Quantification and monitoring of forest cover changes in Agasthyamalai Biosphere Reserve, Western Ghats, India (1920–2012)

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Protected areas need to be monitored regularly to realize the effectiveness of conservation measures. In this study, Agasthyamalai Biosphere Reserve of Western Ghats has been monitored for deforestation in a historic time frame. The study attempted to identify the changes that occurred within the Biosphere Reserve from the early 1920s to the recent by mapping the land use/land cover and quantifying the forest cover changes that have occurred in the Biosphere Reserve individually for each conservation zone and protected area. Multi-temporal satellite datasets and topographical maps were used for mapping the forest cover of the study area. Visual interpretation technique involving on screen digitization was used for mapping and post-classification comparison method was used for carrying out change detection process. In addition, grid wise spatial tracking was carried out for the periods of 1920–1973 and 1973–2012 to prioritize change areas. Results showed that 747.1 km^2 of forests have been lost during the period of 1920–2012. The present study demonstrates the importance of long-term land use/land cover information to examine conservation effectiveness by utilizing remote sensing and GIS techniques to carry out best management practices.

Keywords: Conservation, deforestation, land use/land cover, long-term study, protected area.

LAND use and land cover changes affect the functioning of ecosystems and contribute significantly to global warming in turn, affecting biodiversity[1]. Therefore, understanding the dynamics through monitoring of land use and land cover changes is central to global environmental and biodiversity research[2]. The cause–effect relationship among various interacting variables of the environment can only be understood through a systematic analysis of forest dynamics that play a vital role in charting policies for sustainable management of forest resources[3]. Assessment and monitoring of land use/land cover changes is an important surrogate for evaluating conservation effectiveness especially in a protected area. At present, the efforts towards measuring conservation effectiveness worldwide have increased to a considerable extent. However, the true effectives of conservation actions lack improvement and remain doubtful[4]. There is a need for more systematic planning in conservation approaches to address issues specifically in areas of high conservation values[5] where many species face extinction given the current rate of habitat loss, fragmentation and degradation[6].

Conservation effectiveness may be defined as the success of a certain set of goals or targets directed towards conservation. Assessment of conservation effectiveness refers to evaluation of the present conservation efforts and management practices in an area of interest. An ecosystem or protected area can be considered conserved when all the key ecological attributes are maintained or restored within a range of variation over space and time[4]. The evaluation of conservation effectiveness requires long-term monitoring programmes that provide data for assessment of the past and existing environmental policies and other resource management activities[7,8].

FAO has reported a global loss of 16 M ha in forest resources between 2000 and 2010 whereas 13 M ha of forest area loss was noted between 1990 and 2000 (ref. 9). Many studies that have intricately linked human interventions with ecosystem changes conclude that a comprehensive analysis of land use history and long-term vegetation data are pivotal in assessing the present day landscape scenario[10]. As forest cover estimates derived from global and national databases do not represent the actuality and differ in methodologies, definitions and

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inventory dates[11] long-term research on a regional scale becomes crucial to monitor changes in forest ecosystems[12] to examine conservation effectiveness.

Lack of adequate advancement in the field of remote sensing and GIS had deterred the examination of actual extent of forests much until the recent decade. At present, remote sensing technology is the primary requirement for the assessment of forest cover facilitated through multi-temporal and multi-resolution satellite data, automated methods and high level of human expertise through which considerable accuracy has been achieved[13]. Remote sensing has immense potential to support protected areas monitoring from regional to global scales[14]. This technology is equally helpful in establishing and managing protected areas, and can contribute to prioritization of conservation actions. Remote sensing change detection can be used to distinguish areas that have been altered by natural or anthropogenic processes to quantify the magnitude and understand the pattern of changes; this in turn provides a direction for protected areas management at the landscape level[15]. Optimal use of multi-temporal datasets to derive maximum amount of information has the potential to identify change locations more efficiently and accurately[16]. Hence, the determination of spatial changes in forest area through historical times is of utmost importance for natural resource managers for conservation and management implications[3]. Long-term change detection also provides insight into the drivers of change, allowing management strategies to be targeted towards specific causes rather than just the symptoms of the causes[17]. Therefore, a combination of remote sensing and GIS techniques with ground surveys is imperative for monitoring and management of the critical areas for accurate assessment of conservation effectiveness[18].

Few studies in India have examined long-term forest cover changes using remote sensing data. Forest loss and land use changes (from 1900 to 1960) have been assessed to perform biodiversity gap analysis[19], remotely sensed data have been used for state-wide spatiotemporal changes in forest cover (from 1924 to 2010) and variation in forest type in Odisha, India[20], historical forest cover changes (1920–2012) have been undertaken in Nilgiri Biosphere Reserve, Western Ghats, India using grid-wise method[21] and assessment and monitoring of deforestation in Andhra Pradesh from 1930 to 2011 have been carried[22]. Although a number of studies have quantified and documented forest cover changes in different parts of Western Ghats[23–25], comprehensive information is available only for the part of the landscape before it was declared Agasthyamalai Biosphere Reserve (ABR). Hence, the present study was carried out with the aim to monitor ABR by mapping the land use/land cover in a time frame that begins from the early 1920s to the recent 2012 with the help of topographic maps and satellite images to test the conservation effectiveness in that area. In addition to this, changes that have occurred in the core, buffer and transition zones and the four protected areas in the Biosphere Reserve were assessed through change detection technique, spatial tracking by grid wise analysis and deforestation rate dynamics.

