

Article

# Dynamics of Understory Shrub Biomass in Six Young Plantations of Southern Subtropical China

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**Abstract:** Understory shrubs are an important component of forest ecosystems and drive ecosystem processes, such as ecosystem carbon cycling. However, shrub biomass carbon stocks have rarely been reported, which limits our understanding of ecosystem C stock and cycling. In this study, we evaluated carbon accumulation of shrub species using allometric equations based on height and basal diameter in six subtropical plantations at the age of 1, 3, 4 and 6 years. The results showed that plantation type did not significantly affect the total biomass of shrubs, but it significantly affected the biomass of *Rhodomyrtus tomentosa*, *Ilex asprella*, *Clerodendrum fortunatum* and *Baeckea frutescens*. The biomass of dominant shrub species *R. tomentosa*, *I. asprella*, *Gardenia jasminoides* and *Melastoma candidum* increased with stand age, while the biomass of *C. fortunatum* and *B. frutescens* decreased. The inconsistent biomass-time patterns of different shrub species may be the primary reason for the altered total shrub biomass in each plantation. Consequently, we proposed that *R. tomentosa*, *I. asprella*, *G. jasminoides* and *M. candidum* could be preferable for understory carbon accumulation and should be maintained or planted because of their important functions in carbon accumulation and high economic values in the young plantations of southern subtropical China.

**Keywords:** reforestation; understory plants; stand age; biomass carbon accumulation; *Rhodomyrtus tomentosa*; *Ilex asprella*; *Gardenia jasminoides*; *Melastoma candidum*; *Clerodendrum fortunatum*; *Baeckea frutescens*

## 1. Introduction

Shrubs are a type of vegetal group with a specific structure [1] and are essential to the biophysical and biodynamic processes of different ecosystems [2,3]. In arid and semi-arid ecosystems, shrubs are conducive to the increase in the number of herb-layer plant species [4]. In subtropical forests, shrubs facilitate the growth of understory tree seedling [5,6]. In reclaimed mined sites, shrubs act as ecosystem engineers [7]. In addition, understory shrub increases litter decomposition and the accumulation of litter-derived carbon (C) and nitrogen (N) in forest soils by altering soil microbial activity and community composition [8–10].

Physiological and ecological characteristics of shrubs have been systematically studied [11–13]. Palmroth et al. [14] found that an understory shrub had little response to N additions in terms of photosynthetic physiology or growth in boreal coniferous forests, which indicated that the shrub played a vital role in ecosystem C and N cycling. In addition, understory shrubs can respond quickly to thinning of even-aged stands [15]. Currently, increasing studies on shrubs focus on total shrub biomass

and biomass carbon storage [16,17]. Bai et al. [18] reported the dynamics of two multi-stemmed understory shrubs in two temperate forests. Regarding the dynamics of understory shrub biomass, more attention has been paid to comparisons of different stand ages in a single forest type, or different forest types in a specific stand age [19,20]. Meanwhile, estimation of shrub biomass is addressed at different scales. Shrub biomass was calculated from remote sensing data, terrestrial and airborne LiDAR data in dryland ecosystems [21–23], or biomass allometric equations [19]. Dynamics of total understory shrub biomass and an individual shrub species biomass in different plantations have not been widely reported, especially in young subtropical plantations.

The plantation area of China (69 million hectares) is one third of that of the total global area [24], of which subtropical plantations account for more than 60% [25]. Most subtropical plantations are young plantations. Hanley [15] found that the understory shrub and herb biomass makes up a large proportion of ecosystem productivity in young forests relative to old forests. Indeed, understory vegetation is even recognized as a principal driver of ecosystem function and process [26,27]. Chastain Jr et al. [28] reported that shrubs and herbs could have high potential carbon sequestration in Appalachian forests. Nonetheless, understory and forest floor are recognized as a whole in general [29], and the contributions of shrubs and herbs to the carbon sink are not separated [30,31]. Therefore, more research is needed to clarify the role of understory shrub communities and an individual shrub species in carbon cycling of subtropical forest ecosystems.

