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Research Article

Influence of an Ice Storm on Aboveground Biomass of Subtropical Evergreen Broadleaf Forest in Lechang, Nanling Mountains of Southern China

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This study focuses on the influence of the 2008 ice storm in China and subsequent forest rehabilitation dynamics up until 2011. All seven plots studied exhibited significant damage, with the total number of damaged trees varying between 63 and 92%. In addition, most trees suffered stem bending in 2008 and the extent of damage varied with tree diameter at breast high (DBH). Relationships between loss of biomass as dead trees and stand characteristics were analyzed by multiple stepwise regression. The results showed that the decrease in biomass (Y) could be related to altitude ($X1$), slope ($X2$), and aboveground biomass (AGB) in 2008 ($X5$) according to the following formula: $Y = -0.02456X1 + 0.2815X5 - 1.480X2 + 51.23$. After 2 to 3 years, tree numbers had declined in all seven plots. The mean increase in AGB ($4.9\,\mathrm{t\,ha^{-1}}$) for six of the plots was less than the biomass loss as dead trees ($9.4\,\mathrm{t\,ha^{-1}}$) over the 3 year periods. This corresponds to a release of CO_2 to the atmosphere for each plot. Therefore, the forests of Lechang in the Nanling Montains have probably acted as a carbon source to the atmosphere for a short period after the 2008 ice storm.

1. Introduction

Almost 4,000 abiotic disturbance events occurred from 2000 to 2009, killing over one million people, directly affecting over 2.5 billion people and costing almost a trillion US dollars (over US$971 billion) [1]. Asia experienced the most extreme weather events during that period, with 1,536 events recorded, representing over 38% of the total worldwide. Windstorms and floods together accounted for approximately 70% of total extreme weather events reported and 72% of total economic loss. One such extreme weather event was the 2008 Chinese ice storm, which struck the southern-central region of China and occurred between January and February 2008. This meteorological disaster was characterized by frozen rain and snow with extreme low temperatures [2]. According to statistics released by the Ministry of Civil Affairs of China, the ensuing direct economic losses amounted to more than $22.3 billion and indirect losses may be even greater. In particular, twenty million hectares of forests were destroyed. At the time of the ice storm, most forests in the region were young or middle aged, which is perhaps the most productive stage of stand development. Unfortunately, the ice storm destroyed 30 years' efforts to reforest the region and led to widespread crown decapitation, stem bending, trunk breakage, lodging, and uprooting. The damage to forests also caused secondary problems such as soil erosion and mudslides. Insect infestation and tree disease outbreaks resulted from the sudden increase in damaged or wounded trees. Forest fires increased in subsequent months because of the large accumulation of dead litter on the forest floor, which provided fuel for fires. For example, in the province of Hunan, the number of forest fires in March 2008 was eleven-times higher than the average for the previous 10 years and the fire area was five-times higher than the average [3].

It is possible that forests in southern China could act as carbon sources for many years after such severe large-scale damage as occurred in the 2008 ice storm. Before the storm, the forest in this region accounted for 65% of the total terrestrial carbon sink for the whole country [4]. The ability of forest ecosystems in this region to serve as a net carbon sink largely depends on forest rehabilitation or reestablishment. Therefore, accurate biomass estimation for tropical forests has received considerable attention in recent years to understand the impact of extreme weather events on ecosystems better [5]. Since extreme weather events are generally sudden, sporadic, and unpredictable, their impact is usually difficult to study. Considerable information may exist on individual events, but often little information is available on the impact of a specific event on forests. Global reporting of such effects, particularly quantitative information on the affected areas is usually infrequent and sporadic [6]. To date, very little research has been performed on the Chinese ice storm. For example, there have been only a few limited studies since 1980 into the damage of ice snow between 1982 and 1983 in the Daxinganling Mountains [7]. Although this area of research has attracted increased attention over recent years, studies concerning the effect on biomass are still extremely scarce. The present study investigated the impact of the 2008 ice storm and forest rehabilitation dynamics up until 2011 by evaluating the variation in aboveground biomass (AGB) of evergreen broadleaf forest. The aim of this work was to examine whether the AGB was recovering to levels prior to the ice storm or not. In addition, the impact of the 2008 ice storm was assessed based on tree numbers and AGB. Further, quantitative evaluation of the 2008 ice storm impact could provide a scientific basis for policy makers concerned with postdisaster vegetation recovery.

