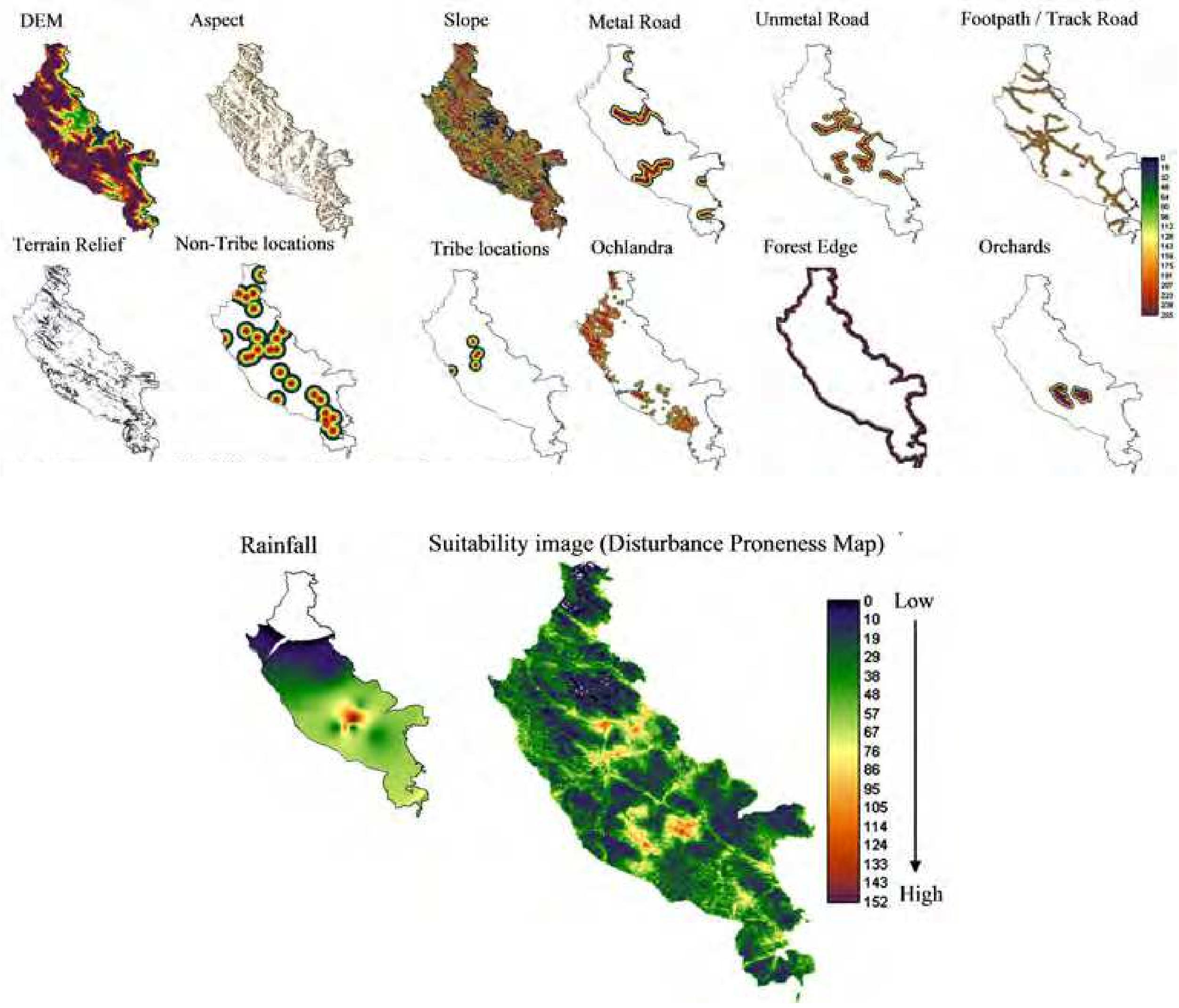


Fig. 6. List of potential spatial drivers generated using multi-criteria decision support to generate suitability image for the evergreen forest change modeling of KMTR, Southern Western Ghats, Tamil Nadu, India.

2.5.3 Validation

To validate the results created by GEOMOD, the actual evergreen map at a known point of time is compared with the predicted evergreen map of that same time, based on analysis of the pattern at an earlier time point using the "Validation" tool available in the IDRISI module. In the past, measures of the 'goodness of fit' commonly were performed by using a simple percent-correct measure or, at best, a multiple-resolution percent-correct measure (Costanza, 1989; Hall et al., 1995), but this provides little assessment of a model's ability to predict the correct quantity of change versus its ability to identify the correct location of change (Pontius & Batchu, 2003; Pontius & Pacheco, 2004). Spatial measures of 'goodness of fit' have been developed, that measures the degree to which a simulated map agrees with a reality map with respect to both location (Kappa-for-location) and quantity of cells correct (Kappa-for-quantity).

3. Results

3.1 Vegetation types

The changes in the vegetation cover based on digital classification of Landsat-MSS and IRS LISS-III data shows a significant decrease of evergreen forest mostly to semi-evergreen forest types (Table 1a). Of the total area covered by natural vegetation (857sq.km) the evergreen and semi-evergreen forest occupied 60% of the area. The map showing multi-temporal vegetation and land-cover classification is given in Fig. 7. In 1973, evergreen forests constituted 316sq.km, followed by semi-evergreen having 194sq.km. In 2004 the evergreen forest had diminished to 188sq.km (i.e. 40% loss of land-cover), whereas semi-evergreen forest gained by 36% to 265.1sq.km. The grassland covering of 73sq.km is largely distributed among the Kodayar, Manjamparai and adjoining areas of the Agasthyamalai region. The area under grassland has shown a significant increase of ca. 166% during the period 1973 – 2004.

S.No	Types	1973	2004
Phenelogical types			
1	Evergreen	316.72	188.49
2	Semi-evergreen	194.40	265.10
3	Moist deciduous	143.59	132.02
4	Dry deciduous	38.95	98.30
5	Dry evergreen	136.14	61.55
6	Grassland	27.36	73.14
	Subtotal	**857.16**	**818.60**
Other landcover types			
7	Shrubs	1.11	16.01
8	Ochlandra	13.56	23.74
9	Orchards	2.33	16.42
10	Fallow/barren	10.04	9.86
11	Water	15.22	16.86
12	Shadow	6.97	2.50
13	Cloud	1.07	3.46
	Grand total	**907.46**	**907.46**

Table 1a. Vegetation and land-cover distribution in KMTR, Southern Western Ghats, Tamil Nadu, India. for the years1973 and 2004 using satellite imagery.