The goal of this study is to evaluate the dynamics of shrub biomass at the early restoration stages in plantations and to select preferable understory shrub species for the carbon sink. To this end, we calculated the biomass of individual shrub species and the total biomass of shrubs in six young subtropical plantations and evaluated their dynamics from age 1 to 6 years. Our research provides useful references on management of understory shrub species based on carbon accumulation of the shrub biomass.

## 2. Materials and Methods

### 2.1. Study Sites

This study was conducted at the Heshan National Field Research Station of Forest Ecosystem (112°54' E, 22°41' N), located in Guangdong province, China. The climate in this region is typical subtropical monsoon, with a distinct wet (April to September) and dry season (October to March), mean annual precipitation of 1700 mm and mean annual temperature of 21.7 °C. The average altitude is 10–80 m. The soil is classified as an Ultisol developed from sandstone. The dynamics of understory shrub biomass were studied in six plantations, including *Eucalyptus urophylla* monoculture plantation (EU), *Acacia crassicarpa* monoculture plantation (AC), *Castanopsis hystrix* monoculture plantation (CH), 10-species mixed plantation (M10), 30-species mixed plantation (M30) and a naturally recovered shrubland (NS). These plantations were established in 2005 on hilly land with similar site characteristics, and the tree seedlings were planted at a spacing of 2 m × 3 m (about 1650 trees per hectare) except for the naturally recovered shrubland where the plants sprouted naturally and were not be planted. Each plantation had three replicate plots, and the area of each plot was 1 hectare. All plots were distributed randomly in the experimental site with an area of 50 hectares. A permanent quadrat plot of 900 m<sup>2</sup> (30 m by 30 m) was established in each plot with an area of 1 hectare. The height of trees in these plantations is shown in Table 1.

**Table 1.** Average height of trees in six plantations (meter).

Plantations	Stand Age (Year)		
	1	4	6
NS	1.20 ± 0.38	0.99 ± 0.12	1.05 ± 0.02
EU	4.76 ± 0.29	10.21 ± 1.15	11.69 ± 1.03
AC	2.58 ± 0.2	7.41 ± 0.33	9.15 ± 0.90
CH	0.79 ± 0.01	3.97 ± 0.22	5.61 ± 0.09
M10	0.90 ± 0.06	2.81 ± 0.19	3.63 ± 0.32
M30	0.90 ± 0.10	2.94 ± 0.03	3.98 ± 0.03

Note: NS, EU, AC, CH, M10 and M30 indicate naturally recovered shrubland, *Eucalyptus urophylla*, *Acacia crassicaarpa*, *Castanopsis hystrix*, 10-species mixed plantation and 30-species mixed plantation, respectively. The value is the average of three plots ± standard error,  $n = 3$ . An average of one plot is based on the average of all trees in the replicated plot.

## 2.2. Methods

Vegetation inventories were conducted in permanent quadrats in 2006, 2008, 2009 and 2011, corresponding to 1 year, 3 years, 4 years and 6 years, respectively, after permanent quadrat plots were established in these plantations. A permanent quadrat plot was divided into nine subplots (four 5 m × 5 m small subplots for each subplot). In each subplot, we selected two bidiagonal small subplots and then measured the height and basal diameter of all shrubs during each inventory. There were eighteen small subplots in a permanent quadrat plot for each inventory. The biomass of each shrub species was estimated by allometric regression equations in all plantations [32].

