

Article

Effects of Stand Origin and Near-Natural Restoration on the Stock and Structural Composition of Fallen Trees in Mid-Subtropical Forests

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Abstract: Fallen trees comprise an important part of forest ecosystems and serve a central role in maintaining the biodiversity and tree regeneration of forests. However, the effects of stand origin and near-natural restoration on the biomass and carbon stock of fallen trees remain unclear. Based on 60 sampling plots of field surveys of mid-subtropical forests in Jiangxi Province, we investigated the stock and structural composition of fallen trees in artificial coniferous forests (*Acf*), natural coniferous forests (*Ncf*) (e.g., different stand origins) and natural evergreen broadleaf forests (*Nebf*) (e.g., near-natural restoration). The following results were obtained: (1) the largest biomass and carbon stocks of fallen trees among three forest types (*Nebf*, *Ncf* and *Acf*) were measured for *Nebf*; (2) the fallen tree biomass and carbon stock in natural *Cunninghamia lanceolata* forest (*Nclf*) were significantly larger than that in artificial *Cunninghamia lanceolata* forest (*Aclf*), and the fallen tree biomass and carbon stock in natural *Pinus massoniana* forest (*Npf*) were also significantly larger than those in artificial *Pinus massoniana* forest (*Apf*); (3) the diameter class allocation in natural forests was more uniform than that in artificial forests; (4) the biomass of fallen trees with mild decay was not significantly different among forest types within stand origin or among the stand origin within forest types; however, the biomass of fallen trees with moderate and heavy decay significantly differed among stand origin (*Aclf* vs. *Nclf*, *Apf* vs. *Npf*), but was not significant among the forest types (*Aclf* vs. *Apf*, *Nclf* vs. *Npf*) within a stand origin. Our results suggested that the large biomass and carbon stock of fallen trees in *Nebf* may serve a significant role in mitigating global warming and carbon cycles in mid-subtropical forests. Therefore, stand origin and near-natural restoration exert significant effects on the carbon stock and structural composition of fallen trees in mid-subtropical forests.

Keywords: fallen tree; carbon; subtropical forest; stand origin; near-natural restoration

1. Introduction

Fallen trees are an important part of forests and can be regarded as carbon and nutrient pools, which serve a crucial role in the biogeochemical cycles and global carbon balance in forest ecosystems. Fallen trees can sustain the stability and biodiversity of forest ecosystems and are beneficial to the

maintenance of primary productivity and sustainable development [1–3]. Therefore, the rational utilization and protection of fallen trees should be central to the sustainable operation and management of forest ecosystems. However, the roles of fallen trees in mitigating global climates and enhancing forest functions have been a significant concern of global ecologists [2–5].

The carbon storage of fallen trees in global forests is $(2.0\text{--}16.0) \times 10^{10}$ mg, which accounts for 1.75%–13.96% of the carbon stock in the global forest ecosystem (114.6×10^{11} mg) [6]. Thus, in order to make a complete estimation of carbon storage in forest ecosystem, the biomass of fallen trees must be considered [7]. Previous studies have demonstrated that disturbance, competition, forest type and stand age significantly affect not only the biomass of fallen trees in forest ecosystems, but also the decomposition and structure of fallen trees [8,9]. Thus, investigation of the direct and indirect effects of external factors (disturbance, competition, forest type and stand age) on the biomass, decomposition and structure of fallen trees is relatively important for the carbon storage and functional balance in forest ecosystems.

The structure and function of a natural forest is more complex and comprehensive than the structure and function of an artificial forest in terrestrial ecosystems [10]. Due to the deforestation of natural forests, a large number of artificial forests have been expanded to satisfy the demand for wood produce. According to the results from the Seventh National Forest Resource Inventory, the artificial plantation maintains the largest area in forest at 6.16×10^7 ha, which accounts for 34.01% of the forest land area in China. Moreover, the artificial forest stock is 1.961×10^{10} m³, which accounts for 14.67% of the total forest stock in China (e.g., ranked first in the world) [11]. However, the structure, function and stability of an artificial forest substantially differs from the structure, function and stability of a natural forest [11,12]. It is believed that artificial forests in China usually have larger planting density with more similarly-aged trees, and the largest number of fallen trees in artificial forests originates from the disturbance of afforestation, human operation management, intra competition and natural pruning [13]. However, natural forests in China have primarily diversely-aged trees and are less disturbed by human management and afforestation. The larger number of fallen trees in natural forests can be attributed to natural competition, density adjustment and natural pruning. Death by aging and external disturbances (e.g., wind, snowstorms, lightning, fire, pests and diseases) causes significant differences in the biomass stock and structure between natural forests and artificial forests [9,14–17].