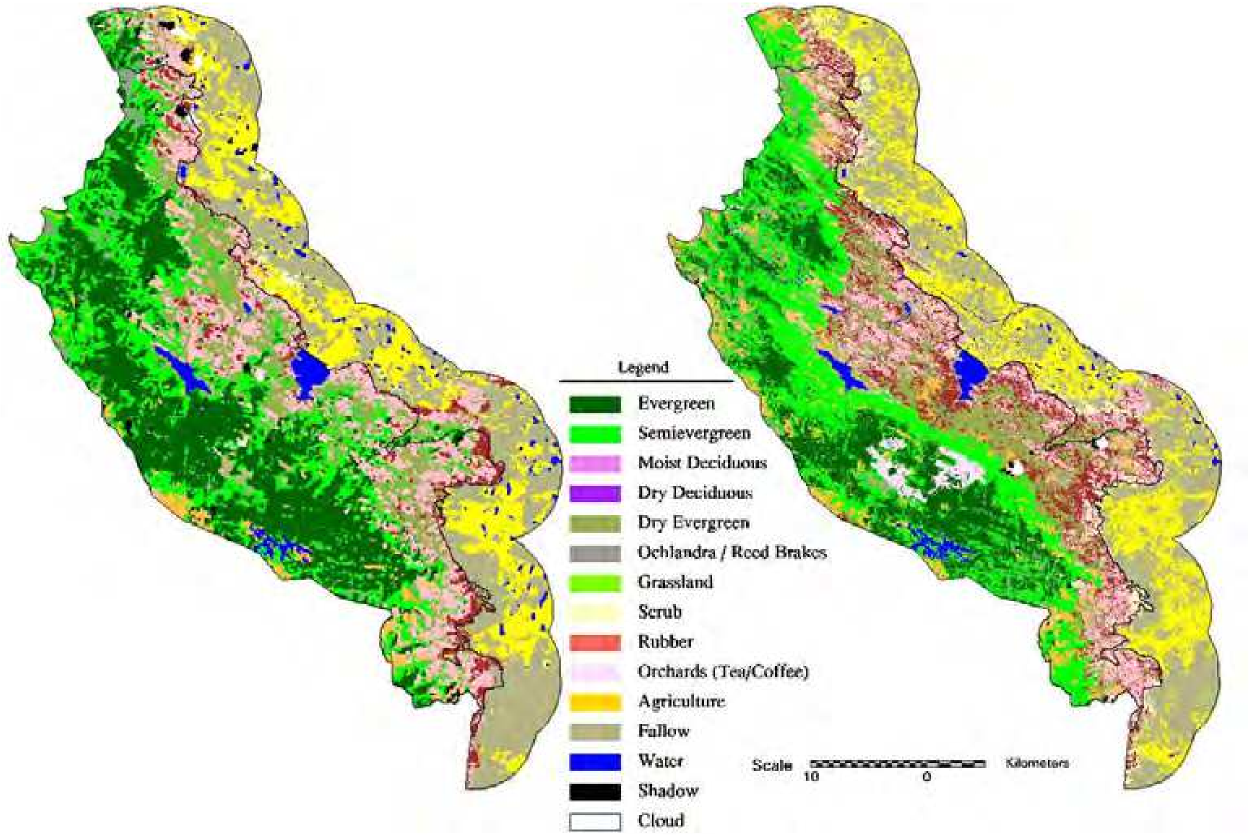


Fig. 7. Vegetation and land cover classification map for the study region (1973 & 2004) of KMTR, Southern Western Ghats, Tamil Nadu, India.

3.2 Spectral analysis

The spectral reflectance of the evergreen forest in the NIR band of 1973 (60±2 SD) is quite similar to the spectral reflectance of the 2004 data having 76±4 SD. The semi-evergreen patch showed a spectral reflectance of 92±3 SD from the 1973 data, while the semi-evergreen reflectance in 2004 was 135±4 SD (Fig. 3). The evergreen patches which had been converted to semi-evergreen patches during 2004 showed a reflectance of 130±5 in the NIR. The SWIR band of IRS P6 LISS-III has shown that the intact evergreen and disturbed evergreen patches can be distinctly differentiated from this reflectance value.

3.3 Land-cover change analysis

Change detection analysis was performed was performed on the data from two time periods – 1973 and 2004 – and change matrix is given in Table 1b. Major changes in the land-cover of KMTR has been the change from evergreen to semi-evergreen forest type (121.74km^2), constituting ca. 38% of the total land-cover changes, evergreen to reeds brake (Ochlandra) (6.64km^2), and evergreen to orchards (4.87km^2). Conspicuous changes in semi-evergreen forest type were to grassland (17.64km^2), Ochlandra (10.72km^2) and orchards (6.76km^2). It is observed that the changed vegetation cover is mostly in patch sizes of either 100ha or more, or in the size of 10 –50ha.

2004 1973	Evergreen	Semi-evergreen	Others	**Total**
Evergreen	166.31	121.74	28.67	**316.72**
Semi-evergreen	21.02	119.19	54.20	**194.40**
Others	1.16	24.17	371.02	**396.34**
Total	**188.49**	**265.10**	**453.88**	**907.46**

Table 1b. Change matrix for KMTR between 1973 and 2004, Southern Western Ghats, Tamil Nadu, India.

3.4 Phytodiversity change analysis

To understand the changes of evergreen to semi-evergreen patches in terms of phytosociological data, a total of 95 sample plots (0.1ha each) were grouped into change (40 plots) and no-change areas (55 plots) for identification of predominant species, percentage of endemic and edge species. Differences in species composition based on predominant species for change and no-change area are given in Table 2. Of the total 266 tree species in the no-change area 38% were endemic and 25% were edge species. While in the change areas having 249 tree species 31% were endemic, 31% belonged to the edge species. Among the saplings in the no-change area (170 species) 44% were endemic and 19% were edge species, in the change area (146 species) 34% were endemic and 29% were of the edge species.

	No-Change area	**Change area**
Tree Species ≥ 30 cm		
No. of plots	55	40
No. of Species	266	249
No. of Individuals	3340	1977
Stand density (ha^{-1})	607	494
Basal area (m^2ha^{-1})	54.39	44.11
No. of endemic species / individuals	100 (38) / 1274 (38)*	78 (31) / 737 (37)
No. of edge species / individuals	66 (25) / 294 (9)	78 (31) / 296 (15)
Saplings (Tree and Shrub) ≤ 30 cm		
No. of plots	51	33
No. of Species	170	146
No. of Individuals	863	535
Stand density (ha^{-1})	169	162
Basal area (m^2ha^{-1})	0.47	0.42
No. of endemic species / individuals	75 (44) / 399 (46)	49 (34) / 155 (29)
No. of edge species / individuals	33 (19) / 60 (7)	42 (29) / 142 (27)

* Figures in bracket indicates percentage

Table 2. Consolidation of phytosociological analysis in no-change and change area plots in KMTR, Southern Western Ghats, Tamil Nadu. India.

The first three predominant species composition in the no-change area is largely composed of *Cullenia exarillata – Myristica dactyloides – Mesua ferrea* when compared to the change areas having *Cullenia exarillata – Dimocarpus longan – Kingiodendron pinnatum* (Table 3a). The percentage of endemic species in the change area is greater by 7% and edge species lesser by 7% when compared to the no-change area. Interestingly in change areas large levels of secondary successional species were noticed, which includes *Epiprinus mallotiformis*, *Macaranga peltata*, *Mallotus philippensis*, *Scolopia crenata*, and *Schleichera oleosa*. Regeneration trend in no-change areas showed a dominance of *Antidesma menasu*, *Cinnamomum malabatrum* and *Mesua ferrea* while in change areas *Dimocarpus longan*, *Mallotus philippensis* and *Mesua ferrea* species are seen to be dominant. Further, the dominants in the semi-evergreen are again *Dimocarpus* longan, *Mallotus philippensis* and *Mesua ferrea* indicating that the evergreen patch is gradually being changed to semi-evergreen (Table 3b). Species similarity between no-change and change areas was found to be at 68%.

