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Research Article

Litter Production and Nutrient Dynamic on a Moso Bamboo Plantation following an Extreme Disturbance of 2008 Ice Storm

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Ice storm is known to play a role in determining forest succession and litter dynamics constitute an important aspect of nutrient cycling in forest ecosystems. However, ice storm effects on amount and pattern of litterfall are not clearly understood. We investigated litter production and litter leaf nutrient dynamic in a moso bamboo plantation in China following an extreme disturbance of ice storm in 2008. The litterfall in on-years was significantly lower than in off-years. Ice storm caused total litterfall increasing from 16.68% to 35.60% and greatly disturbed the litterfall peak rhythm especially in the on-year. The litter leaf nutrient concentrations at two latitudes significantly fluctuated after ice-snow disaster in 2008, litter leaf stoichiometric traits indicated that litter leaf chemistry showed more easily decomposition with higher C/P ratio, N/P ratio, and lower C/N ratio. It is clear from this study that litterfall restoration dynamic would result in long-term changes in litter nutrient cycling and may help predicting below ground carbon dynamic in future research as well as subtropical forest inventories following extreme disturbance.

1. Introduction

The litter on the forest floor acts as an input-output system of nutrients [1] and the rates at which forest litter falls and, subsequently, decays regulate energy flow, primary productivity, and nutrient cycling in forest ecosystems [2]. Litterfall is closely related to the growth rate and productivity of managed forest; litter nutrient return through litter plays an important role in maintaining soil fertility and primary productivity of forest ecosystems [3]. More importantly, litter dynamics constitute an important aspect of nutrient cycling and energy transfer in forest ecosystems [4]. So evaluation of litterfall production and nutrient return are important for understanding nutrient cycling, forest growth, carbon fluxes, disturbance ecology, and interactions with environmental variables in forest ecosystems [5, 6]. Therefore, quantifying rates of litterfall and nutrient return are essential for informed forest management, and it is also important to know the pattern of litterfall, whether distinctly seasonal or more or less continuous [7].

Extreme disturbance exerts great effects on forest litterfall dynamic and nutrient return. Ice storm is one of the most important forms of extreme disturbance. It is known to play a role in determining forest succession and important factors influencing the history and the dynamic of the forests [8]. Earlier studies investigating the impact of ice storms have reported contrasting views on how ice storms may affect species composition and diversity in forest stands [9], while it is consistent that the damage of ice storm led to large accumulation of dead litter on forest floors which provided fuel for fires, resulting in sharp increase in number of forest fires and the burned area [10].

In January 2008 southern China was hit by an ice storm, which was known as one of the most extensive and most severe ice storms in China history. The ice storm slashed large areas of forest across China, with 20.86 million hectares forest and plantation damaged, accounting for one-tenth of China's forests and plantations, according to China's State Forestry Administration [11, 12]. The severe ice storm extensively damaged the canopy of many northeastern forests in China, causing deposition of litter. There were a few studies on the nature of forest recovery over the years following the storm event. Darwin et al. [13] showed that forest appears to see a full recovery 4 years later after the ice storm by comparing forest status before and after the storm. It was necessary to study the litterfall dynamic on the first, second, third, fourth, and fifth years after the 2008 ice storm. However, the effects of ice storm in 2008 on amount and pattern of litterfall are not clearly understood and the response of year-to-year variation of litterfall is poorly known especially at different altitude. This study would gain a better understanding of how to sustain and improve productivity in response to ice storm.

Moso bamboo (*Phyllostachys edulis*) was one of the most severely affected vegetation by the ice storm in January 2008, with a total area of 2.43 million hectares affected. In our study area, average 54.48% of moso bamboo culm was damaged and the damaged patterns included bending, snapping, and uprooting, which accounted for 17.01%, 22.37%, and 15.11% of the total, respectively [12]. This research effort evaluated nearly five-year litterfall dynamic following the extreme disturbance of the 2008 ice storm in China. Specifically, we tested the following two alternate hypotheses: (1) temporal patterns of total litterfall and litterfall leaf nutrient flux were disturbed following the ice storm; (2) the difference of total litterfall, litterfall leaf element concentration and differ between low and high elevations. The results have important management implications regarding forest nutrient cycling and carbon budgets not only for the study site but also for subtropical Asia, which would provide a scientific basis and reference for postdisaster recovery and reconstruction on forest.

2. Materials and Methods

2.1. Study Site. The study sites were located in experimental forest of Experimental Center of Subtropical (114°30′–114°45′E, 27°30′–27°50′N), Fenyi County, Jiangxi Province, China. The region has a subtropical monsoon climate with mean annual temperature of 15.8–17.7°C; the highest temperature is mainly occurring in July at 28.8°C and the lowest temperature is in January at −5.3°C. Mean annual precipitation is 1591 mm, with the rainy season from April to June. The soil types of studied moso bamboo plantations are Haplic luvisol (FAO) [14]. The zonal vegetation of the area is subtropical evergreen broadleaf forest, and the existing vegetation types are natural evergreen broad-leaved forest, deciduous forest, coniferous forest, bamboo forest and Chinese fir plantation, and so forth.

Bamboo produces new shoots at a 2-year interval, with the new shoot production year known as on-year and the following year as off-year. Compared with deciduous trees, moso bamboo leaf changes once every two years and often relies on bamboo shoots in on-year, while it has little or no shoots in off-year. In our study, moso bamboo belongs to uneven-aged forest with obviously on-year and off-year; moso bamboo culm older than six years was harvested and the age structure is relatively simple and balanced. Bamboo shoots are harvested in March-April in on-year, the study bamboo forest is cut through hills every year in August-September. The plots/stands characteristics and regional climate characteristics were summarized in Table 1 and Figure 1.

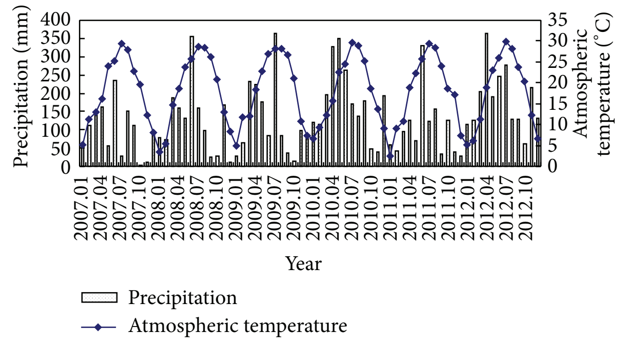

Figure 1: Monthly atmospheric temperature and precipitation during 2007–2012 in Fenyi County.