Materials and methods

Study area

The study area 'ABR' lying in the southern most ends of the Western Ghats, is a world biodiversity hotspot and a world heritage site. ABR falls under Tirunelveli and Kanyakumari districts of Tamil Nadu and Thiruvananthapuram and Kollam districts of Kerala in the coordinates of 8°5′ to 13°00′N and 77°52′ to 77°34′E. Figure 1 shows the location of the study area. This Biosphere Reserve was designated on 12 November 2001 for the Kerala State and later the boundaries were expanded to Tamil Nadu on 4 August 2005 (ref. 26). Biosphere Reserves are demarcated into three inter-related zones, viz. the core zone, the buffer zone and the transition zone, where activities of biodiversity conservation and sustainable management can take place simultaneously. The core zone is the undisturbed zone of a Biosphere Reserve that has been accorded with legal protection by Wildlife Protection Act (1972) to safeguard it against human interventions except, research and management activities. Buffer zone circumvallates the core zone in which certain restoration activities along with recreation, tourism, fishing and grazing are permitted. The outermost part of a Biosphere Reserve is called the transition zone where conservation efforts, knowledge and management efforts are applied and includes human settlements, crop lands, managed forests and demarcated regions for intensive recreation, and other economic activities[27]. ABR covers an area of 3500.36 km^2 with a core zone of 1135 km^2, buffer zones covering 1445 km^2 and transition zones covering 920.36 km^2 (ref. 26). It includes three wildlife sanctuaries – Shendurney, Peppara, Neyyar and one Tiger reserve – Kalakad Mundanthurai (KMTR)[26]. The elevation level within the Biosphere Reserve ranges from 100 to 2000 m. The precipitation in the windward side of the study area is between 2000 and 5000 mm whereas in the leeward side the precipitation plummets from 2000 to 900 mm. The mean temperature of the coldest month lies within the range 13.5°C and 23°C on the western side and within 16°C and 23°C in the east[19,28].

The ABR harbours very rich species diversity with 2000 flowering plant species showing 7.5% endemism[29]. An estimated 1500 endemic plant species are found in the Western Ghats of which at least 150 are found in the Agasthyamalai region itself[30–32]. Abundance of *Glutatravancorica*, an endemic plant species of the Agasthyamalai region, can be found here and in addition to these, 600 medicinal plants occur in this area. Two highly

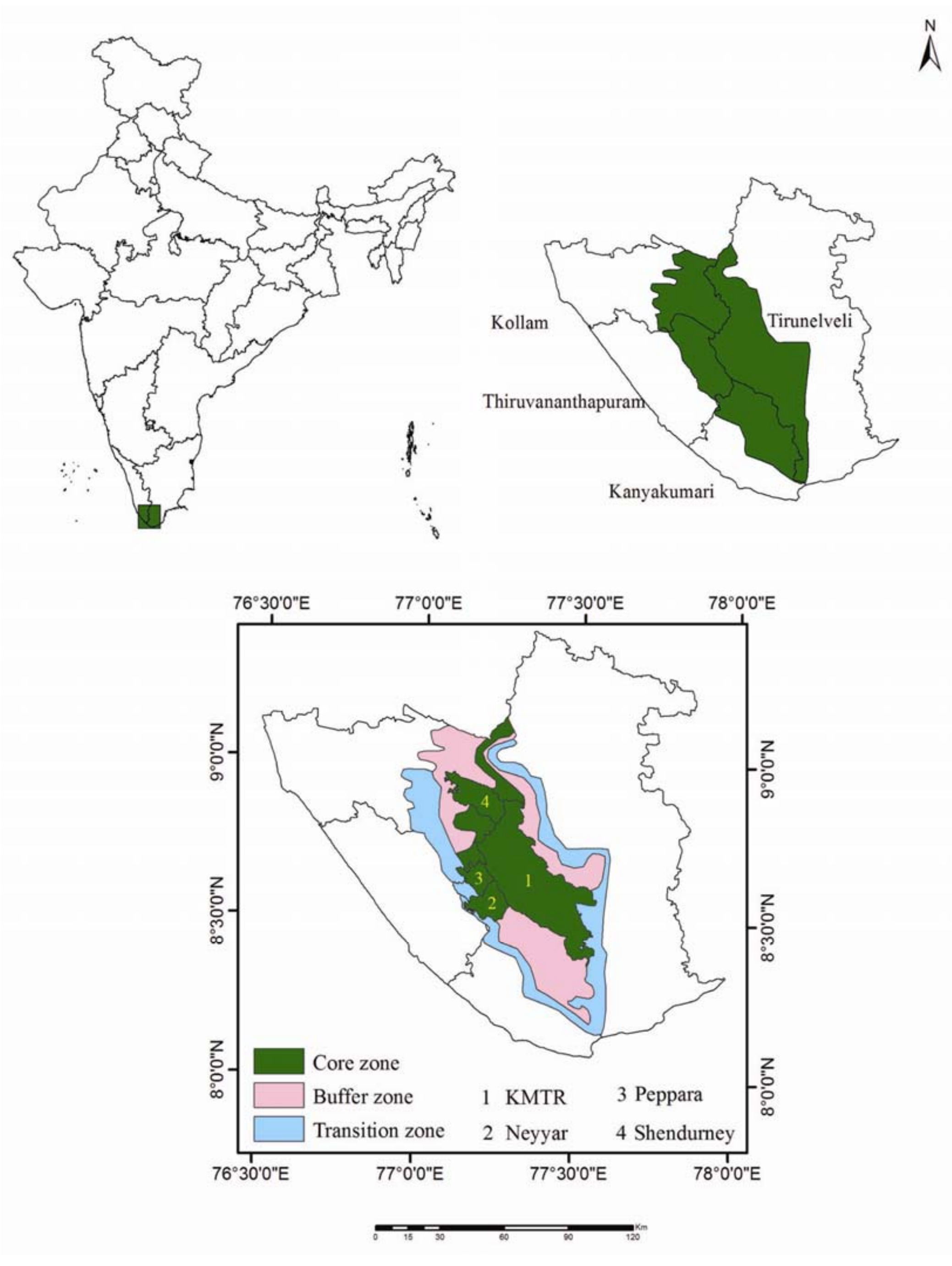


Figure 1. Location map of Agasthyamalai Biosphere Reserve.

endangered animal species – the Lion-tailed macaque and the Nilgiri Tahr can be found in the Biosphere Reserve. The reserve also demonstrates a rich diversity of avifaunal wealth with 337 species of birds reported including migratory, endemic and endangered species[26].

