15

Natural Forest Change in Hainan, China, 1991-2008 and Conservation Suggestions

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1. Introduction

Hainan Island, a tropical island located in southern China, is one of the conservation hotspots of the world (Myers et al, 2000), and represents a large proportion of China's tropical area. In the past hundred years, the natural forest has decreased dramatically in this island. The first distinct and fast decrease was during the World War II, when the Island was occupied by Japanese, a large area of forest was logged. The natural forest has decreased from 169 200 km^2 to 120 000 km^2 from the year 1933 to 1950. The second big loss was from 1950 to 1987, when log was treated as an important natural resource by the government. During this period, many large log companies were established and the forest area decreased from 120 000 km^2 to 39 120 km^2 (Lin & Zhang, 2001). From 1952 to 1990, 3950 km^2 of rubber plantation was established on the island, mainly distributed at the elevation of 0-800 m asl (li, 1995), where most of the original tropical rain forest stood. As the forest decreased, 11 of the log companies transformed from log to plantation industry starting from 1983. After 1984, the local government began to reduce the log quota and reverted to protect the forest. In 1994, the cutting of natural forest was totally banned by the government of Hainan Province (Lin & Zhang, 2001; Zhang et al., 2010). After that, eucalyptus was planted in some barren or logged areas, usually between 800-1300 m. The deforestation took place from coastal plain and mesa to inland hill and basin, and finally to mountainous area in the middle of the island. The main factors affecting the tropical forest were not the same in different phases. From Han Dynasty to 1933, it was due to aboriginal cultivation; from 1933 to 1950, it was due to plundering cutting and destroying (Lin & Zhang, 2001; Zhang et al., 2010); and then, the ultimate cause was due to fast increasing local population and changes in policy, such as crops-economy.

Although it was under the continual pressure of being logged and encroachment of plantation, the remaining large patches of forests still keep unique ecosystem in the central mountainous area of the Island. It harbors many endemic species such as Hainan gibbon (*Nomascus hainanus*), Hainan partridge (*Arborophila ardens*) and Hainan peacock pheasant (*Polyplectron katsumatae*). It is critical to identify these forest patches and the changes that have occurred for understanding the status of conservation priorities in the future.

Geographic Information System (GIS) and Remote Sensing (RS) images have proved to be effective in land cover mapping, habitat evaluation and environmental risk assessment (Osborne, 2001; Mumby and Edwards, 2002; Moufaddal, 2005). This study aims to analyze the changes in natural forest and plantations on Hainan Island between 1991-2008 by using GIS and RS and trying to explore the driving factors of changes based on local policies, and give suggestions for future conservation plan.

2. Method

2.1 Study area

Hainan Island is located between 108°36′–111°04′ E and 18°09′–20°11′ N, with an area of 33 920 km^2. The topography range in elevation is 0-1884 m asl. The island is more mountainous in the middle, and flattened in northern and coastal parts (Zhang et al., 2010; Meng et al., 2011). Annual rainfall is generally high, between 900 and 2500 mm. The rainy season is from May-October and dry season is from November-April. The vegetation shows high diversity. The vertical zonation of vegetation in the mountainous areas with high rainfall encompasses lowland rainforest below 600 m, montane and ravine rainforest from 600 to 1200 m, and evergreen broadleaf forest above 1200 m. In the dry and rigid area, the vegetation developed into seasonal forest or tropical conifer forest while on the ridge and the top of the hill, the vegetation became, evergreen or dwarf forest. There is also a small area of mangroves located by the seashore (Wang & Zhang, 2002; Zhang et al., 2010). The plantations on the island include eucalyptus (*Eucalyptus* spp.), rubber (*Hevea brasiliensis*), horsetail (*Casuarina* spp.), and fruit orchards.