## 2.3. Statistics Analysis

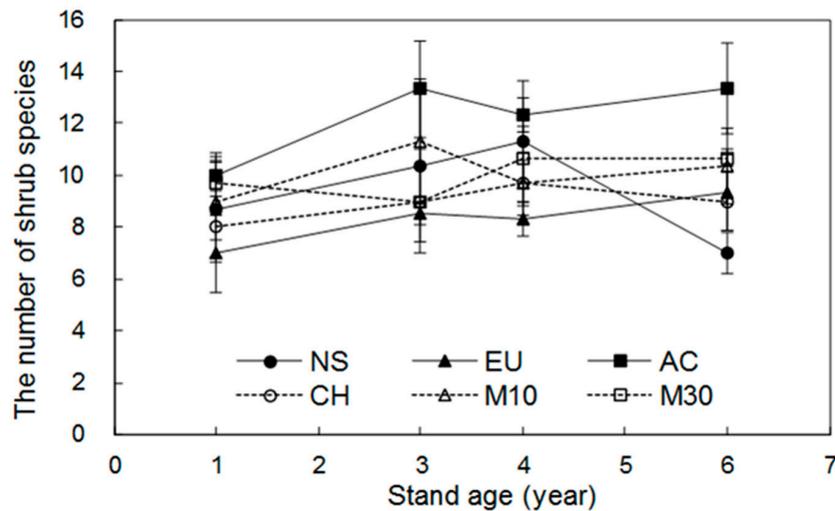
Two-way ANOVAs were employed to test the effects of plantation type and stand age on the number of shrub species, total biomass of shrubs, and biomass of *Rhodomyrtus tomentosa*, *Ilex asprella*, *Gardenia jasminoides*, *Melastoma candidum*, *Clerodendrum fortunatum*, *Baeckea frutescens*. One-way ANOVA and multiple comparison analysis (LSD) were performed to determine the effect of plantation type on the number of shrub species and total biomass of shrubs at the same stand age, and the effect of stand age on the number of shrub species and the total biomass of shrubs in the same plantation. Data were reciprocally or square-root transformed when required to meet the assumptions of normality and homogeneity of variance. Statistical significance was determined at  $P < 0.05$ . All analyses were performed with SPSS software (SPSS. Inc., Chicago, IL, USA).

## 3. Results

### 3.1. Dynamics of Shrub Species

The number of shrub species was significantly affected by plantation type (two-way ANOVA,  $F = 3.18$ ,  $P = 0.015$ ). It was higher in AC than in other plantations (Figure 1). The number of shrub species was the highest in AC at the age of 3 and 6 years (about 13.3 species), and it was the lowest in EU at the age of 1 year and in NS at the age of 6 years (about 7 species). However, stand age did not significantly affect the number of shrub species (two-way ANOVA,  $F = 1.44$ ,  $P = 0.243$ ). The interaction between plantation type and stand age was not significant ( $F = 0.44$ ,  $P = 0.957$ ).

During the period of 1 to 6 years old, 23 shrub species were found in these plantations regardless of plantation type (Table 2). About 16, 13, 16, 13, 13 and 15 species were found in NS, EU, AC, CH, M10 and M30, respectively, 10 of which were shared by these given plantations regardless of replicated quadrats. Endemic species also present included *Glochidion zeylanicum* only in NS, *Glochidion eriocarpum* in AC, *Garcinia oligantha* in CH, *Cassia alata*, *Symplocos chinensis*, and *Psychotria rubra* in M30 (Table 2).



**Figure 1.** Effects of plantation type and stand age on the number of shrub species. NS, EU, AC, CH, M10 and M30 represent naturally recovered shrubland, *Eucalyptus urophylla*, *Acacia crassicarpa*, *Castanopsis hystrix*, 10-species mixed plantation and 30-species mixed plantation, respectively. The value is the average  $\pm$  standard error,  $n = 3$ .

