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ORIGINAL ARTICLE

Assessing spatio-temporal health of forest cover using forest canopy density model and forest fragmentation approach in Sundarban reserve forest, India

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Abstract We used forest canopy density model for examining spatial–temporal variation in canopy closure in Sundarban Forest in India and validated the health with fragmentation model. Statistics derived through forest canopy model revealed that most of the changes in forest canopy density occurred in 60–80 % class during 1990–2011. Areas having >80 % and 40–60 % canopy density registered decrease in density while the remained classes 20–40 % and <20 % gained the proportion of decreased density from upper density classes. Forest fragmentation model classified the forested areas into four categories of disturbance-core, perforated, edge and patch based on 200 m edge width. Fragmentation model revealed that the perforated and edge areas have decreased while patch area has increased. Overall core area has increased due to decline in perforated area and consequently experienced decrease in canopy closure. The study demonstrated usefulness of forest canopy density and fragmentation models for assessing the health of the forests.

Keywords Forest canopy density (FCD) · Forest fragmentation · Remote sensing · Sundarban reserve forest

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Introduction

Forest cover is one of the most important renewable resources on the earth's surface for maintaining ecosystem. The canopy density of forest cover is continuously decreasing both due to natural as well as anthropogenic activities affecting the ecological status. The average annual net loss of forest has reached about 5.2 million hectares in the past 10 years (FAO 2010). Forest canopy density constitutes the single major physiognomic characteristic of the forest (Nandy et al. 2003). Hence assessment of forest density is prerequisite for sustainable management of natural resources at various scales. Since forest canopy density (FCD) model is based on the phenomenal growth of forests, it helps in monitoring transformation of forest conditions over time (Rikimaru et al. 2002). Forest canopy density model (FCD) as a planning tool helps in identifying canopy closures and according priority for afforestation and reforestation (Biradar et al. 2005). Forest fragmentation is the process of dissecting large and contiguous areas of forest into smaller units and isolated patches (Haila 1999; Saunders et al. 1991). It has been recognized as the major threats for the health of the forest (Harris 1984; Forman 1995; Garcia-Gigorro and Saura 2014). Therefore, fragmentation may be considered as an influential indicator of ecologically sustainable forest management (Parry et al. 2000; Brown et al. 2001; Garcia-Gigorro and Saura 2014). Forest canopy density (Rikimaru et al. 2002; Rikimaru 1996) and forest fragmentation (Chapungu et al. 2014) derived data may be useful for characterizing condition of forest. Thus, estimates of forest canopy density and forest fragmentation have been adopted for monitoring and assessing the forest health (Biradar et al. 2005; Panta 2003; Mon et al. 2010).

Various studies have demonstrated the usefulness of forest canopy density model for analyzing forest degradation using remote sensing data. Forest canopy density model was first used by Rikimaru, in 1996 using Landsat TM data processing guide for forest canopy density mapping and monitoring model. Since then it has been used virtually everywhere in the world after 2002. However, the model is frequently used in tropical forest to analyse and estimating the forest canopy cover, afforestation, deforestation, health of forest etc. Azizia et al. (2008) used forest canopy density model old growth forest plantation in north forest division of northern Iran. Mon et al. (2012) utilized the model for assessing tropical mixed deciduous vegetation in Myanmar. Godinho et al. (2014) used the FCD model for estimating montado canopy density in southern Portugal. Panta and Kim (2006) investigated the spatio-temporal dynamic alterations of Forest Canopy Density in Nepal. Wang and Brenner (2009) integrated the FCD model with SVM regression model to estimating forest canopy cover in state of Florida. Baynes (2007) applied this model in Australia and Philippines and Hasmadi et al. (2011) in Malaysia. Many scholars from India have applied FCD model to assess canopy closure using biophysical spectral response (Biradar et al. 2005; Deka et al. 2012; Prasad et al. 2009; Roy et al. 1997; Nugroho 2011). CLEAR researchers first developed fragmentation related GIS tool (CLEAR (2002)). Vogt et al. (2007) refined this model by using morphological image processing for classifying spatial patterns at pixel level. Forest fragmentation was estimated from remotely sensed data by many scholars (Garcia-Gigorro and Saura (2014); Li et al. 2009).

Forests in Sundarban offer costal protection to millions of people in India by stabilizing shorelines and in helping reduce the devastating impact of natural disasters (Roy et al. 1996). These forests, however, are declining at an alarming rate and much of what remains is in degraded condition (Wilkie and Fortune 2003). The magnitude, intensity and causative factors of such changes are not fully authenticated. Remnants of these forests are exposed to cutting, hydrological alterations, salinity and climate change (Ray et al. 2013; Blasco 1975). Remote sensing could play an important and effective role in the assessment and monitoring of mangrove forest cover dynamics. Moreover, it is extremely difficult to get into vast swamps of mangrove forests for conducting field survey (Giri et al. 2014; Nandy et al. 2003). A number of studies in Sundarban delta applied remote-sensing techniques mainly for mapping purposes (Islam et al. 1997; Roy et al. 1996). Ray et al. (2013) attempted to derive vegetation density through remote sensing data using supervised enhancement technique on Ajmalmari Reserve Forest in Indian Sundarban delta. We used forest canopy model for classifying spatial patterns of canopy closure and validated the health of density with the fragmentation classes of mangrove forest of Sundarban reserve forest, India.