2. Materials and Methods

2.1. Study Site. Measurements were taken of seven plots located in subtropical secondary forest severely damaged during the ice storm in the Yangdongshan Shierdushui Forest Reserve (25°21′N, 113°25′E), Lechang, in the Nanling Mountains of southern China. The total area of this reserve is 11,651 hectares. It lies next to the border between the Guangdong and Hunan provinces. The climate and soil conditions are similar to the Yangdongshan Forest Reserve. The average annual temperature is around 19°C. The frost-free period lasts for 300 days. Annual precipitation is over 1,700 mm and the rainfall is generally concentrated between March and August. There are six vegetation types in the reserve: coniferous and broad-leaved mixed forest, coniferous forest, evergreen and deciduous forest, broad-leaved mixed forest, evergreen broad-leaved forest, shrubs, grass, and bamboo forest. The main vegetation type is subtropical evergreen broad-leaved forest. Since flora and fauna resources are abundant, the biodiversity is expected to be relatively high.

2.2. Plots. Seven rectangular plots (SD 01–07) each of $1200\,m^2$ (40×30 m) were set out randomly in the Yangdongshan Shierdushui Forest Reserve and a total of 5178 trees were measured (Table 1). The seven plots had suffered different degrees of damage during the 2008 ice storm (see following section). A census of tree diameter at breast high (DBH) and tree species was conducted in every plot. Measurements of plots SD01-04 were obtained during April, 2008 and August, 2011, whereas, data for plots SD 05∼07 were collected during July, 2009 and September, 2011.

2.3. Tree Numbers and Biomass Estimation. All surviving trees were classified according to the following six categories

(1) Trunk breakage: trees with a break running across the main stem, which could be the result of construction damage. The damage was usually severe and possibly led to tree death. The damage was subdivided into two forms based on breakage position (Figures 1(a1) and 1(a2)).

(2) Uprooting: trees tipped over and roots totally or partly exposed to the air (Figures 1(b1) and 1(b2)).

(3) Lodging: trees fallen on the ground but roots not exposed to the air. Two situations occurred: small trees generally fell with their stems leaning on the ground (Figure 1(c1)), relatively large trees typically fell and leaned on other trees, but their stems were not bent and roots not exposed (Figure 1(c2)).

(4) Stem bending: the drag force, bending moments, and stresses acting on tree stems caused relatively slight mechanical damage (Figure 1(d)). Damage mainly resulted from the pressure of snow cover as a direct factor. A further factor was indirectly caused by other fallen trees or broken branches. Generally, these trees were able to self-repair and regrow. The potential for restoration depended on tree species, bending degree, and so forth.

(5) Crown breakage: trees with crowns damaged by mechanical forces. The damage was usually not serious and trees could potentially recover after the damage (Figure 1(e)).

(6) Healthy: trees that were undamaged and survived the 2008 ice storm.

After 2-3 years, the recovery status of trees was analyzed based on four factors: restoration of stem bending (Figure 2(f)), terminal shoot elongation (Figure 2(g)), sprouting shoot elongation (Figures 2(h1) and 2(h2)), and new trees. Newly dead or dying trees were also recorded in 2011 (Figure 2(i)).

