Front. For. China 2008, 3(2): 206–212
DOI 10.1007/s11461-008-0037-4

RESEARCH ARTICLE

Tangren CHENG, Jing FENG, Qinyan MA, Zhongke FENG, Yanlin ZHANG, Xu LUO, Yutao WANG

Forest biomass at Xiaolong Mountain in Gansu Province, China

Abstract In order to accurately estimate the size of the carbon pool and the capacity of the carbon sink in the forested areas of Xiaolong Mountain in Gansu Province, we have established regression equations of organ biomass of eight tree species. We measured and investigated the biomass of different forest stand types based on data from 1259 standard sample plots and 836 standard sample trees. The results show that stand biomass, expressed in $t \cdot hm^{-2}$ for eight types of forest stands on Xiaolong Mountain, are as follows: *Quercus aliena* var. *acuteserrata* 84.05, *Pinus tabulaeformis* 62.44, *Quercus variabilis* 81.77, *Populus* sp. and *Betula* sp. combined 77.44, *Larix* sp. 69.00, *Pinus armandii* 70.07, *Picea* sp. 96.49 and *Abies* sp. 98.72. We also looked at other broad-leaved mixed forests. Our study shows that the biomass of a single tree of each tree species is closely related to the diameter at breast height (DBH) and to tree height. The biomass of single trees as well as stand volumes is closely related to average DBH, average tree height and to stand density.

Keywords biomass, stand types, tree species, Xiaolong Mountain

1 Introduction

Investigators have reported the results of biomass estimates for various tree species (for an overview, see Pardé, 1980; Canell, 1982; Xiang et al., 2003; Xue and Yang, 2004). As one of the major items of research in ecology and global change, estimates of tree biomass provide a basis for the investigation of terrestrial ecosystem carbon cycles and carbon dynamics (Woodwell et al., 1978; Fang et al., 1998, 2001; Jiang and Zhou, 2001; Yang et al., 2003; Zhao and Zhou, 2004). Studies of forest biomass at Xiaolong Mountain, typically representative of forests in western China, are needed in order to obtain information about forest structures and forest productivity and to study the amount and function of the carbon pool in this area (Ma et al., 2002).

Translated from *Journal of Beijing Forestry University*, 2007, 29(1): 31–36 [译自: 北京林业大学学报]

Tangren CHENG (✉)
National Engineering Research Center for Floriculture, Beijing Forestry University, Beijing 100083, China
E-mail: chengtangren@163.com

Jing FENG
Beijing Forestry University Library, Beijing Forestry University, Beijing 100083, China

Tangren CHENG, Qinyan MA, Zhongke FENG, Yanlin ZHANG, Xu LUO, Yutao WANG
College of Forestry, Beijing Forestry University, Beijing 100083, China

Yanlin ZHANG
Gansu Forestry Technological College, Tianshui 741020, China

2 Site description

The study was conducted in the Xiaolong Mountain area (6238 km^2), in the southeast of Gansu Province, northwestern China (33°30′–34°49′N, longitude 104°22′–106°43′E), located in the western portion of the Qinling Mountains. The study site belongs to a warm temperate moist area, dominated by a subtropical continental monsoon climate. The mean annual temperature ranges from 7 to 12°C. The annual amount of sunshine ranges from 1520 to 2313 h. The number of frost-free days varies from 120 to 218 d per year. The annual rainfall ranges from 460 to 900 mm and the annual evaporation capacity from 989 to 1658 mm. The soil consists largely of loam and light loam (An, 1995; Mao et al. 2003; Suo et al., 2004; Wei, 2004).

The forests of the Xiaolong Mountain contain 824 woody plant species (312 trees and 512 shrubs) and 1687 herb species. The main deciduous trees are *Quercus aliena* var. *acuteserrata*, *Q. variabilis*, *Populus davidiana*, *Betula platyphylla*, *B. albo-sinensis* and *Larix kaempferi*. The major evergreen trees are *Pinus armandii*, *P. tabulaeformis*, *Picea asperata* and *Abies chensiensis*. The main shrubs include *Rubus* sp., *Rosa* sp., *Corylus heterophylla*, *Lespedeza bicolor* and *Cotinus coggygria* and the main herbs are *Stipa bungeana*, *Artemisia lavandulaefolia*, *Bothriochloa ischaemum* and *Pennisetum flaccidum* (An, 1995; Mao et al. 2003; Wei, 2004; Suo et al., 2004).

