Article

A County-level Analysis of the Spatial Distribution of Forest Resources in China

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ABSTRACT

We compared the estimates of forest areas in China from the forest census database (1989-1993) and the land cover database based on remote sensing data of the NOAA AVHRR-derived monthly NDVI composite data from April 1992 to March 1993 at 1-km resolution, and analyzed the spatial distribution of forest resources. According to the land cover database, China has a total forest area of 1.27 million km², about 3% lower than the estimate from the forest census database. Our county-level quantitative analysis of forest area and population in China characterized the scarcity and uneven spatial distributions of forest resources *per capita* in China. On the average, forest area *per capita* in China is less than one-fifth of the global average of 0.64ha. Forest area *per capita* in North, Central, and South China is substantially lower than the national average of 0.11ha, and the spatial distribution in Northeast, Central, and Southwest China is relatively uneven. This study also highlights the challenges for using forest resources to improve the ecological environment, to raise people's living standards, and to spur economic growth in China. Based on analytical results, we proposed three perspectives concerning China's forest resource management in the 21st century.

Keyword: forest resource management, land cover classification, land use/land cover, NDVI data, China

INTRODUCTION

The ecological and economic importance of forest resources in China is determined by their scarcity. Forests cover only about 13.92% of China's territory, less than half of the average world forest coverage of 34%. The forest volume *per capita* in China is only one-eighth of the global average (MINISTRY OF FORESTRY, 1996a, b, c). Forests are valued for their provision of raw materials for industry and their critical role in soil and water conservation for China's agricultural sectors.

With a severely limited amount of arable land, farmland requires the environmental services provided by forests to protect agricultural productivity (HUANG and SCOTT, 1995). In Northeastern, Southern and Southwestern forest regions, it has been estimated that the annual added value of water and soil conservation, air purification, acid rain buffering and other functions was 2-10 times the gross output value of timber, wood processing, and orchard production (KONG *et al.*, 1996). Forests also provide 40% of the fuel for rural households (MINISTRY OF FORESTRY, 1995). For this reason, RICHARDSON calls China the most forest-dependent civilization in the world (RICHARDSON, 1990). In addition to being the world's most populous country, China has a rapidly growing economy, and the combination of these two factors has increased pressure on its natural resources.

Although the voluminous writings on China's forest resources and forest land-use have stressed the national or provincial-level aggregate changes (LI, 1998; HARKNESS, 1998; ALBERS *et al.*, 1998), few studies have dealt with the county-level forest distribution. In this study, we organized four spatial data sets for China: (1) the China Land Cover Characteristics Database, which is part of the global 1-km land cover mapping effort under the guidance of the International Geosphere-Biosphere Program (LOVELAND and BELWARE, 1997); (2) the

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1:1,000,000 map of county-level administration boundaries for China; (3) the 1990 census data of population and agriculture statistics; and (4) the Chinese National Forest Resources Census data for the period 1988-1993. We examined the spatial distribution patterns of forest types, forest areas, and percentage forest cover, as well as forest area *per capita* at the county level. Our objective was to analyze forest distribution in relation to population distribution at the county level. Our study provides detailed information on the spatial characteristics of forest resources in China, and reveals important information for guiding forest resource management in the 21st century.

DESCRIPTION OF SPATIAL DATA SETS

1. China land cover characteristics database :

We used the China Land Cover Characteristics Database that was developed at the U.S. Geological Survey Earth Resources Observation Systems (EROS) Data Center in co-operation with the Chinese Academy of Surveying and Mapping (YANG *et al.*, 1997; ZHI-LIANG ZHU, personal communication). The classification of Seasonal Land Cover Regions (SLCR) was based on monthly Normalized Difference Vegetation Index (NDVI) composite data at 1-km resolution over the period of April 1992 to March 1993 from 1-km resolution National Oceanic and Atmosphere Administration (NOAA) Advanced Very High Resolution Radiometer (AVHRR). The 153 distinct spectral classes were mapped into 118 land cover classes. The first 31 land cover classes characterized various types of forests, and were integrated into five forest types based on the International Geosphere-Biosphere Programme (IGBP) Global Land Cover Classification System (RUNNING *et al.*, 1994; BELWARE and LOVELAND, 1995). Forests are identified as lands dominated by trees with a percentage canopy cover greater than 60% and height exceeding 2 meters. The five forest types are identified as follows:

- (1) Evergreen Needleleaf Forests: Dominated by needleleaf tree communities in which almost all trees remain green all year. Canopy is never without green foliage.
- (2) Evergreen Broadleaf Forests: Dominated by broadleaf tree communities in which almost all trees remain green all year. Canopy is never without green foliage.
- (3) Deciduous Needleleaf Forest: Consist of seasonal needleleaf tree communities with an annual cycle of leaf-on and leaf-off periods.
- (4) Deciduous Broadleaf Forests: Consist of seasonal broadleaf tree communities with an annual cycle of leaf-on and leaf-off periods.
- (5) Mixed Forests: Consist of tree communities with interspersed mixtures or mosaics of the other four forest cover types. None of the forest types exceeds 60% of landscape.

The SLCR database also includes a category of

cropland/natural vegetation mosaic (e.g. tea, rubber, bamboo, eucalyptus and oil palm), representing lands with a mosaic of croplands, forests, shrublands, and grasslands in which no single component comprises more than 60% of the landscape. We excluded this category from our analysis, because we can not quantify the proportions of forest and other vegetation types within a 1-km resolution gridcell.

2. The 1:1,000,000 scale map of administrative boundaries of China :

We used the 1:1,000,000 scale maps of administrative boundaries of China for our geographical analysis, which represents China's national provincial, regional and county administrative boundaries as of 31 December 1990 (CIESIN, 1998). The ARC/INFO (v.7.1.1) GIS package was used in data analysis. The original digital map is in the Lambert conformal conic projection. As the above SLCR database used the Lambert Azimuth projection, we re-projected the county boundary coverage from the Lambert conformal conic projection to the Lambert Azimuth projection. We then gridded the polygon county coverage into meshes at 1-km resolution. We overlaid the gridded county boundary map onto the SLCR land cover map and counted pixels for each land cover class within each county boundary. Thus, a county-SLCR matrix was obtained. According to the National Economic Atlas of China, at the end of 1990, China had 2,833 county-level units (IGCAS, 1994).

3. The population census data for 1990 :

We used the population census and agricultural statistics database of China for 1990 (PCAC90, CIESIN, 1998). This database reported variables for only 2,438 county-level units in mainland China, since some units with small area were merged in the process of gridding (CIESIN, 1998). However, the above administrative boundary map (CIESIN 1998) has 2,875 polygons representing 2,439 county-level units in mainland China. Although the number of counties in the PCAS90 and the SLCR databases differed in number by only one (2,438 versus 2,439), in reality there are much more profound differences. We reviewed the units in each database and generated a consistent set of 2,375 county-level administrative units to use in subsequent analysis. However, we calculated the forest area *per capita* only for 2,366 counties because there are still 9 counties short of corresponding population data.

4. The forestry census database at provincial-level :

We used the Chinese National Forest Resource Census data set for the period of 1989-1993 (MINISTRY OF FORESTRY, 1996b; NFRC93). The forest area estimates in the NFRC93 were inferred statistically from the fourth Continuous Forest Inventory (CFI) through repeatedly measuring the permanent plots using ground inventories and remote sensing techniques. These permanent plots cover almost all land types (except deserts and grasslands) in mainland China at a 4 or 8-km

resolution grid and are normally re-measured every five years. The Chinese Ministry of Forestry published the NFRC93 data at the provincial level, and we used this provincial level NFRC93 data in this study to compare with forest areas derived from the SLCR database.

RESULTS

A Comparison of Provincial Level Forest Area Estimates from the NFRC93 and the SLCR Data Sets

We first compared the total forestland areas from the SLCR and the NFRC93 by using the provincial level values of both. Fig. 1 shows that the forest area estimates from the SLCR are highly correlated with those from the NFRC93 at provincial level ($r^2=0.76$). The total forest area estimate from the SLCR is about 3% lower than that from the NFRC93. However, at the provincial level, total forest areas from the SLCR are greater than the NFRC93 in 10 provincial units mainly in Northeast, Southwest, and Northwest China, while in the other 20 provinces almost all located in North, Central, and South China, total forest areas from the NFRC93 are larger than the SLCR data set (Table 1). In particular, there are remarkable differences between the two databases for Tianjin, Shandong, Henan, Shanghai, Jiangsu, Guizhou and Qinghai, but discussing those problems related to the accuracy of the two databases is beyond the scope of this paper. Consequently, all results in the subsequent sections are based on the forestland area from the China Land Cover Characteristics Database.