2.2. Litterfall Collection and Analysis. At each elevation, aboveground litterfall was estimated by randomly placing three litter traps per plot. Litter traps of 70 cm × 70 cm were made with 2 mm nylon mesh to catch the litter and were installed 50 cm above the forest floor. Litter was collected on monthly intervals from June 2008 to December 2012. To ensure the accuracy of the test data, litter traps were scheduled maintenance inspection. The collected litter samples were brought to the laboratory, separated into leaf and nonleaf components manually, oven-dried to a constant weight at 70°C for 72 h, and weighed to the nearest milligram. Dry samples were ground in a mill (made in China) to pass 1.0-mm mesh sieve and were kept in closed paper envelops.

This work was conducted based on Forestry Standards "Observation Methodology for Long-term Forest Ecosystem Research" of People's Republic of China (LY/T 1952–2011). The dried litterfall was ground using a grinder machine for chemical analyses of C, N, P, K, Ca, and Mg. Organic C content was determined using the wet digestion method with $K_2Cr_2O_7$ [15]. Total nitrogen content was determined by combustion in an UK152 Distillation and Titration Unit (DK20 Heating Digester, Italy). Total P, K, Ca, and Mg contents were determined by an IRIS Instrepid II XSP (Thermo, United States) after digestion of the samples in a mixture of 7.5 mL HNO_3 and 2.5 mL HCL. All chemical analysis of each sample was repeated three times. Nutrient returns at each elevation were calculated by multiplying leaves litter production by each sampling date and adding them over the entire year.

2.3. Data Processing and Statistical Analysis. The annual potential nutrient return (N, P, K, Ca, and Mg) through litterfall was represented by the following equation [1, 16]:

$$La = \sum_{i=1}^{12} \sum_{j=1}^{3} \frac{L_{ij} C_{ij}}{100}, \quad (1)$$

Table 1: The stands characteristics at research sites.

Elevation (m)	Average tree height (m)	Average DBH (cm)	Density (ha)	Density	Management
350 m (low elevation)	12.2	10.7	1800	0.7-0.8	Hilltops once a year, bumper digging bamboo shoots, and bamboo cutting
650 m (high elevation)	12.5	10.1	2025	0.7-0.8	Hilltops once a year, bumper digging bamboo shoots, and bamboo cutting

DBH: diameter at breast height.

where La is litter nutrient return, L_{ij} is litterfall of the i month in j organ, and C_{ij} is the nutrient content of the i month in j organ.

All statistical analyses were performed using SPSS (Version 18.0 for Windows).

One-way ANOVA was used to compare stand characteristics between low elevation and high elevation. Paired t-tests were used to compare monthly quantities, element concentrations, and element fluxes of litterfall between low elevation and high elevation.

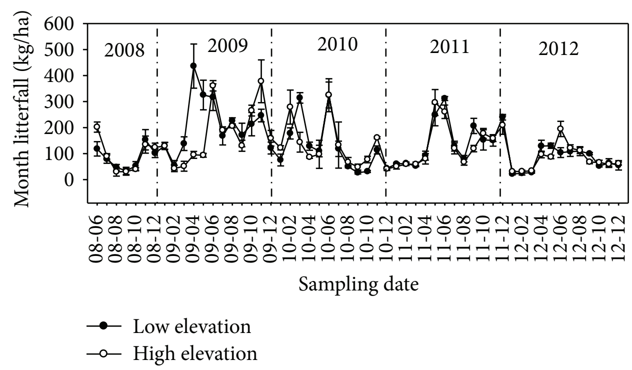

Figure 2: Monthly mean litterfall dynamic of moso bamboo at two elevations from June 2008 to December 2012. The years of 2008, 2010, and 2012 were on-years, while the years of 2009 and 2011 were off-years in our study area.

3. Results

3.1. Temporal Patterns of Litterfall. The collected litter from the litter traps was dominated by leaves. The mean annual percent of leaves in total litterfall was 99% at high elevation and 96% at low elevation, which was consistent across the years. Annual litterfall at low and high elevations from the years of 2009 to 2012 was 2548.35 kg·ha^{-1} and 2101.32 kg·ha^{-1} in 2009, 1514.19 kg·ha^{-1} and 1581.81 kg·ha^{-1} in 2010, 1787.70 kg·ha^{-1} and 1658.76 kg·ha^{-1} in 2011, and 924.38 kg·ha^{-1} and 963.28 kg·ha^{-1} in 2012, respectively (Figure 2). There was significant difference in annual total litterfall among four years at both low elevation ($F = 78.53$, $P = 0.005$) and high elevation ($F = 38.39$, $P = 0.003$) (Figure 3). The moso bamboo litterfall before ice storm in the same region was 1656.02 kg·ha^{-1} in on-year and 1927.92 kg·ha^{-1} in off-year, respectively.

Bamboo produces new shoots at a 2-year interval, with the new shoot production year known as on-year and the following year known as off-year. The years of 2008, 2010, and 2012 were on-years, while the years of 2009 and 2011 were off-years in our study area. The litterfall in on-years were significantly less than the off-years (low elevation: $F = 17.662$, $P = 0.002$; high elevation: $F = 11.018$, $P = 0.008$). At low elevation, the total litterfall in 2009 was 68.30% higher than that in 2010, and the total litterfall in 2011 was 93.39% higher than that in 2012. At high elevation, the counterpart value was 32.84% and 72.20%, respectively.

Ice storm in 2008 caused an increase of litterfall in the following years, especially the first and second years after the disaster. For off-years, litterfall in 2009 was 42.55% higher than that in 2011 at low elevation and was 26.68% at high elevation, while litterfall in 2010 was 63.81% higher than that in 2012 at low elevation and was 64.21% at high elevation, respectively (Figure 3).

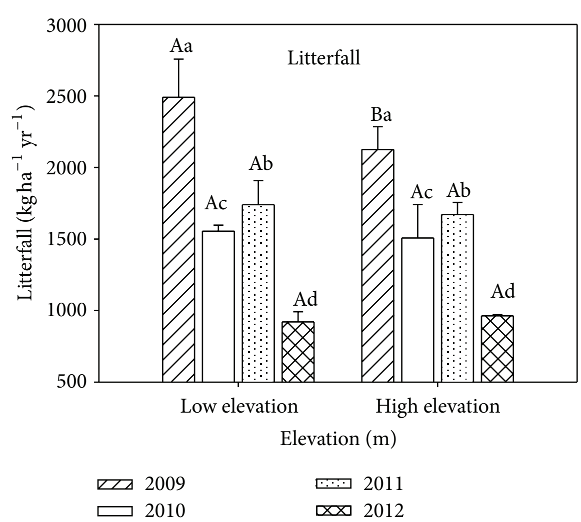

Figure 3: Average annual litterfall of moso bamboo at two elevations from January 2009 to December 2012. Different capital letters in different group at two elevations meant significant difference at 0.05 levels in the same year, and different lower case letters at the same elevation meant significant difference in four years.