2.2 Data collection

To cover the whole Hainan Island and to detect forest change, nine Landsat Thematic Mapper and Enhanced Thematic Mapper-plus (TM/ETM+) images of two time period were needed; the path/row numbers of the images were 123–124/46–47. Landsat TM images of the years 1988 and 1991 were obtained from the website of Globe Land Cover Facility (GLCF, http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp), and ETM+ images of 2004, 2007 and 2008 were obtained from the website of the U.S. Geological Survey (USGS) (http://glovis.usgs.gov/). The resolution of the images were 30 m, they were geo-referenced to a Gauss Kruger/Krasovsky coordinates with a Root Mean Square (RMS) <1 pixel. As 80% of the island was covered by 12447 images which were taken in 1991 and 2008, so we defined our study period as 1991-2008.

In order to collect ground truth data for mapping and validation, we took samples from field by stratified method called Gradsect sampling (Austin and Heyligers, 1989). We partitioned the whole island into 23 cells of 30 minutes in longitude and 20 minutes in latitude. In each cell, the sample size was determined in proportion to the number of pixels in each environmental class: if the class occupied more than 9999 pixels, we took at least 30 samples; if it occupied 1000-9999 pixels, we took at least 10 samples; if it occupied 100-999 pixels, we took at least two samples; if 40-99 pixels, we took at least one sample; if <40 pixels, no sample was collected (Fig. 1). Field surveys were implemented in 2005, one from April to May for the rainy season, and another from October to November for the dry season. The field survey spent 47 days in total. A total of 1225 ground truth samples were collected from the field surveys.

For the images taken in 2008, we randomly selected half of our ground truth samples (613) obtained from the field survey as a reference for classification, and the other half (612) were used for evaluation of the results. For the images taken in 1991, the ground truth data was acquired from 1:100,000 topographic maps produced by the State Bureau of Surveying and Mapping, Beijing, China in 1981. For example, if one area is covered by rubber on the topographic map, and it was still rubber during the field survey of 2005, the place will be defined as rubber. We also consulted local nature reserve staffs for vegetation information. A total of 1315 samples were collected for the interpretation of image in 2008, 658 of them was randomly selected for use in the classification and the rest were used to evaluate the accuracy of the resultant map.

2.3 Images classification

The images were interpreted by using the software Erdas 9.0, with a method of combing the supervised/unsupervised classification or namely guided clustering (Bauer et al., 1994; Reese et al., 2002). The procedure followed is as below:

1. Cut the cloud out of image by hand;
2. Randomly divide the classification samples into two halves;
3. Classified the remote sense images by using supervised classification (with half of the sample from result of step 2);
4. Evaluated the result of step 3 with another half sample from result of step 2, and clipped away those classes with an accuracy higher than 75%;
5. Clipped the images with different classes of samples, ran unsupervised classification on the samples, and then Class A was divided as class A1, A2, A3… An, and these sub-classes were saved as the template for step 6;
6. Used the result of step 5 to classify the images by using supervised classification, and then recombined the classes to Class A, Class B…
7. Used another half of the samples obtained from result of step 2 to evaluate the result of step 6, and then clipped away those classes with an accuracy higher than 75%;
8. Repeated steps 5-7, till the highest accuracy was obtained;
9. Mosaic the results together;
10. Used the evaluation samples to evaluate the overall accuracy.

2.4 Analysis

The change in the area of natural forest and plantations were compared by different elevations of 0-380 m, 380-760 m, 760-1140 m, 1140-1520 m and above 1520 m. The reason of change was analyzed based on local policy change history. The map of natural forest was overlapped with the nature reserves boundaries, using the software ArcGis 9.0, to detect possible conservation gaps, if any.

The resultant map included villages (including bare land and crop), urban areas, water bodies, natural forest and plantations. Here, we defined the forest as areas with a minimum of 40% canopy closure, at 2 m high or above, within 100 * 100 m^2 (0.01 km^2) squares. Those areas planted with artificial mono species were defined as plantations.

3. Result

The remote sensing images were classified to get the land cover map of 1991 and 2008; the overall accuracy of the resultant map was 81% for 1991, and 78% for 2008 (Fig. 1).

