

Impacts of Afforestation, Deforestation, and Reforestation on Forest Cover in China from 1949 to 2003

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ABSTRACT

China's forest cover increased from 8.6% in 1949 to 18.21% in 2003. The change of forest cover in China can be characterized in three stages: (1) transition stage (1949–1981), (2) slow increase stage (1982–1993), and (3) rapid increase stage (1994–2003). Afforestation is the primary factor increasing forest cover in China. Cumulative areas of afforestation in China from 1949 to 2003 were 241 million ha, of which 90 million ha eventually established as plantation forests, i.e., about 37% of the afforested area reach forest status. Harvesting consumed 13 billion m³ in timber volume from 1949 to 2003. Natural forests were the major source of timber production during the early years, and plantation forests became a major source of timber supply as they matured. Of the 90 million ha plantation forests, 53 million ha remained in 2003, the rest were harvested. The remaining plantations in 2003 contributed 5.0 of the 6.4 percentage points of increase in China's overall forest cover from 1949 to 2003. Large areas of afforestation, intensive timber harvesting, and reforestation have made forest ecosystems in China become dominated by young stands, which has profound implications in their ecological functions in the terrestrial ecosystems.

Keywords: afforestation, deforestation, reforestation, forest cover

Forests play a critical role in the global terrestrial ecosystems, including, but not limited to, providing a temporary carbon sink in the global carbon cycle (Wofsy et al. 1993, Dixon et al. 1994, Goodale et al. 2002), preservation of biodiversity (Dobson et al. 1997), and conservation of soil and water resources (Lal 1997, Woo et al. 1997). Therefore, it is extremely important to know the extent of land areas covered by forests to understand the functions of terrestrial ecosystems. The Food and Agriculture Organization (FAO) of the United Nations provided four Forest Resources Assessments (FRA) for 1980, 1990, 2000, and 2005 by country, respectively

(FAO 2001, 2005). However, little is known regarding what factors are changing the forest cover in a country and how these factors are working from the FRAs produced by FAO. The objective of this study was to understand the impacts of afforestation, deforestation, and reforestation on forest cover in China from 1949 to 2003.

Data

Data for afforestation, deforestation, and reforestation were obtained from an initial natural resources survey and six subsequent national forest inventories (NFI) in China during 1949–2003 (Chinese Ministry of Forestry 1977, 1983, 1989, 1994,

1996; State Forestry Administration of China 2000, 2005), which were conducted by the Ministry of Forestry before 1998 and the State Forestry Administration since then.¹ Afforestation refers to forest planting and/or seeding in areas that previously were not classified as forests. The areas of new plantation forests that contribute to national forest cover in a year are not equal to the new afforested areas in the year but are equal to the areas that reach the minimum canopy cover of forests from all the previously afforested areas. Deforestation is the conversion of forests to another land use or long-term reduction of canopy cover below the minimum of that defined as forests. In China, timber harvesting is by far the major mechanism of deforestation. Reforestation occurs in a deforested area through natural or assisted natural regeneration or natural regeneration in a previously nonforest area.

The initial natural resources survey took place during 1950–1962 for 2.95 million km² or 30.7% of the country area. During the early 1950s, the survey was based on statistics obtained from measurements of sample plots made on the ground. In the mid-1950s, air photos were used for large area survey. In the late 1950s, the angle

¹The Ministry of Forestry in China was replaced with the State Forestry Administration in 1998.

Table 1. Forest cover and areas from natural resources survey and NFIs from 1949–2003.