**Table 2.** Shrub species in six plantations.

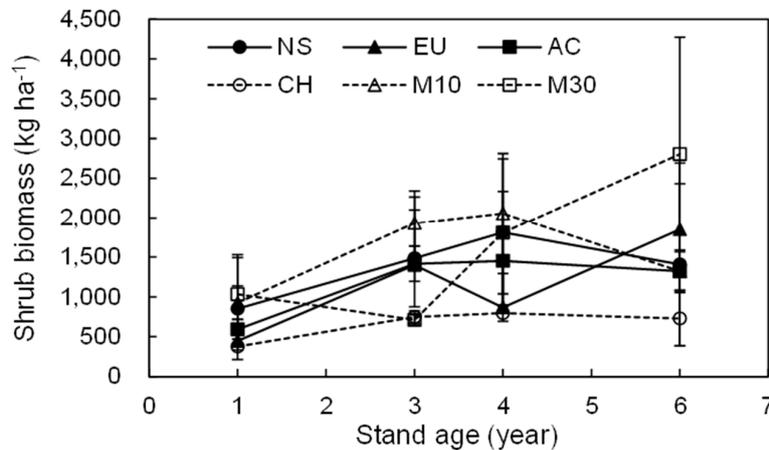
Species Name	Plantations					
	NS	EU	AC	CH	M10	M30
<i>Mallotus apelta</i>	✓	✓	✓	✓	✓	✓
<i>Ficus variolosa</i>	✓	○	✓	○	✓	✓
<i>Cassia alata</i>	○	○	○	○	○	✓
<i>Rhaphiolepis indica</i>	✓	✓	✓	✓	✓	✓
<i>Baeckea frutescens</i>	✓	✓	✓	✓	✓	✓
<i>Clerodendrum fortunatum</i>	✓	✓	✓	✓	✓	✓
<i>Breynia fruticosa</i>	✓	○	✓	○	✓	○
<i>Symplocos chinensis</i>	○	○	○	○	○	✓
<i>Gardenia jasminoides</i>	✓	✓	✓	✓	✓	✓
<i>Psychotria rubra</i>	○	○	○	○	○	✓
<i>Phyllodium pulchellum</i>	○	○	✓	✓	○	○
<i>Wikstroemia indica</i>	✓	✓	✓	○	✓	✓
<i>Glochidion eriocarpum</i>	○	○	✓	○	○	○
<i>Ilex asprella</i>	✓	✓	✓	✓	✓	✓
<i>Eurya chinensis</i>	✓	✓	✓	✓	✓	✓
<i>Evodia leptota</i>	✓	✓	✓	✓	✓	○
<i>Helicteres angustifolia</i>	✓	✓	✓	○	✓	✓
<i>Garcinia oligantha</i>	○	○	○	✓	○	○
<i>Glochidion puberum</i>	○	○	✓	○	○	✓
<i>Rhodomyrtus tomentosa</i>	✓	✓	✓	✓	✓	✓
<i>Ficus hirta</i>	✓	✓	✓	✓	✓	✓
<i>Glochidion zeylanicum</i>	✓	○	○	○	○	○
<i>Melastoma candidum</i>	✓	✓	✓	✓	✓	✓

Note: "✓" and "○" indicate that the species are present or absent, respectively in this plantation regardless of stand age. For abbreviations, please see Table 1.

### 3.2. Dynamics of the Total Shrub Biomass

Two-way ANOVA indicated that plantation type did not significantly affect the total biomass of shrubs (two-way ANOVA,  $F = 1.46$ ,  $P = 0.223$ ). However, to some extent, the total biomass of shrubs was affected by stand age (two-way ANOVA,  $F = 2.74$ ,  $P = 0.054$ ; Figure 2). The interaction between

plantation type and stand age was not significant ( $F = 0.60$ ,  $P = 0.858$ ). In all given plantations, the total biomass of shrubs at the age of 4 and 6 years was significantly higher than that at the age of 1 year ( $P = 0.025$  and  $P = 0.013$ , respectively). The average biomass increased from  $704.09 \text{ kg ha}^{-1}$  at the age of 1 year to  $1571.66 \text{ kg ha}^{-1}$  at the age of 6 years regardless of plantation type (Figure 2).

