

Geospatial assessment and monitoring of historical forest cover changes (1920–2012) in Nilgiri Biosphere Reserve, Western Ghats, India

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Abstract Deforestation in the biosphere reserves, which are key Protected Areas has negative impacts on biodiversity, climate, carbon fluxes and livelihoods. Comprehensive study of deforestation in biosphere reserves is required to assess the impact of the management effectiveness. This article assesses the changes in forest cover in various zones and protected areas of Nilgiri Biosphere Reserve, the first declared biosphere reserve in India which forms part of Western Ghats—a global biodiversity hotspot. In this study, we have mapped the forests from earliest available topographical maps and multi-temporal satellite data spanning from 1920's to 2012 period. Mapping of spatial extent of forest cover, vegetation types and land cover was carried out using visual interpretation technique. A grid cell of 1 km×1 km was generated for time series change analysis to understand the patterns in spatial distribution of forest cover (1920–1973–1989–1999–2006–2012). The total forest area of biosphere reserve was found to be 5,806.5 km² (93.8 % of total geographical area) in 1920. Overall loss of forest cover was estimated as 1,423.6 km² (24.5 % of the total forest) with reference to 1920. Among the six Protected Areas, annual

deforestation rate of >0.5 was found in Wayanad wildlife sanctuary during 1920–1973. The deforestation in Nilgiri Biosphere Reserve is mainly attributed to conversion of forests to plantations and agriculture along with submergence due to construction of dams during 1920 to 1989. Grid wise analysis indicates that 851 grids have undergone large-scale negative changes of >75 ha of forest loss during 1920–1973 while, only 15 grids have shown >75 ha loss during 1973–1989. Annual net rate of deforestation for the period of 1920 to 1973 was calculated as 0.5 followed by 0.1 for 1973 to 1989. Our analysis shows that there was large-scale deforestation before the declaration of area as biosphere reserve in 1986; however, the deforestation has drastically reduced after the declaration due to high degree of protection, thus indicating the secure future of reserve in the long term under the current forest management practices. The present work will stand as the most up-to-date assessment on the forest cover of the Nilgiri Biosphere Reserve with immediate applications in monitoring and management of forest biodiversity.

Keywords Deforestation · Conservation · Biosphere reserve · Remote sensing · Nilgiri · Western Ghats

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Introduction

Tropical forests contain high levels of biodiversity, in terms of both species richness and endemism (Schmitt et al. 2009). Human-induced deforestation has been identified as the main environmental problem (Martinez

1998; Williams 2000). Deforestation can be defined as the process of change of land use with depletion of tree crown cover to less than 10 % (FAO 2011). Forest conversion into other land use is responsible for loss of biodiversity (Skole and Tucker 1991); affects climate, hydrology and carbon fluxes of ecosystems (Defries et al. 2002; Asner et al. 2005); and provides livelihoods (Naughton-Treves et al. 2005). There was a net decrease in global forest area of 1.7 % between 1990 and 2005 at an annual rate of change of 0.11 %. The rate of deforestation was reported as 3 Mha per year between 1990 and 2000 and of 6 Mha per year between 2000 and 2005 (FAO 2012). In addition to this, the global gross forest cover loss was reported to be 0.6 % per year during 2000 to 2005 (Hansen et al. 2010).

Reddy et al. (2013) estimated long-term forest cover change over Odisha, India and observed that there is no comprehensive information available on historical changes in forests of India. Worldwide establishment of Protected Areas is an important strategy to control deforestation (Lovejoy 2006). There is a tenfold increase in number of Protected Areas between 1970 and 1997 (Zimmerer et al. 2004). Study on forest cover changes is one of the

primary indicators of the conservation effectiveness in Protected Areas. The quantitative analysis on the conservation effectiveness of Protected Areas is inadequate (Liu et al. 2001; CBD 2004).

The International Coordination Council (ICC) of UNESCO in its first meeting in Paris held during 9–19 November 1971 introduced the designation “Biosphere Reserve” for natural areas to minimize conflict between development and conservation. The Biosphere Reserves (BRs) are internationally designated landscapes/seascape units under UNESCO’s flagship program “Man and Biosphere (MAB)”. The Biosphere Reserves represent characteristic ecosystem in different biogeographic regions and consider human communities as their integral component (UNESCO 1996). The objectives of Biosphere Reserves are to protect ecological integrity of biota within their natural ecosystems; preserve the genetic diversity of species on which their continuing evolution depends; provide areas for multi-faceted research, monitoring, education and training; and to ensure the sustainable use of natural resources through the most appropriate technologies (Rai 2003). Launching with UNESCO’s Man and the Biosphere Program conservation practice and policy have

