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Effect of Understory on a Natural Secondary Forest Ecosystem Carbon Budget[1]

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Abstract—Lacking of detail data, forest carbon stock estimation with forest inventory data usually excludes or underestimates understory carbon storage. To quantify the effects of understory on carbon sequestration in a natural secondary *Pinus tabulaeformis* forest, organ biomass models for arbor, shrub to their growth indices were regressed. Biomass of herbage was estimated in a stratified sampling method. Soil respiration in forest land was measured. Based on above data, carbon budget of *Pinus tabulaeformis* forest was assessed as 1.882 CO_2 $Mghm^{-2}year^{-1}$, 37.04% of the entire vegetation's yearly net carbon storage belonging to understory.

Keywords: understory, carbon sequestration, carbon storage, soil respiration, carbon budget

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1. INTRODUCTION

As a main component of terrestrial ecosystems, almost 90% of total biomass on the earth is tied up in forests (Monteiro et al., 2009). Forest plays a significant role in this carbon (C) sink (Wang et al. 2009). Carbon distribution in forest ecosystems is an important part of the global carbon budget (Jia and Akiyama, 2005). To accurately and precisely quantize the C in forests has attracted global attention as countries seek to comply with agreements under the UN Framework Convention on Climate Change (Brown, 2002; Rodeghiero et al., 2010; Sharma et al., 2010). Forest inventory data are usually used to estimate carbon stocks (Sharma et al., 2010; Tuyl et al., 2005; Woodbury et al., 2007). Unfortunately, being short of enough information, the understory carbon sequestration was scarcely estimated.

Understory vegetation species in natural secondary forests usually grow profusely in the Qinling Mountains, China. Does the carbon sink intensity of the whole forest ecosystem hardly vary when the understory carbon storage is omitted?

In this study we set out to qualify impacts of each component's (arbor, shrub and herbage) carbon storage on carbon sequestration of a natural secondary *Pinus tabulaeformis* forest in the Qinling Mountains, China. Our main objectives were to quantify the understory C pool and report biomass equations for this forest type.

[1] The article is published in theoriginal.

2. METHODS AND MATERIALS

2.1. The Site Condition

The study was conducted in comprehensive observation plots, Qinling National Forest Ecosystem Research Station (QNFERS) at Huoditang, Ningshan, Shaanxi, China (33°18′ N, 108°20′ E). The altitude is 1530–1610 m. The area has a warm temperate climate. The annual mean temperature is 8–10°C, annual mean precipitation is 900–1200 mm and annual mean evaporation is 800–950 mm. The soil is mountain brown generated from granite and degenerative granite parent material and soil depth ranged from 30 cm to 50 cm. Forest in the comprehensive observation plots were selective cut in 1951. The present common tree species include 60–year–old natural secondary *Pinus tabulaeformis* and associated species, such as *Quercus aliena* var. *acuteserrata, Pinus armandi*, *Larix principis-rupprechtii*, *Betula albo-sinensis*, etc. The main understory plant species are *Euonymus alatus*, *Lonicera hispida* pal, *Cerasus stipulacea*, *Symplocos paniculata*, *Elaeagnus lanceolata*, *Carex leucochloraand Thalictrum minus*, *Deyeuxia sylvatica*, *Thalictrum minus* and *Anemone vitifolia*, etc.

2.2. Field Investigation

There are 14 comprehensive observation plots in the QNFERS along the altitude and area of each plot is 400 m^2 (20 m × 20 m). Height and DBH (diameter at height of breast) of arbor species in the plot was measured from September 25th to 30th in 2006 and

Table 1. Regressions of biomass in various organs of tree species (kg)