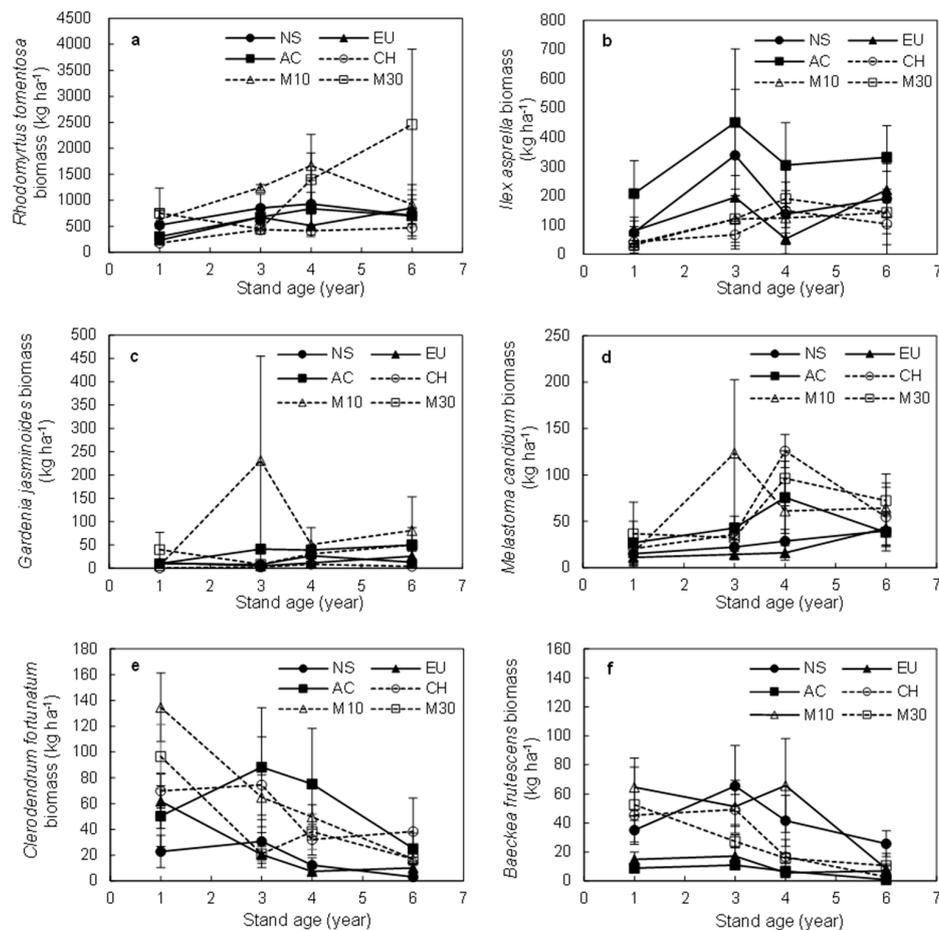


**Figure 2.** Effects of plantation type and stand age on the total biomass of shrubs. The value is the average  $\pm$  standard error,  $n = 3$ . For abbreviations, please see Figure 1.

### 3.3. Biomass of the Dominant Shrub Species

The biomass of each dominant shrub species in all given plantations was separately evaluated and analyzed (Figure 3). From 1 to 6 years, the summation of biomass for these six dominant shrub species, namely, *R. tomentosa*, *I. asprella*, *G. jasminoides*, *M. candidum*, *C. fortunatum* and *B. frutescens*, accounted for about 94.84–97.40%, 91.87–95.56%, 85.19–91.58%, 88.94–98.44%, 91.04–97.98%, and 91.09–98.20% of the total biomass of shrubs in NS, EU, AC, CH, M10, and M30, respectively. Among these six shrub species, the biomass of *R. tomentosa* was the highest (Figure 3), and it accounted for about 42.43–80.92% of the total biomass of shrubs.