This study was conducted to assess the storage, diameter class distribution and decomposition condition of fallen trees in natural coniferous forests (*Ncf*), artificial coniferous forests (*Acf*) and natural evergreen broadleaf forests (*Nebf*) in Jiangxi Province of mid-subtropical China. We pose the following questions: (1) Are there any differences in the biomass of fallen trees among *Acf*, *Ncf* and *Nebf*? (2) Are there any structural differences in stand origin (*Acf* and *Ncf*) and near-natural restoration (*Ncf* and *Nebf*) in these forest types?

2. Materials and Methods

2.1. Study Site

The study area is located in Jiangxi Province of mid-subtropical China ($24^{\circ}29'\sim 30^{\circ}05'$ N and $113^{\circ}34'\sim 118^{\circ}29'$ E). The climate is characterized as humid sub-tropic monsoon, and the soil is predominantly acidic and red. The annual average temperature is 18.9 °C and the precipitation amount is 1438 mm. The dominant vegetation types primarily include evergreen broadleaf forests (e.g., *Cinnamomum camphora*, *Schima superba* and *Castanopsis sclerophylla*), deciduous broadleaf forests (e.g., *Alniphyllum fortunei*, *Choerospondias axillaris* and *Liquidambar formosana*), coniferous forests (e.g., *Pinus massoniana*, *Cunninghamia lanceolata* and *Pinus elliottii*), and bamboo forests (e.g., *Phyllostachys heterocycla*) [18]. In this study, the fallen trees of artificial coniferous forests (including artificial *Cunninghamia lanceolata* forests and artificial *Pinus massoniana* forests), natural coniferous forests (including natural *Cunninghamia lanceolata* forests and natural *Pinus massoniana* forests) and natural evergreen broadleaf forests (a total of 60 sample plots) were selected (Table 1). The plot size was

28.28 m × 28.28 m (0.08 ha). We measured the central diameter and length of a fallen tree, then recorded the decay class of fallen trees with diameter ≥ 2.5 cm in each sample plot. Each structural class (%) of standing tree based on diameter for different stand types was recorded (Table A1). A short section of each fallen tree was sampled to bring back to the laboratory for physical and chemical analysis.

Table 1. General status of the experimental plots.

Forest Types	Stand Types	Number of Plots	Average Age (Years)	Average Stand Density (Stems/hm ²)	Average Canopy Cover (%)	Average DBH (cm)	Average Height (m)
Acf	Aclf	10	20.8	1877 ± 615	75 ± 10	10.3 ± 2.8	10.7 ± 1.5
	Apf	10	20.3	1252 ± 599	64 ± 16	9.39 ± 2.9	9.11 ± 2.8
Ncf	Nclf	10	20.5	1559 ± 402	60 ± 15	10.21 ± 2.1	9.48 ± 1.8
	Npf	10	20.1	887 ± 487	62 ± 17	12.2 ± 4.9	11.8 ± 3.3
NEbf		20	30.4	1216 ± 396	77 ± 11	15.1 ± 5.1	14.2 ± 3.4

DBH, Diameter at breast height 1.3 m over bark; stems, number of trees; Acf, artificial coniferous forest; Ncf, natural coniferous forest; NEbf, natural evergreen broad-leaved forest; Aclf, artificial *Cunninghamia lanceolata* forest; Apf, artificial *Pinus massoniana* forest; Nclf, natural *Cunninghamia lanceolata* forest; Npf, natural *Pinus massoniana* forest. Values are shown with means ± S.E.

2.2. Decay Class of Fallen Trees

Based on the standard established by Sollins [19] and the actual situation to classify different decay classes, the fallen trees of different forest types in our research area of Jiangxi province were divided into three different grades as follows:

Mild decay: bark, lateral branches of fallen trees were complete and sapwood was intact with mild decay.

Moderate decay: the majority of the bark had fallen off and part of the sapwood was decaying.

Heavy decay: no bark, a large area of sapwood and section heartwood were decaying.

2.3. Carbon Content and Biomass Determination

Using the weighting method to select the measuring number (e.g., a plurality of test samples) of fallen trees for each forest type, each test sample of a different decay class was repeated three times, and the carbon contents of the fallen trees were measured using a TOC analyzer (Vario TOC, Elementar, Germany).