Similar trends on endemic and edge species have been noticed in the no-change and change areas. No-change areas of endemic tree species showed dominance in *Mesua ferrea*, *Aglaia bourdillonii* and *Hopea utilis*, while for saplings it was *Mesua ferrea*, *Cinnamomum malabatrum* and *Cryptocarya bourdillonii* (Table 4a). In the case of edge tree species the dominant ones were *Macaranga peltata*, *Mallotus philippensis* and *Memecylon edule* while among saplings *Mallotus philippensis*, *Macaranga peltata* and *Olea dioica* were dominant (Table 4b).

Species no-change area	**IVI**	**Species change area**	**IVI**	**Semievergreen**	**IVI**
Cullenia exarillata	22.51	*Cullenia exarillata*	20.17	*Dimocarpus longan*	31.58
Myristica dactyloides	9.88	*Dimocarpus longan*	20.10	*Mesua ferrea*	15.00
Mesua ferrea	9.72	*Kingiodendron pinnatum*	8.18	*Canarium strictum*	12.18
Agrostistachys meeboldii	9.64	*Mesua ferrea*	7.83	*Diospyros paniculata*	11.04
Syzygium gardneri	7.74	*Filicium decipens*	6.86	*Filicium decipens*	10.93
Dimocarpus longan	7.11	*Hopea parviflora*	5.88	*Holigarna arnottiana*	10.44
Calophyllum austroindicum	6.41	*Vitex altissima*	5.60	*Garcinia gummi-gutta*	8.40
Aglaia bourdillonii	6.23	*Hopea utilis*	5.26	*Kingiodendron pinnatum*	8.06
Antidesma menasu	5.72	*Myristica dactyloides*	5.22	*Madhuca indica*	7.33
Hopea utilis	5.26	*Diospyros foliolosa*	4.25	*Mallotus philippensis*	6.98
Acronychia pedunculata	5.17	*Macaranga peltata*	4.23	*Hopea parviflora*	6.61
Artocarpus heterophyllus	4.98	*Agrostistachys meeboldii*	4.18	*Gordonia obtusa*	6.44
Xanthophyllum flavescens	4.86	*Mallotus philippensis*	3.75	*Wrightia tinctoria*	6.02
Palaquium ellipticum	4.78	*Syzygium mundagam*	3.52	*Schleichera oleosa*	5.67
Mangifera indica	4.66	*Pterospermum diversifolium*	3.40	*Diospyros sp.*	5.43
Gomphandra coriacea	4.27	*Scolopia crenata*	3.24	*Bischofia javanica*	4.85
Cryptocarya bourdillonii	4.04	*Syzygium gardneri*	3.19	*Pterospermum xylocarpum*	4.81
Epiprinus mallotiformis	4.00	*Cinnamomum malabatrum*	3.00	*Persea macrantha*	4.72
Pterospermum xylocarpum	3.82	*Tricalysia apiocarpa*	2.97	*Myristica dactyloides*	4.72
Cinnamomum malabatrum	3.62	*Diospyros paniculata*	2.95	*Acronychia pedunculata*	4.52

Table 3a. Tree species composition in no-change and changes areas of the evergreen and semi-evergreen forests in KMTR, Southern Western Ghats, Tamil Nadu, India.

Species no-change area	IVI	Species change area	IVI	Semievergreen	IVI
Antidesma menasu	12.09	*Dimocarpus longan*	25.19	*Dimocarpus longan*	13.00
Cinnamomum malabatrum	10.61	*Mallotus philippensis*	13.20	*Mallotus philippensis*	12.01
Mesua ferrea	10.61	*Mesua ferrea*	8.07	*Mesua ferrea*	10.00
Cullenia exarillata	9.62	*Hydnocarpus alpina*	7.89	*Macaranga peltata*	9.84
Cryptocarya bourdillonii	8.79	*Nothopegia beddomei*	6.49	*Hydnocarpus alpina*	9.23
Syzygium gardneri	8.75	*Xanthophyllum flavescens*	5.90	*Pavetta hispidula*	8.74
Myristica dactyloides	7.55	*Macaranga peltata*	5.80	*Epiprinus mallotiformis*	8.41
Agrostistachys meeboldii	6.94	*Meliosma pinnata*	5.72	*Chomelia asiatica*	7.84
Xanthophyllum flavescens	6.81	*Pavetta hispidula*	5.24	*Scolopia crenata*	7.00
Palaquium ellipticum	6.33	*Mallotus stenanthus*	5.21	*Acronychia pedunculata*	6.81
Neolitsea scorbiculata	5.82	*Canthium angustifolium*	5.01	*Kingiodendron pinnatum*	6.01
Nothopegia heyneana	5.17	*Kingiodendron pinnatum*	5.01	*Filicium decipens*	5.71
Gomphandra coriacea	5.02	*Olea dioica*	4.87	*Persea macrantha*	5.11
Mallotus stenanthus	4.77	*Holigarna arnottiana*	4.65	*Olea dioica*	4.86
Epiprinus mallotiformis	3.91	*Filicium decipens*	4.42	*Holigarna arnottiana*	4.15
Hydnocarpus alpina	3.84	*Eugenia thwaitesii*	4.11	*Canthium angustifolium*	3.95
Cinnamomum verum	3.83	*Eugenia calcadensis*	4.03	*Meliosma pinnata*	3.11
Litsea mysorensis	3.67	*Chomelia asiatica*	3.82	*Xanthophyllum flavescens*	2.99
Litsea floribunda	3.67	*Epiprinus mallotiformis*	3.77	*Nothopegia beddomei*	2.11
Octotropis travancorica	3.64	*Scolopia crenata*	3.68	*Diospyros paniculata*	2.00

Table 3b. Species composition in tree and shrub saplings of no-change and changes areas of the evergreen and semi-evergreen forests in KMTR, Southern Western Ghats, Tamil Nadu, India.

Species	Trees ≥ 30 cm		Species	Sapling ≤ 30 cm	
	No-change	Change		No-change	Change
Mesua ferrea	116	53	*Mesua ferrea*	34	12
Aglaia bourdillonii	107	16	*Cinnamomum malabatrum*	34	2
Hopea utilis	80	37	*Cryptocarya bourdillonii*	27	1
Litsea floribunda	50	1	*Nothopegia heyneana*	21	5
Cryptocarya bourdillonii	44	1	*Palaquium ellipticum*	21	0
Palaquium ellipticum	43	15	*Mallotus stenanthus*	15	9
Cinnamomum malabatrum	36	29	*Octotropis travancorica*	11	1
Drypetes confertiflorus	36	1	*Litsea mysorensis*	10	2
Calophyllum austroindicum	34	1	*Nothopegia beddomei*	9	10
Symplocos macrocarpa	33	8	*Aglaia bourdillonii*	9	2

Table 4a. Predominant endemic species and its individuals in no-change and change areas of the evergreen forest in KMTR, Southern Western Ghats, Tamil Nadu, India.

