# A full accounting of biomass carbon stocks of trees over 1977-2003 and prediction of forest carbon sequestration by 2050 in China

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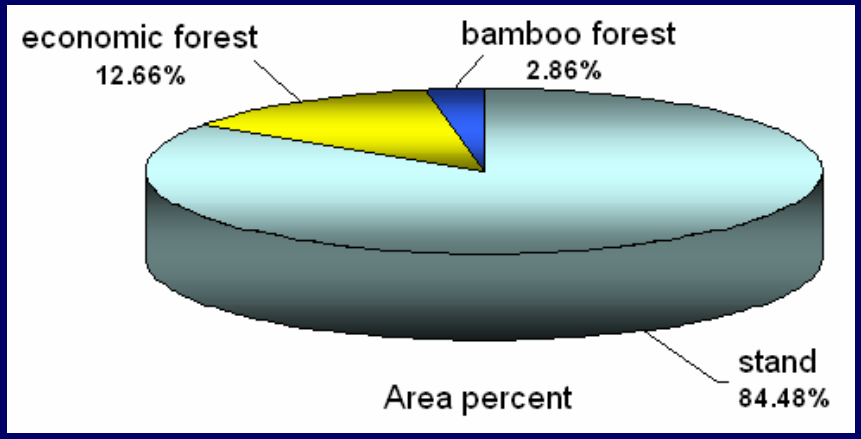
# Categories of forests and trees

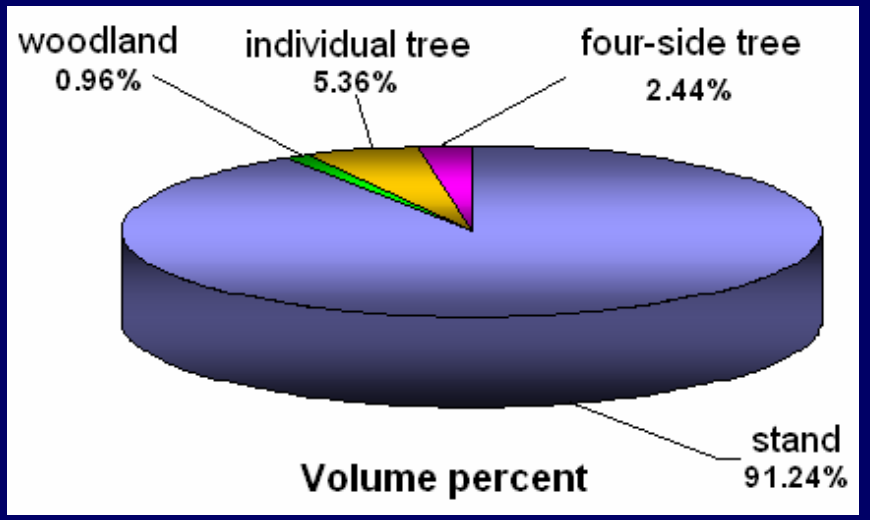
- **Forest**

**(Stands, economic forests, and bamboo forests)**

- **Shrubs**
- **Woodlands**
- **Trees out forests**

**(Four-side trees and individual trees)**



# (1) Forest (Stands, economic forests, and bamboo forests)

- **Stands:** forest with canopy cover of >30% before 1994, after then canopy cover of ≥20% are used.

Spruce (云杉)

Mixed conifer and deciduous (针阔混交林)

- **Economic forests:** woods with the production of fruits, edible oils, drinks, flavorings, industrial raw materials and medicinal materials as the main use.

**Apple (苹果林)**

**Tea-oil tree (油茶树林)**

- **Bamboo forests:** the area of bamboo forests is 4.8 Mha, accounting for 2.86 % of forest in China, among which the area of moso bamboo is 3.4 Mha.

Bamboo

# (2) Shrubs

Shrubs are defined as the shrubland with coverage of >30%.

# (3) Woodlands

Woods of mid- and old-age classes with canopy cover of 10-19% after 1994 (10-29% before 1994)

**Elm tree (榆树林)**

# (4) Trees out forests (TOFs)

**four-side trees and individual trees**

- **four-side trees**

  trees bordering villages, roads, homesteads, and ponds or canals

Bordering roads (路旁)

Bordering homesteads (宅旁)

Bordering ponds or canals (水旁)

- **individual trees**

**big trees scattered in  bamboo forest, economic forest, and non-forest lands, or in young forests**

# Outlines

1. Data sets
2. Forest biomass C stocks and changes (Stands, economic forests, and bamboo forests)
3. Non-forest biomass C stocks and changes (Shrubs, woodlands, TOFs)
4. Prediction of C sink potential
5. Key conclusions

# 1. Data sets

## (1) Forest inventories and field biomass data

- Inventory data:

  5 periods: 1977-81, 1984-88, 1989-93, 1994-98, 1999-2003

- Field biomass data:

  >1000 sets (stand age, stand density, tree height, DBH, stem volume, biomass, etc).

## (2) Shrub biomass data

- **aboveground biomass: 34 sites**

  **Ratio of above- to belowground biomass: 6 types**

## (3) NDVI datasets

GIMMS NDVI data derived from NOAA/AVHRR land dataset, with 8 km resolution for each 15 days from 1982 to 1999.

## (4) Vegetation map with a scale of 1 : 1 million

# 2. Forest biomass C stocks and changes

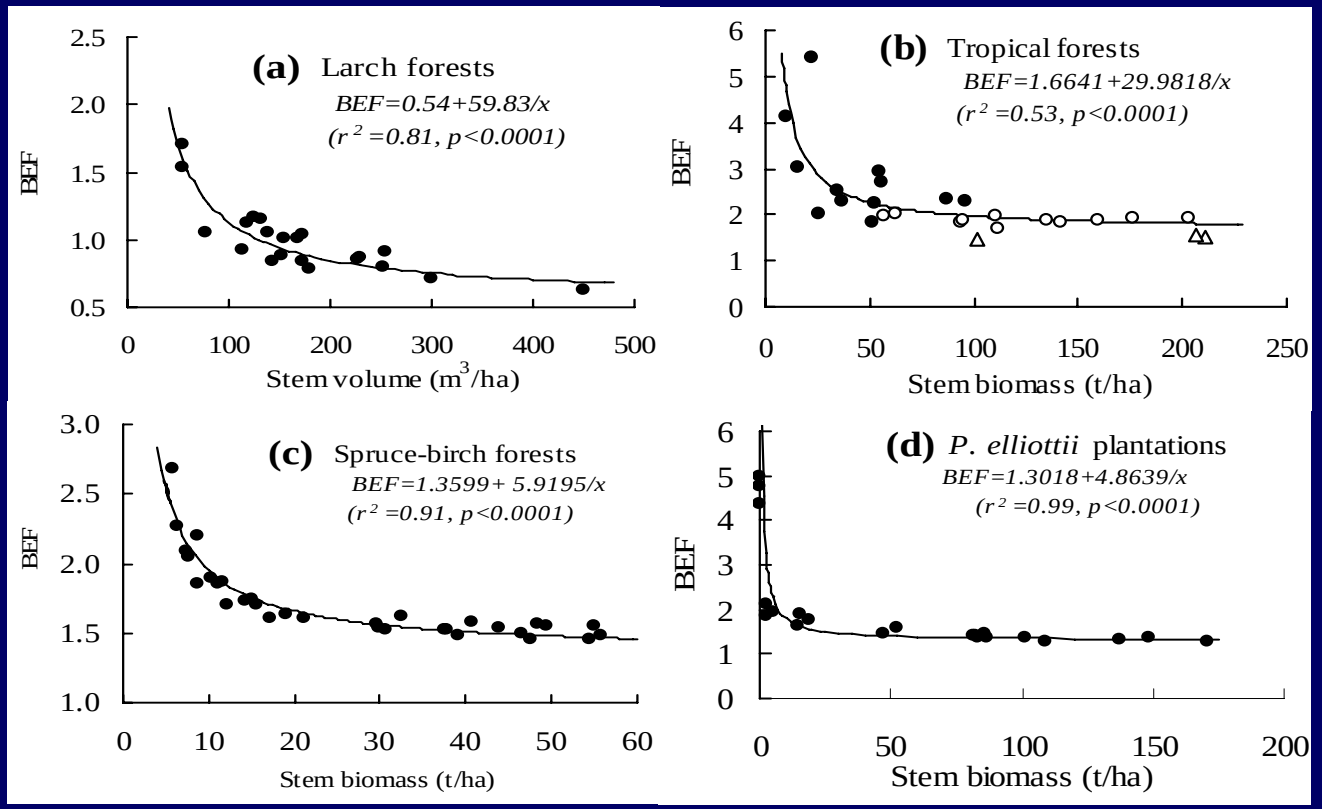
## 2.1 C stocks and changes of stands

## 2.2 C stocks and changes of economic forests and bamboo forests

# Stands

## Variable BEF method

**BEF (Biomass expansion factor), the ratio of biomass to timber volume, expressed as a function of stem volume (x), *BEF = a + b/x***



# Variable BEF method

This method can accurately estimate forest biomass by using forest area, stand volume and *BEF*, without using age and site class and other information.