Study area

The Sundarban region in West Bengal covers the major portion of the districts of North and South 24 Parganas Sundarban area is located at the apex of the Bay of Bengal (21 32′–22 40′ N and 88° 03′–89 07′ E). The region is characterized by sandy beaches, mud flats, coastal dunes estuaries, creeks inlets and mangrove swamps. The total area of Sundarban of India and Bangladesh stands to be 25,000 sq km. The Indian part consists of 9630 sq km and the rest lies within Bangladesh (Bhushan 2012; Fig. 1) Mangrove forest of Indian Sundarban covers an area of about 2400 sq km, which is estimated to be 62 % of the total Indian mangrove forest (Mandal et al. 2010). The Sundarbans eco-region can be categorized into three distinct divisions—the beach/sea face, the swamp forests and the mature delta—based on the bio-geophysical attributes. The term ‘Sundarban’ was probably coined from the dominant mangrove tree ‘Sundari’ (Heritiera fomes). This eco-region is having high biological productivity and biodiversity. In most of the times, the weather remains humid. The monsoon extends from June to September with annual rainfall ranges from 2500 to 3000 mm. Maximum temperatures and minimum temperature ranges consecutively 25–35 °C and 12–24 °C. Tidal level also varies from 4 to 6.5 m seasonally and water pH from 7.2 to 7.9 (Banerjee 2002; Chakraborty 2010). Mangroves are usually divided into ‘true mangroves’ and ‘mangrove associates’. Indian Sundarban supports almost 100 floral species (including mangrove associates) representing 30 species of trees, 32 shrubs and rest are grasses, ferns and herbs (Gopal and Chauhan 2006).

The maze of rivers, estuaries and creeks carry saline water nearly 300 km inland from the Bay of Bengal. Approximately 2069 sq km area is occupied by the regions seven main tidal river systems or estuaries, which finally end up in the Bay of Bengal. The crisis deepened with two consecutive cyclones—the Sidr in 2007 and the Aila in 2009 mauling the Sundarban severely. Apart from the physical damage they caused to the trees, the cyclones also increased the salinity levels in the soil (Gopal and Chauhan 2006; Banerjee 1964; Chaudhuri and Choudhury 1994).

Database and methodology

Landsat Thematic Mapper (Landsat-TM) images of 1990 and 2011 were used for assessing the forest canopy density and forest fragmentation of Sundarban Reserve Forest. The Forest Canopy Density model considers forest canopy density as an essential parameter for characterization of forest conditions. This model involves bio-spectral phenomenon modelling and analysis utilizing data derived