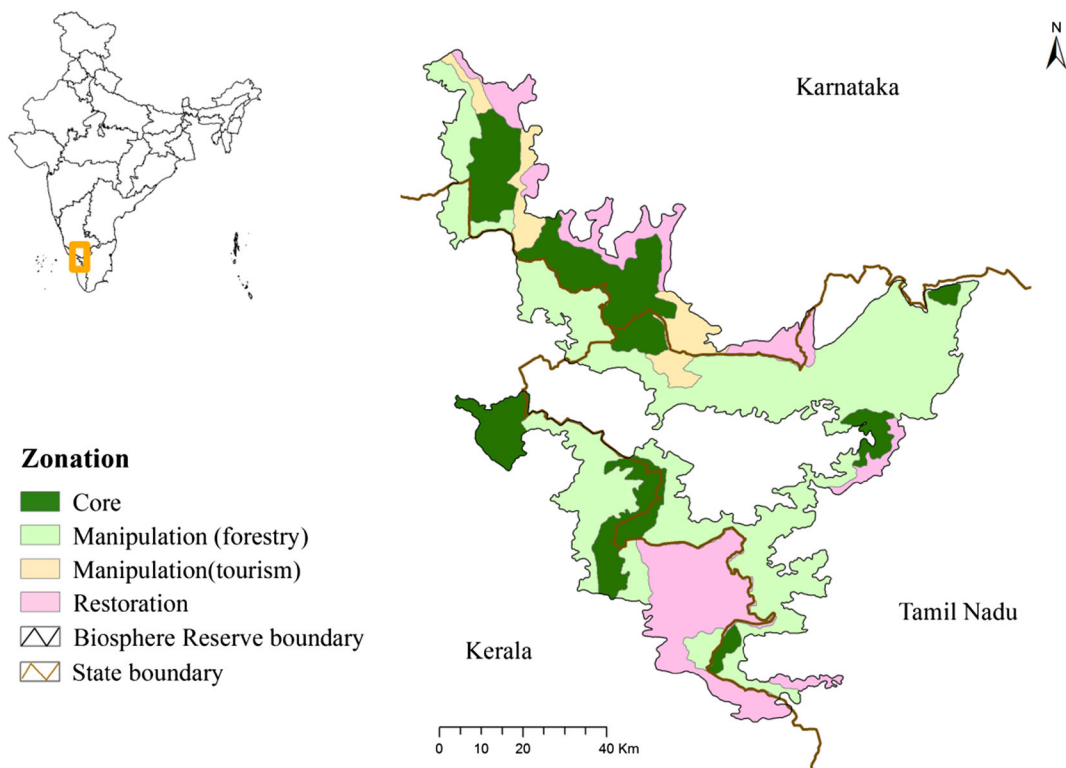


Fig. 1 Map showing location of study area and zones of Nilgiri Biosphere Reserve

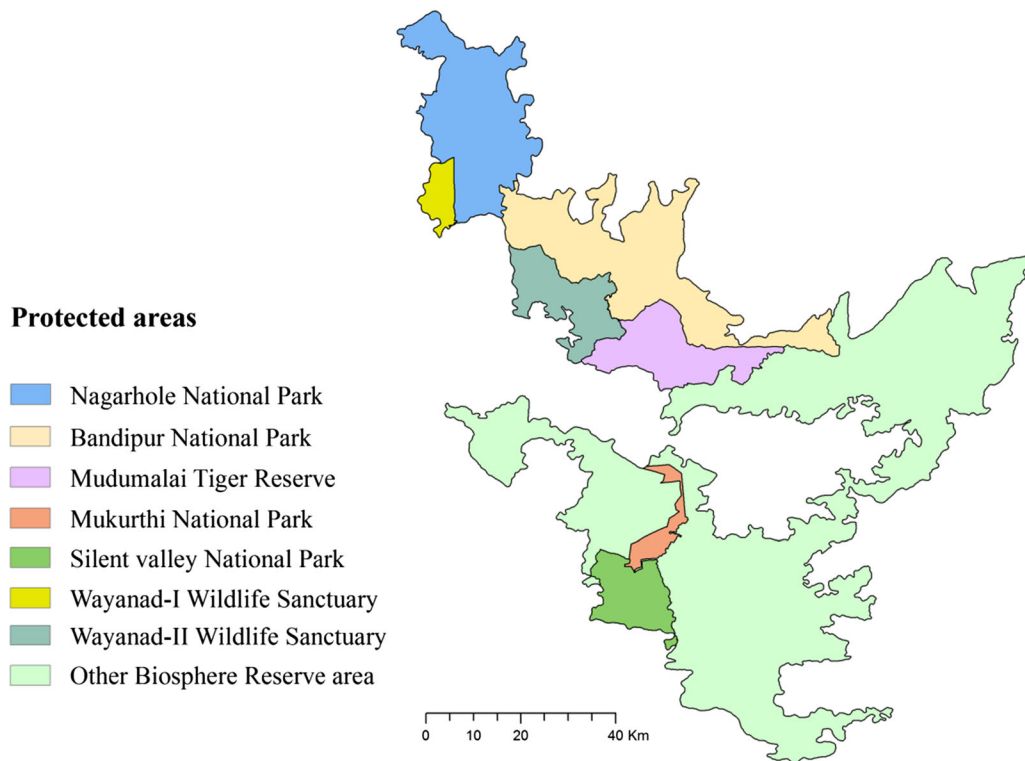


Fig. 2 Map showing protected areas of Nilgiri Biosphere Reserve

undergone a vast change for sustaining biodiversity (Chowdhury 2006). Measuring anthropogenic influence on protected areas is an overwhelming task. Among the various types of Protected Areas, biosphere reserves have been highlighted as key areas for conservation of biodiversity (Schliep and Stoll-Kleemann 2010).

The application of remote sensing and geospatial techniques for monitoring forest cover change have increased greatly due to the reliable quantification and cost-effective information (Coppin et al. 2004; Chape et al. 2005; Reddy et al. 2007). Conversion of forest areas to plantations and establishment of hydroelectric projects have resulted in loss of valuable forest resources in Western Ghats (Menon and Bawa 1997). There are few studies which deal with deforestation in Western Ghats (Ramesh et al. 1997; Menon and Bawa 1997; Prasad 1998; Jha et al. 2000; Joseph et al. 2009; Panigrahy et al. 2010). The study on Maya Biosphere Reserve in Guatemala has addressed the forest cover change before and after the establishment as a biosphere reserve (Sader et al. 2001). Landsat imagery of 1986 to 1997 has been used to quantify time series change (Sader et al. 2001).

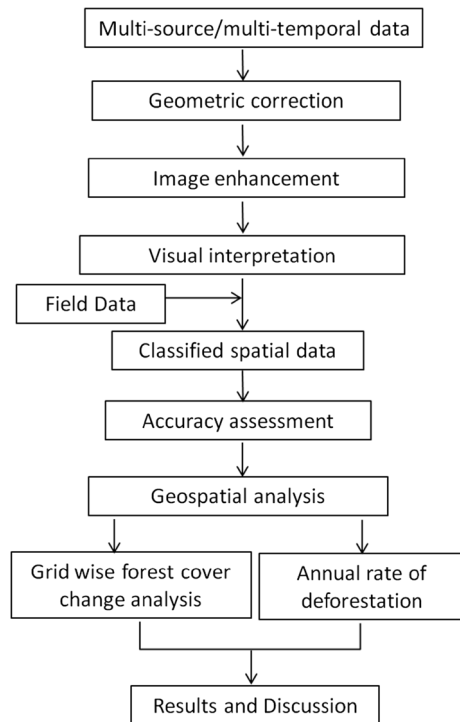


Fig. 3 Flow chart of methodology

Table 1 Details of spatial data used

Serial no.	Type	Period	Scale/resolution	Source
1	Survey of India topographical maps	1916–1925	1:250,000	US Army
2	Landsat MSS	1973	80 m	NASA
3	Landsat TM	1989	30 m	NASA
4	Landsat ETM +	1999	30 m	NASA
5	Resourcesat-1 LISS III	2006	23.5 m	ISRO
6	Resourcesat-2 LISS III	2012	23.5 m	ISRO

The study on Calakmul Biosphere Reserve, Mexico's largest Protected Area, shows increased deforestation in 1987 to 1996 (Chowdhury 2006). The study on Monarch Butterfly Biosphere Reserve in Mexico has analyzed deforestation during 2003–2009 based on remote sensing data (Garcia 2011). Land cover change analysis in Upper Lusatia Biosphere Reserve of Germany reveals management effectiveness during 1992–2005 (Ohnesorge et al. 2013). Saranya et al. (2014) have carried out decadal time scale analysis for addressing anthropogenic impact of fires on forest ecosystems and identification of fire recurrent areas in Similipal

Biosphere Reserve of India. So far, no comprehensive study of deforestation is available for biosphere reserves of India that can be helpful to evaluate the impact of the management effectiveness over time. This article assesses the changes in forest cover in various zones and protected areas of Nilgiri Biosphere Reserve, which is the first declared biosphere reserve and global biodiversity hotspot of India. Hence in this study, we have analyzed the spatial patterns of forest cover from georeferenced historical topographical maps and multi-temporal satellite data in Nilgiri Biosphere Reserve during 1920 to 2012.