The fresh weight of each fallen tree was directly measured using a steelyard (kg, by two decimal places). Each tree under a drying process (e.g., drying at 65 °C to obtain a consistent weight) to retrieve test samples (e.g., disks with a thickness range of 5–10 cm were extracted from each fallen tree) to calculate the dry weight and moisture content of the fallen trees and estimate the biomass of the fallen trees.

2.4. Carbon Stock Calculations

Density of fallen trees: First, the weights of the disks of the fallen trees were measured (m, g), and the disks were placed in a container with a specific amount of water in the container (v_1 , mL), the volume of water (v_2 , mL), and the densities of the fallen trees (ρ , g/cm³) were calculated (Equation (1)).

$$\rho = m / (v_1 - v_2) \quad (1)$$

Volume of fallen trees: A central cross section approximation was utilized to calculate the volume [20] as:

$$V_{LDW_{ij}} = \left(\pi D_{LDW_{ij}}^2 \times h_{LDW_{ij}} \right) / 4 \quad (2)$$

where, $V_{LDW_{ij}}$ (m³) represents the volume of fallen trees with decay class j (e.g., $j = 1, 2, 3$ represent mild decay, moderate decay and heavy decay, respectively), $D_{LDW_{ij}}$ (cm) is the central diameter and $h_{LDW_{ij}}$ (m) represents the lengths of the fallen trees.

The morphologies of the fallen trees were examined to classify the different decaying classes. The volume, density, and carbon content of each corresponding sample were employed to calculate the carbon stock for the fallen trees (Equation (3)).

$$C_{DW_i} = \sum_{j=1}^3 [V_{LDW_{ij}} \times D_{LDW_{ij}} \times C_{FLDW_{ij}}] \quad (3)$$

where, C_{DW_i} is carbon storage of the i th fallen tree in the ecosystem, and the carbon stock of $C_{LDW_{ij}}$. The units are mg/ha.

$V_{LDW_{ij}}$ (m^3) is the volume of fallen trees with decay class j (e.g., $j = 1, 2, 3$ represent mild decay, moderate decay and heavy decay, respectively). $D_{LDW_{ij}}$ (g/cm^3) represents the densities of the fallen trees in different decay classes, and $C_{FLDW_{ij}}$ (g/kg) denotes the average carbon contents of fallen trees in different decay classes.

2.5. Statistical Analysis

Statistical analyses were conducted using SPSS 17.0 software (IBM company, Chicago, IL, USA), and a one-way analysis of variance (ANOVA) was employed to determine the differences among the biomass, carbon stock and diameter class of three forest types (*Acf*, *Ncf* vs. *NEbf*) and two different stand types (artificial and natural). A one-way ANOVA was also performed to determine the significant differences among the carbon stocks of the same forest type and different stand types (artificial forests and natural forests) between the different decay classes. The least significant difference (LSD) was calculated when the treatments significantly differed.

3. Results

3.1. Biomass and Carbon Stock of Fallen Trees in Artificial and Natural Forests

The biomass of fallen trees in *Ncf* ($1.625 \pm 0.22 \text{ t/hm}^2$) was significantly higher than that in *Acf* ($0.813 \pm 0.25 \text{ t/hm}^2$), and *Acf* yielded a significant reduction compared with the *NEbf* climax forests ($11.061 \pm 1.15 \text{ t/hm}^2$) (Figure 1). The carbon storage of fallen trees in *NEbf* ($4.735 \pm 0.33 \text{ mg/hm}^2$) was significantly higher than that in *Ncf* ($0.647 \pm 0.08 \text{ mg/hm}^2$), and in *Ncf* was also significantly higher than that in *Acf* ($0.255 \pm 0.07 \text{ mg/hm}^2$) (Figure 1).

The biomass and carbon stock of fallen trees in *Nclf* was significantly higher than that in *Aclf*, and the biomass and carbon stock of fallen trees in *Npf* was also significantly larger than that in *Apf* (Table 2). However, no significant differences between *Aclf* and *Apf* and, *Nclf* and *Npf* were observed (Table 2).