There were remarkable litterfall peaks and valleys during a year period (Figure 2). Most peaks occurred during the period from April to June (big) and the second peak in October to December (small), and the valleys occurred during the period between January and March. The first peak of litterfall in 2009 was 3.10 times as the amount as 2012 at low elevation, 2.26 times at high elevation. The percent of peaks to

Table 2: The occurring time of litterfall peak and valley value and the percent of extremum value to total litterfall at two elevations.

Extremum	Litterfall peak and lowest value 2009	2010	2011	2012
Low elevation				
First peak	April	June	June	May
%[a]	17.03 ± 1.89	22.87 ± 4.47	17.52 ± 1.51	11.67 ± 0.69
Second peak	November	March	December	—
%[b]	9.93 ± 0.63	22.16 ± 1.42	13.42 ± 0.31	—
Lowest	February	September	January	January
%[c]	2.21 ± 0.73	1.74 ± 0.35	3.38 ± 0.08	2.34 ± 0.29
High elevation				
First peak	November	June	May	June
%[a]	17.85 ± 2.58	23.56 ± 2.26	17.81 ± 2.14	14.00 ± 0.95
Second peak	June	February	December	—
%[b]	17.24 ± 1.61	17.42 ± 2.29	12.60 ± 1.69	—
Lowest	February	September	January	January
%[c]	2.01 ± 0.40	3.05 ± 0.64	3.09 ± 0.08	3.14 ± 0.30

Note: most peaks of moso bamboo occurred during April to June (big) and the second peak in October to December (small), and the lowest value occurred during the period between January and March. [a]The percent of first peak value to total litterfall. [b]The percent of second peak value to total litterfall. [c]The percent of lowest value to total litterfall.

the total litterfall were 11.17%–26.88% of the first peak, 8.14%–23.65% of the second peak, and 1.49%–4.95% of the lowest value (Table 2).

The ice storm seemed to perturb the litterfall rhythm, especially in on-year (Figure 4 and Table 2). For example, the litterfall peaks in 2010 occurred in February (March) and the valley in September, both different from the other years. In 2012, there was only one litterfall peak, which occurred in May at low elevation and in June at high elevation. In our study, the response of litterfall at two elevations to the ice storm was significant, and the time of peak litterfall at high elevation was delayed in 2009 and ahead in 2010 compared with low elevation (Table 2).

3.2. Litter Leaf Nutrient Concentration. The average C concentrations in litterfall were 13.16% and 13.15% at low and high elevations. The nutrients concentrations of leaf litter at low and high elevations were 2.17% and 2.15% for N, 0.41 g$\cdot$kg^{-1} and 0.42 g$\cdot$kg^{-1} for P, 2.16 g$\cdot$kg^{-1} and 2.13 g$\cdot$kg^{-1} for K, 3.47 g$\cdot$kg^{-1} and 3.42 g$\cdot$kg^{-1} for Ca, and 1.48 g$\cdot$kg^{-1} and 1.42 g$\cdot$kg^{-1} for Mg, respectively (Figure 5).

The concentrations of these macroelements in the leaves at two elevations significantly fluctuated after ice-snow disaster in 2008 ($P < 0.05$) (Figure 6). The concentrations of these macroelements were not almost higher at low elevation for every month. Litter N nutrient concentration changed irregularly with lowest concentration in May and highest concentration in September, 2011, and Ca and Mg concentrations generally were lowest in January and highest in April with large fluctuation. Compared with N concentrations, P concentrations changed greatly in 2011 and then kept stable, which were generally not susceptible to leach, so this difference probably reflects retranslocation.

3.3. Litter Leaf Nutrient Return and Stoichiometry Characteristic. Average annual quantities of N, Ca, and Mg transferred to the forest floor via litterfall were substantially higher at low elevation ($P > 0.05$), while N contents return was found to be higher at high elevation ($P > 0.05$) (Table 3). The annual nutrient inputs through leaf litter exhibited the following rank order: N > Ca > K > Mg > P (Table 3). Total annual nutrient return (N + P + K + Ca + Mg) for low and high altitude was 46.3 kg$\cdot$ha^{-1} and 45.49 kg$\cdot$ha^{-1}, respectively.

Litter leaf stoichiometric characteristics at low and high elevations were 18.64 and 19.15 for C/N ratio, 977.63 and 959.74 for C/P ratio, and 53.02 and 50.47 for N/P ratio, respectively (Figure 6), which were no significant difference at two elevations ($P > 0.05$).

3.4. The Influence of Climate Factors on Litterfall. The influence of climate factors on litterfall kept consistent at two elevations. The litterfall at two elevations were positive correlation with atmospheric temperature, precipitation, wind speed, extreme maximum temperature, and extreme minimum temperature, but only wind speed at low elevation was significant, while negative correlation with average relative humidity (Table 4).

4. Discussion

4.1. Litterfall in On-Year and Off-Year following the Disturbance of Ice Storm. Compared with deciduous trees, bamboo leaf changed once every two years rather than one year (new bamboo changes leaf in the same year); therefore, the accumulation, transformation, and consumption of synthetic nutrients occur at a two-year cycle. Generally, there are two peaks every year; the first peak (big) occurred in spring (April-May) and the second peak occurred in late autumn