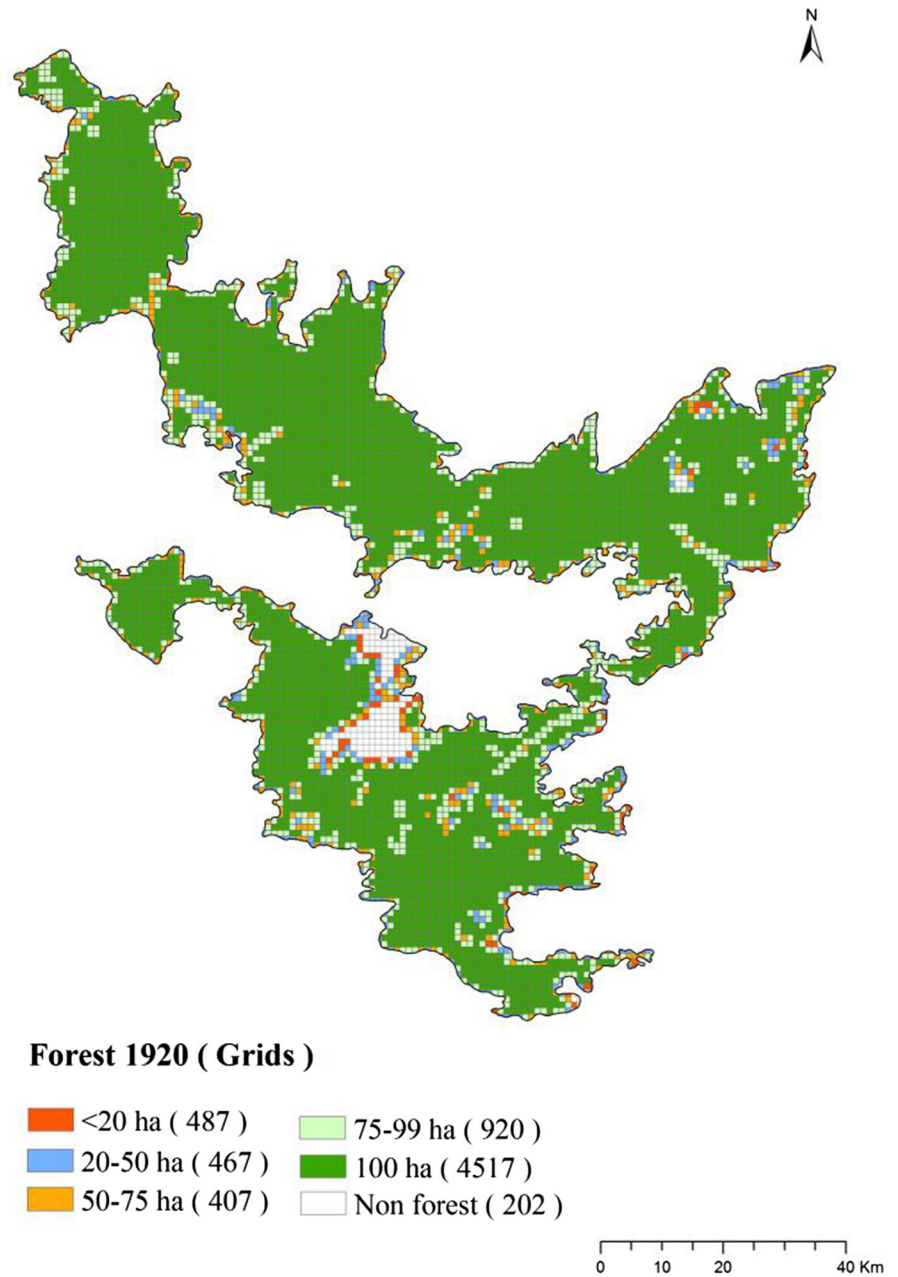
Table 2 Areal extent of forest cover in Nilgiri Biosphere Reserve (km²)

Period	Core	Manipulation-forestry	Manipulation-tourism	Restoration	NBR
1920	1,232.1	3,064.9	312.7	1,196.8	5,806.5
1973	1,160.4	2,240.9	277.2	765.9	4,444.4
1989	1,158.1	2,229.1	264.8	731.7	4,383.6
1999	1,158.1	2,228.7	264.8	731.4	4,383.0
2006	1,158.1	2,228.8	264.8	731.2	4,382.9
2012	1,158.1	2,228.8	264.8	731.2	4,382.9

Table 3 Areal extent of forest cover in protected areas of Nilgiri Biosphere Reserve (km²)

Serial no.	Protected area	1920	1973	1989	1999	2006	2012
1	Nagarhole National Park	700.5	568.7	535.4	535.4	535.4	535.4
2	Bandipur National Park	900.2	750.0	737.0	737.1	737.3	737.3
3	Mudumalai Wildlife Sanctuary	282.3	240.8	240.8	240.8	240.8	240.8
4	Mukurthi National Park	12.7	12.7	12.7	12.7	12.7	12.7
5	Wayanad-I Wildlife Sanctuary	67.2	46.2	46.2	46.2	46.2	46.2
6	Wayanad-II Wildlife Sanctuary	251.1	126.4	126.4	126.4	126.4	126.4
7	Silent Valley National Park	181.7	143.4	143.4	143.4	143.4	143.4
	Total	2,395.7	1,888.2	1,842.0	1,842.0	1,842.2	1,842.2

Fig. 4 Spatial distribution of forest cover: 1920

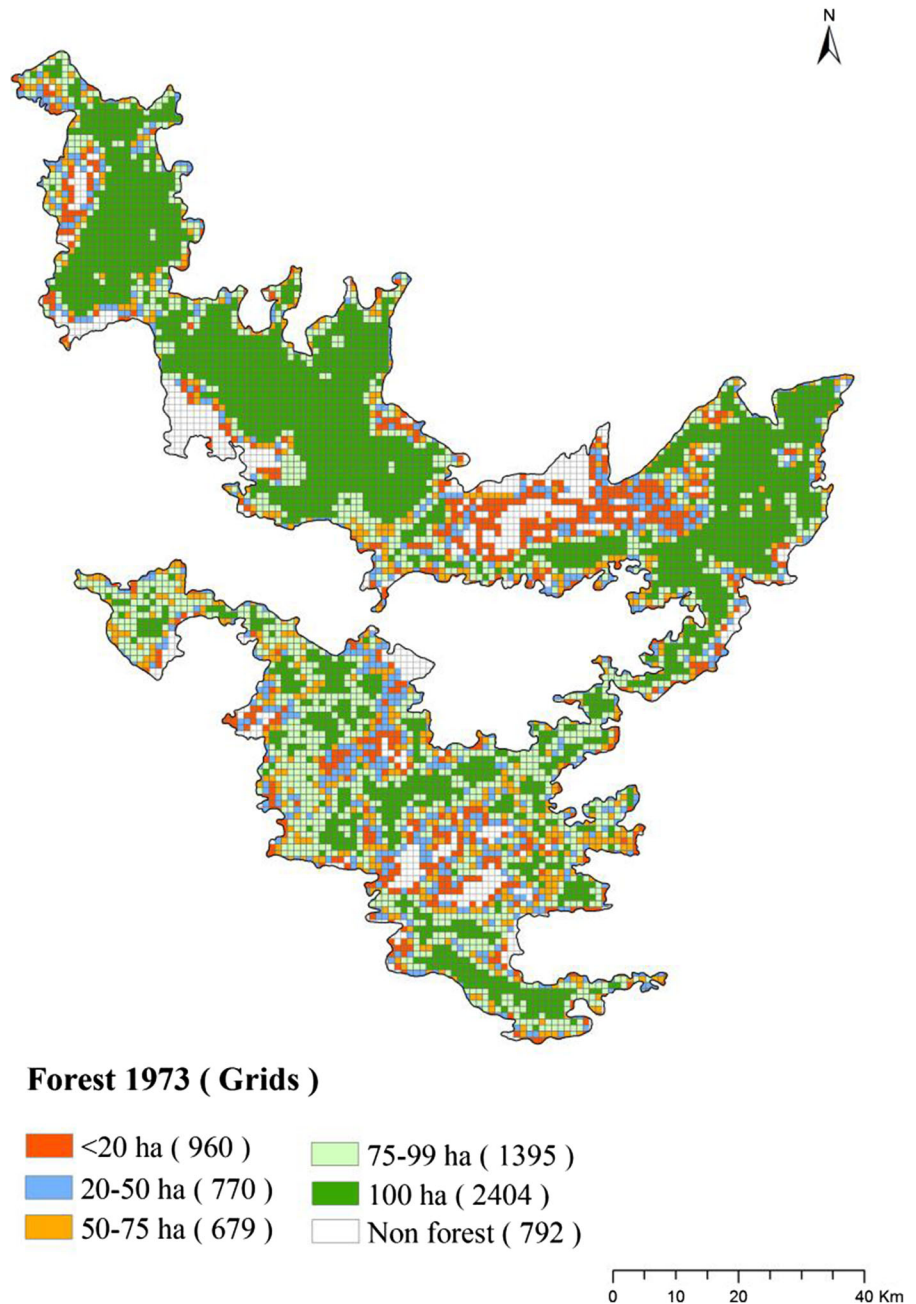


Study area

Nilgiri Biosphere Reserve (NBR) was designated as biosphere reserve in the year 1986. It represents a biodiversity-rich ecosystem in the Western Ghats—a global biodiversity hotspot. It provides an ideal habitat for supporting a high degree of endemic flora and fauna. Spread over an area of 5,520 km², NBR lies between