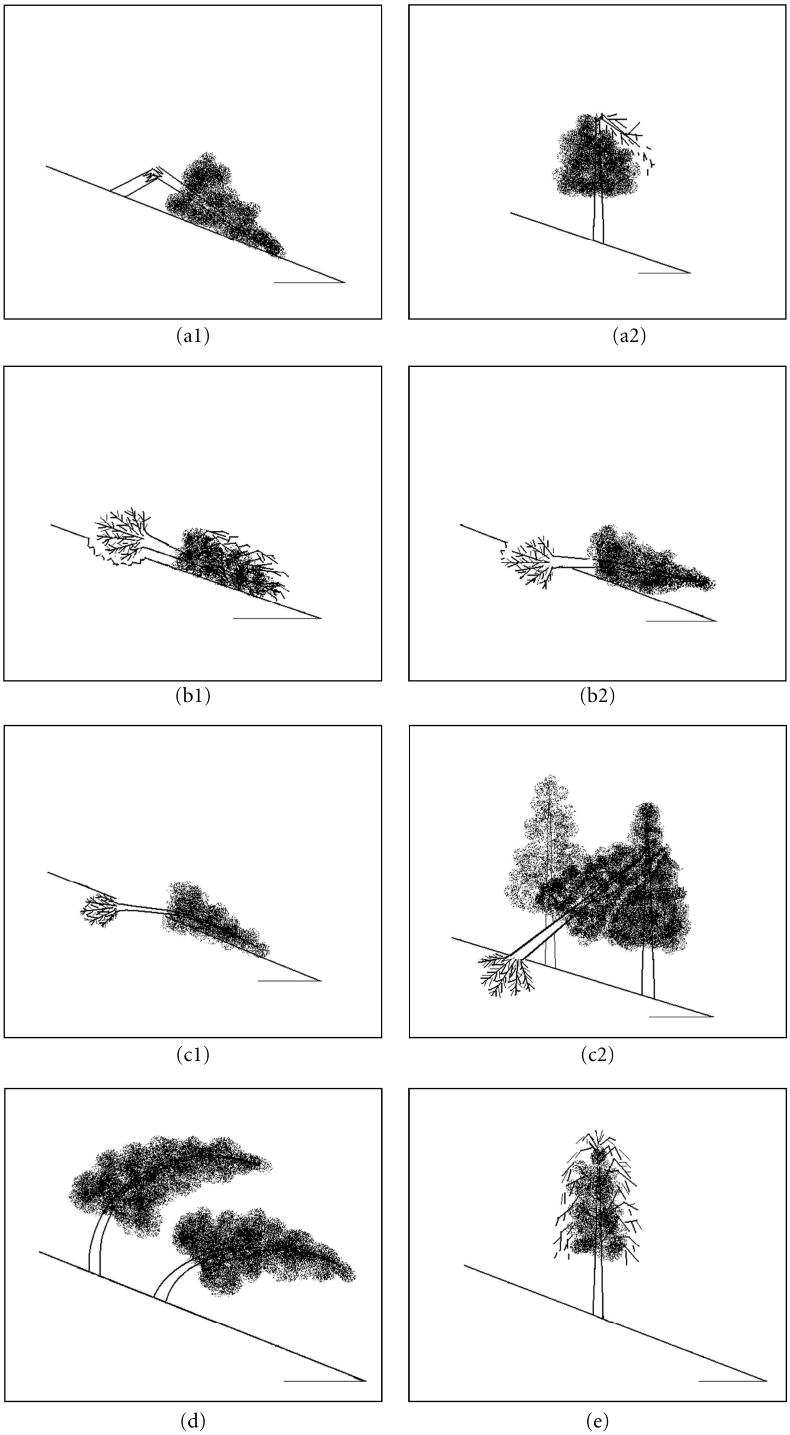

FIGURE 1: Five categories of damage.

Biomass in four plots (SD01–04) in 2008 and 2011 was estimated using DBH census data for each year and the allometric equation AGB (kg) = 0.1378 (DBH (cm))$^{2.3142}$ (R^2 = 0.9776) [8]. No DBH census data was available in the other three plots (SD05–07) in 2008. Therefore, biomass in these plots in 2008 could not be calculated using the above equation. Instead, the average annual variation of biomass could be estimated from DBH census data for 2009 and 2011. Thus, the biomass in 2008 in SD05–07 was estimated by using biomass data for 2011 corrected for the variation of biomass over the three years. DBH data were collected by the Chinese Academy of Forestry in 2008 or 2009 and in the present study in 2011. The variation in biomass of each plot was analyzed based on the type of damage, recovery status, terrain, and other factors. In addition, relationships between the loss of biomass as dead trees and plot characteristics were