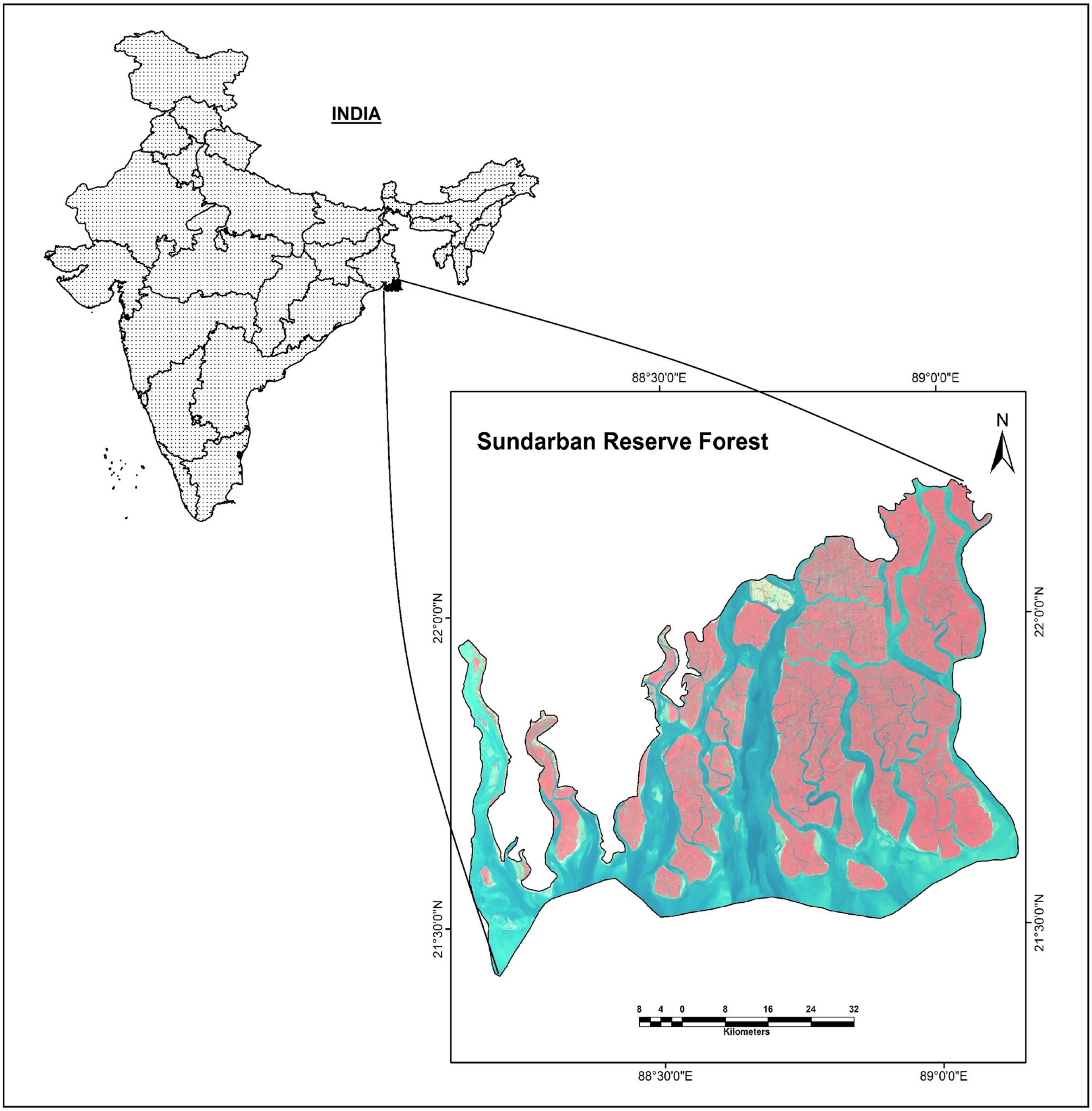

Fig. 1 Location of the study area

from four indices viz. advanced vegetation index (AVI), bare soil index (BI), shadow index or scaled shadow index (SI, SSI) and thermal index (TI). The model determines forest canopy density by these indices (Rikimaru 1996; Roy et al. 1997).

The canopy density is calculated in percentage for each pixel. Phonology of the vegetation is one of the important factors to be considered for effective stratification of the forest density (Defries et al. 1995). Generally August and November months of the year are the optimum growth period of the forest canopy and satellite images acquired in this period are considered most suitable for the assessment of forest canopy density. The detailed methodology involved in assessing health of the forest is presented in Fig. 2 and the steps followed in methodology are presented in sub sections.