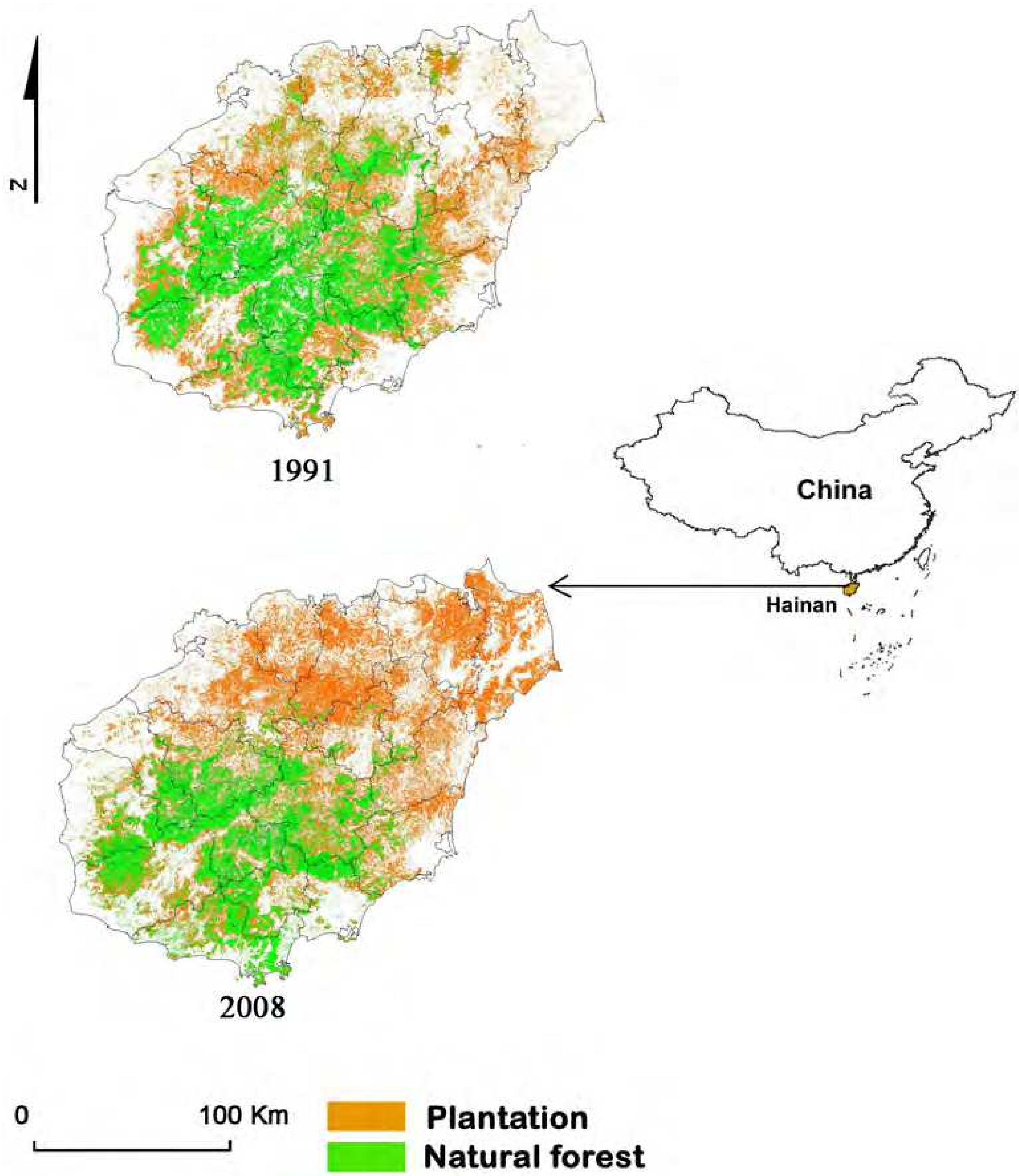

Fig. 1. Landcover map of Hainan Island, China in 1991 and 2008, interpreted from Landsat images.