National-scale Analysis of Forest Areas and Population

For national scale analysis we considered the 2,375 counties in China and five forest types derived from the SLCR database. According to the SLCR database, China has approximately 1.27 million km² of forests (Table 2). The percentage forest cover for China is about 13.48%, which is 0.44% lower than the NFRC93 statistical results. Of the 13.48% forest coverage in China, the fractions of evergreen needleleaf forests, evergreen broadleaf forests, deciduous needleleaf forests, deciduous broadleaf forests, and mixed forests are 3.08%, 0.64%, 1.15%, 2.04% and 6.58% of total land area, respectively.

About 43% of 2,375 counties have a percentage forest cover lower than 1% over the total land area of the county (Fig. 2). Almost all (95%) of these counties are located in North, Central, Southwest and Northwest China. Moreover, about 69% of 2,375 counties have a percentage forest cover lower than the national average of 13.48%. Of 2,375 counties in China, only 400 counties have a percentage forest cover higher than the world-averaged forest coverage of 34% (Ministry of Forestry 1996c; also see Fig. 2), and 76% of these counties are located in Northeast, Central and Southwest China (Table 2). The skewed distribution in Fig. 2 illustrates the low forest coverage and uneven spatial distribution of forest resources in China.

We also calculated forest area *per capita* at the national scale, using the county-level SLCR area estimates and the 1990 China's county-level population census data (CIESIN, 1998). The forest area *per capita* in China is approximately 0.11

Fig. 1 The SLCR versus NFRC93 estimates of provincial-level forestland area (km²) in 30 mainland provinces.

The SLCR area is based on the aggregate pixels classified as forestland in all provinces, while the NFRC93 area is a total of all forestland area. The correlation between natural logarithms of forestland area estimates from SLCR and NFRC93 is $r^2=0.76$.

Table 1 Forestland areas(km²) in China by provinces from National Forest Resource Census(89-93) (NFRC93) and from 1992-1993 NOVA AVHRR spectrums(SCLR)

Province & region	Forestland area		Forest coverage		Forestland area <i>per capita</i>
	NFRC93	SCLR	NFRC93	SCLR	
Total China	1,317,330	1,274,283	13.77	13.48	0.11
<i>Noth China</i>	74,850	44,889	10.83	6.49	0.02
Beijing	2,671	4,801	14.99	28.91	0.04
Tianjin	858	67	7.47	0.57	0.00
Hebei	24,806	21,323	13.35	11.37	0.03
Shanxi	12,700	12,800	8.11	8.17	0.04
Shandong	16,288	193	10.7	0.13	0.00
Henan	17,527	5,705	10.5	3.45	0.01
<i>Northeast China</i>	264,275	323,094	33.49	41.02	0.33
Liaoning	39,186	16,584	26.89	11.37	0.04
Jilin	63,469	68,598	33.6	35.93	0.28
Heilongjiang	161,620	237,912	35.55	52.75	0.68
<i>Cnetral China</i>	246,878	227,146	27.04	24.81	0.07
Shanghai	147	2	2.47	0.03	0.00
Jiangsu	4,122	1,224	4.02	1.21	0.00
Zhejiang	43,759	65,375	42.99	64.07	0.16
Anhui	22,561	31,035	16.33	22.13	0.06
Jiangxi	67,277	62,259	40.35	37.14	0.17
Hubei	39,522	21,341	21.26	11.47	0.04
Hunan	69,490	45,910	32.8	21.66	0.08
<i>South China</i>	197,795	105,940	34.63	18.59	0.07
Fujian	61,484	33,737	50.6	27.72	0.11
Guangdong	65,431	23,125	36.78	13.03	0.04
Guangxi	60,217	32,495	25.34	13.75	0.08
Hainan	10,663	16,583	31.27	48.2	0.27
<i>Southwest China</i>	235,388	264,762	20.92	23.48	0.15
Sichun	115,318	60,152	20.37	10.61	0.06
Guizhou	26,028	7,202	14.75	4.09	0.02
Yunnan	94,042	197,408	24.58	51.37	0.53
<i>Northwest China</i>	298,144	310,337	6.9	7.36	0.30
Inner Mongolia	140,657	189,603	12.14	16.52	0.88
Tibet	71,689	55,246	5.84	4.59	2.52
Shaanxi	49,735	37,972	24.15	18.44	0.11
Gansu	19,486	9,875	4.33	2.44	0.03
Qinghai	2,501	262	0.35	0.04	0.00
Ningxia	1,020	375	1.54	0.73	0.01
Xinjiang	13,056	17,004	0.79	1.04	0.11