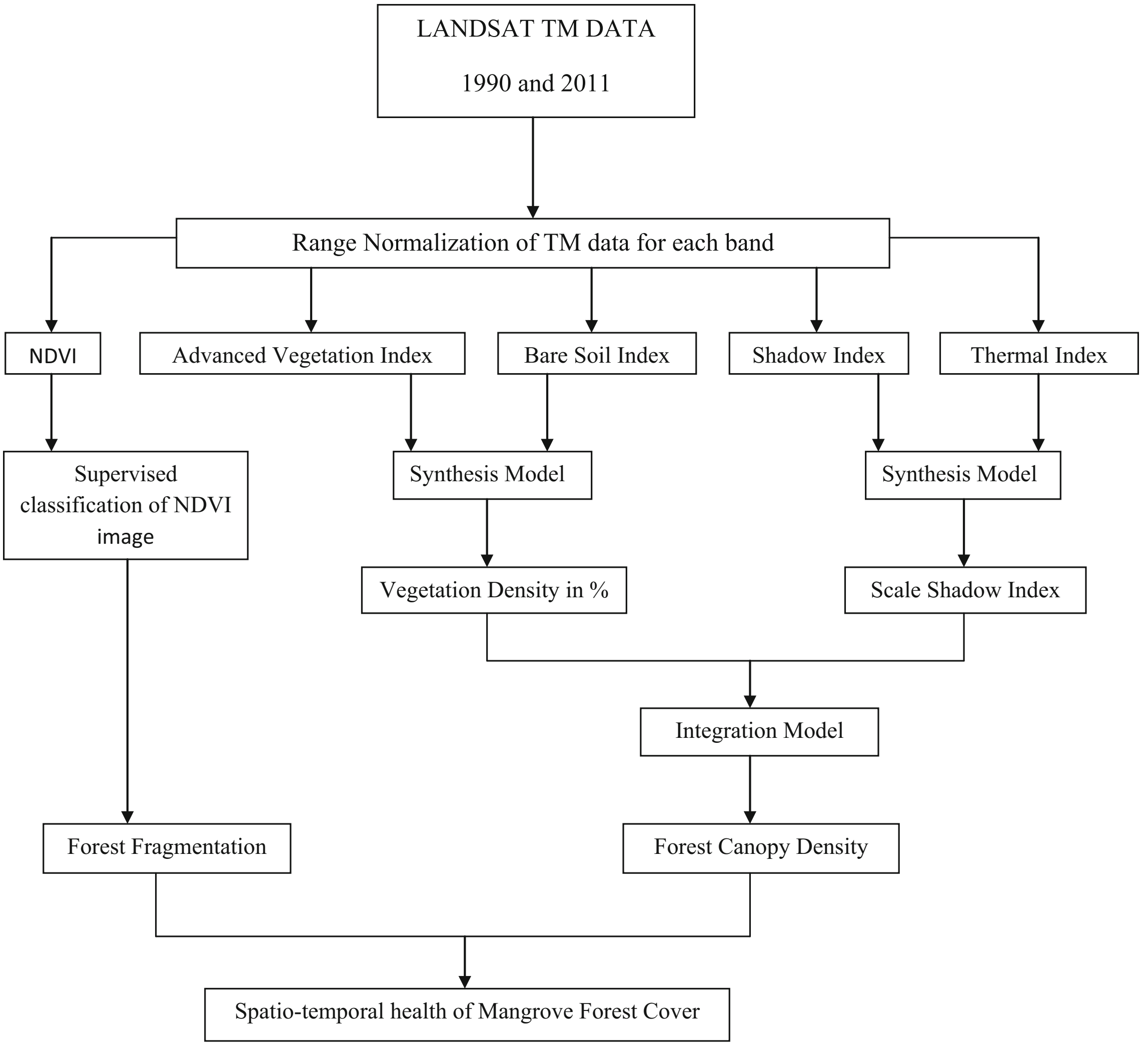

Fig. 2 Methodological framework of the study

Advanced vegetation index (AVI)

Normalized difference vegetation index (NDVI) is often used to classify vegetation and non-vegetated areas. However, subtle differences due to canopy density in the infra red and red are not highlighted in the ratio based indices. This index is also sensitive to canopy foliage activity. The subtle differences can be improved by using power degree of the infrared response (Anonymous 1993). Advanced vegetation index (AVI) has been found to be more sensitive to forest density and physiognomic vegetation classes (Roy et al. 1996). Advanced vegetation index (AVI) was calculated using Eq. 1:

$$AVI = \{(B4+1)(256-B3)(B4-B3)\}^{1/3} \quad (1)$$

AVI = 0 if B4 < B3 after normalization.

Bare soil index (BI)

Bare soil index (BI) is a normalized index of the difference of the sums of two reflective (B4 and B1) and absorption (B5 and B3) bands. This index helps in separating the vegetation with different background viz., completely bare, sparse canopy and dense canopy, etc. (Roy et al. 1996; Rikimaru and Miyatake 1997). The index can be expressed by Eq. 2:

$$BI = \frac{(B5+B3)-(B4+B1)}{(B5+B3)+(B4+B1)} * 100 + 100. \quad (2)$$

Shadow index (SI)

Kind of crown arrangement in forest stands leads to shadow pattern affecting the spectral responses. Mature forest

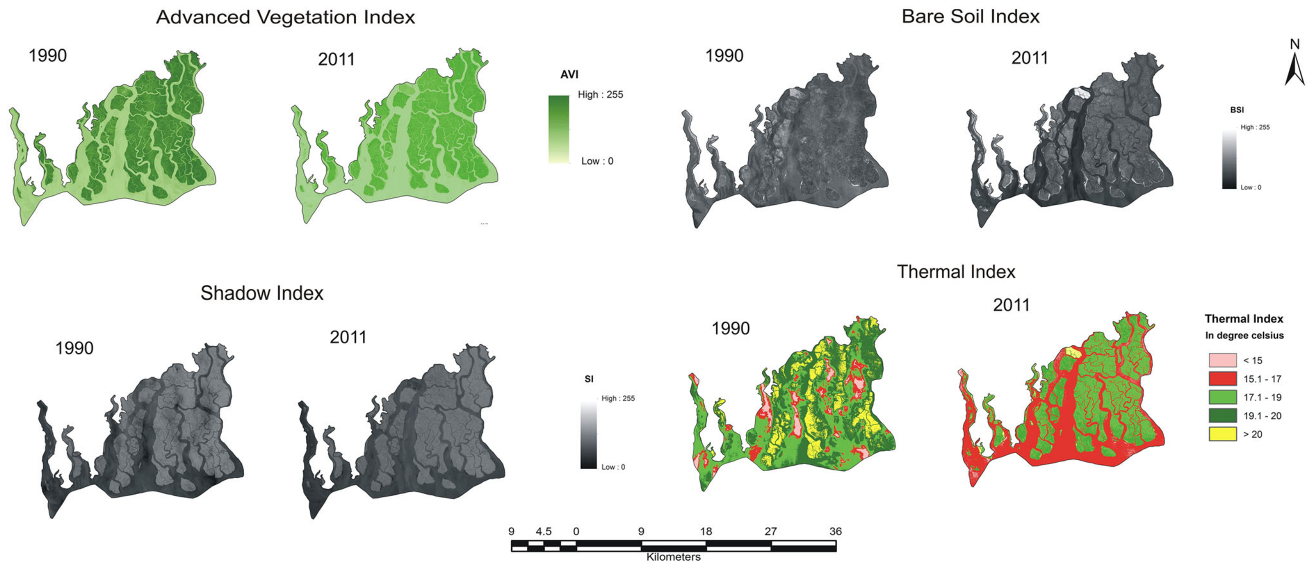

Fig. 3 Forest canopy density model indexes

stands show comparatively flat and low spectral axis in comparison to open area. Thus, young forest stands have low canopy shadow index compared to mature forest stands. The index is calculated by using Eq. 3:

$$SI = \{(256 - B1)(256 - B2)(256 - B3)\}^{1/3} \tag{3}$$

Thermal index (TI)