Tree species	Organ	Regression
Pinus tabulaeformis	Stem	$\ln W_S = 1.04086\,1n(D^2H) - 4.63143$
	Bark	$\ln W_{BA} = 0.77396\,1n(D^2H) - 4.69348$
	Branch	$\ln W_B = 2.57733\,\mathrm{In}\,D - 4.08026$
	Leaf	$\ln W_L = 2.57495\,\mathrm{In}\,D - 5.11712$
	Root	$\ln W_R = 2.28692\,\mathrm{In}\,D - 4.14198$
Pinus armandi	Stem	$\ln W_S = 1.02363\,1n(D^2H) - 4.9970$
	Bark	$\ln W_{BA} = 0.88417\,1n(D^2H) - 5.38472$
	Branch	$\ln W_B = 2.57551\,\mathrm{In}\,D - 4.08452$
	Leaf	$\ln W_L = 2.75687\,\mathrm{In}\,D - 5.75891$
	Root	$\ln W_R = 0.97120\,\mathrm{In}\,D - 5.26301$
Quercus aliena var. *acuteserrata*	Stem	$\ln W_S = 0.91420\,1n(D^2H) - 3.16322$
	Bark	$\ln W_{BA} = 0.8271\,1n(D^2H) - 4.00080$
	Branch	$\ln W_B = 2.63197\,\mathrm{In}\,D - 4.39241$
	Leaf	$\ln W_L = 0.00769D^2 + 0.39450$
	Root	$\ln W_R = 2.41438\,\mathrm{In}\,D - 3.15882$
Larix principis-rupprechtii	Stem	$\ln W_S = 0.99794\,1n(D^2H) - 4.29251$
	Bark	$\ln W_{BA} = 0.80398\,1n(D^2H) - 4.53535$
	Branch	$\ln W_B = 2.04597\,\mathrm{In}\,D - 2.55078$
	Leaf	$\ln W_L = 1.90488\,\mathrm{In}\,D - 3.44704$
	Root	$\ln W_R = 2.18625\,\mathrm{In}\,D - 3.46236$

W_S, W_{BA}, W_L and W_R, is biomass of tree stem, branch, leaf and root respectively.

2007 respectively and organ samples were collected concurrently. Indices of height, basal diameter, DBH, crown width were measured and samples of fresh weight of root stem, leaves and tegument of each shrub species were collected from 294 plots (Area of each shrub plot is 2 m × 2 m). Stratified sampling method was applied to definite numbers of herbage plots (Area of each herbage plot is 1 m × 1 m) and fresh weight of root, stem and leaves of each herbage species was also measured.

2.3. Carbon Content Ratio of Plant

All samples of plants were dried in 85° until their constant weight. Dry samples were grinded until their diameters less than 75 μm. TOC/TON analyzer (TOC–VT H–2000A, Shimadzu Corporation, Japan) was used to measure carbon content ratio of each organ. Three samples of each organ were measured with tolerance less than 2% between two samples.

2.4. Biomass of Arbor and Shrub

Biomass of arbor was calculated according to Peng and Cheng (1996) (Table 1). Sample quantities of *Euonymus alatus*, *Lonicera Hispida* pall, *Cerasus stipulacea*, *Symplocos paniculata* and *Elaeagnus lanceolata* were 162, 155, 158, 166 and 153 respectively. Biomass models describing the relationship among shrub organs and their morphological indices (height, DBH) were established (Table 2).

2.5. Carbon Density of Herbage

To protect herbage in experimental area, a stratified sampling method was used to determine numbers of herbage plot by of gradient and all plots were classified as upperside (length 17–19 m, 23°), middle (length 20–24 m, 38°) and underpart (length 20–28 m, 19°).

$$N_i - L - \frac{t_a^2 \sum_{h=1}^{L} N_h S_h^2}{\Delta^2(\bar{y}_{st})} = 0. \quad (1)$$

Where N_i is total number of herbage plot, L number of layer, t_α the value of two sided t-test when reliability (α) is 90%, N_h number of plot in h layer in pre-survey, S_h^2 variance of fresh weight, abundance and coverage of herbage species above ground in h layer in pre-survey, $\Delta^2(\bar{y}_{st})$ population mean tolerance of fresh weight,

Table 2. Regression models of organ biomass and growing indices in variant shrubs