Data collection and analysis

Satellite data pertaining to distinct time windows need to be used to account for phenological variations in forest ecosystems and delineate different vegetation types in a study area. Remote sensing data from six different time periods pertaining to a total of eight satellite scenes were utilized for this study. Resourcesat-2 LISS–III, Indian Remote Satellite (IRS) P6 LISS III and IRS 1B LISS II scenes were procured from the National Remote Sensing Centre Data Centre. Ortho-rectified Landsat MSS (Multi Spectral Scanner), Landsat TM (Thematic Mapper) and Landsat Enhanced Thematic Mapper (ETM+) datasets were downloaded from Global Land Cover Facility website[33]. Topographical maps of 1 : 250,000 scale prepared

Table 1. Details of satellite data used

Satellite sensor/toposheet number	Path/row	Date of acquisition/ survey period	Spatial resolution (m)
Resourcesat-2 LISS III	101/68	25 March 2012	23.5
Resourcesat-2 LISS III	100/67	25 February 2012	23.5
Resourcesat-2 LISS III	100/68	25 February 2012	23.5
IRS P6 LISS III	101/68	2 April 2006	23.5
Landsat ETM$^+$	143/54	9 April 2001	30
Landsat TM	143/54	11 March 1992	30
Landsat MSS	143/54	10 December 1985	60
Landsat MSS	154/54	9 February 1973	60
NC43_12	–	1919–25	–
NC43_16	–	1920–24	–
Ancillary data			
IRS P6 LISS III	100/68	13 February 2005	23.5
IRS 1B LISS II	25/62	7 February 1995	36.2

by Army Map Service, U.S. Army, Washington were used to obtain data for the year 1920 (ref. 34). The details of the data used are given in Table 1.

Orthorectified satellite data (Landsat ETM+) with UTM projection and WGS 84 datum was used as master reference[33] to carry out geometric corrections for the rest of the satellite images to correct errors of perspective due to the Earth's curvature and sensor motion. This allows us to accurately assess spatial data and measure them from the satellite imagery. Additionally, Top of Atmospheric Correction was applied for radiometric normalization of multi-temporal data. The accurate boundary of the Biosphere Reserve was obtained from the Compendium on Indian Biosphere Reserves and the India Biodiversity portal[26,35]. By using that boundary, a subset of the study area was made and extracted from all the satellite scenes. Initially, major vegetation types were recorded from the satellite imageries (FCCs) by their characteristic features, and thereafter, put to intensive study of its tone, texture, pattern and associated features. An image interpretation key for forest and other land use mapping is given in Table 2. Visual image interpretation technique was used for image classification using ERDAS IMAGINE 2013 software. Visual image interpretation allows identification and classification of objects visually from either, the hard copy photographic prints or on-screen digitization using digital image. There are certain fundamental photo/image characteristics that help in interpretation of earth features, viz. tone, texture, pattern, size, shape and shadow coupled with site/location and associated features. Most of these image characteristics depend on the spectral, spatial, temporal and radiometric resolution of the sensor and the ability of an imaging system to record finer details in a distinguishable manner. The output of the visual interpretation (in vector format) was then converted to a raster format for each dataset by resampling them to 30 m resolution to normalize the data for calculation of area statistics.

Subsequently, the study area was visited through 2012–2014 and each of the vegetation types in view was covered for collecting ground truth information. Stratified random sampling methodology was used for collection of ground points. A total of 100 ground control points were collected with the help of forest department staff. The number of ground control points collected for forests was 25, scrub 8, plantations 18, grasslands 7, water 5, barren land 6 and settlement 11. Survey of published literature and interviews with forest officers and education/local institutions were carried out to enhance capability of understanding the unique vegetation types more precisely. Correspondingly, accuracy assessment was done by dividing the number of points found correctly on the classified image to that of total number of points checked in the field multiplied by hundred using error matrix. This generated the total accuracy and kappa co-efficient of the classified output in percentage.

Change detection is a technique that operates on remotely sensed data based on their radiance values, whose differences can then be analysed for changes with time. The change information was extracted by comparing two or more images of the study area that were acquired at different times. The land use/land cover maps of 1973, 1985, 1992, 2001, 2006 and 2012 in their raster formats were used as inputs for carrying out change detection in the study area. A combination of direct time period 1 (T1) and time period 2 (T2) change detection as well as post-classification comparison through matrix were employed for assessing changes in ABR for the years 1920 to 1973 and 1973 to 2012. Post-classification comparison method requires rectification and classification of each remotely sensed image after which the two maps are compared on a pixel-by-pixel basis using a change detection matrix available in ERDAS IMAGINE. Change areas are those that are not classified within the same category at progressive time periods. The advantage of this method includes the detailed from–to information

Table 2. Image interpretation key for vegetation and other land cover mapping

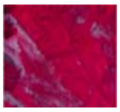
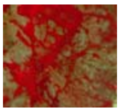
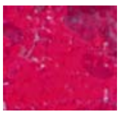
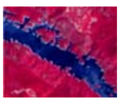
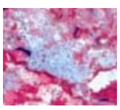
Land use/land cover class	Image chip	Tone	Texture	Shape	Pattern	Description
Evergreen forest		Dark red	Coarse	Varying	Rough	Forest remains evergreen throughout the year, high altitude forests; form a multilayered pattern
Semi-Evergreen forest		Light red	Medium	Varying	Rough	Transitional forests between evergreen and moist deciduous forests
Moist Deciduous forest		Bright red to brown tinged red	Medium	Varying	Rough	Upper canopy of leaf-shedding moist deciduous species, middle canopy of semi-evergreen species
Dry Deciduous forest		Greenish to red	Medium	Varying	Rough	Canopy is represented by deciduous species, entirely leafless in summer season
Dry Evergreen forest		Slightly dark to light reddish brown/ green	Medium	Varying	Rough	Trees evergreen with short boles and spreading crowns
Shola		Dark red	Rough	Scattered	Rough	Evergreen forests found in between grasslands of high altitude
Scrub		Light red	Coarse	Varying	Rough	Bushy vegetation with shrubs or scattered trees/shrubs with exposed ground surface
Reed brakes		Bright red	Smooth	Varying	Smooth	Gregarious bamboo or Ochlandra brakes
Plantations		Red	Smooth	Regular	Grouped	Cultivated crop for commercial purpose
Grasslands		Greyish to brown	Smooth	Irregular	Scattered	Grass predominating areas
Agriculture		Pinkish or light green or light blue	Smooth	Regular	Smooth	Crops/current fallow lands
Water		Blue or black	Smooth	Irregular	Scattered	Rivers and reservoirs
Barren land		Greyish/ whitish	Fine	Irregular/ regular	Smooth	Sparse vegetation cover; in case of sand generally along streams and dried up river beds
Settlement		Cyan	Smooth	Regular	Scattered	Human inhabited areas