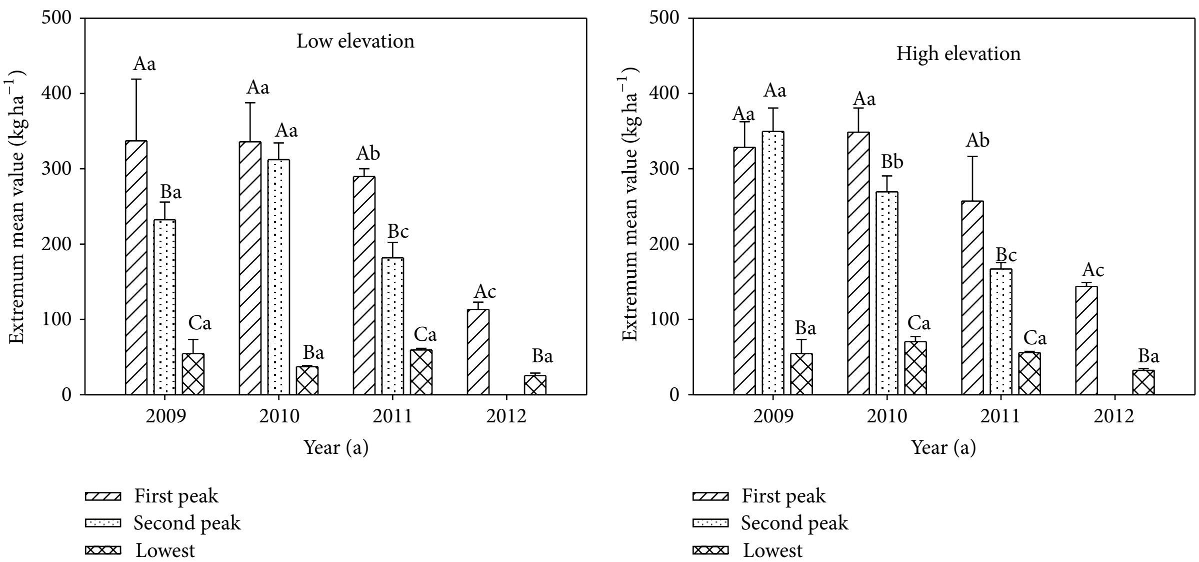

Figure 4: The peak and valley value of litterfall at two elevations in 2009.01–2012.12. Different capital letters in the same group meant significant difference at 0.05 levels in the same year at each elevation; the different lowercase letters among the same indicator in four years meant significant difference at each elevation.

Table 3: Annual means of leaf litter nutrient return at two elevations ($kg{\cdot}ha^{-1}{\cdot}yr^{-1}$).

Elevation	Nutrient return				
	N	P	K	Mg	Ca
Low elevation	32.51 ± 0.54	0.74 ± 0.01	3.84 ± 0.06	2.62 ± 0.12	6.59 ± 0.04
High elevation	33.13 ± 0.49	0.72 ± 0.01	3.47 ± 0.06	2.23 ± 0.03	5.94 ± 0.11

Table 4: The relationships between litterfall and climate factors at two elevations.

Litterfall	Average humidity	Air temperature	Wind speed	Precipitation	Extreme maximum temperature	Extreme minimum temperature
Low elevation	−0.168	0.183	0.288*	0.159	0.257	0.111
High elevation	−0.096	0.159	0.058	0.037	0.201	0.136

Correlation is significant at the 0.05 level.

(November) [17]. The experimental bamboo forest in our study had on- and off-year pattern, and there were significant differences between the on- and off-year in total annual litterfall and the litterfall in first peak. Fu et al. [17] showed that total annual leaf litter and the first peak are smaller in on-year than in off-year, and the percent of the first peak to the total annual litterfall (17–31%) was smaller than off-year (43–56%). In our study, litterfall in bamboo forest existed also obvious in on- and off-year phenomenon, with percent of the first peak to annual total litterfall at low and high elevations ranging from 14.43% and 16.87% in on-years and from 11.67% to 23.56% in off-years. These results could be attributed to ice storm disturbance to the overall structure and bamboo growth rhythm, as well as decreased accumulation of nutrients two years after the disaster.

Extreme events usually come suddenly and unexpectedly, taking the human off-guard. The data of litter production were not collected right before the ice storm in our study sites (e.g., 2007). Fortunately, our colleagues made surveys on this experimental bamboo forest and published the data of the litterfall in the same region which was 1656.02 $kg{\cdot}ha^{-1}$ in on-year and 1927.92 $kg{\cdot}ha^{-1}$ in off-year, respectively [17]. In our study, annual litterfall significantly responded to ice storm disaster in 2008. For off-years, litterfall in 2009 was 42.55% higher than that in 2011 at low elevation and was 26.68% at high elevation, while for on-years, litterfall in 2010 was 63.81% higher than that in 2012 at low elevation and was 64.21% at high elevation, respectively (Figure 2), indicating that ice storm increased litter production. Since 2011, the ice-damaged bamboo forest seemed to recover to the normal condition in terms of the seasonal dynamic of litterfall and the occurring time of the peak value. Hooper et al. [8] reported that the amount of woody biomass was about 10–20 times greater than the annual production of woody litter typical for temperate deciduous forest in northeastern North America after the ice storm of January 1998, while the amount