Shrub species	Regression equations	R^2	Coefficients	tValue	Sig.(α)
Euonyrnus alatus	$B_r = 70.204DBH^3 - 218.429DBH^2 + 301.435\mathrm{DBH} - 85.317$	0.932	constant	−2.347	0.031
			DBH	2.731	0.014
			DBH^2	−2.16	0.045
			DBH^3	2.489	0.022
	$B_s = 62776 + 32268(DBH^2 \cdot H) - 0.941(DBH^2 \cdot H)^2$	0.969	constant	10.475	<0.001
			$DBH^2 \cdot H$	10.480	<0.001
			$(DBH^2 \cdot H)^2$	−3.460	0.03
	$\ln \mathrm{Bl} = 5.261 - \frac{0.952}{CW}$	0.917	constant	40.173	<0.001
			$1/CW$	−14.890	<0.001
	$\ln B_b = 3.219 + 0.580\ln(DBH^2 \cdot H)$	0.960	constant	29.069	<0.001
			$\ln DBH^2 \cdot H$	21.778	<0.001
Lonicera Hispida pall	$\mathrm{In}\, B_r = 3.950 + 1.898\ln(DBH)$	0.950	constant	18.994	<0.001
			$\ln DBH$	15.068	<0.001
	$\ln \mathrm{Bs} = 3.106 + 0.737\ln(DBH^2 \cdot H)$	0.936	constant	9.895	<0.001
			$\ln(DBH^2 \cdot H)$	16.736	<0.001
	$\ln B_l = 4.099 + 2.884\ln(CW)$	0.968	constant	26.606	<0.001
			$\ln CW$	24.067	<0.001
	$B_b = 5.389 + 1.574(DBH^2 \cdot H) + 0.063(DBH^2 \cdot H)^2$	0.998	constant	4.438	<0.001
			$DBH^2 \cdot H$	12.638	<0.001
			$(DBH^2 \cdot H)^2$	17.450	<0.001
Cerasus stipulacea	$\mathrm{Br} = 256.194 - \frac{423.799}{DBH}$	0.971	constant	38.058	<0.001
			$1/DBH$	−25.97	<0.001
	$\ln B_s = 2.066 + 1.082\ln(DBH^2 \cdot H)$	0.969	constant	8.382	<0.001
			$\ln(DBH^2 \cdot H)$	24.92	<0.001
	$\ln B_l = 1.327 + 1.656CW$	0.976	constant	14.921	<0.001
			CW	28.453	<0.001
	$B_b = -22.342 + 16.836\ln(DBH^2 \cdot H)$	0.923	constant	−6.851	<0.001
			$\ln DBH^2 \cdot H$	15.526	<0.001
Symplocos paniculata	$B_r = -114.802DBH^3 + 804.745DBH^2 - 1577.297DBH + 1019.276$	0.934	constant	3.602	0.03
			DBH	−3.703	0.02
			DBH^2	4.027	0.01
			DBH^3	−3.918	0.02
	$\ln B_s = 4.520 + 0.488\ln(DBH^2 \cdot H)$	0.971	constant	18.698	<0.001
			$\ln(DBH^2 \cdot H)$	23.121	<0.001
	$B_l = 59.487 + 136.513\ln CW$	0.926	constant	17.112	<0.001
			$\ln CW$	14.110	<0.001
	$\ln B_b = 2.580 + 0.557\ln(DBH^2 \cdot H)$	0.889	constant	8.017	<0.001
			$\ln(DBH^2 \cdot H)$	11.32	<0.001

Table 2. (Contd.)

Shrub species	Regression equations	R^2	Coefficients	*t*Value	Sig.(α)
Elaeagnus lanceolata	$B_r = 176.736DBH^3 - 715.549DBH^2 + 1003.966DBH - 372.002$	0.989	constant	−4.158	0.001
			DBH	6.104	<0.001
			DBH^2	−7.975	<0.001
			DBH^3	6.274	<0.001
	$\ln B_s = 3.722 + 0.811\ln(DBH^2 \cdot H)$	0.942	constant	8.297	<0.001
			$\ln(DBH^2 \cdot H)$	15.613	<0.001
	$\ln B_l = 7.111 - 2.786/CW$	0.932	constant	36.485	<0.001
			$1/CW$	−14.351	<0.001
	$\ln B_b = 1.647 + 0.857\ln(DBH^2 \cdot H)$	0.944	constant	8.015	<0.001
			$\ln(DBH^2 \cdot H)$	15.932	<0.001

B_r, B_s, B_l and B_b is biomass of root, stem, leaf and tegument respectively.

abundance and coverage of herbage species above ground in pre-survey.

$$\Delta\bar{y}_{st} = (1 - P_c)\bar{y}_{st}. \quad (2)$$

Where P_c is reliability and it is given as 90% in pre-survey and $\bar{y}_{st}$ population mean of fresh weight, abundance and coverage of herbage species above ground in pre-survey. Based on fresh weight, abundance and coverage of herbage species above ground in pre-survey, a few N_i (total number of herbage plot) would be got. We adopted $N_{i\max}$ as N in actual investigation.

