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A complementary measurement of changes in China's forestry area using remote sensing data

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Abstract

Based on the official government statistics, during 1980s until 2000 China's forest cover and the forest quality has been improved steadily. Despite this is a seemingly optimistic trend, however, China's leaders have been introducing new forest policies to restrict timber harvest and increase forest cover. In light of this seemingly contradictory setting, we adopt another methodology to measure the increase or decrease of the forestry area by providing the first detailed statistics for changes in forestry area for the entire China using remote sensing data (Landsat TM/ETM digital images), and attempt to complement the official government statistics. We tracked the changes in forest cover from late 1980s through 2000 and estimated rates of forest cover changes and conversions between forestry areas and other land uses during this period. Our results reveal that during this period, the forest cover in China continued to decrease by approximately 1.15 million ha, or 0.5%. This result is in stark contrast with the official government statistics which reveal that the forestry area increased during this period. Importantly, we find that the two data sets are more consistent for provinces with large areas of forests, while the discrepancy is larger for provinces with small forest areas. We analyzed that some reasons identified may explain this discrepancy. Our results suggest that the two data sources are complementary for future monitoring of forest cover in China.

Key words: Forestry area, forest cover, open forest, closed forest, Landsat satellite images, China.

Introduction

Forests in China are resources for a multitude of environmental services, both locally and globally [1]. On a local scale, forests provide economic benefits from timber, food, fuel and medicines, and help to regulate the water cycle and form soils. On a global scale forests provide benefits for all in their ability to sequester carbon and harboring biodiversity. Forest sequestration activities help prevent global climate change by enhancing carbon storage in trees and soils, preserving existing tree and soil carbon, and by reducing greenhouse gas emissions. As there is a growing interest among China's leaders as well as the international community in utilizing forests in the portfolio of options available to address global climate change, measuring availability of forest land is more important than ever before.

To this end, the official statistics for forestry area in China shows an encouraging trend. According to State Forestry Administration's (SFA) data from the 1980s, China's forestry area is expanding and forest quality is improving. From 1990 to 2005, China's forestry area has grown from 157 million hectares to 197 million hectares, an increase by more than 25%. In terms of forest cover, China experienced an increase from 16.8% in 1990 to 20.6%. This remarkable record places China as one of the few developing countries in the world where forestry area is increasing. These statistics have been cited and analyzed in the literature in China and elsewhere.

Despite the optimistic trend, China's leaders have initiated several substantial forest policies in the past few years. Following disastrous floods in the Yangtze River Basin in 1998, the government imposed a logging ban on the majority of forests under the Natural Forest Protection Plan. China also started the Grain for Green program, which gives compensation to farmers who retire cultivated land on sloped land and instead plant tree seedlings. The program began in 1999 as a pilot set aside program and was primarily designed to set aside cropland in order to increase forest cover and prevent soil erosion on sloped cropland [2].

In response to these questions, the goal of this paper is to provide an alternative measure of forestry area for entire China using remote sensing data. To do so, this paper has four specific objectives. First, we describe the data that were used to estimate China's forest cover during the 1980s and 1990s and identify several shortcomings of the data. Next, we describe remote sensing data as an alternative source of data to estimate forest cover in China. Third, using the remote sensing data, we track the changes in China's forest cover during the 1980s and 1990s and compare them to the estimates from the traditional data sources. Lastly, we attempt to identify what the differences are and systematically explain the areas where the census and the remote sensing data are closely correlated. We conclude with a discussion on the implications of the differences between the two types of data and for what uses each type should be used.

Materials and Methods

Data: Accurate and detailed measures of change in forestry area have been difficult to obtain in China. In the past, most studies have relied on forest inventory data, which is reported by the State Forestry Administration (SFA) in every five to six years. To construct the inventory, the SFA conducts direct observations on spatially sampled plots to produce statistically valid observations at the provincial level. Each province generates its own criteria for variables such as stand age and species composition, and then the national SFA coordination teams approve all provincial criteria. Lastly, SFA then collects and publishes the survey results.

Data on non-forest land uses also suffer from these and other issues. Although some land use data are available through the annual statistical yearbooks, the quality of such data has long been questioned. Such inconsistencies should not be surprising for overall land use data given the fact that during the past three decades a number of different agencies have had responsibility for managing China's land [3]. Time series data for other land uses such as area estimates of urban land were not available before researchers started to use remote sensing data. In sum, due to data limitation for forest and non-forest land uses, it has been a challenge to accurately estimate detailed forestry land conversion, i.e., from which land use the new forest land converted and into what land use forest land converted.