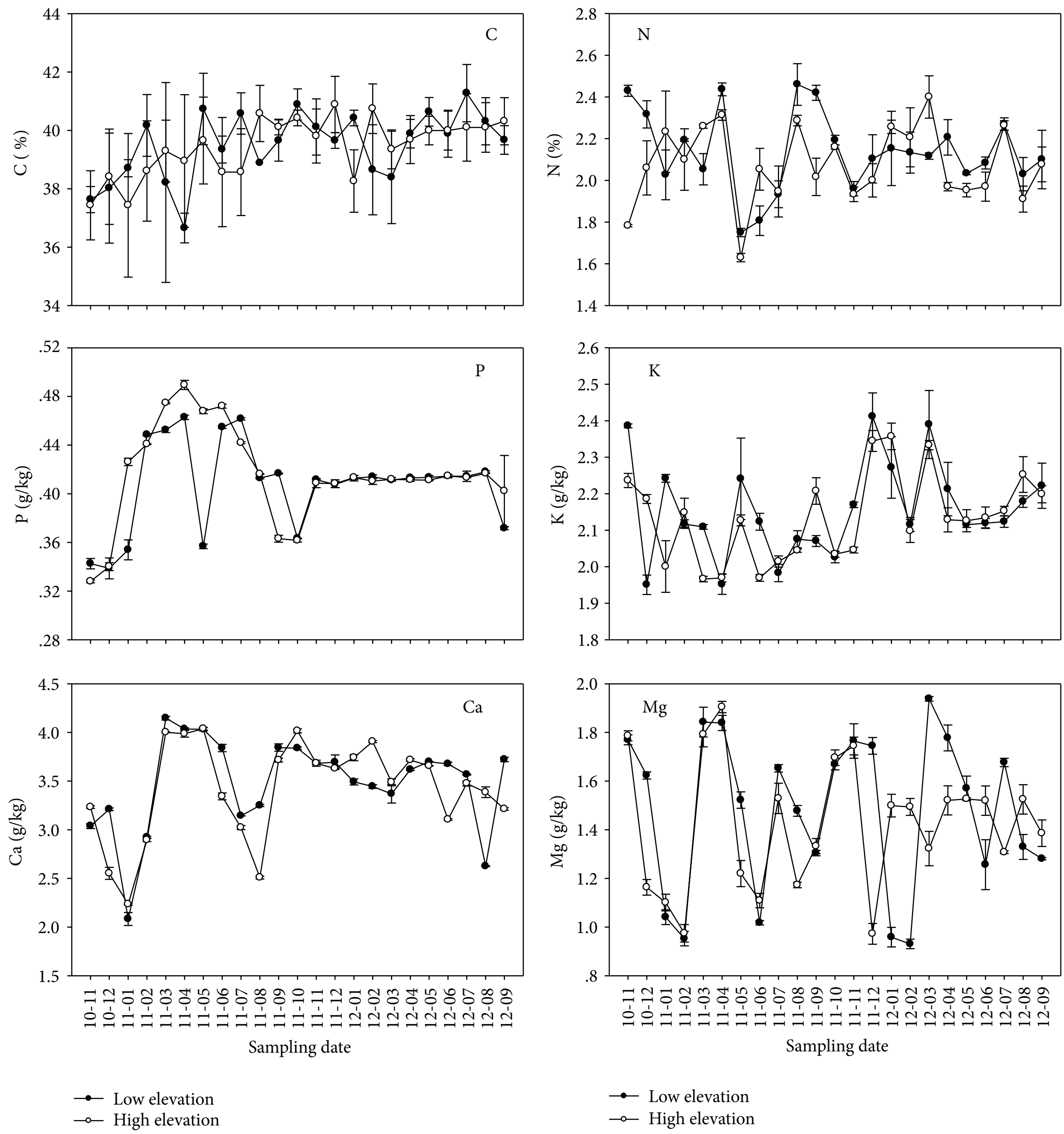

Figure 5: Dynamic variations of C, N, P, K, Ca, and Mg contents on leaf litter at two elevations.

was about 7–10% of the total aboveground biomass in the forest before the storm. Rebertus et al. [18] showed that coarse woody debris input from the ice storm averaged 5.1 m^3/ha. The 1994 ice storm increased coarse debris 3–6 times above normal [19]. Therefore, severe ice storms and related secondary mortality can create a tremendous quantity of wood debris.

4.2. Litter Nutrient Dynamic following the Disturbance of Ice Storm. Foliar nutrient movements from senescing leaves to active plant tissues or woody structures have been considered as a physiological mechanism of nutrient cycling since it plays a major role in nutrient conservation by deciduous tree species because nutrients following this pathway are not lost through litterfall. In addition, rates of nutrient return to the forest soil are controlled not only by the amount of litter production but also by the nutrient concentrations in litter components [5]. Wu et al. [20] showed that N, P, and K concentrations increased from May to July and decreased after July, and Ca concentrations were no significant monthly variation. In our study, litter N, P, and K concentration changed irregularly. N concentration was lowest in May and

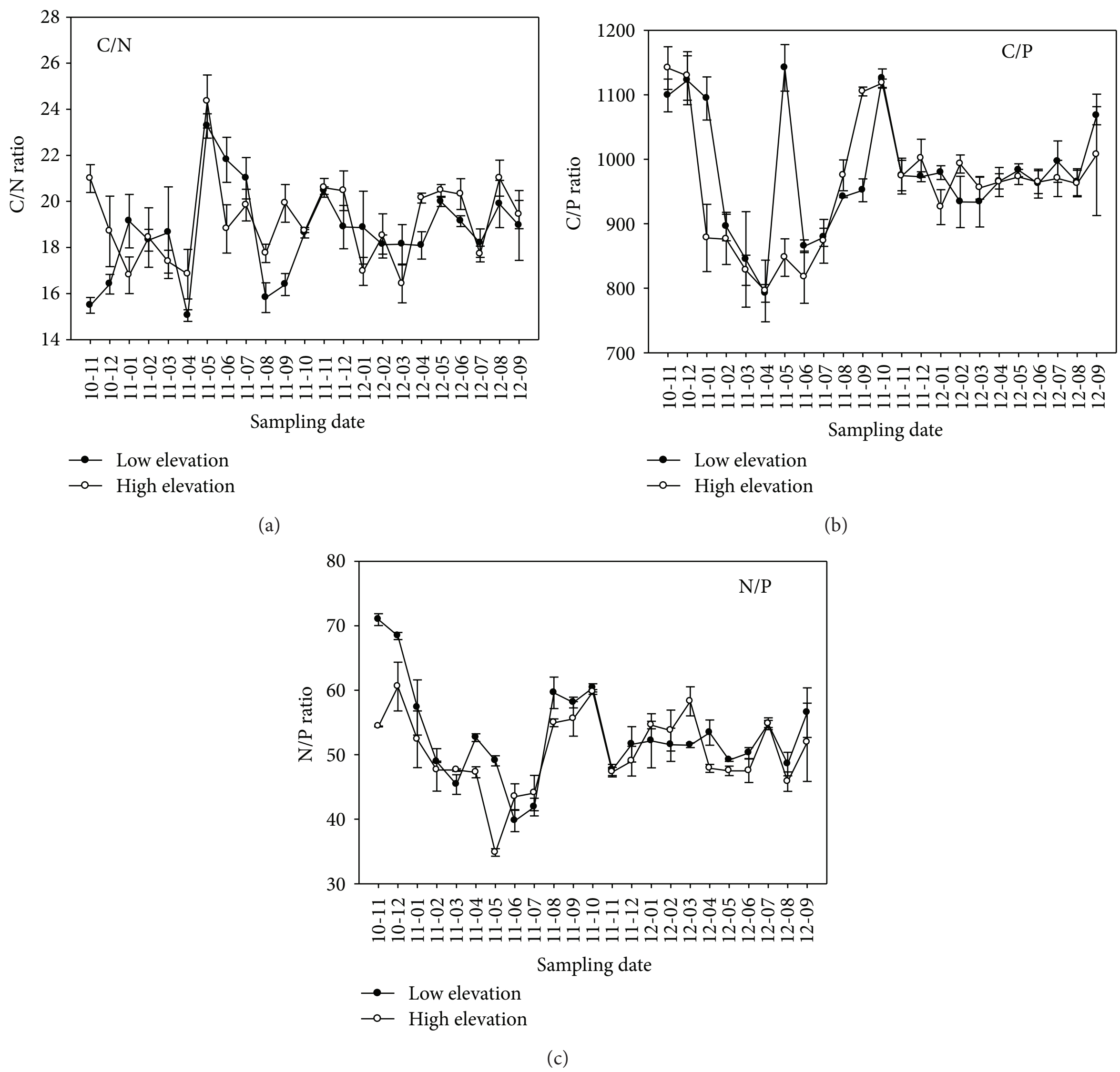

Figure 6: Dynamic variations of C/N ratio, C/P ratio, and N/P ratio on leaf litter at two elevations.