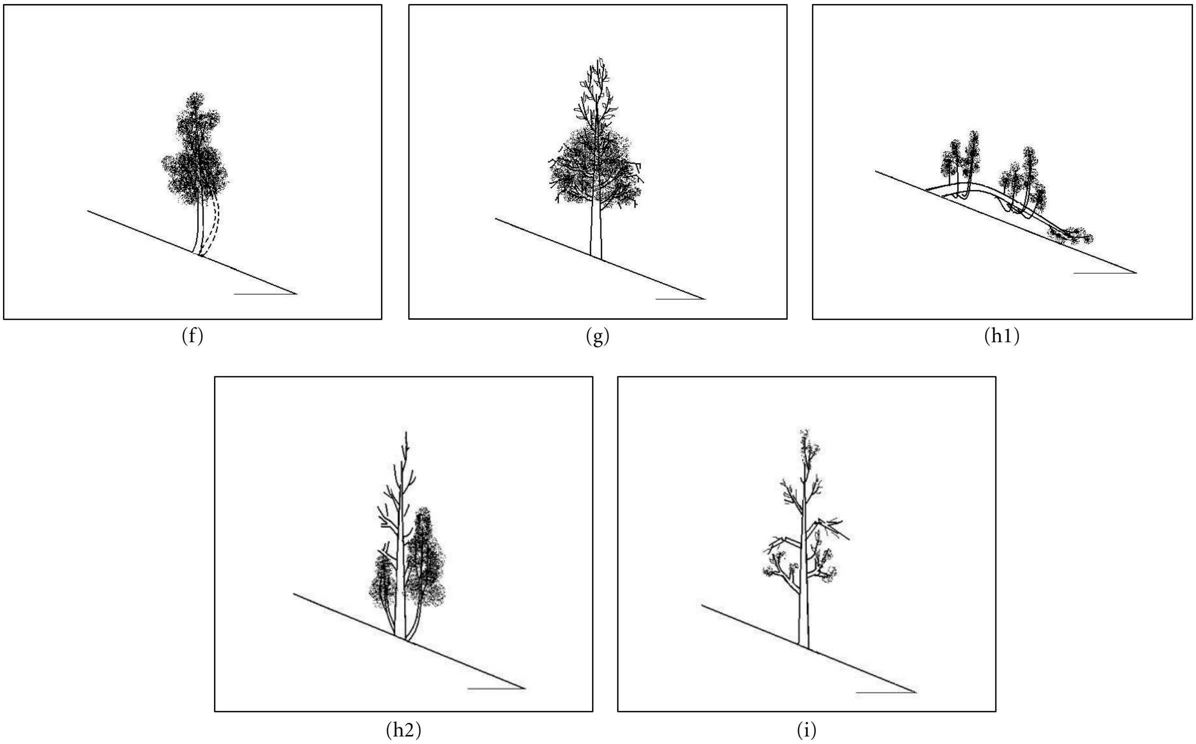

Figure 2: Four types of recovery.

Table 1: Specific information on the seven study plots in the Yangdongshan Shierdushui Forest Reserve in 2011.

	Year	Plot number	Altitude (m)	Slope aspect	Slope angle (°)	Stand density (ha^{-1})	DBH maximum (cm)	Aboveground biomass ($t\ ha^{-1}$)
Damaged areas	2011	SD01	720–740	Northwest	28	6592	37.6	65.5
		SD02	796–820	Southwest	30	5142	43.7	73.6
		SD03	870–890	Northwest	23	6542	39.5	84.6
		SD04	950–970	Southeast	25	3700	63.7	124.5
		SD05	790–810	Southwest	32	3683	47.8	85
		SD06	800–820	Southeast	33	4525	35.7	92.1
		SD07	790–810	Southwest	32	5525	42.4	102.8

analyzed by multiple stepwise regression analysis. Finally, the extent of forest rehabilitation was assessed as well as the variation in AGB.