Investigated number of herbage plot (k_h) in some layer was determined as following.

$$k_h = N\frac{A_h}{A}. \quad (3)$$

Where A_h is area (hm^{-2}) of h layer and A total area (hm^{-2}) of experimental plot.

Carbon storage of herbage on a certain layer and average carbon storage of herb in the comprehensive plots were calculated as following.

$$S_h = \frac{1}{A}\sum_{j=1}^{k} Q_m W_m R_m, \quad (4)$$

where S_h is carbon storage of herbage on a certain layer (Mg hm^{-2}), A the total area of plots (hm^{-2}), Q_m number of herbage species m, W_m organ biomass of herbage species m (Mg), R_m carbon content ratio of herbage species m each organ (%) and k plot numbers in h layer.

$$\bar{S}_{st} = \frac{1}{N}\sum_{h=1}^{L} k_h S_h, \quad (5)$$

where $\bar{S}_{st}$ is average carbon storage of herbage in the comprehensive plots (Mghm^{-2}), N total numbers of herbage plot, k_h numbers of herbage plot in h layer, S_h carbon storage of herbage on a certain layer (Mg hm^{-2}) and L numbers of layer.

2.6. Carbon Density of Vegetation

According to above results, carbon net budget in a natural secondary *Pinus tabulaeformis* forest could be estimated as following.

$$Dc = \frac{\sum A_i R_i + \sum S_j R_j + \sum H_k R_k}{A}.$$

Where Dc (Mghm^{-2}) is Carbon density of plant. A_i (Mg), S_j (Mg) and H_k (Mg) is biomass of arbor, shrub and herbage respectively. R_i (%), R_j (%) and R_k (%) is carbon content ratio arbor, shrub and herbage respectively. A is the total area of comprehensive observation plots (hm^{-2}).

2.7. Soil Respiration, Soil Temperature and Soil Volumetric Moisture

Soil respiration rate (R_s) was measured with an open-path-dynamic chambers system that utilized IRGA (infrared gas analyzer, Li–6252, Li–Cor Inc., Lincoln, NE, USA) technique (Mo et al., 2005). Carbon dioxide efflux from the soil surface was measured from October, 2006 to September, 2007, except from January to April 2007(during this period data collection was hindered by low temperatures that prevented the instrument running). A 30 m-wide swath was selected for the installation of the12 chambers in each experimental plot. PVC chambers, 15 cm tall and

19.5 cm in internal diameter were inserted 5 cm into the soil. Chambers in each group were connected to the sampler with entry and exit tubes with equal lengths of 38 m. Soil respiration was measured on 5th, 15th and 25th day of every month during the observation period. Carbon dioxide from the soil was sampled every 10 s and the gas entering the chamber was sampled at a flow rate of 1.2 L min^{-1}. Data from the IRGA were saved in a datalogger (CR10X, Compbell Company, U.S.A). The air temperature at 1.5 m height above the ground was recorded from a weather station near experimental area.

R_s (mg $m^{-2}h^{-1}$) was calculated as follows.

$$R_s = (\alpha \times 10^{-6} \times L \times \rho \times 10^3) \times 60 - S \times [273.15 - (273.15 + t_{mean})] \times (p_{mean} - 1013),$$

where α is the CO_2 concentration ($\mu molmol^{-1}$) determined from the IRGA, L the flow rate (1.2 L min^{-1}), S the surface area (m^2) of a chamber, ρ the density (g L^{-1}) of CO_2 at normal air pressure, t_{mean} the mean value of soil temperature (°), p_{mean} is the mean air pressure (hPa) at 1.5 m in height.

The exponential function below is used to describe the temperature dependence of soil respiration (Mo et al., 2005):

$$F_c = R_0 e^{kT_s},$$

$$Q_{10} = e^{10k},$$

where F_c is the CO_2 efflux (g $m^{-2}day^{-1}$), R_0 is the respiration rate at a reference temperature of 0°, k is the coefficient related to Q_{10} (sensitivity to temperature), i.e. Q_{10} is the factor by which a reaction increases for an increase of 10°C, and T_s is the daily mean soil temperature (°C) at a certain depth.

