African Journal of Agricultural Research Vol. 7(35), pp. 4971-4978, 11 September, 2012
Available online at http://www.academicjournals.org/AJAR
DOI: 10.5897/AJAR12.216
ISSN 1991-637X ©2012 Academic Journals

Full Length Research Paper

China's forest resource dynamics based on allometric scaling relationship between forest area and total stocking volume

Yi Liu[1,2] and Guang-hui She[1]*

[1]College of Forest Resources and Environment, Nanjing Forestry University, Nanjing 210037, China.
[2]Academy of Forest Inventory and Planning, State Forestry Administration, Beijing 100714, China.

Accepted 4 June, 2012

Forest management may play a critical role in optimizing forest resource structure and increasing harvest yield. Analyzing forest resource growth dynamics is a basis for correctly determining forest management procedures. Thus, allometric scaling equations were developed to estimate forest growth trends based on seven regional forest systems and the overall national forest system in China. Historical trends in all seven regional forest systems were estimated with high coefficients of determination (R^2 > 0.85), and the national forest resource system had a significantly higher coefficient (R^2 = 0.984), which demonstrated the optimized fit of our model. Growth factors of the regional forest resource systems ranged from 0.77 to 1.62, whereas the growth factor of the national resource system was 0.89. Degeneration analysis indicated a semi-degeneration trend in the allometric scaling, possibly caused by limited land availability for afforestation. Consequently, it is imperative to improve forest resource management and focus on enhancing forest resource quality. In general, China's forest resources have developed in an optimized process characterized by continual increases in the total stocking volume and forest area and continued improvement of forest quality and structure. Forest management will play a critical role in China's forestry development in the future.

Key words: China forest resource, allometric fractal growth relationship, forest area, stocking volume.

INTRODUCTION

Forests form major components of terrestrial ecosystems and of global carbon reserves. Forests provide a number of valuable goods and services and greatly influence the lives of other organisms, including humans (Perry, 1994; Kimmins, 2004; Stern and Predmore, 2011). A forest system can be divided into two subsystems: an ecological system and an economic resource system. Because global climate change and ecological issues pose significant challenges to the global environment, more attention is currently being paid to the forest ecological system than to the forest as a natural resource. Stocking volume, defined here as the total harvestable volume, is a fundamental measure of the natural resource components of forests, including fuel energy and wood, and is an important strategic reserve of lumber (Yang YJ, 2007). However, forest resource assessment is essential to predict growth trends of the forest ecological system and determine forest management patterns (Hamburg et al., 1997; Fang et al., 1998, 2001).

Allometric relationships are widely used to estimate the volume or biomass of individual trees and of different forest types (Whittaker and Woodwell, 1968; Jørgensen et al., 1998). Allometry is a term coined by Snell in 1891 (Lee, 1989) and describes a fundamental biological concept. Huxley (1924) noted that the relative growth of one part of an organism is correlated to that of another

*Corresponding author. E-mail: ghshe@njfu.com.cn. Tel: 0086-025-85427797. Fax: 0086-025-85427797.

part, the whole organism, or a metabolic process. In addition, the ratio of the two growth rates, which is now known as the allometric scaling factor, is a constant (Huxley, 1924; Lin et al., 2009) for both animals (LaBarbera, 1989; Harvey and Pagel, 1991) and plants (Primack, 1987; Niklas, 1995; Sun et al., 2006). Allometry has been applied widely in many disciplines (for example, Naroll and Bertalanffy, 1973; Lee, 1989; Makarieva et al., 2004), including forestry research.

Previous research on allometric relationships in forests has been characterized by three notable limitations. First, allometric theory was developed from research on individual animals, and was first applied to plant morphology and plant evolutionary biology at an individual level (Primack, 1987; Niklas, 1995; Sun et al., 2006). Most subsequent studies have focused on allometric relationship models of specific species or specific forest types (Montagu et al., 2005; Fehrmann and Khinn, 2006; Socha and Wezyk, 2007) or on combining individual allometric equations for each of several tree species to develop a relatively generalized equation for a specific geographic region (With and King, 2004; Wang, 2005; Muukkonen, 2007). Second, a long-standing concern involves how widely applicable allometric relationships are (Montagu et al., 2005). Allometric equations are typically site-specific and are thus narrowly applicable to the original objective for which they were developed. However, a few studies have combined data from multiple sites for systematic development of a set of general allometric relationships for specific species or a specific group of species (Pastor et al., 1984; Jenkins et al., 2003; Montagu et al., 2005). Third, few allometric relationships are reported for time-series data (Alados et al., 2005).