3. Results and Discussion

3.1. Analysis of Damage Status. Firstly, all seven plots showed significant damage, with the total number of damaged trees varying between 63 and 92%. This indicates that subtropical evergreen forest in Yangdongshan Shierdushui Forest Reserve was severely affected by the 2008 ice storm. The majority of trees in each plot suffered stem bending in 2008 (Table 2). In addition, 89.8% of all trees were classified as having a DBH of ≤3 or 3.1–9.0 cm and damage status clearly varied with DBH class (Figure 3). Stem bending was the main form of damage for DBH classes of ≤3 and 3.1–9.0 cm. However, crown breakage was the main form of damage in the other three DBH classes of 9.1–15.0, 15.1–21.0, and ≥21.1 cm. Trunk breakage, uprooting, lodging, and healthy trees occurred for each DBH class, but their distribution varied slightly.

Secondly, trees with crown breakage had the highest AGB in six of the studied plots, whereas in remaining plot SD06, the AGB of trees with crown breakage was almost the same as healthy trees, which displayed the highest AGB (Table 3). The reason for this is the highest AGB values primarily occurred for trees with ≥21.1 cm DBH in all the plots except for plot SD01 (Table 4). Trees in the ≥21.1 cm DBH class suffered from crown breakage more than any of the other five types of damage (Figure 3). Therefore, the variation in AGB over the next three years is likely to depend on the recovery status of those trees with crown breakage.

Thirdly, there was generally a decreasing trend in damage from plot SD01 to plot SD07 (Table 2), although the reason for such a trend is difficult to explain with the data currently available. There was no clear explanation for this trend based on plot location or other plot characteristics (altitude, slope

Table 2: Distribution of tree numbers according to the six categories of damage in the seven plots.

Plot number	Tree numbers (ha^{-1})							Proportion of trees damaged (%)
	Stem bending	Trunk breakage	Crown breakage	Uprooting	Lodging	Healthy	Total	
SD01	6092 (68%)	475 (5%)	1150 (13%)	242 (3%)	225 (3%)	758 (8%)	8942	92
SD02	3833 (64%)	83 (1%)	808 (14%)	200 (4%)	233 (4%)	808 (14%)	5965	86
SD03	5167 (68%)	392 (5%)	683 (9%)	667 (9%)	0	742 (10%)	7651	90
SD04	2575 (55%)	600 (13%)	542 (12%)	200 (4%)	0	783 (17%)	4700	83
SD05	2568 (57%)	106 (2%)	505 (11%)	168 (4%)	310 (7%)	823 (18%)	4480	82
SD06	2263 (47%)	273 (6%)	655 (14%)	238 (5%)	255 (5%)	1140 (24%)	4824	76
SD07	2546 (39%)	573 (9%)	775 (12%)	106 (2%)	141 (2%)	2449 (37%)	6590	63

Table 3: Biomass distribution according to six categories of damage in the seven plots in 2008.

Plot number	Aboveground biomass (t ha^{-1})					
	Stem bending	Trunk breakage	Crown breakage	Uprooting	Lodging	Healthy
SD01	22.4	5.3	26.6	2.3	1.5	4.5
SD02	12.7	1.1	30.4	14.7	3.2	13.7
SD03	17.4	9.7	38.6	16.6	0.0	3.9
SD04	9.6	56.2	58.1	9.4	0.0	7.9
SD05	9.5	0.8	41.7	6.6	6.0	13.5
SD06	10.9	3.2	23.3	9.1	8.9	24.2
SD07	10.3	17.2	29.2	8.3	1.0	18.9