It is easily scaled up from field measurements and inventory data to regional/national biomass estimation.

$$Y = \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{l=1}^{l} A_{ijl} \cdot BEF_{ijl} \cdot x_{ijl}$$

**(Stand level)**

$$Y = \sum_{i=1}^{m} A_i \cdot x_i \cdot BEF_i$$

**(Regional level)**

$$Y = A \cdot x \cdot BEF$$

**(National level)**

# Applicability of local measurements to inventory-based estimation of national biomass

Eq. 1 can be rewritten as Eq. 2.

$$BEF = a + \frac{b}{x} \quad (1); \qquad y = ax + b \quad (2)$$

For direct field measurements, if a given forest type is composed of $n$ stands, and their area, mean volume and mean biomass are $A_i$, $x_i$, and $y_i$, then the total biomass ($Y_1$) can be expressed as:

$$Y_1 = A_1 y_1 + A_2 y_2 + \cdots + A_n y_n = A_1(ax_1 + b) + A_2(ax_2 + b) + \cdots + A_n(ax_n + b)$$

$$= a\sum_{i=1}^{n} A_i \cdot x_i + bA \quad (3)$$

On the other hand, in forest inventory, if total forest area and total volume for a given forest type are $A$ and $X$, then its mean volume can be estimated as:

$$x = X / A = (1/A)\sum_{i=1}^{n} A_i \cdot x_i \quad (4)$$

The total biomass ($\boldsymbol{Y_2}$) for this forest type is:

$$Y_2 = A \cdot y = A(ax + b) = A[a(1/A)\sum_{i=1}^{n} A_i \cdot x_i + b]$$

$$= a\sum_{i=1}^{n} A_i \cdot x_i + bA \quad (5)$$

where $\boldsymbol{A}$ and $y$ are total forest area and mean biomass. Thus, we have: $Y_1 = Y_2$ (6)

This is to say, the *BEF* obtained from direct field measurement is applicable to an estimation of regional and national forest biomass.

# Biomass and BEF parameters for major forest types in China, ***BEF = a + b/x***

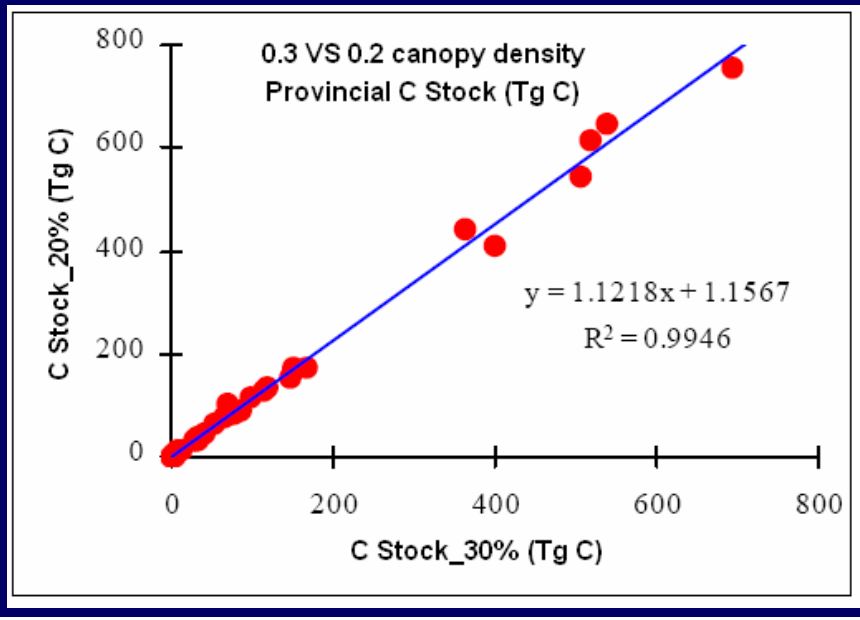
| Forest type | a | b | n | $r^2$ |
|---|---|---|---|---|
| ***Abies,Picea*** | 0.5519 | 48.861 | 24 | 0.78 |
| ***Cunninghamia lanceolata*** | 0.4652 | 19.141 | 90 | 0.94 |
| ***Cypress*** | 0.8893 | 7.3965 | 19 | 0.87 |
| ***Larix*** | 0.6096 | 33.806 | 34 | 0.82 |
| ***Pinus koraiensis*** | 0.5723 | 16.489 | 22 | 0.93 |
| ***P.armandii*** | 0.5856 | 18.744 | 9 | 0.91 |
| ***P.massoniana, P.yunnanensis*** | 0.5034 | 20.547 | 52 | 0.87 |
| ***P.sylyestris* var.*mongolica*** | 1.1120 | 2.6951 | 15 | 0.85 |
| ***P.tabulaefomis*** | 0.869 | 9.1212 | 112 | 0.91 |
| Other pines and conifer forests | 0.5292 | 25.087 | 19 | 0.86 |
| ***Tsuga,Cryptomeria,Keteleeria*** | 0.3491 | 39.816 | 30 | 0.79 |
| Mixed conifer and deciduous | 0.8136 | 18.466 | 10 | 0.99 |
| ***Betula*** | 1.0687 | 10.237 | 9 | 0.70 |
| ***Casuarina*** | 0.7441 | 3.2377 | 10 | 0.95 |
| Deciduous oaks | 1.1453 | 8.5473 | 12 | 0.98 |
| ***Eucalyptus*** | 0.8873 | 4.5539 | 20 | 0.80 |
| ***Lucidophyllous* forests** | 0.9292 | 6.494 | 24 | 0.83 |
| Mixed deciduous and Sassafras | 0.9788 | 5.3764 | 35 | 0.93 |
| Nonmerchantable woods | 1.1783 | 2.5585 | 17 | 0.95 |
| ***Populus*** | 0.4969 | 26.973 | 13 | 0.92 |
| Tropical forests | 0.7975 | 0.4204 | 18 | 0.87 |

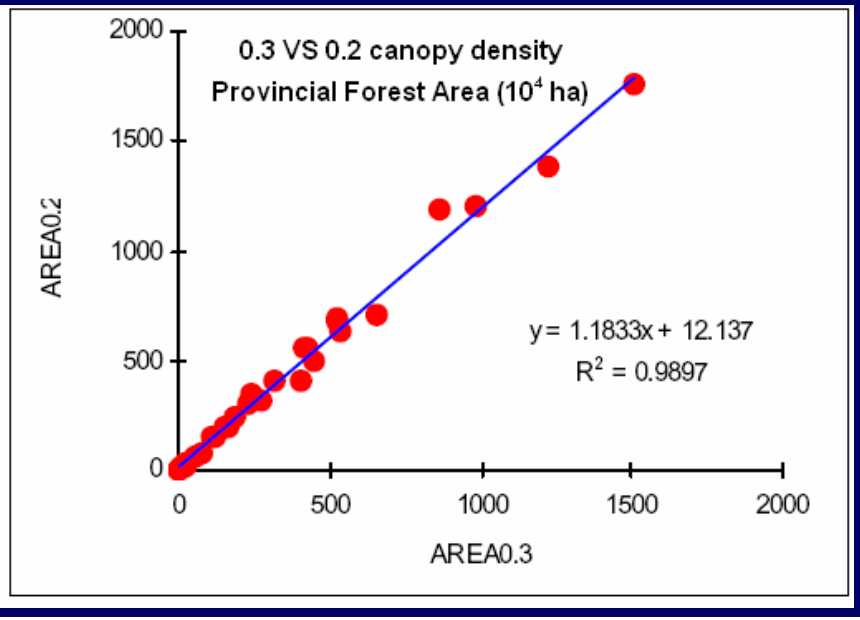
# Uniting forest standards

In China's forest inventory, the "forest" was defined as canopy cover of >30% before 1994, but then it changed to >20%. So, we estimated provincial forest C stocks and forest areas at >20% canopy cover for the periods before 1994 using the relation between provincial C stocks and forest areas at 20% and 30% canopy cover (these two standards of data are available in 1994-99).

$TC_{0.2}$=1.122 $TC_{0.3}$ + 1.157 ($R^2$ = 1.00, n =30)

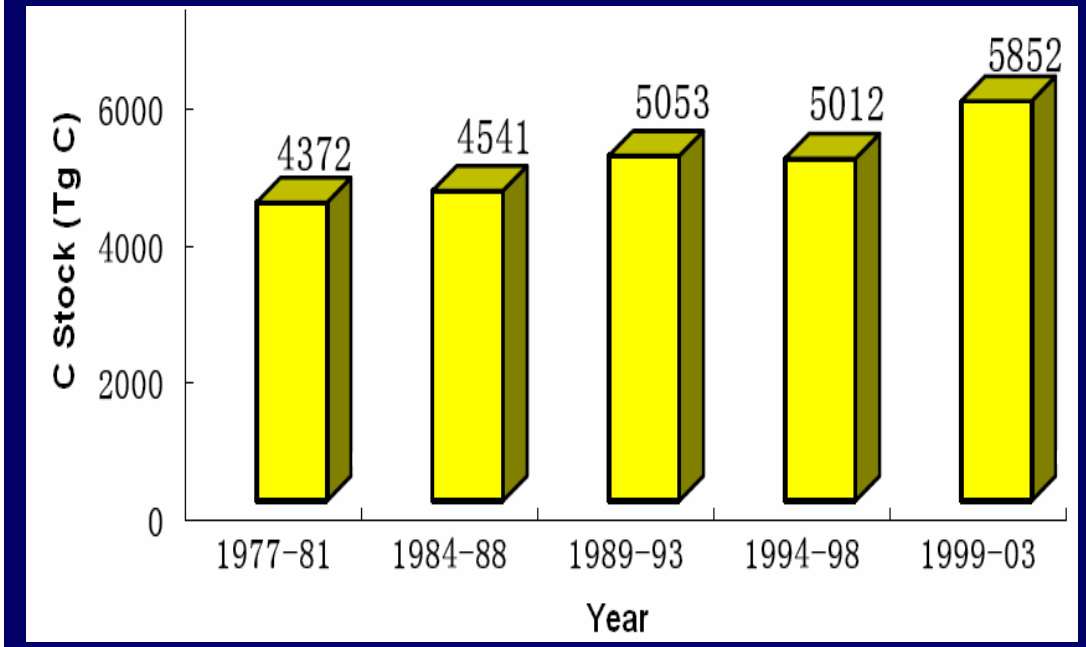
$AREA_{0.2}$=1.183 $AREA_{0.3}$ + 12.137 ($R^2$ = 0.99, n =30)