Many studies in the past have applied remote sensing (RS) technology to measure forest inventory as well as to monitor and manage forests at regional levels. Coops and Culvenor [4] demonstrated that high resolution RS is an effective tool to facilitate the measuring and monitoring of spatial patterns of forest stands. Using satellite images also has been found to be a cost-effective approach to monitor forestry areas over a large area. Many countries periodically produce national reports on the status and changes of forest resources, using statistical surveys and spatial mapping of remotely sensed data [5]. The Food and Agriculture Organization (FAO) of the United Nations has conducted a Forest Resources Assessment (FRA) program every 10 year since 1980, producing statistics and analysis that give a global synopsis of forest resources in the world. For the year 2000 of the FRA program, a global forest cover map was produced to provide spatial context to the extensive survey. Pax-Lenney *et al.* [6] developed algorithms to identify conifer forests across time and space with TM images in northwest Oregon. Their results showed a strong interaction among the elements contributing to forest structure. Le Hégarat-Mascle *et al.* [7] developed a model to detect land cover change using coarse spatial scales based on iterative estimation. Patenaude *et al.* [8] provided a quantitative assessment of RS approaches for land-cover discrimination to monitor deforestation and estimate above-ground forest carbon stocks. In China, implementation of RS methods in forestry began in the early 1980s. Applications concentrated on forest mapping, inventory, fire monitoring, and quality assessment. Significant progress was made in both experimental research and practical implementation. Building on these earlier studies, the major contribution of this manuscript is to use the Landsat TM/ETM imagery for entire China, examine the changes or the succession in forestry area in China, and then compare the estimates with the enumeration-based forest inventory.

A sequence of methodology was developed by CAS to decode the land use information from the remote sensing digital images. Decoding features are divided into two classes – photometric and morphological features. The photometric features refer to the tone (black and white) or the color (spectrazonal and multispectral) of the images to identify the boundaries of vegetation and other objects. The morphological features describe the structure and canopy layer picture of stands, the size of crowns and gaps between them, the characteristics of unforested areas and landscaping features that reflect existing regularities in a location of forest objects, especially the types of site conditions and dominant species connected to landscape structures (Table 1).

The CAS land use data were classified into six primary classes: cultivated land, forestry area, grassland, water area, built-up area, and unused land. These six primary classes were further divided into 25 secondary land-use classes. Forestry area was divided into four classes: (i) natural or planted forests with canopy cover greater than 30%; (ii) land covered by trees less than 2 m high, with a canopy cover greater than 40%; (iii) land covered by trees with canopy cover between 10 to 30%; and (iv) land used for tea-gardens, orchards and nurseries.

Methodology: The interpretation of TM images and land-use classifications were validated against extensive field surveys. The research team conducted ground checks for more than 75,000 kilometers of transects across China, with more than 8,000 photos taken using cameras equipped with global position system (GPS). The average accuracy of interpretation for land use classification is 92.9% for the late 1980s, 98.4% for the mid 1990s and 97.5% for the late 1990s.

In spatial data analyses, the vector data model and the raster data model are two of the most commonly used models. In a vector data model, each location or point is recorded as a single coordinate (x, y). A line is a series of ordered coordinates. Areas are recorded as a series of coordinates defining line segments that enclose an area. The term *polygon* means a many-sided figure. Each surface is represented as a series of isolines. For example, elevation is represented as a series of contours. While the vector data model is useful for displaying information, it is an inconvenient platform for analyzing land surfaces with more than two characteristics,

Table 1. Spectral features of Landsat images used for decoding forest cover.

Category	Spectral features
Closed forests	Patch or belt pattern; board-leaf forest with bright red color; conifer forest with dark read color, even and lighter tone; clear boundary with grassland or cropland; ambiguous boundary with shrubs, but distinguished by texture (closed forests have even texture while shrubs have rough texture); shelter-belt with regular grid pattern, located in the crop fields, or along the waterways and coastlines
Shrubs	Light red color, with dispersed bright red spots for some cases because of scattered trees; rough texture; along the northern aspect (shadow effect) the texture is referenced to distinguish shrubs from grasslands (grasslands have smooth texture, while shrubs have rough texture).
Open forests	Light red color, with dispersed bright red spots; different from closed forest by its uneven and dark tone; different from grassland by its texture and tone.
Other forests	Orchard with bright red color, scattered in crop fields or around residential areas; regenerated areas of other forests with cyan or grey color, mixed with shrubs or open forests.

such as slope and elevation along with some other aspects.