Species	Trees ≥ 30 cm		Species	Sapling ≤ 30 cm	
	No-change	Change		No-change	Change
Macaranga peltata	41	38	*Mallotus philippensis*	2	23
Mallotus philippensis	14	33	*Macaranga peltata*	1	11
Memecylon edule	5	12	*Olea dioica*	5	10
Margaritaria indica	2	12	*Canthium angustifolium*	1	10
Cleistanthus malabaricus	1	12	*Chomelia asiatica*	4	7
Gordonia obtusa	7	11	*Glycosmis mauritiana*	1	7
Olea dioica	7	9	*Ixora lanceolata*	3	5
Canthium dicoccum	6	9	*Oreocnide integrifolia*	2	5
Ixora brachiata	3	8	*Psychotria subintegra*	2	5
Chomelia asiatica	11	7	*Gordonia obtusa*	0	5

Table 4b. Predominant edge species and its individuals in no-change and change areas of the evergreen forest in KMTR, Southern Western Ghats, Tamil Nadu, India.

3.5 Landscape analysis

3.5.1 Forest fragmentation

The area under fragmentation in the evergreen forest type showed varied changes in the different categories from 1973 – 2004 (Table 5a). While the interior category decreased from 113.90sq.km (36%) to 23.27sq.km (12%), the perforated category decreased from 85.0 to 23.7sq.km, whereas the other categories showed significant increase in fragmentation (patch category 14.82 to 25.3sq.km; edge category 66.8 to 80.15sq.km). There appear to be no significant change in the transitional category. In case of semi-evergreen patches, almost all the categories except the perforated and transitional category showed significant increase (Table 5a). Like evergreen forests, in these forests also the transitional category did not show any significant changes from 1973 – 2004. The perforated category showed a decrease from 60.4 to 31.7sq.km. The total forest proportion (TFP) of the evergreen forest has decreased by 40%, while the semi-evergreen patch showed an increase of TFP by 36%. A similar trend was also shown in the weighted forest area (WFA) values in the evergreen and semi-evergreen forests. Evergreen forest continuity (FC) decreased by 88.4% while the semi-evergreen forest continuity was seen to increase by 77% (Table 5b).

3.5.2 Patch analysis

The patch size and distribution for the period of 1973 – 2004 shows a relative decrease in the number of smaller patches and an increase in the number of larger patches in the evergreen as well the semi-evergreen type (Table 6). In the 1973 patches of < 50ha these constitute 7% (131 patches), and in the 100 – 500ha constitute 6.22% (9 patches) of the total evergreen area. Contrastingly in 2004, < 50 ha constituted 9.77% (110 patches) and 100 to 500ha made up 12.53% (10 patches). Interestingly, >1000ha patches in 1973 hold 90% (3 patches) when compared to 2004 making up only 67% (4 patches). Similarly in semi-evergreen forest of 1973 >1000ha patches showed 23% (3 patches) when compared to the 2004 area of 60% (3 patches). The results revealed that the distribution of patches could be categorized into four different patterns, namely, larger areas covered by lesser number of patches (evergreen forest of 1973), lesser areas covered by fewer patches (evergreen forest of 2004), lesser areas covered by large number of patches (Semi-evergreen forest of 1973), and lesser areas covered by least number of patches (Semi-evergreen forest of 2004) as seen in Table 6.

Sl	Evergreen category	1973 (Sq. km)	Area (%)	2004 (Sq. km)	Area (%)
1	Interior	113.90	35.96	23.27	12.35
2	Patch	14.78	4.67	25.33	13.44
3	Transitional	32.95	10.40	31.60	16.76
4	Edge	66.88	21.12	80.15	42.52
5	Perforated	85.00	26.84	23.73	12.59
6	Undetermined	3.20	1.01	4.40	2.33
Total		**316.72**	**100.0**	**188.49**	**100.00**

Sl	Semievergreen category	1973 (Sq. km)	Area (%)	2004 (Sq. km)	Area (%)
1	Interior	10.47	5.39	29.35	11.07
2	Patch	29.56	15.21	35.24	13.29
3	Transitional	49.55	25.49	49.42	18.64
4	Edge	44.16	22.72	115.28	43.49
5	Perforated	60.41	31.08	31.69	11.95
6	Undetermined	0.25	0.13	4.12	1.55
Total		**194.40**	**100.00**	**265.10**	**100.00**

Table 5a. Forest fragmentation categories for the evergreen and semi-evergreen (1973 - 2004) in KMTR, Southern Western Ghats, Tamil Nadu, India.

	Evergreen		**Semievergreen**	
	1973	**2004**	**1973**	**2004**
TFP	0.355	0.212	0.218	0.298
WFA	274.38	147.06	150.28	207.19
FC	0.043	0.005	0.002	0.009

Table 5b. Forest fragmentation conditions based on TFP and FC for evergreen and semi-evergreen (1973 - 2004) in KMTR, Southern Western Ghats, Tamil Nadu, India.

Patches having perimeter-to-area (PA) ratio of <0.015 were 51% in 1973 (i.e. 80 patches), as compared to only 30% in 2004 (i.e. 42 patches) indicating the contiguity of large patches with lesser perimeter (Table 6). The higher PA ratio of >0.025 was observed in 2004 to be 37.4% (from 52 patches) as compared to 10.8% in 1973 (from 17 patches) indicating more complex shapes due to increasingly higher PA ratios.

For evergreen forests, fractal dimension (FD) increased from 1.32 to 1.35 while in the case of semi-evergreen forests, it was constant at 1.37 (Table 6). The patch per unit (PPU), which is an indication of clumping, showed an increase in the case of evergreen forest type from 1.18E-07 to 2.17E-07, while in the case of semi-evergreen the PPU showed a slight decrease from 2.44E-07 to 2.31E-07. The patch shape complexity (SqP) for evergreen forests showed an increase from 0.956 to 0.965, whereas in the semi-evergreen type it showed a marginal increase from 0.973 to 0.974. The degree of fragmentation indicator based on the contagion matrix showed a slight decrease in the case of evergreen forest (0.452 to 0.450), while in the case of semi-evergreen there was an increase from 0.457 to 0.469.