Spectral radiance method was used to retrieve thermal index from Landsat 5 TM data. Based on Lwin (2010) a three step process was followed to derive surface temperature. Spectral radiance was calculated using following equation:

$$L = LMIN + (LMAX - LMIN) * \frac{DN}{255} \tag{4}$$

where, $L =$ spectral radiance, $LMIN = 1.238$, $LMAX = 15.600$, $DN =$ digital number.

Spectral radiance (L) to temperature in Kelvin may be expressed as:

$$T_B = \frac{K_2}{ln\left(\frac{K_1}{L} + 1\right)}$$

where, $K_1 =$ calibration constant 1 (607.76), $K_2 =$ calibration constant 1 (1260.56), $T_B =$ surface temperature.

Scale shadow index (SSI)

It is a relative value. Its normalized value can be utilized for calculation with other parameters; The SSI was developed in order to integrate TI values and SI values. In areas where the SSI value is zero, it indicates that forests have the lowest shadow value (i.e. 0 %) while areas where the SSI value is 100, this corresponds with forests that have the highest possible shadow value (i.e. 100 %). SSI is obtained by linear transformation of SI. Vegetation in the canopy and vegetation on the ground can clearly be differentiated by SSI. It significantly improves the capability to provide more accurate result from data analysis than was possible in the past.

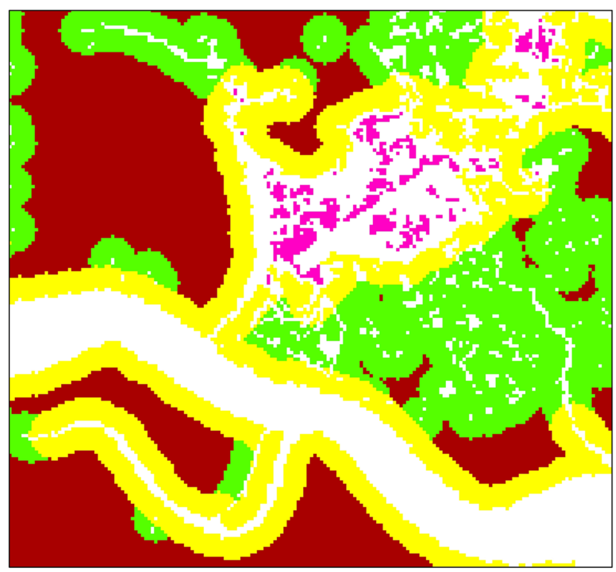

Fig. 4 Magnified view of forest fragmentation. *Brown colour* shows core forest areas, perforated forest is seen in *green*, edge forest in *yellow* and patch forest in *purple*. *White areas* non-forested land