highest in August 2011, which was different from the studies of Finér et al. [21] and Yang et al. [22] who showed that N, P, and K concentration of the highest value in the growing season (March–August), the lowest in almost stopped growing or dormant season (October 1 to next year January), indicating nutrient concentrations significantly were influenced by the ice-snow disaster in 2008. In our study, Ca concentration was lowest in August 2011 and 2012 with large fluctuations, while Mg concentration was lowest in February 2011 and 2012 and highest in March/April, supporting the study of Yang et al. [22] who showed that Ca concentration is lowest in the growing season (May to August) and highest in the stop-growing or sleep season (October 1 to next year January). Ca is a structural element with poor mobility and is not easily reabsorbed by the growing season because some of the Ca is involved in cell division and other metabolic activities. The study of Finér et al. [21] showed that the concentrations of Ca and Mg were highest in the stop-growing season, possibly owing to variation in the mobility of element during senescence. The nutrients concentration was closely related to the ice storm damage, because ice storm could influence the seasonal changes of nutrient concentrations in litter and their potential retranslocation capacity. In our study, nutrient concentration was lowest in January to February when the ice storm happened, and the nutrient content would not experience the normal litter nutrient recycling process, which could quickly release nutrients to accelerate the cycle [23].

Litter substrate quality is an important functional trait explaining the strong effects of plants on soil nutrients [24, 25], and initial litter chemistry parameters including N and P concentrations, C/N ratio, and C/P ratio affected litter decomposition [26]. In our study, litter leaf stoichiometric traits at low and high elevations were 18.64 and 19.15 for C/N ratio, 977.63 and 959.74 for C/P ratio, and 53.02 and 50.47 for N/P ratio, respectively (Figure 6), while litter leaf stoichiometric characteristic without disturbed was 18.70 for

C/N ratio, 444.71 for C/P ratio, and 23.46 for N/P ratio on moso bamboo in Fuyang, Zhejiang Province (unpublished, 2013), and 20.91 for C/N ratio, 538.38 for C/P ratio, and 25.75 for N/P ratio in Lin'an Zhejiang Province (2006) [27]. Compared with undisturbed moso bamboo litter leaf stoichiometric traits, our findings indicated that litter chemistry tends to more easy decomposition with lower C/N ratio and higher C/P ratio and N/P ratio, according to the result of Moore et al. [23] who showed that net N loss positively correlated with the lower C/N ratio in the initial litter and that net P loss likely occurred at C/P ratio between 800 and 1200. This result supports the study of Xu et al. [28] who suggested that snow storm might accelerate litter decomposition rate.

The order of annual nutrient return through leaf litter was Ca > N > K > Mg > P and the total annual nutrient return (N + P + K + Ca + Mg) for low and high elevations was 46.30 kg·ha^{-1} and 45.49 kg·ha^{-1}, respectively (Table 3). Compared with other natural disasters, Lodge et al. [29] showed that the leaf litterfall nutrient return of N, P, K, Ca, and Mg after hurricane was 3.5, 3.2, 2.9, 6.2, and 3.7 times higher than normal (19 kg·ha^{-1}, 0.6 kg·ha^{-1}, 3.4 kg·ha^{-1}, 13 kg·ha^{-1}, and 6 kg·ha^{-1}, resp.). The scale of biomass transferred to the forest floor due to ice storm indicates that ice storm plays a significant role in structuring forests and driving forest succession. The effects of ice storms on forest ecology merit greater attention.

4.3. Different Elevations Litterfall Dynamic following the Disturbance of Ice Storm. Litter production, depending on vegetation cover and influenced by soil fertility [30], which is an important process involved in soil organic matter accumulation and nutrient cycling in terrestrial ecosystems [31]. Elevation indirectly influences the litterfall through insolation, temperature, wind speed, and water availability, and this factor individually accounted for 13% of the litterfall variance [32]. In this study, the influence of elevation on the total annual litterfall was significant only in 2009. The total annual litterfall at low elevation was 17.54% and 7.21% higher than high elevation in 2009 and 2011, respectively, and was 4.47% and 4.21% lower in 2010 and 2012. This result was similar to the previous results, including the result of Zhou et al. [33] who showed that litterfall decreased significantly with altitude and the study of Bellingham et al. [3] showed that fine litterfall declined with increasing altitude in montane rain forests, the mean annual total fine litterfall per plot (2003–2005) was negatively correlated with plot altitude ($r = -0.45$, $P = 0.03$). This trend is likely to result from declining aboveground net primary productivity with elevation for the environmental variables (particularly temperature and soil moisture) affect ecosystem functions [34, 35], while the response of own rhythm characteristics and damaged degree for moso bamboo at different elevations was different, partly because impairment of photosynthetic carbon fixation, litter decomposition processes and nutrient supply from the soil temperature decrease with elevation increasing [3].

The effect of elevation on litterfall peak was obvious. In general, the first peak of litterfall is in April/May, and the second peak occurs in November on moso bamboo. In our study, the occurring time of peak in the first and second years was significantly different from the third and the fourth years. The first peak after ice-storm at low and high elevations occurred April and November in 2009, both June in 2010, June and May in 2011, May and June in 2012, respectively, while the lowest litterfall at low and high elevation both occurred February in 2009, September in 2010, January in 2011 and 2012. According to this result, we speculated that ice storm disturbed litter peak rhythm especially in on-year. Reductions in canopy density and leaf area index (LAI) in the first years after ice storm lead to decrease of photosynthetic efficiency [10].

5. Conclusion

Ice storm caused an increase of 16.68%–35.60% in annual litterfall in moso bamboo plantations and disturbed the litterfall peak rhythm, especially in on-years, indicating that the annual litterfall significantly responded to ice-snow disaster in 2008. The concentrations of macroelements in the leaves at two elevations greatly fluctuated after the 2008 ice storm. The study on stoichiometric dynamic suggested that leaf litter got to decompose more easily after the ice storm. The responses we observed in the litterfall and litter nutrient concentration would result in long-term changes in litter nutrient return dynamic, suggesting the importance of litterfall production not only in terms of nutrient cycling to the forest soil nutrients but also in terms of maintaining fundamental ecological and ecosystem process. On the other hand, the scale of biomass (litter) transferred to the forest floor in ice storm indicates a significant role in structuring forests and driving forest succession. The effect of ice storms on forest ecology merits greater attention.