Xiaolong Mountain has 21 forest farms with a combined forest area of 5152 km^2 (82.6% of total land area) managed by the Xiaolong Mountain Forestry Experiment Bureau. The young and middle-age stands are estimated to account for about 87% of the total timber volume. The near-mature, mature and over-mature stands for account for about 13%. Forests in the study area are dominated by *Quercus aliena* var. *acuteserrata*, *Pinus tabulaeformis* and *Q. variabilis* (71.5% of the total land area and 71.4% of the total timber volume). Broad-leaved mixed forest (mixed with *Fraxinus mandschurica*, *Cornus macrophylla*, *Acer* sp., *Tilia* sp. etc.) is also a typical forest type in the Xiaolong Mountain area. As a good representative of stand types and stand distribution at Xiaolong Mountain (Table 1), Dangchuan, a 468 km^2 forest farm (7.5% of the total land area of Xiaolong Mountain) in the middle of the mountain, was selected as the area in which we established our field plots.

3 Methods

3.1 Sample plots

Both the field data and the inventory data were obtained in the summer of 2004. Altogether, 40 permanent square field plots (0.06 hm^2) were established using a stratified random sampling scheme (Kang, 2001) depending on the component ratio of different stand types and dominant species. Information from 1219 temporary sample plots was collected, based on the forest resource inventory data (Table 2).

3.2 Single tree biomass

The average sample trees and the dominant trees were established from the diameter distribution in the sample plots. Using a method for grading trees in 2 cm diameter classes and with an equi-section diameter class-stem number method, we chose 102 sample trees, including 32 dominant *Quercus aliena* var. *acuteserrata* trees and 19 *Pinus tabulaeformis* trees, to be cut down. The stumps and roots of the sample trees were removed carefully using an excavator and spades (Ma, 1989). The inventory data of the other 734 sample trees had been previously collected by the Forestry Research Institute of Xiaolong Mountain Forestry Experimental Bureau and were used for our study (Tables 3 and 4).

As a first step, the fresh weight of the organs (stems, branches, leaves, bark and roots) of the cut down tree was measured in the field. The second step consisted of measuring by sampling the fresh weight of sampled organs. In

Table 1 Areas and stand volumes of different stand types in Xiaolong Mountain

stand types	Xiaolong Mountain				Dangchuan Forest Farm			
	area/hm^2	%	stand volume/m^3	%	Area/hm^2	%	stand volume/m^3	%
Quercus aliena var. *acuteserrata*	178556.8	52.70	14996712.0	60.36	27987.2	67.66	2838561.0	70.71
Pinus tabulaeformis	46755.8	13.80	1518251.0	6.11	1610.8	3.89	128328.0	3.20
Quercus variabilis	16995.9	5.02	1230770.0	4.95	868.0	2.10	71376.0	1.78
Populus sp. and *Betula* sp.	7082.5	2.09	614588.0	2.47	706.7	1.71	65753.0	1.64
Larix sp.	6241.5	1.84	87177.0	0.35	586.7	1.42	28089.0	0.70
Pinus armandii	4813.0	1.42	286150.0	1.16	428.0	1.04	26624.0	0.66
Picea sp.	143.3	0.04	8250.0	0.03	9.2	0.02	135.0	0.00
Abies sp.	300.7	0.09	29208.0	0.12				
other broad-leaved mixed forests	77925.5	22.99	6074944.0	24.45	9166.9	22.16	855365.0	21.31
water area	14.8	0.00						
total	338829.8	100.00	24846050.0	100.00	41363.5	100.00	4014231.0	100.00