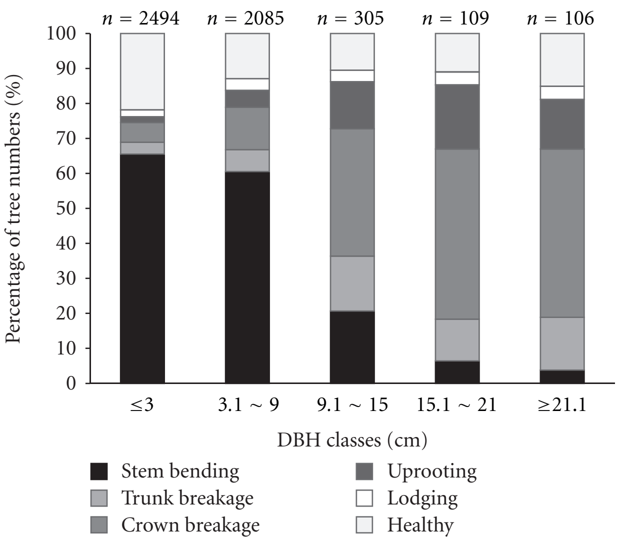

Figure 3: Distribution of trees and types of damage for different DBH classes.

angle, etc.). As a direct consequence of the ice storm, biomass loss due to dead trees in 2011 varied among all seven plots (Table 6). Based on preliminary observations, there was no marked difference in species composition. The dominant species was *Castanopsis fabric* Hance, but a large proportion of the forest also comprised pioneer and late-succession tree species, such as *Castanopsis fissa* Rehder and E. H. Wilson, *Manglietia chingii* Dandy, and *Alniphyllum fortunei* Makino, in all seven plots. Therefore, the relationships between the biomass loss as dead trees and plot characteristics (AGB; slope; altitude; slope aspect; stand density) were analyzed using simple regression analysis in order to identify potential impact factors (Figure 4). The results showed that altitude, slope angle, and AGB in 2008 correlated strongly ($P = 0.019$, 0.030, and 0.023, resp.), with the biomass of dead trees ($R^2 = 0.675$, 0.643, and 0.697, resp.) In contrast, both the slope aspect and stand density appeared to have no link with the biomass of dead trees. Their corresponding R^2 (0.185 and 0.016) were far less than for the other three stand characteristics. In addition, their P values (0.750 and 0.779) were considerably higher than 0.05.

Regression models were generated to examine any relationship in further detail (Table 5). Based on the results of multiple stepwise regression, the best model was as follows: $Y = -0.02456X1 + 0.2815X5 - 1.480X2 + 51.23$ ($X1$: altitude; $X2$: slope angle; $X5$: AGB in 2008). Even though R^2 increased, the significance F was more than 0.05 when the slope aspect ($X3$) or stand density ($X4$) was included in the regression. Therefore, slope aspect ($X3$) and stand density ($X4$) could be disregarded.

3.2. Analysis of Recovery Status. Tree numbers declined up until 2011 in all seven plots following the 2008 ice storm. In addition, few new trees were observed after 2-3 years: the mean number was 149 ha^{-1}, corresponding to only 2.9% of the total number of trees in the seven plots (Table 6). Trees dying during the three year period were largely responsible for the loss of AGB in the seven plots.

The AGB in four of the plots (SD01, 05, 06, and 07) in 2011 was greater than in 2008. Another two plots (SD02 and 03) had values similar to those in 2008. Therefore, following damage in the 2008 ice storm, the forest seems to have returned to the 2008 level with regard to AGB after 2-3 years. One exception was plot SD04, which had a lower AGB in