As an alternative, a raster data model represents each location as a cell. The matrix of cells, organized into rows and columns, is called a grid. Each row contains a group of cells with values representing some geographic phenomenon. Cell values are numbers, indicating nominal data, such as land use types and measures of light intensity.

By combining the advantages of the vector and raster data models, we created a 1-km area percentage data model (1-km APDM), or 1-km area with different land uses model, to detect and represent the land use changes on a 1 km×1 km grid scale. This model has been widely used to analyze spatial and temporal characteristics of land use change in China [9].

Based on the prototype of the 1-km APDM, CAS developed a set of programs to generate the 1-km area percentage data. The procedure is conducted in five steps. The first is to generate land use maps during the study period at the scale of 1:100,000. This is done by operator-computer interactive interpretation in the ArcGIS software environment. The second step is to make a 1-km FISHNET vector map georeferenced to a boundary map of China at the scale of 1:10,000. The third step is to intersect the land use change map with the 1-km FISHNET vector map. This is followed by aggregating the converted areas in each 1-km grid identified by 1-km FISHNET vector cell IDs in the TABLE module of ArcGIS software environment. Finally, the area percentage vector data are transformed into grid raster data to identify the conversion direction and intensification. The procedure design and data-handling ensure no loss of area and the creation of basic data used for monitoring forest changes.

Results

Overall, by using our designed method, we found that between 1988 and 2000 China's forestry area decreased by 1.15 million ha (from 227.91 to 226.76 million ha) or by 0.5% in the national scale. Detailed speaking, however, we found that the spatial distribution of forestry area in China and its changes over time differ dramatically across provinces. China's forests are mainly distributed in the northeast, southwest, and south. These distribution patterns experienced little change from 1988 to 2000. The changes in forest cover, however, differ significantly depending on the region, showing a typical regional characteristic. The northeast, southwest, and southern coastal areas witnessed a decrease in forestry area. Meantime, forestry area increased in the north and the southeast regions. We conjecture that this increase may reflect a series of reforestation and afforestation efforts led by the government. These forests are mainly used in combating desertification, soil erosion and environmental degradation problems [10]. In addition, expansion of forest plantations in places such as Fujian has led to greater forest coverage in the southeast.

To better understand the dynamics of forestry area changes, we further estimated the conversions between forestry areas and other land uses (Table 2). We found that in total forestry area decreased by 3.43 million ha due to the conversions from forestry area to other land uses. Of the total decrease, 1.82 million ha was converted to cultivated land, 1.41 million ha to grassland, and the rest (196,000 ha) to built-up area, water area, and unused land.

At the same time, this decline in forest cover was offset by an expansion in forestry area which was converted from other land uses. In particular, 1.52 million ha of grassland and 638,000 ha of cultivated land was converted into forestry area. All together, China's forestry area decreased by 1.18 million ha due to the conversions between cultivated land and forestry areas, while the conversions between grassland and forestry areas gave forestry areas a net gain of 108,000 ha.

To reflect changes of the forestry cover, we further examined conversions among different forest categories: closed forests, shrubs, open forests and other. We found that there are existing different conversions between the four forest categories over the study period from 1988 to 2000 (Table 3). There were 965,000 hectares of closed forestry area converted to area of shrub forest, open forest, or other forest, of which about 43.7%, or 422,000 hectares were converted to shrub forest, and 23.6% and 32.6% of the lost closed forestry area was taken up by open forest and other forestry area, respectively. At the same time, about 871,000 hectares of shrub forest, open forest and other forest were converted to closed forest, of which other forestry area has the largest share of conversion. About 530,000 of other forest, or 60.8% of the total conversion area, became closed forest, with 32.8 percent coming from open forest and the rest from shrub forest. Therefore, due to the conversions between closed forest and other types of forests, the area of closed forest has shrunken by 94,000 ha.

In addition to representing forestry area changes at a 1 km grid scale (i.e., identifying the percentage of forestry areas with nearly 960 million pixels across China) we aggregated the data to the provincial level to illustrate the spatial variability of forestry areas. It can be seen that eighteen provinces experienced a loss of forestry area, while the rest fourteen provinces witnessed a gain of forestry area (Figs 1 and 2). Heilongjiang, Inner Mongolia, Liaoning, Guizhou, Sichuan and Yunnan, located in the northeast and southwest, suffered significant losses of forestry areas (at least 40,000 ha), while forestry areas in Fujian and Zhejiang expanded by over 17,000 ha. Putting it differently, we find that forestry areas of some coastal provinces (metropolitans), such as Shanghai, declined, while forestry areas in large cities with afforestation projects expanded. For example, Beijing's forestry area expanded by 1.6% during the period. The traditional forest regions, including Heilongjiang, Liaoning, Inner Mongolia, and Guizhou, experienced a large decline in the share of forestry area. On the other hand,

Table 3. Conversions between different forestry areas in the period between 1988 and 2000, 1000 ha.