# Forest C stocks and changes

| Period | Area ($10^6$ ha) | C (Tg C) | C Density (Mg C/ha) | C Change (Tg C/yr) |
|---|---|---|---|---|
| 1977-81 | 116.6 | 4372 | 37.5 | |
| 1984-88 | 124.5 | 4541 | 36.5 | 24 |
| 1989-93 | 132.2 | 5053 | 38.2 | 102 |
| 1994-98 | 129.2 | 5012 | 38.8 | -8 |
| 1999-03 | 142.8 | 5852 | 41.0 | 168 |

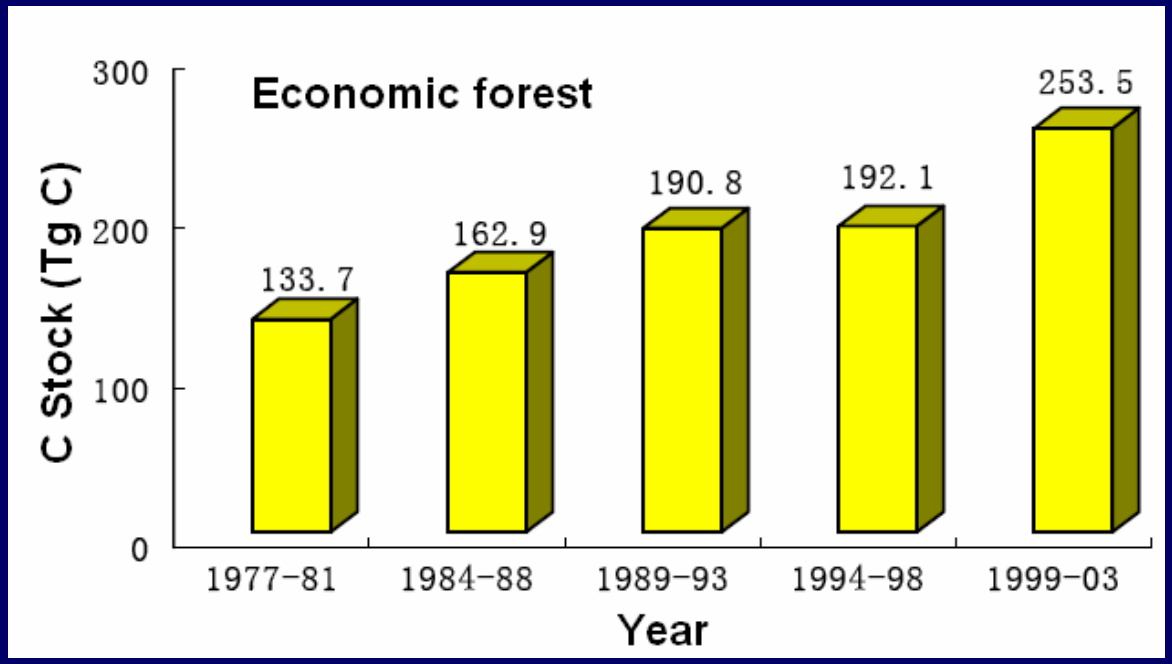



**Over 1980-90s, C stocks increased from 4.4 Pg C to 5.9 Pg C, with a net increase of 1.5 Pg C (72 Tg C/yr)**

# Economic forests

Using a mean biomass of 23.7 Mg/ha (Fang et al. 1996)

| Period | Area ($10^6$ ha) | C (Tg C) | Change (Tg C/yr) |
|---|---|---|---|
| 1977-81 | 11.3 | 133.7 | |
| 1984-88 | 13.7 | 162.9 | 4.2 |
| 1989-93 | 16.1 | 190.8 | 5.6 |
| 1994-98 | 16.2 | 192.1 | 0.3 |
| 1999-03 | 21.4 | 253.5 | 12.3 |



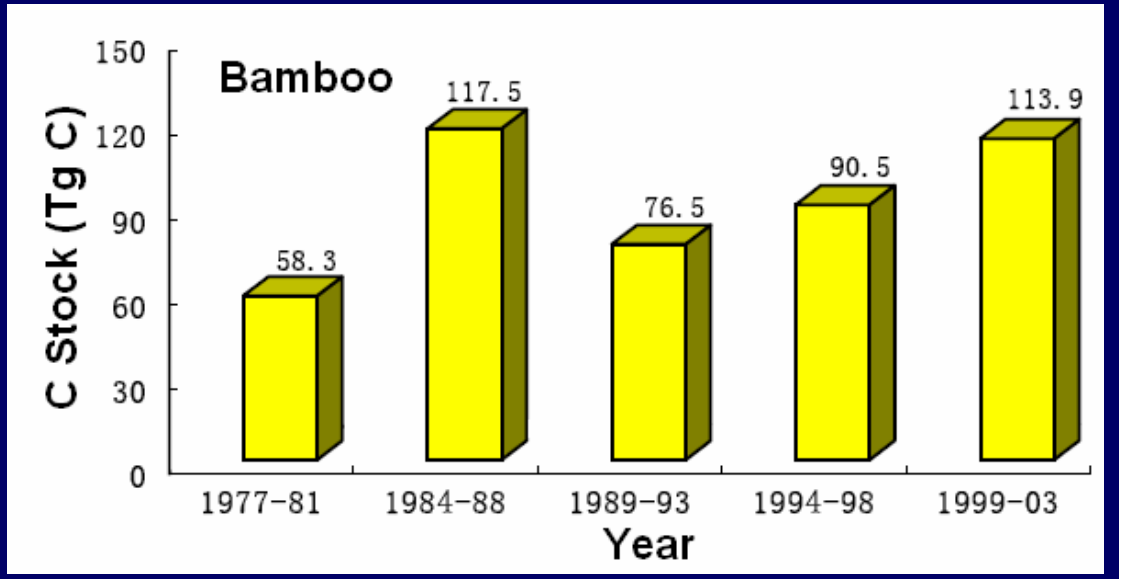

**C stocks increased by 120 Tg C, with an annual increase of 5.5 Tg C**

# Bamboo forests

**Relationship between stem density (x) and biomass (y) :**

**y=0.0227x+7.9569**

**(Pan et al. 2004)**

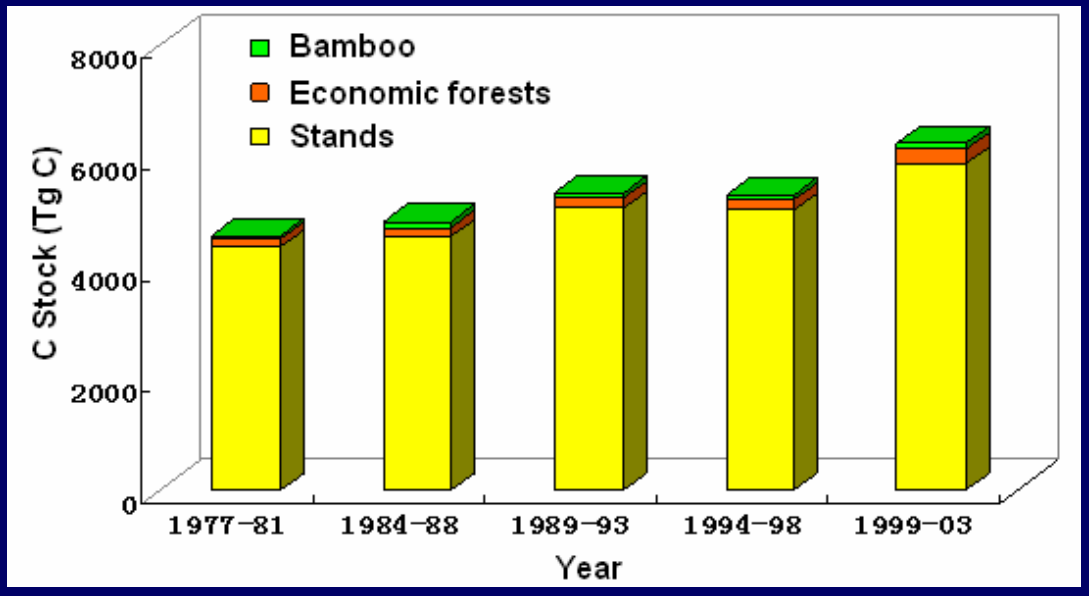



**A slight increase (ca. 2TgC/yr)**

| Period | Area | Density | C | Change |
|---|---|---|---|---|
| | ($10^6$ ha) | (stem/ha) | (Tg C) | (Tg C/yr) |
| 1977-81 | 2.50 | 1434 | 58.3 | |
| 1984-88 | 2.53 | 3255 | 117.5 | 8.5 |
| 1989-93 | 2.60 | 1920 | 76.5 | -8.2 |
| 1994-98 | 2.92 | 2000 | 90.5 | 2.8 |
| 1999-03 | 3.37 | 2212 | 113.9 | 4.7 |