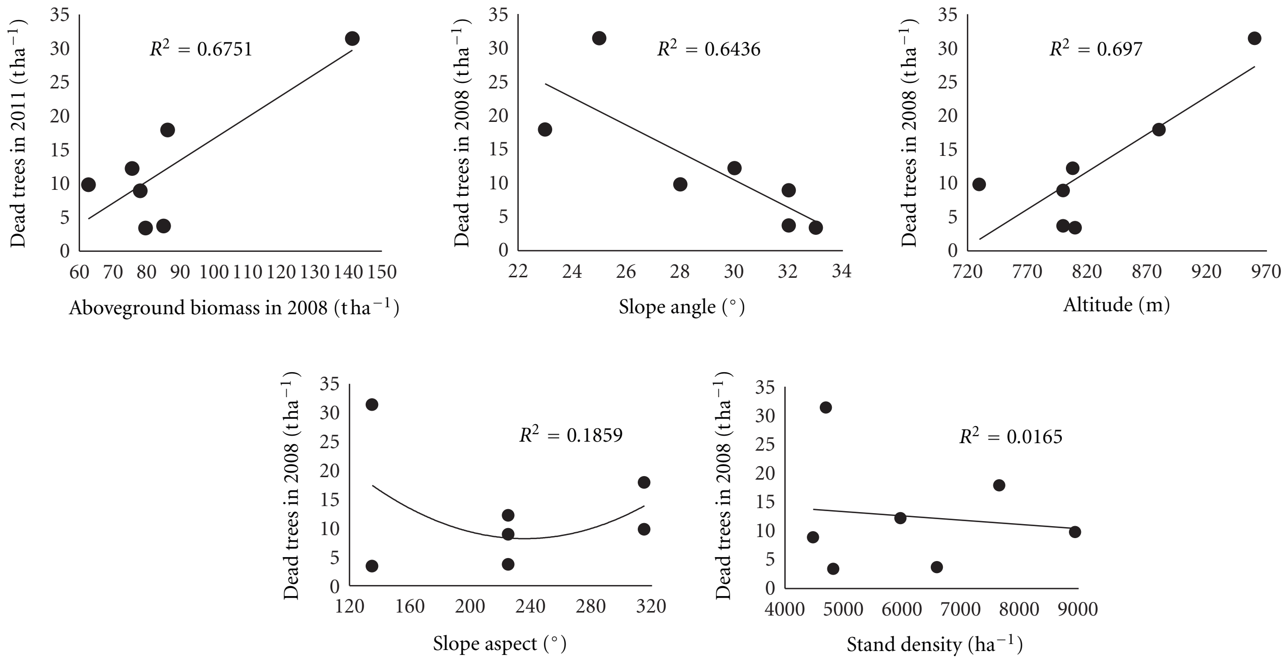

Figure 4: Simple regression analysis of dead tree biomass (2011) at the stand level versus stand characteristics in 2008.

Table 4: Biomass distribution in different DBH classes for the seven plots in 2008.

DBH classes (cm)	Aboveground biomass (t ha^{-1})						
	SD01	SD02	SD03	SD04	SD05	SD06	SD07
≤3	4.4	2.5	2.9	1.6	1.6	1.8	2.6
3.1~9.0	20.4	11.7	19.2	10.1	11.8	11.9	12.0
9.1~15.0	14.1	15.8	18.7	16.6	10.9	10.5	11.2
15.1~21.0	8.0	14.0	14.8	22.5	6.9	13.2	15.7
≥21.1	15.8	31.7	30.8	90.4	46.9	42.2	43.6

Table 5: Multiple stepwise regression of dead tree biomass (2011) at the stand level versus five stand characteristics in 2008 ($X1$: altitude; $X2$: slope angle; $X3$: slope aspect; $X4$: stand density; $X5$: AGB in 2008).

Regression model	R^2	Change in R^2	Standard error	Significance F
$Y = 0.111104X1 - 79.3955$	0.697	0	5.861	0.019
$Y = 0.06866X1 + 0.1338X5 - 55.93$	0.715	0.018	6.356	0.081
$Y = -0.02456X1 + 0.2815X5 - 1.480X2 + 51.23$	0.912	0.197	4.077	0.043
$Y = -0.03726X1 + 0.2400X5 - 1.934X2 - 0.02596X3 + 84.34$	0.917	0.005	4.856	0.159
$Y = -0.1417X1 + 0.3162X5 - 3.454X2 - 0.01006X3 - 0.003919X4 + 228.7$	0.975	0.058	3.789	0.267

Table 6: Variation in biomass and tree numbers following the 2008 ice storm.