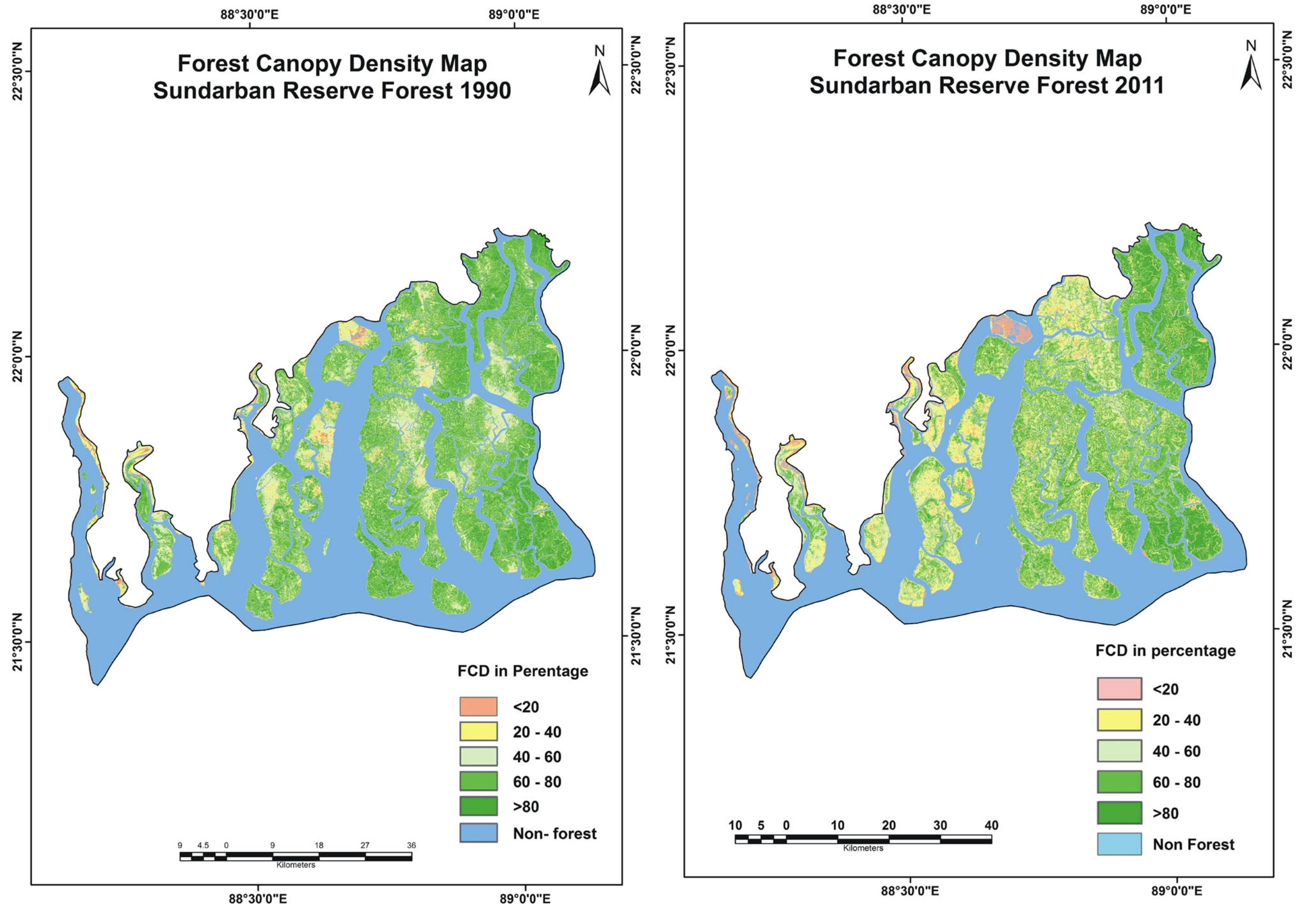

Fig. 5 Forest Canopy Density (FCD) maps of Sundarban reserve forest, 1990 and 2011

Table 1 Spatial-temporal change in forest canopy density (FCD) in Sundarban reserve forest, India

FCD classes	Area in hectares	Area in percentage	Area in hectares	Area in percentage	Change in hectares	Percentage of change
>80 %	50,002	11.51	45,599	10.49	−4402	−8.83
60–80 %	84,380	19.43	63,856	14.7	−2052	−24.35
40–60 %	59,762	13.76	5301	12.2	−6749	−11.32
20–40 %	23,965	5.52	4146	9.54	1750	72.98
<20 %	9419	2.17	18,072	4.16	8653	91.81
Non forest	206,858	47.62	212,518	48.91	5660	2.7

Vegetation density (VD)

Vegetation density was calculated using vegetation index and bare soil index as the prime inputs. These indexes were integrated using principle component analysis (PCA1). Since vegetation and bare soil have highly negative correlation scaling of zero percent point and a hundred percent point is set (Rikimaru et al. 2002).

Forest Canopy Density (FCD)

The vegetation density (VD) and SSI parameters mean transformation were integrated to estimate FCD in percentage scale unit of density. It was possible to synthesize both these indices safely by means of corresponding scales and units of each by using following equation to derive forest canopy density;

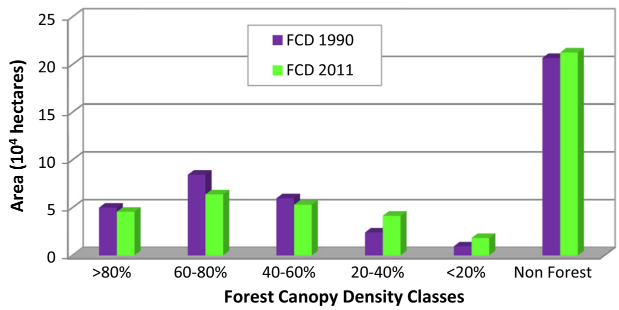

Fig. 6 Variation in forest canopy density classes (1990 and 2011)

$$FCD = (VD * SSI + 1)^{1/2} - 1 \quad (5)$$

Forest fragmentation

Fragmentation maps were generated following Vogt et al. (2007). Forested areas were classified into four main categories of increasing disturbance viz. core, perforated, edge and patch based on a key metric called edge width. We used an edge width of 200 m (Figs. 3 and 4).