10°50' N and 12°16' N latitude and 76°00' E to 77°15' E longitude. It transcends across three Indian states: Tamil Nadu, Kerala and Karnataka (Fig. 1). Topography consists of hill ranges varying in elevation from 300 to 2,655 m. The annual rainfall of the reserve ranges from 500 to 7,000 mm with mean temperature ranging from 4 °C during winter to 41 °C during summer (Palni et al. 2012). The protected areas that lie within this reserve

Fig. 5 Spatial distribution of forest cover: 1973



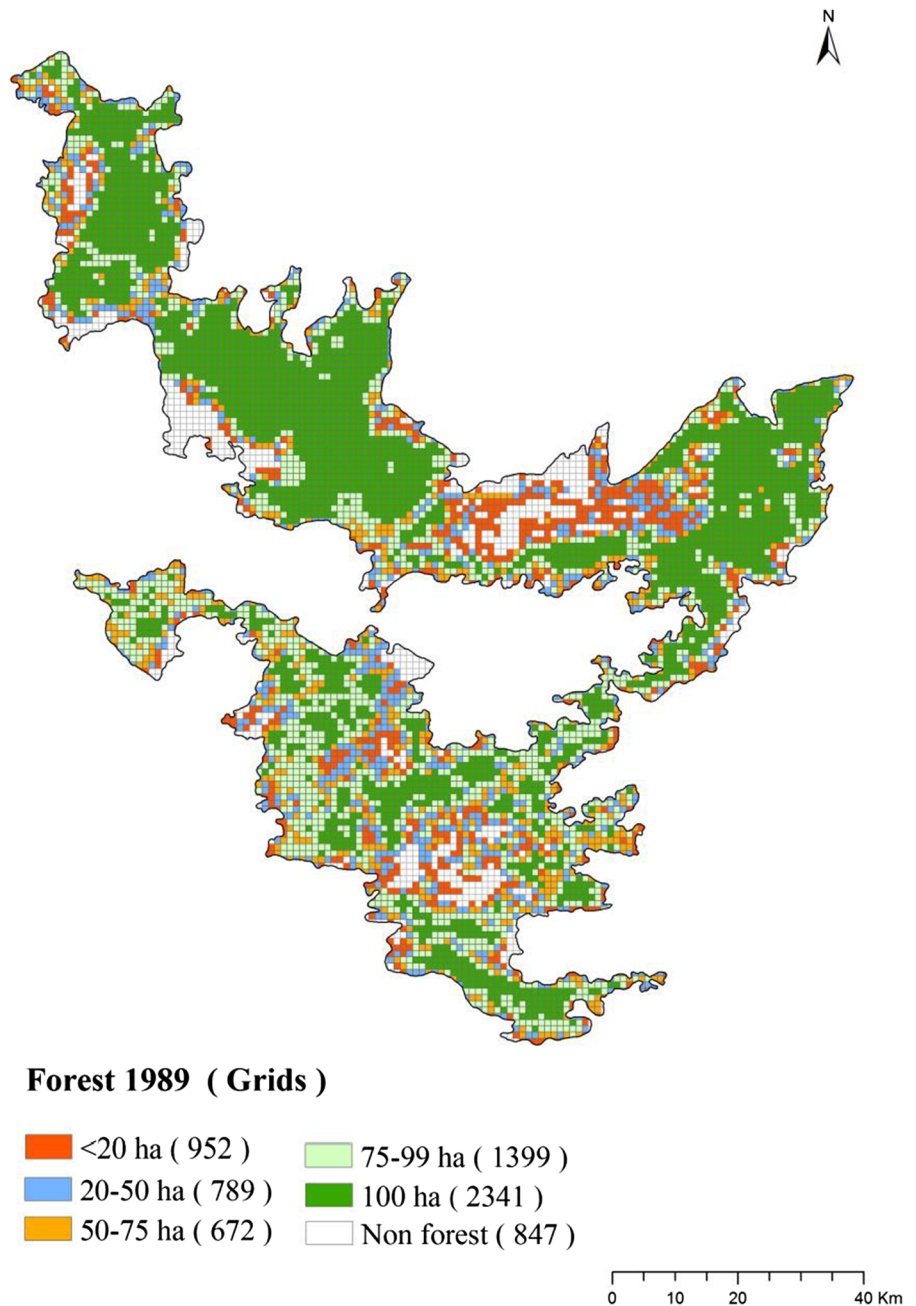
include the following: Mudumalai Wildlife Sanctuary, Wayanad Wildlife Sanctuary, Bandipur National Park, Nagarhole National Park (Rajiv Gandhi National Park), Mukurthi National Park, and Silent Valley National Park (Fig. 2). NBR has various zones such as core, manipulation (forestry), manipulation (tourism) and restoration. The flora comprises about 3,500 species of flowering plants. The fauna includes over 100 species of

mammals, 350 species of birds and 300 species of butterflies (Palni et al. 2012).

Materials and methods

The outline of methodology has been presented in Fig. 3.