Plot number	Aboveground biomass (t ha^{-1})			Biomass of dead trees	Tree numbers (ha^{-1})		Survival rate (%)
	2008	2011 (new trees)	Variation	(t ha^{-1})	2008	2011 (New trees)	
SD01	62.7	65.5 (0.1)	2.8	9.8	8942	6592 (150)	72
SD02	75.7	73.6 (0.1)	−2.1	12.2	5967	5142 (117)	84
SD03	86.3	84.6 (0.2)	−1.7	17.9	7650	6542 (208)	83
SD04	141.2	124.5 (0.2)	−16.7	31.4	4700	3700 (233)	74
SD05	78.1*	85.0 (0.15)	6.9	8.9	4480	3683 (150)	85
SD06	79.7*	92.1 (0.15)	12.4	3.4	4825	4525 (101)	94
SD07	85.1*	102.8 (0.08)	17.7	3.7	6589	5525 (87)	88

*These figures were estimated from 2009 and 2011 data.

2011 than in 2008. The reason for this is not only a relatively lower survival rate for trees in plot SD04 (Table 6) but also a greater number of larger trees died than in other plots. In contrast, the recovery status of plots SD06 and 07 was clearly better than for the other plots due to relatively slight damage during the 2008 ice storm and a high survival rate of trees. In addition, the slope aspect of both the latter plots was south. Superior natural conditions, such as abundant sunshine on the slope, are likely to promote the growth of trees, biomass production, and accumulation.

The increase in AGB in plots SD01 and 06 (2.8 and 6.9 t ha^{-1}, resp.) was less than the biomass loss of dead trees (9.8 and 8.9 t ha^{-1}). Thus, these plots represent a net source of CO_2 to the atmosphere. Further, AGB did not increase in plots SD02, 03, and 04 (-2.1, -1.7, and -16.7 t ha^{-1}). In only two plots SD06 and 07 was the increase in AGB (12.4 and 17.7 t ha^{-1}, resp.) greater than the biomass loss of dead trees (3.4 and 3.7 t ha^{-1}). These results suggest that the secondary evergreen broadleaf forest in areas damaged by the 2008 ice storm may be acting as carbon sources rather than carbon sinks for a short period.

Based on the loss of tree numbers and AGB, some areas such as plot SD04 was not recovering well during three years. Regular monitoring on these areas is definitely needed in order to prevent forest degradation and secondary disasters (forest fire, plant diseases, insect damage, and so on). During the process of monitoring in the future, we could artificially plant some new trees if necessary. Various native tree species should be selected, so that the structure of plant community, which might be originally composed of shrubs and ferns, would be more complex and stable. Through this small scale of afforestation and/or reforestation, an appropriate biodiversity could weather against future natural disasters. In the same time, clearing forest litter would also be an effective measure for the control of forest disease and insects if there were a sign of plant disease or insect damage found in the forests [9, 10].

4. Conclusions

The main conclusions can be summarized as follows

(1) Subtropical evergreen forest in Yangdongshan Shierdushui Forest Reserve was severely affected by the 2008 ice storm. Stem bending was the main form of tree damage. The proportions of other types of damage were relatively low and varied slightly among plots. In addition, there was a decreasing trend in damage from plot SD01 to plot SD07, although the reason for this trend is not yet clear. The loss of biomass as dead trees correlated with the initial AGB (in 2008), slope angle, and altitude, which could be represented by the formula $Y = -0.02456X1 + 0.2815X5 - 1.480X2 + 51.23$ ($X1$: altitude; $X2$: slope angle; $X5$: AGB in 2008).

(2) After 2-3 years, the subtropical evergreen broadleaf forest near Lechang, in the Nanling Mountainous region of southern China has basically returned to the 2008 level with regard to AGB. However, tree numbers were still decreasing in the seven plots. The forest has probably changed from a carbon sink to a carbon source because of the relatively large-scale tree death that has occurred during the three years postdisaster.

(3) Since there were some areas such as plot SD04 which was not recovering well, regular monitoring on these areas is really necessary to prevent forest degradation and future forest disasters. Meanwhile, some specific corresponding measures such as afforestation and/or reforestation and clearing forest litter could be carried on during the process of monitoring in the future.

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