Table 2 Main characteristics of field plots in different stand types

stand types	number of sample plots			average DBH/cm	average tree height/m	stand density /trees·hm^{-2}	stand age/yr	main soil types
	subtotal	permanent sample plots	temporary sample plots					
Quercus aliena var. *acuteserrata*	513	16	497	11.7–24.0	7.6–14.6	371–1990	20–81	cinnamon soil; brown earth
Pinus tabulaeformis	118	9	109	2.8–22.5	1.7–21.5	429–23333	12–72	
Quercus variabilis	111	1	110	6.0–18.6	4.3–13.1	509–2674	20–84	
Populus sp. and *Betula* sp.	98	2	96	2.2–26.0	3.5–21.2	204–9250	6–70	
Larix sp.	120	2	118	1.7–21.0	2.2–20.6	450–6375	8–65	
Pinus armandii	83	2	81	4.7–22.4	4.1–17.8	398–16760	14–57	
Picea sp. and *Abies* sp.	47	2	45	4.6–25.0	4.4–18.0	450–5300	10–69	
other broad leaved mixed forests	169	6	163	12.0–24.0	9.2–14.1	311–1716	22–75	
total	1259	40	1219	1.7–26.0	2.2–21.5	204–23333	6–84	

the third step, the sampled organs were dried to a constant weight in the laboratory and then their dry biomass was determined. Based on the diameter, height and dry biomass, single-tree biomass was estimated by four regression models: a logarithmic regression model, a quadratic regression model, a linear regression and a power function (Ma, 1989; Dang and Wu, 1994; Chen et al., 1996; Ru, 1999; Liu et al., 2001; Yang and Yang, 2004).

3.3 Stand biomass

The biomasses of the tree layer, the shrub layer and the forest litter constituted the stand biomass.

The biomass of the tree layer in every sample plot was calculated from Eq. 1 (Ma, 1989), summed up from single-tree-biomass equations and the data of all sample plots, in order to arrive at the estimate of the stand biomass.

$$W = \sum_{i}^{k} \{ \exp[a + b\ln(D_i^2 H_i)] \} n_i \quad (1)$$

where k is number of the diameter classes, D_i mean DBH, H_i, mean tree height and, n_i the number of stems in ith class.

Five sample quadrats (2 m × 2 m) were set up in every field sample plot along diagonal lines. The fresh biomass of the shrub layer and the herb layer were measured by a harvesting method, described by Satou and Tsutsumi (1977). The litter under the tree was weighed in every sample quadrat. The leaves, branches, stems and roots of shrubs, as well as the leaves and roots of the herbs in every sample quadrat, after sampling, were dried and we calculated the biomass per unit area (Ma, 1989; Dang and Wu, 1994; Chen et al., 1996; Ru, 1999; Liu et al., 2001; Yang and Yang, 2004).

4 Results and analysis

4.1 Single tree biomass regression analyses

Four models (a logarithmic regression, a quadratic regression, a linear regression and a power regression) were used to analyze the relationship between the DBH (D), the tree height (H) and the single tree biomass (W). The results show that all four models had significant correlations. The power models (Eqs. 2 and 3) had the best correlation (Ma, 1989; Dang and Wu, 1994; Chen et al. 1996; Ru, 1999; Liu et al., 2001; Xu and Wang, 2001; Yang and Yang, 2004).

$$\ln W = a + b\ln(D^2 H) \quad (2)$$

$$\ln W = a + b\ln D \quad (3)$$

where W is the biomass of a single tree, D is DBH and H tree height. a and b are model parameters.

The relationships of biomass with DBH and tree height were close. Two regression equations were established (Table 5). Most correlation coefficients were greater than

Table 3 Number of sample trees of different tree species by diameter class

tree species	diameter class/cm																				
	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	>40	total
Quercus aliena var. *acuteserrata*	3	9	5	8	7	10	9	21	18	22	15	8	10	4	9	7	3	4	2	4	178
Pinus tabulaeformis	4	2	5	3	7	11	9	14	12	15	10	9	6	4	5	1	0	2	1	1	121
Quercus variabilis	2	5	5	8	7	6	8	11	9	9	7	4	2	0	3	2	1	1	0	2	92
Populus sp. and *Betula* sp.	0	4	7	6	7	3	5	9	8	10	11	12	3	3	4	1	6	1	1	4	105
Larix sp.	0	1	3	6	1	4	8	15	21	14	2	0	3	0	1	1	0	0	0	0	80
Pinus armandii	2	4	3	3	2	5	12	7	9	16	11	2	3	1	2	2	1	1	0	0	86
Picea sp. and *Abies* sp.	0	2	3	1	0	2	4	8	8	8	5	0	4	2	1	3	1	0	1	4	57
other broad-leaved trees	6	5	9	4	11	3	6	9	11	18	7	8	6	5	2	0	4	2	0	1	117
total	17	32	40	39	42	44	61	94	96	112	68	43	37	19	27	17	16	11	5	16	836