*Note: NFRC93= National Forest Resource Census (1989-1993)

SCLR= Seasonal Land Cover Regions(1992-1993)

hectare (ha) (Table 2). Approximately 74% of the 2,366 counties with population census data in 1990 have a forest area *per capita* less than the national average of 0.11 ha (Fig. 3). Only 195 counties in China have forest area *per capita* exceeding the world average of 0.64 ha (Ministry of Forestry, 1996c; also see Fig. 3). At the provincial level, the forest area *per capita* in 19 provinces was less than 0.11 ha. Tibet has the highest value of 2.52 ha *per capita* of all 30 provinces because of its low population density.

Regional-scale Analysis of Forest Areas and Population

The 30 provincial units in mainland China are often grouped into 6 administrative regions with different natural, social and economic conditions: North, Northeast, Central, South, Southwest, and Northwest China (Table 1). In this section we assessed the forest areas, percentage forest cover by vegetation type, and frequency distribution of counties by percentage forest cover and forest area *per capita* for each of

Table 2 China's county-level distribution of forestland areas (km²) by region derived from 1992-1993 AVHRR spectrums (SLCR)

Region	Item	Total China	North	Northeast	Central	South	Southwest	Northwest
Forestland Area	Number of Provinces	30	6	3	7	4	3	7
	Population	1,130,042,716	279,372,746	98,359,989	330,364,354	141,679,731	176,581,948	103,683,948
	NCFR93	1,317,330	74,850	264,275	246,878	197,795	235,388	298,144
	SLCR	1,274,283	44,889	323,094	227,146	105,940	264,762	310,337
SLCR forestland area by forest type	Evergreen needleleaf forests	290,957	12,052	12,584	113,625	68,527	52,442	31,727
	Evergreen broadleaf forests	60,837	634	1,219	522	8,442	36,109	13,911
	Deciduous needleleaf forests	109,110	195	74,940	84	0	495	33,396
	Deciduous broadleaf forests	192,556	29,548	112,355	5,024	1,177	5,214	39,238
	Mixed forests	622,008	2,460	121,296	107,891	27,794	170,502	192,065
SLCR forest coverage by forest type	Average	13.48	6.49	41.02	24.81	18.59	23.48	5.79
	Evergreen needleleaf forests	3.08	1.74	1.60	12.41	12.02	4.65	0.59
	Evergreen broadleaf forests	0.64	0.09	0.13	0.06	1.48	3.20	0.26
	Deciduous needleleaf forests	1.15	0.03	9.51	0.01	0.00	0.04	0.62
	Deciduous broadleaf forests	2.04	4.27	14.38	0.55	0.21	0.46	0.73
	Mixed forests	6.58	0.36	15.40	11.79	4.88	15.12	3.58
	Total number of counties	2,375	510	184	516	273	399	493
Frequency of county by forest coverage	Under 1.0%	1,025	372	51	135	7	130	330
	1.1-7.0%	355	61	31	67	39	100	57
	7.1-14.0%	248	30	17	58	74	37	32
	14.1-34.0%	347	33	19	112	110	38	35
	Over 34.0%	400	14	66	144	43	94	39
Frequency of county by area <i>per capita</i>	Regional average	0.11	0.02	0.33	0.07	0.07	0.15	0.30
	Total number of counties	2,366	510	184	516	271	399	486
	Under 0.01 ha	1,026	383	54	162	14	141	272
	0.01-0.11 ha	723	83	51	190	184	104	111
	0.12-0.61 ha	415	40	32	147	69	67	60
	Over 0.61 ha	202	4	47	17	4	87	43