Table 3. Land use/land cover information of ABR from 1920 to 2012 (area in km^2)

	Year						
Class	1920	1973	1985	1992	2001	2006	2012
Forest	3079.5	2332.4	2322.2	2316.8	2291.3	2291.3	2291.3
Plantation	35.1	506.8	495.2	495.2	494.6	494.6	494.5
Water	23.2	100.4	105.4	111.0	122.5	127.8	121.5
Other land use	1010.6	1208.6	1225.4	1225.1	1239.9	1234.5	1240.9
Total	4148.4	4148.2	4148.2	4148.2	4148.2	4148.2	4148.2

that can be extracted and the fact that the classified map for the next base year is already complete[36]. This exercise yielded change maps for the study period that showed areas of considerable changes intended for further analysis. A gridwise analysis of forest change was also carried out by generating grids of size 1 km × 1 km for the years 1920–1973 and 1973–2012. For this, forest cover information of each year was spatially expressed in the form of grids after which the changes were calculated. This aided in the process of spatial tracking of changes on a priority basis.

Further, an overlay analysis was carried out to quantify primary and secondary forests. CBD defines primary forest as 'a forest that has never been logged and has developed following natural disturbances and under natural processes, regardless of its age' and secondary forest as 'a forest that has been logged and has recovered naturally or artificially'[37]. Overlay analysis was carried out by stacking classified forest cover maps of various study periods using the model maker tool in ERDAS IMAGINE. This revealed areas of primary forest that have been persistent since the early 1920s and the ones that have been recently regenerated. Deforestation rates for the core, buffer and transition zones and also for the four protected areas, viz. Neyyar, Peppara, Shendurany wildlife sanctuaries and KMTR in the Biosphere Reserve were calculated. Deforestation rates were derived from the compound interest formula due to its explicit biological significance[38]. The formula is as follows

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

where r is the annual rate of change (percentage per year), a_1 and a_2 are the forest cover estimates at time t_1 and t_2 respectively. The final maps were composed in ARC GIS 10.2 software.

Results

Forest cover

The land use/land cover information for the major classes across ABR for all the years studied are given in Table 3. It can be seen that the total forest cover of the Biosphere Reserve has decreased from 3079.5 km^2 in the year 1920 to 2291.3 km^2 in 2012. A drastic increase in the area of plantation (from a mere 35.1 km^2 to 506.8 km^2) is evident. The areal extent of water is rather dynamic that it witnessed a sharp rise from 1920 to 1973 and thereafter, varied seasonally. The area of other land uses through 1920 to 2012 can also be seen to have increased gradually.

Vegetation types and land use: 2012

The area of each land use/land cover class present in the 2012 land cover map is shown in Table 4. A total of six different forest types were identified during the process of mapping and subsequent field visits consisting of both tropical moist and tropical dry forests. These vegetation types[39] were identified as tropical evergreen forest and sholas, tropical semi-evergreen forest, tropical moist deciduous forest, tropical dry deciduous forest and tropical dry evergreen forest.

Forests covered 51.5% of the study area in 2012 (Table 4), with moist deciduous forests occupying the greatest forest area (812.6 km^2), and shola forests the least (5.03 km^2). Within the non-forest class, agriculture is spread across a vast area of 813.9 km^2 and plantations occupy the second largest extent of 494.5 km^2. Other important classes worth mentioning are reed brakes covering 111.6 km^2, scrub 145.2 km^2, water (mostly consisting dams/reservoirs) 121.5 km^2 and grasslands 87.9 km^2 in the study area. Figure 2*a* shows the land use/land cover maps of all the years studied. The land use/land cover information for the year 2012 is illustrated in Figure 2 *b*. The overall mapping accuracy of the current map is estimated to stand at 92%.

Conversion of forests and change area matrix

Tables 5 and 6 show the change from forest to other land use and vice versa studied in ABR for the periods 1920–1973 and 1973–2012 respectively. A huge amount of forest area (309.6 km^2) had been converted to other land use from 1925 to 1973. Also, as much as 414.6 km^2 of forest area was converted to plantations and 28.5 km^2 to water within the same time period. Similarly, during the period of 1973–2012, 27.3 km^2 of forests were converted to