Two-way ANOVA showed that plantation type significantly affected the biomass of *R. tomentosa*, *I. asprella*, *C. fortunatum* and *B. frutescens* (Table 3). The biomass of *R. tomentosa* was significantly higher in M30 than in other plantations, it was also higher in M10 than in CH ( $P < 0.034$ , and  $P = 0.027$ , respectively). Biomass of *I. asprella* was significantly higher in AC than in CH, M10 and M30 ( $P < 0.021$ ). Biomass of *C. fortunatum* was significantly lower in NS than in AC, CH and M10 ( $P < 0.021$ ), and it was also lower significantly in EU than in M10 ( $P = 0.031$ ). Stand age significantly affected the biomass of *I. asprella*, *M. candidum*, *C. fortunatum* and *B. frutescens*. Stand age also had an effect on the biomass of *R. tomentosa* to some extent (Table 3). The biomass of *R. tomentosa*, *I. asprella*, *M. candidum* increased from  $453.13$ ,  $84.99$ ,  $25.42 \text{ kg ha}^{-1}$  at the age of 1 year to  $1049.26$ ,  $204.15$ ,  $56.15 \text{ kg ha}^{-1}$  at the age of 6 years, regardless of plantation type (Figure 3). The biomass of *R. tomentosa* and *M. candidum* was higher in plantations at the age of 4 and 6 years than that at the age of 1 year ( $P = 0.034$ , and  $P = 0.011$ , respectively), and the biomass of *I. asprella* was higher in plantations at the age of 3 and 6 years than that at the age of 1 year ( $P = 0.005$ , and  $P = 0.038$ , respectively). However, the biomass of *C. fortunatum* and *B. frutescens* decreased significantly from  $72.65$ ,  $36.88 \text{ kg ha}^{-1}$  at the age of 1 year to  $18.44$ ,  $9.19 \text{ kg ha}^{-1}$  at the age of 6 years regardless of plantation type ( $P < 0.001$ , and  $P < 0.001$ , respectively). Neither plantation type nor stand age affected the biomass of *G. jasminoides*, but its average biomass increased to  $41.33 \text{ kg ha}^{-1}$  at the age of 6 years relative to  $15.79 \text{ kg ha}^{-1}$  at the age of 1 year regardless of plantation type.



**Figure 3.** Effects of plantation type and stand age on the biomass of individual shrub species. (a) *Rhodomyrtus tomentosa*; (b) *Ilex asprella*; (c) *Gardenia jasminoides*; (d) *Melastoma candidum*; (e) *Clerodendrum fortunatum* and (f) *Baeckea frutescens*. The value is the average  $\pm$  standard error,  $n = 3$ . For abbreviations, please see Figure 1.

**Table 3.** Effects of plantation type and stand age on the biomass of *Rhodomyrtus tomentosa*, *Ilex asprella*, *Gardenia jasminoides*, *Melastoma candidum*, *Clerodendrum fortunatum*, and *Baeckea frutescens*.

Shrub Species	PT		SA		PT $\times$ SA	
	F	P	F	P	F	P
<i>Rhodomyrtus tomentosa</i>	2.682	0.032	2.754	0.053	1.162	0.332
<i>Ilex asprella</i>	2.586	0.039	3.198	0.032	0.413	0.967
<i>Gardenia jasminoides</i>	1.479	0.215	0.535	0.661	0.682	0.789
<i>Melastoma candidum</i>	1.669	0.160	3.276	0.029	1.169	0.327
<i>Clerodendrum fortunatum</i>	2.910	0.023	8.359	<0.001	1.477	0.152
<i>Baeckea frutescens</i>	5.537	<0.001	6.188	0.001	0.875	0.594

Note: PT, plantation type; SA, stand age; PT  $\times$  SA, interactions between plantation type and stand age. Results are from two-way factorial ANOVA. The factors used for the ANOVA were plantation type (levels: naturally recovered shrubland, *Eucalyptus urophylla*, *Acacia crassicaarpa*, *Castanopsis hystrix*, 10-species mixed plantation and 30-species mixed plantation), and stand age (levels: 1, 3, 4 and 6 years old).