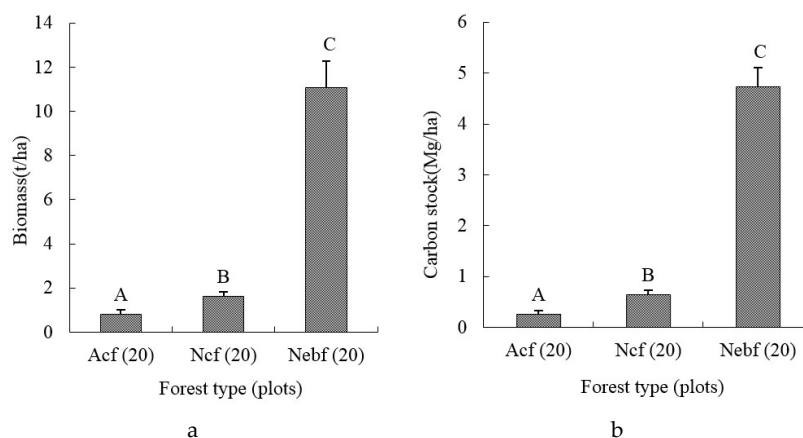


Figure 1. Biomass (a) and carbon stock (b) of fallen trees in artificial and natural forest. *Acf*, artificial coniferous forest; *Ncf*, natural coniferous forest; *NEbf*, natural evergreen broad-leaved forest; Different uppercase letters indicate significant differences among different forest types (*Acf*, *Ncf* or *NEbf*) at $p < 0.05$.

Table 2. Biomass and carbon stock of fallen trees for different stand and forest types.

Stand Types (Plots)	Biomass (t/ha)	Carbon Stocks (mg/ha)
<i>Aclf</i> (10)	0.424 ± 0.06a ^A	0.143 ± 0.04a ^A
<i>Nclf</i> (10)	0.815 ± 0.17b ^A	0.329 ± 0.09b ^A
<i>Apf</i> (10)	0.389 ± 0.08a ^A	0.112 ± 0.05a ^A
<i>Npf</i> (10)	0.810 ± 0.14b ^A	0.318 ± 0.08b ^A

Different uppercase letters indicate significant differences among different forest types (*Cunninghamia lanceolata*, *Pinus massoniana*) of the same stand type (artificial or natural) at $p < 0.05$. Different lowercase letters indicate significant differences among different stand types for the same forest type ($p < 0.05$).

3.2. Fallen Trees Diameter Class Structure of Artificial and Natural Forests

According to the diameter class distribution of fallen trees in subtropical forests, the diameter class was divided into five grades (e.g., 0–5 cm, 5–10 cm, 10–15 cm, 15–20 cm and ≥ 20 cm (upper limit exclusion)) with intervals of 5 cm, which refer to diameter classes I, II, III, IV, and V.

The diameter class distributions of the biomass of fallen trees between natural forests and artificial forests significantly differed (Figure 2). The biomass of diameter class I exhibited no significant difference among *Acf*, *Ncf* and *Nebf*, but demonstrated significant difference in diameter classes II, III and IV, with the consistent pattern *Nebf* > *Ncf* > *Acf* (Figure 2). The biomass of fallen trees with diameter I (0–5 cm) did not significantly differ among the stand origins within forest type (*Aclf* vs. *Nclf*, *Apf* vs. *Npf*) and within stand origin (*Aclf* vs. *Apf*, *Nclf* vs. *Npf*). However, the biomass of fallen trees with diameter class II, III and IV was significantly different among stand origins (*Aclf* vs. *Nclf*, *Apf* vs. *Npf*), but not significant among forest types within stand origin (*Aclf* vs. *Apf*, *Nclf* vs. *Npf*) (Table 3).

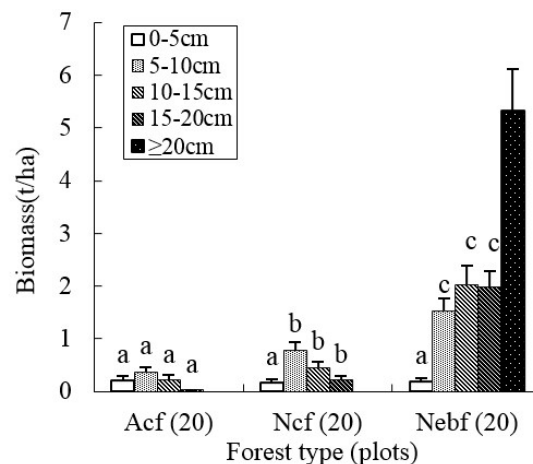


Figure 2. Biomass of fallen trees for different diameter classes in artificial and natural forests. Different lowercase letters indicate significant differences between different forest types (*Acf*, *Ncf* or *Nebf*) of the same diameter class ($p < 0.05$).

Table 3. Biomass of fallen trees by diameter class for different stand and forest types.