Years	Plantation forest areas ($\times 10^6$ ha)	Total forest areas ($\times 10^6$ ha)	Total forest cover (%)	Plantation forest cover (%)	New planted areas ($\times 10^6$ ha)
1949	—	—	8.60	—	—
1950–1962	5.11	113.36	11.81	0.53	34.12
1963–1972	—	—	—	—	—
1973–1976 (I)	23.69	121.86	12.70	2.47	56.13 ^a
1977–1981 (II)	22.19	115.28	12.00	2.31	22.44
1984–1988 (III)	31.01	124.65	12.98	3.23	43.63 ^b
1989–1993 (IV)	34.25	133.70	13.92	3.57	27.76
1994–1998 (V)	46.67	158.94	16.55	4.86	25.29
1999–2003 (VI)	53.26	174.91	18.21	5.55	31.85

Forest cover is calculated based on the country area of 960 million ha (i.e., 9.6 million km²) for China, including Taiwan, Hong Kong, and Macao. Forests in Taiwan, Hong Kong, and Macao are not separated into plantation and natural forests in the NFIs. New planted areas are the areas planted during the inventory period. These areas are not forests until the canopy cover reaches 30 and 20% before and after the fifth NFI, respectively. There are numerous reports for forest areas in China in the literature. However, existing reports are inconsistent. Discretion should be given to the definition of forests in various reports. For example, the Global FRA 2000 and 2005 of the United Nations FAO reported larger forest areas for China than we reported here because of the difference in forest definitions (FAO 2001, Su et al. 2005). Data in this table are direct results from NFI (Chinese Government Documents 1977–2005). The roman numbers indicate sequence of NFI. There was no forest resource information during 1963–1972.

^a This figure includes new planted areas during 1963–1972.

^b This figure includes new planted areas during 1982–1988.

gauge instrument or prism was introduced, which significantly expedited the process. There was no national forest resource information in China during 1963–1972.

The first NFI was performed during 1973–1976, in which a stratified systematic sampling technique was used to locate NFI sample plots. Each province, autonomous region, or municipal city designed one or more sampling populations according to the physiographic conditions and forest resource distributions. The size of the sample plots varied from 0.06, 0.08, and up to 1.0 ha in circular, square, or rectangle shapes. The sampling grid varied from 1 \times 2 km up to 8 \times 8 km. The second NFI took place during 1977–1981. A total of 160,000 sampling plots were measured, of which 140,000 were permanent plots. An NFI system began to emerge.

The third, fourth, and fifth NFIs took place during 1984–1988, 1989–1993, and 1994–1998, respectively. These subsequent inventories were performed with additional standardized techniques and provided more information than the earlier NFIs. Starting from the fourth NFI, remote sensing sample plots were established. The most recent one, the sixth NFI, took place during 1999–2003, covering the entire country for the first time. This NFI established 415,000 permanent sample plots and 2,844,400 remote sensing sample plots. Data from the sixth NFI were released in August 2005.

Data from the initial forest resources survey and the subsequent six NFIs are the most comprehensive data set available for forest resources in China. Because of the fact that NFIs were an evolving process, data in-

consistencies were inevitable. However, the data set reflects the overall trajectory of change of forests in China. We have extracted the total new forested areas from afforestation, deforestation, and reforestation from this data set. Consequently, we were able to assess the impact of these activities on China's forest cover from 1949 to 2003.

Analysis and Results

Overall Forest Cover Dynamics. China's forest cover increased dramatically from 8.6 to 18.21% from 1949 to 2003 (Table 1). It is the result of the combined effects of afforestation, deforestation, and reforestation. From 1949 to 2003, the cumulative planted areas in China were 241 million ha, equivalent to 25 percentage points in forest cover (Table 1). However, the actual contribution from afforestation was equivalent to an increase of 9.4 percentage points in forest cover or 90 million ha in forest areas. The majority of the afforested areas failed to reach minimum canopy cover required to be classified as forests. Only 37% of the afforested areas eventually established as plantation forests. The most recent NFI in 2003 found that plantation forests covered 53 million ha of the country's land area, suggesting 37 of the 90 million ha of the established plantation forests were harvested. The total timber volume harvested from both plantation and natural forests during 1949–2003 was 13.0 billion m³, equivalent to 16 percentage points in forest cover at a stocking volume of 85 m³/ha. In reality, timber harvesting had affected much larger areas because of selective and staged cutting, implying almost all forests suitable for harvesting

might have been harvested at least once, and many areas may have been harvested multiple times. From 1962 to 2003 China's forest cover increased 6.4 percentage points, of which 5.0 percentage points was contributed by afforestation.