## 4. Discussion

### 4.1. Effects of Plantation Type

Plantation type affected the number of shrub species significantly. The number of shrub species was obviously higher in AC than that in other plantations, which was the highest in AC, and the lowest

in NS. This can be ascribed to the understory abiotic and biotic conditions and the characteristics of species [33,34]. Shrub germination may be affected by herbs through competition for nutrients and light; higher herb biomass hinders shrub species germination [35,36]. In these studied plantations, herbs were dominated by *Dicranopteris dichotoma* [27]. The herb biomass was the lowest in AC, and the highest in NS [32].

Regardless of plantation type and stand age, 23 shrub species were found in the studied plantations. The number of shrub species was very close to the previous research result (13–23 species) [37]. Carneiro et al. [38] found that the average number of understory species was 6–15 in *Eucalyptus* plantations aged 1 and 10 years old. Luo et al. [39] also found the diversity of shrub species was similar among subtropical plantations in southern China. In our research, some endemic species in the specific plantations were found, yet the possible reasons why these endemic species were only present in specific plantations are still unclear and could need further study.

Plantation type significantly affected the biomass of *R. tomentosa*, *I. asprella*, *C. fortunatum* and *B. frutescens*. Soil physicochemical properties could make contributions to the difference [40]. However, we previously found that there were no significant differences in soil organic carbon among these plantations [41], and there were no significant differences in soil pH, soil nitrogen, soil available phosphorus among the above six plantations [42]. Moreover, in our experimental sites, the effects of plantation type on mean soil temperature, soil water content, and leaf area index were not significant either [43]. Therefore, we speculate that it could be ascribed to the differences in microenvironment among different plantations. For instance, AC had the highest canopy density (from direct observation); thus, the light in the understory could be the weakest for all studied plantations.

#### 4.2. Effects of Stand Age

Stand age did not significantly affect the number of shrub species. This is inconsistent with another study in humid tropical plantations [44]. The diverse climates could be responsible for the differences [45,46]. A previous study suggested that understory richness was driven by loss of early colonists [47]. In our study, these plantations were still young and the understory shrub species may have not developed to the stage of loss of early colonists. Therefore, the effect of stand age on the number of shrub species could be negligible.

The total biomass of shrubs increased from 704.09 kg ha<sup>-1</sup> at the age of 1 year to 1571.66 kg ha<sup>-1</sup> at the age of 6 years regardless of plantation type, which was higher than the result (158 kg ha<sup>-1</sup>) of the previous study [48]. Plantation type did not significantly influence the total biomass of shrubs in our study. The likely reasons were that all studied plantations were young and the canopies were not completely closed (from direct observation). A large proportion of shrub species received sufficient light for growth [49]. In addition, shrubs can adopt an arborescent shape under a tree canopy to some extent [50]. The change in biomass with stand age was consistent with Li et al. [51]. In these studied plantations, the total biomass of shrubs were mainly from the biomass of *R. tomentosa*, *I. asprella*, *G. jasminoides*, *M. candidum*, *C. fortunatum* and *B. frutescens*. The summed biomass of these six shrub species accounted for about 85.19–98.44% of the total biomass of shrubs. The result from the survey of shrub species also suggested that *R. tomentosa*, *G. jasminoides*, *C. fortunatum* and *B. frutescens* were dominant understory shrub species in subtropical forests in eastern Guangdong, China [52]. Furthermore, the dominant shrub species *R. tomentosa*, *M. candidum*, *I. asprella* and *G. jasminoides* have high economic values. For instance, Rhodomyrtone is a natural antibacterial drug candidate from *R. tomentosa* [53]. The root extracts from *I. asprella* lessen acute respiratory distress syndrome in mice infected with the influenza virus [54].

