Research paper

The Trend of Growth Characteristics of Moso bamboo (*Phyllostachys pubescens*) Forests under an unmanaged Condition in Central Taiwan

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【Summary】

Moso bamboo (*Phyllostachys pubescens*) is one of the important bamboo species in Taiwan. In this study, we investigated the stand density, growth characteristics, and aboveground biomass (AGB) of moso bamboo in an unmanaged condition between 2008 and 2014 in Sanjiaolun District, central Taiwan. The moso bamboo plantations had stand densities of between 5733±896 and 13,067±551 culms ha^{-1} and values of diameter at breast height (DBH) of between 5.5±0.5 and 6.3±0.2 cm. Biomass was estimated by allometric models, and the prediction indicated that the moso bamboo forest had AGB of 38.4±6.3 to 60.4±6.9 Mg ha^{-1}. All results indicated that the average DBH decreased after 2 yr, the density of small bamboo (diameter class < 4.0 cm) increased, and the AGB of old bamboo was sharply increasing in an unmanaged condition of moso bamboo forests.

Key words: moso bamboo (*Phyllostachys pubescens*), unmanaged, stand density and structure, biomass.

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研究報告

台灣中部地區放棄經營的孟宗竹林生長性狀變化趨勢

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摘 要

孟宗竹(*Phyllostachys pubescens*)為東亞重要的物種之一。本研究於2008~2014年間調查台灣中部三角崙地區放棄經營孟宗竹的林分密度、生長性狀及地上部生物量。調查結果顯示，孟宗竹的林分密度在5733±896與13,067±551株ha^{-1}，胸徑大小約於5.5±0.5~6.3±0.2 cm之間。地上部生物量方面，則以異率回歸模式推估，介於38.4±6.3~60.4±6.9 Mg ha^{-1}。綜合所有結果顯示，孟宗竹林必須要經營，如不經營，DBH經過兩年後會開始下降，新生的小徑竹(DBH > 4 cm)也會增加，而老竹的株數密度及地上部生物量會大幅度的增加。

關鍵詞：孟宗竹、放棄經營、林分密度與結構、生物量。

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INTRODUCTION

Bamboo belongs to the Gramineae family, and has about 90 genera with over 1200 species globally (Lobovikov et al. 2007). Bamboo is naturally distributed in the tropical and subtropical belt between 46° north and 47° south latitude, but mostly in South and East Asia, which totally has more than 18 million ha, which is nearly 80% of the total world bamboo area (Shanmughavel and Francis 1996, Isagi et al. 1997, Scurlock et al. 2000, Embaye et al. 2005). Bamboo plays an integral role in the social, cultural, and economic lives of the people in Asian countries (Nath et al. 2009, Tandon and Barik 2012).

Because the Tropic of Cancer crosses Taiwan and there are high elevations of the Central Mountain Range, different types of bamboo can be found here. In total 46 species and varieties of bamboo are found in Taiwan, of which 20 are indigenous and are 26 exotic (Lin 1967). Moso bamboo (*Phyllostachys pubescens*), one of the 6 economic bamboo species in Taiwan (Lu 2001), was introduced from southeastern China to Taiwan around the middle of the 18th century by emigrants (Lai and Hsiao, 1997). Both the culms and shoots of moso bamboo are very useful (Yen et al. 2010, Chen et al. 2014).

Village bamboo has many values, and proper utilization and scientific management can provide benefits on local, national, and global levels through providing a livelihood, and economic and environmental security for many millions of rural people (Nath et al. 2009).

Recently, some studies indicated that the biomass of moso bamboo forest notably varied among different sites ranging from 30 to 290 Mg ha^{-1} (Isagi et al. 1997, He et al. 2003, Kumemura et al. 2009, Wang et al. 2009, Yen et al. 2010, Chen et al. 2011, Sun et al. 2013), and was usually lower than those of woody forests (IPCC 2008).

Growth patterns of moso bamboo differ from those of woody plants. In the former, the rapid growth from a shoot to a mature plant can be completed within a couple of months (Yen et al. 2010). Due to the fact that newborn shoots which are then transformed to culms are produced from underground rhizomes each year, moso bamboo forests form uneven-aged stands (Isagi et al. 1997, Show 2010, Yen and Lee 2011). Therefore, if selective cutting is carried out each year in moso bamboo forests, the sustainable management of moso bamboo forests would be feasible (Yen et al. 2010). Furthermore, it was reported that the aboveground biomass (AGB) of moso bamboo forests increased 33% with selective cutting after the first year, and the production of bamboo culms in high quantity was maintained for the next 2 yr (Wang et al. 2010).

However, recently, due to cheap bamboo imports from China and only slight profits to support foresters, lots of moso bamboo forests in Japan and Taiwan have become an unmanaged condition (Kumemura et al. 2009, Senba et al. 2010, Lin 2011, Chen et al. 2014).