Table 4 Main characteristics of sample trees of different tree species

tree species	number of sample trees			average DBH/cm	average tree height/m
	subtotal	felled trees	forest resources inventory date		
Quercus aliena var. *acuteserrata*	178	32	146	3.8–47.7	2.5–24.0
Pinus tabulaeformis	121	19	102	2.3–40.0	3.8–19.4
Quercus variabilis	92	5	87	3.3–46.3	3.5–15.0
Populus sp. and *Betula* sp.	105	13	92	5.1–44.2	5.0–22.3
Larix sp.	80	7	73	6.3–31.5	5.0–20.0
Pinus armandii	86	10	76	4.0–38.3	3.0–20.1
Picea sp. and *Abies* sp.	57	6	51	5.5–45.7	6.0–20.5
other broad–leaved trees	117	10	107	3.8–43.1	2.0–22.0
total	836	102	734	2.3–47.7	2.0–24.0

Table 5 Single tree biomass equations of two models for different tree species

tree species	organ	$\ln W = a + b\ln(D^2H)$			$\ln W = a + b\ln D$		
		a	*b*	*r*	*a*	*b*	*r*
Quercus aliena var. *acuteserrata*	stem	−4.0347	0.9953	0.9947	−2.9678	2.5264	0.9851
	branch	−8.4741	1.3674	0.9680	−7.0805	3.4944	0.9652
	leaf	−8.4170	1.0888	0.9545	−7.1844	2.7422	0.9379
	bark	−4.5914	0.8657	0.9792	−3.6377	2.1889	0.9660
	root	−3.3630	0.7773	0.9857	−2.8660	2.0976	0.9964
	total	−3.5426	0.9979	0.9920	−2.5075	2.5444	0.9869
Pinus tabulaeformis	stem	−3.8828	0.9359	0.9962	−2.8101	2.2933	0.9919
	branch	−6.3807	1.1242	0.9826	−5.1822	2.7855	0.9893
	leaf	−5.3277	0.8812	0.9496	−4.4174	2.1931	0.9603
	bark	−5.1129	0.8649	0.9862	−4.1587	2.1321	0.9878
	root	−4.7557	0.9204	0.9816	−4.0294	2.3569	0.9820
	total	−3.5234	0.9655	0.9910	−2.4587	2.3803	0.9927
Quercus variabilis	stem	−3.7447	0.9679	0.9981	−2.8739	2.3952	0.9934
	branch	−4.8449	1.0013	0.9917	−3.9439	2.4778	0.9871
	leaf	−3.3569	0.6050	0.9611	−2.7505	1.4752	0.9425
	bark	−3.2565	0.7156	0.9852	−2.5819	1.7600	0.9745
	root	−2.9066	0.8144	0.9941	−2.3470	2.1003	0.9933
	total	−2.0060	0.8579	0.9943	−1.2141	2.1159	0.9863
Populus sp. and *Betula* sp.	stem	−3.8023	0.9631	0.9919	−2.9492	2.5040	0.9889
	branch	−5.9070	1.0903	0.9430	−5.0421	2.8669	0.9509
	leaf	−3.9108	0.6104	0.7910	−3.4756	1.6207	0.8054
	bark	−5.8330	0.9682	0.9561	−4.9540	2.5104	0.9507
	root	−3.2756	0.7692	0.9815	−2.6185	2.0024	0.9831
	total	−2.8360	0.9222	0.9879	−2.0537	2.4088	0.9894
Larix sp.	stem	−3.6844	0.9303	0.9597	−2.7707	2.4048	0.9944
	branch	−7.6840	1.2554	0.9765	−6.2259	3.1639	0.9864
	leaf	−12.0638	1.4968	0.9620	−10.4105	3.8032	0.9798
	bark	−5.0754	0.8708	0.9768	−4.0515	2.1900	0.9847
	root	−5.1872	0.9709	0.9857	−3.8721	2.3669	0.9839
	total	−3.3583	0.9552	0.9728	−2.3442	2.4419	0.9968
Pinus armandii	stem	−3.9041	0.9630	0.9955	−3.1480	2.4567	0.9872
	branch	−4.0957	0.9186	0.9384	−3.6496	2.4380	0.9682
	leaf	−4.8359	0.7936	0.9479	−4.4190	2.0955	0.9730
	bark	−4.6176	0.8060	0.9893	−3.9933	2.0589	0.9825
	root	−8.3710	1.3456	0.9911	−6.1087	3.0376	0.9886
	total	−2.9132	0.9302	0.9901	−2.2962	2.4119	0.9980
Picea sp. and *Abies* sp.	stem	−3.9744	0.9434	0.9858	−2.7745	2.3188	0.9899
	branch	−4.6350	0.9257	0.9550	−3.4124	2.2606	0.9527
	leaf	−5.9391	0.9753	0.9848	−4.6636	2.3859	0.9841
	bark	−5.5587	0.8930	0.9855	−4.4164	2.1928	0.9886
	root	−5.2791	0.9457	0.9919	−4.0598	2.3192	0.9937
	total	−3.2999	0.9501	0.9934	−2.0770	2.3307	0.9955
other broad-leaved trees	stem	−3.8852	0.9803	0.9844	−2.3970	2.3157	0.9846
	branch	−5.6360	1.0851	0.8869	−4.1076	2.6045	0.9013
	leaf	−4.5320	0.7377	0.8705	−3.2468	1.6856	0.8421
	bark	−4.4480	0.7713	0.9140	−3.3642	1.8520	0.9292
	root	−3.1575	0.7758	0.8282	−2.3113	1.9541	0.8571
	total	−2.5700	0.9037	0.9731	−1.2325	2.1468	0.9787