*Note: 7.0%, 14.0% and 34.0% represent the half of national average, the national average and the world average of forest coverage, respectively
0.11 ha and 0.61 ha are the national average and the world average of forestland area *per capita*, respectively

Fig. 2 National frequency distribution by county based on the county-level forest coverage estimated from the SLCR database

Fig. 3 Frequency distribution of forestland area *per capita* based on the county-level areas estimated from the SLCR database and China's population census data

the six regions (Table 2). This highlights the geographical differences in spatial distributions of forests and population across the six regions in China.

1. North China :

North China covers six provincial units (Beijing, Tianjin, Hebei, Shanxi, Shandong and Henan) and 510 counties, with a total land area of 691,774 km² (7.3% of China's territory). On the average, there is a 6.5% percentage forest cover in North China. Total forest area in North China accounts for 3.5% of China's total forest area. Deciduous broadleaf and evergreen needleleaf plantations are the dominant forest types in this region. Approximately 73% of 510 counties in North China have less than 1% forest cover (North in Fig.4). Only 15% of 510 counties have a forest cover greater than the national average. Only 3% of these counties have a forest cover exceeding the global average of 34%. The skewed frequency distribution of counties, as shown in Fig. 4, shows a very scarce

and uneven distribution of forest resources in North China.

On the average, forest area *per capita* in North China is less than one-fifth of the national average of 0.11 ha, and is the lowest of all the regions in China (Table 2). Because of the low forest cover and high population density in North China, over 90% of 510 counties have a forestland area *per capita* lower than the national average, and only 4 counties have a forest area *per capita* exceeding the global average of 0.64 ha (North in Fig. 5).

2. Northeast China :

Northeast China includes Liaoning, Jilin and Heilongjiang provinces with 184 counties. Total land area in this region is 787,722 km². Forests are mostly deciduous broadleaf and mixed natural forests, and this region has the nation's highest percentage forest cover at 41%. Although the land area accounts for just 8.3% of China's territory, Northeast China has about 25% of China's forest area. 46% of 184 counties have abundant forest resources with a forest coverage higher than the national average of 13.48%, and nearly 36% of all counties have a forest coverage exceeding the world average of 34%. The frequency distribution of counties in Northeast China shows, while having the highest mean, the distribution is the most uneven of the six regions (Northeast in Fig. 4).

As one of the most important bases for timber production, Northeast China also has the highest forestland area *per capita*, about three times the national average (Table 2). Of 184 counties, there are 79 counties with a forestland area *per capita* higher than the national average (Northeast in Fig. 5). In particular, forestland area *per capita* in Xunhe, Mohe and Huma counties located in Heilongjiang province is as high as 16.87 ha, 19.55 ha and 67.15 ha, respectively.

3. Central China :

Central China comprises seven provinces (Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei and Hunan) and 516 counties. Central China has a total land area of 915,427 km², which is 9.7% of China's territory. Forestland in Central China contributes 17.8% of China's forest area, and covers 24.8% of regional land area. Main forest types in this region include evergreen needleleaf and mixed forests accounting for nearly 98% of regional forest area. 26% of the 516 counties have a forest coverage less than 1%, and about 50% of the 516 counties have a forest coverage lower than the national average of 13.48%. At the same time, 22% of 516 counties have adequate forest with a forest coverage exceeding the world average of 34% (Central in Fig. 4). These results indicate the forestland distribution at county-level in Central China is relatively uneven.

Although the percentage forest cover in this region is the second highest in China, forestland area *per capita* is only 0.07 ha due to a high population level. There are 164 counties with a forestland area *per capita* higher than the national average of 0.11 ha, but forestland area *per capita* in almost all counties is

Fig. 4 Regional frequency distribution of forest coverage based on the county-level areas estimated from the SLCR database

Fig. 5 Regional frequency distribution of forestland area *per capita* based on the county-level areas estimated from the SLCR and China's population census data

lower than the world average (Central in Fig. 5).