While many studies have been carried out on moso bamboo plantations in the past (Wang et al. 2009, 2010, Chen et al. 2011, 2014), none regarding changes in the stand structure of unmanaged moso bamboo forest has been reported yet. Thus, in this study, the objectives were (1) to investigate the growth responses of moso bamboo in an unmanaged condition, (2) to reveal the dynamics of the stand structure after a period of an unmanaged condition, and (3) to estimate the AGB of different-aged moso bamboo forests. We hypothesized that the average diameter at breast height (DBH) would decrease, the density of small bamboo (diameter class < 4.0 cm) would go up, and the AGB of old bamboo (age $\geqq$ 5) would sharply increase in moso bamboo forests in an unmanaged condition.

MATERIALS AND METHODS

Study area

The study area was located at Sanjiaolun (23°55′55″N, 120°53′46″E) in Nantou County, central Taiwan. Nantou County is dominated by bamboo forests that played very important roles in the local economy a few decades ago. The elevation of the study site is 769 m with a monsoonal subtropical climate. The average annual temperature and average annual precipitation in the study area from 1970 to 2015 were 15.3℃ and 1558 mm, respectively (TCWB 2015). The moso bamboo forest of the study site was planted 30 yr ago.

Sample plots

Starting in 2008, the moso bamboo forest on the site began to be in an unmanaged condition. Three square plots of 100 m^2 each (10×10 m) were set up. In these plots, all bamboo culms were tagged, and their DBH and height were measured annually.

Diameter distribution model (DDM)

The DDM, a type of approach to standardize a description of the diameter distribution, is based on a probability density function (PDF). Being quite flexible in shape and easily used, Weibull's function was quite often used to describe the DBH distribution in timber plantations (Bailey and Dell 1973, Clutter et al. 1983, Wang et al. 2006). Yen et al. (2010) for the first time used Weibull's function to simulate the distribution of diameters in bamboo plantations in Taiwan. The PDF of the 2-parameter model for the Weibull random variable, χ, utilizing notation by Dubey (1967) based on Weibull (1951), is:

$$f(\chi;\lambda,\kappa)=\begin{cases}\dfrac{\kappa}{\lambda}\left(\dfrac{\chi}{\lambda}\right)^{\kappa-1}e^{-\left(\frac{\chi}{\lambda}\right)^{\kappa}} & \chi\geqq 0,\\ 0 & \chi<0,\end{cases}; \qquad (1)$$

where λ and κ are parameters of the Weibull function.

It is characterized by the scale parameter, λ, and the shape parameter, κ. We used Eq. (1) to make the DDM of the moso bamboo plantation between 2008 and 2014.

Stand density and AGB estimates

Stand density was taken as the number of standing bamboo culms of different ages per hectare during 2008 to 2014. The AGB for each culm was estimated using an allometric equation (Eq. (1)) developed from a moso bamboo plantation (Lu and Liu 1982).

$AGBi = 10^{(-0.9950+2.2465\times \log D)}$ and (3)

$AGB = [(\sum AGBi)\ kg/1000]\times[1,000,000\ m^2/(10\times 10\ m)]$; (4)

where AGB_i is the AGB per culm expressed in kg, D is the DBH expressed in cm, and AGB is the aboveground biomass expressed in Mg ha^{-1}.

Analysis of the stand structure

The number of diameter classes, the frequency and density of bamboo culms in different ages, and the AGB were determined every sampling time. Furthermore, they were calculated each year independently.

Statistical analysis

Data presented in this paper are the average of 3 replicates. A 1-way analysis of variance (ANOVA) was conducted to test unmanaged effects on the stand structure and AGB. When the 1-way ANOVA indicated a significant treatment effect, the least significant difference (LSD) test was used to recognize means in different years. An α level of 0.05 for significance was used in all statistical analyses, which were performed using SAS 9.2 (SAS Institute, Cary, NC, USA).

RESULTS

The trend of DBH after being unmanaged

Overall, average DBH values in all ages and in age 1 yr in 2008 and 2009 were higher than those between 2010 and 2014 (Fig. 1). In the first 2 yr of no management the average DBH in all age classes was significantly

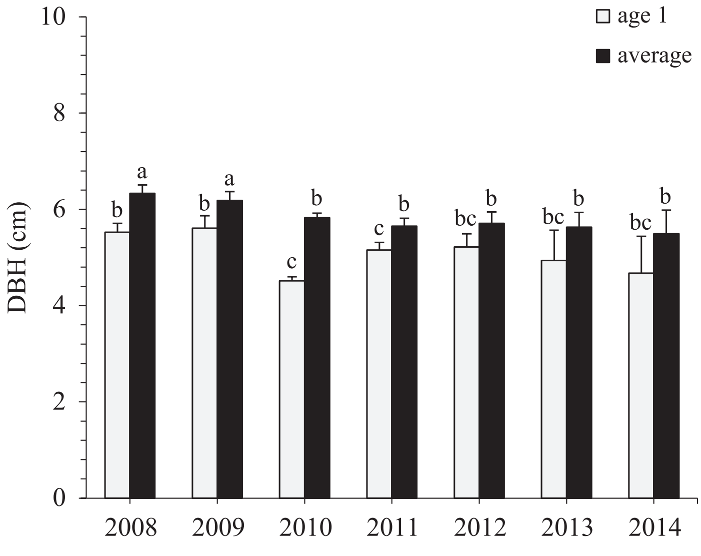

Fig. 1. Trend of diameter at breath height DBH at an age of 1 yr and on average after non-management of the moso bamboo stand.