Note: all correlation coefficients are significant at the 0.01 level.

0.9. Especially the correlation coefficients of the two power functions of biomass, equations 2 and 3, were very high, > 0.97.

4.2 Tree layer biomass

The biomass of stems, branches, leaves, bark and roots of the tree layer of the eight major stand species (Table 6) were calculated with equation 2 in Table 5, as well as from the data of the diameter distribution in the sample plots. From the sample plot data and the results in Table 6, the two tree layer regression models, biomass (W)-forest stand volume (V) regression model, the tree layer biomass (W) mean DBH ($\overline{D}$), mean tree height ($\overline{H}$) and forest density (ρ) regression model, were calculated (Table 7). All of the correlation coefficients were greater than 0.92. Both models have excellent power to estimate tree layer biomass, using the data of sample plots and forest stand volumes.

Table 6 Average biomass of trees in different stand types (unit: t·hm^{-2})

stand types	above ground						blow ground		total
	stem	branch	leaf	bark	subtotal	%	root	%	
Quercus aliena var. *acuteserrata*	45.3128	10.3889	1.1920	9.2650	66.1588	80.84	15.6800	19.16	81.8388
Pinus tabulaeformis	29.8330	9.7309	4.7486	5.2395	49.5519	81.64	11.1457	18.36	60.6976
Quercus variabilis	31.7434	13.5573	3.1675	7.9277	56.3960	70.67	23.4020	29.33	79.7980
Populus sp. and *Betula* sp.	39.7200	13.5709	2.2448	5.4315	60.9672	80.88	14.4156	19.12	75.3828
Larix sp.	39.1974	9.2443	0.8152	6.1793	55.4361	82.29	11.9345	17.71	67.3706
Pinus armandii	32.7020	19.6744	3.9062	5.2956	61.5783	90.58	6.4003	9.42	67.9786
Picea sp. and *Abies* sp.	46.2327	20.6606	8.4199	6.2807	81.5940	86.46	12.7793	13.54	94.3733
other broad-leaved mixed forests	48.9142	20.0460	3.5258	5.0449	77.5309	80.30	19.0224	19.70	96.5533