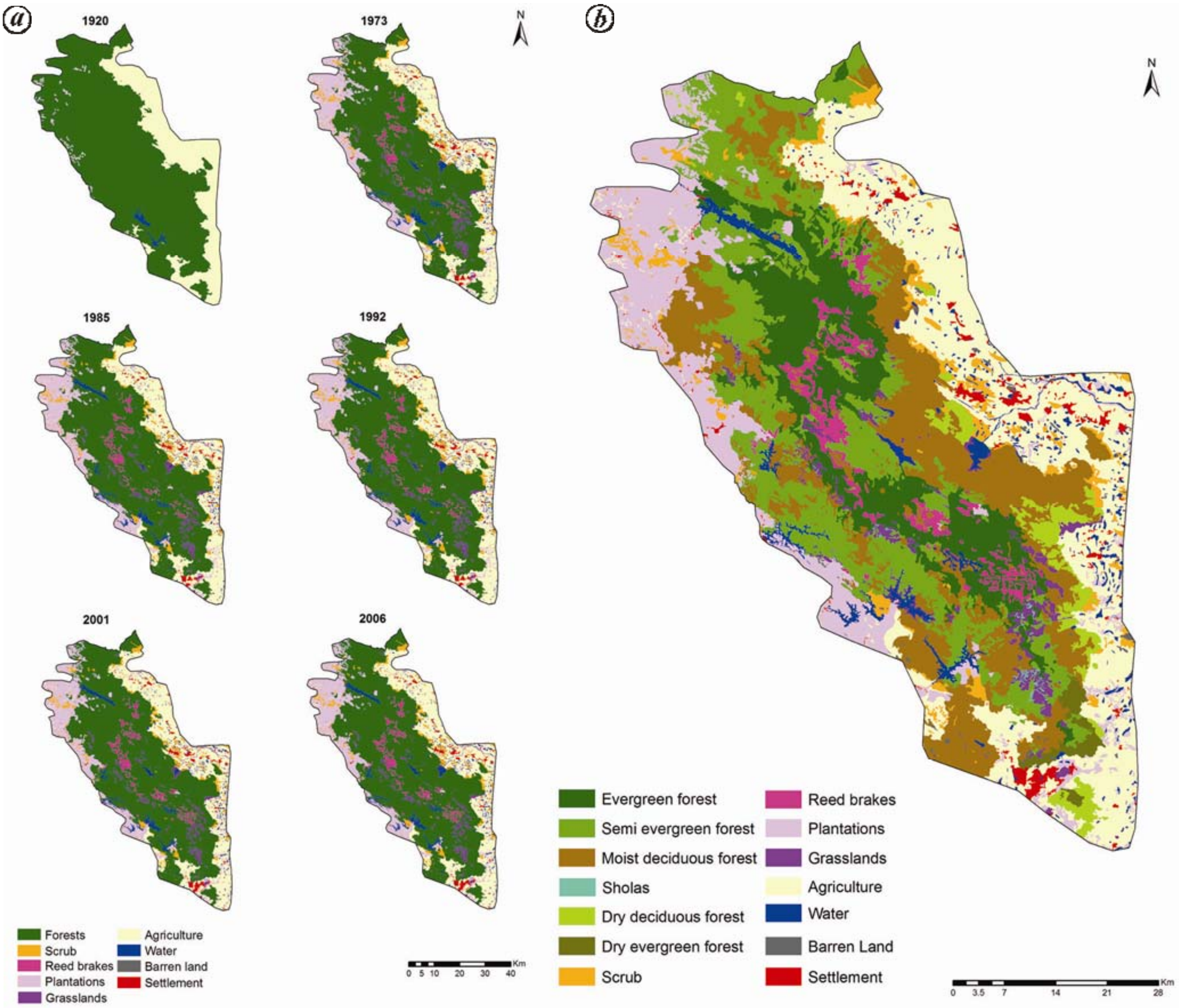


Figure 2. ***a***, Maps showing land use/land cover classes of ABR. ***b***, Map showing land use/land cover classes of ABR, 2012.

reed brakes and 10.7 km^2 to water. The change area maps for the year 1920–1973 and 1973–2012 are shown in Figure 3 *a* and *b* respectively.

Overlay analysis revealed that as much as 2284.9 km^2 of forests in the Biosphere Reserve are primary old growth forests and only 5.9 km^2 are secondary forests.

Grid wise analysis

The grid map of 1920–1973 (Figure 3 *c*) shows that as many as 522 grids underwent negative change in the range 0.61–1 km^2 and 875 grids in the range of 0.11–0.61 km^2. 1491 grids evidenced no change and a low number of grids (6) went through a positive change in the range 0.21–0.65 km^2. The grid map of 1973–2012 (Figure 3 *d*) shows the highest number of grids (111) having experienced negative change in the range 0.11–0.61 km^2. Positive change was negligible and grids with no change were 2733.

Rate of deforestation

Figure 4 presents the trend of deforestation throughout the historical periods studied (1920–1973, 1973–1985, 1985–1992, 1992–2001, 2001–2006 and 2006–2012) in the zones of ABR. The trend line clearly shows the gradual decline of deforestation rates from the period of 1925–1973 to 1985–1992 in all the zones. During the period of 1992–2001, there was only a slight rise in the deforestation rate that can be attributed to the massive invasion of reed brakes encroaching upon the open and degraded habitat of natural forest cover (Figure 5 *a*).

After 1992–2001 period, the rate decreased again, and after 2001, finally became stable. In Neyyar sanctuary, the deforestation rates were found to be high during 1920–1973 and in Peppara sanctuary and Shendurney sanctuary, the deforestation rates were estimated to be –0.38% and –0.32% respectively during the 1973–1985 period due to establishment of their respective dams adjoining the sanctuaries (Figure 5 *b* and *c*)[40]. The details of deforestation rates from 1920 to 2012 for each year in the protected areas of ABR are given in Table 7.

Discussion

The Western Ghats region like any other protected area has been studied by various researchers from different perspectives. However, long-term forest cover monitoring and assessment had been taken up by only one study for the Agasthyamalai region in the past[19]. To fill this gap and to test the true conservation effectiveness in the protected area, a recent update for the land use/land cover was highly imperative which has been covered in the present study. In a study involving analyses of the gross and net deforestation rates in India, Reddy *et al.*[40] have summarized the deforestation rates studied by various authors in the Western Ghats. In a forest cover dynamics analysis carried out in the Agasthyamalai region, a total of 47 km^2 of forest was found to have been lost accounting to a deforestation rate of –0.07% during the 40-year period of 1920–1960 (ref. 19). According to our study in ABR, the rate of deforestation in the contemporary period was found to be –0.52% (1920–1973), which is much higher and can be attributed to conversion of forests to plantations and reed brakes. Also a deforestation rate of –1.34% was recorded in the southern part of the Western Ghats from 1973 to 1995 (ref. 24). But the calculation of deforestation rate for the period of 1973–1992 in our study yielded the same to be lower (–0.04%). The deforestation rates were found to be high (–0.51%) between 1920 and 1990 and forests being transformed into agriculture and monoculture plantations in a similar study[23]. In agreement to the above, our study within the 1920–1992 period showed a similar deforestation rate of –0.40%. The drivers of change for the above studies have been identified as human interventions through expansion of plantations and population pressure. In a long-term assessment study in the Nilgiri Biosphere Reserve[21], deforestation rate from 1920 to 2012 was found to be –0.3; forest being lost due to conversion into agriculture, plantations as well as submergence due to dam constructions. Also, this study addressed the issue of conservation effectiveness, found to be lacking in earlier studies. Sheeja *et al.*[25] in their land cover assessment over a century (1914–2007) of the Neyyar Basin, part of Agasthyamalai region have observed most notable changes as decrease in areas of paddy cultivation, mixed crops, scrub lands and evergreen forests, and an increase in built-up areas, rubber plantations and water bodies. Our study during the period of 1920 to 2001 found major decrease in forest cover, with considerable changes from the forest to other land use, and a gradual increase in the areas of water, plantation and other land use. The rates of deforestation differ considerably as these studies were carried out at different time periods in various subsets of the entire Western Ghats utilizing individual definitions, methodologies and sources of data.