Stand Types (Plots)	Diameter Class			
	I (0–5cm)	II (5–10cm)	III (10–15cm)	IV (15–20cm)
<i>Aclf</i> (10)	0.106 ± 0.04a ^A	0.218 ± 0.08a ^A	0.101 ± 0.03a ^A	0.017 ± 0.08a ^A
<i>Nclf</i> (10)	0.099 ± 0.03a ^A	0.424 ± 0.14b ^A	0.217 ± 0.08b ^A	0.119 ± 0.04b ^A
<i>Apf</i> (10)	0.097 ± 0.04a ^A	0.153 ± 0.05a ^A	0.112 ± 0.04a ^A	0.009 ± 0.003a ^A
<i>Npf</i> (10)	0.091 ± 0.02a ^A	0.357 ± 0.09b ^A	0.242 ± 0.11b ^A	0.096 ± 0.03b ^A

Different uppercase letters indicate significant differences among different forest types (*Cunninghamia lanceolata*, *Pinus massoniana*) of the same stand type (artificial or natural) ($p < 0.05$). Different lowercase letters indicate significant differences among different stand types for the same forest type ($p < 0.05$).

The results of the diameter class ratios for different forest types indicated that fallen trees of artificial forests are primarily distributed by small diameter classes less than 10 cm (I and II), which accounts for 86.7%, but accounts only for 64.1% (*Ncf*) and 48.0% (*Nebf*) in natural forests (Table 4). In addition, the diameter class distribution in natural forests was relatively uniform compared with artificial forest (Table 4).

Table 4. The relative proportion of fallen trees across diameter classes.

Stand Types (Plots)	Diameter Class Ratios			
	I (0–5 cm)	II (5–10 cm)	III (10–15 cm)	IV (15–20 cm)
<i>Acf</i> (20)	38.5 ± 5.1a	48.2 ± 5.7b	10.4 ± 1.7c	2.9 ± 0.9d
<i>Ncf</i> (20)	14.6 ± 4.2a	49.5 ± 5.5b	22.3 ± 3.6a	13.6 ± 2.1a

Different lowercase letters indicate significant differences among different diameter classes of the same forest type (*Acf*, *Ncf* or *Nebf*) ($p < 0.05$).

3.3. Decomposition Differences of Fallen Trees in Artificial and Natural Forests

The mild decay class of fallen trees (accounts for 61.8%) was significantly higher than the remaining two decay classes (e.g., a moderate decay ratio, which accounts for 25.9% and a heavy decay ratio, which accounts for 12.3%) in artificial forests; whereas the biomass for the moderate decay class of fallen trees (e.g., *Ncf* and *Nebf* accounts for 68.3% and 49.0%, respectively) was significantly higher than that for the mild and heavy decay classes in natural forests (Figure 3). The biomass of fallen trees of mild, moderate and heavy decay classes in artificial forests significantly differed, while the biomass of fallen trees of moderate decay in *Ncf* and *Nebf* was significantly higher than those of mild and heavy decay (Figure 3). The biomass of fallen trees with mild decay was neither significant among forest types within stand origins nor among stand origin within forest type (Table 5); however, the biomass of fallen trees of moderate and heavy decay was significantly different among stand origins (*Aclf* vs. *Nclf*, *Apf* vs. *Npf*), but was not significant among forest types within stand origin (*Aclf* vs. *Apf*, *Nclf* vs. *Npf*) (Table 5).

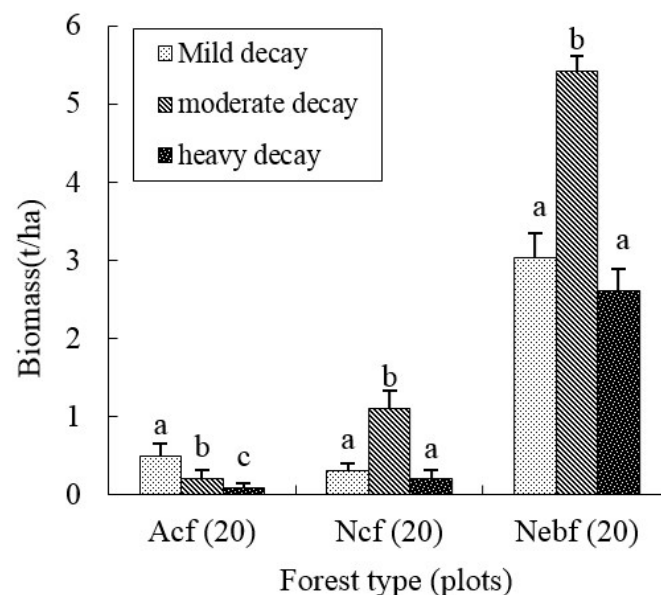


Figure 3. Biomass of fallen trees of different decay classes. Different lowercase letters indicate significant differences among different decay classes of the same forest type (*Acf*, *Ncf* or *Nebf*) ($p < 0.05$).