Results and Discussion

Landsat TM 30 m resolution forest-non forest raster map generated through forest canopy density model (FCD) was used to compare canopy density with fragmentation approach during 1990 and 2011. Forest canopy density map was sliced into five density classes (Fig. 5). Statistics of each density classes is shown in the Table 1 and Fig. 6. Overall analysis of forest canopy density indicates that most of the forest in the study area has canopy closure of 60 to 80 % in both the study period. One of the most conspicuous changes in forest canopy density was noticed in 60–80 % density class which has gone down from 19.43 % in 1990 to 14.70 % in 2011 at the rate of 24.35 %. This change is attributed to natural degradation of forest canopy density in the southern and south eastern part of the study area. The study further indicates that >80 % density area has decreased from 11.51 % in 1990 to 10.49 % in 2011 registering a decrease of 8.83 %. This change is remarkable in the Sundarban bird sanctuary and Sundarban national park of the study area. The non forest area has a slight increase at the rate of 2.70 %. This is mainly due to

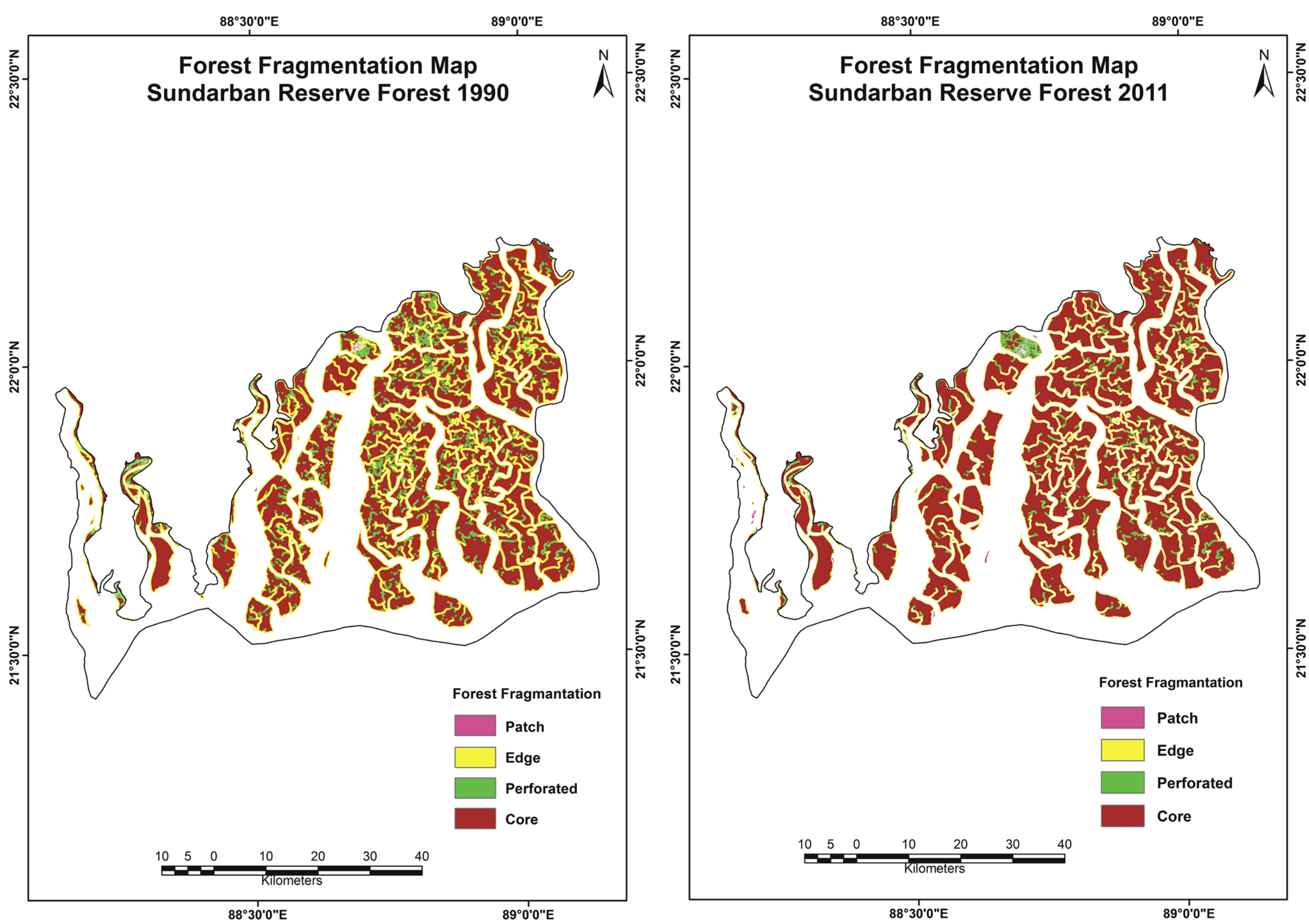

Fig. 7 Forest fragmentation maps of Sundarban reserve forest, 1990 and 2011

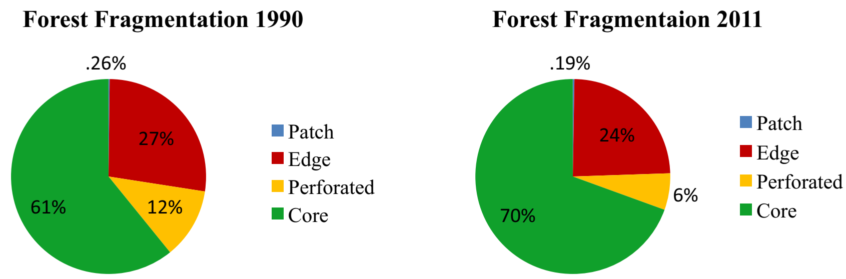

Fig. 8 Forest cover by fragmentation type, 1990 and 2011

submergence of islands in southern area of the reserve forest. Area under <20 % and 20–40 % canopy density classes has increased as a result of formation of some islands due to deposition near Ajmalmari reserve forest and Dalhousie reserve forest. Further, classes of >80, 60–80 % and 40–60 % have experienced decrease in the area. The proportion of this area slips to the next two lower classes which gained this area.

Forest fragmentation model based four classes are discussed here. Core forest pixels are outside the "edge effect," being over 200 meters in all directions from non-forested areas. Perforated pixels constitute the interior edge of small non-forested areas within a core forest and it is the next least disturbed class. Edge pixels are the exterior periphery of core forest tracts where they meet with non-forested areas. Patch pixels are small fragments of forest that are completely surrounded by non-forested areas. This is the most disturbed class of the fragmentation (Fig. 7). The total area of the forest in the study area decreased from 53 % in 1990 to 51 % in 2011 experiencing a decrease of 2.4 % (Fig. 8). This area has gone to non- forest class. However core area has increased at the rate of 14 %. The main reason of increase in core forest is natural growth of mangrove in perforated and edge forest. Some new island also emerged in the core area in Sundarban reserve forest. Fragmentation analysis revealed that the patch area has increased at the rate of 34.2 % while edge and perforated have decreased at the rate of 11 and 48 % (Fig. 9). Edge is decreasing due to erosion of island. Perforated area is mainly covered by swamp land and inner tidal cannel in the study area so decrease in perforated forest is indicative of decrease of swamp land and inner cannel. Patch pixels are surrounded by non forested areas. Increase in patch area has resulted in increase in non-forested area.