Most studies centered on an individual region have focused on applying allometric relationships to inventory data at a single point in time. The scarcity of time-series data poses challenges to studying allometric scaling relationships. Thus, most previous research on the allometric relationships of forests has been species-specific, region-specific (or site-specific), or time-specific. Because sustainable forest management is of increasing concern, research on regional forest allometric scaling relationships is important to understand how to promote forest growth potentials and increase harvest yield. In China, certain forest characteristics, including uneven spatial distributions, unsatisfactory quality, and insufficient coverage, have persisted for decades (Li, 2004). However, with implementation of six key forestry programs, increased financial support of the forestry sector by the state, and enhancement of public awareness, great improvements are being made in forestry, especially in forest resource conservation (Yang JP, 2007).

In order to properly implement sustainable forest management in China, the objectives of this study were to: (1) develop allometric scaling equations using stocking volume and forest area for seven geographic regions of China, (2) analyze the past allometric characteristics of China's forest resource systems, and (3) make predictions about future trends in China's forest resource systems. Given the difficulties associated with long-term and large-scale estimation, allometric models for estimation of forest volume were not a focus of the present research.

MATERIALS AND METHODS

Study regions

The geography of China ranges from mostly plateaus and mountains in the west to lower-altitude lands in the east. The diverse climate is dominated by dry seasons and wet monsoons. For this study, China (excluding Hong Kong, Macao, and Taiwan) was divided into seven study regions on the basis of natural environment, human history, and development level (CAS, 2004; Lei, 2005): the northeast, north, northwest, south, southwest, east, and central regions (Figure 1).

Data selection

At an individual-tree level, tree volume or biomass can be predicted from easily measurable variables, such as diameter at breast height (dbh) or total tree height (*h*), using allometric relationships determined for sample trees in monitored plots (Socha and Wezyk, 2007). Similarly, to develop regional allometric scaling equations, variables that reflect certain fundamental characteristics of regional forests are necessary. We identified such variables using two principles: (1) an essential forest resource attribute was represented by the variable, and (2) the variable was easily measurable or accessible.

A forest resource system is determined by slow-changing rather than rapidly changing variables (Haken, 2004). Area, which is comparatively stable and changes at a relatively slow speed, is an important factor in a forest resource system (Lei, 2005). Therefore, forest area is an excellent variable for analysis of forest resource systems. In addition, area data for China can be extracted conveniently from the National Forest Inventory (NFI) data published by the State Forestry Administration (SFA). The NFI has been conducted every 5 years since 1972 to evaluate forest resource status and changes for each administrative division of China. Systematic sampling methods are used and have not changed since the NFI began (Xiao, 2005). However, the first NFI did not cover all of the provinces of China, so we excluded the data from 1972 for this study. Table 1 summarizes the regional forest resources of the seven study regions as extracted from the data from the six most recent NFIs released by the SFA.

Allometric scaling equation

System theory assumes that a finite number of connected variables can describe a forest resource system (Bertalanffy, 1973). With the measurements (x_i) of variables (p_i) ($i = 1, 2, \cdots, n$), temporal relations between the variables can be described as differential equations:

$$\frac{dx_i}{dt} = f_i(x_1, x_2, \cdots, x_n) \quad (1)$$

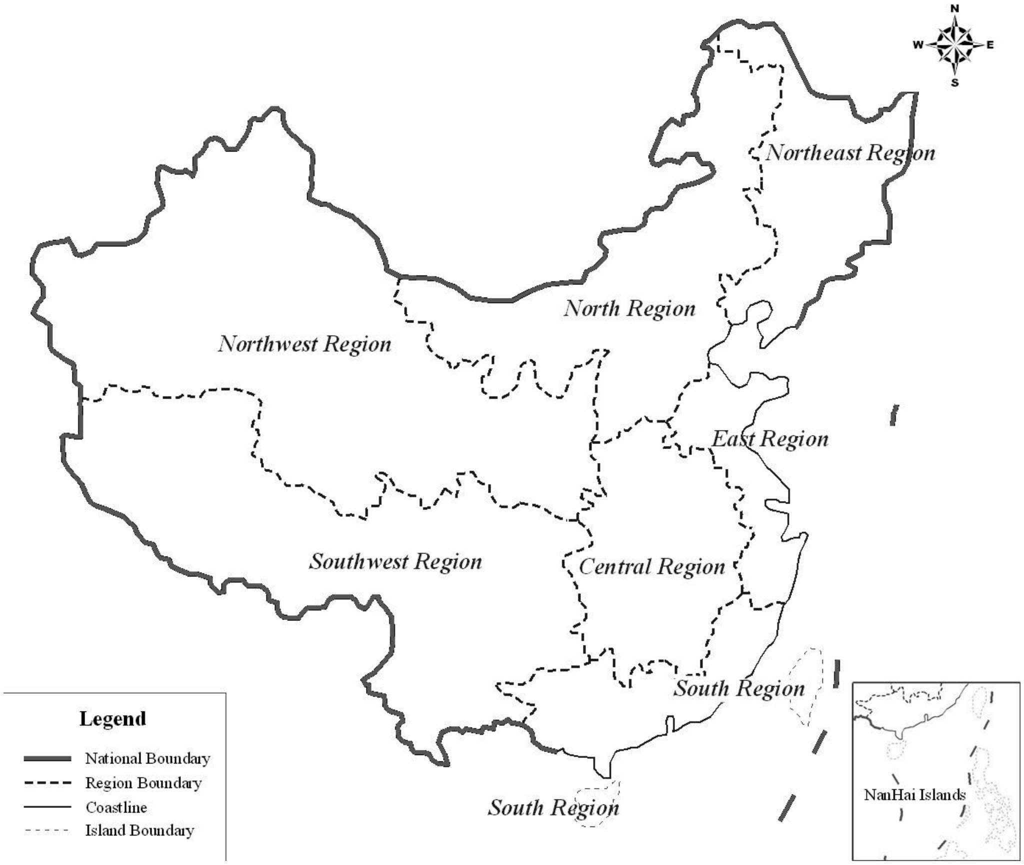

Figure 1. Administrative map of China showing delineation of the seven regions recognized for the forest resource system analysis.

Consider a system that consists of two variables, such as the Taylor series expansion on the right side:

$$\frac{dx_i}{dt} = a_i x_i, \frac{dx_j}{dt} = a_j x_j \quad (2)$$

where a_i and a_j are the relative growth rates. The allometric scaling equation can be deduced from equation (2) as:

$$x_i = b_j x_j^{a_{ij}} \quad (3)$$

where $a_{ij} = a_i / a_j$. Equations (1) to (3) were derived by Bertalanffy (1973).

In the present study, the variables forest area, *A*, and volume, *V*, were selected to represent the forest resource system. The variable *A* represents the total forest area of a region (excluding commercial plantations and bamboo forests) and *V* represents the stocking volume of that region.

Fractal properties of the allometric scaling equation

Suppose the dimension of x_i is D_i, and D_j is the dimension of x_j. According to the principle of dimensional analysis, if the measures are transformed in the same dimension, then the result is:

$$x_i \propto x_j^{D_i / D_j} \quad (4)$$

Comparing equations (3) and (4), we find that:

$$a_{ij} = D_i / D_j \quad (5)$$

Because a_{ij} represents the fractal dimension, the allometric scaling equation is considered to be a general fractal property.

Degeneration of the allometric relationship

The allometric relationship is usually described as a power-exponent equation. However, in reality, a power-exponent equation may semi-degenerate into an exponential equation or a logarithmic equation, or even totally degenerate into a linear equation (Chen, 2008). In equation (2), if $x_j = x_{0j}$ is a constant, then $dx_j / dt = a_j x_{0j}$. Here, x_{0j} refers to the variable of stocking volume corresponding to forest area, which means that the growth

Table 1. National Forestry Inventory (NFI) forest resource data for China.