Fig. 6 Spatial distribution of forest cover: 1989

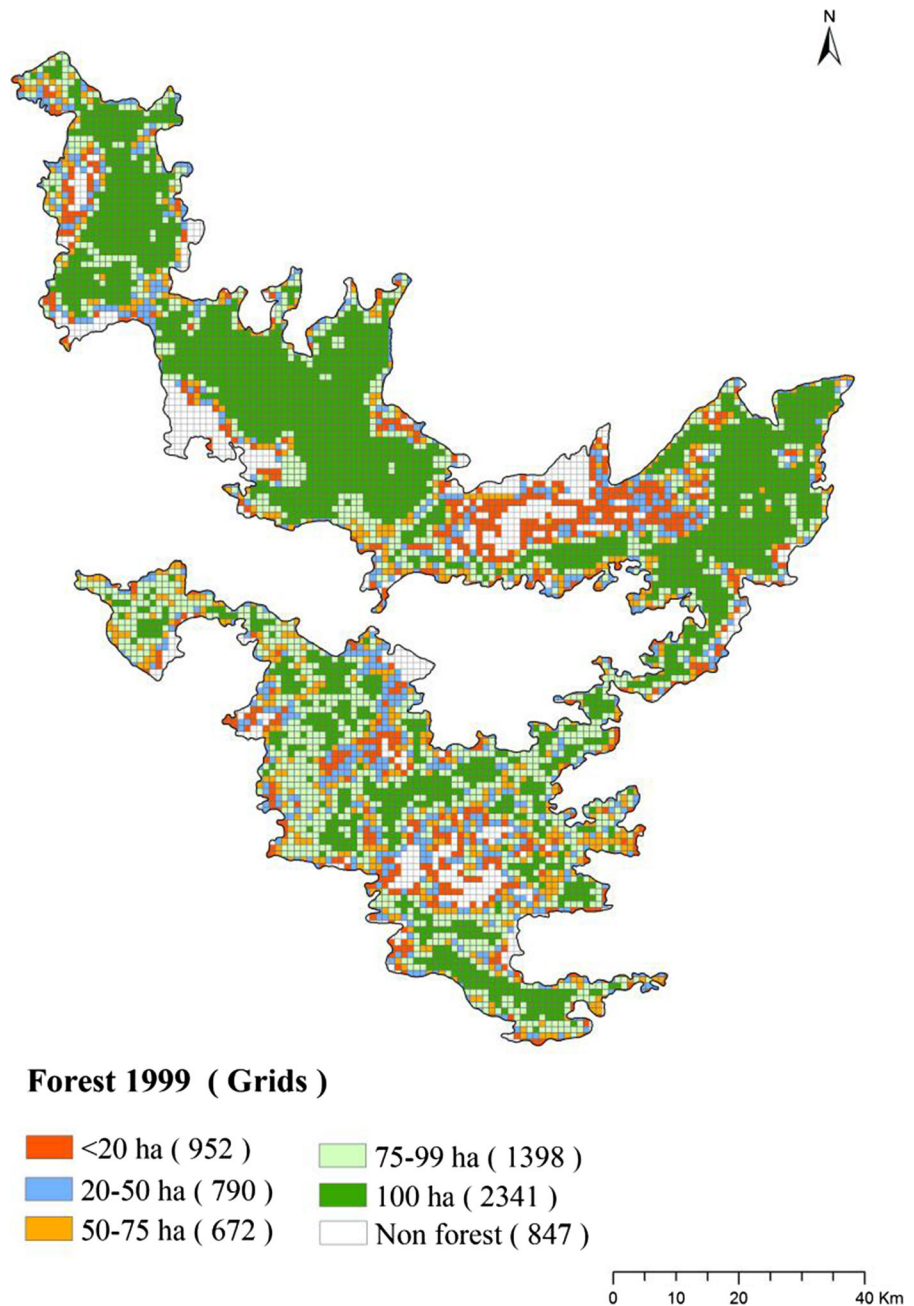


Data

The various sources of data have been used in the present study. The change period considered is approximately nine decades. The survey of India topographical maps (1:250,000 scale) prepared by Army Map Service, United States Army, Washington were

only the earliest available source for historical forest cover information (<http://www.lib.utexas.edu/maps/ams/india/>). Landsat Multispectral scanner (Landsat MSS) data since 1972 and the higher spatial resolution Landsat Thematic Mapper (Landsat TM) data since 1987 were available. Remote sensing data pertaining to Landsat MSS (1973), Landsat TM

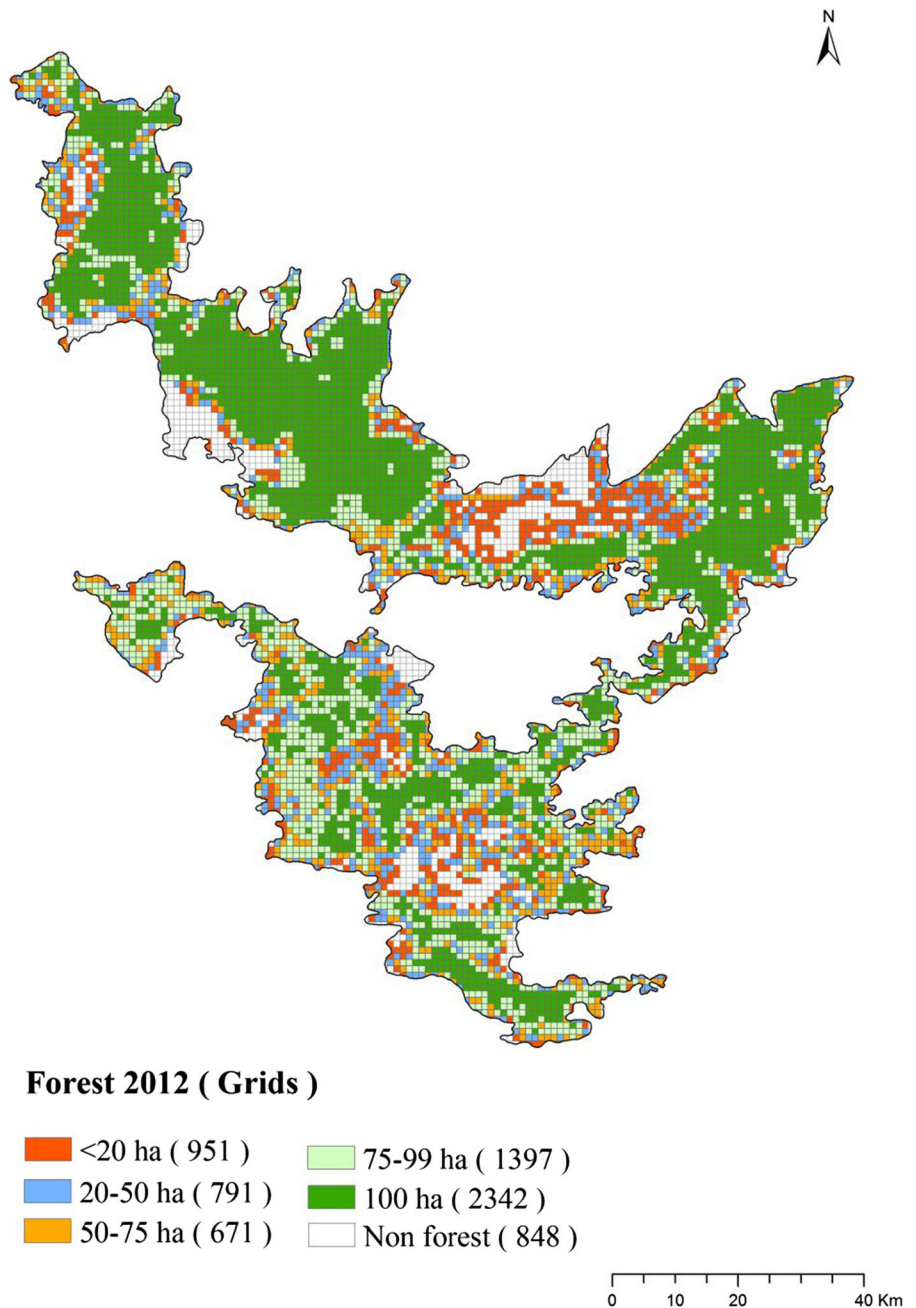
Fig. 7 Spatial distribution of forest cover: 1999



(1989), Landsat Enhanced Thematic Mapper plus (Landsat ETM+) (1999), Resourcesat-1 Linear imaging self-scanning system III (Resourcesat-1 LISS III) (2006) and Resourcesat-2 LISS III (2012) were used (Table 1). Geometric correction of raw satellite data was achieved through first-order polynomial transformation fit based on orthorectified Landsat TM

data (<http://glcf.umiacs.umd.edu/>) for reference. A nearest-neighbor algorithm was used to perform the resampling procedure. Image-to-image registration yielded a root-mean-square error of <1 pixels for all satellite data. The study area was extracted from the multiple satellite data scenes by subsetting. The boundary of biosphere reserve