Land cover type	Area in 1991 (km^2)	Area in 2008 (km^2)	Area change (km^2)	Change percentage (%)
Natural forest	7314	5852	-1462	-20
Plantation	7807	10736	2929	38
Total	**15121**	**16588**	**567**	**10**

Table 1. The area change of natural forest and plantation from 1991 to 2008 on Hainan Island, China

The area changes of forest and plantations are shown in Table 1. During the 18 years, the natural forest decreased by 20%, while plantation increased by 38%. In different elevations, the 18 years' change of land cover type showed different trends. The natural forest decreased by 1557 km^2 below elevation of 760 m, while the plantation increased by 2896 km^2. The change above 760 m was minor in comparison with the change in the lower elevation; the natural forest increased by 95 km^2, and the plantation also increased by 32 km^2 (Fig. 2).

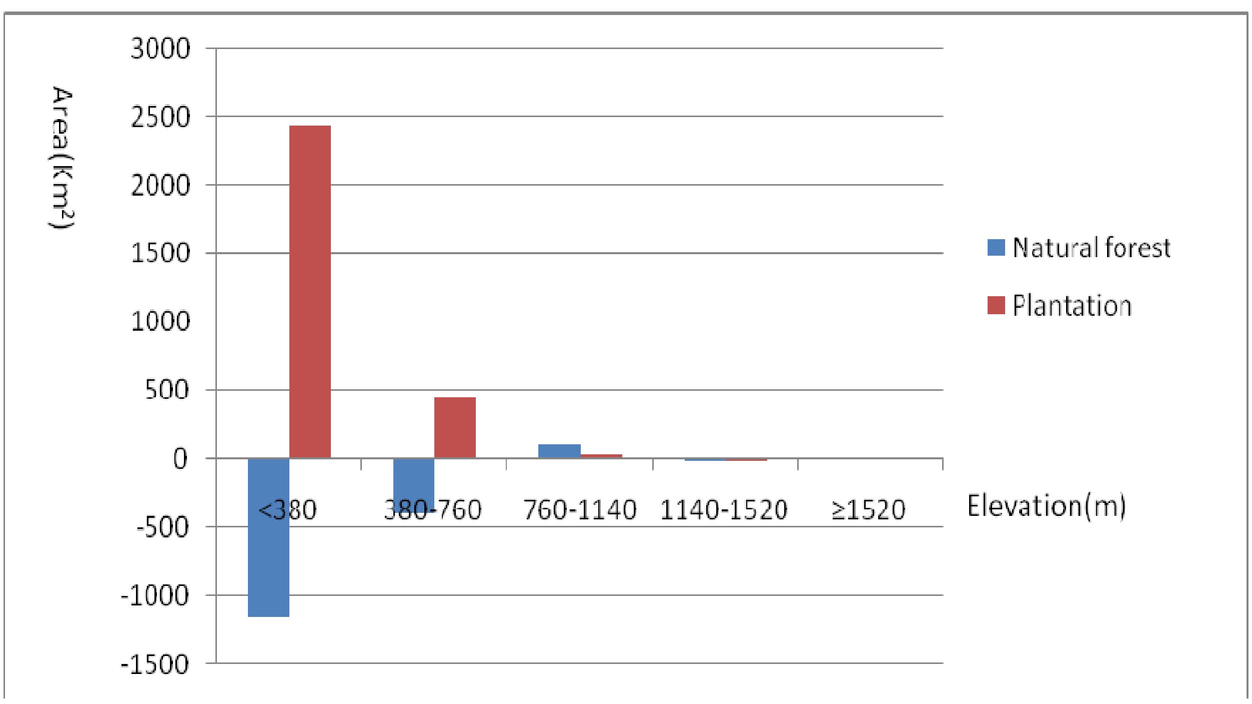

Fig. 2. Area changes of natural forest and plantation in different elevations in Hainan Island, China, 1991-2008.

The remained natural forests of the whole island were mainly distributed in the central and moutainous area, the west part of these forests were well protected due to the establishiment of several large nature reserves. But in the lower east part, the nature reserves covered only a small proportion of the forest (Fig. 3).