# Summary:

## C stocks and changes in forests




| Period | Stands | | Economic forests | | Bamboo | | Total | |
|---|---|---|---|---|---|---|---|---|
| | C (Tg C) | Change (Tg C/yr) | C (Tg C) | Change (Tg C/yr) | C (Tg C) | Change (Tg C/yr) | C (Tg C) | Change (Tg C/yr) |
| 1977-81 | 4372 | | 134 | | 58 | | 4564 | |
| 1984-88 | 4541 | 24.1 | 163 | 4.2 | 117 | 8.5 | 4821 | 36.8 |
| 1989-93 | 5053 | 102.4 | 191 | 5.6 | 77 | -8.2 | 5320 | 99.8 |
| 1994-98 | 5012 | -8.2 | 192 | 0.3 | 90 | 2.8 | 5295 | -5.1 |
| 1999-03 | 5852 | 168.0 | 253 | 12.3 | 114 | 4.7 | 6219 | 185.0 |

**Net meanC sink is 79 TgC/yr.**

# 3. Non-forest biomass C stocks and changes

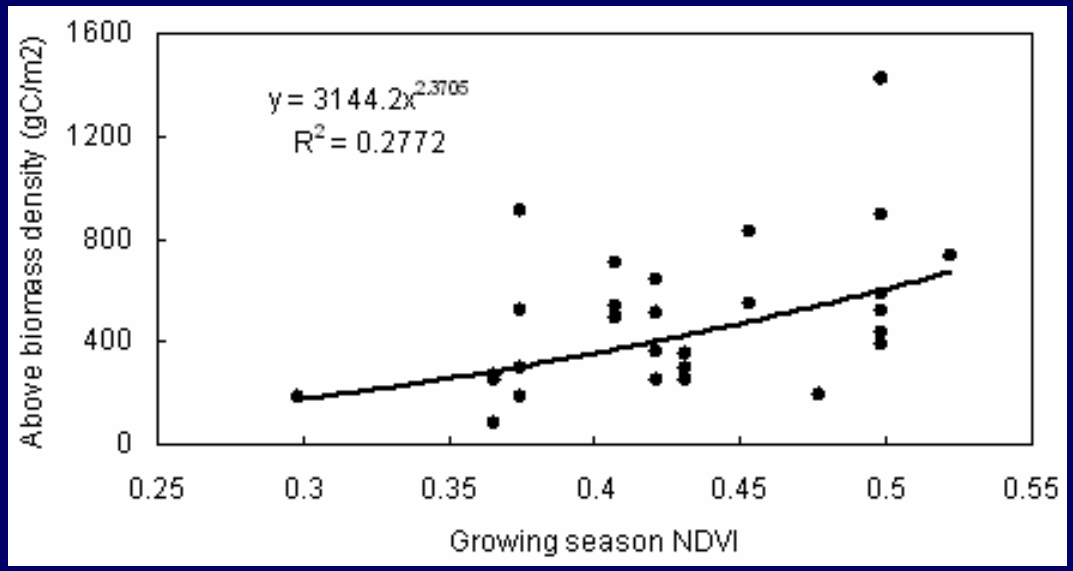
3.1 Shrubs

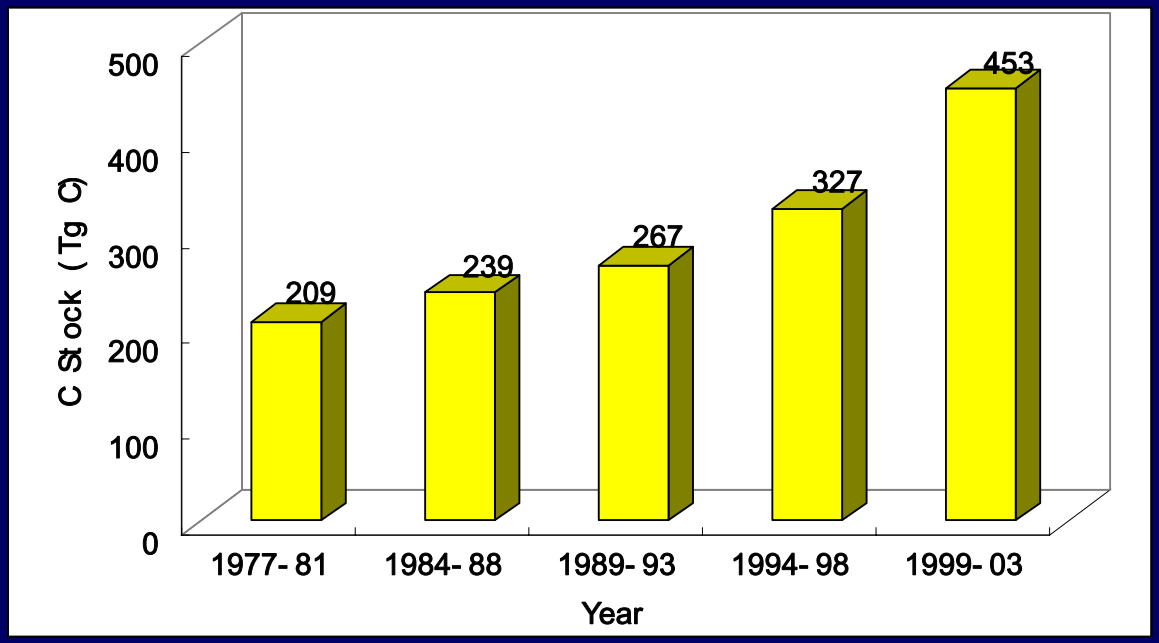
3.2 woodlands

3.3 TOFs (four-side trees and individual trees)

# 3.1 Shrubs

**We estimate biomass C of shrubs using relationship between aboveground biomass and seasonal NDVI at 34 shrub sites.**



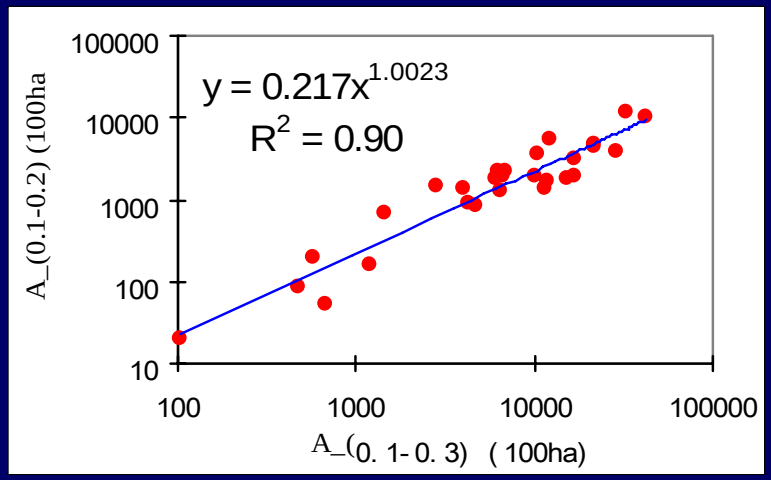

**During the last 2 decades, C stock in shrubs has increased by 244 Tg C.**

# 3.2 Woodlands

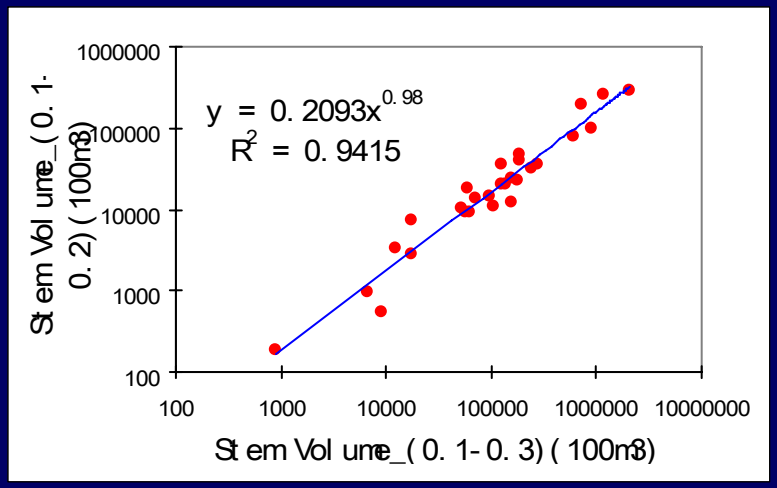
we first establish relation between provincial stem volume and areas of woodlands at 10-20% and 10-30% canopy covers (these data are available in 1994-99), then estimate provincial forest C stocks and forest areas at 10-20% canopy cover for periods before 1994.