higher, at 6.49±0.18 and 6.35±0.19 cm than these with no significant change in any of the other years, at 5.84±0.09, 5.70±0.16, 5.78±0.24, 5.64±0.30, and 5.48±0.45 cm from 2008 to 2014, respectively (Fig. 1).

The trend of DBH in age 1 yr shows that it was higher in 2008 at 5.53±0.18 cm and in 2009 at 5.61±0.26 cm. However, after reaching a peak, DBH fell rapidly to 4.52±0.08 cm in 2010. There was a sharp increase over the next 2 yr, with the DBH of newly born bamboo reaching a peak of 5.22±0.27 cm in 2012. It then fell again to 4.67±0.77 cm in 2014 (Fig. 1).

Regarding the trend of average DBH in all ages after no management, it was notably high in the first 2 yr, but was low after the third year (Fig. 1).

Over the period of 2008 to 2014 as a whole, there was an increase in the number of culms ha^{-1} below diameter class 7 cm (Fig. 2). Moreover, peaks of newly born bamboo culms (i.e., age 1 yr) were always below diameter class 7 cm (Fig. 3).

Diameter distribution

Regarding the distribution of diameter classes, it is evident that the largest proportion of bamboo culm was in class 4.1~6.0 cm every year, and there was a steady increase in diameter classes 0~2.0 and 2.1~4.0 cm over the past 7 yr (Table 1).

Out of 5 diameter classes, diameter class 4.1~6.0 cm had the highest proportion of bamboo culms that fluctuated between 52.1% and 60.6% from 2008 to 2014. The proportion of bamboo culms in diameter class 6.1~8.0 cm dipped from 30.8% to 14.2% between 2008 and 2014. On the other hand, there was a moderate increase in smaller diameter classes over the past 7 yr, with the percentage of bamboo culms rising from 8.1% to 25.7% in diameter class 2.1~4.0 cm, and from 1.2% to 5.2% in diameter class 0~2.0 cm (Table 1).

It can be seen that the total culm density increased between 2008 and 2013 (Fig. 4). In 2008, the density of bamboo culms was 5733 culms ha^{-1}. It then rose moderately over the next 3 yr, with the density of culms reaching a

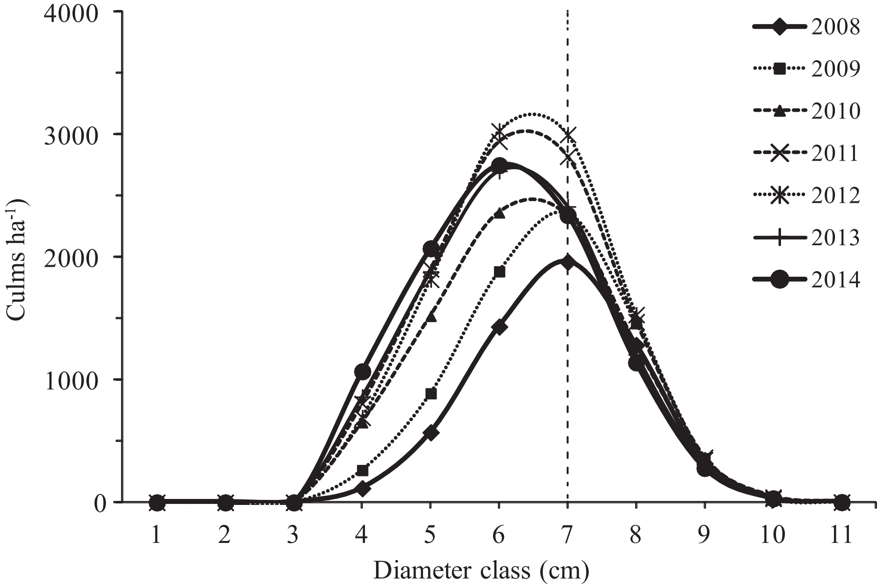

Fig. 2. Diameter distribution of all ages in the moso bamboo stand from 2008 to 2014.