Statistics derived through fragmentation model and FCD models (Table 2) illustrate that the average density of forest canopy decreased in edge at the rate of 3.7 % followed by core (3.4 %), perforated (2.5 %) and patch (1.8 %) during 1990–2011. Core class experienced decrease in canopy density due to natural as well as anthropogenic factors. Canopy density in patch has decreased since area under non-forest has increased. Perforated class registered decrease in density due to new growth of forest in non forested areas within core forest while canopy density in edge decreased as a consequence of non-forested areas at the exterior side of the core forest (Fig. 9).

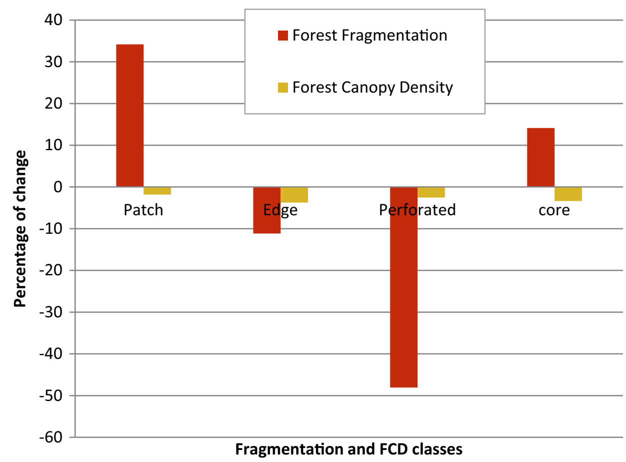

Fig. 9 Percentage change in forest canopy density and area under forest fragmentation types

Table 2 Average forest canopy density within fragmentation classes (1990–2011)

Fragmentation class	FCD 1990 (%)	FCD 2011 (%)	FCD change (%)
Patch	45.08	44.26	−1.8
Edge	67.49	64.97	−3.7
Perforated	64.22	62.59	−2.5
Core	70.48	68.10	−3.4

Conclusions

The research presented forest canopy density (FCD) and fragmentation models for stimulating their effectiveness in analyzing spatial–temporal health of the forest. Forest canopy density analysis based on integration of its four component indexes viz. average vegetation index, bare soil index, shadow index and thermal indexes revealed that the healthy forests have undergone remarkable degradation as higher classes (>80 %, 60–80 % and 40–60 %) of forest canopy density witnessed substantial loss during 1990-2011. Hydrological alteration, salinity and cutting of forest nearby built up area are peculiar reasons for hampering forest density in the study area. Low canopy density classes experienced increase in area due to formation of some islands during the reference period. Fragmentation analysis also showed the deterioration of forest health. Non-forested areas in patch and edge have increased outside the core forest while it has decreased in perforated class within the core during 1990–2011. Canopy closure decreased in all classes of fragmentation during reference period. Fragmentation model validates the results obtained through forest canopy density model. These models thus can be used as important planning tools for examining spatial forest condition and can be applied in other forest ecological system for sustainable management of forest cover.

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