Sl.	Parameters	Evergreen		Semievergreen	
		1973	2004	1973	2004
1	Area (sq.km)	290.25	150.14	193.45	229.89
2	Number of Patches	157	139	361	199
3	Patch density	0.54	0.93	1.87	0.87
5	Patch size (ha)				
	< 50	7.05^{+} (131)*	9.77 (110)	24.52 (292)	10.54 (171)
	50 to 100	3.18 (14)	6.58 (14)	10.37 (29)	2.81 (10)
	100 to 500	6.22 (9)	12.53 (10)	32.83 (34)	12.14 (11)
	500 to 1000	0.00	3.33 (1)	8.87 (3)	13.90 (4)
	>1000	90.60 (3)	67.79 (4)	23.41 (3)	60.61 (3)
6	Perimeter / area ratio				
	< 0.015	50.96 (80)	30.22 (42)	48.75 (176)	14.57 (29)
	0.016 - 0.020	38.22 (60)	32.37 (45)	41.00 (148)	39.20 (78)
	> 0.025	10.83 (17)	37.41 (52)	10.25 (37)	46.23 (92)

+ Non Bracketed number indicate % of evergreen forest

* Bracketed number indicate number of patches

Type	LSI	Patch Cohesion	Contagion	D	PPU	SqP
	Evergreen					
1973	16997.04	99.9976	0.452	1.32	1.1764E-07	0.965
2004	16373.33	99.9952	0.450	1.36	2.1697E-07	0.966
	Semievergreen					
1973	16997.04	99.9961	0.457	1.38	2.4433E-07	0.973
2004	16373.33	99.9967	0.460	1.38	2.3063E-07	0.974

Table 6. Patch characteristics and other landscape metrics analyzed for the evergreen and semi-evergreen forest in KMTR, Southern Western Ghats, Tamil Nadu, India.

3.6 Predictive modelling of evergreen forest cover

This study revealed considerable type changes from evergreen to semi-evergreen forests within the KMTR in three decades. Ideally we should have a database of 1973 to validate these changes in terms of species composition or its drivers of land-cover changes. However, in the absence of such databases, two approaches are being used to discuss the observed changes: spectral similarity and species similarity. Evergreen ground sample points of 2004 showed similar spectral characteristics when overlaid on the MSS data of 1973. Comparison of the 1973 data based on spectral signature similar to the 2004 evergreen signature showed that the area classified as evergreen was observed to be around 128 sq km more in the former than the 2004 extent. On evaluating the ground sample points of the area shown to be evergreen in the 1973 data but not in the 2004 data, it was observed that the species composition of the latter were of the semi-evergreen type and showed spectral characteristics similar to the semi-evergreen of the 1973 data. Thus these patches are spectrally distinct in terms of their tone and texture. (See Fig. 2). Table 3a&b highlights the evergreen plots of change areas and the intact evergreen plots which differ widely in terms of their species compositions. Similarly, the evergreen changed areas are closer towards semi-evergreen areas. Based on these findings the changed evergreen areas are considered to be semi-evergreen forest types.

Results indicate that between 1973 and 1990 (the protection began in 1987) about 42% of the total non-degraded forest was actually lost to the degraded category. However the rate of degradation substantially reduced after the protection became effective and the results indicate that only 9% of the total forest that remained in 1990 was lost to the degraded category (Fig. 8 & Table 7). Using GEOMOD it is perceived that even if the same level of protection persists; an additional 27% of the non-degraded forest would be lost to the degraded category by 2020. The results were validated using the validation tool of IDRISI software. The pixel location and quantity comparison of the actual and predicted map of 1990 showed 80% accuracy, while for the 2004 maps it was 88% accuracy (Fig. 9). Based on the validation inputs, the predicted maps of 2010 and 2020 were prepared (Fig. 8).

Evergreen Forest	Area (sq.km)
1973	316
1990	182
2004	166

Current Scenario

Category	No. of Pixels
Evergreen forest - 1973	47709
Evergreen forest - 1990	27616
Total change	20093

Total change (Sq.km)	129
Annual rate of change (Sq km)	7.56

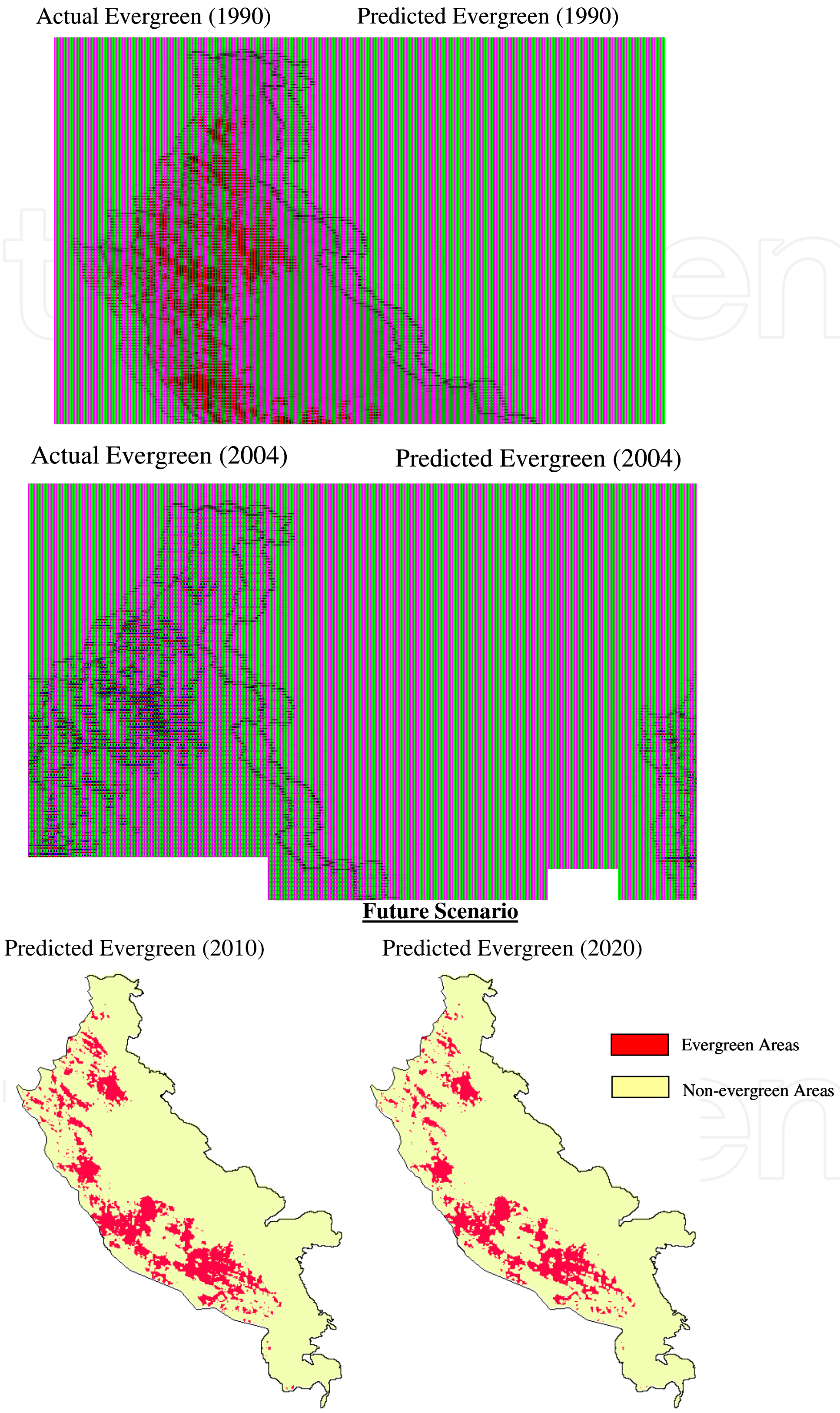
Evergreen forest - 2004	24903
Total change	2713

Total change (Sq.km)	17
Annual rate of change (Sq km)	1.2

Future Scenario

Change in Evergreen Forest	Area (Sq.km)
2010	134.72
2020	112.79

Table 7. Current and future scenarios for the evergreen forest changes using GEOMOD approach in KMTR, Southern Western Ghats, Tamil Nadu, India.