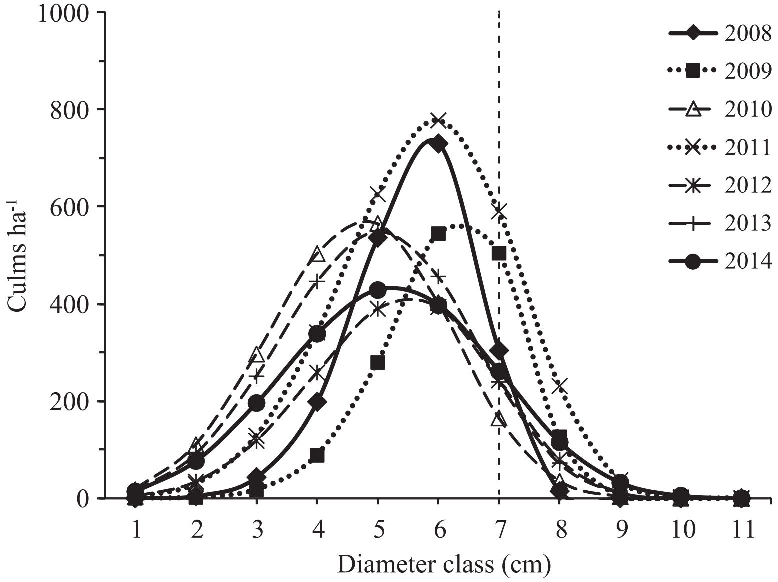

Fig. 3. Diameter distribution at an age of 1 yr in the moso bamboo stand from 2008 to 2014.

Table 1. Percentages of bamboo culms in each diameter class after non-management

Year / Diameter class (cm)	2008	2009	2010	2011	2012	2013	2014
0~2.0	1.2±1.8[1)]	1.4±1.3	4.3±2.1	4.9±2.0	3.6±1.2	3.7±3.1	5.2±5.5
2.1~4.0	8.1±3.3	12.7±2.7	19.9±2.2	22.8±3.8	23.6±3.5	24.9±5.2	25.7±9.5
4.1~6.0	59.9±8.0	60.6±8.7	53.1±5.2	53.2±5.0	52.1±5.6	53.3±3.5	54.6±4.1
6.1~8.0	30.8±10.3	25.4±8.7	22.7±5.5	19.1±6.1	20.8±4.4	17.8±5.8	14.2±4.6
8.1~10	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.0±0.0	0.3±0.4	0.3±0.5

[1)] Mean±standard deviation.

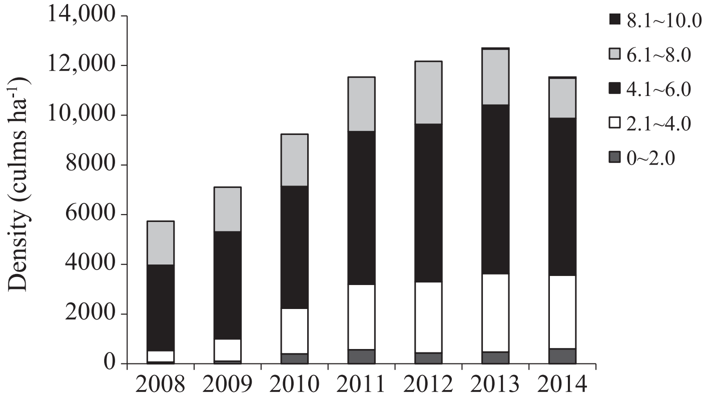

Fig. 4. Trend of the diameter distribution after non-management in a moso bamboo stand from 2008 to 2014.

flat of 12,000 culms ha^{-1} (Fig. 4). From 2012 to 2014, the density fluctuated between 11,833 and 13,067 culms ha^{-1} (Fig. 4). Noticeably, the density of culms in diameter classes 0~2.0 and 2.1~4.0 cm went up from 67 to 567 culms ha^{-1}, and 467 to 2633 culms ha^{-1} from 2008 to 2011, and then it fluctuated between 433 and 600 culms ha^{-1} for diameter class 0~2.0 cm, and between 2633 and 3167 culms ha^{-1} for diameter class 2.1~4.0 cm from 2012 to 2014.

The dynamics of frequency for each age range

Table 2 reveals the proportion and density of bamboo culms of different ages from 2008 to 2014. It indicates that there was a continual increase in the age of ≧ 5 yr in an unmanaged condition over the next 7 yr.

After 3 yr in an unmanaged condition, among bamboo culms of different ages, culms aged ≧ 5 yr had the greatest proportion that fluctuated between 41.1 and 30.2% from 2011 to 2014. On the contrary, proportions of bamboo culms with respect to ages 1~4 yr were dipped below 25% after 2010 (Table 2).

The total density of all ages increased from 2008 to 2013, then dropped in 2014 (Fig. 5). Furthermore, the most important thing is that the density of old bamboo culms (i.e., age over 4 yr) grew from 267 culms ha^{-1} in 2008 to 5767 culms ha^{-1} in 2011 after 3 years in an unmanaged condition, and then, at a high

Table 2. Dynamics of the frequency of different ages after non-management in a moso bamboo stand (%)

Year Age (yr)	2008	2009	2010	2011	2012	2013	2014
1	29.1±3.7[1)]	20.9±4.3	20.1±3.0	23.7±1.7	11.8±3.1	16.3±1.9	17.6±1.9
2	24.3±4.8	24.4±3.1	16.3±3.3	15.8±3.4	21.5±1.5	11.5±3.0	19.6±3.0
3	33.3±9.7	20.4±4.1	19.1±2.4	13.3±2.7	11.5±3.1	17.5±1.7	11.3±1.7
4	4.2±6.0	28.0±8.1	16.3±3.7	14.7±2.0	10.3±2.2	9.3±1.6	15.2±1.6
≧5	0.0±0.0	3.6±5.0	24.3±4.9	30.2±8.7	38.5±9.5	41.1±5.8	39.6±5.8

[1)] Mean±standard deviation.