Impacts of Afforestation, Deforestation, and Reforestation. Table 2 shows the changes in China's forest cover caused by afforestation, deforestation, and reforestation from 1949 to 2003. The impacts are assessed for plantation and natural forests, respectively. The net change in forest cover of plantation forests is the decrease caused by deforestation of plantation forests after compensation of the increase in plantation forest areas from afforestation. The net change in forest cover of natural forests is the decrease caused by deforestation of natural forests after compensation of the increase in natural forest areas via reforestation. The net change in overall forest cover is the sum of the net changes from plantation and natural forests.

Because of World War II and the subsequent Civil War in China before the establishment of China, data were scarce for accurate estimates of China's forest cover in 1949. The former Ministry of Forestry estimated China's forest cover was 8.6% in 1949. The initial forest resource survey during 1950–1962 found that natural forests decreased 1.20 percentage points in forest cover, and plantation forests increased 0.53 percentage points in forest cover. However, overall forest cover was estimated to be 11.81% in 1962. This increase in forest cover can not be explained by the contribution from afforestation, deforestation, and

Table 2. Change in forest cover caused by afforestation, deforestation, and reforestation in China from 1949 to 2003.

Years	New plantation forests	Plantation forests harvested	Natural forests regenerated	Natural forests harvested	Planted net change	Natural net change	Net forest change
1949	—	—	—	—	—	—	—
1950–1962	0.53	0.0	1.18	-2.38	0.53	-1.2	+3.21 ^a
1963–1972	—	—	—	—	—	—	—
1973–1976	1.94	0.0	2.58	-3.63	1.94	-1.05	+0.89
1977–1981	0.45	-0.61	0.69	-1.23	-0.16	-0.54	-0.70
1984–1988	2.14	-1.22	0.60	-0.54	0.92	0.06	+0.98
1989–1993	1.34	-1.00	0.73	-0.13	0.34	0.6	+0.94
1994–1998	1.42	-0.35	1.08	-0.74	1.07	0.34	+2.63 ^b
1999–2003	1.56	-0.89	0.78	-0.23	0.67	0.55	+1.66 ^c

Units in all columns are in percentage points (%) with respect to the country area (960 million ha). Natural net change is the sum of natural forests regenerated and natural forests harvested; planted net change is the sum of new plantation forests and plantation forests harvested; net forest change is the sum of natural net change and planted net change.

^a The net increase in forest cover does not match the survey results, indicating that China forest cover in 1949 might have been underestimated.

^b The net increase in forest cover includes 1.22 percentage points in forest cover caused by change in forest definition from 30 to 20 in minimum canopy cover.

^c The net increase in forest cover includes 0.39 percentage points from special purpose scrubs that were previously excluded as forests and 0.05 percentage points from Taiwan, Hong Kong, and Macao.

Table 3. Timber volume resources in China's forests and timber volume harvested from 1949 to 2003.

Years	Total volume in stock ($\times 10^9$ m ³)	Mean volume density (m ³ /ha)	Total volume growth ($\times 10^6$ m ³ /yr)	Total volume harvested ($\times 10^6$ m ³ /yr)
1949	—	—	—	—
1950–1962	10.2	98.9	126.0	87.8
1963–1972	—	—	—	—
1973–1976 (I)	9.5	79.0	226.9	195.6
1977–1981 (II)	10.3	83.4	275.3	294.1
1984–1988 (III)	10.6	79.2	316.0	344.0
1989–1993 (IV)	11.8	83.7	420.0	320.0
1994–1998 (V)	12.5	78.1	457.5	370.0
1999–2003 (VI)	13.6	84.7	497.0	365.0

Note that the total volumes in stock do not equal to the mean volume density times the total forest areas in Table 1 because of data inconsistency in NFI at different times. We also see that the mean volume density is higher during 1977–1981 than that during 1973–1976 even though total volume harvested exceeded total volume growth during 1977–1981, indicating comparability problems among data from different NFIs.

reforestation, indicating China's forest cover might have been underestimated in 1949.