Region	Inventory[a]	Area (million ha)	Volume (million m^3)	Region	Inventory[a]	Area (million ha)	Volume (million m^3)
Northeast China	1977-1981	2370.26	219399.64	North China	1977-1981	1482.99	90926.42
	1984-1988	2450.99	214827.21		1984-1988	1523.36	95125.82
	1989-1993	2512.59	224111.09		1989-1993	1601.26	100006.96
	1994-1998	2769.81	235863.01		1994-1998	1761.03	110601.71
	1999-2003	2826.31	236624.39		1999-2003	2003.26	123844.05
	2004-2008	3000.71	256744.10		2004-2008	2182.92	134975.73
Northwest China	1977-1981	724.11	63575.54	South China	1977-1981	1279.2	72044.77
	1984-1988	810.19	64916.75		1984-1988	1266.03	65364.07
	1989-1993	765.98	67521.73		1989-1993	1539.43	75471.85
	1994-1998	897.39	76725.07		1994-1998	1941.11	90530.64
	1999-2003	900.25	80305.25		1999-2003	2061.08	116395.41
	2004-2008	996.28	87692.69		2004-2008	2135.67	132769.06
Southwest China	1977-1981	2353.48	367276.68	East China	1977-1981	306.11	8726.59
	1984-1988	2713.16	420474.885		1984-1988	379.43	10562.29
	1989-1993	2831.32	455830.3		1989-1993	383.41	11784.78
	1994-1998	3409.66	494648.19		1994-1998	429.39	13492.69
	1999-2003	3802.15	542315.73		1999-2003	489.52	17056.01
	2004-2008	4059.2	574843.18		2004-2008	627.57	27164.37
Central China	1977-1981	1367.01	53846.09	China	1977-1981	9883.16	875795.73
	1984-1988	1438.59	52815.71		1984-1988	10581.75	924086.74
	1989-1993	1550.45	56264.01		1989-1993	11184.44	990990.72
	1994-1998	2032.17	68976.93		1994-1998	13240.56	1090838.24
	1999-2003	2196.1	93222.84		1999-2003	14278.67	1209763.68
	2004-2008	2556.64	122070.33		2004-2008	15558.99	1336259.46

[a]The NFI has occurred every 5 years since 1972. The first NFI did not include all regions of China, so we used only data from the second (1977 to 1981) through the seventh (2004 to 2008) NFIs in this study.

of x_j is independent of its own scale. Deduced from equation (3):

$$x_i = ae^{bx_j} \quad (6)$$

Where $b = a_{ij} / x_{0j}$. The growth of x_j is independent of its scale size, which is why the power-exponent equation degenerates and then semi-degenerates into an exponential equation. Similarly, if $x_i = x_{0i}$ is a constant, then $dx_i / dt = a_i x_{0i}$. Here, x_{0i} refers to the variable of forest area corresponding to stocking volume, which means that the growth of x_i is independent of its own scale, thus:

$$x_i = a + b \ln x_j \quad (7)$$

Where $b = a_{ij} \cdot x_{0i}$. If $x_i = x_{0i}$ and $x_j = x_{0j}$ refer to the synchronous variables of forest area and stocking volume, the power-exponent equation perfectly degenerates into a linear equation:

$$x_i = a + bx_j \quad (8)$$

Where $b = a_{ij} \cdot x_{0i} / x_{0j}$.

The essence of the degeneration of the allometric relationship is a restriction on the growth of variables in which the growth of one (or both) variable(s) is no longer connected with its scale size. The degeneration of the allometric relationship can be regarded as a sign of fractal structure degeneration in the forest system. To examine the allometric scaling relationships in the seven study regions of China, time-series data for forest area and stocking volume in each region was plotted on a log-log graph. We performed the same analysis on China's national forest resource data as a whole.

RESULTS

Regional allometric scaling equations

The scatter plots (Figure 2) demonstrated that, in general, as forest area increases, so does stocking volume. From the best-fit lines in the scatter plots (Figure 2), the variables in these regional forest resource systems showed a general uniformity with the allometric relationship (coefficient of determination $R^2 > 0.85$). Here, $A(t)$ refers to the forest area data series, and $V(t)$ refers to the stocking volume data series. The analysis of the allometric scaling relationship implied that there was no negative growth in any variable, that is $dx_i / dt \geq 0$. In reality, any organic system may have partial regression even when normally allometric scaling equations are expected to increase. Of the seven regions, three (north, east, and southwest) showed a strong linear correlation ($R^2 > 0.95$) between forest area and stocking volume on the log-log graphs, in contrast to the lower goodness of fit of the other four regions, which probably differ because of climatic conditions. However, the national forest resource system showed a relatively high coefficient of determination ($R^2 = 0.9565$), which indicated that increasing stocking volume depended on expansion of the forest area.