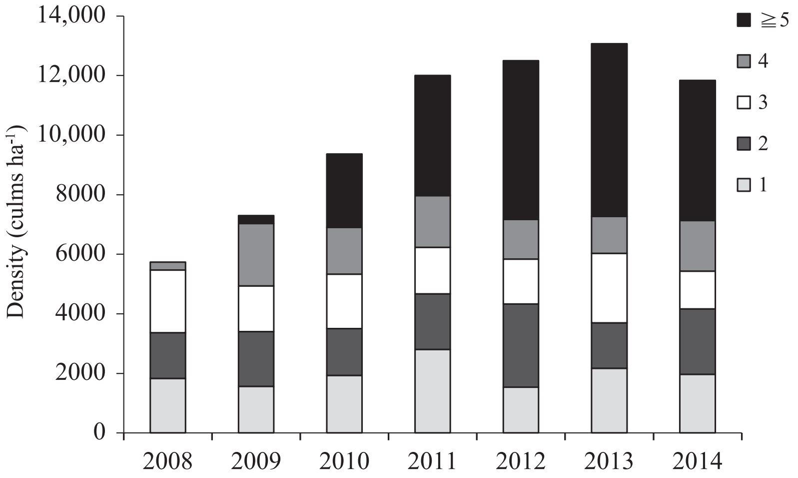

Fig. 5. Density of culms of different ages after non-management in a moso bamboo stand.

density fluctuated between 5767 and 7033 culms ha^{-1} from 2011 to 2014 (Fig. 5).

The trend of AGB after non- mangement

The trend of total AGB was the same as that of the culm density, and increased rapidly from 38.4 Mg ha^{-1} in 2008 to 59.2 Mg ha^{-1} in 2011 after non-mangement (Table 3). Then, the total AGB fluctuated between 60.4 and 51.7 Mg ha^{-1} from 2011 to 2014 (Table 3). The most notable point to mention is that after non-mangement, the AGB of age ≧ 5 yr increased dramatically from 0 to 24.7 Mg ha^{-1} between 2008 and 2011, and the higher proportion of total AGB fluctuated between 21.2 and 28.7 Mg ha^{-1} from 2011 to 2014 (Table 3).

DISCUSSION

Plants play a variety of roles to accumulate and sequester carbon dioxide from the atmosphere into plant biomass (IPCC, 2008). A key issue in the profitability of bamboo plantations is the productivity of those plantations (Hunter and Juni 2002). Many studies focused on the contributions to AGB of not only woody trees (Gifford 2000, Fukuda et al. 2003, Losi et al. 2003, Lamolom and Savidge 2006, Nogueira et al. 2008, Salimon et al. 2011) but also bamboos (Yen et al. 2010, D'Oliveria et al. 2013, Rockwell et al. 2014).

Our original hypotheses that a lack of management would affect DBH, density of bamboo culm, and AGB, were supported by our findings. On the whole, the average DBH dipped slightly, the density of small bamboo culms increased, and the AGB of old bamboo rose after non-mangement. This discussion reveals 3 objectives mentioned above.

Impacts on DBH

Previous studies pointed out that the average DBH increased after selective cutting which focused on small or old culms (e.g., Wang et al. 2010), but there was no evidence to support the hypothesis that average DBH would decrease if bamboo plantations were in an unmanaged condition. In our study, the average DBH significantly decreased to a lower level from the third year with no managment (Fig. 1), and there was a steady increase in culm density in the smaller diameter class (e.g., 0~2.0 and 2.1~4.0 cm) from 2008 to 2014 (Table 1, Fig. 4). Moreover, the DDM approach in the diameter distribution analysis showed that the density of small culms would increase the same as the results shown in Fig. 1.