Table 5. Biomass of fallen trees of decay classes in different stand and forest types.

Stand Types (Plots)	Decay Class		
	Mild Decay	Moderate Decay	Heavy Decay
<i>Aclf</i> (10)	0.274 ± 0.08a ^A	0.115 ± 0.03a ^A	0.058 ± 0.01a ^A
<i>Nclf</i> (10)	0.179 ± 0.09a ^A	0.539 ± 0.13b ^A	0.121 ± 0.03b ^A
<i>Apf</i> (10)	0.229 ± 0.07a ^A	0.096 ± 0.01a ^A	0.041 ± 0.01a ^A
<i>Npf</i> (10)	0.133 ± 0.03a ^A	0.571 ± 0.15b ^A	0.082 ± 0.02b ^A

Different uppercase letters indicate significant differences among different forest types (*Cunninghamia lanceolata*, *Pinus massoniana*) of the same stand type (artificial or natural) ($p < 0.05$). Different lowercase letters indicate significant differences among different stand types of the same forest type ($p < 0.05$).

4. Discussion

4.1. Characteristics of Biomass and Carbon Stock of Fallen Trees

Fallen trees comprise an important functional unit of a forest ecosystem, their stock not only directly affects succession and biodiversity conservation in forest communities [21], but also serves an irreplaceable role in maintaining the stability of nutrient cycling and enhancing the ability to resist interference in a forest ecosystem [22]. Our results indicated that the biomass of fallen trees in *Nebf* was significantly higher than the biomass of fallen trees in *Acf* and *Ncf*. However, the carbon stock of fallen trees manifested a consistent pattern among different forests, *Nebf* > *Acf* > *Ncf*. We also discovered that the biomass of fallen trees in *Nebf* in Jiangxi Province was less than that in *Abies fargesii* forest [23], evergreen broad-leaved forests in the Daming Mountain [24], and other forests [25–28]; but was higher than the biomass of fallen trees in tropical seasonal rain-forests in Xishuangbanna [29], evergreen broad-leaved forests in Guangzhou [30] and natural forests of *Castanopsis kawakamii* in Sanming [31]. Conversely, the biomass of fallen trees in *Ncf* was less than that in *Pinus tabulaeformis* secondary forests in the Qinling Mountains [32], and Korean pine forests in the Changbai Mountains [33]. Compared with *Larix gmelinii* forests in the Daxing'anling Mountains, the biomass of fallen trees in *Ncf* was determined to be at the middle level [34]. However, the biomass of fallen trees in *Acf* was higher than those in coniferous forests in Guangzhou [30], artificial *Castanopsis kawakamii* forests and Chinese Fir forests in Sanming [31], but less than the biomass of fallen trees in mixed coniferous forests and broad-leaved forests in Guangzhou [30] (Table A2). Therefore, the largest amount of biomass and carbon stocks of fallen trees among three forest types (*Nebf*, *Ncf* and *Acf*) in Jiangxi Province was measured for *Nebf*, which may serve a central role in the carbon cycles in subtropical regions.

Previous studies indicated that artificial forests exhibited a larger planting density and had similarly-aged trees with small disturbances that originated from afforestation and human management [13]; whereas natural forests had predominantly diversely-aged trees with smaller disturbances that originated from human management and afforestation [14]. These findings suggested that stand origin would certainly impact tree lodging, but the underlying mechanisms were still unclear. We found that the biomass and carbon stock of fallen trees in *Nclf* were significantly higher than that in *Aclf*, and that the biomass and carbon stock of fallen trees in *Npf* were also significantly larger than that in *Apf*; however, no significant differences between *Aclf* and *Apf*, or between *Nclf* and *Npf* were observed (Table 2). This finding further suggested that stand origin was the major factor that affected fallen tree biomass and carbon stock in Jiangxi Province. However, the forest types (neither *Aclf* and *Apf*, nor *Nclf* and *Npf*) had no significant effect on the biomass and carbon stock of fallen trees in subtropical forests. The disturbance and management of afforestation in artificial forests were significantly greater than those in natural forests. Although the biomass of fallen trees in artificial forests was significantly less than that in natural forests, the average forest age between artificial forests and natural forests was relatively similar (Table 1), which indicated that the stand origin had a significant impact on tree lodging.