$$A_{0.1\text{-}0.2} = 0.217(A_{0.1\text{-}0.3})^{1.0023},\ R^2 = 0.90$$

$$V_{0.1\text{-}0.2} = 0.2093(V_{0.1\text{-}0.3})^{0.98},\ R^2 = 0.94$$



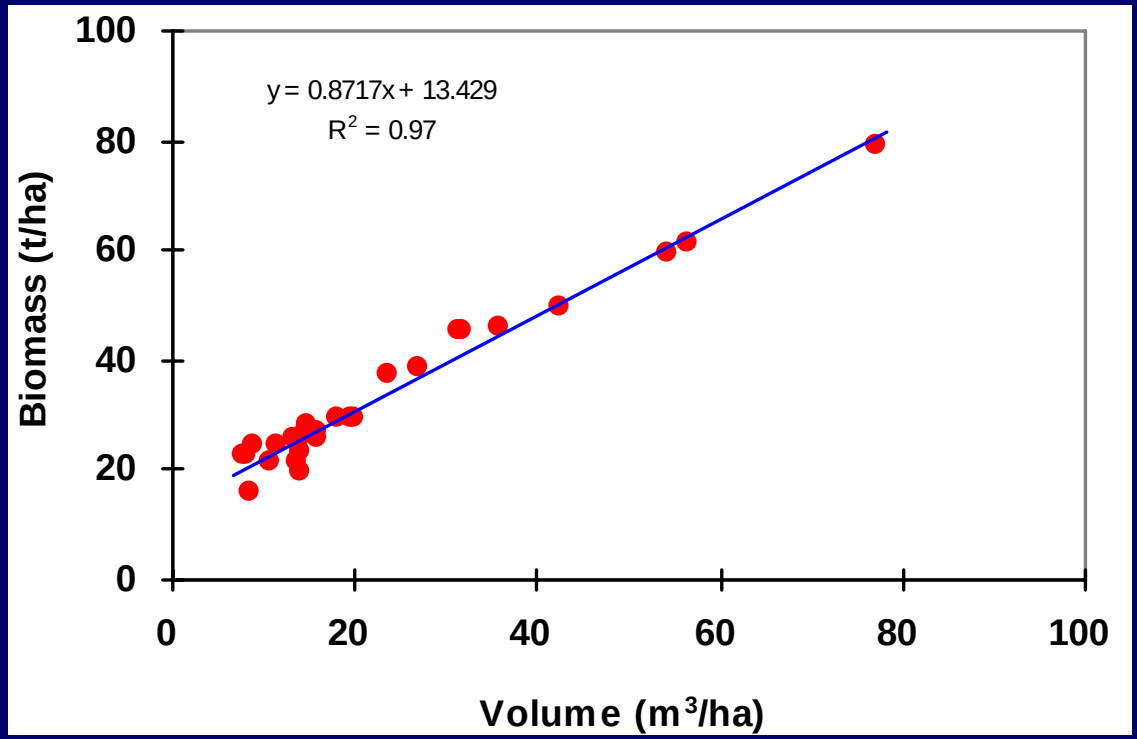

Relation between provincial shrub area at 10-20% and 10-30% canopy densities

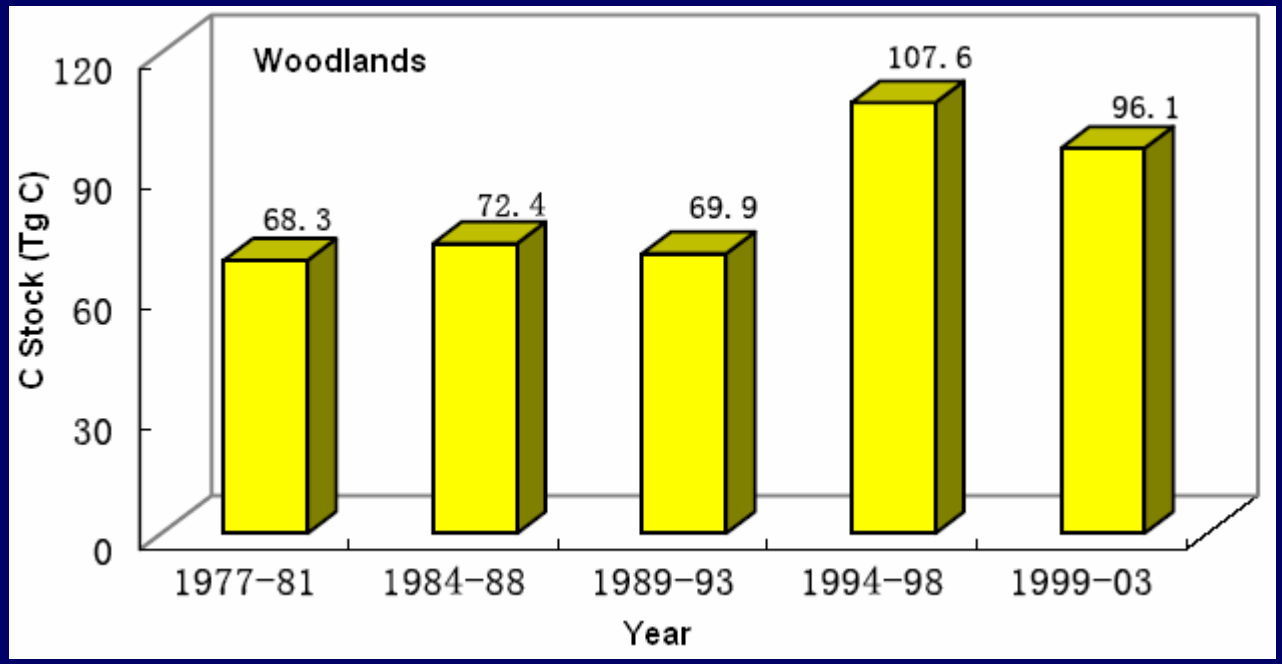



Relation between provincial stem volume at 10-20% and 10-30% canopy densities

# Relationship between provincial biomass and stem volume:

*y* = 0.8717*x*+*13.429* (n=30, $R^2$ = 0.97)





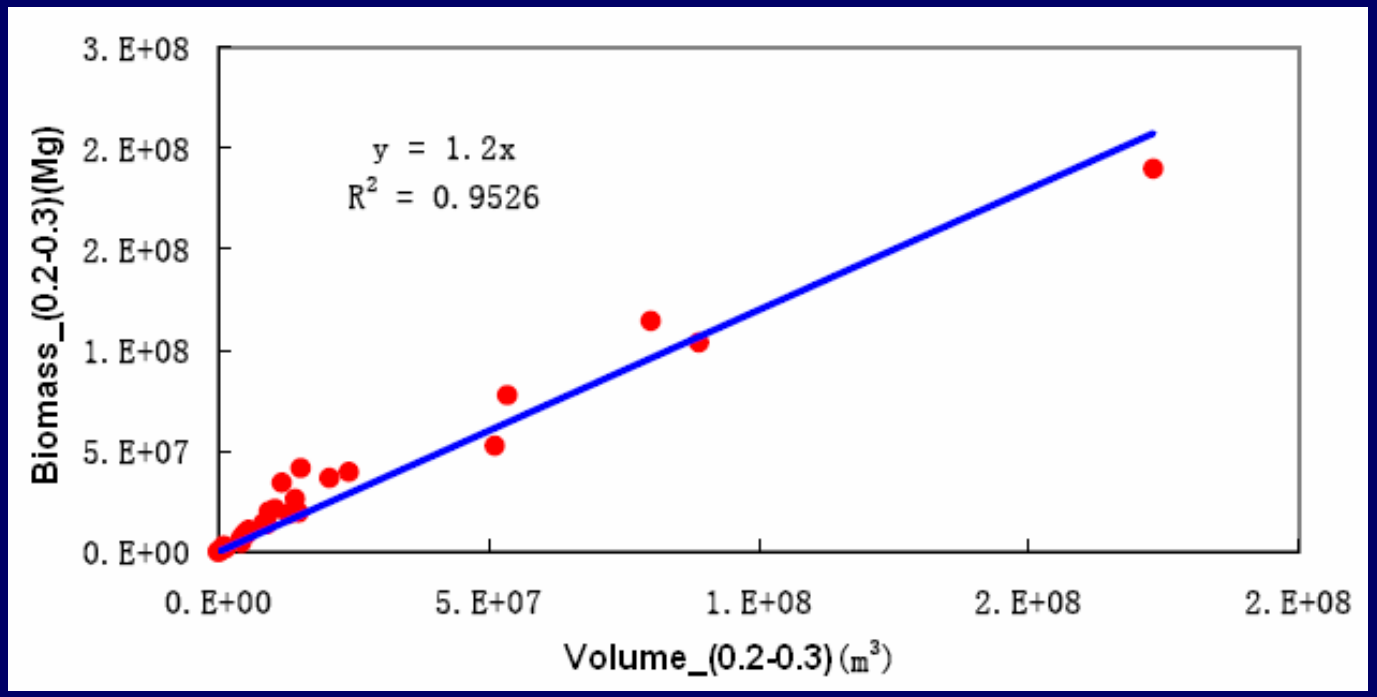

**C stocks had a small increase by 1.2 Tg C/yr.**

| Period | Area ($10^6$ ha) | C (Tg C) | Change (Tg C/yr) |
|---|---|---|---|
| 1977-1981 | 4.03 | 68.3 | |
| 1984-1988 | 4.60 | 72.4 | 0.6 |
| 1989-1993 | 4.23 | 69.9 | -0.5 |
| 1994-1998 | 7.20 | 107.6 | 7.6 |
| 1999-2003 | 6.00 | 96.1 | -2.3 |