Fig. 8 Spatial distribution of forest cover: 2012



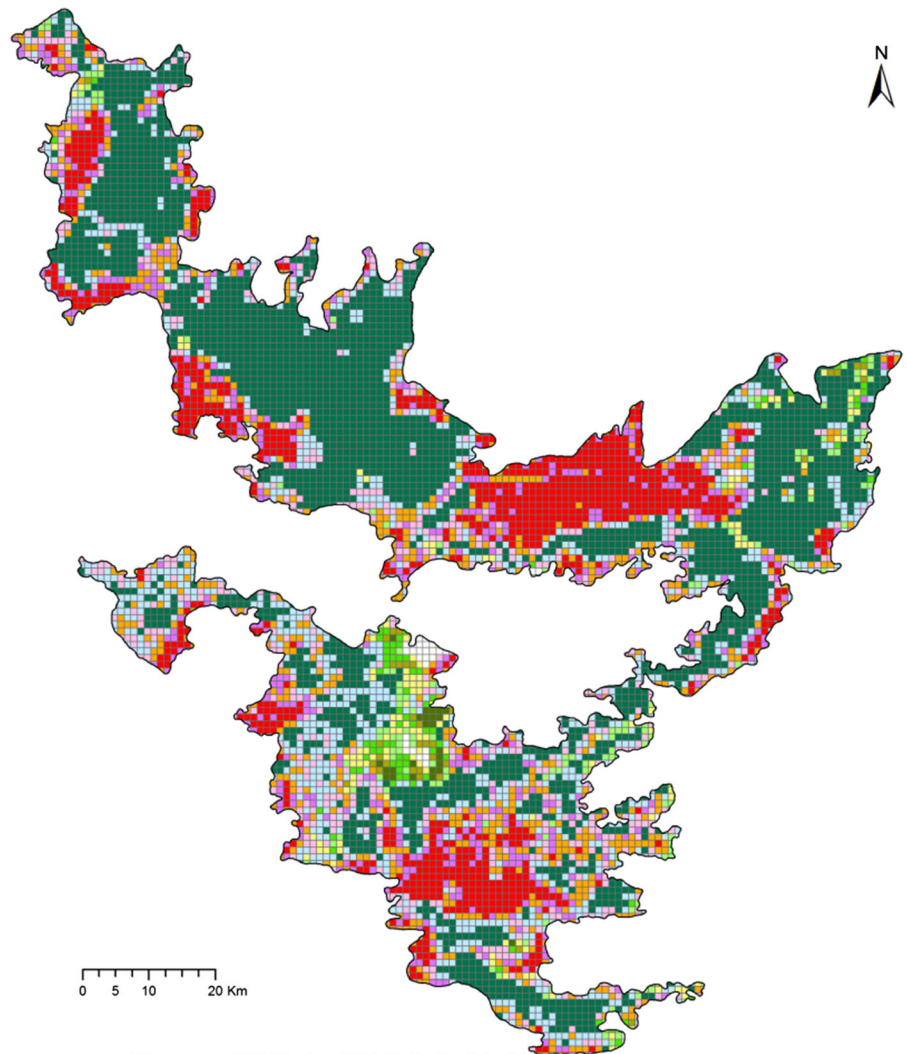
was obtained from Ministry of Environment and Forests (MoEF) (Palni et al. 2012). The images were georeferenced to the Universal Transverse Mercator (UTM) coordinate system and World Geodetic System 1984 (WGS84) datum. Survey of India topographical maps of 1:50,000 scale, multi-season Resourcesat-2 Advanced Wide Field

Sensor (AWiFS) data of 2012 has been used as reference.

Forest cover mapping






Image processing and GIS softwares, Earth Resource Data Analysis System (ERDAS) imagine

Fig. 9 Spatial forest cover change: 1920–2012










Change 1920 to 2012 (Grids)

Negative change

	<10 ha loss (1190)
	10-25 ha loss (708)
	25-50 ha loss (672)
	50-75 ha loss (471)
	>75 ha loss (884)

Positive change

	<10 ha gain (176)
	10-25 ha gain (133)
	25-50 ha gain (76)
	50-75 ha gain (34)
	>75 ha gain (25)

	No forest change (2659)
	Non forest (72)

and ArcGIS have been utilized. Mapping of areal extent of forest cover, vegetation types and land use was carried out using on-screen visual image

interpretation technique. After interpretation of topographical maps and satellite data, the statistics were generated for forest cover category.

Table 4 Analysis of grid wise forest cover loss in Nilgiri Biosphere Reserve (no. of grids)

Class	1920–1973	1973–1989	1989–2012
<10 ha loss	1,176	147	12
10 to 25 ha loss	688	66	0
25 to 50 ha loss	644	52	0
50 to 75 ha loss	449	23	0
>75 ha loss	851	15	0
Total grids	3,808	303	12

Accuracy assessment

Random field samples (214 locations) collected during 2012 and 2013 have been used for verification of classification accuracy. Validation of maps for 1973, 1989, 1999, 2006 and 2012 was done based on visual assessment of satellite images and the temporal consistency of field samples.

Rate of deforestation

The annual rate of forest cover change was calculated based on compound interest formula (Puyravaud 2003)

$$r = \frac{1}{(t_2 - t_1)} \times \ln \frac{a_2}{a_1}$$

Where *r* is the annual rate of change (percentage per year) and *a*₁ and *a*₂ are the forest cover estimates at time *t*₁ and *t*₂ respectively.

Analysis of forest changes

A grid cell of 1 km×1 km was generated for time series analysis to understand the patterns in spatial distribution of forest cover (1920–2012). On each spatial data, the area covered by forest was calculated

for any trend of change. Spatial extent of change was categorized across the five classes i.e., <10, 10–25, 25–50, >50–75 and >75 ha.

Results and discussion

Long-term monitoring of forests has detected forest cover change events in Nilgiri Biosphere Reserve. Geospatial analysis has addressed (1) distribution of forest cover (2) deforestation rates in zones and Protected Areas of biosphere reserve (3) grid wise distribution and changes in forest cover (4) change in forest types.

Distribution and change of forest cover

Distribution and changes in forest cover were analyzed using the area statistics derived from multi-temporal classified maps. Our results indicate that there is manifestation of significant loss of forest cover change during 1920 to 1973 and gradual decline in the period of 1973–1989. We calculated the total forest area of biosphere reserve as 5,806.5 km² (93.8 %) in 1920’s period. The resulting classification for 1973 and 1989 indicates that the forest cover account for 4,444.4 and 4,383.6 km² respectively. Within a period of 92 years (1920–2012), the forest cover decline was 1,423.6 km² (24.5 % of the total forest). There was 23.5 % (1,362.1 km²) of reduction in the forest cover between 1920 and 1973. The loss of forest cover during 1973–2012 was estimated at 61.5 km². As elsewhere in the study area, deforestation started mainly after India’s independence due to the development of physical infrastructure, dam construction and population growth (Reddy et al. 2013). The forest cover has no negative change after 1999 which indicates that strict conservation efforts were taken up by state forest departments of

Table 5 Net rate of deforestation in Nilgiri Biosphere Reserve

Serial no.	T1/T2	1920	1973	1989	1999	2006	2012
1	1920	–	–0.5	–0.4	–0.4	–0.3	–0.3
2	1973	–	–	–0.1	–0.1	–	–
3	1989	–	–	–	–	–	–
4	1999	–	–	–	–	–	–
5	2006	–	–	–	–	–	–