The primary old growth forests in the Western Ghats have existed since the beginning of the 4th millennium BP[41]. The primary forest areas in our study site have been converted directly to plantations and reed brakes without having gone through the secondary succession stages. As a result, the secondary forest areas were found to be extremely low as compared to primary forest areas. It is

Table 4. Area statistics and percentage of land use/land cover classes of ABR, 2012

Class	Area (km^2)	Percentage of area
Tropical moist forests		
Evergreen forest	540.7	13.0
Semi Evergreen forest	778.7	18.8
Moist Deciduous forest	812.6	19.6
Shola	5.0	0.1
Sub-total	2137.0	51.5
Tropical dry forests		
Dry Deciduous forest	116.4	2.8
Dry Evergreen forest	37.9	0.9
Sub-total	154.3	3.7
Total (forest)	2291.3	55.2
Scrub	145.2	3.5
Reed brakes	111.6	2.7
Plantations	494.5	11.9
Grasslands	87.9	2.1
Agriculture	813.9	19.6
Water	121.5	2.9
Barren land	15.3	0.4
Settlement	66.9	1.6
Sub-total (other land use)	1856.9	44.8
Grand total	4148.2	100.0

Table 5. Change area matrix for the period 1920–1973 in ABR (area in km^2)

	1973				
1920	Forest	Plantation	Water	Other land use	Total
Forest	2326.7	414.6	28.5	309.6	3079.3
Plantation	4.2	26.2	0.2	4.5	35.1
Water	1.0	0.1	22.1	0.0	23.1
Other land use	0.3	65.9	49.7	894.6	1010.5
Total	2332.3	506.8	100.4	1208.6	4148.1

Table 6. Change area matrix for the period 1973–2012 in ABR (area in km^2)

	2012														
1973	Evergreen forest	Semi-Evergreen forest	Moist Deciduous forest	Shola	Dry Deciduous forest	Dry Evergreen forest	Scrub	Reed brakes	Plantations	Grasslands	Agriculture	Water	Barren land	Settlement	Total
Evergreen forest	540.7	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.1	0.0	0.0	0.0	0.0	541.9
Semi-Evergreen forest	0.0	777.1	0.0	0.0	0.0	0.0	0.0	9.4	0.0	0.3	0.0	0.2	0.0	0.0	786.9
Moist Deciduous forest	0.0	1.6	812.4	0.0	0.0	0.0	0.0	16.8	0.0	3.0	0.0	10.5	0.0	0.0	844.2
Shola	0.0	0.0	0.0	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.0
Dry Deciduous forest	0.0	0.0	0.0	0.0	116.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	116.4
Dry Evergreen forest	0.0	0.0	0.0	0.0	0.0	37.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	37.9
Scrub	0.0	0.0	0.0	0.0	0.0	0.0	145.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	145.2
Reed brakes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	84.3	0.0	0.0	0.0	0.0	0.0	0.0	84.3
Plantations	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	494.5	0.0	0.0	12.2	0.0	0.0	506.8
Grasslands	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	77.7	0.0	0.2	0.0	0.0	78.1
Agriculture	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	813.9	4.8	0.0	5.9	824.6
Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.7	0.0	93.6	0.0	0.0	100.4
Barren land	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.3	0.0	15.3
Settlement	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	61.0	61.0
Total	540.7	778.7	812.5	5.0	116.4	37.9	145.2	111.6	494.5	87.9	813.9	121.5	15.3	66.9	4148.2