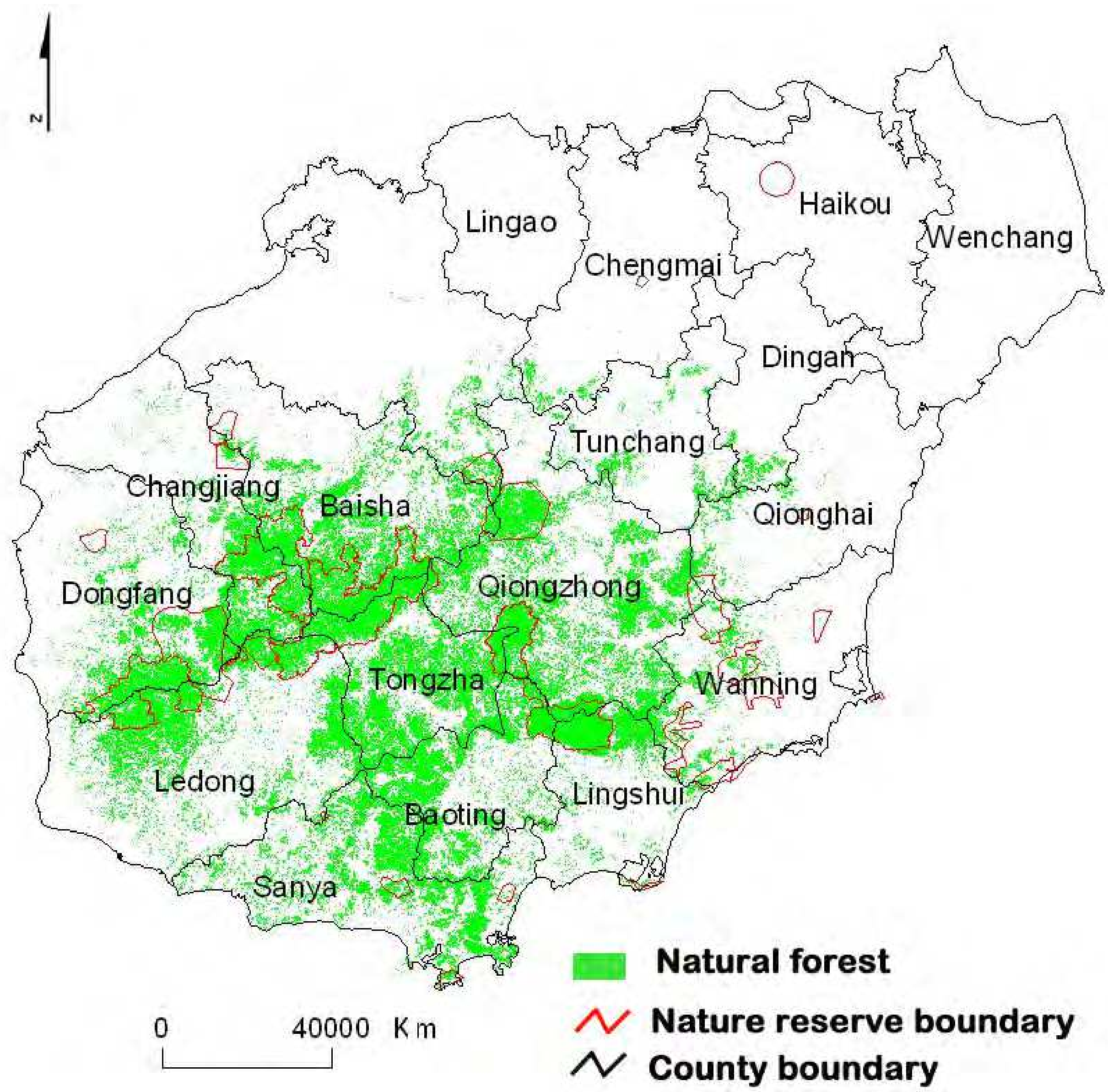

Fig. 3. The natural forest of Hainan, China in 2008 and overplayed with nature reserve boundaries.