# 3.3 Trees out forests (TOFs) (four-side trees and individual trees)

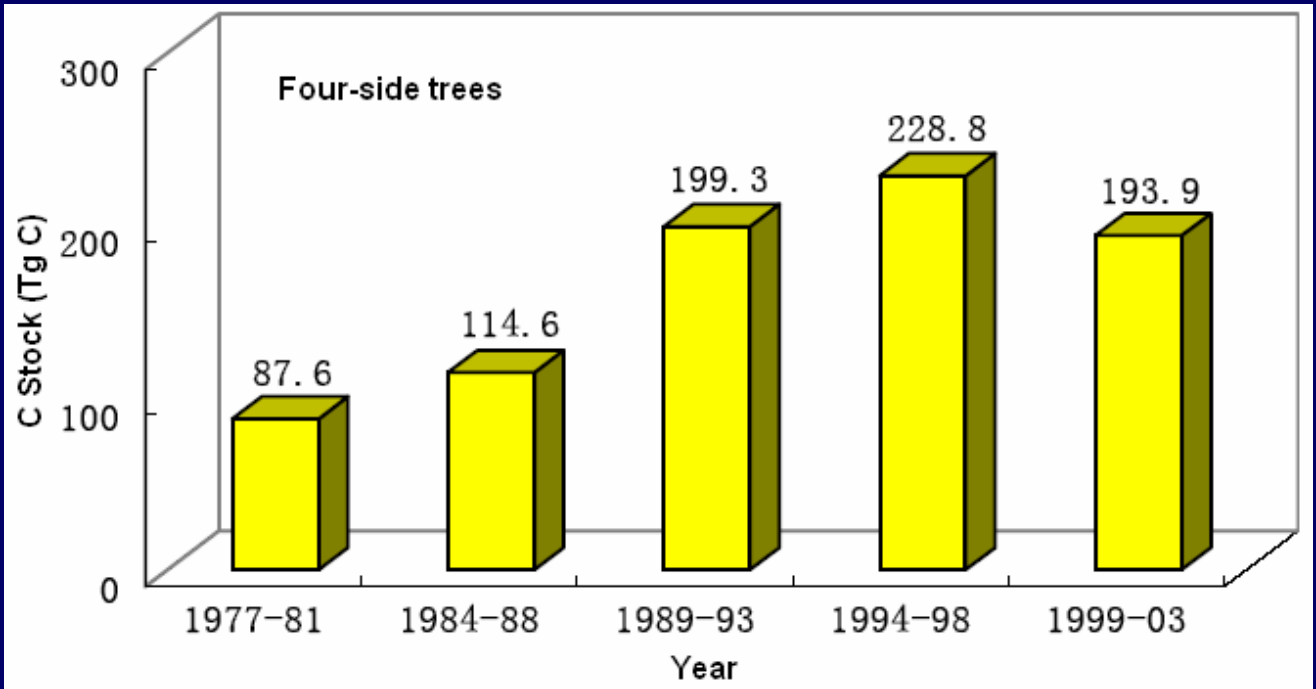
**Relationship between provincial total biomass (y, Mg) and total stem volume (x, $m^3$) at coarse stands (20-30%canopy cover):**

$$y = 1.2\,x \quad (n=30,\ R^2 = 0.95)$$



# Four-side trees

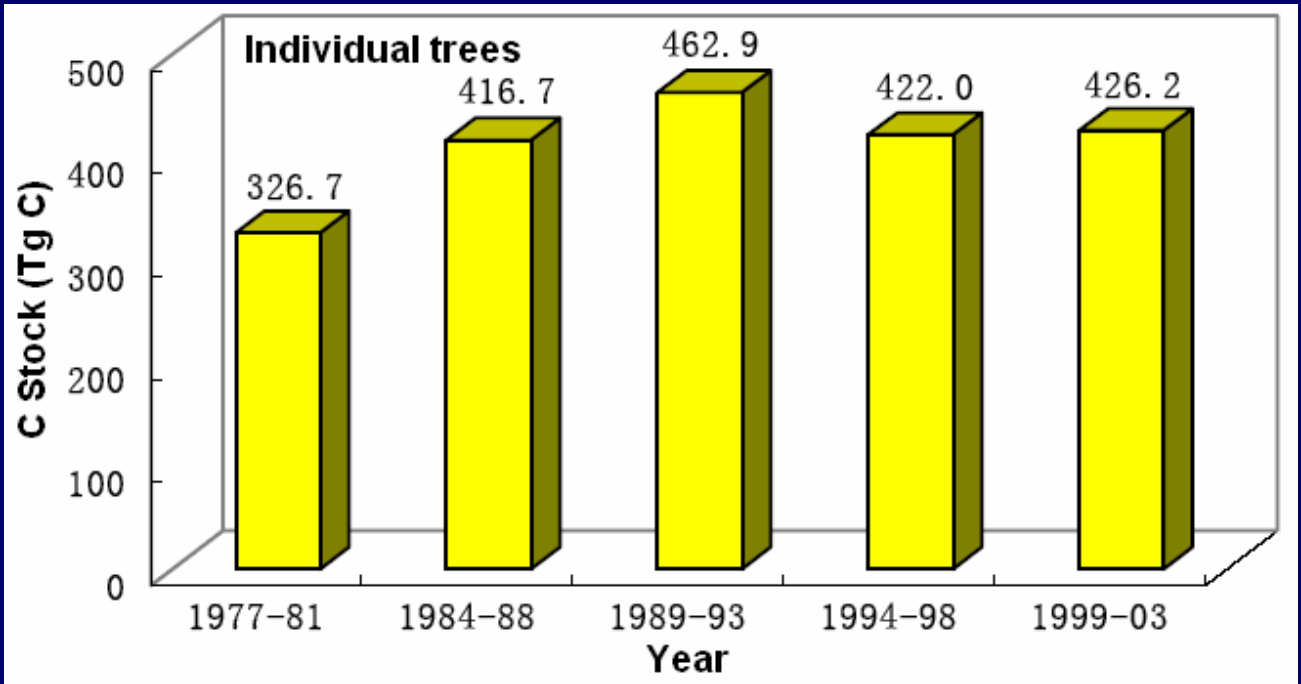
| Period | Volume | C | Change |
|---|---|---|---|
| | $10^6$ m$^3$ | Tg C | Tg C/yr |
| 1977-81 | 146.1 | 87.6 | |
| 1984-88 | 191.0 | 114.6 | 3.9 |
| 1989-93 | 332.1 | 199.3 | 16.9 |
| 1994-98 | 381.3 | 228.8 | 5.9 |
| 1999-03 | 323.2 | 193.9 | -7.0 |




**C stock is quite big and had a mean increase of 5 Tg C/yr.**

# Individual trees

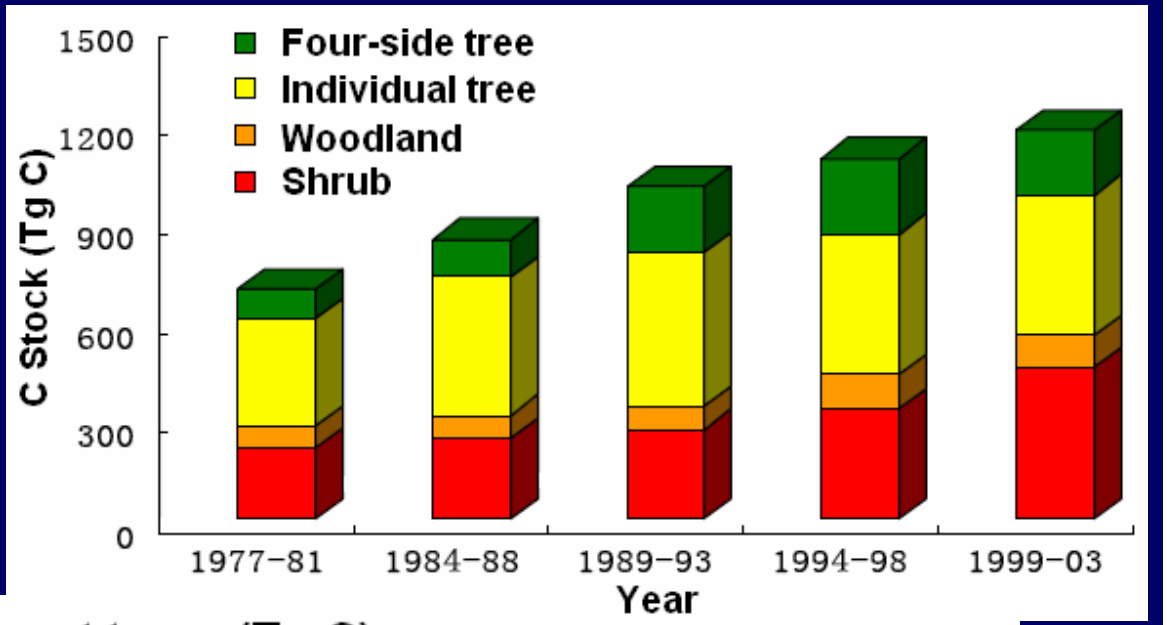
| Period | Volume | C | Change |
|---|---|---|---|
| | $10^6$ m$^3$ | Tg C | Tg C/yr |
| 1977-81 | 544.5 | 326.7 | |
| 1984-88 | 694.5 | 416.7 | 12.9 |
| 1989-93 | 771.4 | 462.9 | 9.2 |
| 1994-98 | 703.4 | 422.0 | -8.2 |
| 1999-03 | 710.3 | 426.2 | 0.8 |