4. South China :

South China has four provinces (Fujian, Guangdong, Guangxi and Hainan) with 273 counties. This region has a total

land area of 569,926 km², 6% of China's territory. South China possesses 8.3% of China's forest, and, on the average, has a percentage forest cover of 18.6%. Major forest types include evergreen needleleaf and mixed forests. Approximately 56% of the 273 counties have a percentage forest cover higher than

14%, and only 3% of the 273 counties have a forest coverage lower than 1% (South in Fig. 4). From Fig. 4, we also found the frequency distribution by county is less skewed than other regions.

There are two islands in Zhejiang lacking the population census data, so we calculated forestland area *per capita* for the 271 counties in South China. The frequency distribution of forestland area *per capita* in South China is very similar to that in Central China (South in Fig. 5). One significant difference between South and Central China, however, is that approximately 95% of the 271 counties in South China have a forestland area *per capita* higher than 0.01ha. There are only 4 counties with a forestland area *per capita* exceeding the global average (Fig. 5).

5. Southwest China :

Southwest China has three provinces (Sichun, Guizhou and Yunnan) with 399 counties, and has a total land area of 1,125,194 km², which is 11.9% of China's territory. Forestland in Southwest China covers 23.5% of its territory and accounts for 20.8% of China's forestland. The dominant vegetation types include evergreen needleleaf and mixed forests. 33% of the 399 counties only have a forest coverage of less than 1%, while 24% of the 399 counties holds a percentage forest cover higher than the world average (Southwest in Fig. 4). Based on the frequency distribution by county in Fig. 4, it was clear that only a small proportion of 399 counties in this region have a percentage forest cover around the average value. That means forest distribution in Southwest China displays a clearly uneven pattern.

Forest coverage in Southwest China is slightly lower than in Central China, but forestland area *per capita* in Southwest China is more than double that in Central China, and 0.04ha higher than the national average. This is because the population density in Southwest is lower than that in Central China. Furthermore, there are as many as 83 counties with a forestland area *per capita* higher than the global average (Southwest in Fig. 5).

6. Northwest China :

Northwest China contains seven provinces (Inner Mongolia, Tibet, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang) with 493 counties. Northwest China has a total land area of 4,319,061km², about 44.6% of China's territory. Forests cover 5.8% of its land area, and account for 24.2% of China's forestland. Mixed forests, which occupy 62% of the total forest area, are the dominant forest types in this region. Approximately 67% of the 493 counties have a percentage forest cover lower than 1%. Only 15% of 493 counties have a percentage forest cover equal to or higher than the national average (Northwest in Fig. 4). Basically, the pattern of frequency distribution by county in Northwest China was very similar to that in North China.

In Northwest China, since there is 1 county in Qinghai

and 6 counties in Tibet without population data, we calculated forestland area *per capita* for 486 counties. Nearly 56% of the 486 counties have a forestland area *per capita* lower than 0.01 ha, but forest area *per capita* on the average is as high as 0.30 ha, which ranks second highest among the six regions. Because of sparse population in Inner Mongolia and Tibet, the forestland area *per capita* in several counties is as high as 253 ha (Northwest in Fig. 5). There are 103 counties with a forestland area *per capita* higher than the national average.

DISCUSSION AND SUMMARY

Analytical results on China's forest area estimates from the SLCR at county level have revealed the characteristics of China's forest resources at national and regional scales. According to the SLCR database, there is about 1.27 million km² of forestland area in mainland China, representing a forest coverage of 13.48% of the total land area. The forest coverage in Northeast, Central, South, and Southwest China is above the national average, but less than 6.5% of land area in North and Northwest China is covered by forestland. Of 2,375 counties, there are 1,025 counties with a percentage forest cover less than 1%, and 68% of these counties are located in North and Northwest China. North and Northwest China possesses 52% of China's territory, but only 28% of China's forestland area. Moreover, there are only 400 mainland counties with a percentage forest cover exceeding the world average of 34%. This result implies China has a low percentage forest cover compared with most countries, and the spatial distribution of forest resources is a very uneven at the regional scale.