Scaling factors

The growth factor, defined as $a_{ij} = a_i / a_j$, characterizes the relative growth rates of x_i and x_j. The ratio of x_i to x_j can be deduced from equation (5):

$$\frac{x_i}{x_j} = b_j x_j^{\,a_{ij}-1} \tag{9}$$

When $a_{ij} > 1$, the growth rate of x_i exceeds that of x_j, whereas when $a_{ij} < 1$, the opposite relationship is true. When $a_{ij} = 1$, the two variables possess identical growth rates. Table 2 shows the growth factors of the seven regional forest resource systems and the national forest resource system. Of the seven regions, the growth factors of the northwest, central, south, and southeast regions were above 1, the growth factors of the northeast and southwest regions were below 1, the growth factor of the north region was nearly 1, and the growth factor of China overall was below 1.

Degeneration analysis

Degeneration of the allometric relationship is mainly caused by growth limitation of the variables to which it is restricted. To determine whether the Chinese forest systems showed degenerate trends, the coefficients of determination of the models were compared. Among the power-exponent equation models-the exponent, power, and linear equations-the best-fit equation is that with the highest R^2 value. Because the power-exponent equation did not have the highest R^2 value among the models, we concluded that a degenerate trend existed. A rapid degeneration trend was observed in this study. For example, for the east region, the exponent equation model ($R^2 = 0.980$) had a higher R^2 value than the power-exponent equation model ($R^2 = 0.980$). Because the simpler equation showed a better fit to the data, an ongoing semi-degeneration trend existed in this region; the trend was connected directly with restrictions to increases in forest area in the region. Further analysis of the other regions revealed similar semi-degeneration trends.

DISCUSSION

The allometric scaling equation has a general fractal property, and fractal structure is always regarded as a characteristic of a stable and optimized system (Lee, 1989). In the case of system analysis, a highly accurate estimation of the allometric scaling equation implies that forest management has a positive effect on the optimal forest structure (Chen, 2008). The present results revealed that all of the seven regional forest resource systems were estimated accurately by the allometric models ($R^2 > 0.85$) (Figure 2). The models with logarithmic transformations of these regional forest resource systems had high R^2 values that ranged from 0.869 to 0.997. We concluded that these regional forest resource systems had optimized growth structures and were in stable growth trends. In general, a regional forest resource system is influenced mainly by environmental conditions and local forest management policy. The regeneration ability of a forest is the most important factor that regulates forest resource system restoration. An adverse ecological environment has a negative influence on the quality of forest resources. For example, both the north and northwest regions are deficient in forest coverage because of the adverse environmental conditions and fragile ecological systems. However, the north and northwest regions in 1978 addressed the protection of forest resources and afforestation, and the unremitting efforts resulted in remarkable afforestation achievements, as confirmed by the high R^2 values (0.997 and 0.909) (Figure 2) of the allometric scaling models for these two regions.

Surprisingly, the national forest resource system had a higher coefficient of determination ($R^2 = 0.957$) than the seven forest regions. Because of dramatic increases in the areas of non-commercial forest and a variety of shelterbelts, China has successfully expanded its forest area and stocking volume in recent decades, especially in the north, east, and central regions. The high R^2 value demonstrates the optimized growth structure of the national forest resource system. China is a vast country