Actual Evergreen (1990) Predicted Evergreen (1990)

Actual Evergreen (2004) Predicted Evergreen (2004)

Future Scenario

Predicted Evergreen (2010) Predicted Evergreen (2020)

Fig. 8. Comparison of actual and predicted evergreen forest change between 1990 & 2004 using GEOMOD modeling and also the future scenario map of 2010 & 2020 for the study region (KMTR), Southern Western Ghats, Tamil Nadu, India.

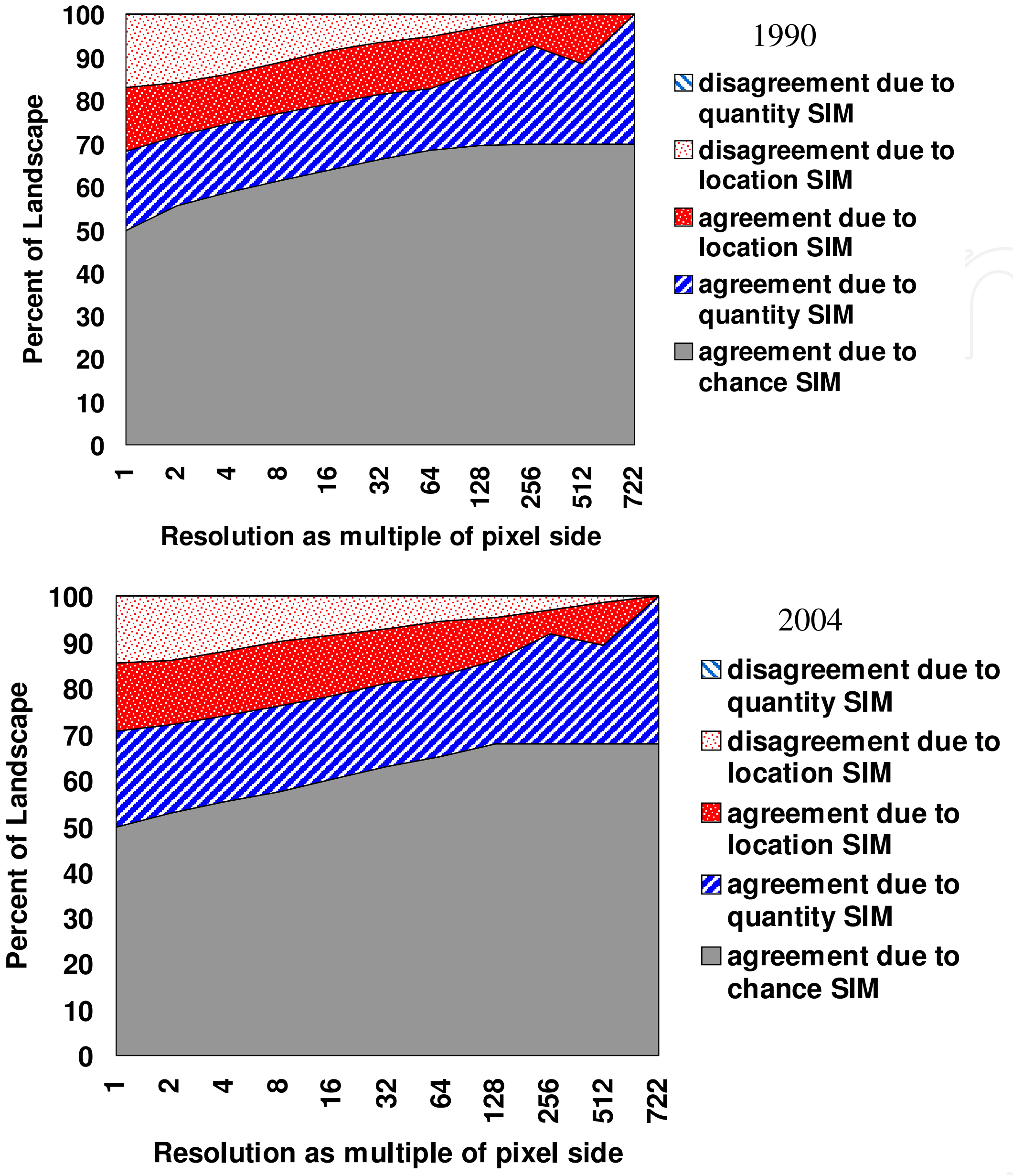


Fig. 9. Evaluation of the evergreen forests change using Kappa validation module (IDRISI) for the actual and reference image (1990 & 2004) of KMTR, Southern Western Ghats, Tamil Nadu, India.

4. Discussion

4.1 Area loss and type transition

The maintenance of biodiversity in a landscape depends on the extrinsic and intrinsic factors regulating the ecosystem and its functioning. Extrinsic factors include area loss (forest to non-forest), forest type transitions, destruction of natural vegetation by overgrazing, encroachment, logging, changes in landscape parameters (i.e. porosity, fragmentation, patchiness, shape and neighbourhood), forest edge influences, forest fires, and developmental activities within forest areas (i.e. road, tourism related pressure, fuel wood extraction, and NTFP extraction). Intrinsic factors which affect these changes are wildlife movements, invasive species, functional change in regeneration, modes and rate of propagule dispersion, decrease in girth-class distribution, and change in species composition, to name a few. These can directly or indirectly influence the process, function and regulators of biodiversity.

In most of the tropical regions, the major threat to forests is not outright deforestation. Rather, forests and their biota are affected by (1) simplification, where structurally rich native forests are converted to simplified secondary stands or other forest types due to harvesting of selective species, (Noss & Cooperrider, 1994; Perry, 1994) and (2) fragmentation, where the remaining tracts of native forests are separated into smaller patches by anthropogenic activities, resulting in a terrain that is hostile to many species and poses barriers to movement (Noss & Csuti, 1997; Saunders et al., 1991; Wilcove et al., 1986).

For studies involving change estimation over a spatial and temporal domain it is important to have ground-based surveys to validate the observed changes, but such surveys are rare and in most cases simply do not exist in the tropics. Since tropical forests are the most stressed among all the forest types and are rich in biodiversity, it is important that the changes in these forests are monitored effectively. For such analysis, we need to find some indirect method to validate the satellite-derived data. The comparative evaluation of the spectral property of NIR, SWIR and species composition has been found to be good indirect evidence and has helped in demarcating the distinct vegetation types which have undergone changes over three decades. The study has clearly identified the areas of secondary formation. This approach provides a reliable means of monitoring the landscape level transformation over a temporal frame.