Headings

Ice storm significantly increased litter production. Litterfall peak rhythm was greatly disturbed by the ice storm. Leaf nutrient concentrations significantly fluctuated after ice-snow disaster.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgments

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References

[1] P. M. Vitousek, "Litterfall, nutrient cycling, and nutrient limitation in tropical forests.," *Ecology*, vol. 65, no. 1, pp. 285–298, 1984.

[2] S. M. Sundarapandian and P. S. Swamy, "Litter production and leaf-litter decomposition of selected tree species in tropical forests at Kodayar in the Western Ghats, India," *Forest Ecology and Management*, vol. 123, no. 2-3, pp. 231–244, 1999.

[3] P. J. Bellingham, C. W. Morse, R. P. Buxton, K. I. Bonner, N. W. H. Mason, and D. A. Wardle, "Litterfall, nutrient concentrations and decomposability of litter in a New Zealand temperate montane rain forest," *The New Zealand Journal of Ecology*, vol. 37, no. 2, pp. 162–171, 2013.

[4] V. A. Kavvadias, D. Alifragis, A. Tsiontsis, G. Brofas, and G. Stamatelos, "Litterfall, litter accumulation and litter decomposition rates in four forest ecosystems in northern greece," *Forest Ecology and Management*, vol. 144, no. 1–3, pp. 113–127, 2001.

[5] H. González-Rodeíguez, T. G. Domínguez-Gómez, I. Cantú-Silva et al., "Litterfall deposition and leaf litter nutrient return in different locations at Northeastern Mexico," *Plant Ecology*, vol. 212, no. 10, pp. 1747–1757, 2011.

[6] Q. Wang, S. Wang, B. Fan, and X. Yu, "Litter production, leaf litter decomposition and nutrient return in *Cunninghamia lanceolata* plantations in south China: effect of planting conifers with broadleaved species," *Plant and Soil*, vol. 297, no. 1-2, pp. 201–211, 2007.

[7] L. B. Guo, R. E. H. Sims, and D. J. Horne, "Biomass production and nutrient cycling in *Eucalyptus* short rotation energy forests in New Zealand: II. Litter fall and nutrient return," *Biomass and Bioenergy*, vol. 30, no. 5, pp. 393–404, 2006.

[8] M. C. Hooper, K. Arii, and M. J. Lechowicz, "Impact of a major ice storm on an old-growth hardwood forest," *Canadian Journal of Botany*, vol. 79, no. 1, pp. 70–75, 2001.

[9] K. Takahashi, K. Arii, and M. J. Lechowicz, "Quantitative and qualitative effects of a severe ice storm on an old-growth beech-maple forest," *Canadian Journal of Forest Research*, vol. 37, no. 3, pp. 598–606, 2007.

[10] B. Zhou, L. Gu, Y. Ding et al., "The great 2008 Chinese ice storm its socioeconomic-ecological impact and sustainability lessons learned," *Bulletin of the American Meteorological Society*, vol. 92, no. 1, pp. 47–60, 2011.

[11] R. Stone, "Natural disasters: ecologists report huge storm losses in China's forests," *Science*, vol. 319, no. 5868, pp. 1318–1319, 2008.

[12] B. Z. Zhou, Z. C. Li, X. M. Wang et al., "Impact of the 2008 ice storm on moso bamboo plantations in southeast China," *Journal of Geophysical Research G: Biogeosciences*, vol. 116, no. 3, Article ID G00H06, 2011.

[13] A. T. Darwin, D. Ladd, R. Galdins, T. A. Contreras, and L. Fahrig, "Response of forest understory vegetation to a major ice storm," *Journal of the Torrey Botanical Society*, vol. 131, no. 1, pp. 45–52, 2004.

[14] Z. T. Gong, *Chinese Soil Taxonomy (Revised Proposal)*, China Science Press, Beijing, China, 2003.

[15] S. Y. Yu, F. G. Jian, S. C. Guang, S. X. Jin, P. C. Li, and P. Lin, "Litterfall, nutrient return, and leaf-litter decomposition in four plantations compared with a natural forest in subtropical China," *Annals of Forest Science*, vol. 61, no. 5, pp. 465–476, 2004.

[16] E. González, E. Muller, B. Gallardo, F. A. Comín, and M. González-Sanchis, "Factors controlling litter production in a large Mediterranean river floodplain forest," *Canadian Journal of Forest Research*, vol. 40, pp. 1698–1709, 2010.

[17] M. Y. Fu, M. Y. Fang, J. Z. Xie, Y. F. Chen, and H. X. Wang, "Nutrient cycling in bamboo stands. I. Leaf litter and its decomposition in pure *Phyllostachys pubescens* stands," *Forest Research*, vol. 2, no. 3, pp. 207–213, 1989.

[18] A. J. Rebertus, S. R. Shifley, R. H. Richards, and L. M. Roovers, "Ice storm damage to an old-growth oak-history forest in Missouri," *The American Midland Naturalist*, vol. 137, no. 1, pp. 48–61, 1997.

[19] D. C. Bragg, M. G. Shelton, and B. Zeide, "Impacts and management implications of ice storms on forests in the southern United States," *Forest Ecology and Management*, vol. 186, no. 1–3, pp. 99–123, 2003.

[20] F. Z. Wu, K. Y. Wang, W. Q. Yang, Y. J. Lu, and Y. Z. Qiao, "Effect of *Fargesia denudata* density on seasonal changes in litter nutrient concentrations and their potential retranslocation," *Acta Phytoecologica Sinica*, vol. 29, no. 4, pp. 537–542, 2005.

[21] L. Finér, "Variation in the amount and quality of litterfall in a *Pinus sylvestris* L. stand growing on a bog," *Forest Ecology and Management*, vol. 80, pp. 1–11, 1996.

[22] H. Yang, S. Wang, F. Bing, and W. Zhang, "Dynamics of annual litter mass and nutrient return of different age *Masson pine* plantations," *Chinese Journal of Ecology*, vol. 29, no. 12, pp. 2334–2340, 2010.

[23] T. R. Moore, J. A. Trofymow, C. E. Prescott, and B. D. Titus, "Nature and nurture in the dynamics of C, N and P during litter decomposition in Canadian forests," *Plant and Soil*, vol. 339, no. 1, pp. 163–175, 2011.

[24] B. Berg, M. P. Berg, P. Bottner et al., "Litter mass loss rates in pine forests of Europe and Eastern United States: some relationships with climate and litter quality," *Biogeochemistry*, vol. 20, no. 3, pp. 127–159, 1993.

[25] A. E. Nikolaidou, A. K. Pavlatou-Ve, S. K. Kostopoulou, A. P. Mamolos, and K. L. Kalburtji, "Litter quality and decomposition of *Vitis vinifera* L. residues under organic and conventional farming systems," *European Journal of Soil Biology*, vol. 46, no. 3-4, pp. 208–217, 2010.