The trend of DBH across the investigated years apparently followed the assumed hypothesis of bamboo forests in previous studies (i.e., the DBH of culms would drop if bamboo forests are unmanaged) (Wang et al. 2009, Yen et al. 2009). This study is the first

Table 3. Dynamic of aboveground biomass (AGB) of different ages after non-management in a moso bamboo stand (Mg ha^{-1})

Age (yr)	2008	2009	2010	2011	2012	2013	2014
1	9.1±1.1[1)]	8.3±2.4	6.5±1.1	12.2±0.2	7.2±2.5	9.0±3.1	7.0±1.5
2	11.3±2.9	9.1±1.1	8.2±2.3	5.8±1.6	11.3±0.1	6.5±2.8	8.6±2.8
3	16.0±5.4	11.3±2.9	8.9±1.1	7.8±2.0	5.4±1.3	9.9±0.5	5.7±2.0
4	3.1±3.1	16.0±5.4	10.8±4.0	8.7±0.9	7.7±2.1	3.6±1.0	9.2±0.4
≧5	0.0±0.0	2.0±2.8	15.5±5.3	24.7±10.1	28.7±9.3	24.3±8.6	21.2±6.5
Total	38.4±6.3	46.7±4.0	49.8±6.5	59.2±7.9	60.4±7.0	53.2±3.0	51.7±8.4

[1)] Mean±standard deviation.

to show that there was a decrease in the average DBH after 2 yr in an unmanaged condition.

Dynamics of frequency and density for each age range

Our study indicated that there was a continual increase in the frequency and density from young to old bamboo in an unmanaged condition from 2008 to 2012 (Fig. 5, Table 2). In order to maximize the carrying capacity, bamboo stands need to be harvested by selectively cutting old bamboo to create space for new-born bamboo growth, and therefore, maintaine a high productivity of the bamboo forest (Embaye et al. 2005, Wang et al. 2010). Selection cutting is vital to maintain the vigor of bamboo stands (Yen and Lee 2003, Wang et al. 2009), and to enhance regeneration due to an open canopy and soil disturbance in the bamboo forest (Larpkern et al. 2011, Montti et al. 2011).

Moreover, selecting cutting is more profitable to land owners and culm manufacturers. On the average, about 20% of culms are cut every year in a managed condition according to previous studies (Wang et al. 2009, Yen et al. 2010). However, this has not been verified by experiments. In this case, this study suggested that about 30% of old bamboo culms, aged > 4 yr, could be logged by selective cutting at the first year, and about 40~50% after the second year in an unmanaged condition (Table 2).

A healthy system of roots (rhizomes) and culms is quite important to build up a productive bamboo stand. For monopodial bamboo, rhizomes provide nutrition for bamboo shoot development. Then, through photosynthesis of the foliage, the resulting soluble carbohydrates feed back to rhizome growth and regeneration (Wang 2012). Thus a mutual interrelated system of rhizomes and culms is formed in a bamboo stand (Hsiao 2010). The age distribution of culms affects rhizomes regeneration, in that the regeneration capacity of rhizomes increases first with an increase in age because of the expansion of the leaf surface area and root system. Later, however, in older bamboo, due to a rapid decrease in vigor caused by a diminution of the leaf surface area, its root regeneration ability will be sharply diminished. Therefore, the age distribution structure of bamboo is crucial to culm growth and regeneration of bamboo forests.

Ideally, to reach the maximum productivity in a bamboo forest, the age distribution of bamboo should be managed so that the proportion of young bamboo (e.g., aged 1, 2, and 3 yr) is greatest and is the least for old bamboo (e.g., aged > 4 and 5 yr) (Wang et al. 2010, Chen et al. 2014). However, the age distribution in our study showed a quite non-profitable trend of age allocation in the unmanaged bamboo stand because of a continual increase in the frequency and density of old bamboo in an unmanaged condition from 2008 to 2014 (Fig. 5, Table 2). In other words, our study suggests that a sustainable yield of bamboo is not maintained if the bamboo is abandoned. Therefore, bamboo forests must be managed by the selective cutting of old culms aged > 5 yr for sustainable usage.

Changes in the ABG in different ages

The trend of AGB among ages over time showed the same trend as that for the density of culms; it increased rapidly over 3 yr from 2008, and then fluctuated between 60.4 and 51.7 Mg ha^{-1} from 2011 to 2014 (Table 3). While in unmanaged bamboo forests, both the density of culms and AGB in the stand will continue to increase up to the carrying capacity of AGB in the bamboo forest because of the accumulation of aged culms (D'Oliveira et al. 2013), so the AGB distribution of the age structure should be of greeater concern for the health and vigor of bamboo stands. Our study showed an inappropriate AGB distribution among ages, in that the proportion of young culms was much lower than that of old culms after 2010. This finding suggests that for bamboo forests, after 2 yr after being abandoned, the structure of AGB in the age distribution will change into an undesirable stage over time.

In East Asia, AGB production in different moso bamboo stands has a wide range of 30 to 290 Mg ha^{-1} (Wu 1983, Li et al. 1993, Isagi et al. 1997, Peng et al. 2002, He et al. 2003, Xiao et al. 2007, Wang et al. 2009, 2010, Yen et al. 2010, Chen et al. 2011, 2012, 2014). In an unmanaged condition, the AGB (51.7 Mg ha^{-1}) observed during the last measurement in this study was still lower than these of most earlier studies in a managed condition, at 73.2~91.6 (Chen et al. 2011) and 85.4 Mg ha^{-1} (Chen et al. 2014).