4.2. Diameter Class Distribution of Fallen Trees

The diameter class affected the decomposition and stock of fallen trees. It is generally known that smaller diameter classes of fallen trees with greater contact area with the ground yield faster decomposition rates [2]; whereas larger diameter classes of fallen trees exhibit a slower rate of decomposition. These may allow the storage of a greater carbon stock of fallen trees in a forest ecosystem [2,3]. The distribution of the diameter class of fallen trees was affected by the structural composition of forest stands, site conditions and disturbance [32–34]. For example, Liu *et al.* [35] reported that coarse woody debris in evergreen broadleaved forests after an ice storm in Northern Guangdong Province yielded a large diameter class of forest stands on windward slopes that facilitated the formation of a large number of fallen trees, whereas the small diameter class of forest stands on leeward slopes was affected by low temperature and frost damage [35]. In native forests in the Ailao Mountains, fallen trees and stumps were primarily associated with large diameter class: the majority exceeded 40 cm, and the fallen trees in secondary forests were primarily associated with a small diameter class [28]. Our results revealed that the fallen trees in artificial forests were associated with small diameter class, in which the diameter was always less 10 cm (Table 3), and the ratios of fallen trees in natural forests with small diameters were less than those in artificial forests. Each diameter class allocation for natural forests was more uniform compared with the diameter class for artificial forests (Table 4). This result may be due to the observation that artificial forests were predominantly similarly aged with densities that exceeded the densities of natural forests (Table 1). Therefore, the mortality of a small diameter class was greater as a result of competition in forest ecosystems, and the small diameter class of fallen trees was easily attributed to fallen trees due to snow and pests. These results suggested that the transformation from natural forest to artificial forest by degradation not only altered the composition of stand and communities, but also significantly changed the composition and diameter class distribution of fallen trees.

4.3. Differences in the Decomposition of Fallen Trees

The decomposition of fallen trees serves an important role in the function of a forest ecosystem [36–38]. The decomposition of fallen trees has a close relationship with the tree species, diameter class and forest land environment [39,40]. The biological, physical and chemical properties of wood vary among tree species, which creates differences in the decomposition process of fallen trees. The decomposition of fallen trees is dependent on forest land temperature, humidity, light and biological environment. Conversely, the decomposition of fallen trees was found to be closely related to the microbial community [41], fungal richness [42,43], and microbial environment [44,45], as well as the densities of fallen trees, nutrient concentrations and ratios [39,44,46]. Using decay class to classify the decomposition of fallen wood can reflect the community history and function. Our results indicated that the biomass of fallen trees with mild, moderate and heavy decay in artificial forests significantly differed; however, the biomass of fallen trees with moderate decay in *Ncf* and *Nbf* was significantly higher than in fallen trees with mild and heavy decay (Figure 3), which suggests that the natural forest was dominated by the fallen trees with moderate decay class. The biomass of fallen trees with mild decay was neither significant among forest types within stand origin nor among stand origin within forest types (Table 5). However, the biomass of fallen trees with moderate and heavy decay was significantly different among stand origin (*AcLf* vs. *Nclf*, *Apf* vs. *Npf*), but there was no significant difference among forest types within stand origin (*AcLf* vs. *Apf*, *Nclf* vs. *Npf*) (Table 5). This finding was consistent with the previous results for the subtropical forests of China [26,47–49], which illustrates that stand origin and near-natural restoration significantly influence the decomposition of fallen trees in mid-subtropical forests.

5. Conclusions

The amounts of biomass and carbon stock of fallen trees in natural evergreen broadleaf forests were significantly larger than those in coniferous forests, and the amounts of biomass and carbon stock

of fallen trees in *Ncf* were significantly larger than those in *Acf* in subtropical China. The effects of stand origin on the large diameter classes (II, III and IV) of fallen trees were greater than those on the small diameter class (I). After the development of forest succession and near-natural restoration, the mortalities of the fallen trees in the small diameter class decreased. Stand origin is a major factor that affects the biomass and carbon stock of fallen trees in Jiangxi Province. Differences in stand origin also play a primary role in the decomposition of fallen trees and carbon cycles in subtropical forests. Additional studies are necessary to investigate the underlying mechanisms of fallen tree decomposition with respect to stand origin and near-natural restoration.