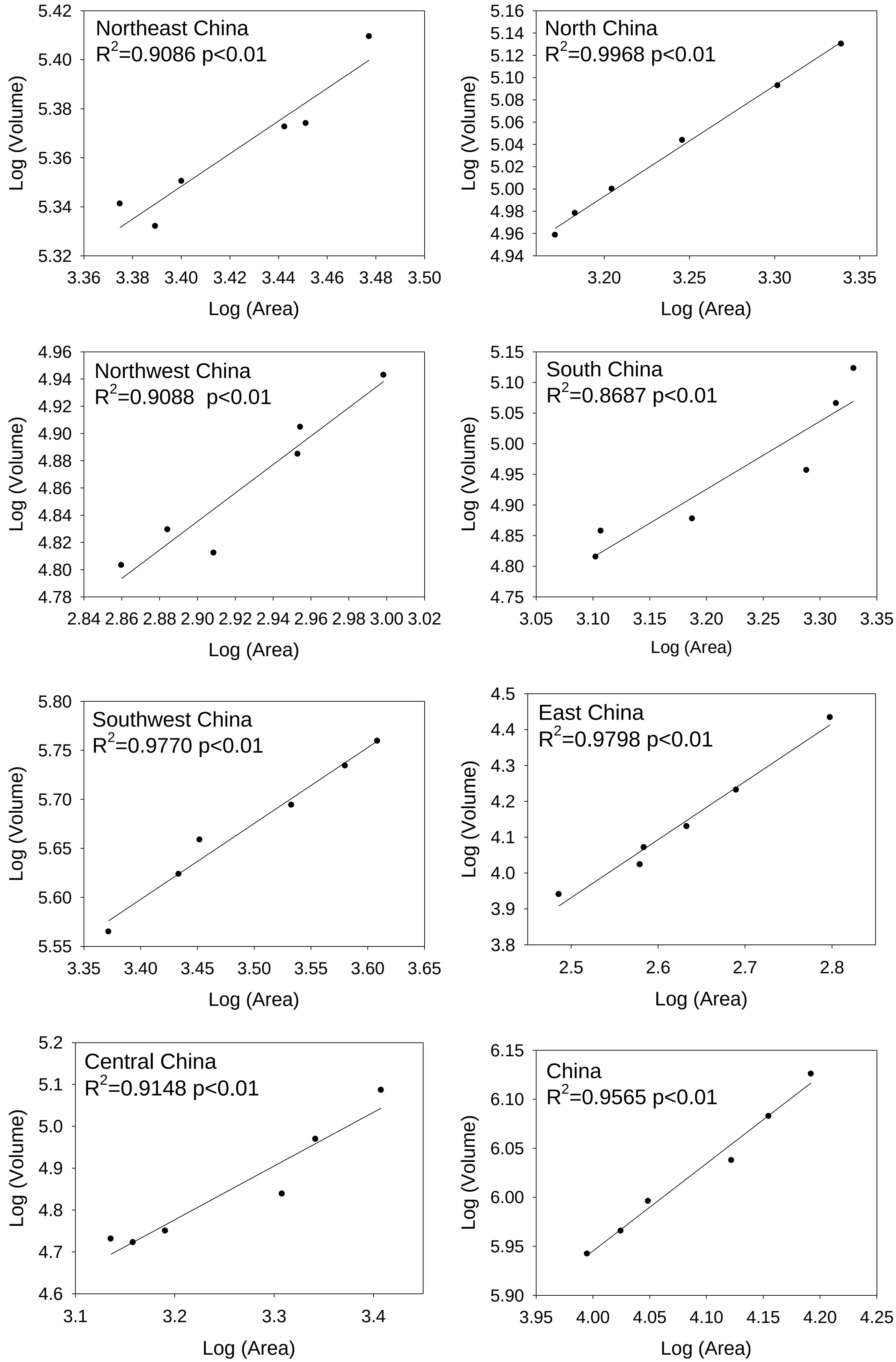

Figure 2. Relationships between forest area and stocking volume in the seven regions and China's national forestry system. The points plotted in each graph are data from National Forest Inventories of China.

Table 2. Fitting equations and growth factors.

Region	Fitting equation	Growth factor	Region	Fitting equation	Growth factor
Northeast China	$\ln V = 0.667 \ln A + 7.0928$	$a_{ij} = 0.667$	North China	$\ln V = 0.9947 \ln A + 4.1687$	$a_{ij} = 0.9947$
Northwest China	$\ln V = 1.0454 \ln A + 4.1534$	$a_{ij} = 1.0454$	South China	$\ln V = 1.1097 \ln A + 3.1648$	$a_{ij} = 1.1097$
Southwest China	$\ln V = 0.7744 \ln A + 6.8275$	$a_{ij} = 0.7744$	East China	$\ln V = 1.6185 \ln A - 0.2647$	$a_{ij} = 1.6185$
Central China	$\ln V = 1.284 \ln A + 1.5377$	$a_{ij} = 1.284$	China	$\ln V = 0.893 \ln A + 5.4649$	$a_{ij} = 0.893$

with diverse physical environments. For this reason, we conclude that some of the regional forest resource systems, which are subsystems of the overall national forest resource system, are in different stages of maturity. For example, the northeast forest region is mostly covered with young forest because of excessive harvesting during the 1950s; the southwest forest region is characterized by over-mature forest for the inconvenient road transportation.