Because of cessation of selective cutting in an unmanaged condition, both the density of culms and AGB continued to increase until they were similar to adjacent unmananged bamboo forests (D'Oliveira et al. 2013).

Notably, the AGB of old bamboo sharply increased after being unmanaged from 2008 to 2011, and then was much higher compared to young bamboo and fluctuated after 2011 until 2014. Due to the weak vitality, high mortality, and mature property of old bamboo, it is essential to remove it to maximize bamboo culm production.

CONCLUSIONS

In response to the research hypothesis, we investigated the growth responses of moso bamboo in an unmanaged condition, examined dynamics of the stand structure after being unmanaged, and estimated the AGB for different ages of a moso bamboo forest. Overall, we confirmed that the average DBH had decreased after 2 yr of no management, the density of small DBH bamboo had grown, and the AGB of old bamboo had increased in an unmanaged condition in the moso bamboo forest.

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LITERATURE CITED

Bailey RL, DELL TR. 1973. Quantifying diameter distributions with the Weibull function. For Sci 19(2):97-104.

Chen TH, Liu CP, Chung HY. 2011. Growth and biomass of moso bamboo in Fenghuang Mountain, Nantou County. Q J Chin For 44(1):19-28. [in Traditional Chinese with English summary].

Chen TH, Liu CP, Chung YJ, Wang S. 2014. Investigation on stand of moso bamboo shoots (*Phyllostachys Pubescens*) in Fenghuangsam Area, Nantou County. Q J Chin For 47(2):169-80. [in Traditional Chinese with English summary].

Chen TH, Wang DH, Chung HY. 2012. Effects of management strategy on growth and shoot products in *Dendrocalamus latiflorus*. Q J For Res 34(4):297-304. [in Traditional Chinese with English summary].

D'Oliveria MVN, Guarino ES, Oliveira LC, Ribas LA, Acuña MHA. 2013. Can forest management be sustainable in a bamboo dominated forest? A 12-year study of forest dynamics in western Amazon. For Ecol and Manage 310:672-9.

Dubey SD. 1967. Some percentile estimators for Weibull parameters. Technometrics 13:171-82.

Embaye K, Weih M, Ledin S, Christersson L. 2005. Biomass and nutrient distribution in a highland bamboo forest in southwest Ethiopia: implication for management. For Ecol and Manage 204:159-69.

Fukuda M, Iehara T, Matsumoto M. 2003. Carbon stock estimates for sugi and hinoki forests in Japan. For Ecol and Manage 184:1-16.

Gifford RM. 2000. Carbon contents of aboveground tissues of forest and woodland trees. National Carbon Accounting System Technical Report no. 22. Canberra: Australian Greenhouse Office 17 p.

He DJ, Hong W, Wu CZ, Lan B, Huang H, Wu XS. 2003. Study on biomass and energy distribution of natural *Phyllostachys heterocycla* cv. *pubescensin* Wuyi Mountainsand its comparison with high-yield forest. Acta Bot Boreali-occidentalia Sin, 23(2):291-6. [in Simplified Chinese with English summary].

Hsiao JH. 2010. Bamboo forest management in China. Peking, China: Science Press. [in Simplified Chinese].

IPCC. 2008. Availableat http://www.ipcc.ch. Accessed October 2008.

Isagi Y, Kawahara T, Kamo K, Ito H. 1997. Net production and carbon cycling in a bamboo *Phyllostachys pubescens* stand. Plant Ecol 130(1):41-52.

Kumemura A, Teraoka Y, Takeuchi I. 2009. The above-ground biomass and stand structure of unmanaged moso bamboo (*Phyllostachys pubescens*) stands in Kagoshima Prefecture. Res Bull Kagoshima Univ. For 36:1-8.

Lai CC, Hsiao JY. 1997. Genetic variation of *Phyllostachys pubescens* (Bambusoideae, Poaceae) in Taiwan based on DNA polymorphisms. Bot Bull Acad Sin 38:145-52.

Lamolom SH, Savidge RA. 2006. Carbon content variation in boles of mature sugar maple and giant sequoia. Tree Physiol 26:459-68.

Larpkern P, Moe SR, Totland O. 2011. Bamboo dominance reduces tree regeneration in a disturbed tropical forest. Oecologia 165:161-8.

Li ZJ, Lin P, Qiu XH. 1993. Studies on the biomass and productivity of *Phyllostachys pubescens* community in South Fujian. J Xiamen Univ. 32(6):762-7. [in Simplified Chinese with English summary].

Lin WC. 1967. Bamboo species and distribution in Taiwan. J Taiwan 3(2):1-20. [in Traditional Chinese].

Lin YJ. 2011. Review, current status, and prospects of the bamboo industry in Taiwan. Taiwan J For Sci 26:99-111.

Lobovikov M, Paudel S, Plazza M, Ren H, Wu J. 2007. World bamboo resources-A thematic study prepared in the framework of the global forest resources assessment 2005. FAO. Rome: Food and Agriculture Organization.