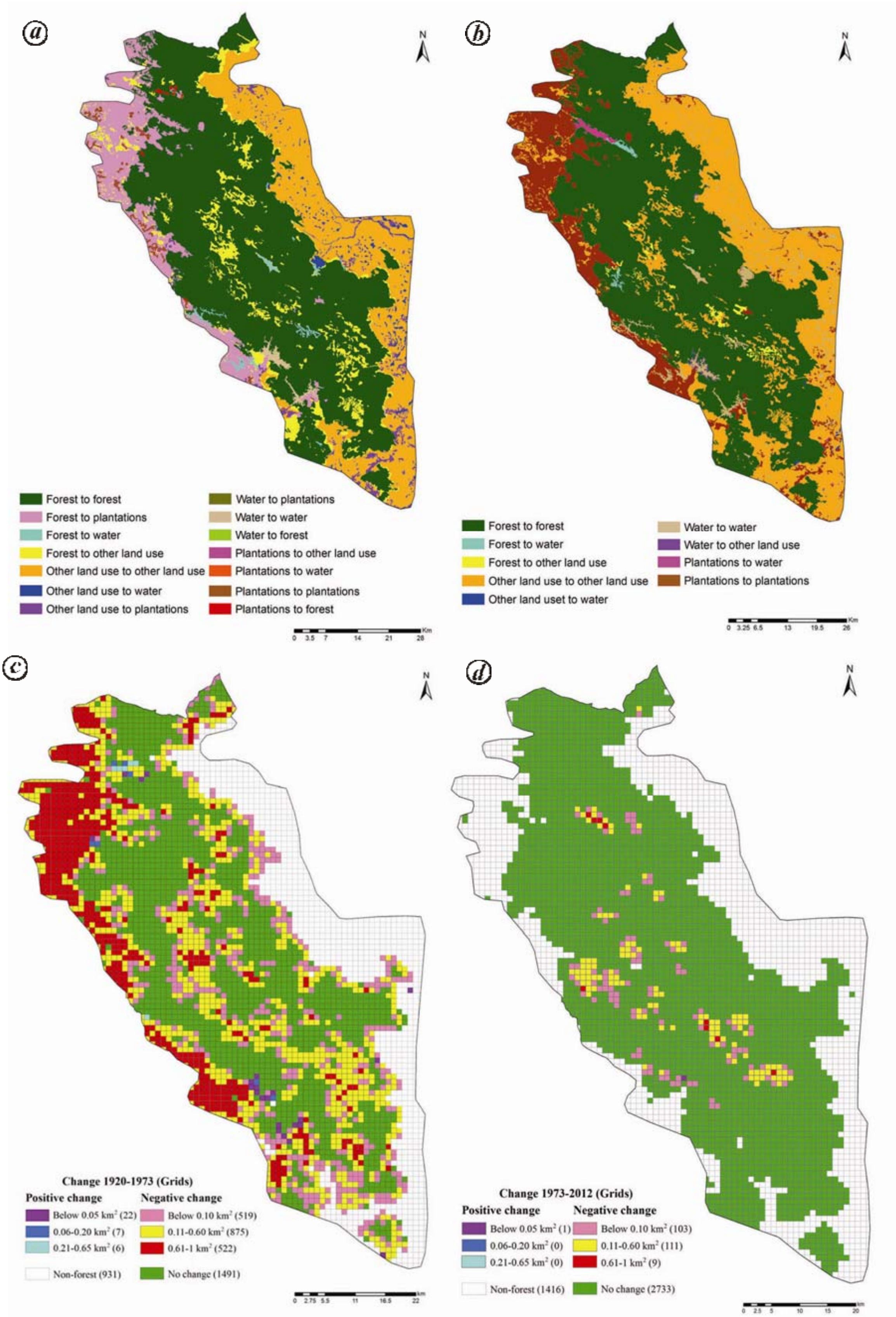


Figure 3. Change area map for the period (***a***) 1920–1973 and (***b***) 1973–2012 of ABR. Gridwise map for the period (***c***) 1920–1973 and (***d***) 1973–2012 of ABR.

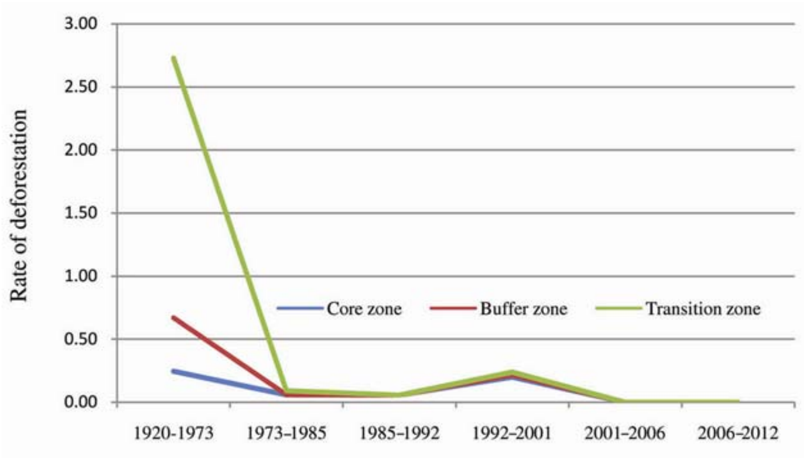


Figure 4. Deforestation rates throughout the study period in all the zones of ABR.