The ratio of stocking volume to forest area (x_i / x_j), which is also called unit volume, represents the quality of forest resources. The growth factor (a_{ij}) for a forest resource system is of great practical importance. If $a_{ij} > 1$, then the unit volume rises when the forest area expands. If $a_{ij} < 1$, then the unit volume is predicted to diminish as the forest area increases. The regional forest resource systems of the north, southwest, and east regions had the highest unit volumes of the seven regions. However, their growth factors differed greatly from 0.77 to 1.62. In the north region of China, $a_{ij} = 0.9947 \approx 1$, which indicates that, through long-term mass afforestation, the forest area of this region is growing sustainably and the stocking volume is growing at the same rate as forest area, but without any improvement in forest quality or increase in unit volume. The southwest region covers a wide altitudinal range and is rich in near-mature, mature and over-mature stands.

In the forest resource system of the southwest region, the growth factor (a_{ij} = 0.774) was much lower than one, which indicated that the growth rate in forest area was higher than that of stocking volume. As forest area increased, the unit volume in the southwest region actually decreased. In contrast, the growth factor in the east region (a_{ij} = 1.619) exceeded one and the unit volume increased rapidly with area. This trend is mainly attributable to the favorable hydrothermal conditions and decades of forest management. The growth factor of the national forest resource system (a_{ij} = 0.893) was less than one. China's objective of accelerating forest resource development has achieved significant increases in forest area and timber volume, and thus the trend of long-term decline in forest resources has been reversed.

Rapid afforestation, however, has meant that the rate of growth in forest area greatly exceeds the increase in volume. The unit volume in China is less than 86 m^3/ha, which is only three-quarters of the world average of 110 m^3/ha (FAO, 2009). The growth in unit volume in China is 3.85 m^3/ha/year, which is about 50% of that in nations with developed forestry systems (State Forest Administration, 2009). The government of China has implemented an afforestation plan to increase the forest area by 40 million ha and stocking volume to 1.3 billion m^3 by 2020 to address the effects of climate change. On the basis of environmental conditions and land-use strategies, the land area suitable for further expansion of forest area is likely to be limited after 2020. The semi-degeneration trend identified in this study provides evidence of the limitation of available area for afforestation in some regions. This semi-degeneration trend could be considered as the loss of a well-established forest resource allometric scaling structure.

Given the restriction on available land for afforestation, it is imperative that forest resource management is further improved and the quality of forest resources is continually enhanced. Sustainable forest management is likely to play a critical role in the development of Chinese forestry in the future.

Conclusion

China’s forest resources have experienced an uninterrupted period of expansion characterized by continual increases in total stocking volume and forest area as well as continued improvement in forest quality and structure. The results of the present study indicate that the allometric scaling characteristics of the seven regional forest resource systems conform to the current forest resource situation within China. Since the beginning of the twenty-first century, China’s forestry system has experienced a period of rapid improvement. To maintain the optimal growth of its forest resource systems, enhancing unit volume (or forest resource quality) is essential. After decades of implementing a strategy for sustainable forest management, China has succeeded in fostering a healthy, stable, and efficient forest system.

REFERENCES

Alados CL, Pueyo Y, Navas D, Cabezudo B, Gonzalez A, Freeman DC (2005). Fractal analysis of plant spatial patterns: A monitoring tool for vegetation transition shifts. Biodivers. Conserv. 14:1453-1468.

Bertalanffy LV (1973). General System Theory: Foundations, Development, and Applications. George Breziller, New York, USA. P.1-295

CAS (2004). Chinese Sustainable Develop Strategy Report (In Chinese). Science Press, Beijing, China (In Chinese). Pp.1-537.

Chen YG (2008). Fractal urban system: Scaling· Symmetry· Spatial complexity. Science Press, Beijing, China (In Chinese. Pp. 1-410

Fang JY, Chen AP, Peng CH, Zhao SQ, Ci J (2001). Changes in forest biomass carbon storage in China between 1949 and 1998. Science 292:2320-2322.

Fang JY, Wang G, Liu GH, Xu SL (1998). Forest biomass of China: an estimate based on the biomass-volume relationship. Ecol. Appl. 8:1084-1091.

FAO (2009). State of the World's Forests, 2009. FAO Communication Division, Rome, Italy.

Fehrmann L, Khinn C (2006). General consideration about the use of allometric equations for biomass estimation on the example of Norway spruce in central Europe. For. Ecol. Manag. 236:412-421.

Haken H (2004). Synergetics: Introduction and Advanced Topics. Springer, Berlin. Pp.1-63.

Hamburg SP, Zamolodchikov DG, Korovin GN, Nefedjev VV, Utkin AI, Gulbe JI, Gulbe TA (1997). Estimating the Carbon Content of Russian Forests; A Comparison of Phytomass/Volume and Allometric Projections. Mitig. Adapt. Strat. Global Change 2:247-265.