Although China's forest resources have increased in area as well as stocking volume because of increased plantation establishment and control of timber harvesting in past decades, there are still serious problems with the existing forest resources related to the low forest coverage, uneven distribution, and dramatic decline in natural forest at a county-level. These problems with forest resources have constrained China's capacity for timber production, biodiversity conservation, and environmental services. However, the ecological and economic demands on forest resources have been increasing through growth of economy and population, improvement of living standards, and raising of environmental awareness. Despite significant progress in China's forestry, there is still a big gap between China and most other countries with regard to forestland area, quality of forest resources, and forest productivity. In particular, because the population in forest regions has increased fivefold over the past 50 years, the natural forest has declined to 30% of the total forest area in China (ZHANG *et al.*, 1999).

From the analytical results on forest area *per capita*, we have concluded that China's forest area *per capita* is only one-fifth of the global average, and 43% of all counties are lower than 0.01ha. In the intensively agricultural regions of North, Central, and South China, forest area *per capita* is much lower

than the national average because of the concentration of population and the lack of abundant forest resources. Approximately 66% of Chinese live in the above three regions, but only 30% of China's forestland area is found there. Although the percentage forest cover in Northwest is the lowest in China, the region's forest area *per capita* is the second highest, as high as 0.30ha.

On the other hand, there are about 263.3 million ha of land area for forestry in China, but forest occupies only 60.4% of total land area for forestry (STATE FORESTRY ADMINISTRATION, 2000). At the same time, China still has 46.9 million ha of land suitable for afforestation need to be afforested. The land suitable for afforestation almost equals to China's existing plantation area 46.7 million ha.

Regional scale analysis on county-level forest distribution can provide an important practical reference for China's future afforestation. Analysis at this scale provided a helpful perspective for China's forest resource management in the 21st century. First of all, enlarging the forest area is the most important task in North and Northwest China because of low forest coverage in these two regions. Of 1,003 counties in North and Northwest China, there are 702 counties with percentage forest cover less than 1%, and only 53 counties with percentage forest cover higher than the world average. At the same time, the composition of forest types and tree species should be regulated to improve the ecological and economic functions of forest resources in North China. Secondly, forest resource management in Central, South and Southwest China should be concentrated on increasing forestland area, raising the quality of forest resources, and improving the composition of forest types and tree species. The average percentage forest cover in these regions is higher than the national average, but there are still 272 counties with percentage forest cover less than 1%. Hence, it is crucial to utilize the large amount of land suitable for afforestation comprehensively. On the other hand, if monoculture forests replace natural mixed forest and naturally regenerated forest, biodiversity and perhaps other environmental services in Central and South China will be reduced. It is necessary to plant mixed forest and to conserve natural and secondary forests in these regions. Thirdly, the conclusion based on regional scale analyses suggests the function of timber supply in Northeast China should be enhanced to ease the timber supply shortage in China, by raising the productivity of forest.

Although China's forestland areas derived from the SLCR and from the NFRC93 are not completely consistent at the regional scale, county-level analysis of the distribution of forest resources using forest areas from the SLCR reveals the regional characteristics of China's forest resources. The discrepancies between the SLCR and NFRC93 forest area estimates can be explained by three main reasons. First, forest area in the NFRC93 is defined as land covered by trees with a percent canopy cover greater than 30%, while the five forest types in IGBP are the land dominated by trees with a

percentage canopy cover greater than 60%. This factor may make the NFRC93 report greater forest areas in some provinces, compared to the SLCR. Secondly, the inherent inadequacy in spatial resolution of remote sensing data may also influence the accuracy of land cover classification, resulting in overestimation in some areas but underestimation in other areas. If a pixel is classified as forest, we allocate the entire area (1 km²) of that pixel to forest, with no land area for infrastructure (e.g. road, buildings, and idle land) or other land covers. In reality, the amount of non-forest area in each pixel assigned to forest may vary from 10-40%. For instance, in the forest districts of Heilongjiang, Yunnan and Inner Mongolia, small scale cropland surrounded by large scale forests would be classified as 100% forest, and this may cause overestimated forest areas in those provinces. Inversely, the forest in North and South China mixed with croplands might be identified as cropland or cropland/forest mosaic, and this problem probably results in the underestimation of forest areas in these regions. Thirdly, although approximately 1.07 million km² of the cropland/natural vegetation mosaic are distributed over mainland China, the quantitative proportions of forest and other vegetation types can not be easily determined within a 1-km resolution pixel.

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