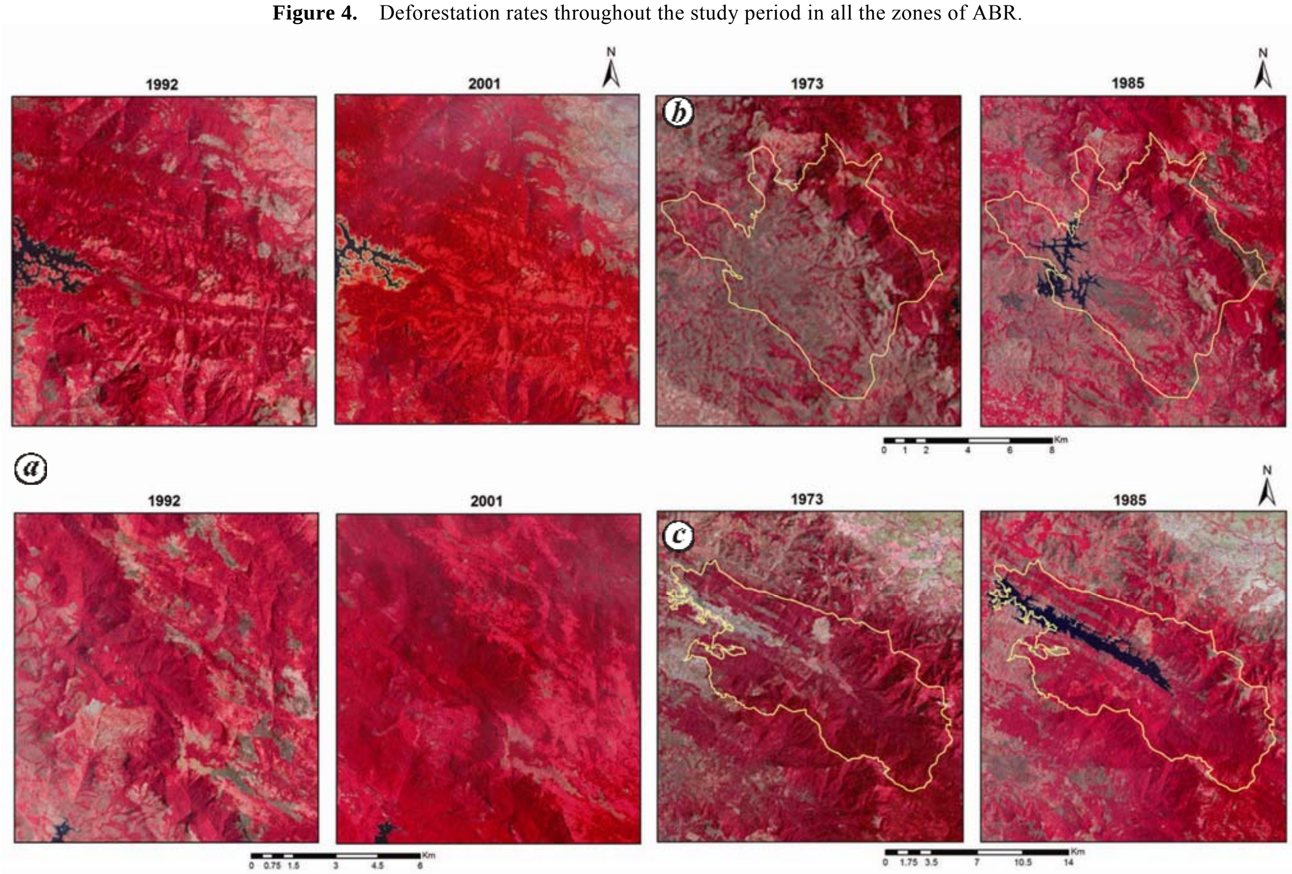


Figure 5. ***a***, Invasion of reed brakes in parts of KMTR during the period 1992–2001. ***b***, Deforestation due to the establishment of Peppara dam in Peppara Wildlife Sanctuary during the period 1973–1985. ***c***, Deforestation due to the establishment of Thenmala dam in Shendurney Wildlife Sanctuary during the period 1973–1985.

possible that there have been degradations within the primary forest areas, being converted from dense to open forests which have not been covered in this study due to absence of density information in the topographic sheets.

George and Chattopadhyay[42] highlighted four distinct phases of deforestation, viz. (1) extensive conversion of forestlands to plantations following a Royal Proclamation in the late nineteenth century, (2) the 'Grow More Food' campaign of the mid-1940s when substantial areas of forests were opened up for the cultivation of food crops, (3) colonization during the 1950s and 1960s which created new settlements in the deforested areas and (4) infrastructure development of the post-independence era (1947) during which projects in power, irrigation and transportation sectors were set up on forest lands. In the pre-independence period, wildlife reserves were created to function as game reserves after which in Kerala most of the areas surrounding irrigation or hydroelectric reservoirs were declared as wildlife sanctuaries. The deforestation rates were elevated in Neyyar sanctuary during

Table 7. Rate of deforestation for all the periods in protected areas of ABR

Time period (t1)	Time period (t2)	KMTR	Neyyar	Peppara	Shendurney
1920	1973	–0.26	–0.31	–0.17	–0.24
1973	1985	0.00	0.00	–0.38	–0.32
1985	1992	–0.08	0.00	–0.12	0.00
1992	2001	–0.25	–0.13	–0.44	–0.04
2001	2006	0.00	0.00	0.00	0.00
2006	2012	0.00	0.00	0.00	0.00

1920–1973 and in Peppara sanctuary and Shendurney sanctuary during 1973–1985. Neyyar Wildlife Sanctuary is a part of this long history which was declared as wildlife sanctuary in 1958 subsequent to the establishment of the Neyyar dam in the same year. In an almost similar manner, Peppara sanctuary and Shendurney sanctuary were declared as wildlife sanctuary in 1983 and 1984 respectively, after the construction of Peppara dam and Thenmala dam. The dams were built mainly for providing drinking water and for meeting agricultural needs of the adjoining sub-urban areas. The sanctuaries being located in upstream catchments of the dams were thus rendered vulnerable to any future alterations in the landscape[43,44]. The deforestation rates appeared to be decreasing in KMTR from the 1920–1973 period to 1985–1992 period but again increased during the 1992–2001 period which can be attributed to reed brakes invasion. Deforestation and degradation as a result of land use/land cover change usually create openings in the forests exposing large areas which give opportunities for a number of unwanted and fast growing species to invade the natural ecosystem replacing native flora and gradually establishing themselves[45]. Such is the case with reed brakes, a native bamboo species of the Western Ghats, found invading large stretches of areas in the study site with potentially serious implications in the future.

Although a gradual decrease in deforestation rates can be observed in all the zones, when individually assessed, a steep decline from the 1920 rate to the current year in the transition zone can be seen. Also a decrease in the same can be seen in the buffer zone. This is due to the establishment of plantations and settlements in the earlier years as transition zone and buffer zone are open for management and restoration activities as well as human interventions. The core zone, on the other hand, shows a hike in deforestation rate for the period 1992–2001 after which the rates fall to nil. This indicated that the core zone faced threats from invasive species during that period but due to strengthening of conservation measures after the declaration of the Biosphere Reserve in 2001, the encroachment decreased and henceforth deforestation ceased. Exploration of the deforestation dynamics in the individual protected areas clearly presented the threats they were subjected to, before declaration of the sanctuary status. This is in agreement with the forest cover mapped through the satellite images and the history of the protected areas. The results of the present study aided in examination of the status of protection provided to the different zones and protected areas of ABR and manifested the importance of long-term land/use land cover studies in the context of testing conservation effectiveness, proving the Biosphere Reserve effectively conserved.

Conclusions

Deforestation through plantation, water and other land use and degradation through invasion of reed brakes were the major indicators of forest cover change before declaration of the Biosphere Reserve. Assessment of deforestation rates in the core, buffer and transition zones exhibited the dynamics of the landscape and the gradual decrease of deforestation rates from 1973 to 2001. The year 2001, the year of declaration of Biosphere Reserve, proved conservation effective in preventing deforestation. This shows that the conservation and management measures taken up for the Biosphere Reserve are in place. Systematic geospatial monitoring is essential for assessment of forest cover and observation of deforestation rate dynamics for conservation of the status of the protected area and for management interventions to take place.

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