**C stock is quite big and had a mean increase of 3.7 Tg C/yr.**

# Summary:

## C stocks and changes in non-forest trees



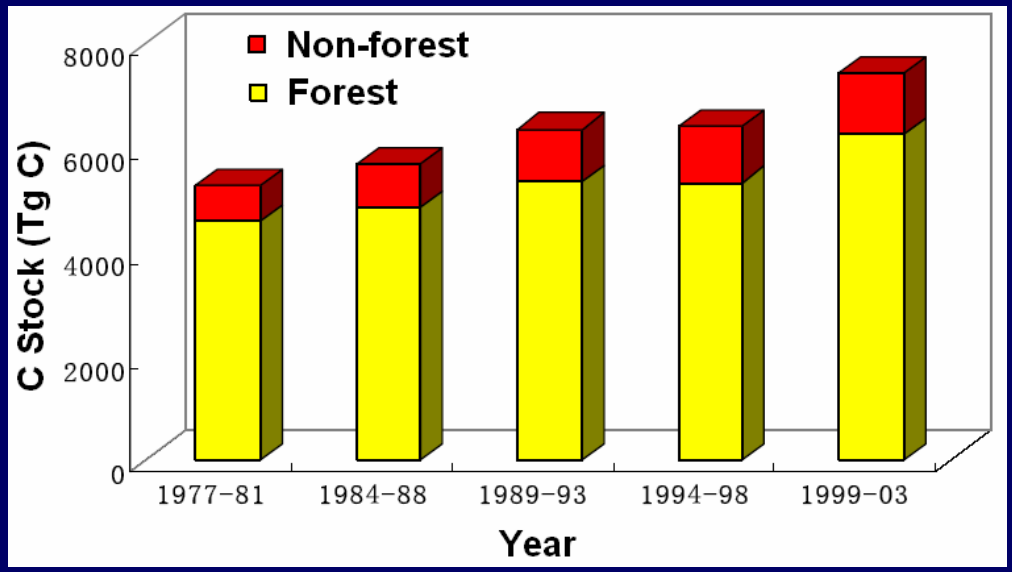

Carbon stocks in non-forest trees (Tg C)

| Period | Shrub | Woodland | Individual tree | Four-side tree | Non forest |
|---|---|---|---|---|---|
| 1977-81 | 209 | 68 | 327 | 88 | 692 |
| 1984-88 | 239 | 72 | 417 | 115 | 843 |
| 1989-93 | 267 | 70 | 463 | 199 | 999 |
| 1994-98 | 327 | 108 | 422 | 229 | 1086 |
| 1999-03 | 453 | 96 | 426 | 194 | 1169 |

C stock increases from 0.7 PgC to 1.2 PgC over the years

# Summary:

## C stocks and changes in all trees




| Period | Forest | | Non-forest | | Total | |
|---|---|---|---|---|---|---|
| | C (Tg C) | Change (Tg C/yr) | C (Tg C) | Change (Tg C/yr) | C (Tg C) | Change (Tg C/yr) |
| 1977-81 | 4564 | | 692 | | 5256 | |
| 1984-88 | 4821 | 36.8 | 843 | 22 | 5664 | 58 |
| 1989-93 | 5320 | 99.8 | 999 | 31 | 6319 | 131 |
| 1994-98 | 5295 | -5.1 | 1086 | 17 | 6381 | 12 |
| 1999-03 | 6219 | 185 | 1169 | 17 | 7388 | 202 |

C stock increases from 5.3 PgC to 7.4 PgC, with a net increase of 2.1 PgC.

# 4. Prediction of C sink potential

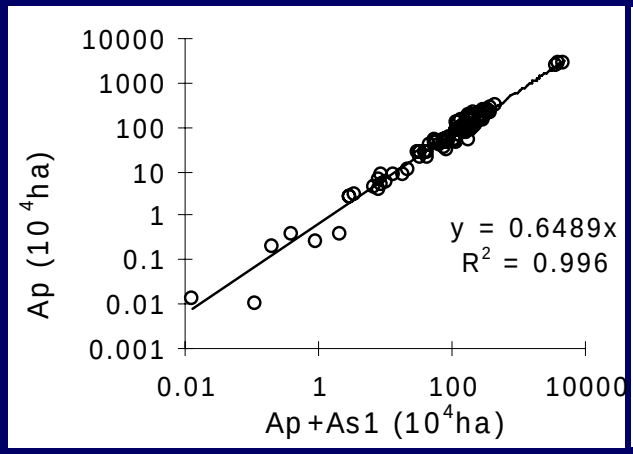
# Prediction based on area change

## Plan of afforestation and reforestation in China (2002)

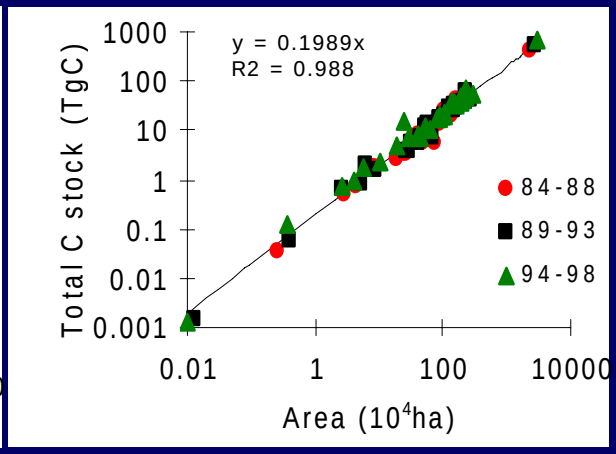
| Period | Coverage (%) | Total area ($10^6$ ha) |
|---|---|---|
| 2003 | 17.6 | 16901.9 |
| 2010 | 20.4 | 19568.4 |
| 2020 | 23.5 | 22528.9 |
| 2030 | 25.5 | 24503.3 |
| 2050 | 28.4 | 27226.6 |
| Net increase | 10.8 | 10324.7 |