Timber harvesting during the first NFI from 1973 to 1976 was primarily natural forests, most of which were recovered through reforestation. The overall forest cover increased during 1973–1976 as a result of the increase in plantation forests (Table 2). Plantation forests established earlier began reaching harvesting status during the second NFI from 1977 to 1981, leading to a sharp increase in harvesting of plantation forests. Consequently, harvesting of natural forests decreased. However, there was a net loss of forest cover for both plantation and natural forests. The overall forest cover decreased 0.7 percentage points during 1977–1981.

The area of natural forests harvested continued to decrease during the third NFI from 1984 to 1988 because of compensation from plantation forests harvested. The overall natural forest cover managed to increase marginally. Another important reason for the decrease in areas of natural forests harvested was the changes in timber harvesting

methods and concurrent efforts to protect natural forests. Timber harvesting shifted from earlier clearcutting to include selective and staged cuttings, which did not change overall forest cover. In fact, the total volume harvested during 1984–1988 increased significantly from 1977 to 1981 (Table 3). Thus, the actual areas affected by harvesting were much larger than the areas deforested. Because of earlier intensive harvesting of the natural forests, most of the deforested areas were plantation forests during 1984–1988, indicating plantation forests were becoming a major source for timber production (Table 2). The rapid increase in forest cover from afforestation was partly caused by a higher standard for afforestation adopted in 1985, raising the survival rates from 40 to 85% in the south and to 70% in the north to pass afforestation inspection (Chinese Ministry of Forestry 1989). The new standard for afforestation should improve the contribution rate from afforested areas to national forest cover in the years to come. Natural forest cover increased sharply during the fourth NFI from 1989 to 1993, exceeding that of

plantation forests for the first time because of continued intensive harvesting of plantation forests. Plantation forests continued to be a major source of timber production. The overall forest cover increased 0.94 percentage points during 1989–1993 (Table 2).

Overall forest cover in China sharply increased 2.63 percentage points during the 1994–1998 NFI (Table 2). One major reason for the dramatic increase was a change in the definition of forest. Forest definition by former Ministry of Forestry in China was different from that of other developing countries. In the FRA 1980 and 1990 of FAO of the United Nations (FAO 2001), the minimum canopy cover required to be classified as a forest² is 10% for developing countries and 20% for the developed countries. The same definition of a minimum 10% canopy cover was used for all countries

²FAO definition of forest also included temporarily unstocked forest areas that were not included as forested areas in China's NFI.

in FRA 2000 and 2005 (FAO 2001, 2005). The definition of forests in China was adjusted from a minimum of 30 to 20 percent canopy cover in 1994, adding 1.22 percentage points to overall forest cover. Thus, the definition of forests in China remains different from the definition in FAO FRA 2000. Therefore, the forested areas reported to FAO in FRA 2005 (Su et al. 2005) are different from the areas reported here. After accounting for the increase in forest cover caused by change in forest definition in China, the net contribution to the increase of forest cover from plantation and natural forests was 1.41 percentage points during 1994–1998. After intensive harvesting of plantation forests during the previous two NFI periods, areas of plantation forests harvested decreased. In the meantime, harvesting of natural forests increased (Table 2).

The sixth NFI during 1999–2003 covered the entire country for the first time. Natural forest cover increased 0.55 percentage points. There was an increase in harvesting of plantation forests again after a brief slowdown during 1994–1998. Although new plantation forests increased forest cover by 1.56 percentage points, timber harvesting of plantation forests offset the net increase in forest cover to merely 0.67 percentage points. In 2004, the definition of forests was modified again to include special purpose scrubs, which grow in areas with an annual precipitation below 400 mm or above the tree line in the mountains with a minimum canopy cover of 30% and in which its primary function is environmental protection. The expansion of forest definition to include the special purpose scrubs added 0.39 percentage points to overall forest cover. China's forest cover reached 18.21% at the end of 2003 with an increase of 1.66% from the previous inventory period (Table 2).

Characteristic Developmental Stages.

Based on the change of forest cover (Table 1), the dynamics of forests in China can be characterized in three stages. The goals of forest management were the major factor driving the change.