4. Discussion

Although the natural forest of Hainan kept the trend of decreasing in the past two decades, the "green" area of the Island on the remote sense image had increased when plantations were included. The forest cover rate was used as an environment-friendly criteria in the state government's annual statistics report, in which the plantation was also defined as forest (Xue, 2011). But the eco-function of mono species plantation has been widely debated, especially if the plantation was built on the degraded land area rather than by replacing the natural forest, and if the native species were planted rather than the exotic species, they were more likely to contribute to the biodiversity (Bremer & Farley, 2010; Xue, 2011). In Hainan Island, the plantations were mainly exotic species (such as eucalyptus, rubber, oil palm and some of the fruit crops) and were cultivated after the forest was cleared. The conversion of natural forests into crop plantations, not only cause severe loss of local biodiversity, but also release considerable amounts of carbon dioxide into the atmosphere (Li et al., 2007; Cotter et al., 2009). In this study, we seperated plantations from the natural forest, and we do think the results were more appropriate for the evaluation of the ecosystem. Thus, we suggest that the plantations should be considered seperately from forest in the future goverment statistics reports, to release more accurate and useful information on the ecosystem changes for policy making.

The land cover change was largely dependant on the local policy and people's livelihood (Rao & Pant, 2001; Zhao et al., 2006). On the topographic map of Hainan Island, more than 95% of townships were distributed below the elevation of 800 m. The growth of human population led to the expansion of agricultural land. The rubber plantings was encouraged during 1970s-1980s. The rubber plantation and other crops land together had wiped out the natural forest between 0-760 m. The natural forest cover above 760 m expanded slowly (Fig. 2) because of lower human density and inappropriate condition for rubber and crops plantations. Even after the logging-ban policy of the local goverment began from 1994 (Lin & Zhang, 2001; Zhang et al., 2010), the collection of fuel or husbandary grazing in the forest could still disturb the forest. In the future, we suggest to freeze the expansion of additional plantations in the low elevation area, and begin to take procedures for low land forest recovery.

About 8.4% of Hainan Island was protected by nature reserves, the coverage was geographically biased toward its central and west mountainous areas with higher elevation, rugged terrain, and fertile soils. Nature reserve coverage was not enough to capture biodiversity features in lowlands, north and northeast plains (Wu et al., 2011). To improve the conservation system of Hainan, more nature reserves should be established in the north and northeast plains, and also the west mountainous region, such as forest patches not covered by the current nature reserve system in Sanya, Baoting, Tongzha and Ledong (Fig. 3).

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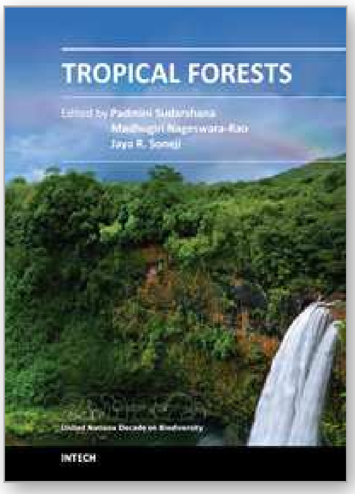

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The astounding richness and biodiversity of tropical forests is rapidly dwindling. This has severely altered the vital biogeochemical cycles of carbon, phosphorus, nitrogen etc. and has led to the change in global climate and pristine natural ecosystems. In this elegant book, we have defined "Tropical Forests" broadly, into five different themes: (1) tropical forest structure, synergy, synthesis, (2) tropical forest fragmentation, (3) impact of anthropogenic pressure, (4) Geographic Information System and remote sensing, and (5) tropical forest protection and process. The cutting-edge synthesis, detailed current reviews, several original data-rich case studies, recent experiments/experiences from leading scientists across the world are presented as unique chapters. Though, the chapters differ noticeably in the geographic focus, diverse ecosystems, time and approach, they share these five important themes and help in understanding, educating, and creating awareness on the role of "Tropical Forests" for the very survival of mankind, climate change, and the diversity of biota across the globe. This book will be of great use to the students, scientists, ecologists, population and conservation biologists, and forest managers across the globe.