# Relationships between forest variables at provincial level

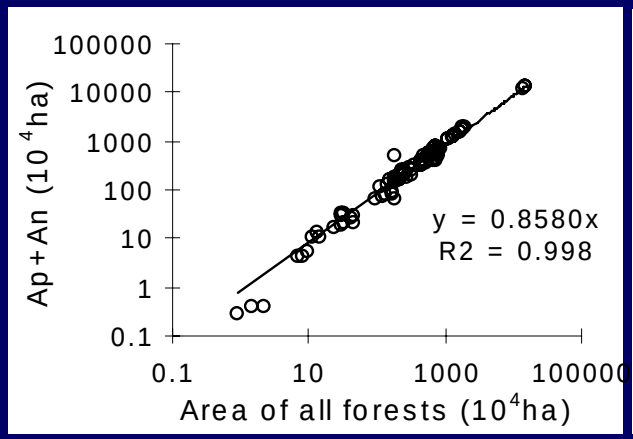
**i: Planted forests**



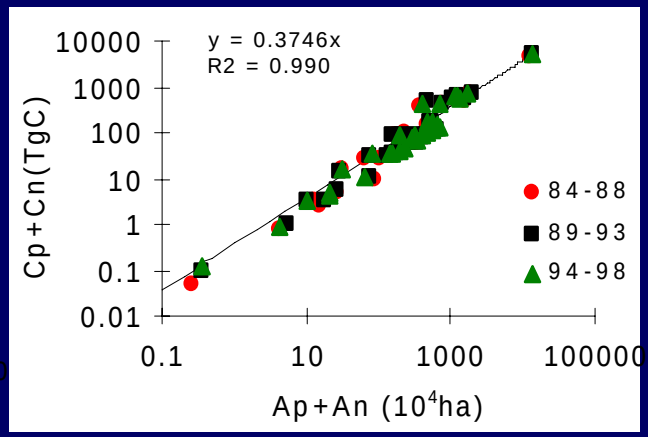

**ii: Planted forests**




**iii : Planted & natural forests**




**iv: Planted & natural forests**




**Ap:** area of planted forests

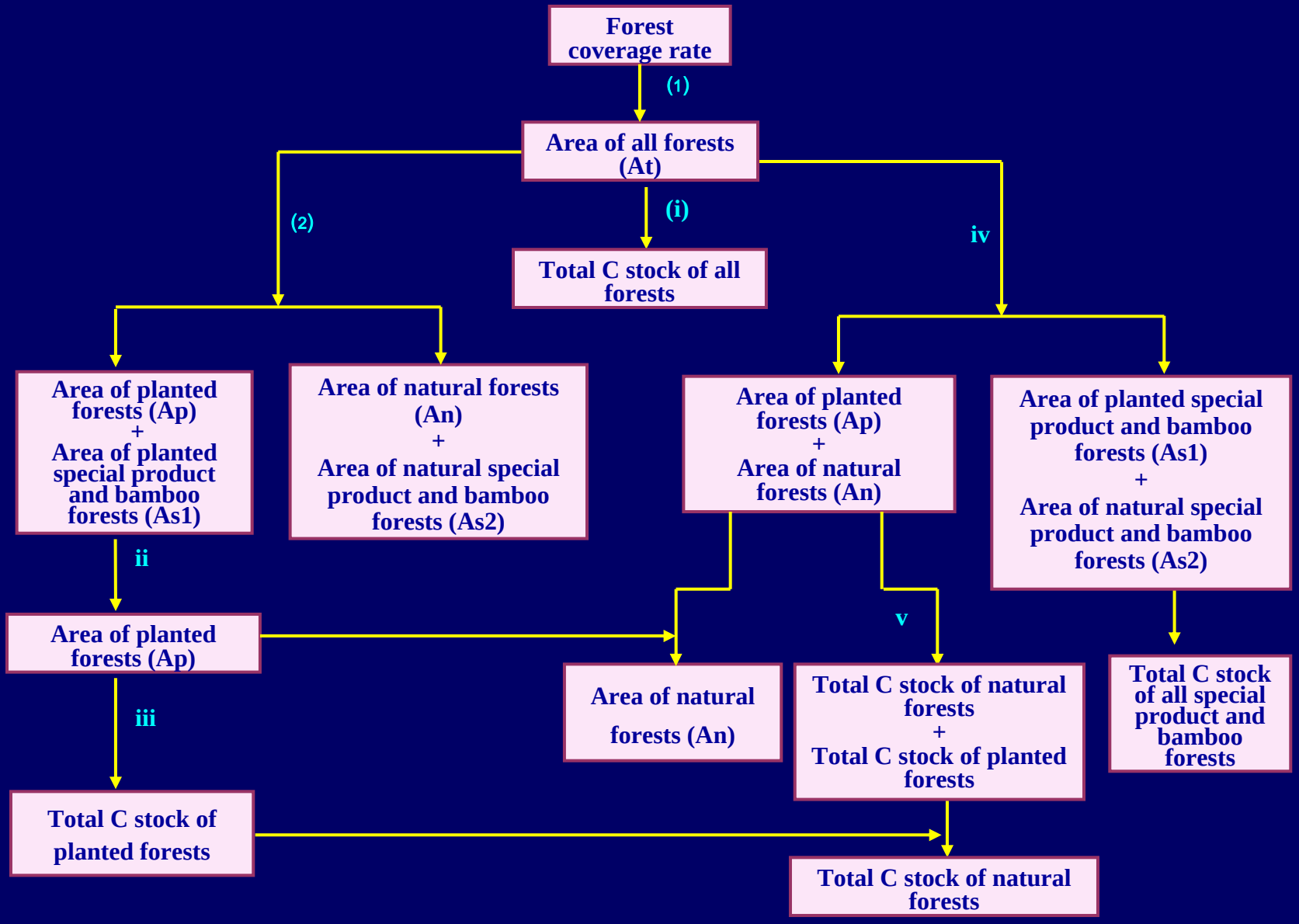
**An:** Area of natural forests

**As1:** area of planted economic and bamboo forests

**Cp:** Total C stock of planted forests

**Cn:** Total C stock of natural forests

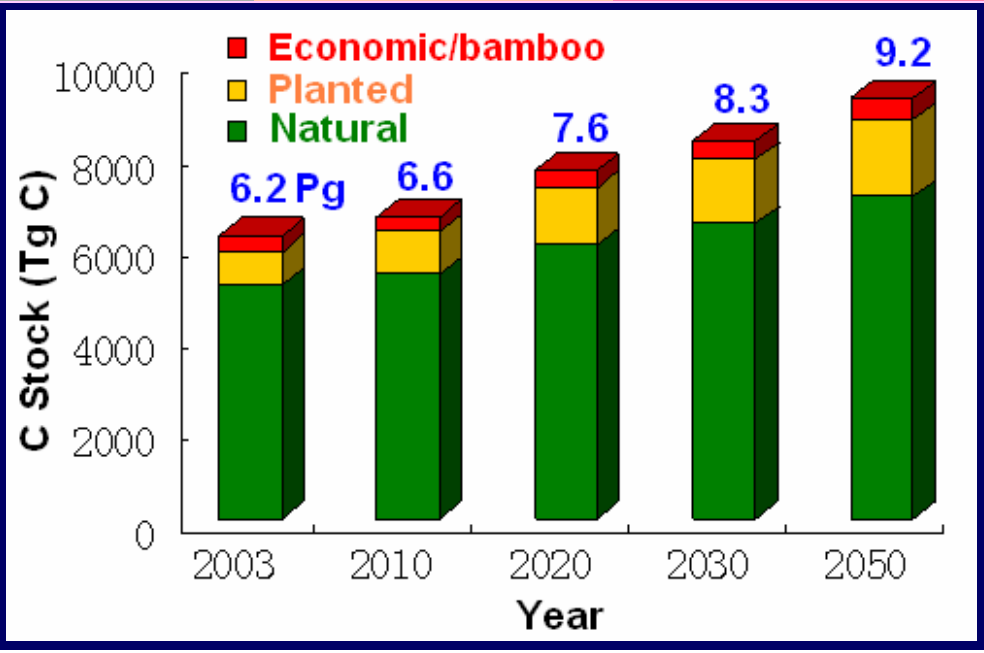
# Flow chart for calculating forest area and C stocks from planned forest coverage using allometric relationships between forest variables derived from forest inventory data



# Total area and total C of existing (2003) and planned forests in China (2010-2050)

| Period | All forests | | Natural forests | | Planted forests | | Economic/ bamboo forests | |
|---|---|---|---|---|---|---|---|---|
| | Total area | Total C | Total area | Total C | Total area | Total C | Total area | Total C |
| 2003 | 16902 | 6189 | 11049 | 5099 | 3229 | 753 | 2623 | 337 |
| 2010 | 19568 | 6612 | 12036 | 5344 | 4754 | 945 | 2779 | 323 |
| 2020 | 22529 | 7612 | 13135 | 6009 | 6194 | 1232 | 3199 | 372 |
| 2030 | 24503 | 8280 | 13869 | 6452 | 7155 | 1423 | 3479 | 404 |
| 2050 | 27227 | 9200 | 14880 | 7064 | 8481 | 1687 | 3866 | 449 |

**Forest C stock in 2050 increases from 6.2 PgC in 2003 to 9.2 Pg C in 2050, increasing by ~50%, with a mean increasing of 0.065 Pg C/yr.**



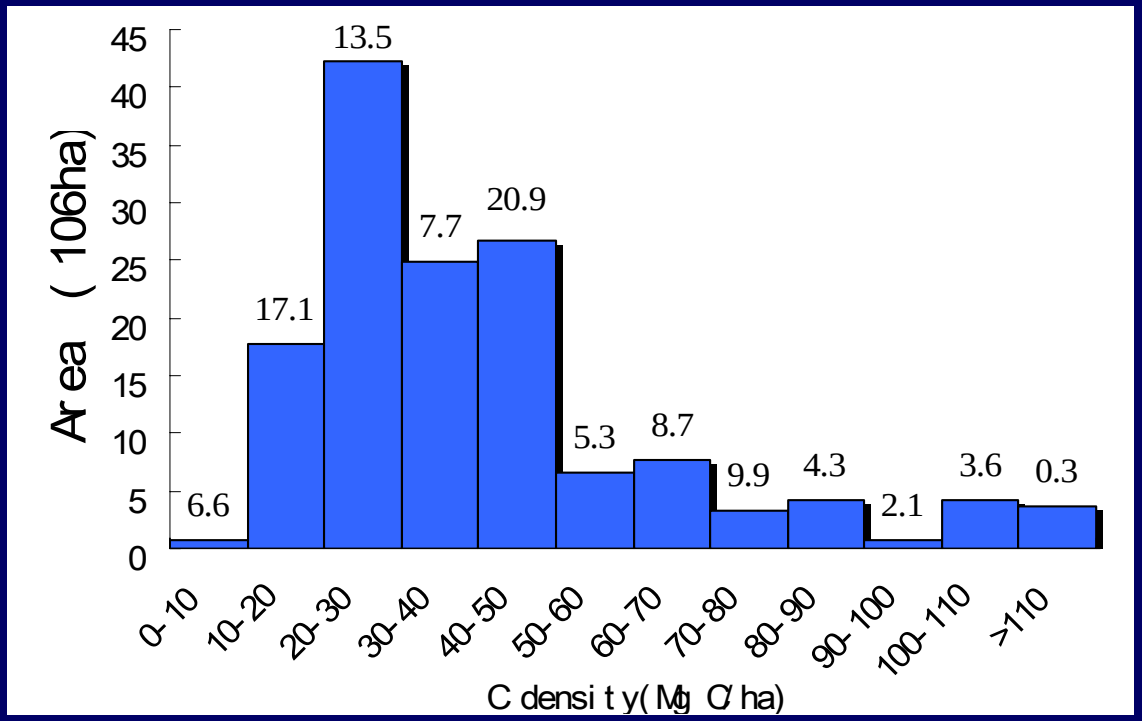
# 5. Key conclusion

- Over the past 2 decades, total C stocks of China's trees have increased by 2.13 PgC, of which C stock of forests increased by 1.65PgC, and that of non-forest trees by 0.48 PgC.
- Non-forest trees are important C stocks, being about 15-19% of total forest C stocks.
- China has a large potential for C sinks by forests: in the future 30-40 yrs, forests can absorb additional 3 PgC at a scenario of current forestry plan.

Thank you!

# 4.1 Prediction based on carbon density

**Forest area frequency of C density for 1999-2003**




Assume: mean C density of China's forests to be 50 t C/ha. If the 78.7% of China's forests with lower C density grow to the assumed level, then the forests could absorb an additional carbon of 2.22 Pg.

60 t C/ha ——3.34 Pg ; 40 t C/ha ——1.22 Pg