Table 6 Net rate of deforestation in protected areas of Nilgiri Biosphere Reserve

Serial no.	Protected area/period	1920–1973	1973–1989	1989–1999	1999–2006	2006–2012
1	Nagarhole National Park	0.4	0.4	0.0	0.0	0.0
2	Bandipur National Park	0.3	0.1	0.0	0.0	0.0
3	Mudumalai Wildlife Sanctuary	0.3	0.0	0.0	0.0	0.0
4	Wayanad-I Wildlife Sanctuary	0.7	0.0	0.0	0.0	0.0
5	Wayanad-II Wildlife Sanctuary	1.3	0.0	0.0	0.0	0.0
6	Silent Valley National Park	0.4	0.0	0.0	0.0	0.0

Karnataka, Kerala and Tamil Nadu (Table 2). During the whole study period, Restoration zone has undergone 38.9 % of forest cover loss followed by Manipulation-Forestry zone (27.3 %), Manipulation-Tourism zone (15.3 %) and Core zone (6 %) (Table 2). The reserve has accorded high degree of protection in core zone, manipulation zone as well as restoration zones after declaration as biosphere reserve.

Nilgiri Biosphere Reserve has six Protected Areas on contiguous landscape. Mudumalai Wildlife Sanctuary (1940) is the oldest declared protected areas of Western Ghats followed by Wayanad, Bandipur, Nagarhole (1974) and Silent Valley National Park (1984). Wayanad-I and Wayanad-II which are isolated from each other are part of the Wayanad District of Kerala. Bandipur National Park and tiger reserve has the highest forest cover, followed by Nagarhole National Park and Mudumalai Wildlife Sanctuary (Table 3). The loss of forest cover in Nagarhole and Bandipur is mainly due to construction of dams and agricultural expansion. These five protected areas have shown significant loss of forest cover before declaration. Wayanad-II part of Wildlife Sanctuary has undergone large-scale deforestation accounted as 251.1 km² (49.6 %), followed by Wayanad-I part of Wildlife Sanctuary (31.3 %), Nagarhole National Park (23.6 %), Silent Valley National Park (21.1 %) and Bandipur National Park (18.1 %). The deforestation in Wayanad wildlife sanctuary is mainly attributed to conversion of forests to plantations during 1920 to 1973. Overall loss of forest cover in the protected areas was estimated at 553.5 km² (23.1 %) with reference to 1920's base period.

Grid wise analysis of forest cover change

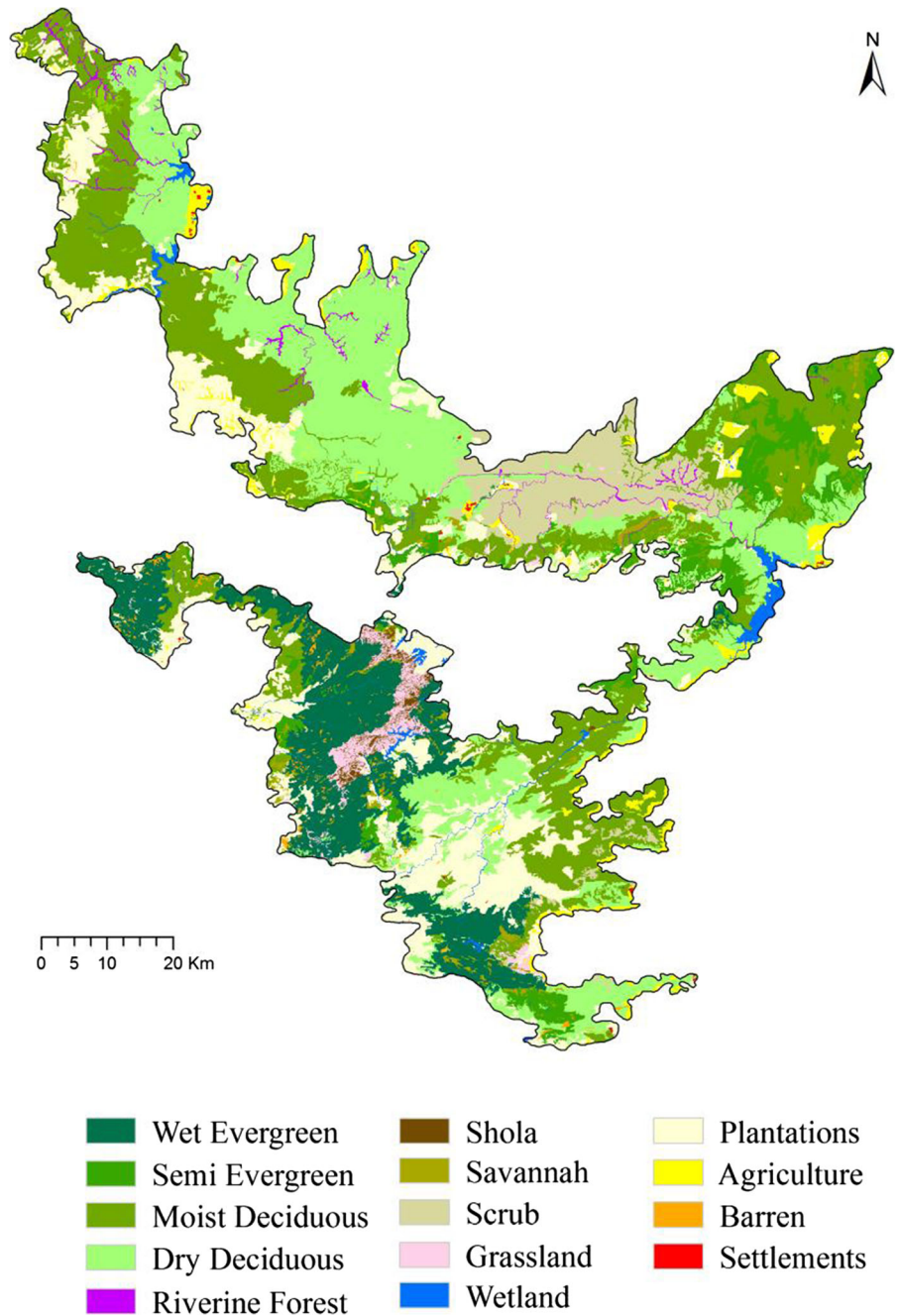
Grid wise forest cover and change analysis was performed for the entire reserve. The classified maps for

1920, 1973, 1989, 1999 and 2012 were displayed along with grid wise representation of forest cover in Figs. 4, 5, 6, 7 and 8. The time series forest map of 1920 to 2012 indicating locations of spatial change have been represented in Fig. 9. A total of 7,000 grids have been identified in NBR. Of these, 6,189 are full grids and 811 are partial grids. Grid wise analysis clearly states that the highest number of grids undergone negative changes during 1920–1973 followed by 1973–1989 and 1989–1999; out of which, 303 grids have shown loss of forest cover in 1973–1989, 12 grids have shown loss in forest area in 1989–1999 and there is no deforestation observed during 1999–2012 (Table 4). On the whole, 3,925 grids had shown loss of forest cover during 1920–2012. It is partly attributed to construction of dam resulted into submergence of forest cover in western parts of Nagarhole National Park and northern parts of Bandipur National Park. The positive change (increase) in forest cover is very less (0.13 km²) during 1989–1999. During the study period, the gain in forest cover was found to be 99.2 km² and represented in 444 grids. It is a clear indication that natural regrowth and protection has contributed to the increase of forest cover. But, in overall net forest cover loss during 1989–2012 was calculated as an area of 0.7 km². It shows declining trend of deforestation in the biosphere reserve.