Stand age significantly affected the biomass of *I. asprella*, *M. candidum*, *C. fortunatum* and *B. frutescens*. It also slightly influenced the biomass of *R. tomentosa* (Table 3). The biomass of *R. tomentosa*, *I. asprella*, *M. candidum* increased with stand age. The increase in biomass resulted from plant height and basal diameter increases. However, the biomass of *C. fortunatum* and *B. frutescens* decreased with stand ages. The decrease in biomass was mainly caused by individuals being reduced (Table 4).

The biomass of *G. jasminoides* did not show obvious changes with stand age, which could be a result of the wide environmental adaptation of *G. jasminoides* [55,56]. Overall, different shrub species had varied responses to stand age. However, the soil physiochemical properties (i.e., soil moisture content, soil pH, and soil organic matter content) and soil microbial communities of different shrub species were very similar in a Eucalyptus plantation [57]. Thus, changes in the light environment could be one of the main reasons. Furthermore, there are various optimum light levels for the growth of different shrubs [6,58]. For example, *G. jasminoides* showed its optimum growth rate above 52% sunlight [49], and there was a very rigorous light demand by *B. frutescens* [59].

**Table 4.** Density of shrub species (individuals per hectare).

Shrub Species	Plantation	Stand Age (Year)			
		1	3	4	6
<i>Rhodomyrtus tomentosa</i>	NS	6853	4437	3789	1991
	EU	4652	5416	0.4193	3151
	AC	9481	7756	6770	4000
	CH	6104	3281	2570	1526
	M10	14148	8207	7415	2370
	M30	12207	2637	4089	5015
<i>Ilex asprella</i>	NS	189	517	316	317
	EU	430	489	228	489
	AC	415	785	533	578
	CH	178	156	311	193
	M10	267	422	230	356
	M30	133	178	341	193
<i>Melastoma candidum</i>	NS	789	411	415	333
	EU	578	444	656	575
	AC	741	511	919	644
	CH	1096	578	756	630
	M10	385	1415	896	548
	M30	1822	570	1059	578
<i>Gardenia jasminoides</i>	NS	244	98	231	206
	EU	415	185	156	254
	AC	519	593	548	526
	CH	89	74	96	207
	M10	222	496	215	296
	M30	726	267	193	400
<i>Clerodendrum fortunatum</i>	NS	3459	3693	1849	289
	EU	6040	2159	548	800
	AC	5452	3941	2807	1030
	CH	12415	4793	2415	2000
	M10	10622	1785	3207	711
	M30	11615	4096	2681	852
<i>Baeckea frutescens</i>	NS	5933	5867	5485	2133
	EU	3072	2244	1800	565
	AC	1733	1593	1741	156
	CH	9274	4037	2644	222
	M10	13244	8356	7296	748
	M30	9244	2541	1926	333

Note: NS, EU, AC, CH, M10 and M30 indicate naturally recovered shrubland, *Eucalyptus urophylla*, *Acacia crassiparva*, *Castanopsis hystrix*, 10-species mixed plantation and 30-species mixed plantation, respectively.

## 5. Conclusions

In this study, plantation type significantly affected the number of shrub species, but stand age did not. The effects of plantation type and stand age on the total biomass of shrubs were not

significant. Moreover, there were similar dominant shrub species in the six plantations. The biomass of the dominant shrub species *R. tomentosa*, *I. asprella*, *G. jasminoides* and *M. candidum* increased with stand age, while the biomass of *C. fortunatum* and *B. frutescens* decreased. These results suggest that shrub species such as *R. tomentosa*, *I. asprella*, *G. jasminoides* and *M. candidum* could be suitable for carbon accumulation by understory plant biomass in young plantations in southern subtropical China. These four species have high economic values. Consequently, we propose that *R. tomentosa*, *I. asprella*, *G. jasminoides* and *M. candidum* should be maintained or planted under plantations.

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