2.8. Data Analysis

Organ biomass models of shrub species were shown in Table 2.

Root mean square error (RMSE), modeling efficiency (EF), coefficient of residual mass (CRM) and relative errors (RE) were used to test accuracy of regression models (Amaducci et al., 2008).

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (y_1 - \hat{y}_i)^2}{n}},$$

$$EF = 1 - \frac{\sum_{i=1}^{n} (\hat{y}_i - y_i)^2}{\sum_{i=1}^{n} (y_i - \hat{y}_i)^2},$$

$$CRM = \frac{\sum_{i=1}^{n} y_i - \sum_{i=1}^{n} \hat{y}_i}{\sum_{i=1}^{n} y_i}.$$

Where $\bar{y}, \hat{y}_i$ and n is observed value, average of observed value, model prediction value and sample size.

The less the *RMSE* and the closer *EF* to1 mean the higher efficiency of models. If *CRM* is positive value, the predicted value would be less than observation value. When the *CRM* equals to1, the model has the highest efficiency (Amaducci et al., 2008).

Accuracy of shrub organ biomass models and precision of soil respiration models was shown Table 3 and Table 4, respectively.

Carbon sink can be shown as following.

$$NEP = NPP - R_S.$$

Where *NEP* and *NPP* is net ecosystem productivity and primary productivity, respectively. R_s is respiration of ecosystem. Ignoring animal's consummation of *NPP*, R_s is soil respiration.

In our study, flux of *NPP* (D_f) of forest ecosystem was calculated as following.

$$D_f = D_{c2007} - D_{c2006}.$$

From the basic chemical equation, $C + O_2 = CO_2$, it could be found that CO_2 productivity was 11/3 times of C.

All data analyses were performed using SPSS 13.0.

3. RESULTS AND DISCUSSION

3.1. Results

3.1.1. Carbon storage of arbor. The results illustrated organic carbon stored in arbors was estimated as 15.177 ± 2.336 CMg hm^{-2} in 2006 and 22.987 ± 5.732 CMg hm^{-2} in 2007 (Table 5). The net carbon storage in arbor between 2006 and 2007 was 7.810 CMg hm^{-2}. Stem was the main organ to store organic carbon, which 25.65 to 31.22% of total organic carbon in wholes tree was allocated in stem (Table 5). Various tree species have different carbon storage strategy. Besides stem, coniferous trees stored more than 24% of total organic carbon of whole trees in their branches and broad-leaved deciduous trees stored 20.61% of total organic carbon of whole trees in their roots.

3.1.2. Carbon storage of shrub. To quantify the relationship between organ biomass of shrub and their growing indices, we conducted regression analysis using Quadratic, compound, Logarithmic and exponential models, and the best fitting equation of them with the largest R^2 was chosen to describe their relationship.

We found that Compound, Power, Quadratic, Cubic, Logarithmic, Exponential and Inverse could

Table 3. Differences between average values from models and measuring in field for variant shrub organs (kg)

Shrub species	Organ	RMSE	EF	CRM	$\hat{y}$	$\bar{y}$	Relative error (%)
Euonymus alatus	Root	0.75	0.997	0.003	79.38	84.50	6.06
	Stem	1.30	0.975	–0.021	155.59	147.75	–5.31
	Leaf	1.04	0.992	–0.001	51.05	46.80	–9.09
	Tegument	1.70	0.957	–0.034	48.85	45.64	–7.03
Lonicera Hispida pall	Root	0.96	0.999	0.005	113.39	124.03	8.58
	Stem	0.97	0.999	–0.002	152.80	143.02	–6.84
	Leaf	0.81	0.999	0.003	116.45	124.74	6.65
	Tegument	0.72	0.9999	0.011	38.41	40.54	5.25
Cerasus stipulacea	Root	0.96	0.999	–0.010	94.66	89.90	–5.29
	Stem	1.11	0.999	0.002	193.34	200.95	3.78
	Leaf	0.83	0.997	–0.031	26.79	28.10	4.69
	Tegument	1.08	0.981	–0.049	27.43	25.93	–5.79
Symplocos paniculata	Root	1.15	0.999	–0.002	224.25	233.32	3.89
	Stem	1.12	0.999	–0.002	335.47	318.94	–5.18
	Leaf	1.36	0.996	–0.010	91.16	84.70	–7.63
	Tegument	1.13	0.988	–0.006	57.90	55.40	–4.50
Elaeagnus lanceolata	Root	0.90	0.999	–0.004	117.14	123.92	5.47
	Stem	1.29	0.999	–0.002	274.84	276.42	0.57
	Leaf	0.95	0.999	–0.004	87.08	82.74	–5.25
	Tegument	1.09	0.997	0.007	38.42	36.28	–5.92