Rate of deforestation

The rate of deforestation was most evident during the periods 1920–1973 and 1973–1989 respectively (Table 5). The highest forest loss was noticed for the period 1920–1973 and estimated as 25.7 km²/year. The average annual loss of forest cover is 3.8 km² during 1973–1989, 0.1 km² during 1989–1999 and no deforestation has been observed from 1999 to 2012. The annual forest loss for the period of 1973–2012 was

Fig. 10 Classified map showing vegetation types and land use/land cover of Nilgiri Biosphere Reserve (2012)



1.6 km²/year. Annual net rate of deforestation for the period of 1920 to 1973 was estimated at 0.5 followed by 0.1 for 1973 to 1989. Average annual rate of deforestation is calculated as 0.3 during 1920 to 2012. Due to enforcement of forest conservation policies, the trend of deforestation ceased during recent period. Within the Protected Areas, high deforestation rates (>0.5) were

observed in Wayanad Wildlife Sanctuary during 1920–1973 (Table 6). Nagarhole National Park, Silent Valley National Park, Mudumalai Wildlife Sanctuary shows annual rate of deforestation less than 0.5 during 1920–1973.

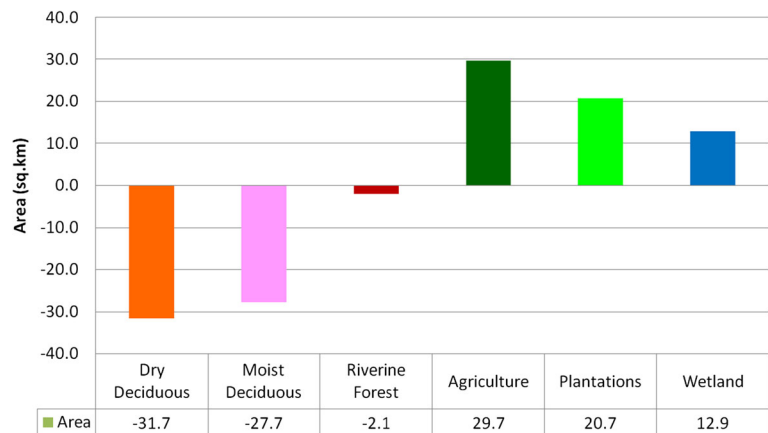
Ramesh et al. (1997) have estimated annual net rate of deforestation in southern Western Ghats as 0.19

Table 7 Distribution of forest types and other land cover in 1973 and 2012 (area in km²)

Serial no.	Land cover type	1973		2012		Change (1973–2012) Area
		Area	% of area	Area	% of area	
I	Forest					
1	Wet evergreen	736.0	11.9	736.0	11.9	0.0
2	Semi evergreen	335.7	5.4	334.5	5.4	-1.2
3	Moist deciduous	1,625.3	26.3	1,597.6	25.8	-27.7
4	Dry deciduous	1,591.0	25.7	1,559.2	25.2	-31.7
5	Riverine forest	56.8	0.9	54.7	0.9	-2.1
6	Shola	33.4	0.5	33.3	0.5	-0.1
7	Savannah	66.1	1.1	67.5	1.1	1.4
	Subtotal	4,444.4	71.8	4,382.9	70.8	62.6
II	Non-forest					
8	Scrub	398.9	6.4	397.7	6.4	-1.2
9	Grassland	105.6	1.7	104.0	1.7	-1.6
10	Plantations	957.1	15.5	977.7	15.8	20.7
11	Agriculture/fallow	177.2	2.9	207.0	3.3	29.7
12	Barren land	25.3	0.4	26.1	0.4	0.8
13	Settlements	7.2	0.1	7.5	0.1	0.3
14	Wetland	73.7	1.2	86.6	1.4	12.9
	Subtotal	1,744.9	28.2	1,806.5	29.2	61.6
	Total	6,189	100	6,189	100	

between 1920 and 1960. Menon and Bawa (1997) estimated the annual rate of deforestation in the Western Ghats to be 0.57 during 1920 to 1990. A study in the southern part of the Western Ghats was carried out using satellite data that showed annual net rate of deforestation as 1.34 between 1973 and 1995 (Jha et al. 2000). Studies in Kerala indicate the loss of forest between 1961 and 1988 to be 8.4 at an average annual rate of 0.28 (Prasad 1998). Panigrahy et al. (2010) have reported the annual

net rate of deforestation as 0.15 in the Western Ghats of Maharashtra. Joseph et al. (2009) have reported net rate of deforestation as 0.04 in the Indira Gandhi Wildlife Sanctuary, Anamalais during 1973 to 2006. This was far lower than previous estimates available for the Western Ghats region. The present study reveals that there is no quantifiable rate of deforestation in Nilgiri Biosphere Reserve after declaration which indicates conservation effectiveness.

Fig. 11 Major changes in forest types and land cover of Nilgiri Biosphere Reserve

Change in forest types

Among the seven forest types mapped, wet evergreen, semi evergreen, moist deciduous, shola and riverine forests belong to the category of tropical moist forests (Fig. 10). The moist deciduous forest is the most predominant forest type of the biosphere reserve. The total area of wet evergreen forest is estimated to be 736 km² which occupies 16.6 % of forest cover and 11.9 % of geographical area of Nilgiri Biosphere Reserve (Table 7). Dry deciduous and savannah type of tropical dry forests represent 25.2 and 1.1 % of area respectively. Among the forest types, the annual rate of deforestation is high (0.10) for riverine forests during last four decades. The construction of dams resulted in submergence of 2.1 km² of riverine forests in Nagarhole and Bandipur National Parks. Economically important forest types i.e., dry deciduous forests and moist deciduous forest have decreased by 31.7 and 27.7 km² respectively during 1973 to 2012 (Fig. 11). Biodiversity-rich forests types i.e., semi evergreen and shola forests were affected by least rate of deforestation (0.01), while wet evergreen forests have no change during 1973 to 2012. Among the non-forest land use categories, agriculture, plantations and wetlands have gained much due to loss of forest cover.

The analysis on 93 Protected Areas in tropical countries has proved that the majority of Protected Areas have stopped land clearing and to a lesser degree have been effective in controlling hunting, fire and grazing (Bruner et al. 2001). As compared to Maya, Monarch butterfly and Calakmul Biosphere Reserves, the present study area (Nilgiri Biosphere Reserve) has been successful in protection of forest cover (Sader et al. 2001; Chowdhury 2006; Garcia 2011).

The overall accuracy of the classified forest type map of 2012 was 93.2 % and the estimated Kappa coefficient was 0.89.

Conclusions

The study results demonstrate the value of utilizing historical topographical maps and satellite remote sensing to analyze the changing scenario of forests in Nilgiri Biosphere Reserve. The study has found different rates of deforestation in protected areas and on the whole for a period of nine decades to compare changes at different phases (1920–2012). The anthropogenic pressure on the

forests of Nilgiri Biosphere Reserve has reduced due to management effectiveness which is reflected in the rates of deforestation. Overall results indicate a remarkable effectiveness of conservation of forests, after the declaration of the reserve in 1986. The support from local communities will be important for enforcing conservation measures and long-term management. However, there is a need to consider other threats such as forest fires and invasive alien species for holistic management of forest biodiversity.

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