Harvey PJ, Pagel MD (1991). Comparative Method in Evolutionary Biology. Oxford University Press, Oxford, UK pp.1-248

Huxley JS (1924). Constant differential growth—ratios and their significance. Nature 114:895.

Jenkins JC, Chojnacky DC, Heath LS, Birdsey RA (2003). National-scale biomass estimators for United States tree species. For. Sci. 49:12-35.

Jørgensen SE, Mejer H, Nielsen SN (1998). Ecosystem as self-organizing critical systems. Ecol. Model. 111:261-268.

Kimmins JP (2004). Forest Ecology: A Foundation for Sustainable Forest Management and Environmental Ethics in Forestry, 3rd Ed. Prentice Hall, New Jersey, USA. Pp. 25-30

LaBarbera M (1989). Analyzing body size as a factor in ecology and evolution. Ann. Rev. Ecol. Syst. 20:97-117.

Lee Y (1989). Allometric analysis of the US urban system: 1960-1980. Environ. Plan. A 4:463-476.

Lei JF (2005). Forest Resource of China. China Forestry Publishing House, Beijing, China (In Chinese). Pp. 1-12

Li WH (2004). Degradation and restoration of forest ecosystem in China. Forest Ecol. Manag. 201:33-41.

Lin H, Cao M, Stoy PC, Zhang Y (2009). Assessing self-organization of plant communities—A thermodynamic approach. Ecol. Model. 220:784-790.

Makarieva AM, Gorshkov VG, Li BL (2004). Body size, energy consumption and allometric scaling: A new dimension in the diversity-stability debate. Ecol. Complex. 1:139-175.

Montagu KD, Düttmer K, Barton CVM, Cowie AL (2005). Developing general allometric relationships for regional estimates of carbon sequestration- an example using Eucalyptus pilularis from seven contrasting sites. For. Ecol. Manag. 204:113-127.

Muukkonen P (2007). Generalized allometric volume and biomass equations for some tree species in Europe. Eur. J. For. Res. 126:157-166.

Naroll RS, Bertalanffy LV (1973). The principle of allometry in biology and the social sciences. Ekistics 36:244-252.

Niklas KJ (1995). Size-dependent allometry of tree height, diameter and trunk-taper. Ann. Bot. 75:217-227.

Pastor J, Aber JD, Melillo JM (1984). Biomass prediction using generalized allometric regressions for some northeast tree species. Forest Ecol. Manag. 7:265-274.

Perry DA (1994). Forest Ecosystems. The Johns Hopkins University Press, Baltimore, USA. P. 649

Primack RB (1987). Relationships among flowers, fruits and seeds. Ann. Rev. Ecol. Syst. 18:409-430.

Socha J, Wezyk P (2007). Allometric equations for estimating the foliage biomass of Scots pine. Eur. J. For. Res. 126:263-270.

State Forest Administration (2009). China Forest Resource Report – The 7th National Forest Inventory. China Forestry Publishing House, Beijing, China. (in Chinese). P. 1-12

Stern MJ, Predmore SA (2011). Decision making, procedural compliance, and outcomes definition in U.S. forest service planning processes. Environ. Impact Assess. Rev. 31:271-278.

Sun SC, Jin DM, Shi PL (2006). The leaf size-twig size spectrum of temperate woody species along an altitudinal gradient: an invariant allometric scaling relationship . Ann. Bot. 97:97-107.

Wang CK (2005). Biomass allometric equations for 10 co-occurring tree species in Chinese temperate forests. Forest Ecol. Manag. 222:9-16.

Whittaker RH, Woodwell GM (1968). Dimension and production relations of trees and shrubs in the Brookhaven Forest, New York. J. Ecol. 56: 1–25.

With KA, King AW (2004). The effect of landscape structure on community self-organization and critical biodiversity. Ecol. Model. 179:349–366.

Xiao XW (2005). National Forest Resource Inventory of China. China Forestry Publishing House, Beijing, China (in Chinese). P.20-36

Yang JP (2007). China's Forestry (1999–2005). China Forestry Publishing House, Beijing, China (in English). P.1-76.

Yang YJ (2007). Essential concepts and thoughts about strategic storage of forest resources. Cent. S. For. Invent. Plan. 26:4-7 (in Chinese).