Table 4. Precision test for soil respiration modelling (CO_2 $gm^{-2}day^{-1}$)

Period	Depth (cm)	RMSE	EF	CRM	Relative error (%)	$\hat{y}$	$\bar{y}$
Growing period	0–5	0.12	0.96	0.005	0.47	46.76 ± 2.26	46.98 ± 2.21
	5–10	0.09	0.97	–0.007	0.66	47.29 ± 2.33	
Dormant period	0–5	0.17	0.85	–0.005	0.50	36.12 ± 0.96	35.94 ± 1.01
	5–10	0.21	0.86	0.003	0.36	35.81 ± 0.89	

better express relationship between organ biomass of shrub and their growing indices with maximum relative error not more than 9.01%. Diverse models demonstrated complicated relationship of vegetative growth among variant organs in shrub species.

Organic carbon storage of shrub was estimated as 5.107 CMg hm^{-2} in 2006 and 7.872 CMg hm^{-2} in 2007. The net carbon storage in shrub between 2006 and 2007 was 2.765 CMghm^{-2}.

3.1.3. Carbon storage of herbage. The net organic carbon storage in herbage was estimated as 1.829 ± 0.0198 CMg hm^{-2} between 2006 and 2007 (Table 6).

3.1.4. Soil respiration. Combination soil mean respiration value in Table 4 to observation days during growing and dormant period, mean CO_2 flux in the comprehensive plots was estimated as 43.199 CO_2 Mg hm^{-2} $year^{-1}$.

3.1.5 Carbon dioxide net budget of forest. Soil carbon pool is stable under normal environmental condition. In this study, we discussed carbon net budget of forest ecosystem without soil carbon storage.

Arbor, shrub and herb in comprehensive plots could store CO_2 28.867 CO_2 Mg hm^{-2}, 10.138 CO_2 Mg hm^{-2} and 6.076 CO_2Mg hm^{-2} between 2006 and 2007, respectively. That meant plant stored 45.081 CO_2 Mg hm^{-2} CO_2 between 2006 and 2007. Carbon *dioxide* net budget of a natural secondary *Pinus tabulaeformis* forest would be 1.882 CO_2Mg$hm^{-2}year^{-1}$.

3.2. Discussion

3.2.1. Contribution of understory to forest ecosystem carbon budget. Understory vegetation is an impor-

Table 5. Carbon density of arbor (C Mg hm^{-2})

Year	Organ	Tree species			
		P. tabulaeformis	*P. armandi*	*Q. aliena* var. *acuteserata*	*L. principisrupprechtii*
2006	Stem	1.375 ± 0.454	1.036 ± 0.315	1.014 ± 0.301	0.963 ± 0.298
	Bark	0.637 ± 0.178	0.510 ± 0.147	0.594 ± 0.168	0.459 ± 0.143
	Branch	1.076 ± 0.324	1.019 ± 0.302	0.607 ± 0.177	0.850 ± 0.211
	Leaf	0.754 ± 0.215	0.663 ± 0.181	0.563 ± 0.154	0.417 ± 0.141
	Root	0.561 ± 0.154	0.812 ± 0.189	0.721 ± 0.189	0.544 ± 0.149
	Total	15.177 ± 2.336			
2007	Stem	2.083 ± 0.412	1.570 ± 0.482	1.535 ± 0.484	1.459 ± 0.473
	Bark	0.964 ± 0.296	0.773 ± 0.218	0.900 ± 0.290	0.695 ± 0.211
	Branch	1.630 ± 0.489	1.544 ± 0.479	0.919 ± 0.293	1.288 ± 0.364
	Leaf	1.142 ± 0.362	1.004 ± 0.299	0.852 ± 0.217	0.631 ± 0.173
	Root	0.850 ± 0.217	1.229 ± 0.367	1.092 ± 0.317	0.825 ± 0.199
	Total	22.987 ± 5.732			