1. Transition stage (1949–1981). Overall forest cover was unstable. Timber production was the primary goal of forest management during this stage. Natural forests were the primary target for timber harvesting in the early years, and plantation forests were the target for harvesting as they matured. Such a management goal suited the immediate timber

needs for economic recovery after many years of war in China before 1949. Timber volume harvested each year increased rapidly and eventually exceeded timber volume annual growth during 1977–1981 (Table 3). The cumulative areas harvested were 7.85 percentage points in forest cover, of which 92% was natural forest (Table 2). Although forest cover did not decrease as much because of compensation from afforestation and reforestation, forest age structure in China was altered significantly.

2. Slow increase stage (1982–1993). Overall forest cover increased slowly. Timber production remained a major forest management goal, but with greater consideration of ecological effects of forests. Timber harvesting continued to deplete forest resources; however, a significant difference from the previous stage was that plantation forests became the major target for harvesting as those planted during the early years reached harvesting status. Consequently, plantation forests contributed 76% of the forest cover harvested (Table 2). In the meantime, China started a series of major ecological projects aimed at environmental protection with forests, such as preventing soil erosion, desert migration, and others. Forest cover increased 1.26 percentage points from afforestation. With a relief in harvesting, natural forests began to grow back. Although harvested timber volume continued to increase (Table 3), harvested volume was eventually controlled below the volume of annual growth.

3. Rapid increase stage (1994–2003). Forest cover increased rapidly. Timber production was no longer the primary goal of forest management, but rather forest ecological effects on the improvement of environmental conditions. The rapid increase of forest cover resulted from increased efforts in afforestation and the change in the definition of forest. A new national forest policy, aiming at sustainable management of forest resources and environmental protection, was adopted in 1998 (Zhang et al. 2000). The new forest policy was implemented with significant investments. In 1998, the Chinese government started six major forest projects with a total investment of over 700 billion yuan (approximately US\$85 billion) by the end of 2010. Given the large afforested areas during this stage

(Table 1) and future commitments, China's forest cover will continue to increase in the next 10 years.

Discussion

Forest cover is a major index of forest resources in a country. Although timber volume stocking is closely related to its forest cover, they are, in fact, quite different. The key difference is that forest successional stages do not have an impact on forest cover as long as the canopy cover reaches the threshold value of forests. However, forest successional stages have a significant impact on timber volume. Old-growth forests have much higher timber volumes than young ones. It is clear from the data shown in Tables 1–3 that China's forests have become much younger because of afforestation, extensive timber harvesting, and reforestation. Table 3 shows that the total forest volumes increased 33% by 2003 from the 1950–1962 survey volumes, while area of forest cover increased 54% during the same period according to Table 1. A higher forest cover is not a guarantee of higher timber volume. These forests need to be managed carefully to increase China's timber volume.

The increase in forest cover in China is consistent with the recent observation of enhanced vegetation activities from remote sensing (Fang et al. 2004, Xiao and Moody 2004). Caution should be taken in interpreting the enhanced vegetation activities based on vegetation index derived from satellite observations over China. This may be the result of a massive shift toward younger forests because of extensive afforestation, deforestation, and reforestation. Dramatic change in age structure has significant implication for forest ecosystem functions. For example, deforestation of mature and old-growth forests has long-lasting impacts on carbon fluxes (Harmon et al. 1990, Song and Woodcock 2003). The intensive timber harvesting and the rapid increase of forest cover imply that forests in China released significant amounts of carbon over the last 50 years, but there is a great potential for carbon sequestration in the following decades.

Conclusions

Afforestation, deforestation, and reforestation have significantly modified the age structure of forests in China, reflected in the current forest ecosystems dominated by young stands. Reforestation has kept China's forest cover from dramatically decreasing

ing from intensive harvesting. Afforestation is not only the primary factor increasing forest cover in China, but also is an important source of timber supply. Because of the practice of selective logging, impacts of timber harvesting were much more widespread than the reduction in forest cover. The recent rapid increase of forest cover and timber volume indicates that the young forests in China are becoming a carbon sink and will have greater potential in carbon sequestration in the coming decades if properly managed.

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