Losi CJ, Siccama TG, Condit R, Morales JE. 2003. Analysis of alternative methods for estimating carbon stock in young tropical plantations. For Ecol Manage 184:355-68.

Lu JM, Liu ZZ. 1982. Moso bamboo stand reforestation and improved cultivation test (2) Study on stand structure and growth characteristics. Taipei, Taiwan. Forestry Research Report no. 376.

Lu JM. 2001. Cultivation and management of bamboo forests. TFRI Extension Series no. 135. Taipei, Taiwan. Taiwan Forestry Research Institute. [In Chinese].

Monttia L, Campanello PI, Goldstein G. 2011. Flowering, die-back and recovery of a semelparous woody bamboo in the Atlantic forest. Acta Oecol 37(4):361-8.

Nogueira EM, Fearnside PM, Nelson BW, Barbosa RI, Keizer EWH. 2008. Estimates of forest biomass in the Brazilian Amazon: new allometric equations and adjustments to biomass from wood-volume inventories. For Ecol and Manage 256:1853-1867.

Peng ZQ, Lin YM, Liu JB, Zhou XH, Guo ZJ, Guo QR, Lin P. 2002. Biomass structure and energy distribution of *Phyllostachs heterocycla* cv. *pubescens* population. J of Xiamen Univ. 41(5):579-583. [in Simplified Chinese with English summary].

Rockwell CA, Kainer KA, d'Oliveira MVN, Staudhammer CL, Baraloto C. 2014. Logging in bamboo-dominated forests in southwestern Amazonia: caveats and opportunities for smallholder forest management. For Ecol and Manage 315:202-210.

Salimon CI, Putz FE, Menezes-Filho L, Anderson A, Silveira M, Foster Brown I, Oliveira LC. 2011. Estimating state-wide biomass carbon stocks for a REDD plan in Acre, Brazil. For Ecol and Manage 262:555-560.

Scurlock JMO, Dayton DC, Hames B. 2000. Bamboo: an overlooked biomass resource? Biomass Bioenergy 19:229-244.

Senba T, Yoshikawa S, Tanaka K. 2010. Landscape analysis of bamboo groves in Kyoto by using geo-information technology. Theory Appli GIS 18(2):63-72. [in Japanese with English summary].

Shanmughavel P, Francis K. 1996. Aboveground biomass production and nutrient distribution in growing bamboo (*Bambusa bambos* (L.) *Voss*). Biomass Bioenergy 10:383-91.

Sun BK, Chen YT, Yen TM, Li LE. 2013. Stand characteristics, aboveground biomass and carbon storage of moso bamboo (*Phyllostachys pubescens*) stands under different management levels in central Taiwan. Q J For Res 34(4):297-304. [in Traditional Chinese with English summary].

Tandon V, Barik SK. 2012. Bamboo flowering and rodent control. Unknow: Regency publications.

TCWB (Taiwan Central Weather Bureau). 2015. Available at http://www.cwb.gov.tw/ Accessed 07 Jan 2015.

Wang S, Chen TH, Chang HC, Chung HY, Li TI, Liu CP. 2009. The structures, aboveground biomass, carbon Storage of *Phyllostachys pubescens* Stands in Huisun Experimental Forest Station and Shi-Zhuo. Q J For Res 31(4):17-26. [in Traditional Chinese with English summary].

Wang S, Chen TH, Chen SY, Chung HY, Liu EU, Li TI, Liu CP. 2010. Estimating aboveground biomass and carbon sequestration of moso bamboo grown under selection cutting after two years. Q J For Res 32(3):35-43. [in Traditional Chinese with English summary].

Wang S. 2012. To evaluate felling and utilization of moso bamboo (*Phyllostachys pubescens*) from physiological and biochemical traits. Master's thesis. Taichung, Taiwan: Department of Forestry, National Chung Hsing University. [in Traditional Chinese with English summary].

Weibull W. 1951. A statistical distribution function of wide applicability. Journal of Appli Mechanics 18:293-7.

Wu QX. 1983. Types and stand structures of Phyllostachys pubescens in Guizhou Province. J Bamboo Res 2(1):112-124. [in Simplified Chinese with English summary].

Xiao FM, Fan SH, Wang SL, Xong CY, Zhang C, Lu SP, Zhang J. 2007. Carbon storage and spatial distribution in *Phyllostachy pubescens* and *Cunninghamia lanceolata* plantation ecosystem. Acta Ecol Sin 27(7):2794-801. [in Simplified Chinese with English summary].

Yen TM, Ji YJ, Lee JS. 2010. Estimating biomass production and carbon storage for a fast-growing makino bamboo (*Phyllostachys* *makinoi*) plant based on the diameter distribution model. For Ecol and Manage 260:339-44.

Yen TM, Lee JS. 2011. Comparing aboveground carbon sequestration between moso bamboo (*Phyllostachys heterocycla*) and China fir (*Cunninghamia lanceolata*) forests based on the allometric model. For Ecol Manage 261(6):995-1002.