Table 7 Regression equations of biomass of trees in different stand types

stand types	stand volume/m^3·hm^{-2}	biomass of trees/t·hm^{-2}	$\ln W = a + b \ln V$			$\ln W = a + b\ln(\overline{D}^2 \overline{H} \rho)$		
			a	b	r	a	b	r
Quercus aliena var. *acuteserrata*	96.8741	81.8388	−0.0788	0.9793	0.9310	−10.2613	0.9914	0.9999
Pinus tabulaeformis	92.9415	60.6976	−0.4664	1.0052	0.9633	−9.4347	0.9249	0.9980
Quercus variabilis	75.2035	79.7980	0.4925	0.9016	0.9832	−8.5573	0.9022	0.9973
Populus sp. and *Betula* sp.	89.4017	75.3828	−0.0404	0.9713	0.9930	−8.4850	0.8735	0.9984
Larix sp.	91.0451	67.3706	−0.4173	1.0211	0.9905	−9.9258	0.9559	0.9999
Pinus armandii	91.8743	67.9786	−0.6127	1.0661	0.9959	−9.3533	0.9326	0.9987
Picea sp. and *Abies* sp.	143.5253	94.3733	−0.3916	0.9943	0.9959	−9.3743	0.9177	0.9984
other broad-leaved mixed forests	97.9426	96.5533	−0.1482	1.0274	0.9264	−9.7302	0.9634	0.9983

Note: correlation coefficients significant at the 0.01 level.

Table 8 Biomass of shrubs and herbs in different stand types (unit: t·hm^{-2})

stand types	storey	above ground				below ground		total
		leaf	stem & branch	subtotal	%	root	%	
Quercus aliena var. *acuteserrata*	shrub layer	0.1183	0.7270	0.8453	55.88	0.6673	44.12	1.5126
	herb layer	0.0458		0.0458	37.91	0.0750	62.09	0.1208
	total	0.1641	0.7270	0.8911	54.55	0.7423	45.45	1.6334
Pinus tabulaeformis	shrub layer	0.0933	0.5758	0.6691	67.70	0.3193	32.30	0.9884
	herb layer	0.0683		0.0683	30.14	0.1583	69.86	0.2266
	total	0.1616	0.5758	0.7374	60.69	0.4776	39.31	1.2150
Quercus variabilis	shrub layer	0.1058	0.6513	0.7571	60.55	0.4933	39.45	1.2504
	herb layer	0.0570		0.0570	32.80	0.1168	67.20	0.1738
	total	0.1628	0.6513	0.8141	57.16	0.6101	42.84	1.4242
Populus sp. and *Betula* sp.	shrub layer	0.1468	0.6770	0.8238	59.93	0.5508	40.07	1.3746
	herb layer	0.1215		0.1215	59.47	0.0828	40.53	0.2043
	total	0.2683	0.6770	0.9453	59.87	0.6336	40.13	1.5789
Larix sp.	shrub layer	0.1510	0.6523	0.8033	58.99	0.5585	41.01	1.3618
	herb layer	0.1033		0.1033	38.86	0.1625	61.14	0.2658
	total	0.2543	0.6523	0.9066	55.70	0.7210	44.30	1.6276
Pinus armandii	shrub layer	0.1488	0.6665	0.8153	59.55	0.5538	40.45	1.3691
	herb layer	0.0478		0.0478	24.29	0.1490	75.71	0.1968
	total	0.1966	0.6665	0.8631	55.12	0.7028	44.88	1.5659
Abies sp.*	shrub layer	0.1468	0.6770	0.8238	59.93	0.5508	40.07	1.3746
	herb layer	0.1215		0.1215	59.47	0.0828	40.53	0.2043
	total	0.2683	0.6770	0.9453	59.87	0.6336	40.13	1.5789
other broad-leaved mixed forests	shrub layer	0.2173	0.6313	0.8486	53.22	0.7458	46.78	1.5944
	herb layer	0.0358		0.0358	25.70	0.1035	74.30	0.1393
	total	0.2531	0.6313	0.8844	51.01	0.8493	48.99	1.7337

Note: *no shrubs and herbs, only forest litter, in *Picea* sp. forests because most *Picea* sp. plantations had formed a canopy structure. The shrub and herb layers in *Abies* sp. forests are similar to those in *Betula albo-sinensis* forests.

4.3 Biomass of shrub layer and herb layer

Based on the dry biomass of leaves, branches, stems and the roots of shrubs and the dry biomass of leaves and roots of herbs, the mean value of each organ was calculated, from which the biomass of the shrub and herb layers were obtained (Table 8).

4.4 Litter biomass

From the litter biomass in the sample plots, we calculated the stand litter biomass (Table 9).

4.5 Stand biomass

The stand biomass (Table 10) was calculated from the biomass of the tree layer (Table 6), the shrub and herb layers (Table 8) and the litter biomass (Table 9).

5 Conclusions

The single tree biomasses of the eight tree species at Xiaolong Mountain are closely correlated with DBH and tree height.