The evergreen forests of the KMTR have undergone extensive degradation during the two and half decades with 16% of the evergreen forest being degraded primarily in the form of selective logging and clear felling to raise plantations of coffee, tea and cardamom resulting in secondary succession stages such as semi-evergreen among the major phenological types. Ramesh et al., (1997) have pointed out that there is significant loss of biologically rich areas between 1960 and 1990 (85.6km^2 to plantation, 42.0km^2 to encroachment and 36.4km^2 to reservoirs). The present study quantified an 8% increase of Ochlandra patches since 1972. The increase is further continuing due to anthropogenic pressure on the intact forest and can lead to secondary succession or degradation process. One of the most important causes for the growth of these reed brakes is the encroachment of cardamom and coffee plantation into evergreen forests over vast areas, including Uttu, Kakachi and Sengaltheri. Abandoned plantations are invaded by Ochlandra undergrowths, which prevent all other regeneration, as this reed is highly combustible during the dry season. Additionally recurring fires gradually enlarge the openings in the forest and gradually are replaced by Ochlandra reeds.

The loss of evergreen forest in KMTR has resulted in decreased spatial extent of interior or core forest. In case of semi-evergreen forests the spatial extent of interior category was increased due to conversion from evergreen forest. The absence of any significant change in the area under the edge category points to the fact that the process of transition of the evergreen to the semi-evergreen is still continuing. Most of this forest is actually lost to areas that are closer to settlements, roads and plantations. It is also observed that the reed growth is more prolific (Ochlandra reeds) in the vicinity of settlements and roads. Further, the rainfall intensity has significant impact over the natural degradation of the forests in the east-facing slopes where the intensity of erosion and runoff is more due to heavy downpour.

Temporal change analysis using GEOMOD using the three time scale data of years 1973, 1990 and 2004 has shown that an additional 27% of the non-degraded forest would be lost to the degraded category by 2020.

4.2 Forest fragmentation

Fragmentation in KMTR is mainly a result of anthropogenic activities like encroachment by plantations and orchards or natural changes like invasion of reed brakes. The initial invasion of reed brakes is due to the creation of canopy gaps in the intact forest patch, either due to felling or the death of mature trees. Once reed brakes establish themselves in the cleared patch, they start competing with the seedlings of the primary species for nutrients leading to the removal of the next generation of primary species. Apart from competing with the seedlings of the primary species, the reed brakes are also prone to fire during dry seasons. This leads to a further opening up of the forest region and results in to more fragmentation (Pascal, 1988). The evergreen forests are poor in soil nutrients due to increased assimilation by mature trees and can lead to irreversible damages resulting from the conversion of intact evergreen patches into degraded successions such as disturbed evergreen, or the invasion of deciduous and exotic species (Artaxo et al., 2002; Lewis et al., 2004; Lugo & Zimmerman, 2003).

We have observed an increase in fragmentation over time, which may lead to an increase in the isolation of evergreen patches in the KMTR. Decreasing patch size may lead to a reduction in the size of populations and to an increased risk of extinction of the remnant populations. Furthermore, colonization rates may be reduced in isolated patches (Joshi et al., 2006; Soons & Heil, 2002). Intuitively, the forests fragmented by anthropogenic sources are at higher risk of further fragmentation or removal than forest fragmented by natural causes. This isolation of the forest patches leads to a negative impact on the stand regeneration and also adversely affects the survival of species, which require contiguous forest patches for their survival and regeneration (Laurance et al., 1998, 2002; Niemi et al., 1998). Most of the disturbance to the forest patches is as a result of indirect anthropogenic pressure rather than direct encroachment or clear felling. This is indicated by a significant increase in the fractal dimension, which is a representation of the patch shape complexity (Krummel et al., 1987; Díaz-Delgadol et al., 2004). Identifying the forest fragmentation solely attributable to human activity may be a useful tool for policy and decision makers, allowing for improved risk assessments and better targeting of areas for protection or remedial action. The method presented produces data that may be summarized and displayed in a myriad of ways, each of which may be useful in the decision process.

4.3 Patch characterization

Patch characteristics of the 1973 and 2004 data in terms of size, proportion, shape and context were significantly different because of type transitions like evergreen to semi-evergreen, and expansion of Ochlandra and orchards. The variation in the physical environment viz., climate, soil, topography, and other landform features may lead to heterogeneous spatial distribution of resources like water, nutrients, and light resulting in the formation of vegetation patches of different characters (Burnett et al., 1998; Kolasa & Pickett, 1991; Nichols et al., 1998; Peters & Goslee, 2001). In addition, naturally occurring and man-made disturbances also play a vital role in patch formation and characteristics (Fuller et al., 1998; Platt, 1975). Factors such as wildlife grazing, wildlife movement, fuel wood extraction, fire, collection of honey and non-timber forest products by local people are also prevalent at different degrees of biotic pressure. The extent of forest and commercial plantation activity, and protection and conservation measures followed in the area also vary in degree and kind.

Remarkably the contiguous patches of >1000ha in 1973 had 90% of evergreen forest with less porosity due to a lesser degree of anthropogenic pressure compared to 2004, when there was 67% of evergreen forest with high level of porosity. The reduction in the patch area might be due to Ochlandra spread and increased plantations and habitation, resulting in the loss of such contiguous patches. These patches may be large enough to allow the natural disturbance regime to operate, maintain characteristic species composition, support mosaics of community formations, and sustain succession patterns and system functions (Pickett & Thompson, 1978). Further, the increase in the fractal dimension also point out to the fact that the KMTR is constantly under indirect pressure from the surrounding area's biotic or climatic/edaphic conditions.

Patch analysis thus provides a simple framework for goal-oriented monitoring and management in a forest landscape that has experienced several degenerative trends: primary evergreen forest have been replaced by semi-evergreen forests and plantation; structurally complex forests of all ages have been replaced by simplified stands; large, well connected patches have been replaced by smaller, more isolated patches; infrastructure has been developed in undisturbed landscapes; and natural fires have been suppressed. Several forests in Western Ghats and elsewhere in tropics have experienced these kinds of changes, with a concomitant loss of native biodiversity and ecological integrity (Dutt et al., 2002; Muthuramkumar et al., 2006). It is commonly accepted that species richness reduces with the fragmentation of tropical forests (Benitez-Malvido & Martinez-Ramos, 2003; Bierregaard, 1992; Chittibabu & Lovejoy, 1986; Laurance & Luizão, 2007). The smaller the fragments are, the lesser species richness the fragments display (Laurance, 1994; Leigh et al., 1993; Newmark, 1991; Pither & Kellman, 2002). Research articles published elsewhere related to forest fragments mostly focused on various animal groups. Studies on plants related to tropical forest fragments are relatively fewer, although there have been some important ones (Benitez-Malvido, 1998; Benitez-Malvido & Martinez-Ramos, 2003; Cadotte et al., 2002; Laurance & Luizão, 2007; Laurance et al., 1998; Leigh et al., 1993; Muthuramkumar et al., 2006; Oliveira-Filho et al., 1997; Turner & Corlett 1996).