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Author Contributions: The authors contributed equally to investigating, collecting data and completing the project. Chunsheng Wu, Xiaohua Wei, Yuanqiu Liu and Qinglin Li were responsible for the research design and wrote early drafts of the manuscript with contributions from Xiaohua Wei, Xiaodong Li, Liangying Liu, Chunjie Shu and Qifeng Mo through the editorial process.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix 1

Table A1. Standing trees ratios (%) of diameter class in artificial and natural forests.

Stand Types (Plots)	Diameter Class Ratios			
	5–10 cm	10–15 cm	15–20 cm	≥20 cm
Aclf (10)	66.1 ± 7.4a ^A	19.8 ± 4.2a ^A	8.4 ± 1.9a ^A	5.7 ± 1.3a ^A
Apf (10)	41.4 ± 4.5a ^B	48.8 ± 5.2a ^B	6.8 ± 1.5a ^A	3.0 ± 0.7a ^B
Nclf (10)	49.7 ± 6.3b ^A	30.1 ± 4.2b ^A	15.8 ± 3.6b ^A	4.4 ± 1.1a ^A
Npf (10)	37.2 ± 4.9a ^B	27.7 ± 4.1b ^A	23.5 ± 3.7b ^B	11.6 ± 2.9b ^B
Nebf (20)	49.8 ± 6.3	20.3 ± 4.3	9.5 ± 2.8	20.4 ± 3.3

The starting measurement of standing trees DBH was 5 cm. Different uppercase letters indicate significant differences among different forest types (*Cunninghamia lanceolata*, *Pinus massoniana*) of the same stand type at $p < 0.05$. Different lowercase letters indicate significant differences among different stand types for the same forest type ($p < 0.05$).

Table A2. Comparison of fallen tree biomass in various forest ecosystems.

Forest Type, China	Fallen Trees (mg/ha)	References
<i>Abies fargesii</i> forest in the Qinling Mountains	15.850	Li, <i>et al.</i> , 1998 [23]
Evergreen broad-leaved forests in the Daming Mountains	22.945	Liang, <i>et al.</i> , 2012 [24]
Tropical seasonal rain forest in Xishuangbanna of southwestern China	4.500	Deng, <i>et al.</i> , 2012 [29]
<i>Larix gmelinii</i> forests in Daxing'anling Mountains of northeast China	0.489–6.683	Wang, <i>et al.</i> , 2012 [34]
Monsoon evergreen broad-leaved forest in the Dinghushan Nature Reserve	32.810	Yang, <i>et al.</i> , 2011 [25]
Natural <i>Quercus aliena</i> forest in the Xiaolong Mountains, Gansu	29.35	He, <i>et al.</i> , 2011 [27]
<i>Pinus tabulaeformis</i> forest in the Xiaolong Mountains, Gansu	7.72	
Moist evergreen broad-leaved forest in the Ailao Mountains of Yunnan Province	61.720	Yang, <i>et al.</i> , 2007 [28]
<i>Pinus tabulaeformis</i> Secondary forest in the Qinling Mountains	5.740	Yuan, <i>et al.</i> , 2012 [32]
<i>Toxicodendron vernicifluum</i> forest in the Qinling Mountains	2.510	
Mid-subtropical evergreen broad-leaved forest in Wanmulin Nature Reserve, Fujian	17.909	He, <i>et al.</i> , 2010 [26]
Broad-leaved and Korean pine mixed forest in Changbai Mountains of Jilin Province	7.900–16.200	Dai, <i>et al.</i> , 2000 [33]

Table A2. Cont.

Forest Type, China	Fallen Trees (mg/ha)	References
Conifer forest in Guangzhou	0.163	Zhang, <i>et al.</i> , 2009 [30]
Mixed conifer and broad-leaved in Guangzhou	2.063	
Evergreen broad-leaved forest in Guangzhou	3.353	
Natural forest of <i>Castanopsis kawakamii</i> in Sanming, Fujian	1.320	Yang, <i>et al.</i> , 2005 [31]
Artificial forest of <i>Castanopsis kawakamii</i> in Sanming, Fujian	0.460	
Artificial forest of <i>Chinese Fir</i> in Sanming, Fujian	0.230	
Natural evergreen broadleaf forest in subtropical, China	11.293	This study
Natural coniferous forest in subtropical, China	1.647	
Artificial coniferous forests in subtropical, China	0.825	

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