The tree layer biomass of the eight stand types, *Quercus aliena* var. *acuteserrata*, *Pinus tabulaeformis*, *Quercus variabilis*, *Populus* sp. and *Betula* sp., *Larix* sp., *Pinus armandii*, *Picea* and *Abies* sp. and other broad-leaved mixed forests were 81.84, 60.70, 79.80, 75.38, 67.37, 67.98, 94.37 and 96.55 t/hm^2, respectively. The above-ground biomass accounted for 70.67%–90.58% and the below-ground biomass made up 9.42%–29.33% of the total biomass. The shrub layer biomass was 1.51, 0.99, 1.25, 1.37, 1.36, 1.37, 1.37 and 1.59 t/hm^2, respectively. The above-ground biomass accounted for 53.22%–67.70% and below-ground for 32.30%–46.78% of the total, The herb layer biomass was 0.12, 0.23, 0.17, 0.20, 0.27, 0.20, 0.20 and 0.14 t/hm^2, respectively. The above-ground biomass of the herb layer made up 24.29%–59.47% and the below-ground biomass 40.53%–75.71% of the total. The stand biomass was 84.05, 62.44, 81.77, 77.44, 69.00, 70.07, 96.49 and 98.7 t/hm^2, respectively. The above-ground biomass made up 70.64%–89.86% and the below-ground 10.14%–29.36% of the total stand biomass.

Given the close correlation between stand tree layer biomass with stand volume and between the stand tree layer biomass with mean DBH, mean tree height and forest density, the stand biomass models designed by us can be used to estimate the forest biomass in other sample plots or other inventory data and avoid destroying the forest resource with our traditional ways of measuring biomass.

Table 9 Biomass of forest litter in different stand types (t·hm^{-2})

stand types	biomass of forest litter layer
Quercus aliena var. *acuteserrata*	0.5750
Pinus tabulaeformis	0.5298
Quercus variabilis	0.5525
Populus sp. and *Betula* sp.	0.4750
Larix sp.*	0
Pinus armandii	0.5250
Picea sp.*	0.5343
other broad-leaved mixed forests	0.4365

Note: *no forest litter under the *Larix* sp. plantations and *Abies* sp. forests.

Table 10 Average biomass of different stand types (unit: t·hm^{-2})

stand types	tree layer			shrub & herb layer			forest litter layer	stand biomass				
	above ground	below ground	total	above ground	below ground	total		above ground	%	below ground	%	total
Quercus aliena var. *acuteserrata*	66.1588	15.6800	81.8388	0.8911	0.7423	1.6334	0.5750	67.6249	80.46	16.4223	19.54	84.0472
Pinus tabulaeformis	49.5519	11.1457	60.6976	0.7374	0.4776	1.2150	0.5298	50.8191	81.39	11.6233	18.61	62.4424
Quercus variabilis	56.3960	23.4020	79.7980	0.8141	0.6101	1.4242	0.5525	57.7626	70.64	24.0121	29.36	81.7747
Populus sp. and *Betula* sp.	60.9672	14.4156	75.3828	0.9453	0.6336	1.5789	0.4750	62.3876	80.57	15.0492	19.43	77.4367
Larix sp.	55.4361	11.9345	67.3706	0.9066	0.7210	1.6276	0.0000	56.3427	81.66	12.6555	18.34	68.9982
Pinus armandii	61.5783	6.4003	67.9786	0.8631	0.7028	1.5659	0.5250	62.9664	89.86	7.1031	10.14	70.0695
Picea sp. and *Abies* sp.	81.5940	12.7793	94.3733	0.9453	0.6336	1.5789	0.5343	83.0736	86.10	13.4129	13.90	96.4865
other broad-leaved mixed forests	77.5309	19.0224	96.5533	0.8844	0.8493	1.7337	0.4365	78.8518	79.87	19.8717	20.13	98.7235

Acknowledgements The project was financially supported by the National Natural Science Foundation of China (Grant No. 90302014).