[26] R. Aerts, "Climate, leaf litter chemistry and leaf litter decomposition in terrestrial ecosystems: a triangular relationship," *Oikos*, vol. 79, no. 3, pp. 439–449, 1997.

[27] Y. Ma, H. Jiang, S. Yu et al., "Effects of simulated acid rain on the decomposition of *Phyllostachys pubescens*," *Acta Scientiarum Natralium Universitatis Sunyatseni*, vol. 49, no. 2, pp. 95–99, 2010.

[28] H. M. Xu, J. M. Ding, and S. Liu, "Influence of the snow storm on the leaf litter decomposition dynamics of *Phyllostachys heterocycla* ecosystem in Wuyi Mountain," *Journal of Nanjing University*, vol. 34, pp. 131–135, 2010.

[29] D. J. Lodge, F. N. Scatena, C. E. Asbury, and M. J. Sanchez, "Fine litterfall and related nutrient inputs resulting from Hurricane Hugo in subtropical wet and lower montane rain forests of Puerto Rico," *Biotropica*, vol. 23, no. 4 A, pp. 336–342, 1991.

[30] K. Descheemaeker, B. Muys, J. Nyssen et al., "Litter production and organic matter accumulation in exclosures of the Tigray highlands, Ethiopia," *Forest Ecology and Management*, vol. 233, no. 1, pp. 21–35, 2006.

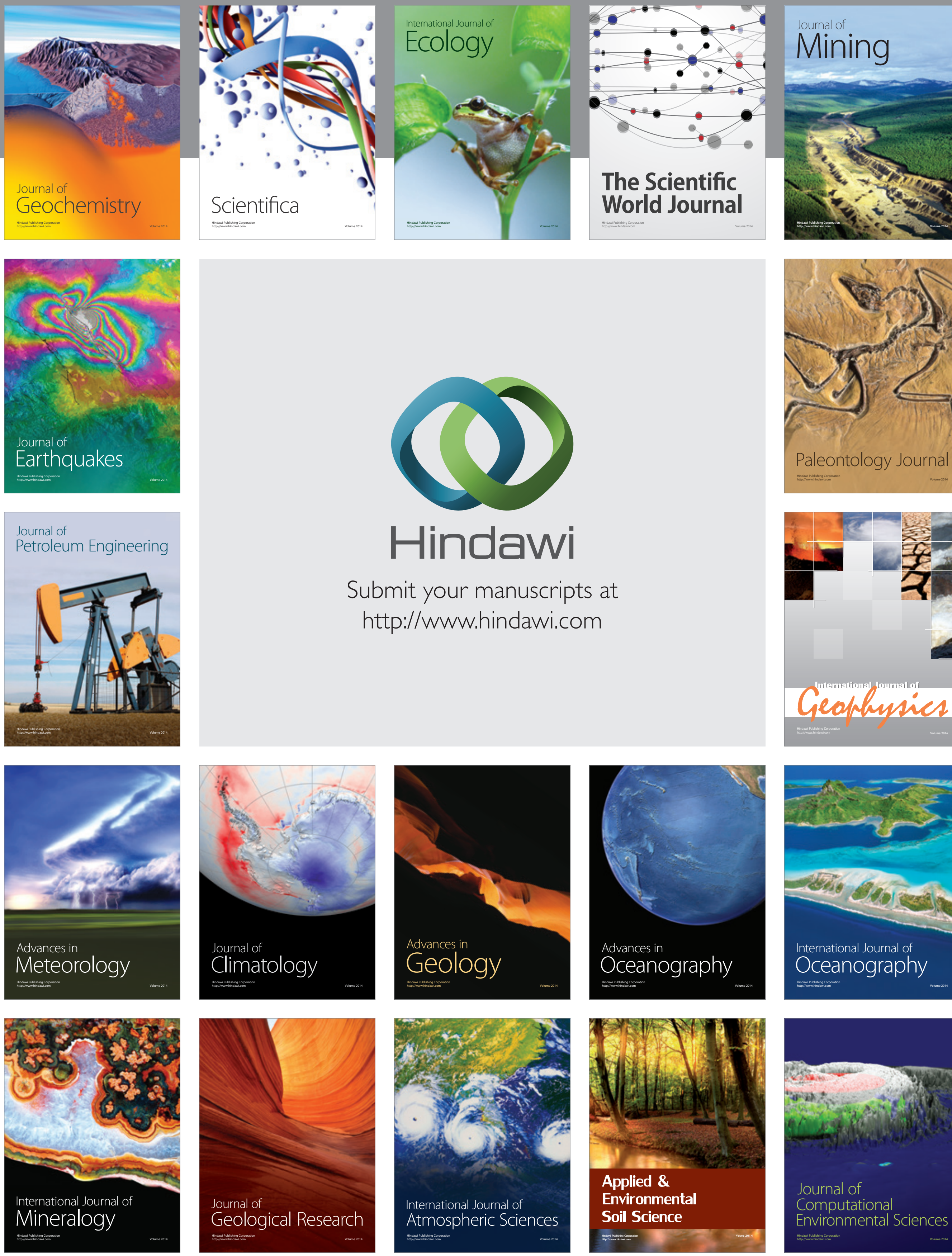
[31] K. I. Paul and P. J. Polglase, "Predication of decomposition of litter under eucalypts and pines using the FullCAM model," *Forest Ecology and Management*, vol. 191, pp. 73–92, 2004.

[32] P. Saenger and S. C. Snedaker, "Pantropical trends in mangrove above-ground biomass and annual litterfall," *Oecologia*, vol. 96, no. 3, pp. 293–299, 1993.

[33] Y. Zhou, J. Su, I. A. Janssens, G. Zhou, and C. Xiao, "Fine root and litterfall dynamics of three Korean pine (*Pinus koraiensis*) forests along an altitudinal gradient," *Plant and Soil*, vol. 374, pp. 19–32, 2013.

[34] K. Kitayama and S. Aiba, "Ecosystem structure and productivity of tropical rain forests along altitudinal gradients with contrasting soil phosphorus pools on Mount Kinabalu, Borneo," *Journal of Ecology*, vol. 90, no. 1, pp. 37–51, 2002.

[35] C. A. J. Girardin, Y. Malhi, L. E. O. C. Aragão et al., "Net primary productivity allocation and cycling of carbon along a tropical forest elevational transect in the Peruvian Andes," *Global Change Biology*, vol. 16, no. 12, pp. 3176–3192, 2010.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