Forest categories	Closed forest	Shrub	Open forest	Other forest
Closed forest	0	422	228	315
Shrub	55	0	29	38
Open forest	286	11	0	32
Other forest	530	160	66	0

Table 2. Conversions between forests and other land uses during 1988-2000 (1000 ha).

	Cultivated land	Grassland	Water area	Built-up area	Unused land	Total
Forestry area converted to:	1820	1414	54	92	50	3430
Forestry area converted from:	638	1522	33	6	85	2284
Net change of forestry area	-1182	108	-21	-86	35	-1146

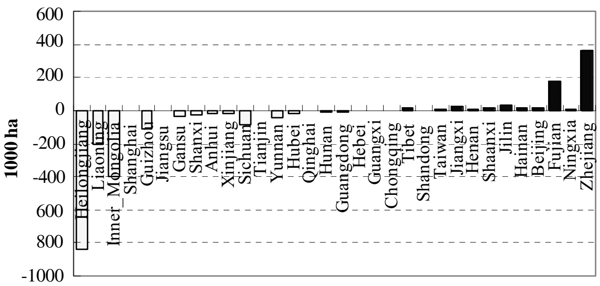

Figure 1. Changes of forestry area estimated by remote sensing by province from 1988 to 2000.

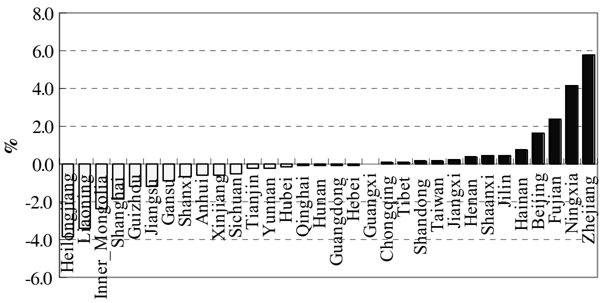

Figure 2. Percentage changes of forestry areas estimated by remote sensing by province from 1988 to 2000.

Fujian and Zhejiang gained more than 2% of forestry area due to the effects of expanding the area of economic forest.

Discussion and Conclusions

This study introduced a complementary statistics for China's forest resources based on remote sensing data and compared them to traditional statistics often used in the literature. We found that forest cover decreased in the 1980s and 1990s in the northeast, southwest, and southern coastal areas – some primary forest regions. In contrast, the north, northeast, and the southeast regions experienced an increase in forest cover, presumably due to the establishment of protective forests and forest plantations. Altogether, China's forestry area decreased by 1.15 million ha during this period. Our finding is consistent with previous studies which found that some regions in China experienced large-scale deforestation in the past several decades**.** This continued decline of forestry area by the remote sensing data contradicts with the enumeration-based statistics published by the SFA, which shows that China forestry area was increasing during this time period.

Based on our analysis, the enumeration-based forestry inventory data and the remote sensing data are more consistent in those provinces where there are large forestry areas. In fact, the absolute level and the trends are almost identical in some provinces with large forestry areas. This result is an encouraging and important result for previous studies that have been analyzing the changes in forestry areas using the traditional statistics in regions that are important for forestry, i.e., in the southwest and northeast China regions. To the contrary, the difference between our measure of forestry area and the traditional statistics are larger in provinces where there is less forestry area.

Overall, our result suggests that the two types of data sets are complementary. Which data set is more appropriate depends on the context of the research. We believe that the statistics based on remote sensing is more suitable than the enumeration-based inventory-based data when constructing large-scale statistics such as at the regional and the national scale. Remote sensing data are more time consistent (if using imageries from the same period) less prone to aggregation errors and can provide information in a shorter time frame compared to the enumeration-based forest inventory. From this perspective, we believe that the application of remote sensing technology is a necessary and important part of any large-scale, cost-effective system of forest inventory and monitoring. On the other hand, the traditional inventory complements the remote sensing data by providing field-based information, especially on the quality of the forests which is more difficult to detect using remote sensing data. Quality of forests is becoming increasingly important to understanding the changes in ecosystem services from forests such as biodiversity. Combined, improved information on forest resources will form the foundation for developing national and regional forest policies and management plans. The development of such a system is essential for the Chinese forestry to move into a more sustainable management.

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