Despite legal protection from major human activities, the region is subjected to various processes that ultimately prove detrimental to the sustenance of the native forest system. The focused priority on conservation of these patches may be helpful to sustain the biological diversity as these patches of evergreen forests provide unique habitats for various endemic plant species and wildlife. In this context the moderate spatial and high spectral resolution data from wide field sensors, can be used for generation of extensive information regarding vegetation area, patch shape and size, fragmentation patterns and porosity which are the major indicators of the disturbance and land-use change in a region.

Natural disturbances like fire, wildlife, proliferation of reeds and introduced exotic species, associated changes in geomorphology and soil, along with human pressure on the forests over the decades are the reasons for changes in the overall composition and the resulting establishment of habitat generalist species in KMTR. It is disturbing to note that the change areas have very high species diversity compared to no-change areas indicating that the ecosystem is undergoing changes in species composition and that the probability of further invasion of these species leading to a replacement of the habitat specialist species is high.

Temporal variation in species diversity can be strongly associated to the external disturbance (Chesson et al., 2004; Holt & Lawton, 1994). Disturbances like deforestation, fire, and harvest of selective species can strongly influence patterns of species diversity. A buffer of 100m was analyzed on the selected patches to understand the biotic pressure (e.g. orchards, secondary formations like reeds and semi-evergreen) and exchanges among patches, which determine the ecosystem structure and function. It reveals that 6.38% of evergreen and 5.13% of semi-evergreen forest have undergone several changes in the period between 1973 and 2004. Similar attempts were carried out to understand the patch dynamics and biotic exchanges among patches, and to determine the ecosystem structure and function (Lewin, 1984; Nagendra, 2001). On similar lines as the previous study, high diversity relationship was related to the characteristics of the community, the habitat, the disturbance and the sampling designs, as explained by Huston (1994); Mackey & Currie (2000, 2001); Noss (1996); and Reice (1985). In the present study, the disturbance showed the impact of strong local interactions and thus increased the relative importance of regional-scale processes (dispersal among the patches) in controlling the number of species within a patch. In this connection, the spatial organization of the patches as identified in the study can form a baseline for continuous monitoring and assessment of the changes in habitat conditions. Other similar case studies include Caswell & Cohen (1993); He et al., (2005); Mouquet et al., (2003); and Mouquet & Loreau (2003).

4.4 Trends in species richness and diversity pattern

The density of 607 trees ha^{-1} found in the no-change areas with a comparable girth threshold of ≥ 30cm, is greater than that of 419 trees ha^{-1} reported as mean tree density for WG closed-canopy evergreen forest (Ghate et al., 1998), 482ha^{-1} reported at the Mylodai site in Courtallum RF (Parthasarathy & Karthikeyan, 1997), Kakachi in the Southern WG (583ha^{-1}, Ganesh et al., 1996) and that of Uppangala, central WG (635ha^{-1}, Pascal & Pelissier, 1996). It is interesting to note that changed areas having stand density of 494 ha^{-1} are comparable with the frequently disturbed area having 575 trees ha^{-1} (Parthasarathy, 1999). The tree basal area having 54.39m^{2}ha^{-1} is well within the range of tropical wet forest: 55.34m^{2}ha^{-1} values in Sengaltheri mid-elevation forest, KMTR (Parthasarathy, 2001), and 66.87m^{2}ha^{-1} in Kalakad National Park, Tirunelveli (Parthasarathy, 1999). The nearby Nelliampathy wet evergreen forests of WG have also been reported to be in the range of 61.9m^{2}ha^{-1} (Chandrashekara & Ramakrishnan, 1994). In the tropical wet evergreen forests the stand basal area ranged from 25.5m^{2}ha^{-1} in Rio Xingu, Brazil (Campbell et al., 1992) to 82.67m^{2}ha^{-1} in the tropical rainforest of Reunion islands (Strasberg, 1996).

The study reveals that there is significant change in terms of species composition, stand density, basal area and percentage of endemic and edge species in the change and no-change areas. In the no-change area, the predominant species *Cullenia exarillata – Mesua ferrea – Myristica dactyloides* are well compared in the work carried out by Pascal (1988), Ganesh et al., (1996) and Parthasarathy (2001). In change areas, the floristic structure of *Cullenia exarillata – Dimocarpus longan – Kingiodendron pinnatum* has undergone several changes. This might be because of selective logging for establishment of tea and cardamom plantation. Interestingly the saplings of the trees and shrubs have also shown significant difference in the no-change and change areas. In the no-change area the species include *Antidesma menasu – Cinnamomum* malabatrum – *Mesua ferrea* whereas in the change area it consists of *Dimocarpus longan – Mallotus philippensis – Mesua ferrea* (Table 4a&b). Bresee et al., (2004), quantified these changes and rates of change in vegetative composition and structure within the Washburn Ranger

District in northern Wisconsin using Landsat images. The predominant families occurring in no-change areas include Euphorbiaceae, Lauraceae and Bombacaceae. These differ from those occurring in the change areas such as Euphorbiaceae, Sapindaceae and Lauraceae. Species composition, especially the abundance of some species and the dominant ranks of some families have changed with fragmentation (Zhu et al., 2004).

5. Conclusions

The study has demonstrated the capacity of remote sensing and GIS in detecting the land-cover change with data from different sensors in spite of the absence of past ground data, with appreciable level of accuracy. The different disturbance regimes mainly due to land-use and land-cover changes have led to the alteration in the patch size and shape in KMTR. Temporal change analysis using GEOMOD has shown that an additional 27% of the non-degraded forest would be lost to the degraded category by 2020 in the region. Furthermore, the creation of corridors has led to major changes in the biological diversity with bigger patches retaining higher species richness while smaller patches are dominated mainly by the edge species. The rarity of woody species and a greater number of singletons in the site underline the need to preserve the vast area of this forest, as a single large reserve. The establishment of plantations involves alternations of the rainforest habitat. Habitat alteration includes clear felling (for tea estates) and removal of many large trees, climbers and under storey vegetation (in coffee and cardamom plantations). Such a habitat change poses severe threats to wildlife (for e.g. lion tailed macaque, malabar spiny dormouse, nilgiri langur). The KMTR, besides being a biologically important area with unique flora and fauna, is also a habitat for wild relatives of cultivated plants, such as mango, jackfruit and cardamom. It is also a catchment area for more than 6 major river systems. Hence, the protection of this reserve is crucial for the biological conservation of species and human welfare.

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The book covers several topics of biodiversity researches and uses, containing 17 chapters grouped into 5 sections. It begins with an interesting chapter considering the ways in which the very biodiversity could be thought about. Noteworthy is the chapter expounding pretty original "creativity theory of ecosystem". There are several chapters concerning models describing relation between ecological niches and diversity maintenance, the factors underlying avian species imperilment, and diversity turnover rate of a local beetle group. Of special importance is the chapter outlining a theoretical model for morphological disparity in its most widened treatment. Several chapters consider regional aspects of biodiversity in Europe, Asia, Central and South America, among them an approach for monitoring conservation of the regional tropical phytodiversity in India is of special importance. Of interest is also a chapter considering the history of the very idea of biodiversity emergence in ecological researches.

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