References

An D G (1995). Flora of Xiaolong Mountain, Gansu Province. Lanzhou: Gansu Nationalities Press (in Chinese)

Canell M G R (1982). Wood Forest Biomass and Primary Production data. London: Academic Press, 361

Chen C G, Gong L Q, Peng H, Liu X Z (1996). Biomass and productivity of the sharptooth oak forests in the Qinling Mountains. J Northwest For Coll, 11(Supp.): 103–114 (in Chinese)

Dang C L, Wu Z L (1994). Studies on the biomass of *Cyclobalanopsis delavayi* community. J Yunnan Univ (Nat Sci), 16(3): 205–208 (in Chinese)

Fang J Y, Wang G G, Liu G H, Xu S L (1998). Forest biomass of China: An estimation based on the biomass-volume relationship. Ecol Appl, 8: 1084–1091

Fang J Y, Chen A P, Peng C H, Zhao S Q, Ci L J (2001). Changes in forest biomass carbon storage in China between 1949 and 1998. Science, 292: 2320–2322

Jiang Y L, Zhou G S (2001). Carbon equilibrium in *Larix gmelinii* forest and impact of global change on it. Chin J Appl Ecol, 12(4): 481–484 (in Chinese)

Kang X G (2001). Forest Resource Management. Beijing: China Forestry Publishing House, 79 (in Chinese)

Liu Y C, Wu M Z, Guo Z M, Jiang Y X, Liu S R, Wang Z Y, Liu B D, Zhu X L (2001). Studies on biomass and net production of *Quercus autidentata* forest in Baotianman Nature Reserve. Acta Ecol Sin, 21(9): 1450–1456 (in Chinese)

Ma Q Y (1989). A Study on the biomass of Chinese pine forests. J Beijing For Univ, 11(4): 1–10 (in Chinese)

Ma Q Y, Chen X L, Wang J, Lin C, Kang F F, Cao W Q, Ma Z B, Li W Y (2002). Carbon content rate in constructive species of main forest types in northern China. J Beijing For Univ, 24(5/6): 96–100 (in Chinese)

Mao X W, Zhang H L, Kong H (2003). A study on composition and characteristics of floristic in Xiaolong Mountains. Bull Bot Res, 23(4): 485–491 (in Chinese)

Pardé J (1980). Forest Biomass. Forestry abstracts. Review article (Vol. 41). Oxford: Commonwealth Forestry Bureau, 343–362

Ru W M (1999). A studies on the biomass of *Pinus tabulaeformis* forest on Laoding Mountains. Henan Sci, 14(Supp.): 64–65 (in Chinese)

Satou D, Tsutsumi T (1977). Mass Production of Terrestrial Communities (in Chinese, trans. Nie S Q, Ding B Y, 1986). Beijing: Science Press, 21–47 (in Chinese)

Suo A N, Ju T Z, Zhang J H, Wang Q H (2004). Analysis of biodiversity characteristics of *Quercus aliena* var. *acuteserrata* community on Mt. Xiaolong in Gansu. Acta Bot Boreal-Occident Sin, 24(10): 1877–1881 (in Chinese)

Wei Z H (2004). An analysis on social and economic benefits of the Natural Forest Resources Protection Project in Xiaolongshan Forestry Bureau. J Northwest For Univ, 19(1): 156–160 (in Chinese)

Woodwell G M, Whittaker R H, Reiners W A, Likens G E, Delwiche C C, Botkin D B (1978). The biota and the world carbon budget. Science, 199: 141–146

Xiang W H, Tian D L, Yan W D (2003). Review of researches on forest biomass and productivity. Centr South For Invent Plan, 22(3): 57–60 (in Chinese)

Xu H, Wang M L (2001). Comparison of CAR and VAR biomass models. For Stud China, 3(1): 32–36

Xue L, Yang P (2004). Summary of research on forest biomass. J Fujian Coll For, 24(3): 283–288 (in Chinese)

Yang D, Yang X Q (2004). Studies on biomass and productivity of *Pinus tabulaeformis* planation in the Wufengshan of Wudu, Gansu Province. J Northwest Norm Univ (Nat Sci), 40(1): 70–75 (in Chinese)

Yang P Q, Li M G, Wang B S (2003). Dynamics of biomass and net primary productivity in succession of south subtropical forests in Southwest Guangdong. Chin J Appl Ecol, 12(12): 2136–2140 (in Chinese)

Zhao M, Zhou G S (2004). Forest Inventory Data (FID) –Based biomass models and their prospects. Chin J Appl Ecol, 15(8): 1468–1472 (in Chinese)