Table 6. Quantity of plots, average biomass and carbon storage density of herbs in various layers (C Mg hm^{-2})

Layer	Quantities of plots	Average biomass	Carbon density
Upperside	29	3.364 ± 0.943	1.363 ± 0.424
Middle	33	3.046 ± 0.976	1.249 ± 0.628
Underpart	45	5.885 ± 1.523	2.413 ± 0.732
Average			1.829 ± 0.198

tant component of forest ecosystem in maintaining biodiversity, sequestering carbon dioxide and providing animals food. During the past years, lack of enough information, as a vital component of forest ecosystems, the understory was thought to contain only a small portion of the total carbon stocks in forests (Woodbury et al., 2007). Biomass of understory was often ignored (Tuyl et al., 2005; Ni et al., 2001) and contribution of understory sequestering carbon had rarely been qualified (Jarosz et al., 2008).

Based on arbor, shrub organ biomass models, herbage biomass estimation, and soil respiration measurement in a natural secondary *Pinus tabulaeformis* forest in this study, yearly net carbon sequestration in near mature coniferous forest was implemented to facilitate to be better understood. Contribution of understory to the forest ecosystem carbon budget was explicitly demonstrated. The cumulative GPP of forest floor vegetation in no snow period was 131 gCm^{-2} (Kolari et al., 2006). In this study, the total net carbon sequestration of shrub and herb species was 4.594 CMg hm^{-2} $year^{-1}$, equivalently sequestrating16.85 CO_2Mg hm^{-2} $year^{-1}$, which was 37.04% of the whole vegetation's. Provided ignoring CO_2 sequestration of understory, the natural secondary *Pinus tabulaeformis* forest would be a carbon source and sequestrated −16.214 CO_2 Mg hm^{-2} $year^{-1}$. Especially, with forest aging, growth of predominant tree species will gradually slow. More and more individuals of windthrow appear in the natural secondary forest at Huoditang forest region, Qinling Mountains, and much more gaps have formed which provide positive conditions for understory vegetation invading and growing. The understory will be another important contributor to forest ecosystem carbon sink.

3.2.2. Prediction of understory biomass. Most studies on developing biomass predictive models for shrubs (Rittenhouse and Sneva et al., 1977; Bryant and Kothmann, 1979; Lufafa et al., 2009) have found many equations to be the most useful for a number of species. Residual errors analysis indicated that the biomass predictive models in this study were Compound, Power, Quadratic, Cubic, Logarithmic, Exponential and Inverse, and these models achieved higher accuracy and had better applicability with the maximum value of RMSE (root mean square error) not more than 1.70. All EF (modeling efficiency) and CRM (coefficient of residual mass) values closed to 1 and 0. The absolute values for relative error in shrub organ biomass between the model estimated and the field measured ranged from 3.89–8.58% (roots), 0.57–

6.84% (stems), 4.69–9.09% (leaves) and 4.50–7.03% (tegument). The models' determining coefficients and estimating accuracy exceeded 90% and 95%, respectively, which provided an efficacious way to estimate organ biomass of studying subjects. However, the samples were collected from special forest types (*Pinus tabulaeformis* pure forest and mixed forest of *Pinus tabulaeformis* and *Quercus aliena* var. *acuteserrata*) in the experimental area and the indices were limited in some scale. These models could not be used generally. It is difficult to estimate carbon dioxide sequestration of fasciculate shrub species, such as *Rosa swginzowii*, for no model being fit to the relationship of organ biomass and the morphological indices yet. Understory vegetation has traits of diverse species, wide distribution, strong germination and high productivity. The same shrub species under different environmental conditions has variant biomass and carbon assimilation ways. Appropriate models for predicting shrub biomass are still expected to attain more accuracy of forest vegetation carbon sequestration dynamic.

4. CONCLUSIONS

Our data indicate that leaving the understory carbon storage without calculation may misunderstand the role in forest ecosystem carbon cycle. The work on a natural secondary forest carbon sequestration demonstrates the 60-year-old *Pinus tabulaeformis* forest is weak carbon sink with intensity 1.882 CO_2 Mg $hm^{-2}year^{-1}$. The yearly net carbon storage of understory is 37.04% of the entire vegetation's. The central thesis of this paper is to clarify importance of understory in forest carbon budget and attract more attention on understory.

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